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# MetOceanWorks

## Arklow Bank Wind Park Phase 2

### Metocean Analysis for Site Assessment: Eastern Zone

11 May 2022

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SSE\_C00004\_R05\_Metocean\_Input\_For\_Design\_East

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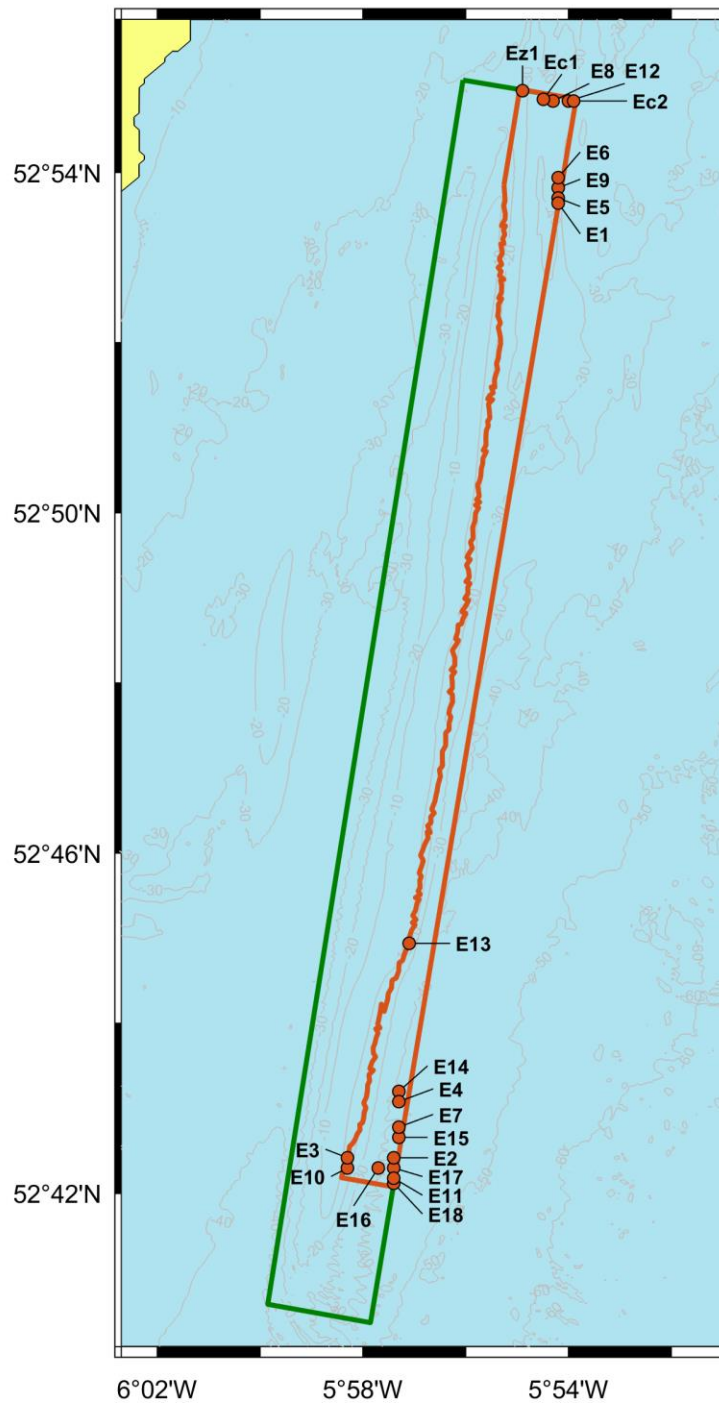
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## FRONTISPIECE



## 1 Executive summary

Sure Partners Limited (SPL) is developing the Arklow Bank Wind Farm Phase 2 (ABWF) located in the Irish Sea. ABWF is situated on a long narrow sandbank approximately 10 km off the Wicklow Coast, near the town of Arklow. The site area is approximately 27 km x 2.5 km and water depths within the lease area range from approximately 2 m to more than 40 m below LAT. SPL contracted MetOceanWorks to conduct a suite of analyses to quantify the normal and extreme oceanographic conditions (waves, currents and water levels) at ABWF.

As described in the accompanying document “Arklow Bank Wind Park Phase 2; MetOcean Analysis for Site Assessment: Overview” (document ref: SSE\_C00004\_R05\_MetOcean\_Analysis\_Overview), the lease area has been split into Eastern, Western and Southern zones for detailed analysis. This document provides diagnostic plots and tables for the **Eastern Zone** to support the statistics provided in the Microsoft Excel Spreadsheet **SSE\_C00004\_R05\_MetOcean\_Input\_For\_Design\_East.xlsx**.



## Table of contents

|          |                                                                         |            |
|----------|-------------------------------------------------------------------------|------------|
| <b>1</b> | <b>Executive summary .....</b>                                          | <b>iii</b> |
| <b>2</b> | <b>Units and Conventions .....</b>                                      | <b>9</b>   |
| 2.1      | Units and Conventions.....                                              | 9          |
| 2.2      | Glossary of commonly used metocean terms .....                          | 9          |
| <b>3</b> | <b>Introduction .....</b>                                               | <b>11</b>  |
| 3.1      | Background .....                                                        | 11         |
| 3.2      | Report Structure .....                                                  | 12         |
| <b>4</b> | <b>Analysis Locations .....</b>                                         | <b>13</b>  |
| <b>5</b> | <b>Water Level Criteria .....</b>                                       | <b>15</b>  |
| 5.1      | Data Sources .....                                                      | 15         |
| 5.2      | VORF .....                                                              | 15         |
| 5.3      | Water levels and Significant Wave Heights .....                         | 15         |
| 5.4      | Extrapolation for Extreme Water Levels.....                             | 16         |
| 5.5      | Sea level changes .....                                                 | 18         |
| <b>6</b> | <b>Currents .....</b>                                                   | <b>19</b>  |
| 6.1      | Data Sources .....                                                      | 19         |
| 6.2      | Current Rose .....                                                      | 19         |
| 6.3      | Joint Distribution of Current Speeds and Significant Wave Heights ..... | 19         |
| 6.4      | Joint Distribution of Current Speeds and Hub Height Wind Speeds.....    | 21         |
| <b>7</b> | <b>Wind-Wave Directionality .....</b>                                   | <b>25</b>  |
| 7.1      | Data Sources .....                                                      | 25         |
| <b>8</b> | <b>Misalignment .....</b>                                               | <b>26</b>  |
| 8.1      | Data Sources .....                                                      | 26         |
| 8.2      | Misalignment Scatter Plots .....                                        | 26         |
| <b>9</b> | <b>Normal Sea States .....</b>                                          | <b>30</b>  |
| 9.1      | Data Sources .....                                                      | 30         |
| 9.2      | NSS Significant Wave Height.....                                        | 30         |
| 9.3      | NSS Peak Wave Period .....                                              | 30         |

---



|           |                                                         |           |
|-----------|---------------------------------------------------------|-----------|
| <b>10</b> | <b>Directional Extreme Currents .....</b>               | <b>35</b> |
| 10.1      | Data Sources .....                                      | 35        |
| 10.2      | Extrapolation for Extreme Current Speeds .....          | 35        |
| <b>11</b> | <b>Directional Extreme Waves .....</b>                  | <b>42</b> |
| 11.1      | Data Sources .....                                      | 42        |
| 11.2      | Significant Wave Height .....                           | 42        |
| 11.3      | Maximum Individual Wave and Crest Heights .....         | 42        |
| 11.4      | Associated Wave Periods .....                           | 53        |
| <b>12</b> | <b>Extreme Sea States .....</b>                         | <b>61</b> |
| <b>13</b> | <b>Severe Sea States .....</b>                          | <b>65</b> |
| 13.1      | Data Sources .....                                      | 65        |
| 13.2      | Significant Wave Heights .....                          | 65        |
| 13.3      | Associated Peak Periods .....                           | 66        |
| <b>14</b> | <b>Associated Parameters .....</b>                      | <b>67</b> |
| 14.1      | Data Sources .....                                      | 67        |
| 14.2      | Parameters Associated with $H_{m0}$ .....               | 67        |
| 14.3      | Parameters Associated with Hub Height Wind Speeds ..... | 71        |
| <b>15</b> | <b>Figure List .....</b>                                | <b>75</b> |
| <b>16</b> | <b>References .....</b>                                 | <b>76</b> |



## List of Figures

|                                                                                                                                                               |    |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------|----|
| Figure 3.1: Analysis zones .....                                                                                                                              | 11 |
| Figure 4.1: Analysis locations.....                                                                                                                           | 14 |
| Figure 5.1: Relationship between significant wave height and still water level (tide + surge) relative to MSL, location Ez1.....                              | 15 |
| Figure 5.2: Extrapolation of positive surge relative to MSL, location Ez1. ....                                                                               | 16 |
| Figure 5.3: Extrapolation of negative surge relative to MSL, location Ez1. ....                                                                               | 16 |
| Figure 5.4: Extrapolation of positive still water level relative to MSL, location Ez1. ....                                                                   | 17 |
| Figure 5.5: Extrapolation of negative still water level relative to MSL, location Ez1.....                                                                    | 17 |
| Figure 6.1: All-year rose plot of depth-average current speed and direction, location Ec1.....                                                                | 19 |
| Figure 6.2: Scatter plot of depth-average current speed and Hm0, location Ec1. ....                                                                           | 20 |
| Figure 6.3: Scatter plot of depth-average current speed component in the direction of waves and Hm0, location Ec1. ....                                       | 20 |
| Figure 6.4: Scatter plot of total near-surface current speed and hub height wind speed, location Ec1. ....                                                    | 21 |
| Figure 6.5: Scatter plot of tidal near-surface current speed and hub height wind speed, location Ec1. ....                                                    | 22 |
| Figure 6.6: Scatter plot of residual near-surface current speed and hub height wind speed, location Ec1.....                                                  | 22 |
| Figure 6.7: Scatter plot of total near-surface current speed component in the direction of hub height winds and hub height wind speeds, location Ec1. ....    | 23 |
| Figure 6.8: Scatter plot of tidal near-surface current speed component in the direction of hub height winds and hub height wind speeds, location Ec1. ....    | 23 |
| Figure 6.9: Scatter plot of residual near-surface current speed component in the direction of hub height winds and hub height wind speeds, location Ec1. .... | 24 |
| Figure 8.1: Scatter plot of wind-wave misalignment versus wind-speed, total sea-state, location E2. ....                                                      | 27 |
| Figure 8.2: Scatter plot of wind-wave misalignment versus wind-speed, swell, location E2. ....                                                                | 28 |
| Figure 8.3: Scatter plot of wind-wave misalignment versus wind-speed, wind-sea, location E2.....                                                              | 29 |
| Figure 9.1: Hm0 for NSS, wind-sea, location E2.....                                                                                                           | 31 |
| Figure 9.2: Hm0 for NSS, swell, location E2. ....                                                                                                             | 32 |
| Figure 9.3: Hm0-Tp relationships for NSS, wind-sea, location E2.....                                                                                          | 33 |
| Figure 9.4: Hm0-Tp relationships for NSS, swell, location E2. ....                                                                                            | 34 |
| Figure 10.1: Extrapolation of omni-directional depth-average total current speed, location Ec1.....                                                           | 35 |
| Figure 10.2: Extrapolation of omni-directional depth-average total current speed, location Ec2.....                                                           | 36 |
| Figure 10.3: Extrapolation of omni-directional depth-average total current speed, location Ez1. ....                                                          | 36 |
| Figure 10.4: Extrapolation of omni-directional depth-average total current speed, location E3.....                                                            | 37 |
| Figure 10.5: Extrapolation of directional depth-average total current speed, location Ec1. ....                                                               | 38 |
| Figure 10.6: Extrapolation of directional depth-average total current speed, location Ec2. ....                                                               | 39 |
| Figure 10.7: Extrapolation of directional depth-average total current speed, location Ez1. ....                                                               | 40 |
| Figure 10.8: Extrapolation of directional depth-average total current speed, location E3. ....                                                                | 41 |
| Figure 11.1: Extrapolation of omni-directional total Hm0, location E1.....                                                                                    | 43 |
| Figure 11.2: Extrapolation of omni-directional total Hm0, location E2.....                                                                                    | 43 |
| Figure 11.3: Extrapolation of omni-directional total Hm0, location E3.....                                                                                    | 44 |
| Figure 11.4: Extrapolation of omni-directional total Hm0, location E4.....                                                                                    | 44 |
| Figure 11.5: Extrapolation of directional total Hm0, location E1. ....                                                                                        | 45 |
| Figure 11.6: Extrapolation of directional total Hm0, location E2. ....                                                                                        | 46 |
| Figure 11.7: Extrapolation of directional total Hm0, location E3. ....                                                                                        | 47 |

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## Metocean Analysis Eastern Zone – Arklow Bank Wind Park Phase 2

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|                                                                                                                        |    |
|------------------------------------------------------------------------------------------------------------------------|----|
| Figure 11.8: Extrapolation of directional total $H_{m0}$ , location E4. ....                                           | 48 |
| Figure 11.9: Extrapolation of omni-directional total $H_{mp}$ (Forristall deep water distribution), location E1. ....  | 49 |
| Figure 11.10: Extrapolation of omni-directional total $H_{mp}$ (Forristall deep water distribution), location E2. ...  | 49 |
| Figure 11.11: Extrapolation of omni-directional total $H_{mp}$ (Glukhovskiy distribution (Klopman)), location E3. .... | 50 |
| Figure 11.12: Extrapolation of omni-directional total $H_{mp}$ (Forristall deep water distribution), location E4. ...  | 50 |
| Figure 11.13: Extrapolation of omni-directional total $C_{mp}$ (Forristall 3D distribution), location E1.....          | 51 |
| Figure 11.14: Extrapolation of omni-directional total $C_{mp}$ (Forristall 3D distribution), location E2.....          | 51 |
| Figure 11.15: Extrapolation of omni-directional total $C_{mp}$ (Forristall 3D distribution), location E3.....          | 52 |
| Figure 11.16: Extrapolation of omni-directional total $C_{mp}$ (Forristall 3D distribution), location E4.....          | 52 |
| Figure 11.17: Omni-directional and directional relationships between total $H_{m0}$ and $T_{m02}$ , location E1. ....  | 53 |
| Figure 11.18: Omni-directional and directional relationships between total $H_{m0}$ and $T_p$ , location E1. ....      | 54 |
| Figure 11.19: Omni-directional and directional relationships between total $H_{m0}$ and $T_{m02}$ , location E2. ....  | 55 |
| Figure 11.20: Omni-directional and directional relationships between total $H_{m0}$ and $T_p$ , location E2. ....      | 56 |
| Figure 11.21: Omni-directional and directional relationships between total $H_{m0}$ and $T_{m02}$ , location E3. ....  | 57 |
| Figure 11.22: Omni-directional and directional relationships between total $H_{m0}$ and $T_p$ , location E3. ....      | 58 |
| Figure 11.23: Omni-directional and directional relationships between total $H_{m0}$ and $T_{m02}$ , location E4. ....  | 59 |
| Figure 11.24: Omni-directional and directional relationships between total $H_{m0}$ and $T_p$ , location E4. ....      | 60 |
| Figure 12.1: Omni-directional extreme depth averaged current speeds, locations Ec1, Ec2, Ez1 and E3.....               | 61 |
| Figure 12.2: Directional extreme depth averaged current speeds, locations Ec1, Ec2, Ez1 and E3. ....                   | 62 |
| Figure 12.3: Omni-directional extreme significant wave heights, locations E1, E2, E3 and E4. ....                      | 62 |
| Figure 12.4: Directional extreme significant wave heights, locations E1, E2, E3 and E4. ....                           | 63 |
| Figure 12.5: Omni-directional maximum wave heights, locations E1, E2, E3 and E4. ....                                  | 63 |
| Figure 12.6: Omni-directional maximum crest heights, relative to still water level, locations E1, E2, E3 and E4. ....  | 64 |
| Figure 12.7: Omni-directional maximum crest heights, relative to LAT, locations E1, E2, E3 and E4. ....                | 64 |
| Figure 13.1: Significant Wave Height contour for the SSS, location E1. ....                                            | 65 |
| Figure 13.2: Peak period relationship for the SSS, location E1. ....                                                   | 66 |
| Figure 14.1: Percentiles of hub height wind speeds conditional on $H_{m0}$ . ....                                      | 68 |
| Figure 14.2: 1- and 50-year IFORM contours of hub height wind speeds conditional on $H_{m0}$ .....                     | 68 |
| Figure 14.3: Percentiles of positive still water levels conditional on $H_{m0}$ . ....                                 | 69 |
| Figure 14.4: 1- and 50-year IFORM contours of positive water levels conditional on $H_{m0}$ . ....                     | 69 |
| Figure 14.5: Percentiles of negative still water levels conditional on $H_{m0}$ . ....                                 | 70 |
| Figure 14.6: 1- and 50-year IFORM contours of negative water levels conditional on $H_{m0}$ . ....                     | 70 |
| Figure 14.7: Percentiles of $H_{m0}$ conditional on hub height wind speed. ....                                        | 72 |
| Figure 14.8: 1- and 50-year IFORM contours of $H_{m0}$ conditional on hub height wind speed. ....                      | 72 |
| Figure 14.9: Percentiles of positive still water levels conditional on hub height wind speed. ....                     | 73 |
| Figure 14.10: 1- and 50-year IFORM contours of positive water levels conditional on hub height wind speed. ....        | 73 |
| Figure 14.11: Percentiles of negative still water levels conditional on hub height wind speed. ....                    | 74 |
| Figure 14.12: 1- and 50-year IFORM contours of negative water levels conditional on hub height wind speed. ....        | 74 |

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## List of Tables

|                                     |    |
|-------------------------------------|----|
| Table 4.1: Analysis Locations. .... | 13 |
|-------------------------------------|----|



## 2 Units and Conventions

### 2.1 Units and Conventions

The following list describes the units and conventions used in this report. Unless stated otherwise, units have been expressed using the SI convention.

- Wind direction is expressed in compass points or degrees, relative to true North [°T], and describes the direction **from** which the winds are blowing.
- Wind speeds are expressed in metres per second [m/s].
- Wave direction is expressed in compass points or degrees, relative to true North [°T], and describes the direction **from** which the waves are propagating.
- Wave heights are expressed in metres [m].
- Wave periods are expressed in seconds [s].
- Current direction is expressed in compass points or degrees, relative to true North [°T], and describes the direction **towards** which the currents are flowing.
- Current speeds are expressed in metres per second [m/s].
- Water levels are expressed in metres [m].
- Positions are quoted relative to WGS 84 except where stated.
- All times are quoted in Coordinated Universal Time [UTC].

### 2.2 Glossary of commonly used metocean terms

The following list describes common metocean terms used throughout this report.

| Winds                                            | Description                                                                                                                                                                                                 |
|--------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| ASL                                              | Above Sea Level. Refers to the height of the wind measurements above sea level.                                                                                                                             |
| U <sub>3-hr</sub>                                | Mean wind speed averaged over a 3-hour period at 10 m ASL.                                                                                                                                                  |
| Wind gust                                        | Wind speeds persisting for less than 1 minute are generally termed wind gusts.                                                                                                                              |
| Wind speed                                       | Magnitude of local wind flow. Must be accompanied by an elevation ASL and averaging period for valid interpretation.                                                                                        |
| Waves                                            | Description                                                                                                                                                                                                 |
| C <sub>max</sub>                                 | The maximum individual wave crest elevation occurring within a defined period.                                                                                                                              |
| C <sub>mp</sub>                                  | The most probable maximum individual wave crest elevation occurring within a storm.                                                                                                                         |
| H <sub>max</sub>                                 | The maximum individual wave height occurring within a defined period.                                                                                                                                       |
| H <sub>mp</sub>                                  | The most probable maximum individual wave height occurring within a storm.                                                                                                                                  |
| H <sub>m0</sub>                                  | Significant wave height. Approximately the average height of the highest one third of the waves in a defined period, estimated from the wave spectrum as $4\sqrt{m_0}$ .                                    |
| m <sub>0</sub> , m <sub>1</sub> , m <sub>2</sub> | The zeroth, first and second moments of the wave spectrum respectively.                                                                                                                                     |
| Significant steepness                            | A measure of the steepness of the sea state, though with no precise physical meaning. Calculated from the wave spectrum as $\frac{2\pi H_{m0}}{g T_{m02}^2}$ where $g$ denotes the acceleration of gravity. |
| T <sub>ass</sub>                                 | The period associated with H <sub>max</sub> .                                                                                                                                                               |



## Metocean Analysis Eastern Zone – Arklow Bank Wind Park Phase 2

| Tp                   | The spectral peak period. The period at which most energy is present in the wave spectrum.                                                                                                                                   |
|----------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Tm02                 | The mean zero-crossing wave period. Estimated from the wave spectrum as $\sqrt{m_0/m_2}$ .                                                                                                                                   |
| Wave crest elevation | The vertical distance between the still water level and the maximum elevation of an individual wave.                                                                                                                         |
| Wave height          | The vertical distance between the minimum and maximum elevations of an individual wave.                                                                                                                                      |
| Levels               | Description                                                                                                                                                                                                                  |
| ETWL                 | Extreme Total Water Level.                                                                                                                                                                                                   |
| HAT                  | Highest Astronomical Tide. Maximum level of sea surface due to tidal forcing alone.                                                                                                                                          |
| LAT                  | Lowest Astronomical Tide. Minimum level of sea surface due to tidal forcing alone.                                                                                                                                           |
| MHW                  | Mean High Water. Mean of all high water levels.                                                                                                                                                                              |
| MHWN                 | Mean High Water Neap. Mean high water level during neap phase of tidal cycle.                                                                                                                                                |
| MHWS                 | Mean High Water Spring. Mean high water level during spring phase of tidal cycle.                                                                                                                                            |
| MLW                  | Mean Low Water. Mean of all low water levels.                                                                                                                                                                                |
| MLWN                 | Mean Low Water Neap. Mean low water level during neap phase of tidal cycle.                                                                                                                                                  |
| MLWS                 | Mean Low Water Spring. Mean low water level during spring phase of tidal cycle.                                                                                                                                              |
| MSL                  | Mean Sea Level. Mean sea surface elevation over a prolonged period of time.                                                                                                                                                  |
| Still water level    | Instantaneous water level in the absence of waves, but including water level variations due to tide and meteorologically induced forcing.                                                                                    |
| Surge level          | Difference between the tidal level estimated by harmonic analysis/prediction and the actual level. Includes any errors due to failure to adequately resolve the tidal signal. Includes meteorologically induced storm surge. |
| Tidal level          | Still water level relative to a defined datum due to astronomical forcing. Tidal elevations exclude all meteorologically induced forcing.                                                                                    |
| Currents             | Description                                                                                                                                                                                                                  |
| Current speed        | Magnitude of local current flow.                                                                                                                                                                                             |
| Tidal current        | Current driven by astronomical forcing.                                                                                                                                                                                      |
| Total current        | Combination of tidal and residual current.                                                                                                                                                                                   |
| Residual current     | Current driven by processes excluding astronomical forcing and wave induced motions.                                                                                                                                         |



## 3 Introduction

### 3.1 Background

SPL contracted MetOceanWorks to conduct a suite of analyses to quantify the normal and extreme oceanographic conditions at the Arklow Bank Wind Farm Phase 2 (AWBF). For the purposes of these analyses, the lease area has been split into the three Zones shown in Figure 3.1. This document contains a number of diagnostic plots and tables to support the analyses for the Eastern Zone. Results of the analyses themselves can be found in the Microsoft Excel Spreadsheet SSE\_C00004\_R05\_Metocean\_Input\_For\_Design\_East.xlsx. Where possible, duplication of results through their inclusion in this document is avoided.

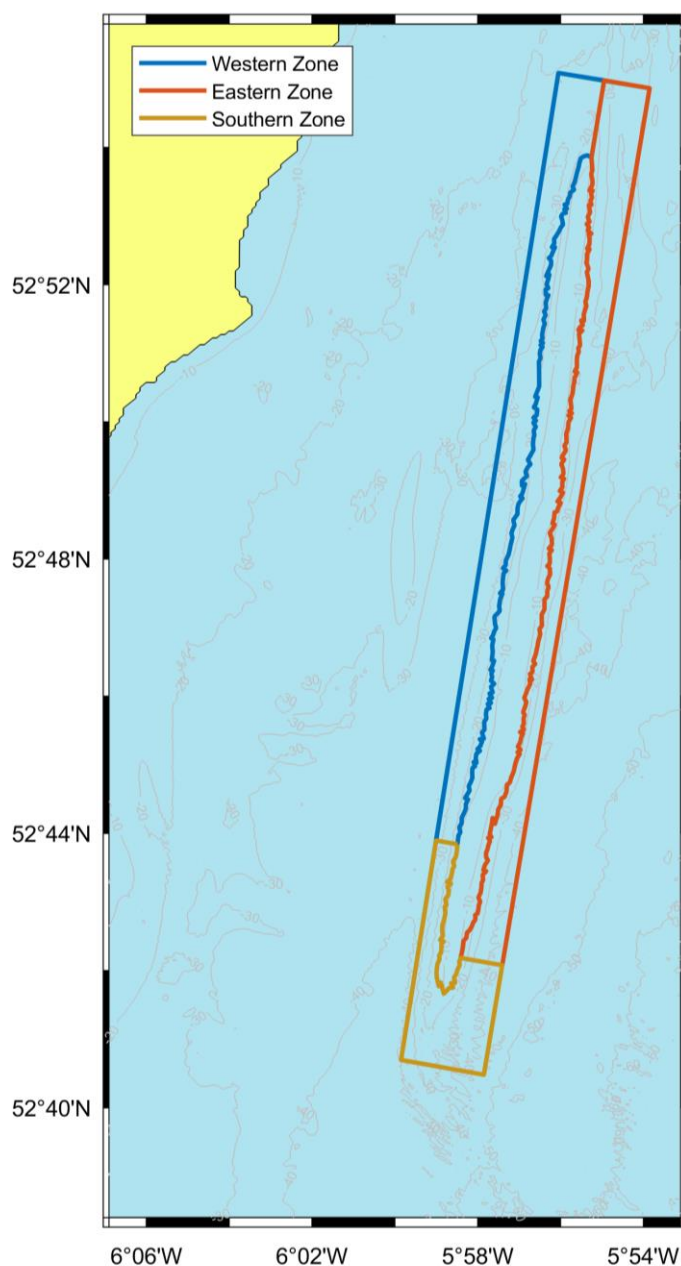


Figure 3.1: Analysis zones.



## 3.2 Report Structure

This document forms only one part of the full analysis report. For convenience, methodology details and the results of analyses are split across a number of documents as follows:

- **Metocean Analysis Overview (SSE\_C00004\_Rxx\_Metocean\_Analysis\_Overview):** Describes the data sources and analysis methods used to derive the criteria presented in all other documents.
- The Microsoft Excel spreadsheet **SSE\_C00004\_Rxx\_Metocean\_Input\_For\_Design\_East.xlsx** provides analysis results for the Eastern Zone of the wind farm. The document **Metocean Analysis for Site Assessment: Eastern Zone (SSE\_C00004\_Rxx\_Metocean\_Input\_For\_Design\_East.pdf)** provides a number of diagnostic plots and tables related to the results.
- The Microsoft Excel spreadsheet **SSE\_C00004\_Rxx\_Metocean\_Input\_For\_Design\_West.xlsx** provides analysis results for the Western Zone of the wind farm. It is accompanied by **Metocean Analysis for Site Assessment: Western Zone (SSE\_C00004\_Rxx\_Metocean\_Input\_For\_Design\_West.pdf)**, containing a number of diagnostic plots related to the results.
- The Microsoft Excel spreadsheet **SSE\_C00004\_Rxx\_Metocean\_Input\_For\_Design\_South.xlsx** provides analysis results for the Southern Zone of the wind farm. It is accompanied by **Metocean Analysis for Site Assessment: Southern Zone (SSE\_C00004\_Rxx\_Metocean\_Input\_For\_Design\_South.pdf)**, containing a number of diagnostic plots related to the results.

Throughout, Rxx denotes the report revision, for example R01 is used for the first revision, R02 for the second, etc.



## 4 Analysis Locations

Details of the selection of locations for analysis can be found in Section 4 of the “Arklow Bank Wind Park Phase 2; Metocean Analysis for Site Assessment: Overview” (SSE\_C00004\_R05\_Metocean\_Analysis\_Overview). Those used for analysis in the Eastern Zone are shown in Table 4.1, and Figure 4.1.

Table 4.1: Analysis Locations.

| Location ID | Latitude  | Longitude | MSL Depth [m] | Usage in Design Statistics                                                                  |
|-------------|-----------|-----------|---------------|---------------------------------------------------------------------------------------------|
| E1          | 52.894° N | 5.903° W  | 34.2          | Extreme waves<br>Severe Sea States                                                          |
| E2          | 52.707° N | 5.957° W  | 42.3          | Extreme waves<br>Wind vs wave directionality<br>Wind-wave misalignment<br>Normal Sea States |
| E3          | 52.707° N | 5.972° W  | 13.9          | Extreme waves<br>Extreme currents                                                           |
| E4          | 52.718° N | 5.955° W  | 43.6          | Extreme waves                                                                               |
| Ec1         | 52.914° N | 5.908° W  | 34.7          | All current statistics                                                                      |
| Ec2         | 52.914° N | 5.898° W  | 30.0          | Extreme currents                                                                            |
| Ez1         | 52.916° N | 5.915° W  | 29.2          | All water level statistics<br>Extreme currents                                              |

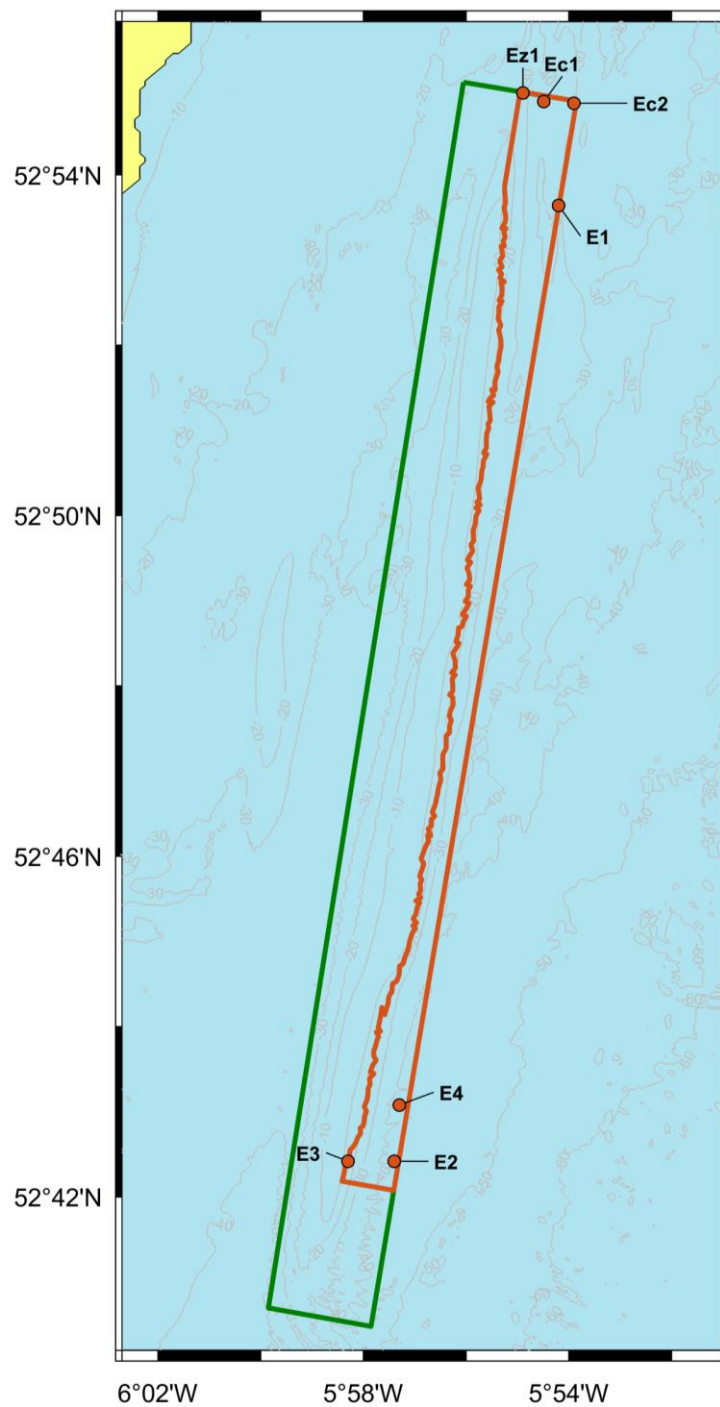


Figure 4.1: Analysis locations.



## 5 Water Level Criteria

This Section contains supplementary information and diagnostics for the worksheet “1-Levels” of the Microsoft Excel Spreadsheet SSE\_C00004\_R05\_Metocean\_Input\_For\_Design\_East.xlsx.

### 5.1 Data Sources

All water level statistics were derived from modelled hindcast data for the location Ez1.

### 5.2 VORF

The Lowest Astronomical Tide (LAT) calculated from the hindcast data was determined to be 1.38 m below MSL. However, as requested by SPL, this has been substituted with a value taken from the Vertical Offshore Reference Frames project (VORF). This value, of 1.33 m, is taken from the closest available VORF location to Ez1.

The user is advised that the MSL to LAT separation varies spatially, however a fixed separation may be defined as part of the turbine foundation design process, and this is unlikely to be the same as the 1.33 m value noted herein.

### 5.3 Water levels and Significant Wave Heights

A scatter plot of simultaneous significant wave heights and water levels is shown in Figure 5.1. This suggests that extreme waves and water levels are likely to occur at the same time. As a result, the more conservative approach described in ISO 19902, Equation 2, is used for the derivation of extreme water levels.

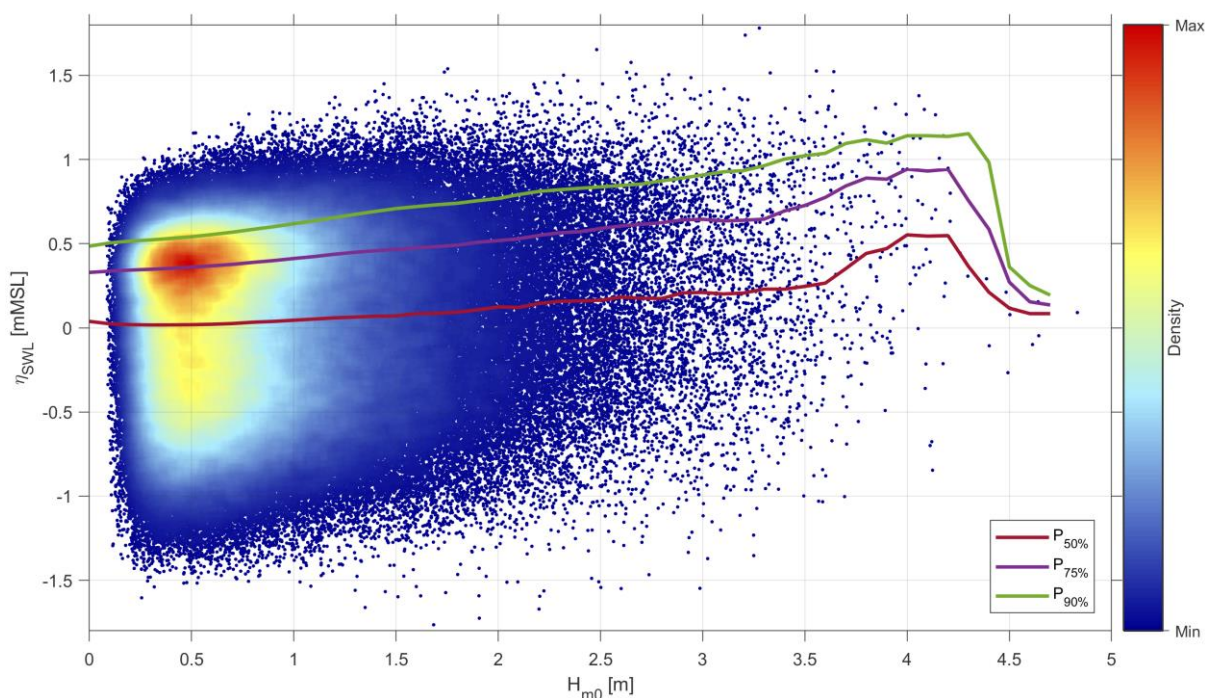


Figure 5.1: Relationship between significant wave height and still water level (tide + surge) relative to MSL, location Ez1.



## 5.4 Extrapolation for Extreme Water Levels

Extrapolations used to derive extreme criteria for water levels are shown in Figure 5.2 through Figure 5.5.

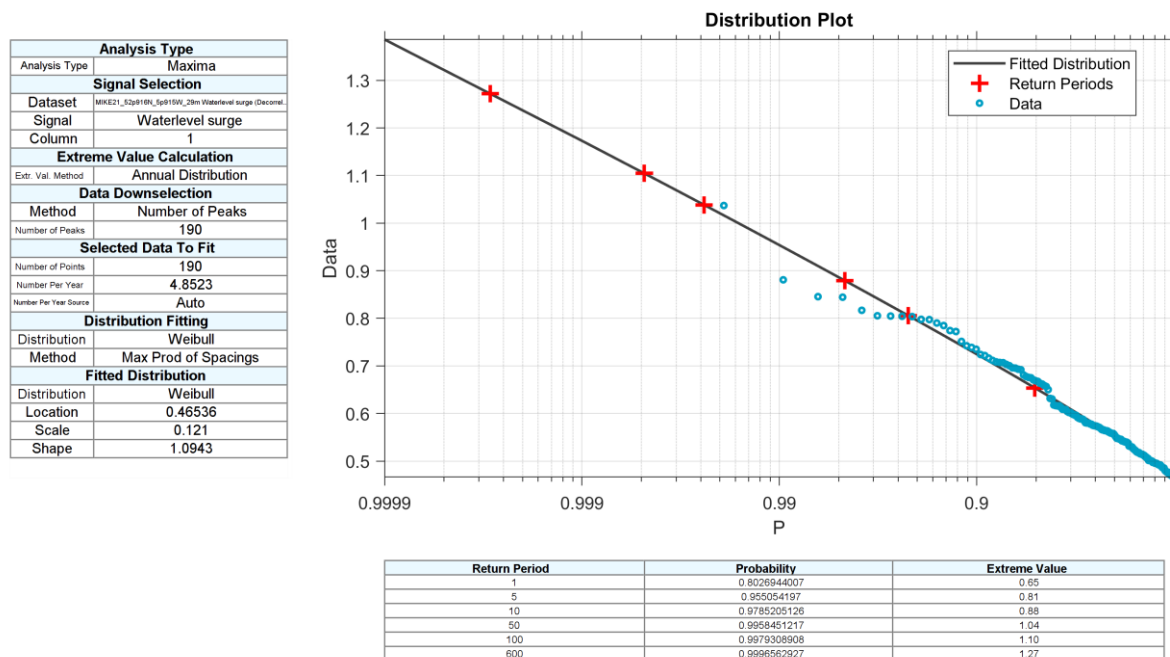


Figure 5.2: Extrapolation of positive surge relative to MSL, location Ez1.

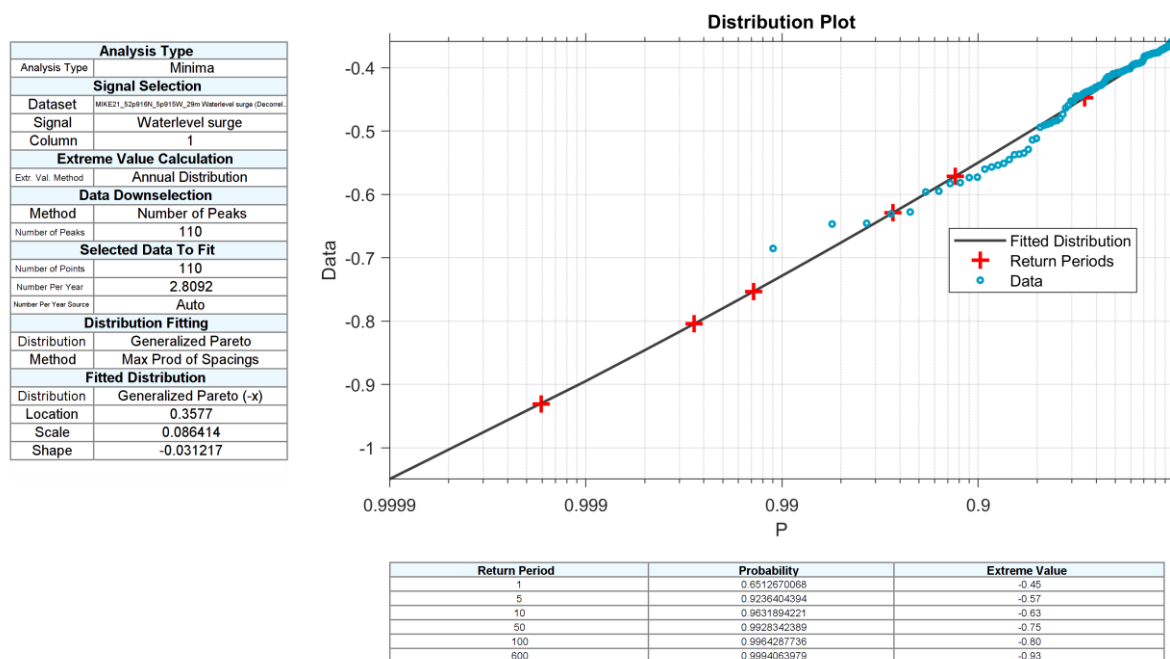
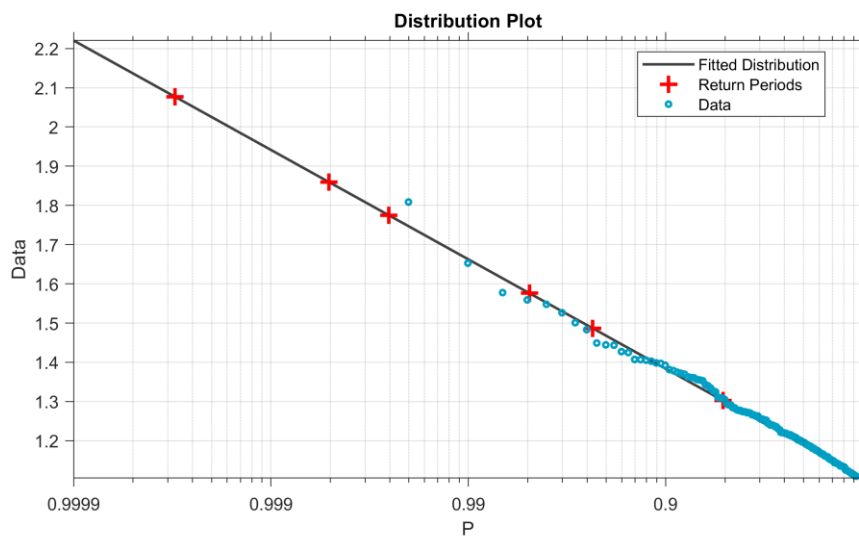


Figure 5.3: Extrapolation of negative surge relative to MSL, location Ez1.



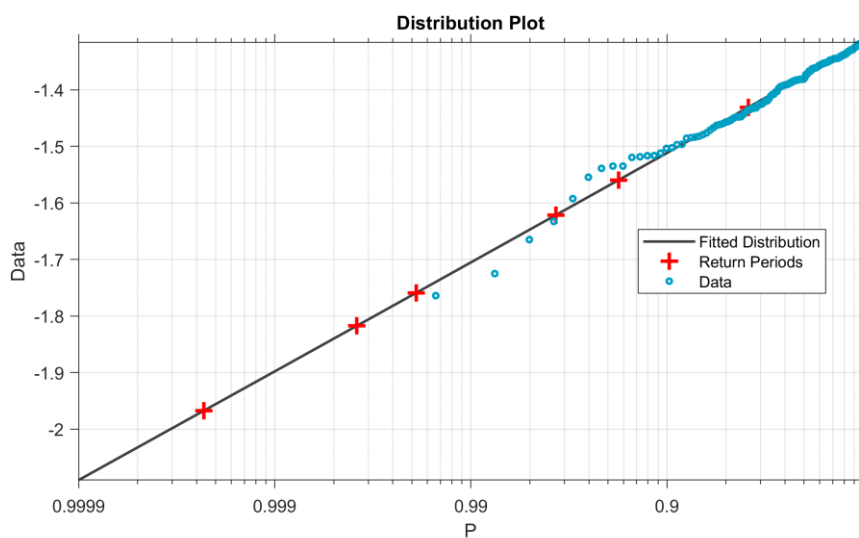
| Analysis Type             |                                                   |
|---------------------------|---------------------------------------------------|
| Analysis Type             | Maxima                                            |
| Signal Selection          |                                                   |
| Dataset                   | MIKE21_S2p918L_Sp015V_20m Waterlevel (Decomlated) |
| Signal                    | Waterlevel                                        |
| Column                    | 1                                                 |
| Extreme Value Calculation |                                                   |
| Extr. Val. Method         | Annual Distribution                               |
| Data Downselection        |                                                   |
| Method                    | Number of Peaks                                   |
| Number of Peaks           | 200                                               |
| Selected Data To Fit      |                                                   |
| Number of Points          | 200                                               |
| Number Per Year           | 5.1077                                            |
| Number Per Year Source    | Auto                                              |
| Distribution Fitting      |                                                   |
| Distribution              | Exponential                                       |
| Method                    | L-Moments                                         |
| Fitted Distribution       |                                                   |
| Distribution              | Exponential                                       |
| Location                  | 1.1047                                            |
| Scale                     | 0.12113                                           |



| Return Period | Probability  | Extreme Value |
|---------------|--------------|---------------|
| 1             | 0.8042164526 | 1.30          |
| 5             | 0.9572527366 | 1.49          |
| 10            | 0.9795834462 | 1.58          |
| 50            | 0.9960524655 | 1.78          |
| 100           | 0.9980342445 | 1.86          |
| 600           | 0.9996734752 | 2.08          |

Figure 5.4: Extrapolation of positive still water level relative to MSL, location Ez1.

| Analysis Type             |                                                   |
|---------------------------|---------------------------------------------------|
| Analysis Type             | Minima                                            |
| Signal Selection          |                                                   |
| Dataset                   | MIKE21_S2p918L_Sp015V_20m Waterlevel (Decomlated) |
| Signal                    | Waterlevel                                        |
| Column                    | 1                                                 |
| Extreme Value Calculation |                                                   |
| Extr. Val. Method         | Annual Distribution                               |
| Data Downselection        |                                                   |
| Method                    | Number of Peaks                                   |
| Number of Peaks           | 150                                               |
| Selected Data To Fit      |                                                   |
| Number of Points          | 150                                               |
| Number Per Year           | 3.8308                                            |
| Number Per Year Source    | Auto                                              |
| Distribution Fitting      |                                                   |
| Distribution              | Weibull                                           |
| Method                    | Max Prod of Spacings                              |
| Fitted Distribution       |                                                   |
| Distribution              | Weibull (-x)                                      |
| Location                  | 1.316                                             |
| Scale                     | 0.085605                                          |
| Shape                     | 1.0085                                            |



| Return Period | Probability  | Extreme Value |
|---------------|--------------|---------------|
| 1             | 0.7401569181 | -1.43         |
| 5             | 0.9434136495 | -1.56         |
| 10            | 0.9728709823 | -1.62         |
| 50            | 0.9947400726 | -1.76         |
| 100           | 0.9973798518 | -1.82         |
| 600           | 0.9995646573 | -1.97         |

Figure 5.5: Extrapolation of negative still water level relative to MSL, location Ez1.



## 5.5 Sea level changes

The UKCP18 and IPCC Fifth Assessment Report projections use Representative Concentration Pathways (RCPs) to describe four different 21<sup>st</sup> century scenarios of Greenhouse gas emissions and atmospheric concentrations, air pollutant emissions and land use. The reader is referred to Section 8 of the document “Metocean Data Overview: Arklow Bank Offshore Wind Farm” (document ref: SSE\_C00002\_R03\_Metocean\_Data\_Overview [1]) for full details on the various scenarios and their estimated impact on the lease area.

For this report, sea-level change has been based on the assumption of the P50 scenario of RCP 8.5 and a decommissioning date of 2060.



## 6 Currents

This Section contains supplementary information and diagnostics for the worksheet “2-Currents” of the Microsoft Excel Spreadsheet SSE\_C00004\_R05\_Metocean\_Input\_For\_Design\_East.xlsx. Please note that supporting material for the sheet “6a - Directional Extreme Cur” can be found in Section 10.

### 6.1 Data Sources

All current statistics were derived from modelled hindcast data for the location Ec1.

### 6.2 Current Rose

A rose plot showing depth-averaged current speed and direction at the location Ec1 is shown in Figure 6.1.

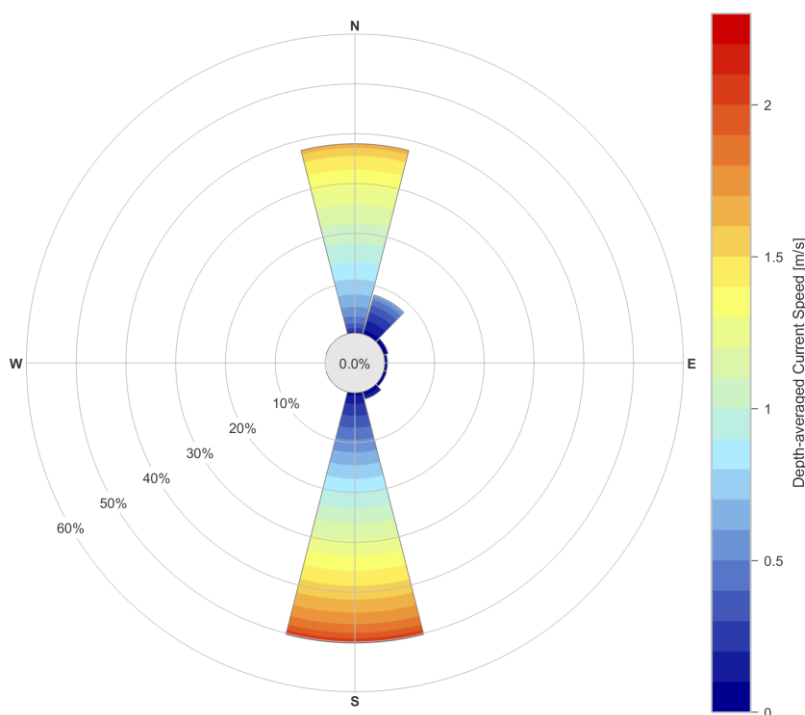


Figure 6.1: All-year rose plot of depth-average current speed and direction, location Ec1.

### 6.3 Joint Distribution of Current Speeds and Significant Wave Heights

Figure 6.2 shows a scatter plot of the depth-average current speed against significant wave height for the location Ec1. In Figure 6.3, only the component of the current speed aligned with the *mean* wave direction is plotted against significant wave height. This current speed component is given by:

$$CS_{DA,Aligned} = CS_{DA} \cdot \cos(\theta_{wave,mean} - \theta_{current} + 180^\circ)$$

Where  $CS_{DA}$  is the depth-averaged current speed,  $\theta_{wave,mean}$  the mean wave direction,  $\theta_{current}$  the direction of the depth-average current, and  $180^\circ$  is added to adjust for the difference in directional conventions between currents (towards) and waves (from).

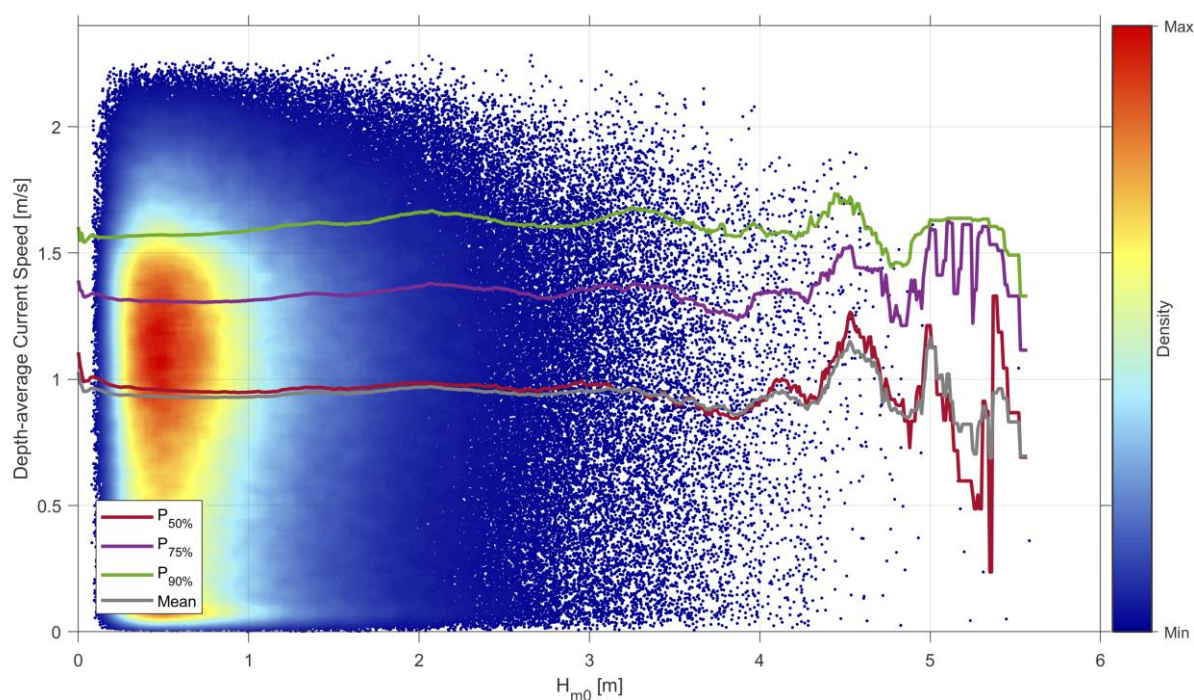


Figure 6.2: Scatter plot of depth-average current speed and  $H_{m0}$ , location Ec1.

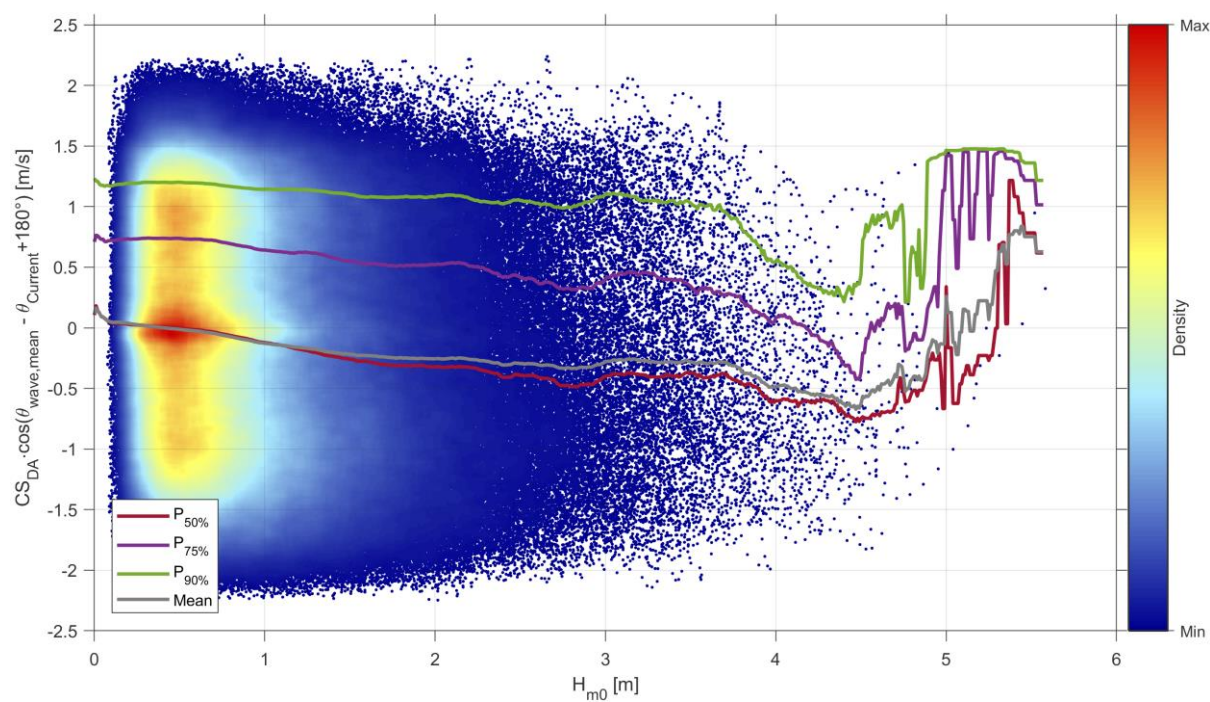


Figure 6.3: Scatter plot of depth-average current speed component in the direction of waves and  $H_{m0}$ , location Ec1.



## 6.4 Joint Distribution of Current Speeds and Hub Height Wind Speeds

Figure 6.4 shows a scatter plot of the near-surface (1 metre below surface) current speed against hub height wind speed for the location Ec1. Thereafter, Figure 6.5 and Figure 6.6 show tidal and residual components of near-surface current speeds against hub height wind speed for the same location.

Figure 6.7 through Figure 6.9 then show only the component of total, tidal and residual current speeds that are aligned with the hub height wind direction. This component is given by:

$$CS_{Aligned} = CS \cdot \cos(\theta_{wind,Hub} - \theta_{current} + 180^\circ)$$

Where  $CS$  is the appropriate near-surface current speed component,  $\theta_{wind,Hub}$  the hub height wind direction,  $\theta_{current}$  the direction of the appropriate current component, and  $180^\circ$  is added to adjust for the difference in directional conventions between currents (towards) and winds (from).

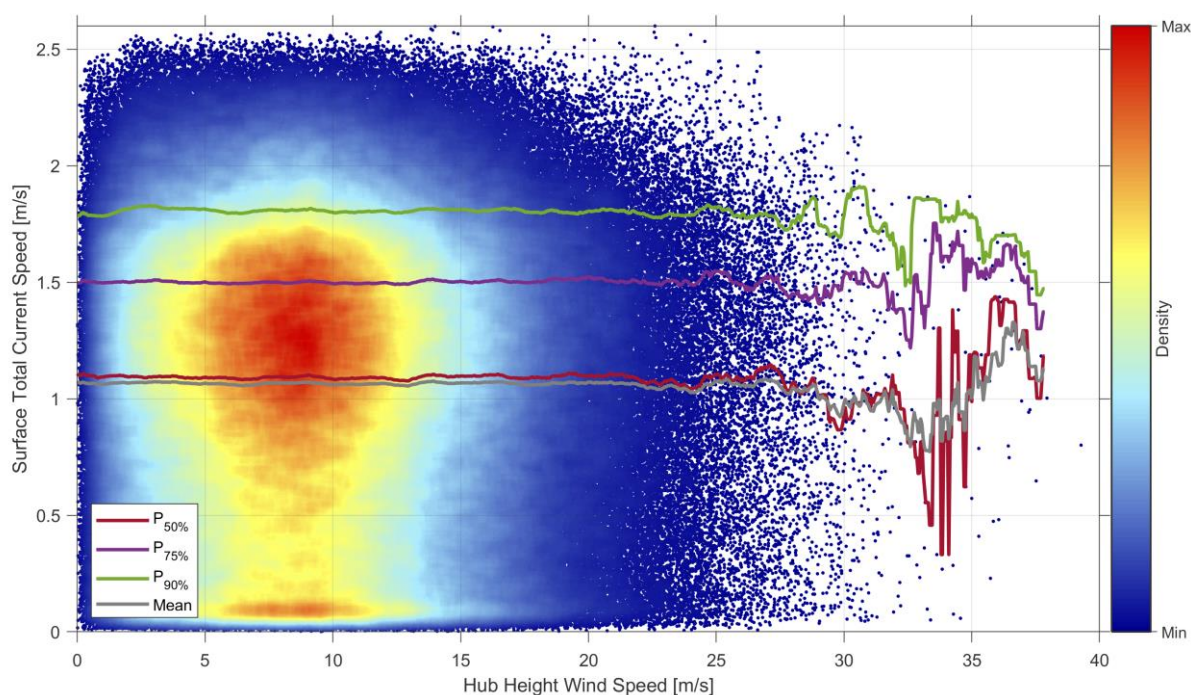


Figure 6.4: Scatter plot of total near-surface current speed and hub height wind speed, location Ec1.

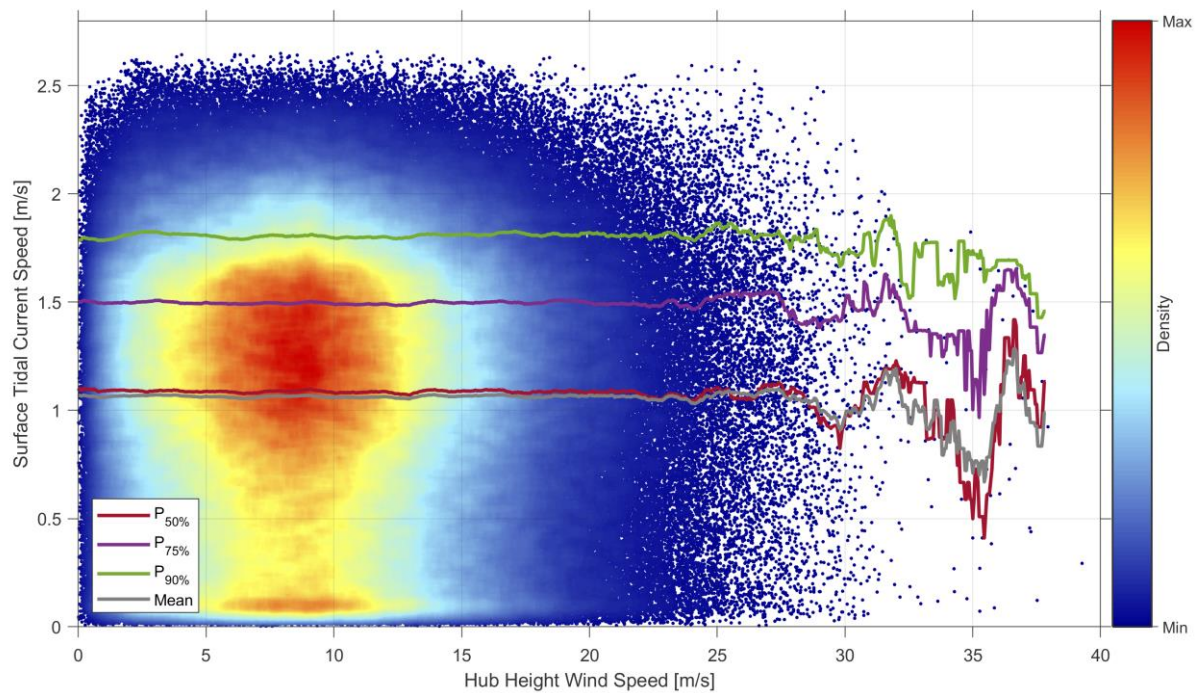


Figure 6.5: Scatter plot of tidal near-surface current speed and hub height wind speed, location Ec1.

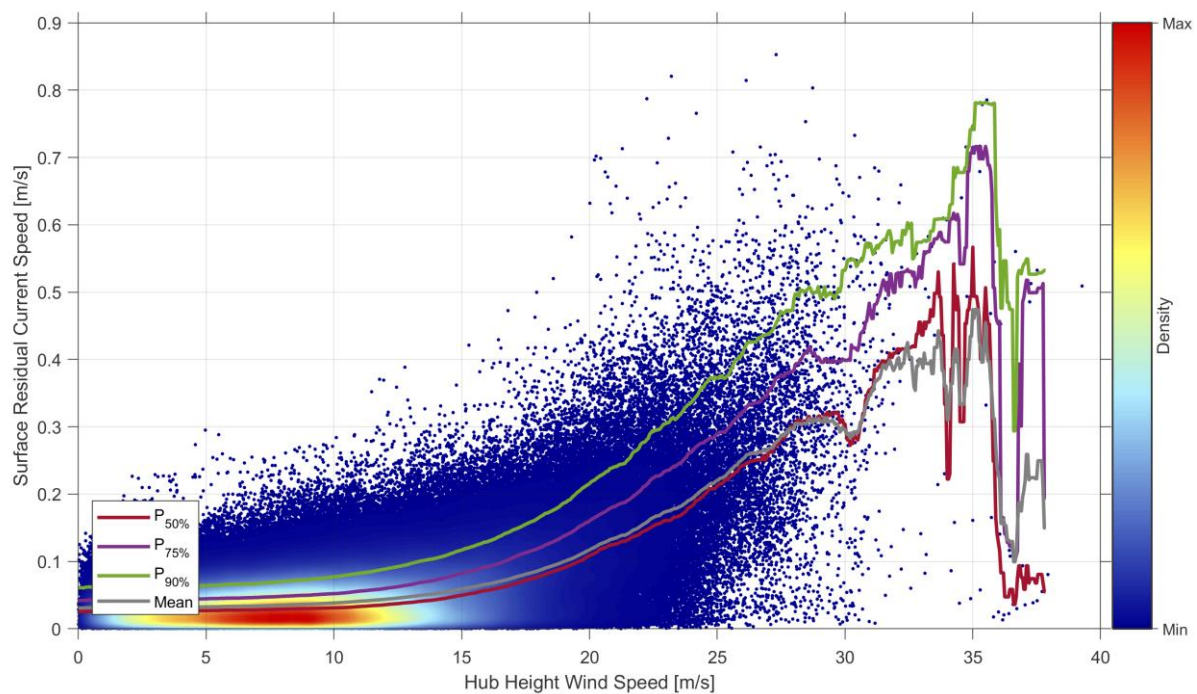


Figure 6.6: Scatter plot of residual near-surface current speed and hub height wind speed, location Ec1.

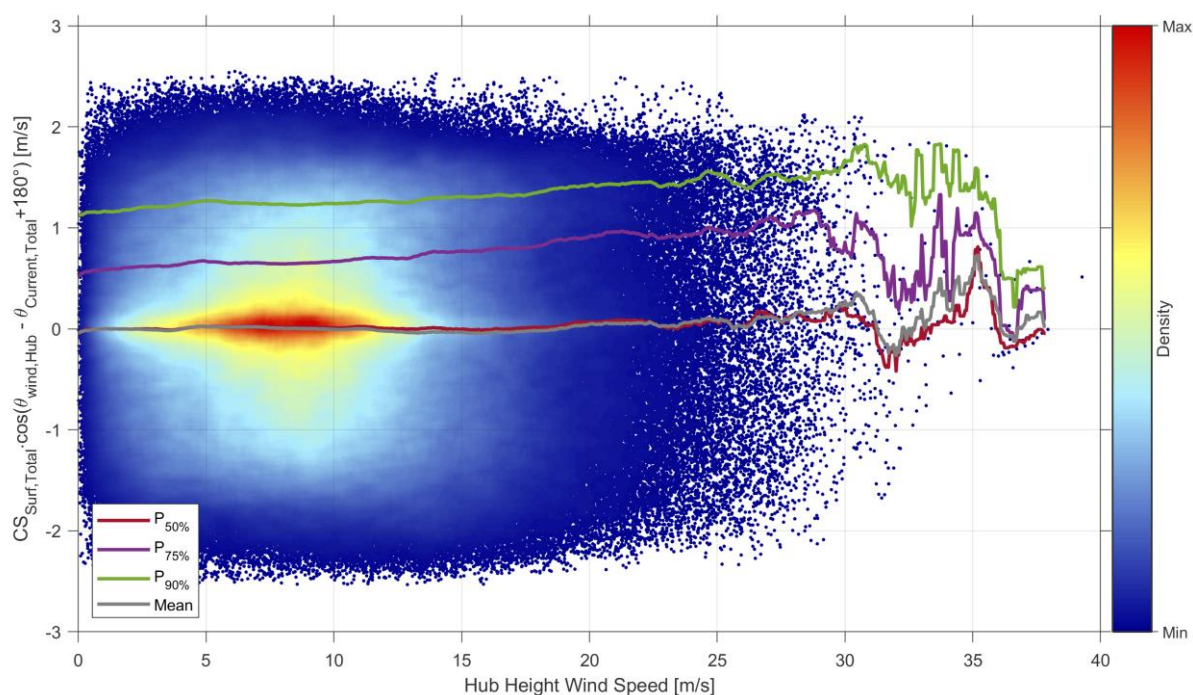


Figure 6.7: Scatter plot of total near-surface current speed component in the direction of hub height winds and hub height wind speeds, location Ec1.

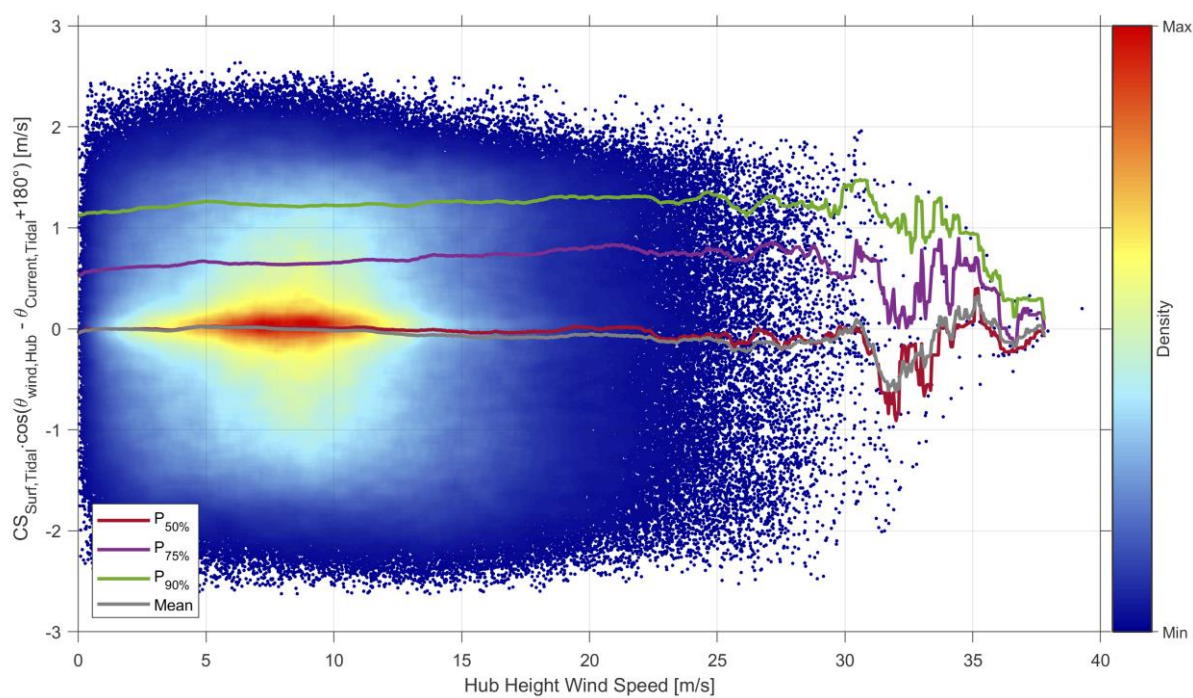


Figure 6.8: Scatter plot of tidal near-surface current speed component in the direction of hub height winds and hub height wind speeds, location Ec1.

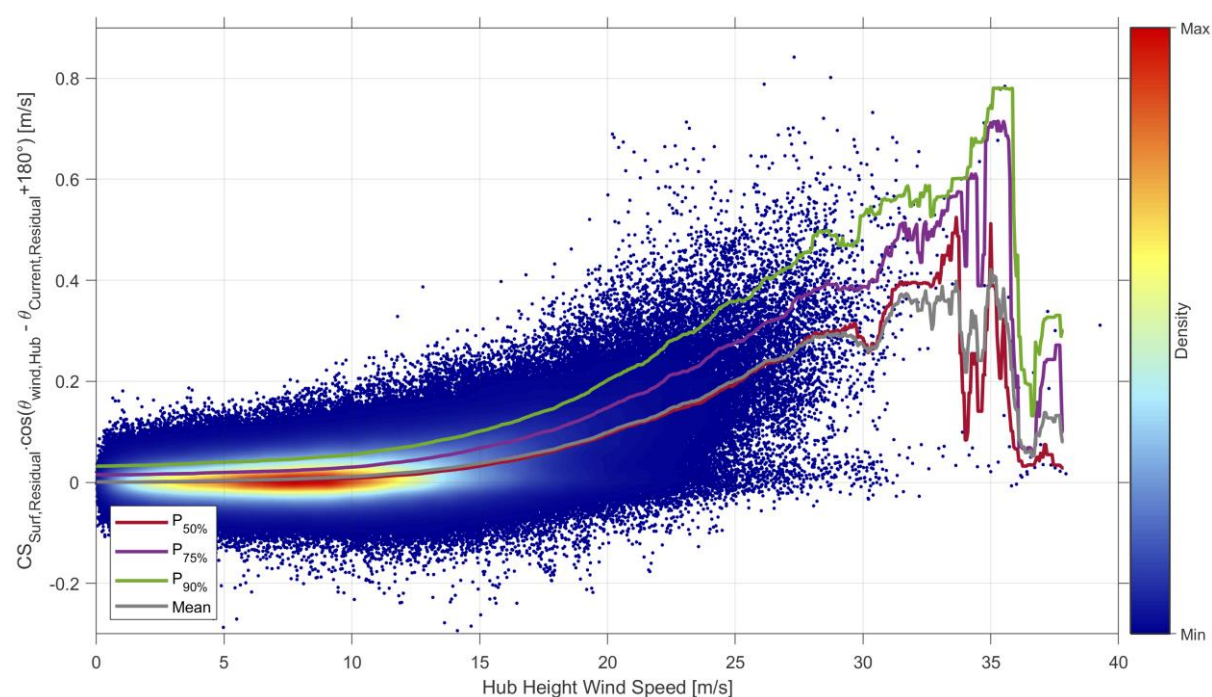


Figure 6.9: Scatter plot of residual near-surface current speed component in the direction of hub height winds and hub height wind speeds, location Ec1.



## 7 Wind-Wave Directionality

This Section contains supplementary information and diagnostics for the worksheet “3 Wind- Wave Directionality” of the Microsoft Excel Spreadsheet SSE\_C00004\_R05\_Metocean\_Input\_For\_Design\_East.xlsx.

### 7.1 Data Sources

All wind-wave directionality statistics were derived from modelled hindcast data for the location E2.



## 8 Misalignment

This Section contains supplementary information and diagnostics for the worksheet “4 - Misalignment” of the Microsoft Excel Spreadsheet SSE\_C00004\_R05\_Metocean\_Input\_For\_Design\_East.xlsx.

### 8.1 Data Sources

All misalignment statistics were derived from modelled hindcast data for the location E2.

### 8.2 Misalignment Scatter Plots

Scatter plots showing wind-wave misalignment against wind speed are shown for the total sea-state (i.e. combined wind-sea and swell) in Figure 8.1, for swell only in Figure 8.2 and for wind-sea in Figure 8.3.

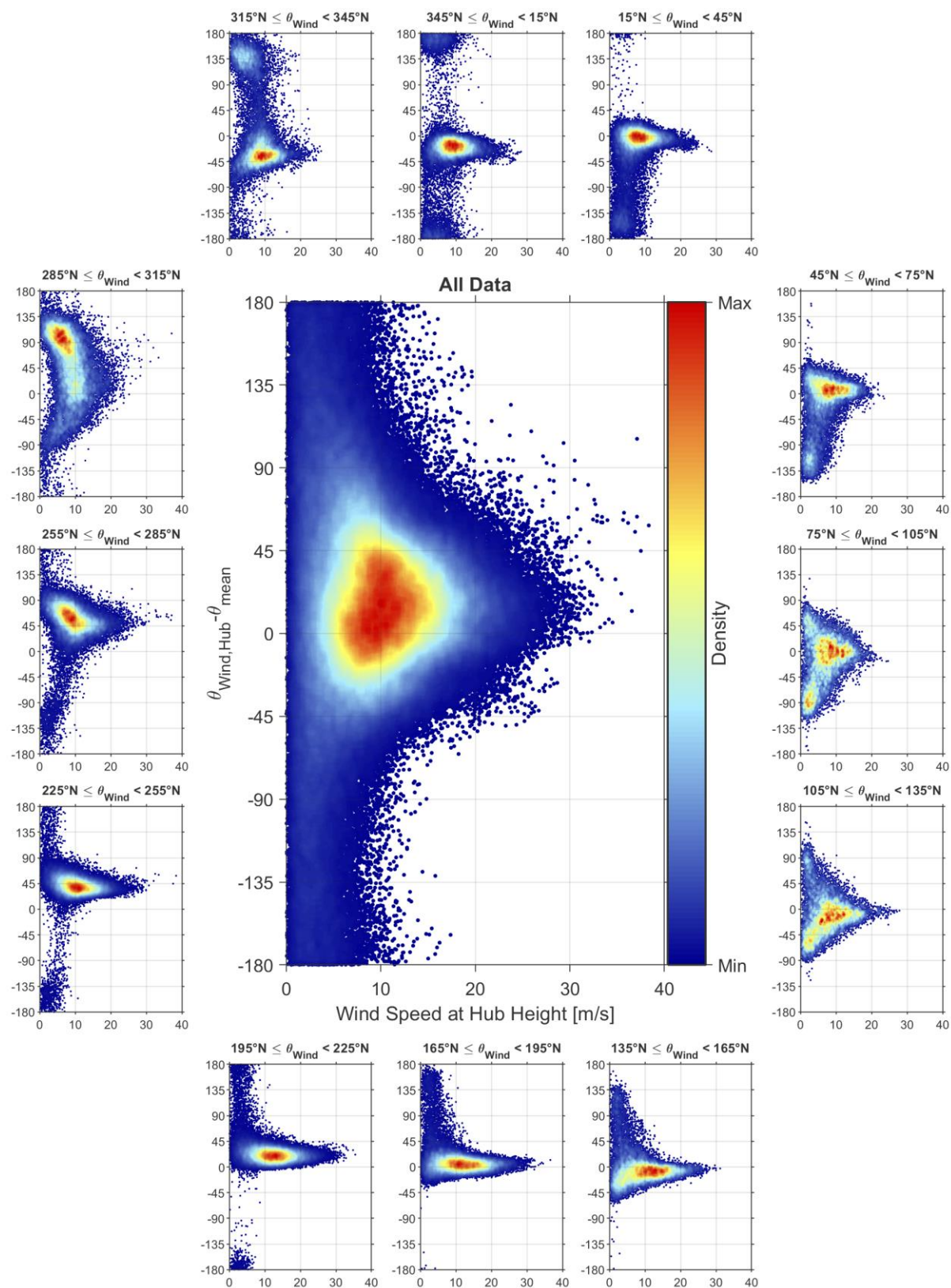


Figure 8.1: Scatter plot of wind-wave misalignment versus wind-speed, total sea-state, location E2.

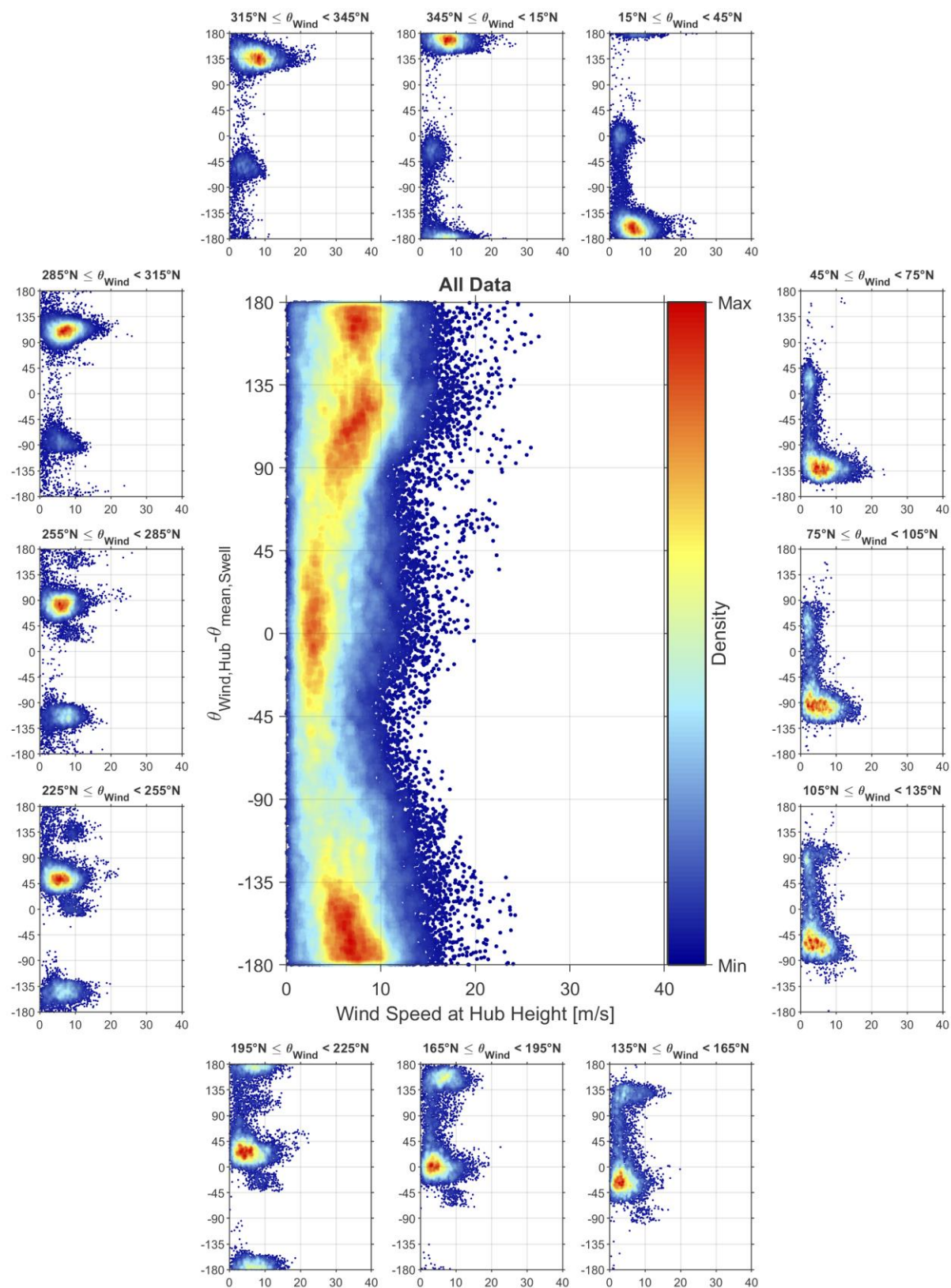


Figure 8.2: Scatter plot of wind-wave misalignment versus wind-speed, swell, location E2.

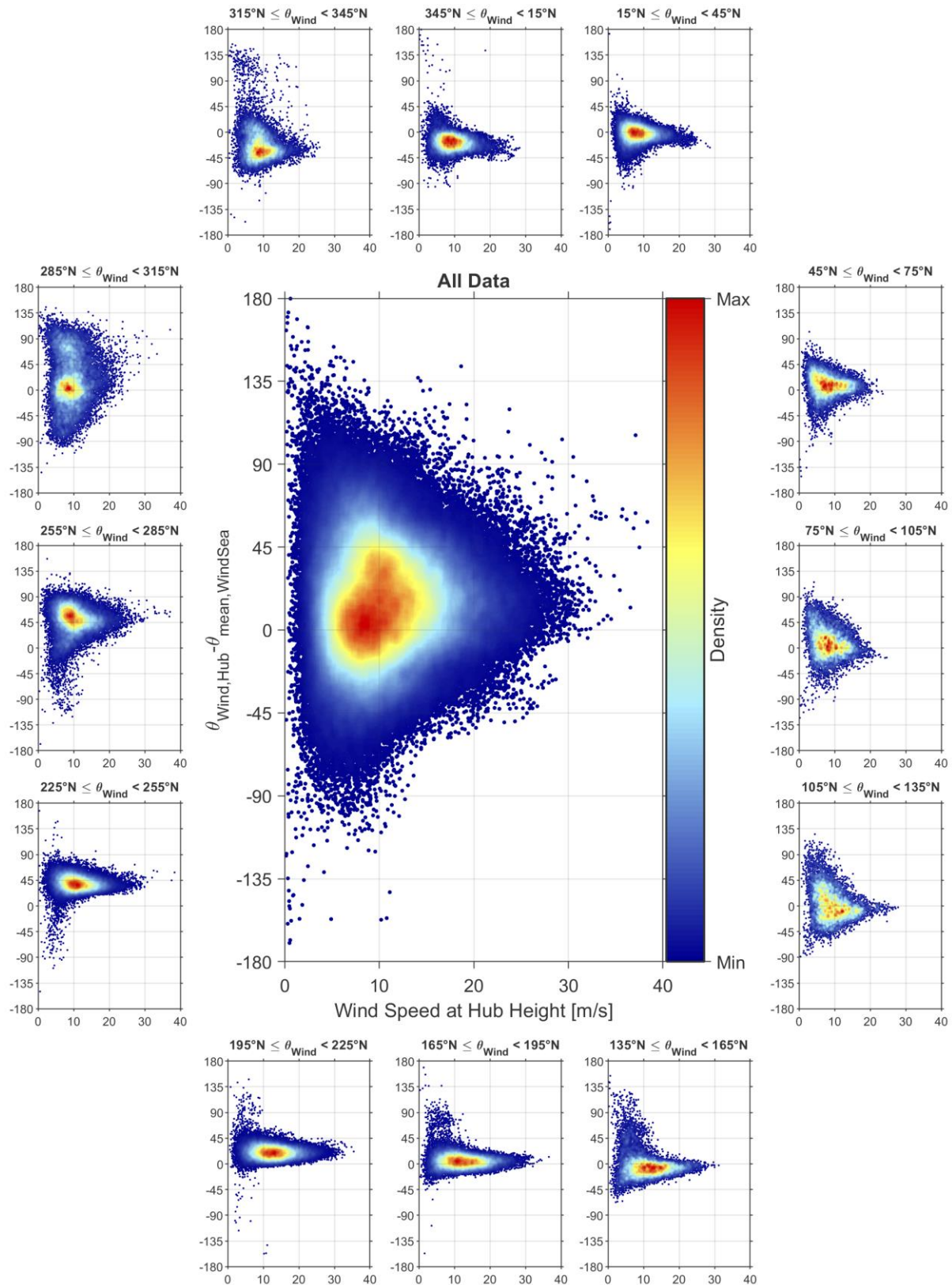


Figure 8.3: Scatter plot of wind-wave misalignment versus wind-speed, wind-sea, location E2.



## 9 Normal Sea States

This Section contains supplementary information and diagnostics for the worksheet “5 - Normal Sea States” of the Microsoft Excel Spreadsheet SSE\_C00004\_R05\_Metocean\_Input\_For\_Design\_East.xlsx.

### 9.1 Data Sources

All Normal Sea State (NSS) statistics were derived from modelled hindcast data for the location E2. Hub height wind data were subjected to a Weibull adjustment, as described in Section 5.2 of the Metocean Analysis Overview document, SSE\_C00004\_R05\_Metocean\_Analysis\_Overview.

### 9.2 NSS Significant Wave Height

Significant wave height values for the NSS are plotted against wind speed at hub height for wind-sea in Figure 9.1 and for swell in Figure 9.2.

### 9.3 NSS Peak Wave Period

The relationships between peak wave period and significant wave height for the NSS are shown in Figure 9.3 for wind-sea and in Figure 9.4 for swell.

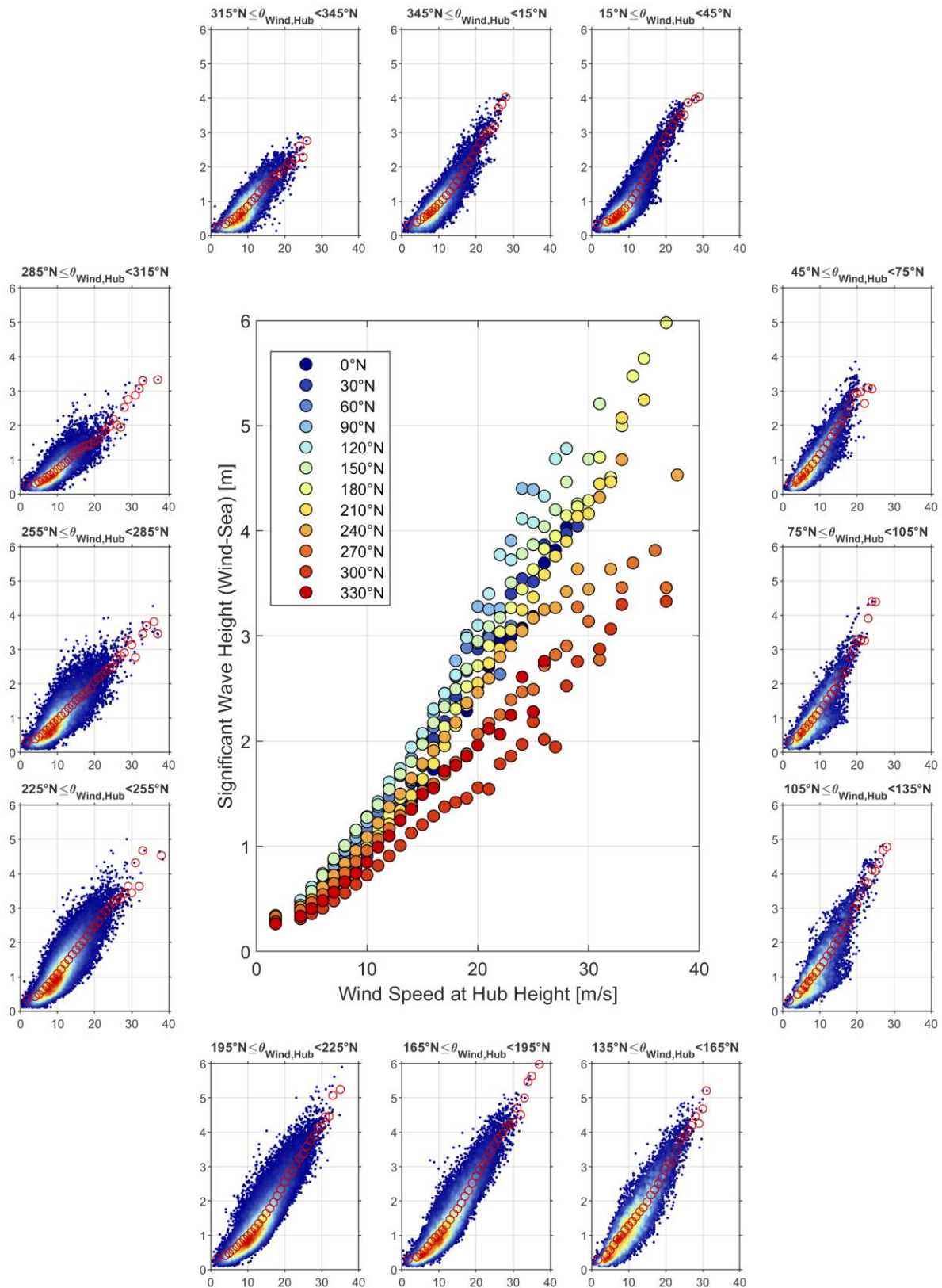


Figure 9.1: Hm0 for NSS, wind-sea, location E2.

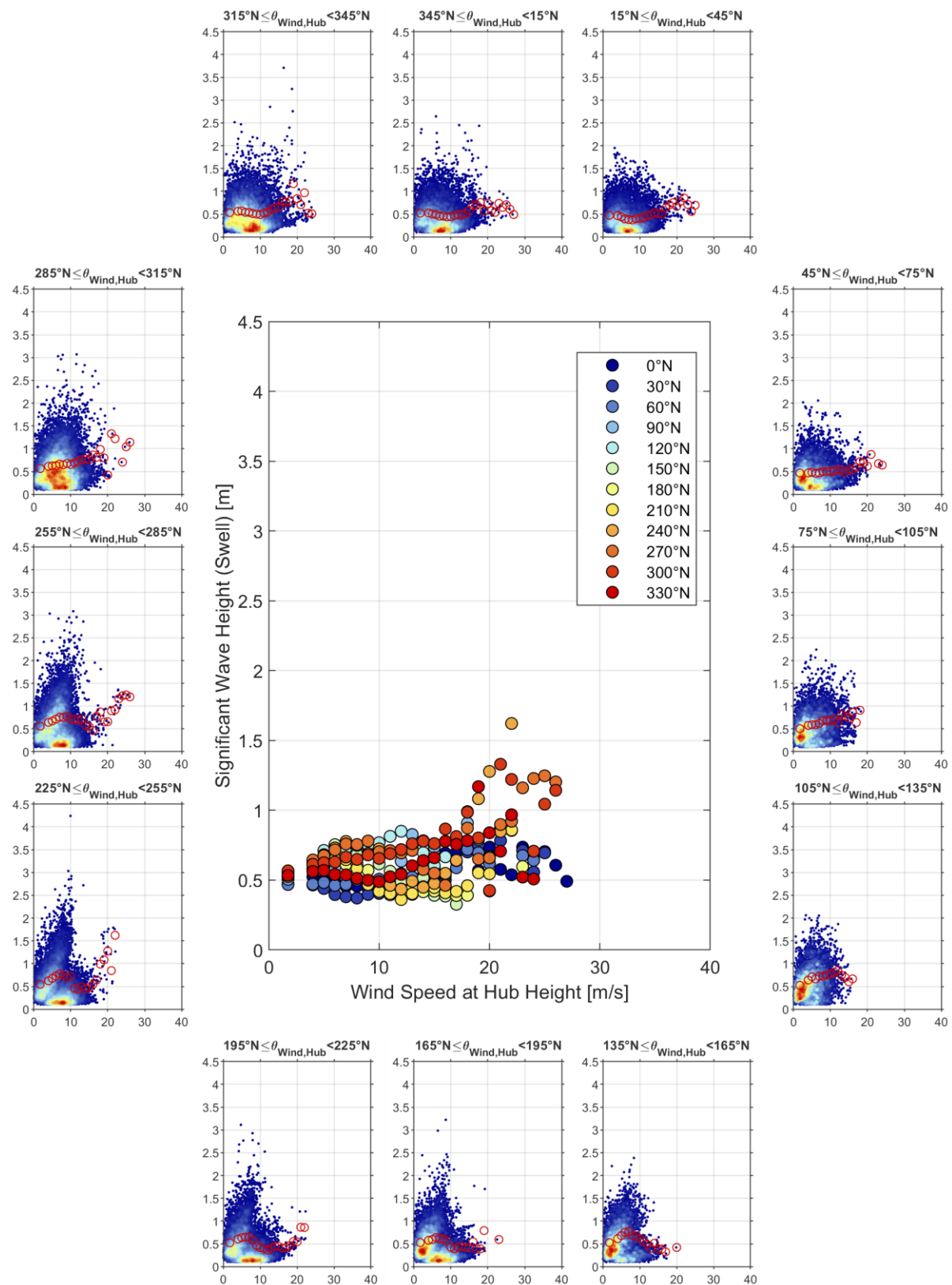


Figure 9.2: Hm0 for NSS, swell, location E2.

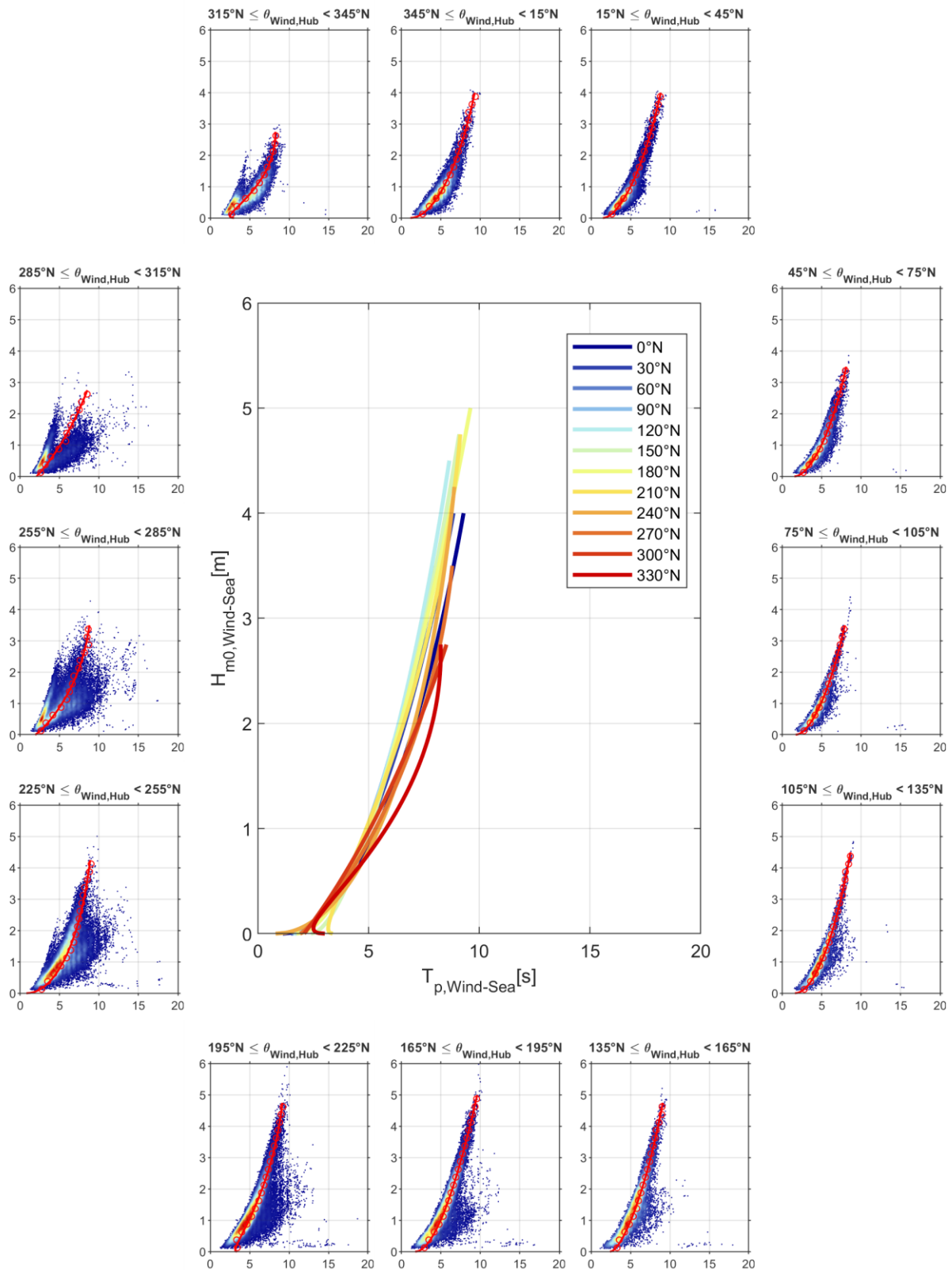


Figure 9.3: Hm0-Tp relationships for NSS, wind-sea, location E2.

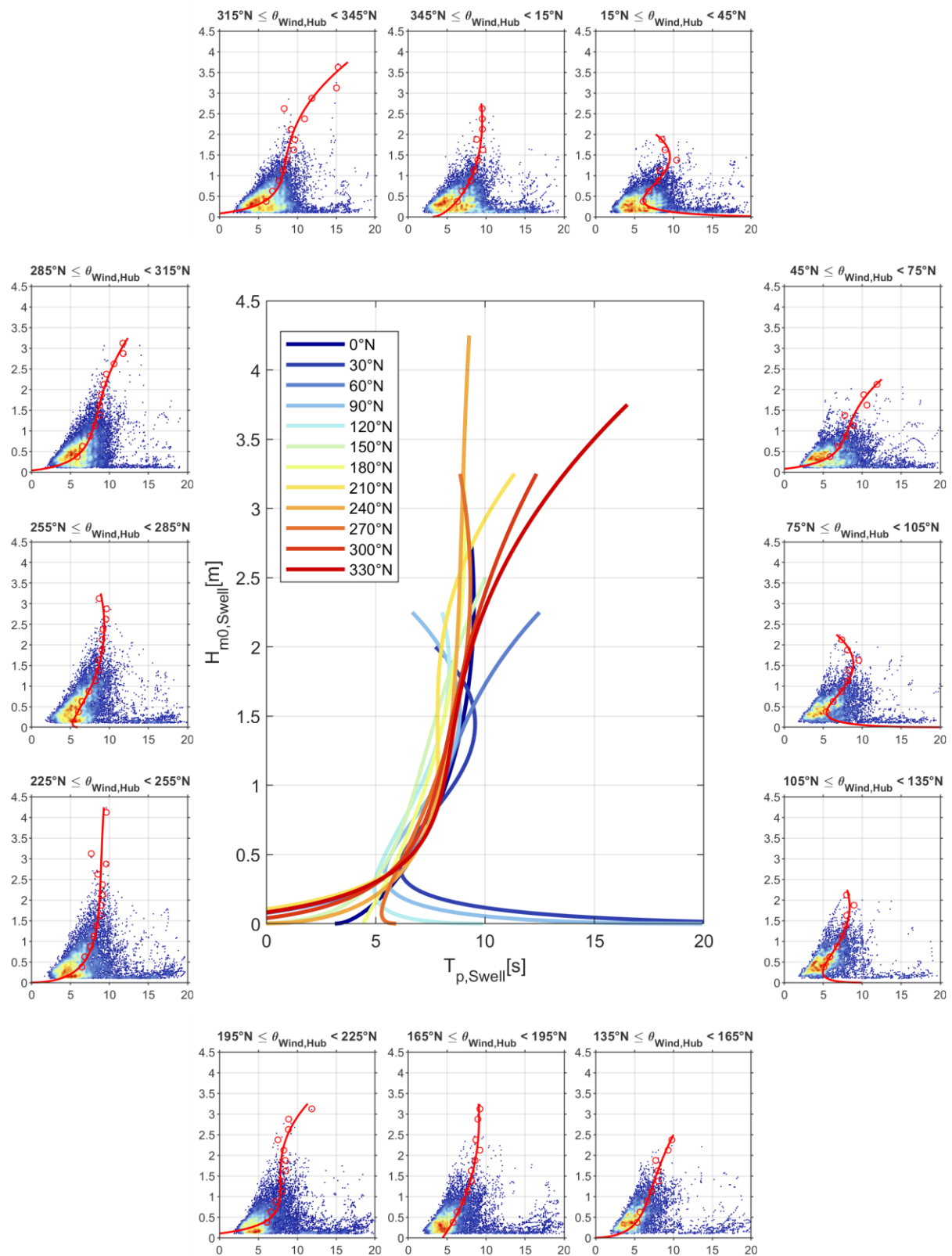


Figure 9.4: Hm0-Tp relationships for NSS, swell, location E2.



## 10 Directional Extreme Currents

This Section contains supplementary information and diagnostics for the worksheet “6a - Directional Extreme Cur” of the Microsoft Excel Spreadsheet SSE\_C00004\_R05\_Metocean\_Input\_For\_Design\_East.xlsx.

### 10.1 Data Sources

Extreme currents were calculated from hindcast data for the locations Ec1, Ec2, Ez1 and E3.

### 10.2 Extrapolation for Extreme Current Speeds

The omni-directional extrapolation of depth-averaged extreme current speeds at Ec1 is shown in Figure 10.1, and thereafter, those for Ec2, Ez1 and E3 in Figure 10.2 through Figure 10.4. Those used for directional sectors can be found in Figure 10.5 through Figure 10.8.

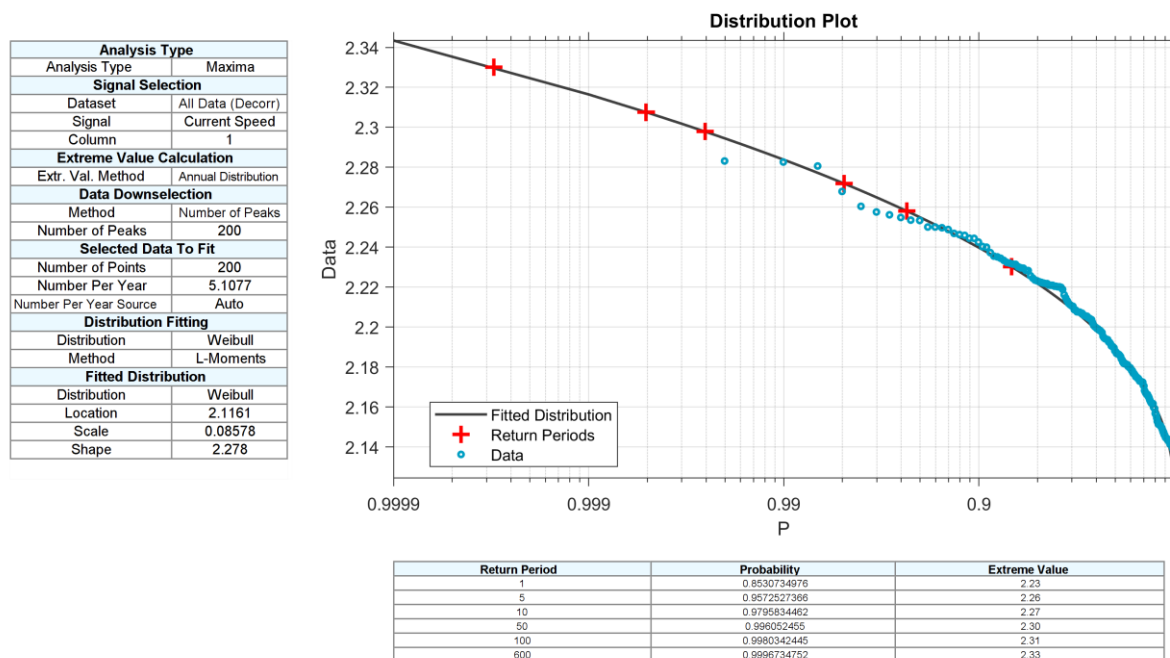


Figure 10.1: Extrapolation of omni-directional depth-average total current speed, location Ec1.

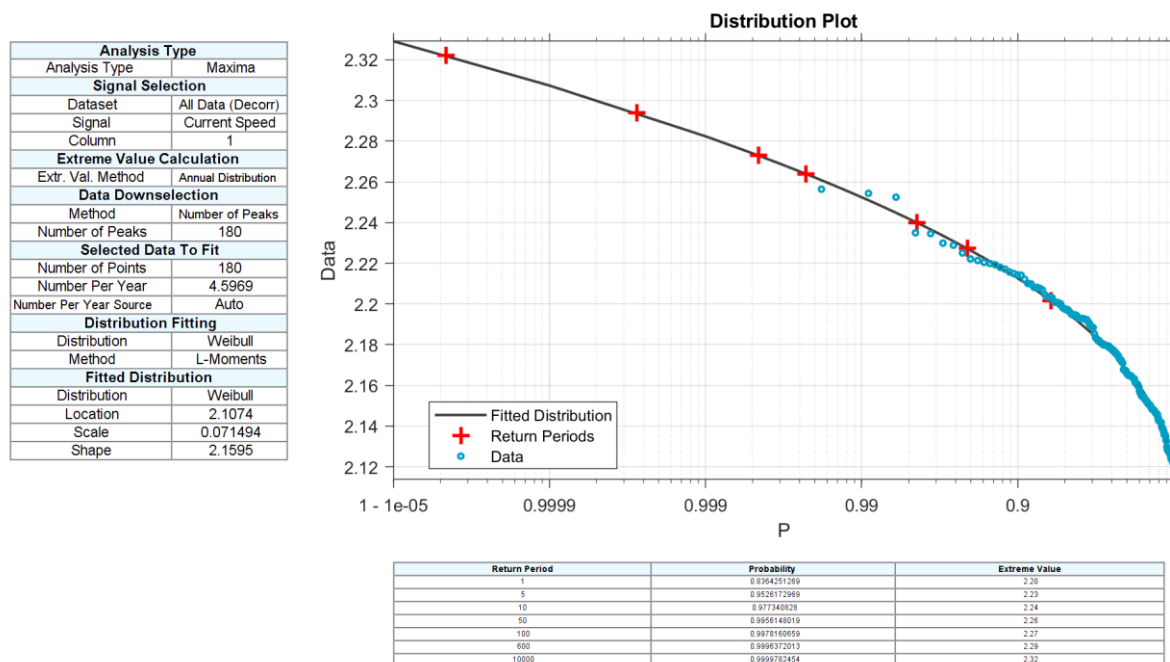


Figure 10.2: Extrapolation of omni-directional depth-average total current speed, location Ec2.

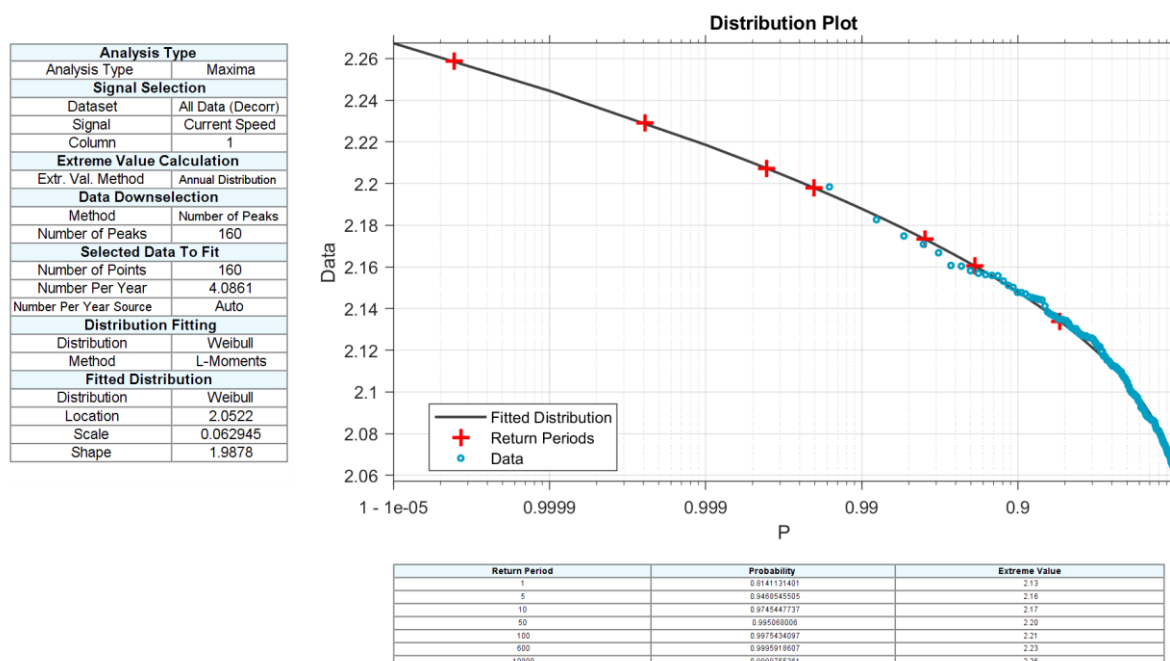


Figure 10.3: Extrapolation of omni-directional depth-average total current speed, location Ez1.

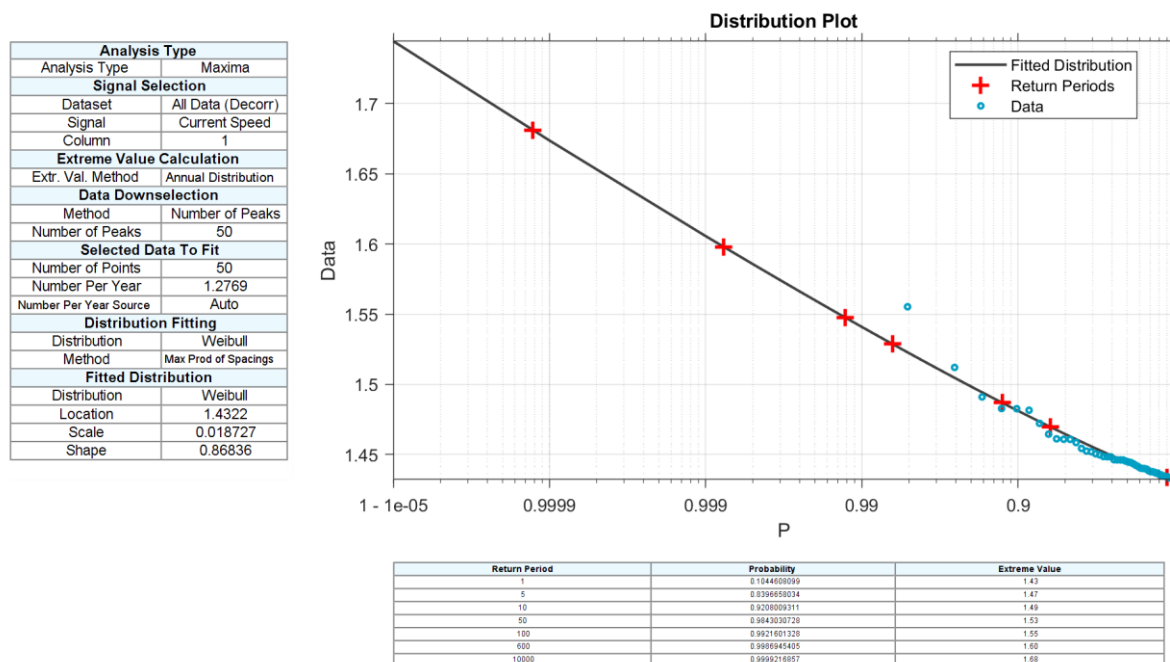


Figure 10.4: Extrapolation of omni-directional depth-average total current speed, location E3.

With regard to the directional extremes, it should be noted that for some locations, there is insufficient data to carry out any reasonable fit for a number of sectors to the west. However, a fit can be carried out for each directional sector for at least one location, and as such, alternative methods such as relative severity factors (RSFs) have *not* been used in this revision of the report to fill any gaps in the analyses.

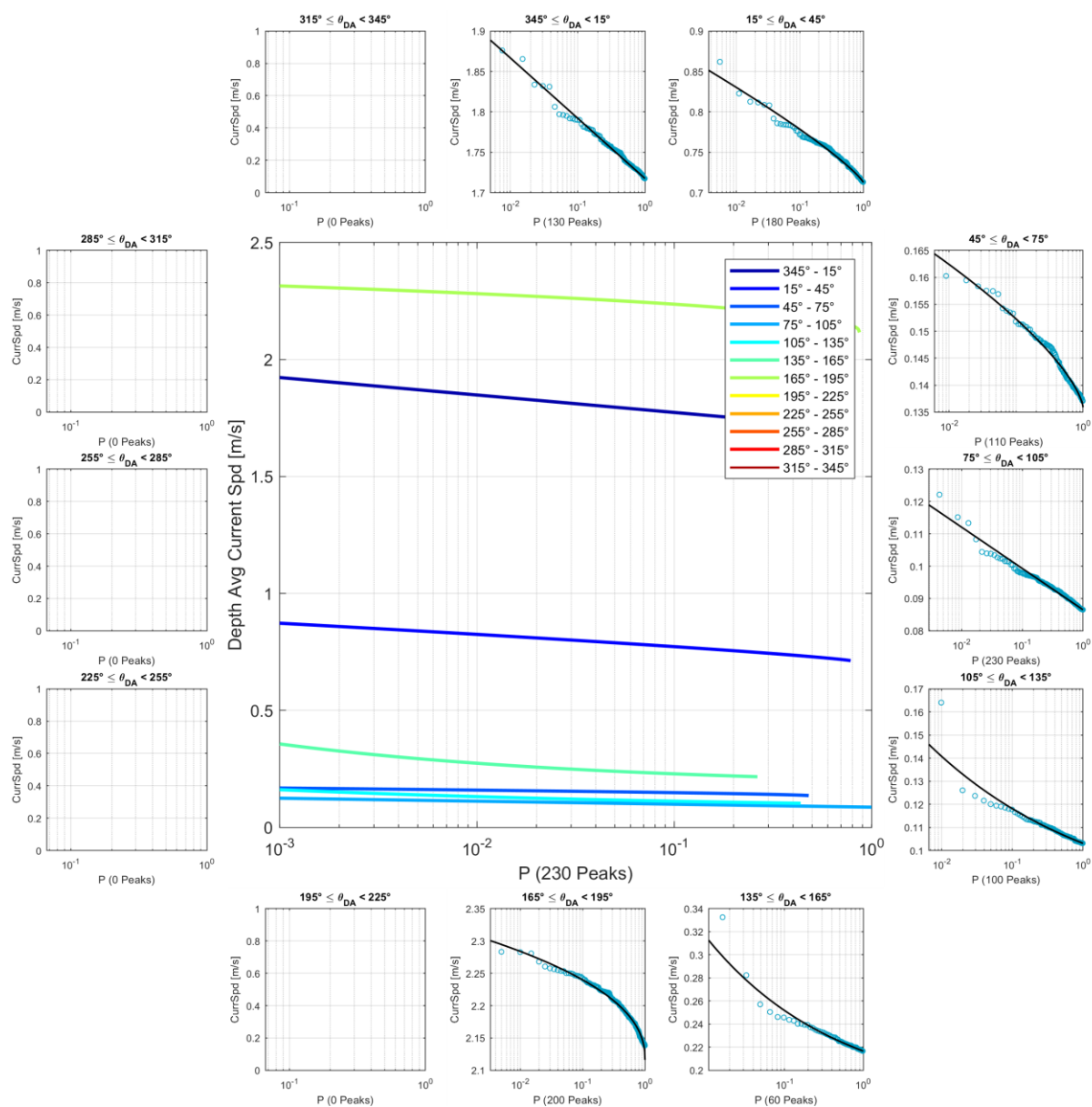


Figure 10.5: Extrapolation of directional depth-average total current speed, location Ec1.

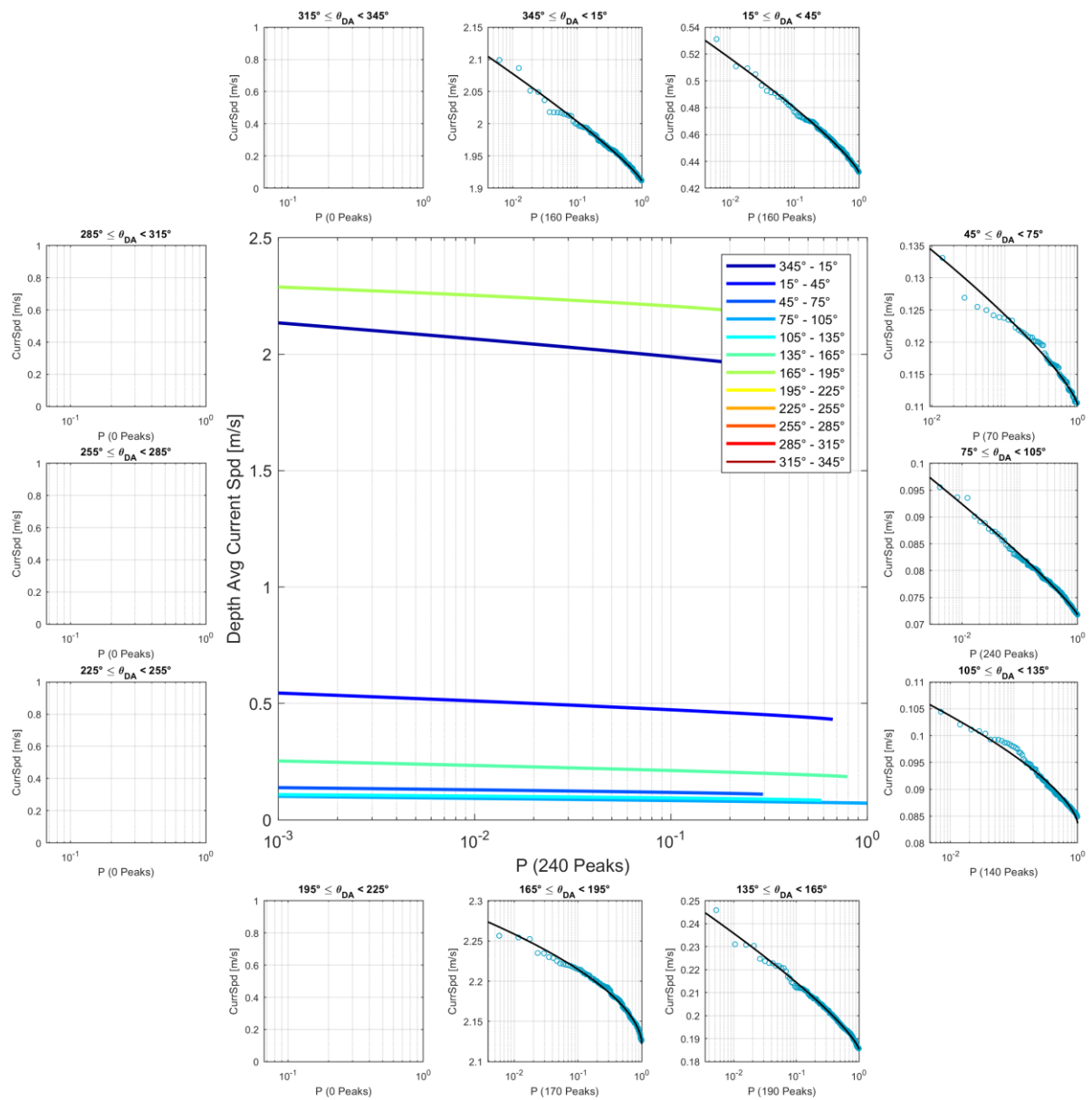


Figure 10.6: Extrapolation of directional depth-average total current speed, location Ec2.

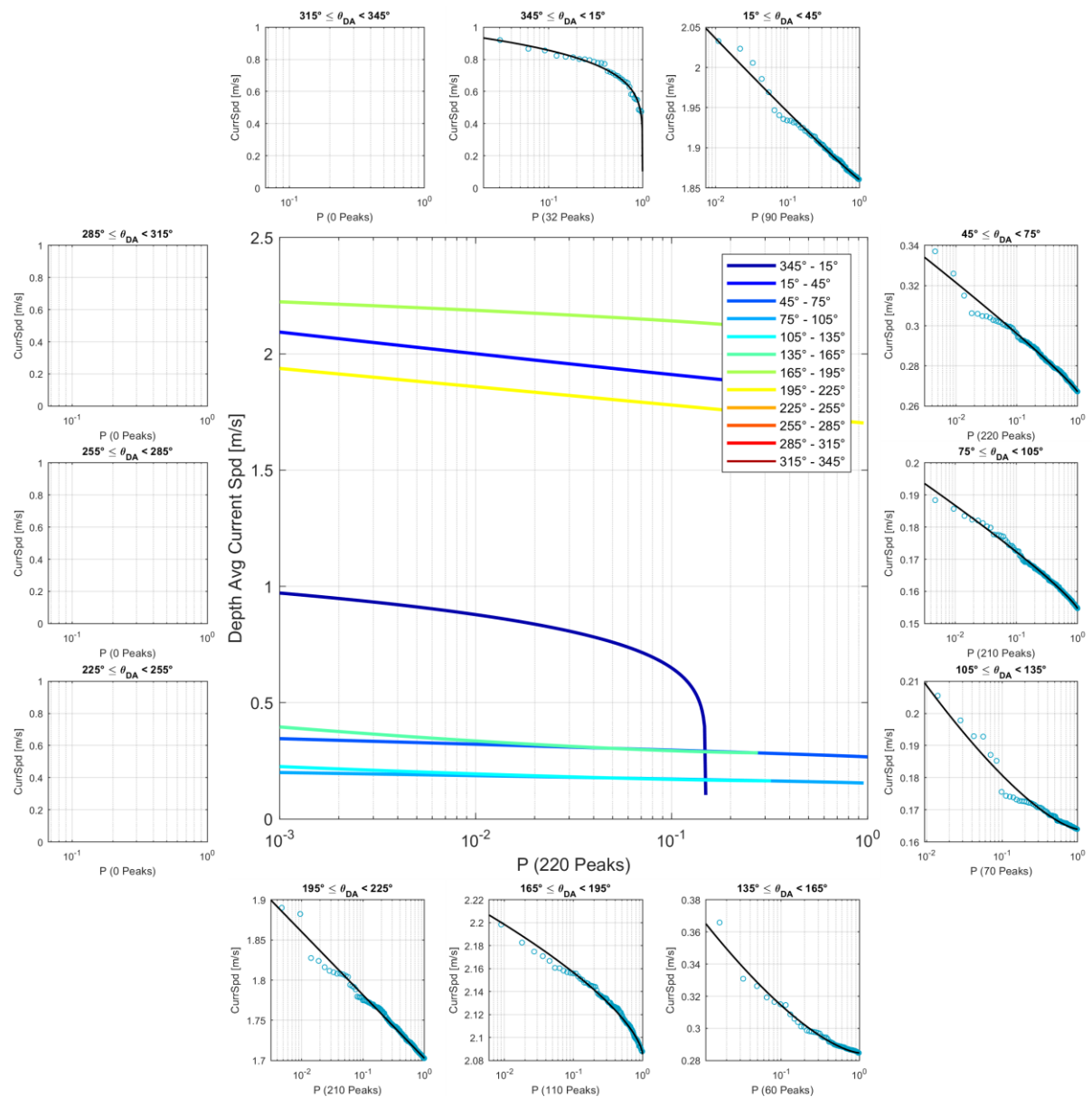


Figure 10.7: Extrapolation of directional depth-average total current speed, location Ez1.

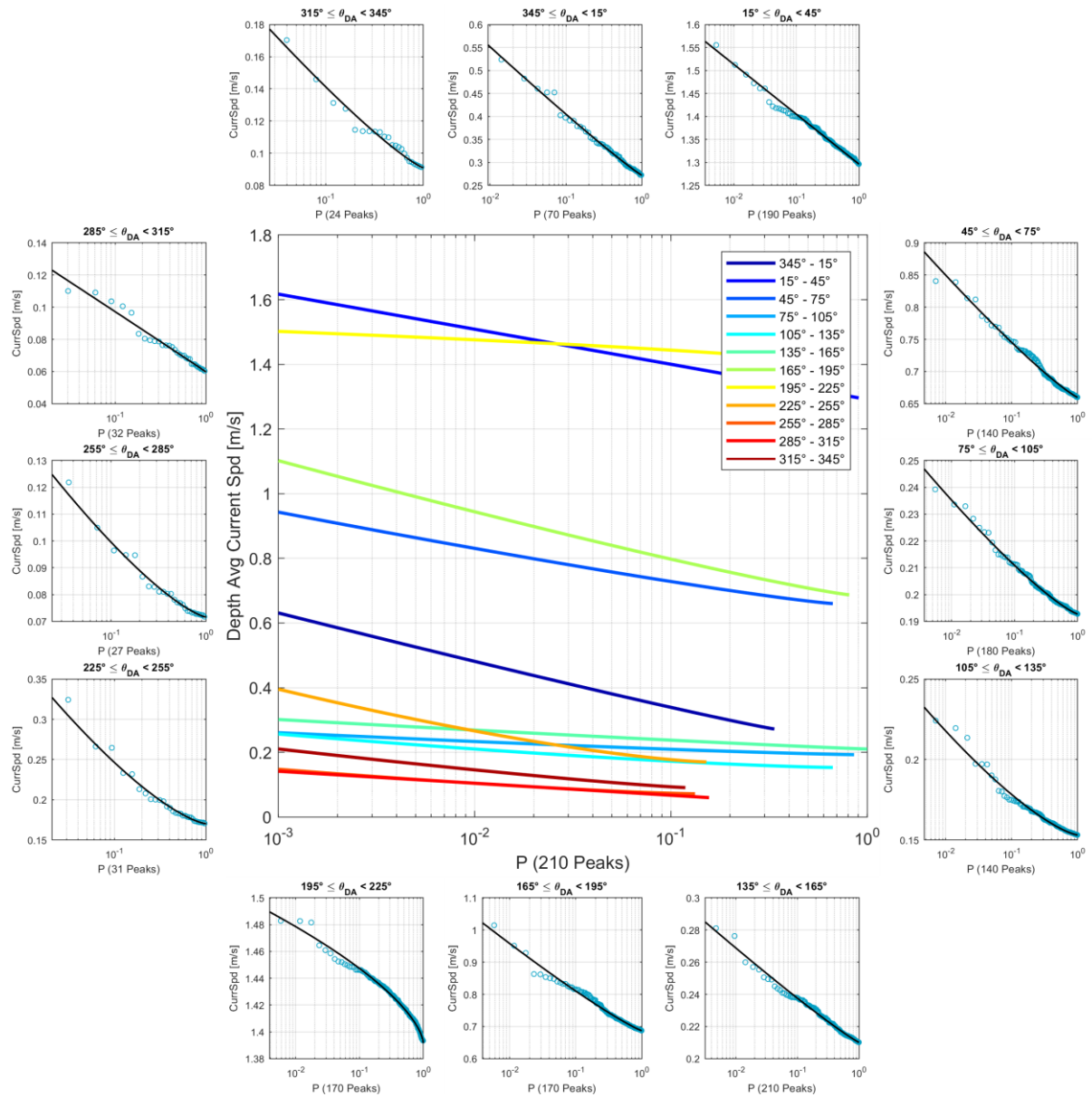


Figure 10.8: Extrapolation of directional depth-average total current speed, location E3.



## 11 Directional Extreme Waves

This Section contains supplementary information and diagnostics for the worksheet “6b - Directional Extreme Waves” of the Microsoft Excel Spreadsheet SSE\_C00004\_R05\_Metocean\_Input\_For\_Design\_East.xlsx.

### 11.1 Data Sources

Extreme wave heights were calculated from hindcast data for the locations E1, E2, E3 and E4.

### 11.2 Significant Wave Height

Extrapolations for omni-directional significant wave height for the four locations considered can be found in Figure 11.1 through Figure 11.4, whilst those for directional sectors are included in Figure 11.5 through Figure 11.8.

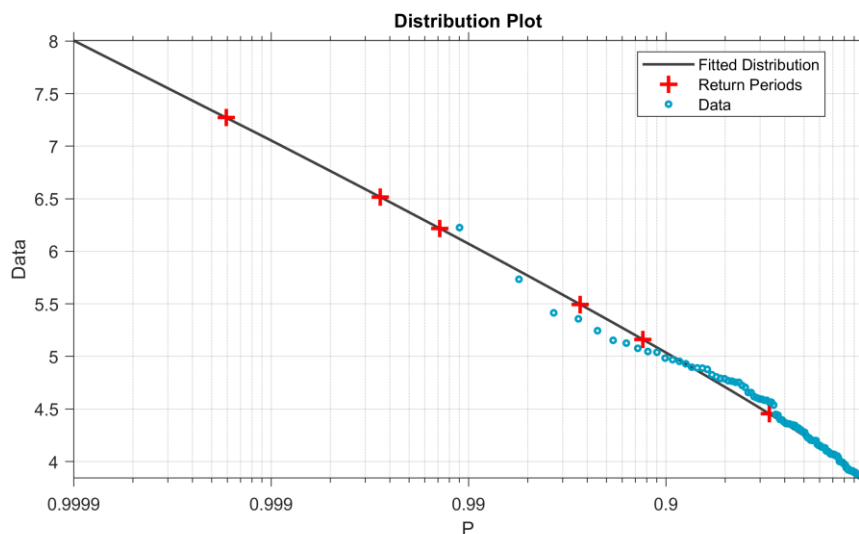
### 11.3 Maximum Individual Wave and Crest Heights

Extrapolations for maximum individual wave heights can be found for the four locations considered in Figure 11.9 through Figure 11.12, whilst those for crest heights are shown in Figure 11.13 through Figure 11.16.

Please note that, as discussed in the Metocean Analysis Overview which accompanies these statistics (SSE\_C00004\_R05\_Metocean\_Analysis\_Overview), when considering *individual* locations, water depth limitations may need to be taken into account. In particular, in the shallower waters of the Zone, stream function theory may predict crest heights that exceed those presented herein.



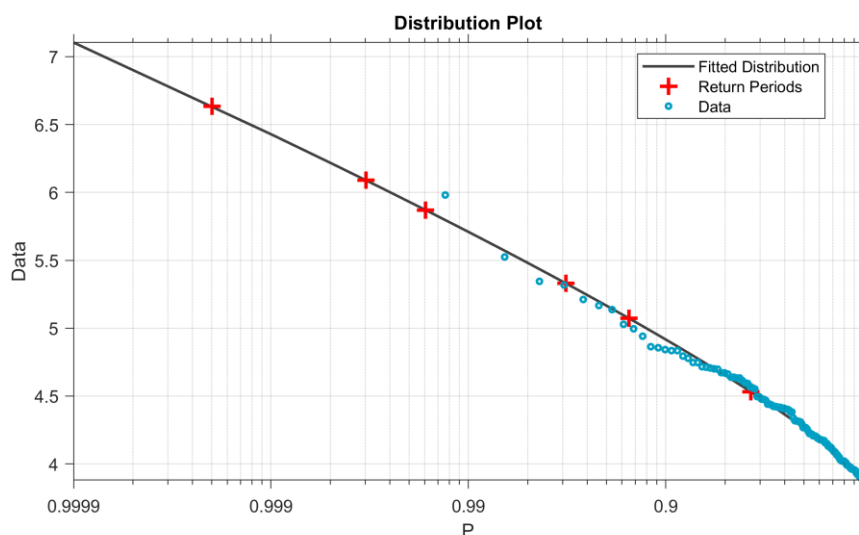
| Analysis Type             |                     |
|---------------------------|---------------------|
| Analysis Type             | Maxima              |
| Signal Selection          |                     |
| Dataset                   | All Data (Decorr)   |
| Signal                    | Wave Hm0            |
| Column                    | 1                   |
| Extreme Value Calculation |                     |
| Extr. Val. Method         | Annual Distribution |
| Data Downselection        |                     |
| Method                    | Number of Peaks     |
| Number of Peaks           | 110                 |
| Selected Data To Fit      |                     |
| Number of Points          | 110                 |
| Number Per Year           | 2,8092              |
| Number Per Year Source    | Auto                |
| Distribution Fitting      |                     |
| Distribution              | Weibull             |
| Method                    | Max Likelihood      |
| Fitted Distribution       |                     |
| Distribution              | Weibull             |
| Location                  | 3.8413              |
| Scale                     | 0.56409             |
| Shape                     | 1.1107              |



| Return Period | Probability  | Extreme Value |
|---------------|--------------|---------------|
| 1             | 0.6655866327 | 4.45          |
| 5             | 0.9236405819 | 5.16          |
| 10            | 0.9631894923 | 5.49          |
| 50            | 0.9928342528 | 6.22          |
| 100           | 0.9964287806 | 6.52          |
| 600           | 0.9994063991 | 7.27          |

Figure 11.1: Extrapolation of omni-directional total Hm0, location E1.

| Analysis Type             |                      |
|---------------------------|----------------------|
| Analysis Type             | Maxima               |
| Signal Selection          |                      |
| Dataset                   | All Data (Decorr)    |
| Signal                    | Wave Hm0             |
| Column                    | 1                    |
| Extreme Value Calculation |                      |
| Extr. Val. Method         | Annual Distribution  |
| Data Downselection        |                      |
| Method                    | Number of Peaks      |
| Number of Peaks           | 130                  |
| Selected Data To Fit      |                      |
| Number of Points          | 130                  |
| Number Per Year           | 3.32                 |
| Number Per Year Source    | Auto                 |
| Distribution Fitting      |                      |
| Distribution              | Weibull              |
| Method                    | Max Prod of Spacings |
| Fitted Distribution       |                      |
| Distribution              | Weibull              |
| Location                  | 3.8711               |
| Scale                     | 0.52979              |
| Shape                     | 1.2276               |

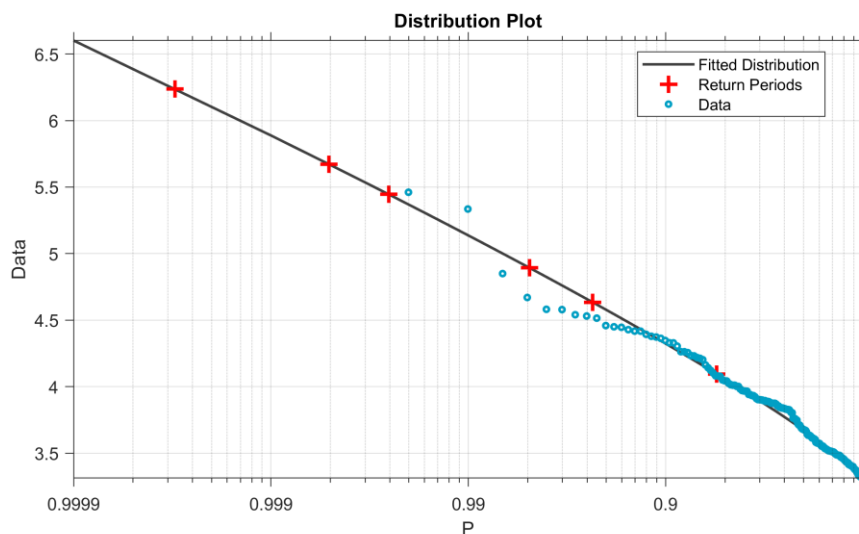


| Return Period | Probability  | Extreme Value |
|---------------|--------------|---------------|
| 1             | 0.7299365544 | 4.53          |
| 5             | 0.9346970401 | 5.07          |
| 10            | 0.9687631771 | 5.33          |
| 50            | 0.993933324  | 5.87          |
| 100           | 0.9969773677 | 6.09          |
| 600           | 0.9994976993 | 6.63          |

Figure 11.2: Extrapolation of omni-directional total Hm0, location E2.



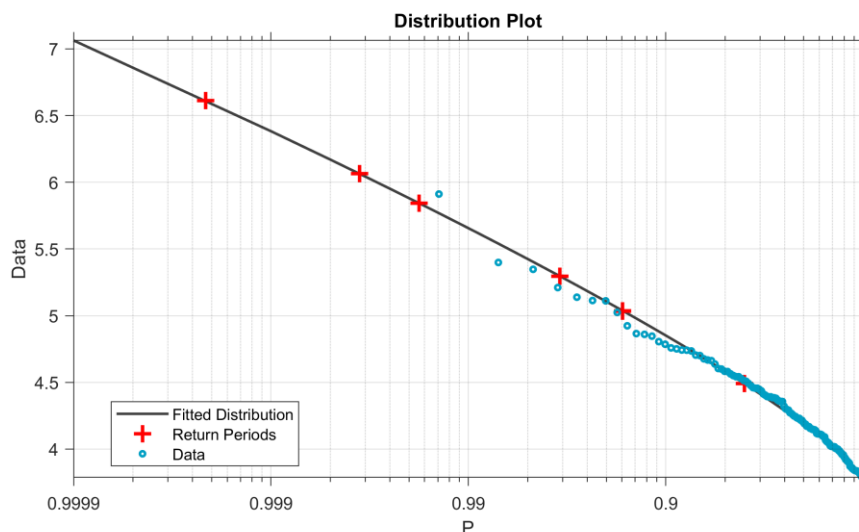
| Analysis Type             |                      |
|---------------------------|----------------------|
| Analysis Type             | Maxima               |
| Signal Selection          |                      |
| Dataset                   | All Data (Decorr)    |
| Signal                    | Wave Hm0             |
| Column                    | 1                    |
| Extreme Value Calculation |                      |
| Extr. Val. Method         | Annual Distribution  |
| Data Downselection        |                      |
| Method                    | Number of Peaks      |
| Number of Peaks           | 200                  |
| Selected Data To Fit      |                      |
| Number of Points          | 200                  |
| Number Per Year           | 5.1077               |
| Number Per Year Source    | Auto                 |
| Distribution Fitting      |                      |
| Distribution              | Weibull              |
| Method                    | Max Prod of Spacings |
| Fitted Distribution       |                      |
| Distribution              | Weibull              |
| Location                  | 3.3073               |
| Scale                     | 0.50067              |
| Shape                     | 1.1786               |



| Return Period | Probability  | Extreme Value |
|---------------|--------------|---------------|
| 1             | 0.8184455328 | 4.10          |
| 5             | 0.9572528178 | 4.63          |
| 10            | 0.9795834854 | 4.89          |
| 50            | 0.9960524626 | 5.45          |
| 100           | 0.9980342483 | 5.67          |
| 600           | 0.9996734759 | 6.24          |

Figure 11.3: Extrapolation of omni-directional total Hm0, location E3.

| Analysis Type             |                      |
|---------------------------|----------------------|
| Analysis Type             | Maxima               |
| Signal Selection          |                      |
| Dataset                   | All Data (Decorr)    |
| Signal                    | Wave Hm0             |
| Column                    | 1                    |
| Extreme Value Calculation |                      |
| Extr. Val. Method         | Annual Distribution  |
| Data Downselection        |                      |
| Method                    | Number of Peaks      |
| Number of Peaks           | 140                  |
| Selected Data To Fit      |                      |
| Number of Points          | 140                  |
| Number Per Year           | 3.5754               |
| Number Per Year Source    | Auto                 |
| Distribution Fitting      |                      |
| Distribution              | Weibull              |
| Method                    | Max Prod of Spacings |
| Fitted Distribution       |                      |
| Distribution              | Weibull              |
| Location                  | 3.7771               |
| Scale                     | 0.54816              |
| Shape                     | 1.2398               |



| Return Period | Probability  | Extreme Value |
|---------------|--------------|---------------|
| 1             | 0.7495968975 | 4.49          |
| 5             | 0.939496139  | 5.04          |
| 10            | 0.9709618531 | 5.30          |
| 50            | 0.9943654348 | 5.84          |
| 100           | 0.9971929667 | 6.05          |
| 600           | 0.9995335696 | 6.61          |

Figure 11.4: Extrapolation of omni-directional total Hm0, location E4.

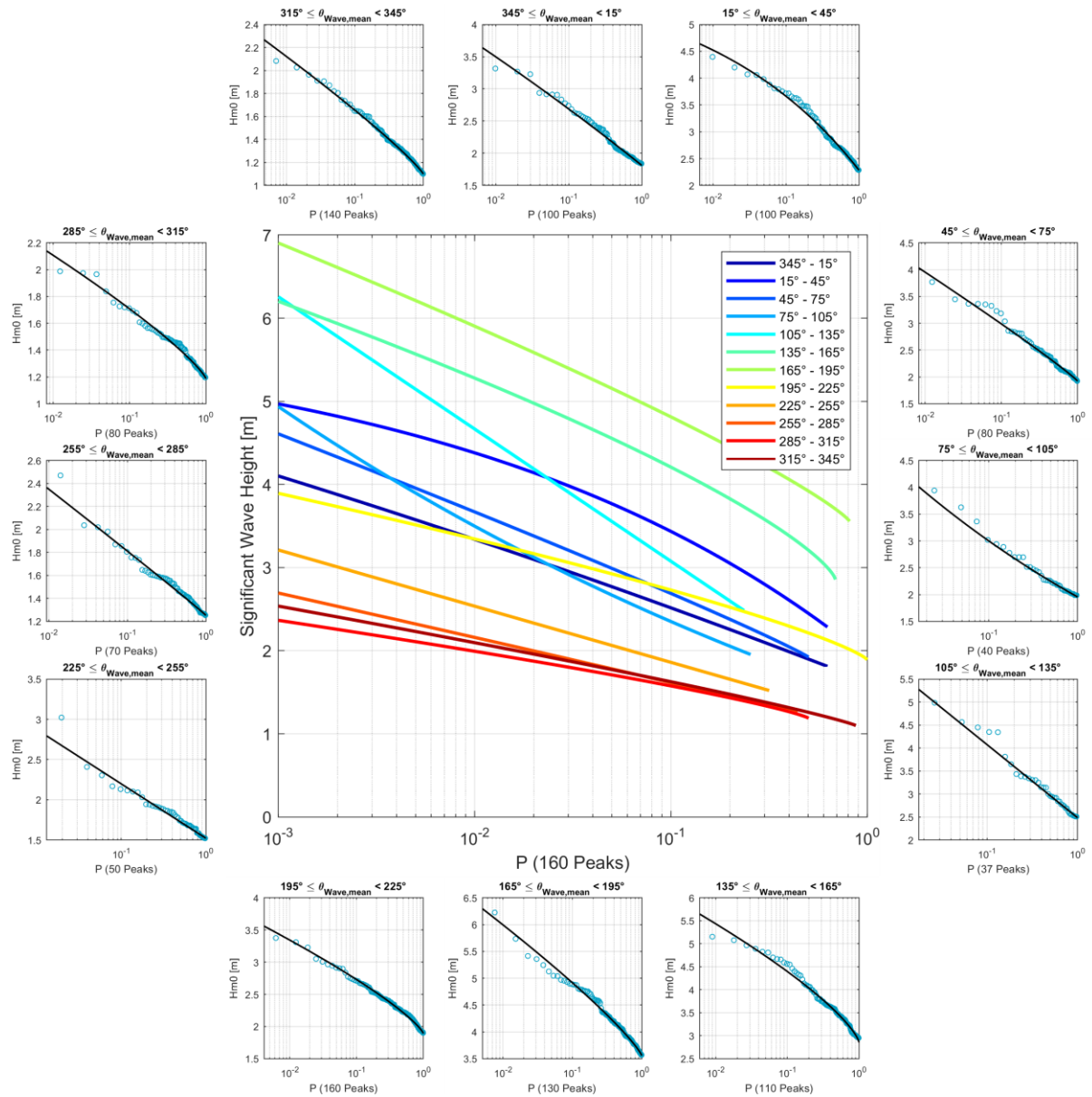


Figure 11.5: Extrapolation of directional total Hm0, location E1.

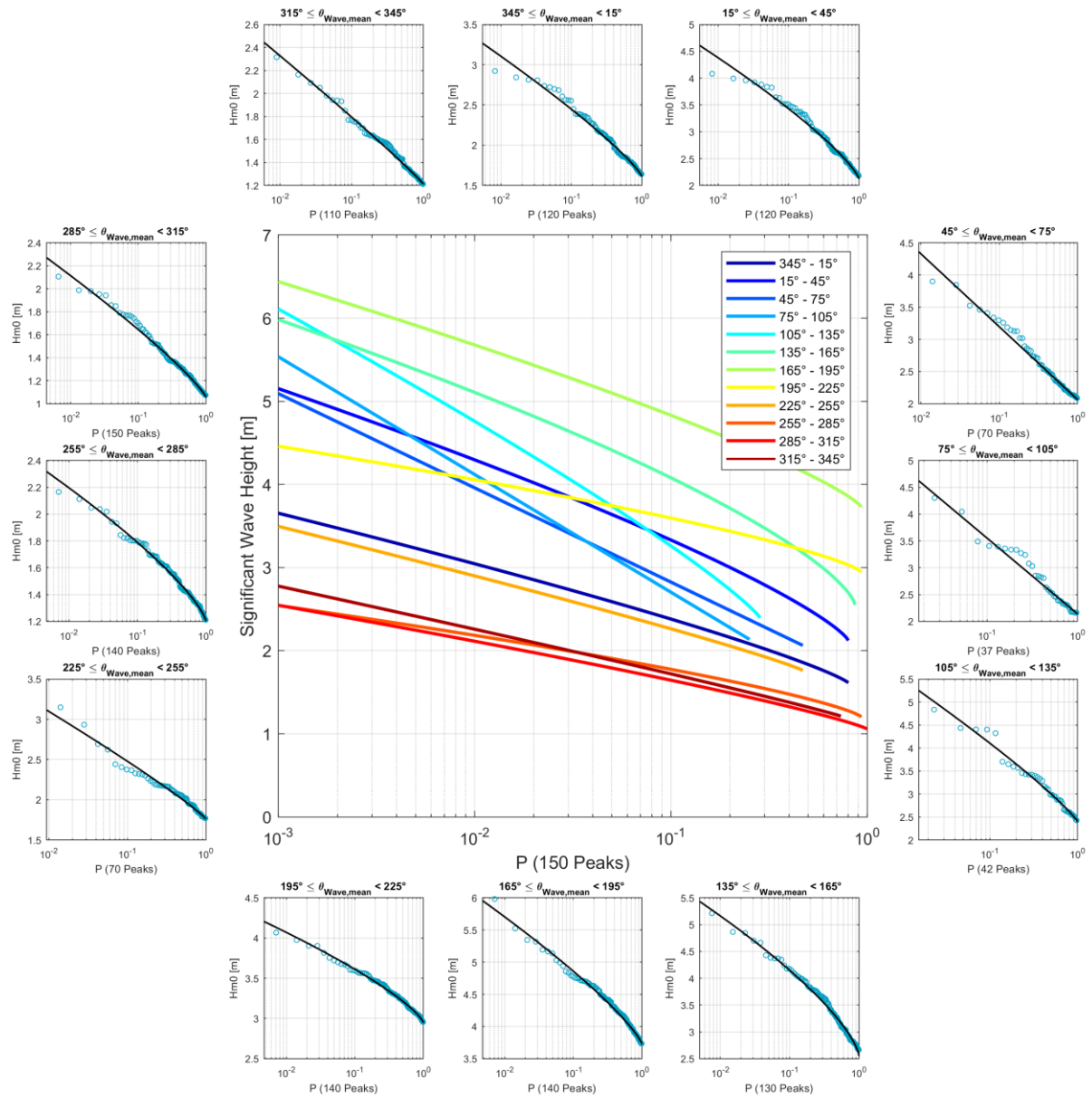


Figure 11.6: Extrapolation of directional total Hm0, location E2.

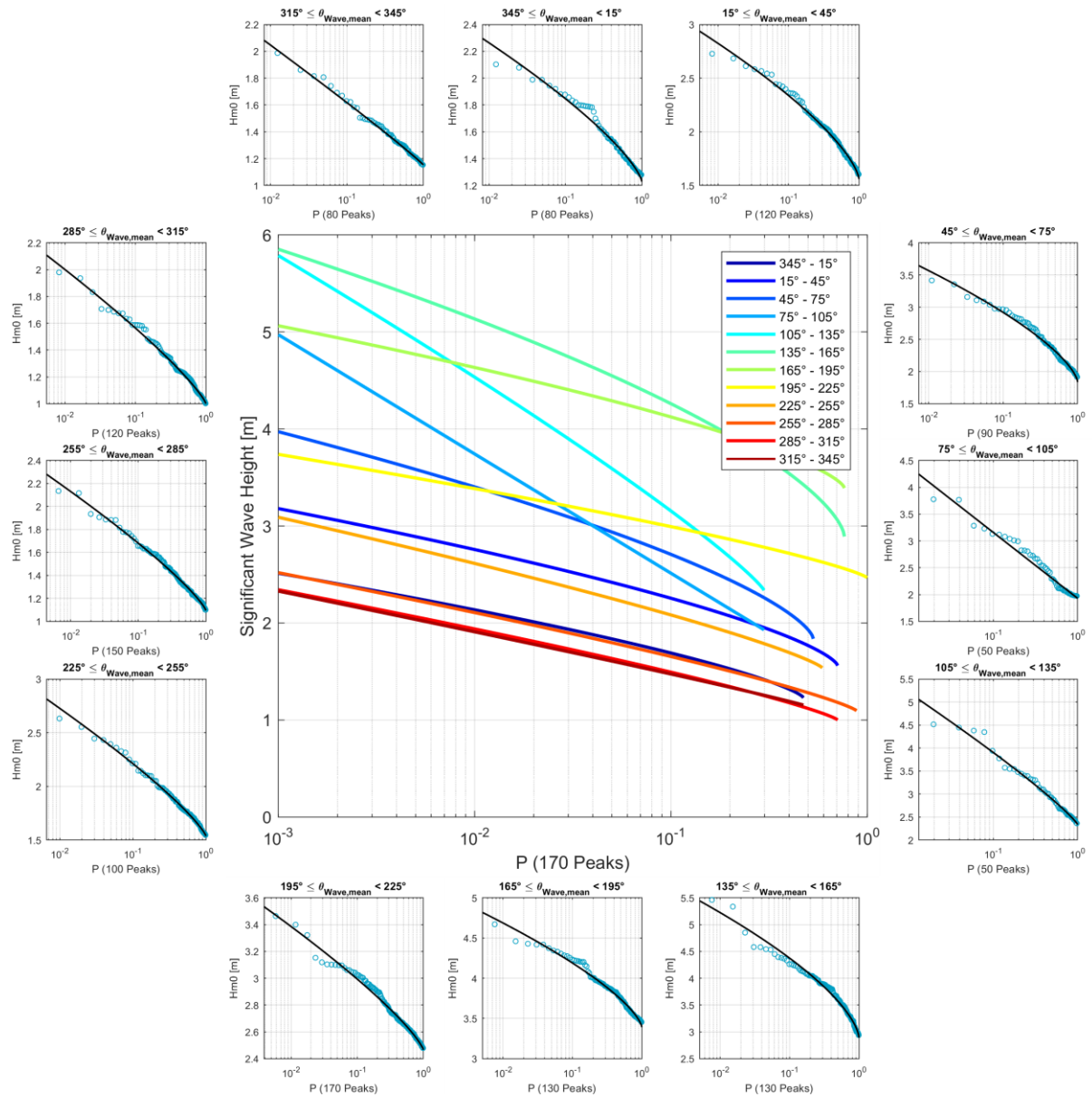


Figure 11.7: Extrapolation of directional total Hm0, location E3.

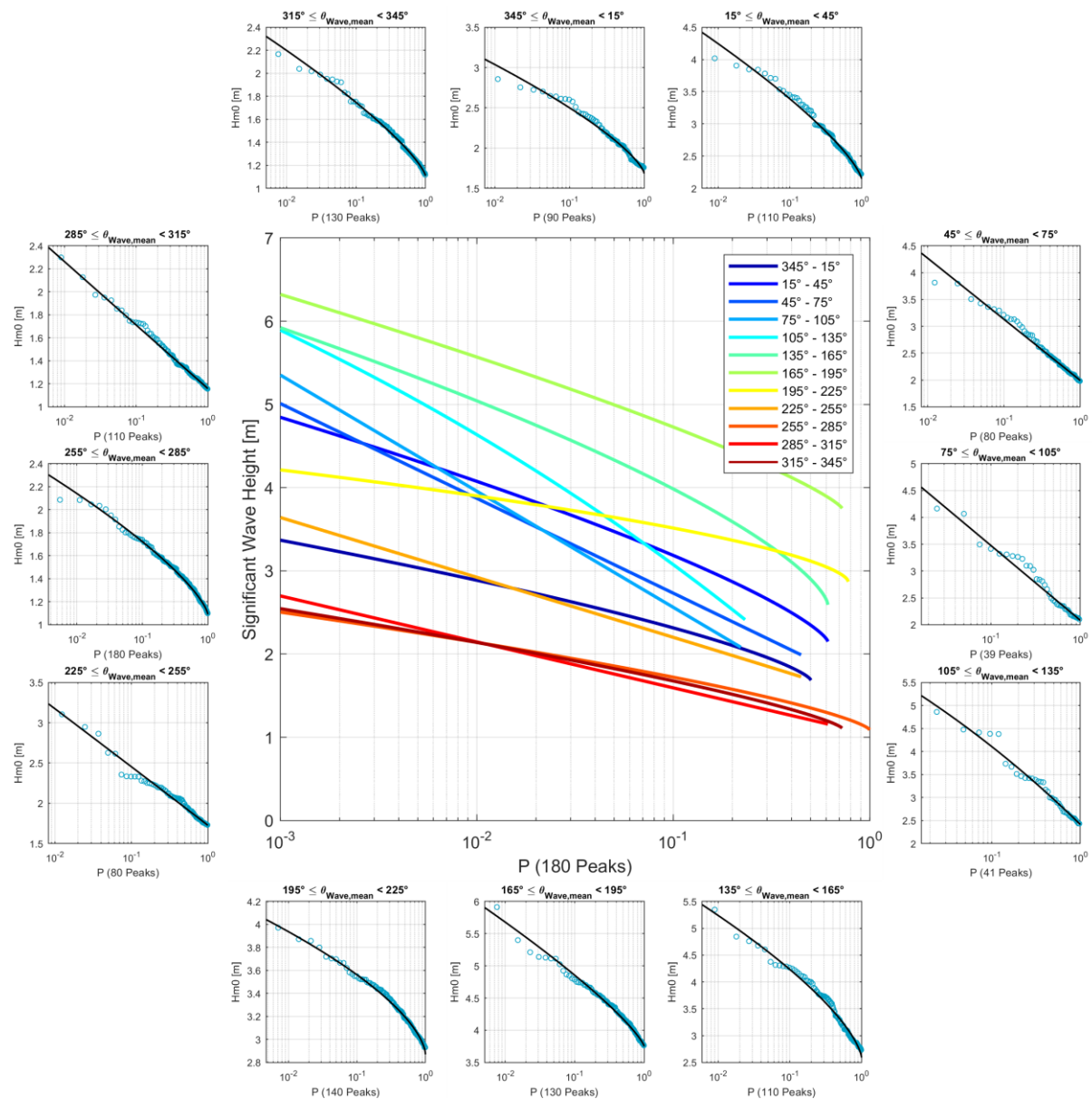
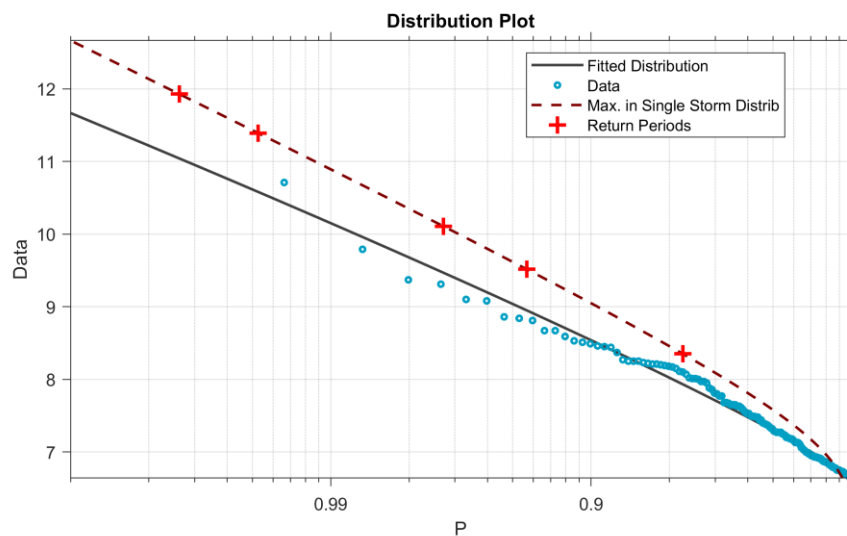


Figure 11.8: Extrapolation of directional total Hm0, location E4.



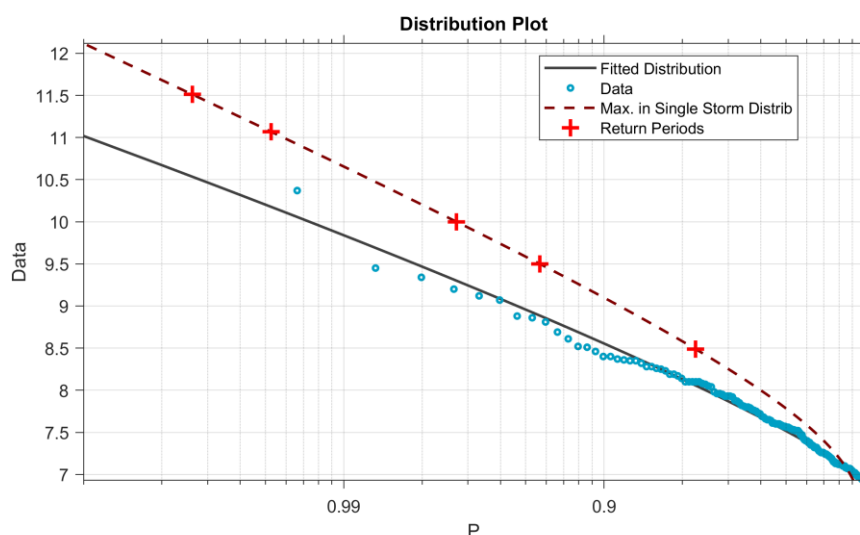
| Signal Selection        |                                                            |
|-------------------------|------------------------------------------------------------|
| Hm0 Dataset             | SWAN_52p894L_5p853W_34m Wave Hm0 (Storms)                  |
| Hm0 Signal              | Wave Hm0                                                   |
| Hm0 Column              | 1                                                          |
| Tm02 Dataset            | SWAN_52p894L_5p853W_34m Wave Hm0 (Storms)                  |
| Tm02 Signal             | Wave Tm02                                                  |
| Tm02 Column             | 1                                                          |
| Short Term Distribution |                                                            |
| Short Term Distribution | Wave Height: Forristal Deep (Shape = 2.126, Scale = 0.881) |
| Data Downselection      |                                                            |
| Method                  | Number of Peaks                                            |
| Number of Peaks         | 150                                                        |
| Selected Data To Fit    |                                                            |
| Number of Points        | 150                                                        |
| Number Per Year         | 3.8108                                                     |
| Number Per Year Source  | Auto                                                       |
| Distribution Fitting    |                                                            |
| Distribution            | Weibull                                                    |
| Method                  | Max Likelihood                                             |
| Fitted Distribution     |                                                            |
| Distribution            | Weibull                                                    |
| Location                | 6.8387                                                     |
| Scale                   | 0.80793                                                    |
| Shape                   | 1.1289                                                     |
| Hmp Extreme Values      |                                                            |
| Ext. Val. Method        | Annual Distribution                                        |
| 1 Year                  | 7.869                                                      |
| 5 Year                  | 8.9499                                                     |
| 10 Year                 | 9.4665                                                     |
| 50 Year                 | 10.5832                                                    |
| 100 Year                | 11.0406                                                    |
| 600 Year                | 12.1995                                                    |
| 10000 Year              | 13.8576                                                    |



| Return Period | Probability  | Extreme Value |
|---------------|--------------|---------------|
| 1             | 0.7749045489 | 8.35          |
| 5             | 0.9434137562 | 9.52          |
| 10            | 0.9728710342 | 10.11         |
| 50            | 0.9947400828 | 11.39         |
| 100           | 0.9973798568 | 11.93         |
| 600           | 0.9995645562 | 13.30         |
| 10000         | 0.9999738946 | 15.44         |

Figure 11.9: Extrapolation of omni-directional total Hmp (Forristal deep water distribution), location E1.

| Signal Selection        |                                                            |
|-------------------------|------------------------------------------------------------|
| Hm0 Dataset             | SWAN_52p707N_5p857W_42m Wave Hm0 (Storms)                  |
| Hm0 Signal              | Wave Hm0                                                   |
| Hm0 Column              | 1                                                          |
| Tm02 Dataset            | SWAN_52p707N_5p857W_42m Wave Hm0 (Storms)                  |
| Tm02 Signal             | Wave Tm02                                                  |
| Tm02 Column             | 1                                                          |
| Short Term Distribution |                                                            |
| Short Term Distribution | Wave Height: Forristal Deep (Shape = 2.126, Scale = 0.881) |
| Data Downselection      |                                                            |
| Method                  | Number of Peaks                                            |
| Number of Peaks         | 150                                                        |
| Selected Data To Fit    |                                                            |
| Number of Points        | 150                                                        |
| Number Per Year         | 3.8108                                                     |
| Number Per Year Source  | Auto                                                       |
| Distribution Fitting    |                                                            |
| Distribution            | Weibull                                                    |
| Method                  | Max Prod of Spacings                                       |
| Fitted Distribution     |                                                            |
| Distribution            | Weibull                                                    |
| Location                | 6.9168                                                     |
| Scale                   | 0.81552                                                    |
| Shape                   | 1.1864                                                     |
| Hmp Extreme Values      |                                                            |
| Ext. Val. Method        | Annual Distribution                                        |
| 1 Year                  | 8.0193                                                     |
| 5 Year                  | 8.8865                                                     |
| 10 Year                 | 9.2988                                                     |
| 50 Year                 | 10.1796                                                    |
| 100 Year                | 10.5347                                                    |
| 600 Year                | 11.4273                                                    |
| 10000 Year              | 12.762                                                     |



| Return Period | Probability  | Extreme Value |
|---------------|--------------|---------------|
| 1             | 0.775636699  | 8.49          |
| 5             | 0.9434137562 | 9.50          |
| 10            | 0.9728710342 | 10.00         |
| 50            | 0.9947400828 | 11.07         |
| 100           | 0.9973798568 | 11.51         |
| 600           | 0.9995645562 | 12.84         |
| 10000         | 0.9999738946 | 14.38         |

Figure 11.10: Extrapolation of omni-directional total Hmp (Forristal deep water distribution), location E2.

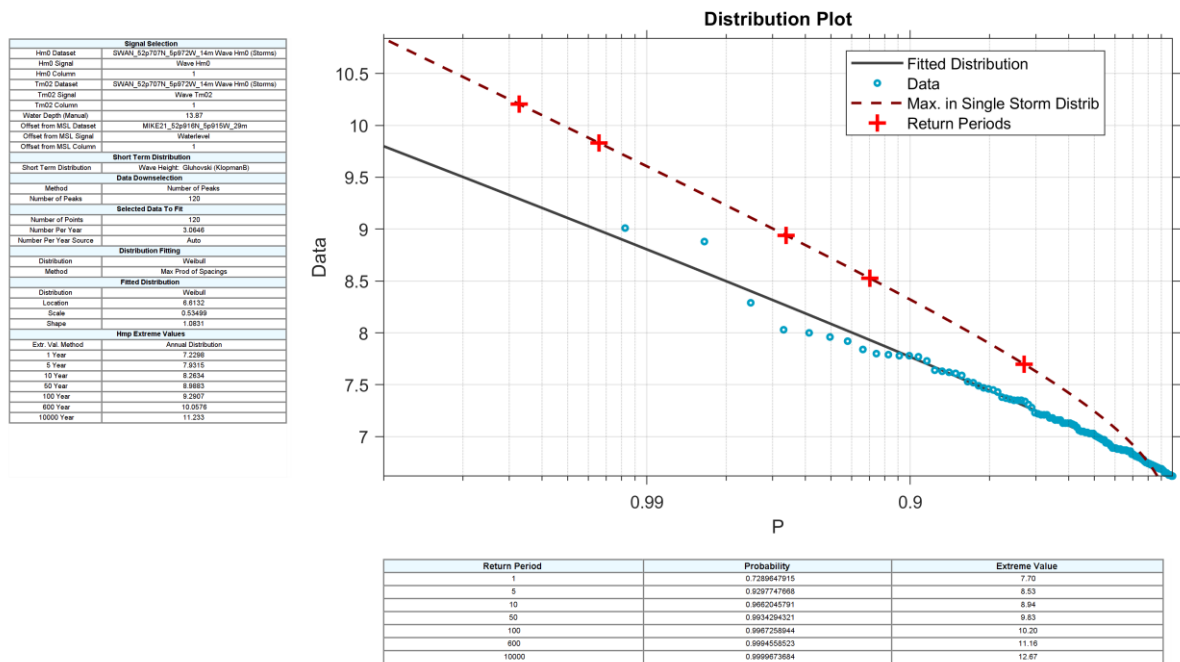


Figure 11.11: Extrapolation of omni-directional total Hmp (Glukhovskiy distribution (Klopman)), location E3.

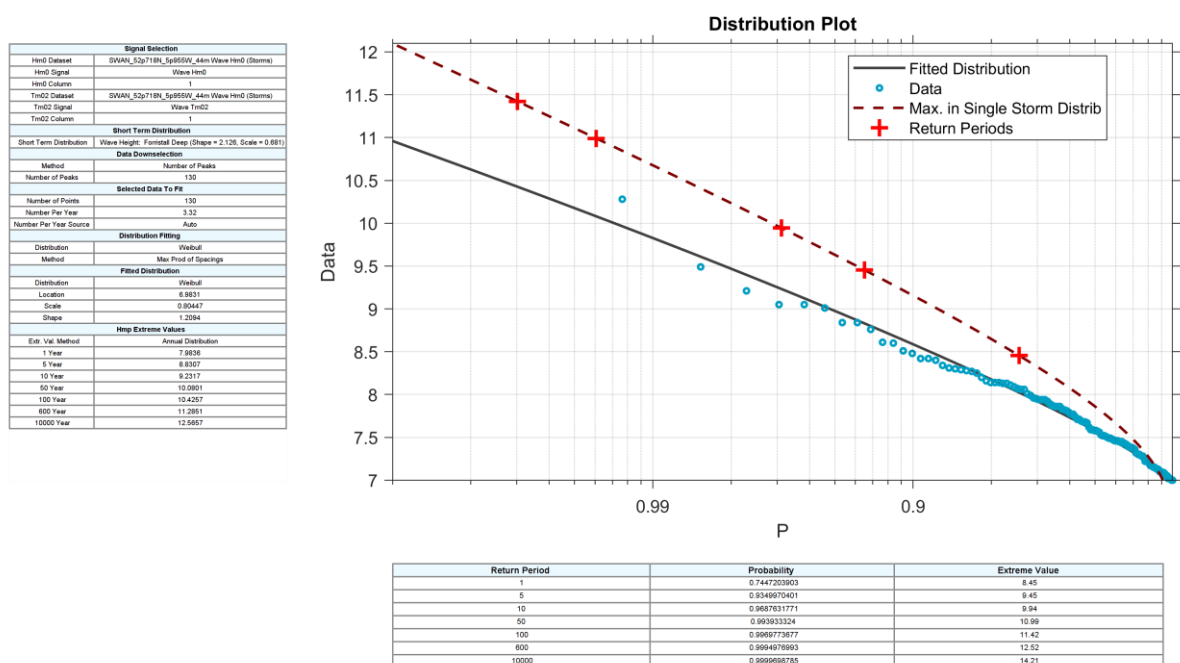


Figure 11.12: Extrapolation of omni-directional total Hmp (Forristall deep water distribution), location E4.

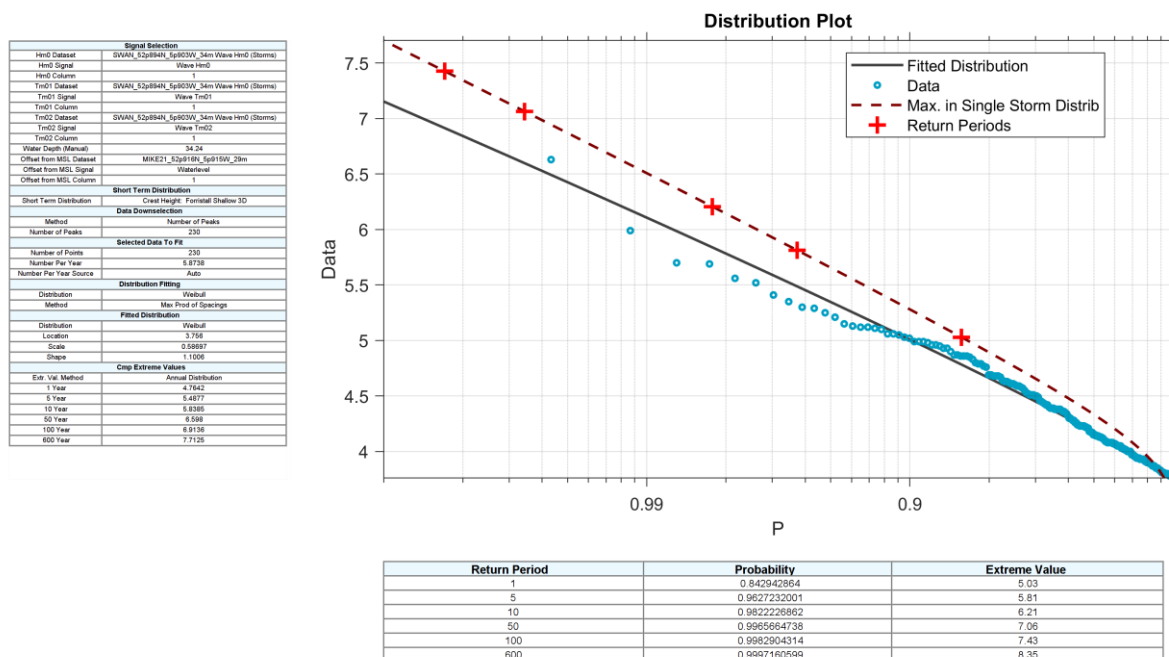


Figure 11.13: Extrapolation of omni-directional total Cmp (Forristall 3D distribution), location E1.

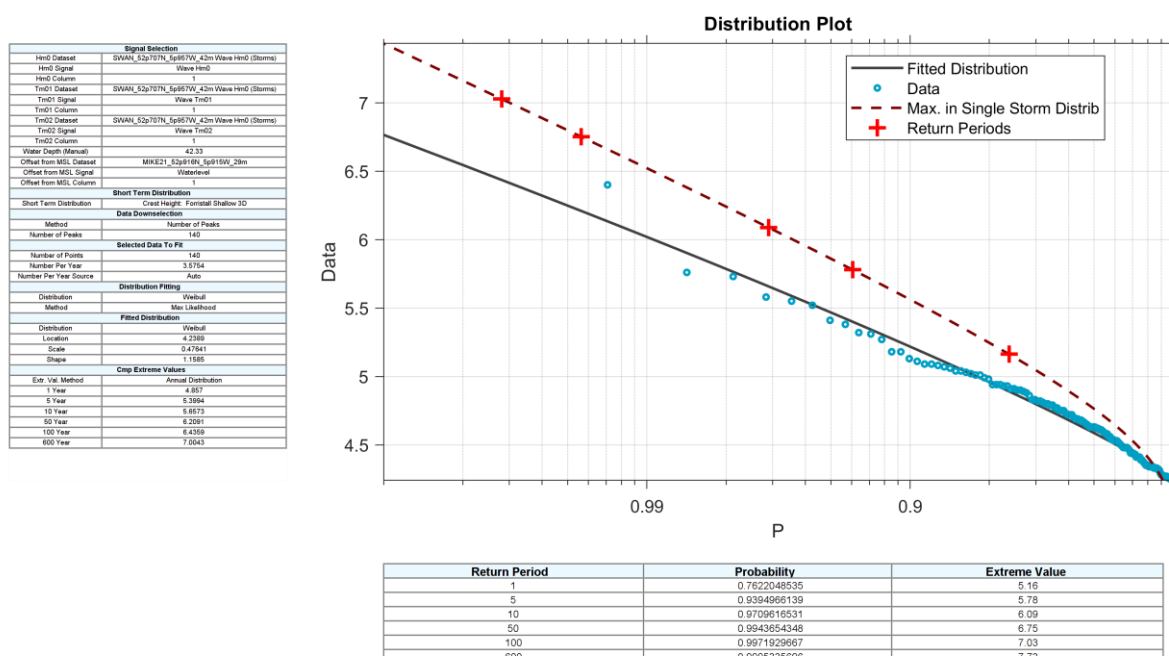


Figure 11.14: Extrapolation of omni-directional total Cmp (Forristall 3D distribution), location E2.

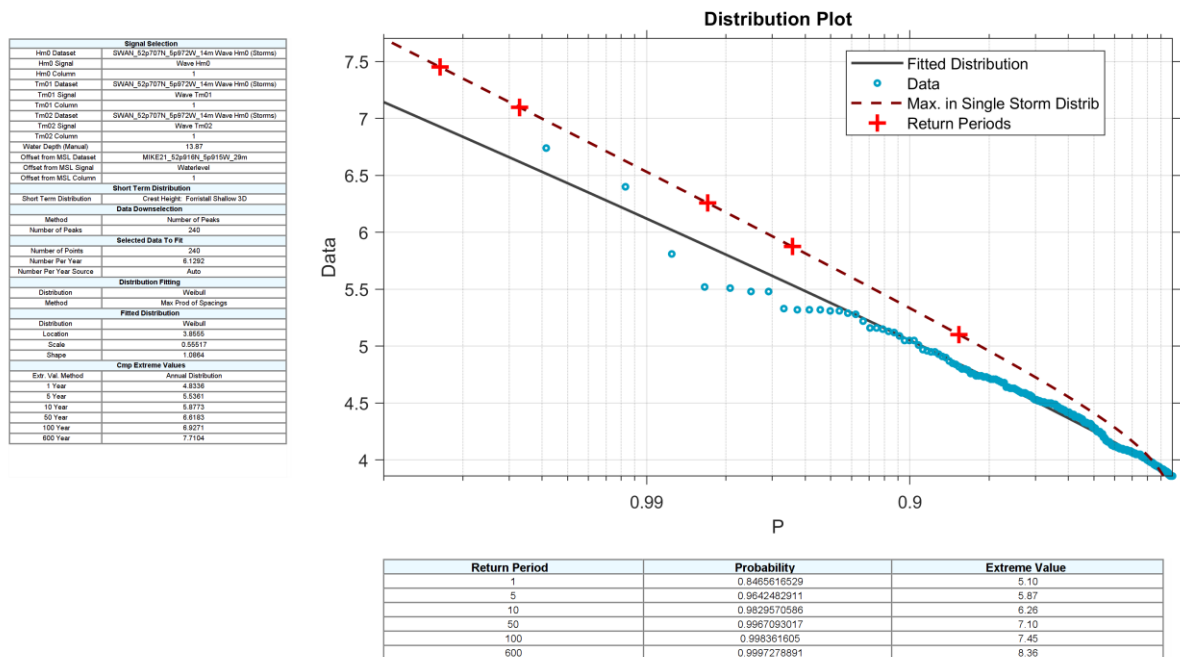


Figure 11.15: Extrapolation of omni-directional total Cmp (Forristall 3D distribution), location E3.

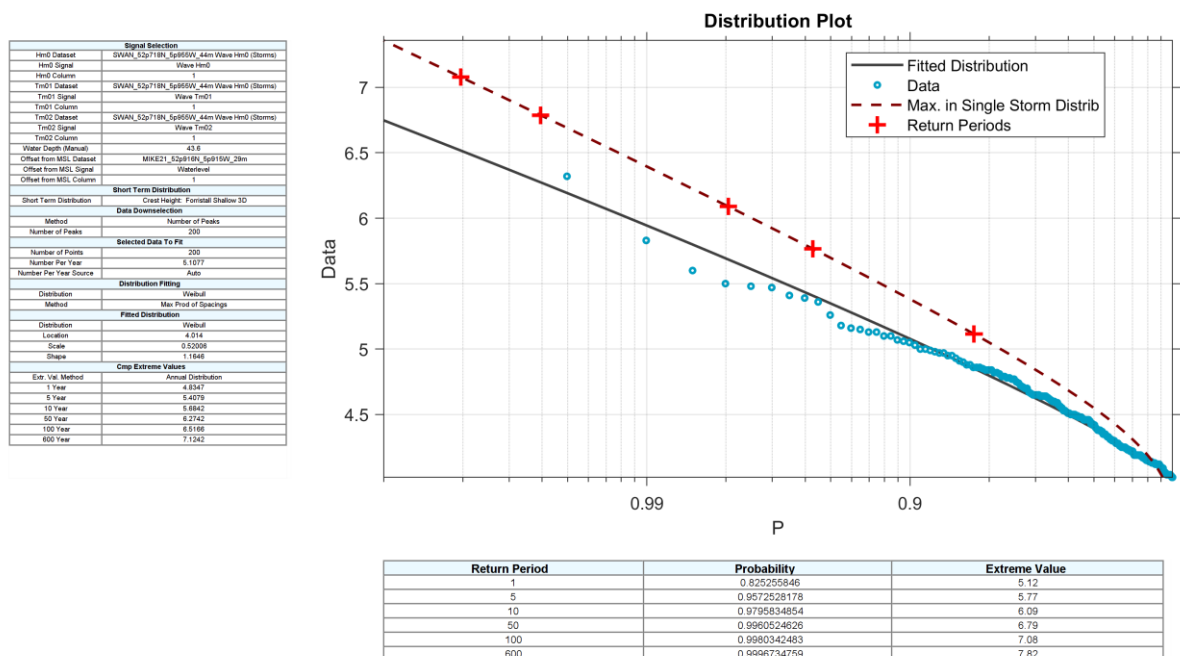


Figure 11.16: Extrapolation of omni-directional total Cmp (Forristall 3D distribution), location E4.

## 11.4 Associated Wave Periods

Relationships between mean zero crossing wave period (Tm02) and significant wave height (Hm0) are shown for the location E1 in Figure 11.17, whilst those for Tp and Hm0 are included in Figure 11.18. Thereafter, corresponding relationships for the locations E2, E3 and E4 are shown in Figure 11.19 through Figure 11.24.

As discussed in the Metocean Analysis Overview which accompanies these statistics (SSE\_C00004\_R05\_Metocean\_Analysis\_Overview), for some locations and directional sectors *two* Tp relationships are presented: a “Primary” relationship (coloured red) and a “Secondary” relationship (coloured blue). In addition to the fits themselves, the steepness range used to determine each fit is also shaded appropriately, and the percentage of data values above the 1-year extreme significant wave height in each shaded region given in the top left of each plot.

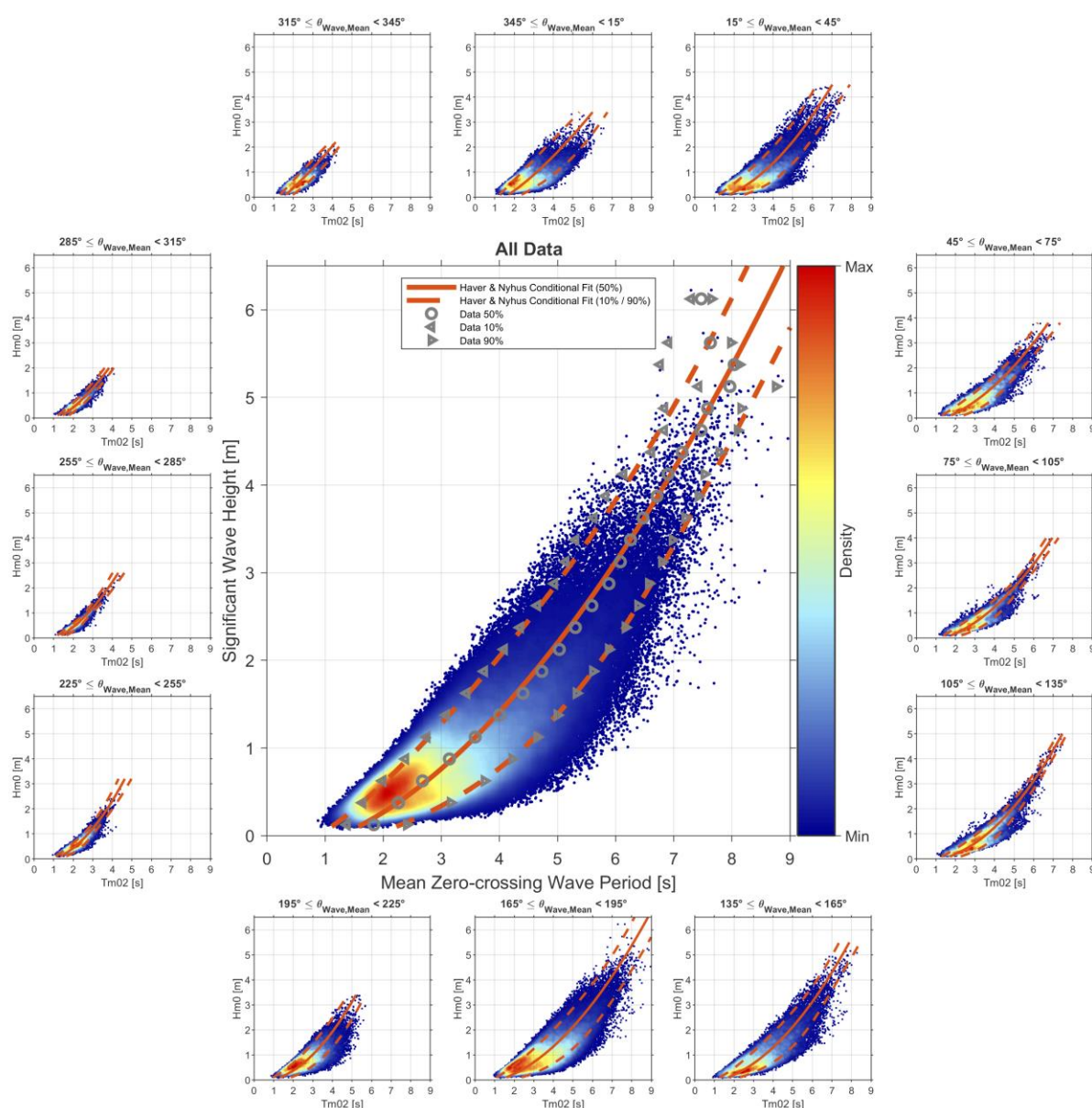


Figure 11.17: Omni-directional and directional relationships between total Hm0 and Tm02, location E1.

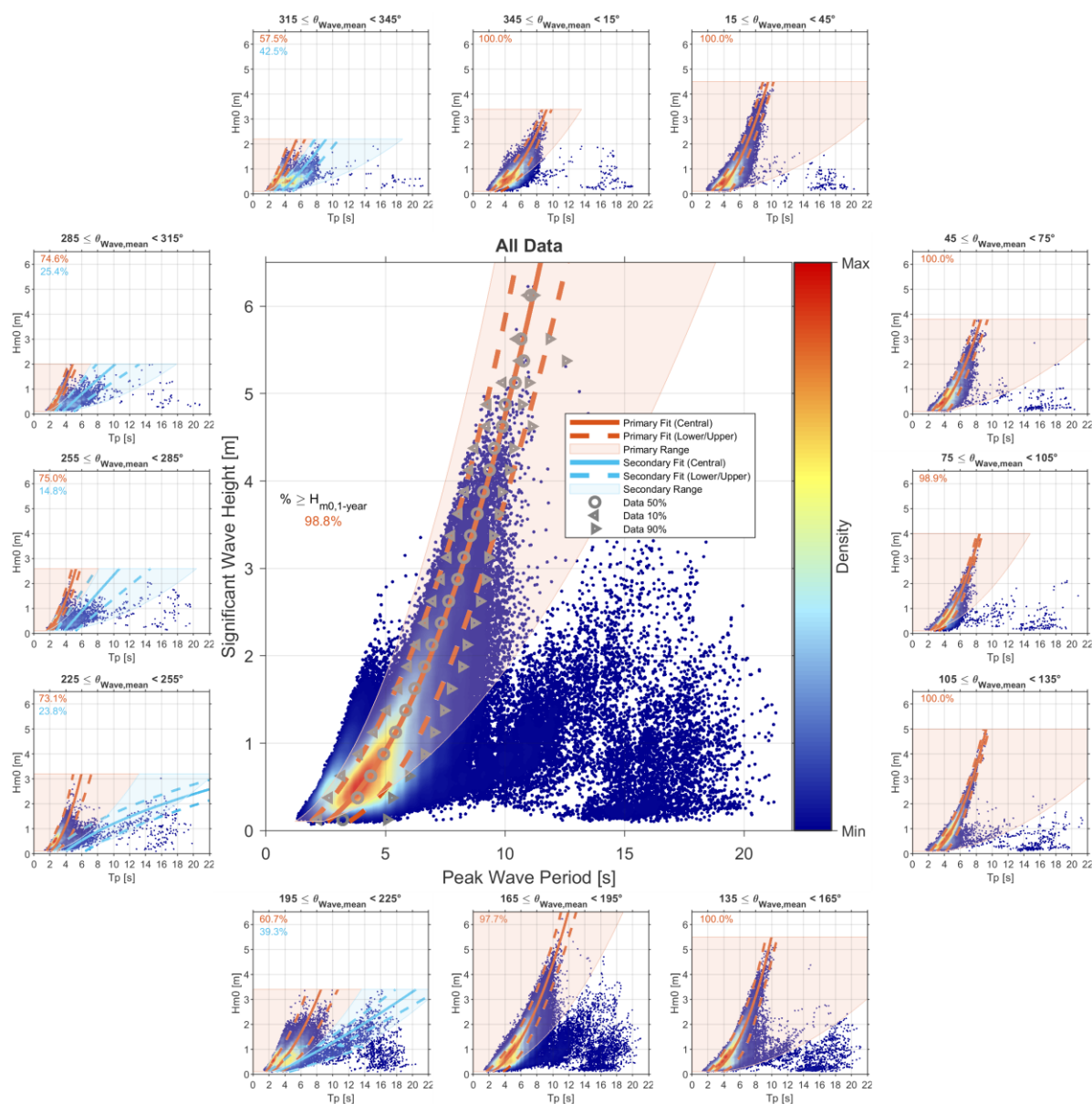


Figure 11.18: Omni-directional and directional relationships between total Hm0 and Tp, location E1.

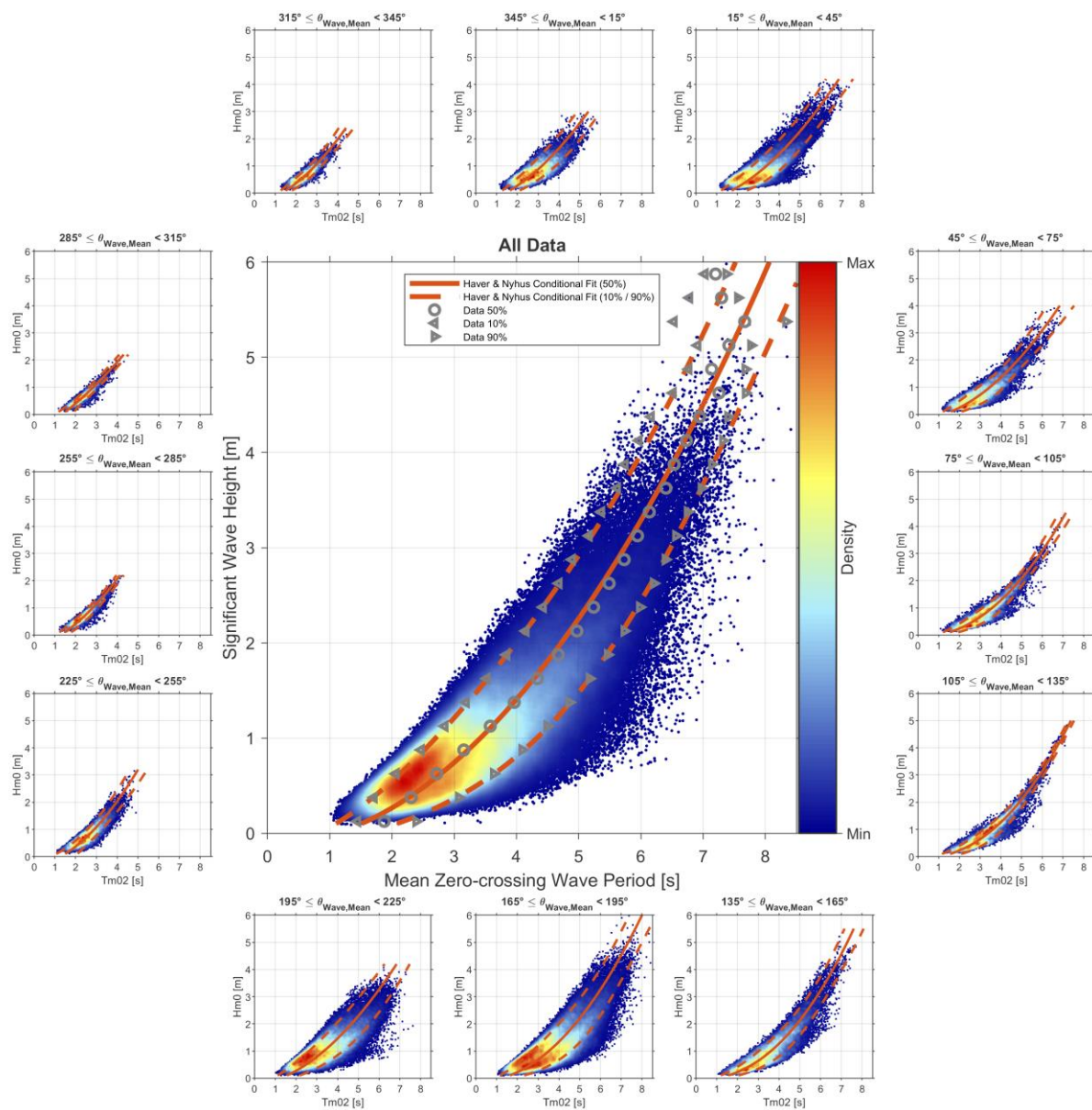


Figure 11.19: Omni-directional and directional relationships between total  $H_{m0}$  and  $T_{m02}$ , location E2.

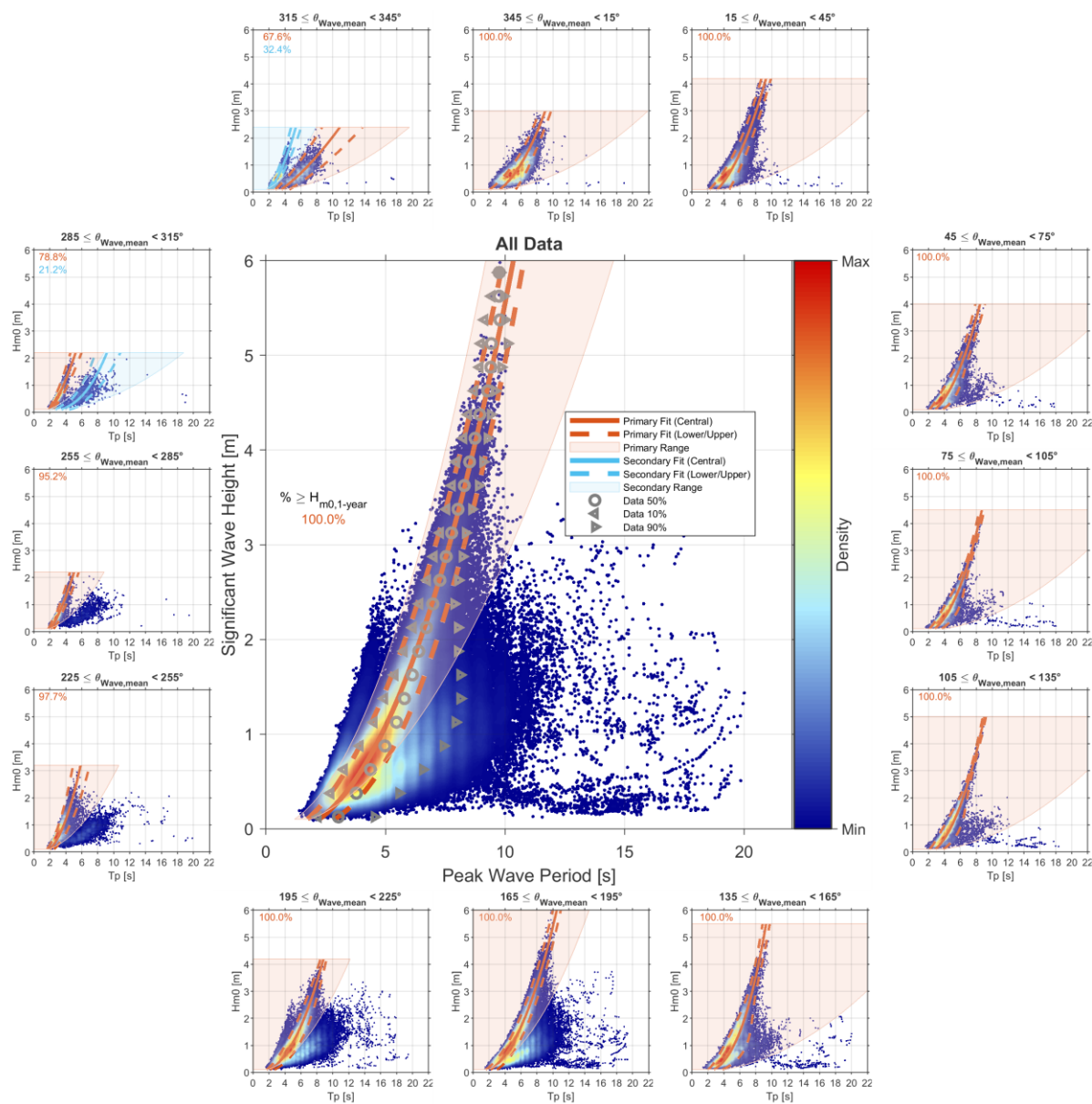


Figure 11.20: Omni-directional and directional relationships between total Hm0 and Tp, location E2.

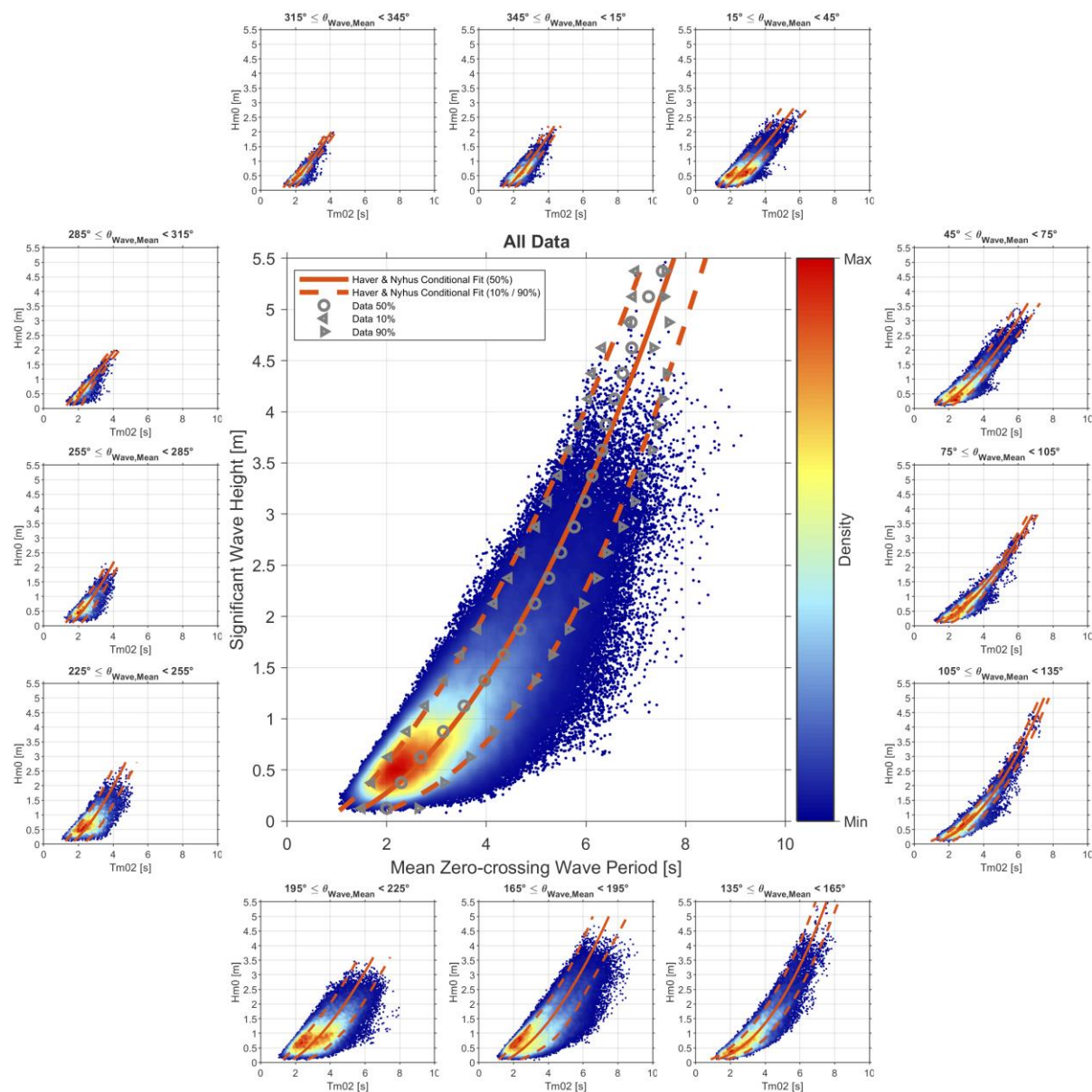


Figure 11.21: Omni-directional and directional relationships between total Hm0 and Tm02, location E3.

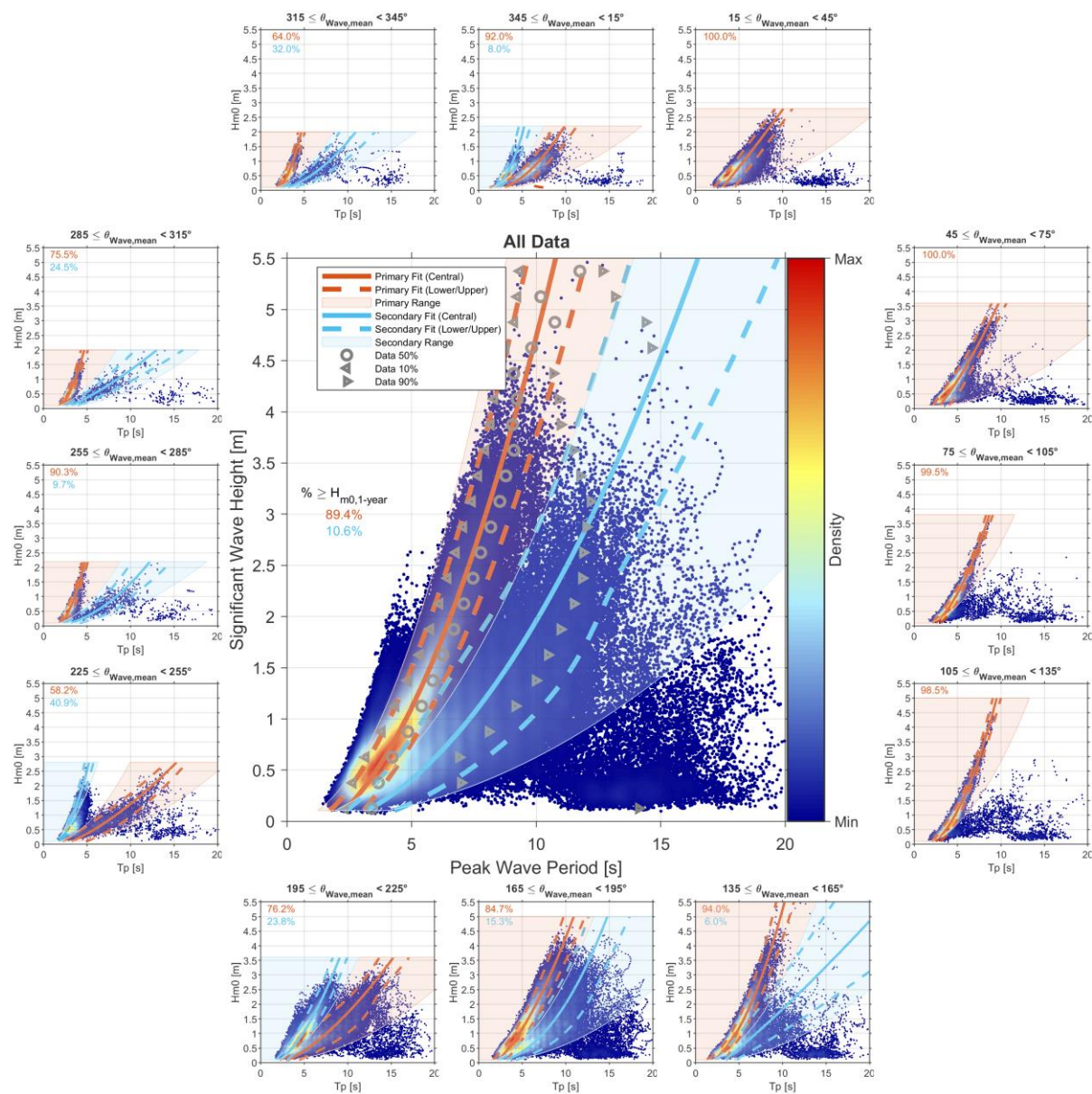


Figure 11.22: Omni-directional and directional relationships between total Hm0 and Tp, location E3.

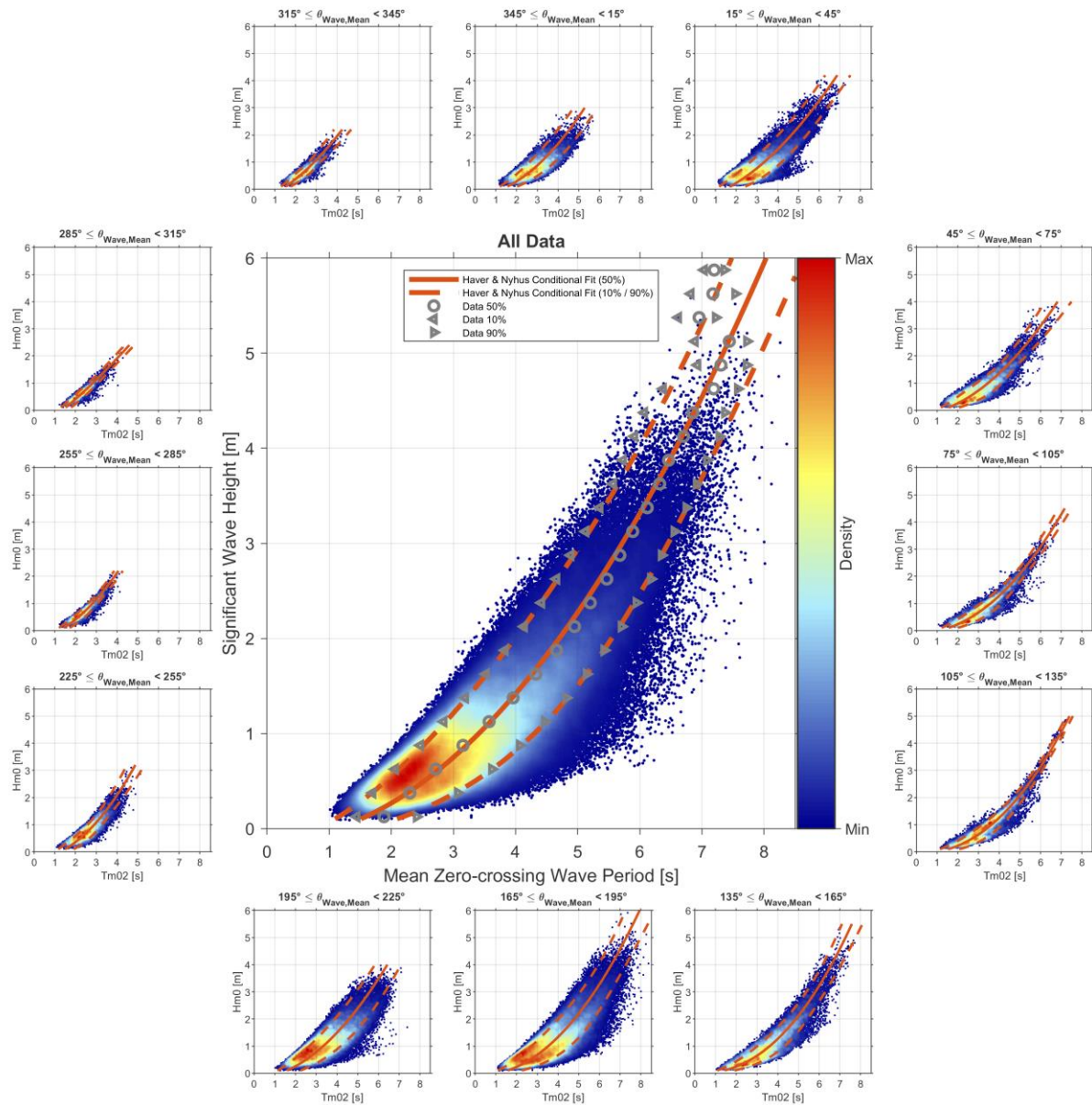


Figure 11.23: Omni-directional and directional relationships between total Hm0 and Tm02, location E4.

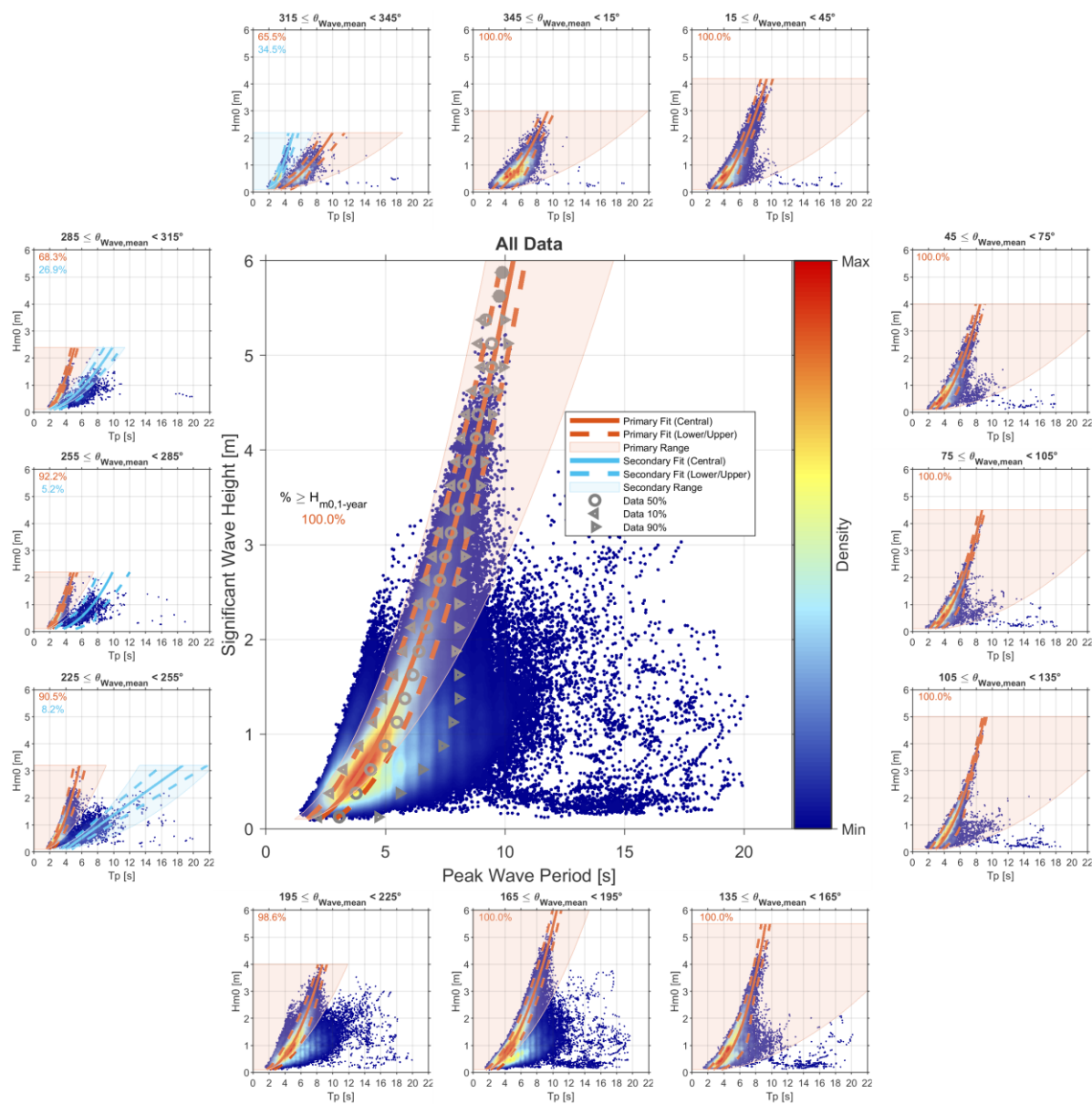


Figure 11.24: Omni-directional and directional relationships between total Hm0 and Tp, location E4.



## 12 Extreme Sea States

This Section contains supplementary information and diagnostics for the worksheet “7 - Extreme Sea states” of the Microsoft Excel Spreadsheet SSE\_C00004\_R05\_Metocean\_Input\_For\_Design\_East.xlsx.

Omni-directional extreme depth averaged current speeds for locations Ec1, Ec2, Ez1 and E3 are compared in Figure 12.1 whilst directional values are shown in Figure 12.2. Thereafter, analogous plots are included for significant wave heights at E1, E2, E3 and E4 in Figure 12.3 and Figure 12.4, whilst omni-directional maximum wave heights, crest heights relative to still water level, and crest heights relative to LAT are shown (also for E1, E2, E3 and E4) in Figure 12.5, Figure 12.6 and Figure 12.7 respectively.

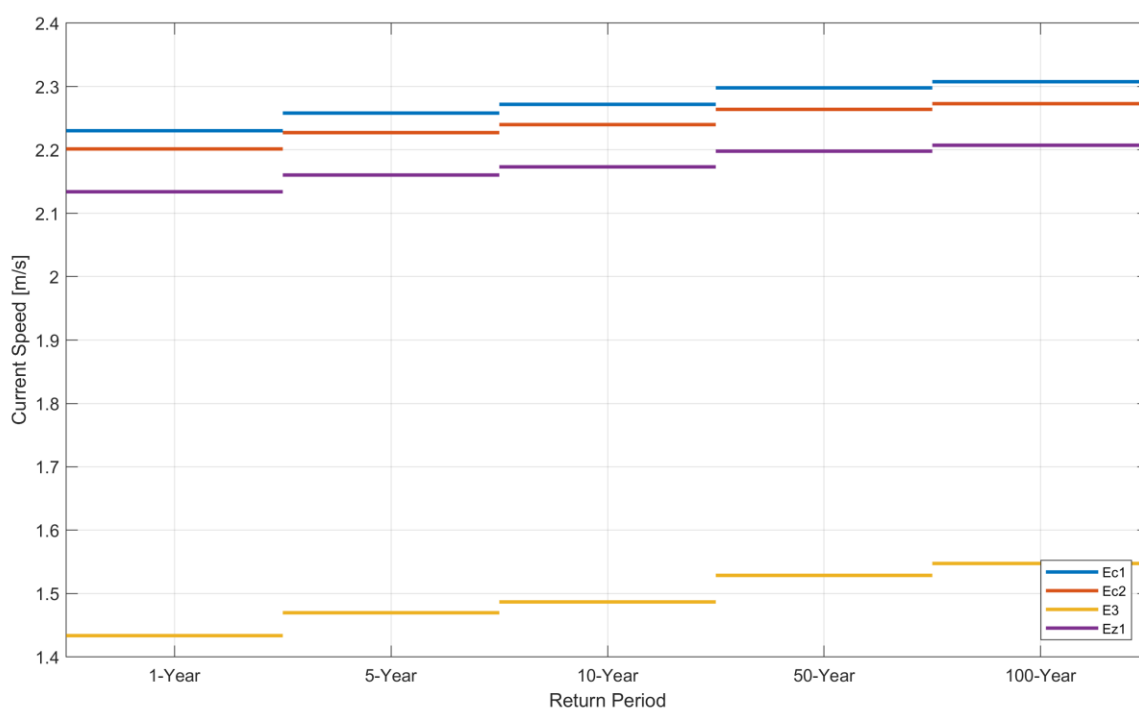


Figure 12.1: Omni-directional extreme depth averaged current speeds, locations Ec1, Ec2, Ez1 and E3.

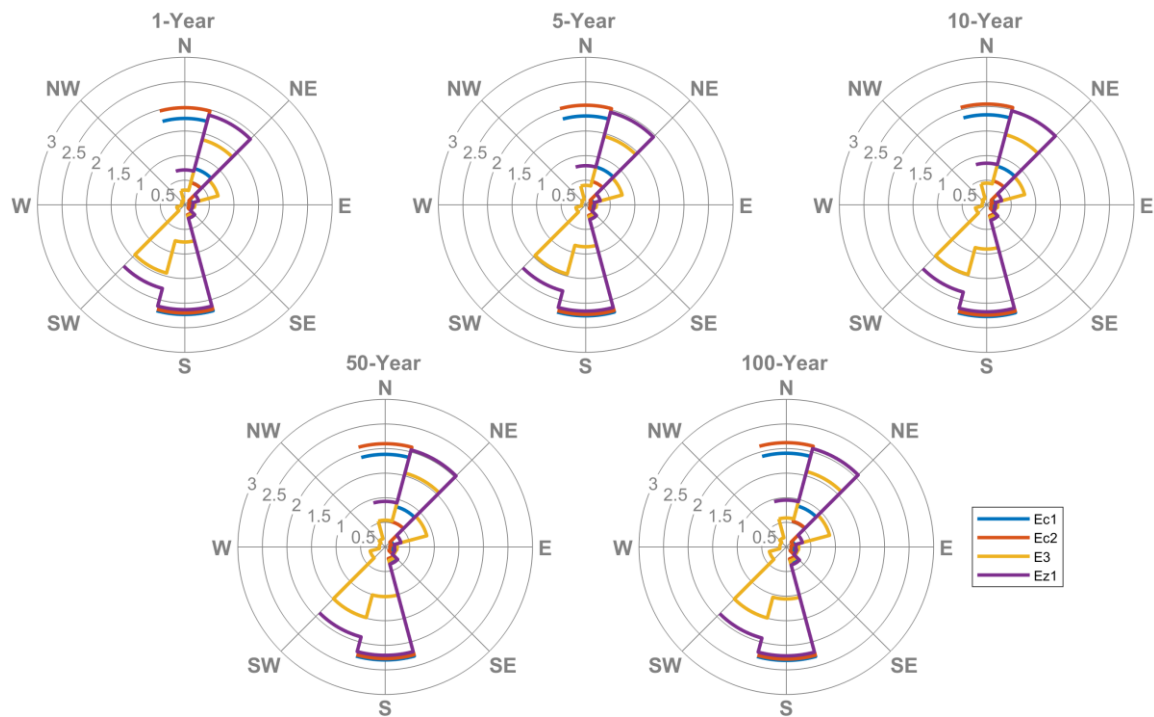


Figure 12.2: Directional extreme depth averaged current speeds, locations Ec1, Ec2, Ez1 and E3.

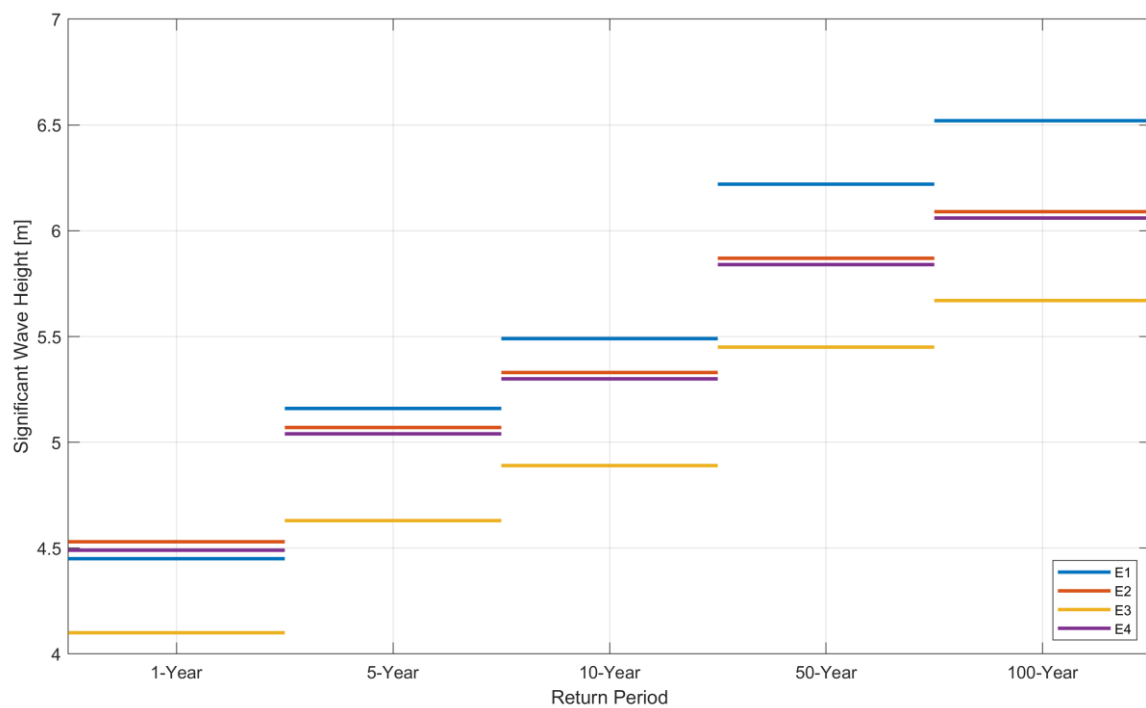


Figure 12.3: Omni-directional extreme significant wave heights, locations E1, E2, E3 and E4.

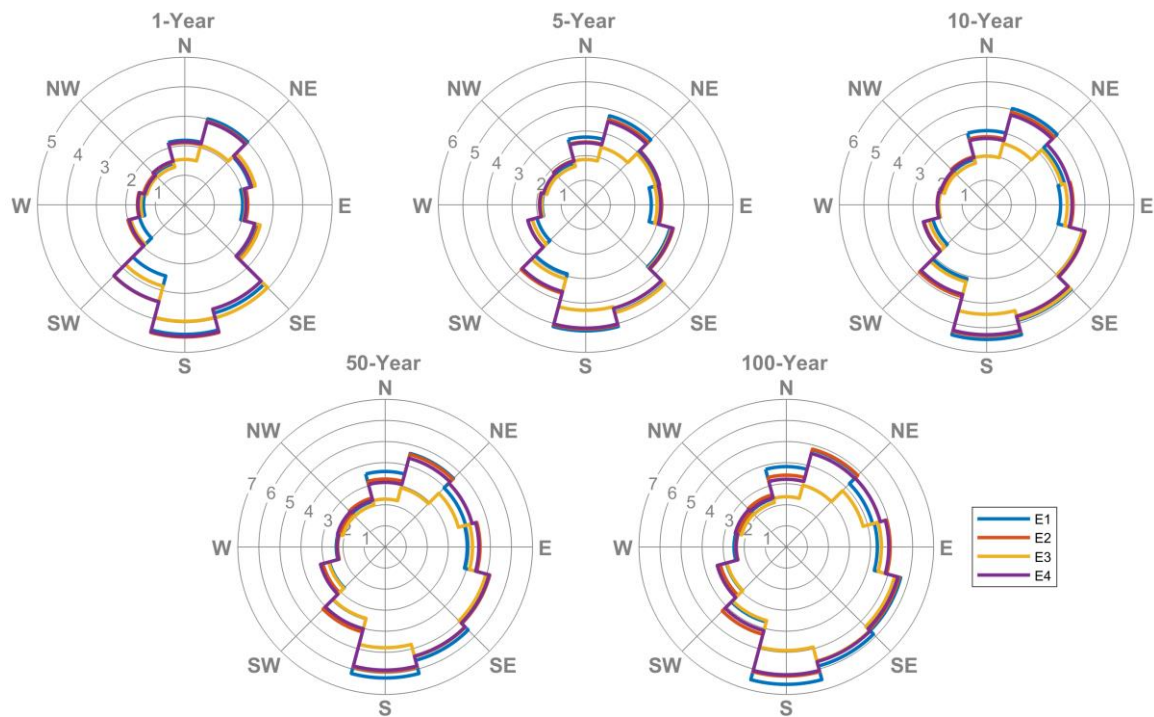


Figure 12.4: Directional extreme significant wave heights, locations E1, E2, E3 and E4.

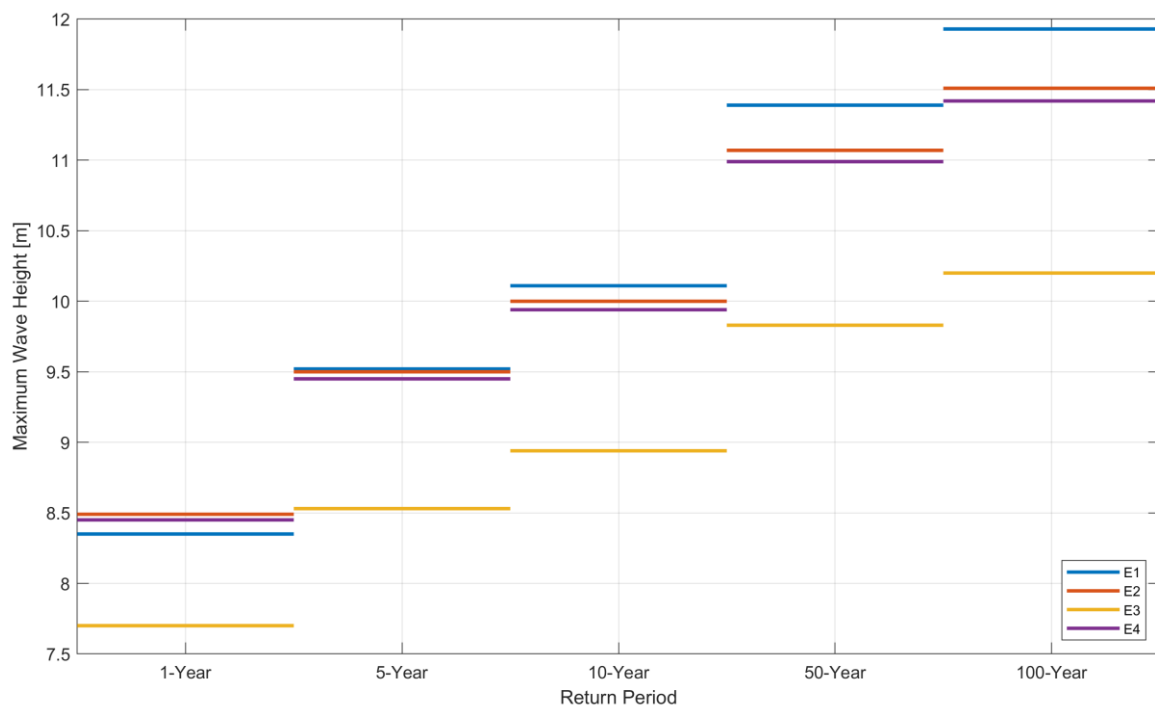


Figure 12.5: Omni-directional maximum wave heights, locations E1, E2, E3 and E4.

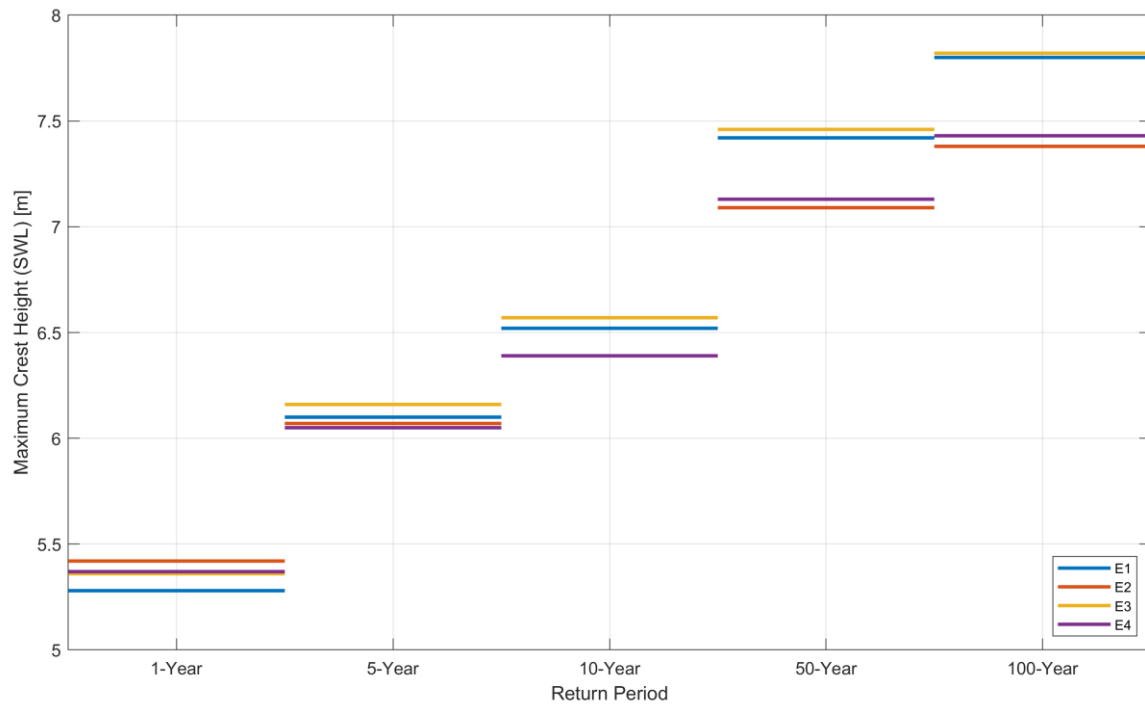


Figure 12.6: Omni-directional maximum crest heights, relative to still water level, locations E1, E2, E3 and E4.

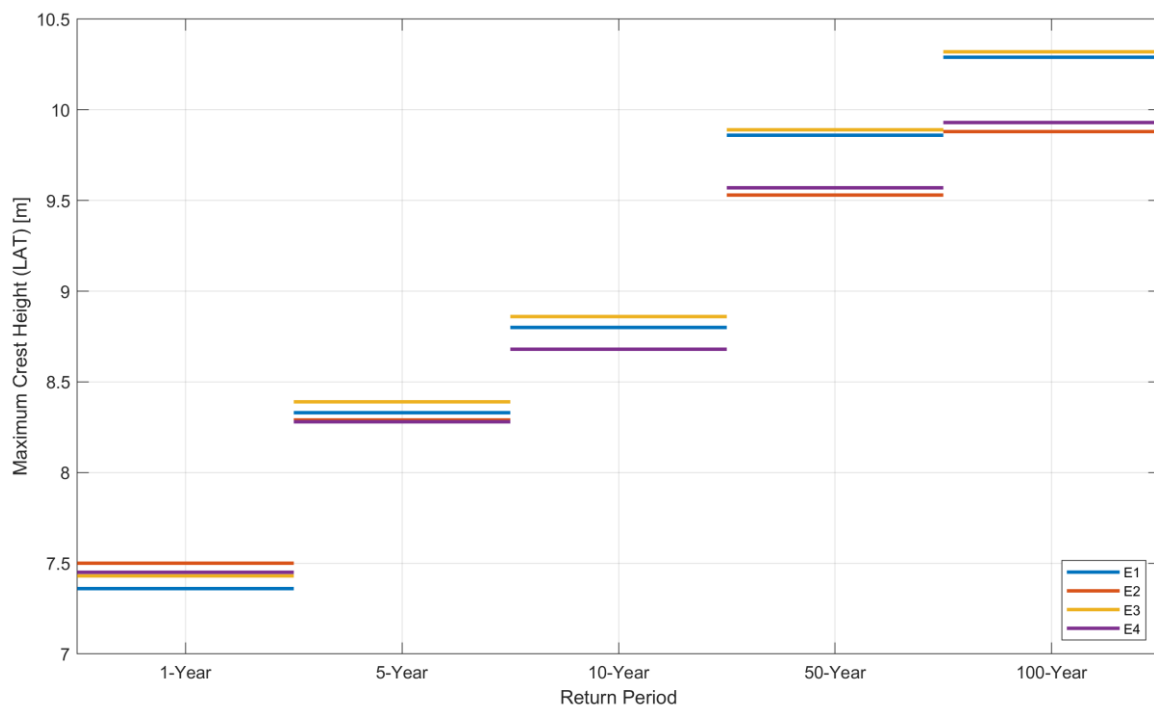


Figure 12.7: Omni-directional maximum crest heights, relative to LAT, locations E1, E2, E3 and E4.



## 13 Severe Sea States

This Section contains supplementary information and diagnostics for the worksheet “8 - Omni -Severe Sea states” of the Microsoft Excel Spreadsheet SSE\_C00004\_R05\_Metocean\_Input\_For\_Design\_East.xlsx.

### 13.1 Data Sources

Severe Sea State statistics were calculated from hindcast data for the location E1.

### 13.2 Significant Wave Heights

The final significant wave height contour for the location E1 is shown in Figure 13.1, alongside a number of intermediate results used in its construction.

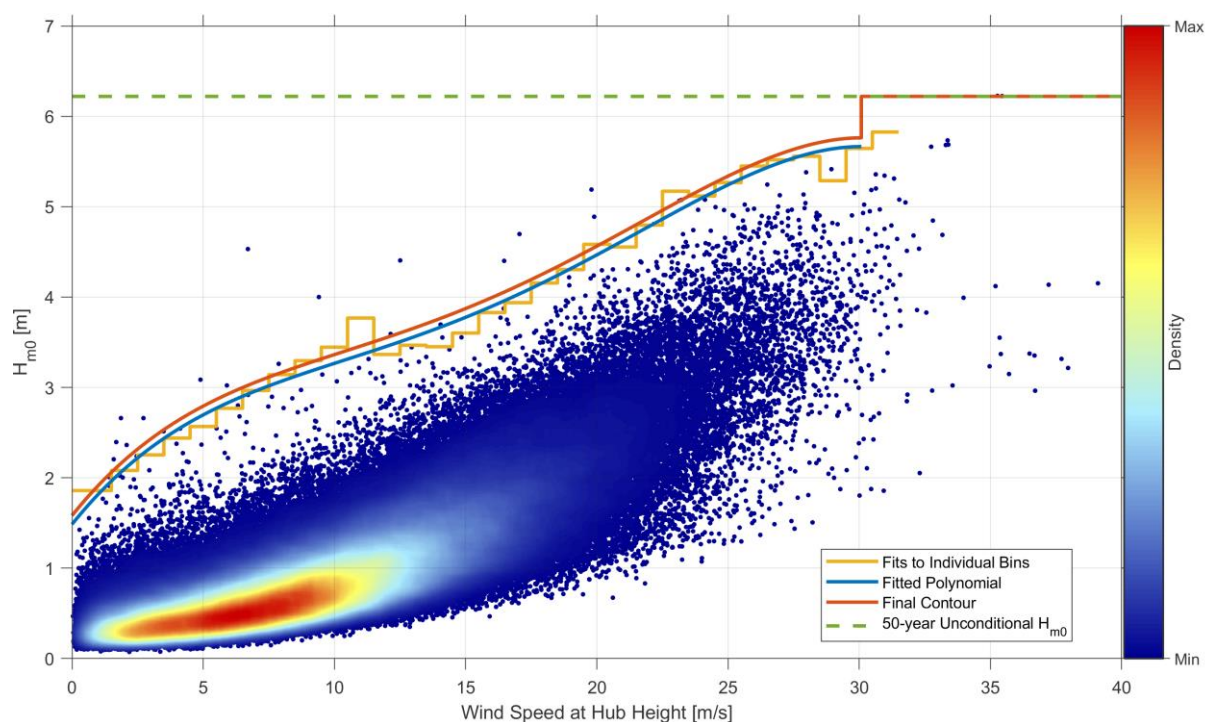


Figure 13.1: Significant Wave Height contour for the SSS, location E1.



### 13.3 Associated Peak Periods

The relationships used to determine peak period values to associate with the SSS contour are shown in Figure 13.2.

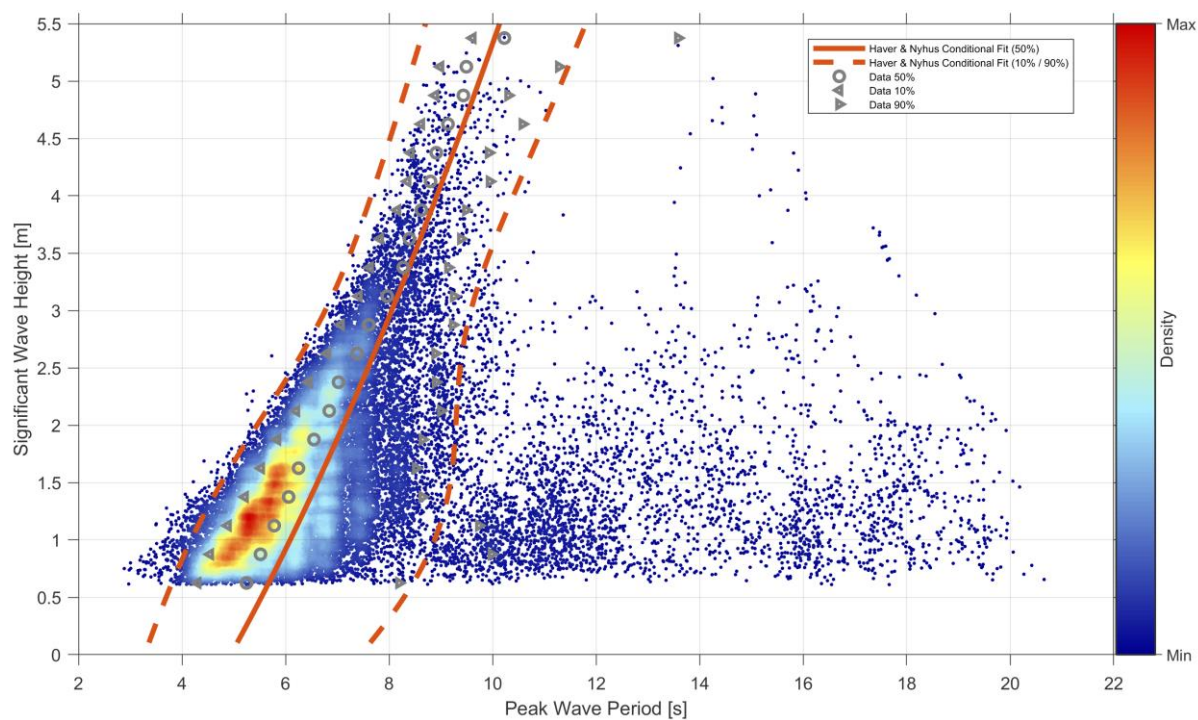


Figure 13.2: Peak period relationship for the SSS, location E1.



## 14 Associated Parameters

This Section contains supplementary information and diagnostics for the worksheets “9a - Associated Parameters Wave” and “9b - Associated Parameters Wind” of the Microsoft Excel Spreadsheet SSE\_C00004\_R05\_Metocean\_Input\_For\_Design\_East.xlsx.

### 14.1 Data Sources

All wind and wave parameters are taken from the location E1, whilst current speeds are taken from the location Ec1 and water levels from the location Ez1.

### 14.2 Parameters Associated with $H_m0$

Percentiles of 3-hour mean hub height wind speeds conditional on significant wave height ( $H_m0$ ) are shown in Figure 14.1 followed by 1- and 50-year IFORM contours in Figure 14.2. Thereafter, analogous figures for positive still water levels (Figure 14.3 and Figure 14.4) and negative still water levels (Figure 14.5 and Figure 14.6) are included. As discussed in Appendix J of the Metocean Analysis Overview document, SSE\_C00004\_R05\_Metocean\_Analysis\_Overview, only unconditional current speed statistics are used and as such, no model is fitted, nor diagnostic plots included herein.

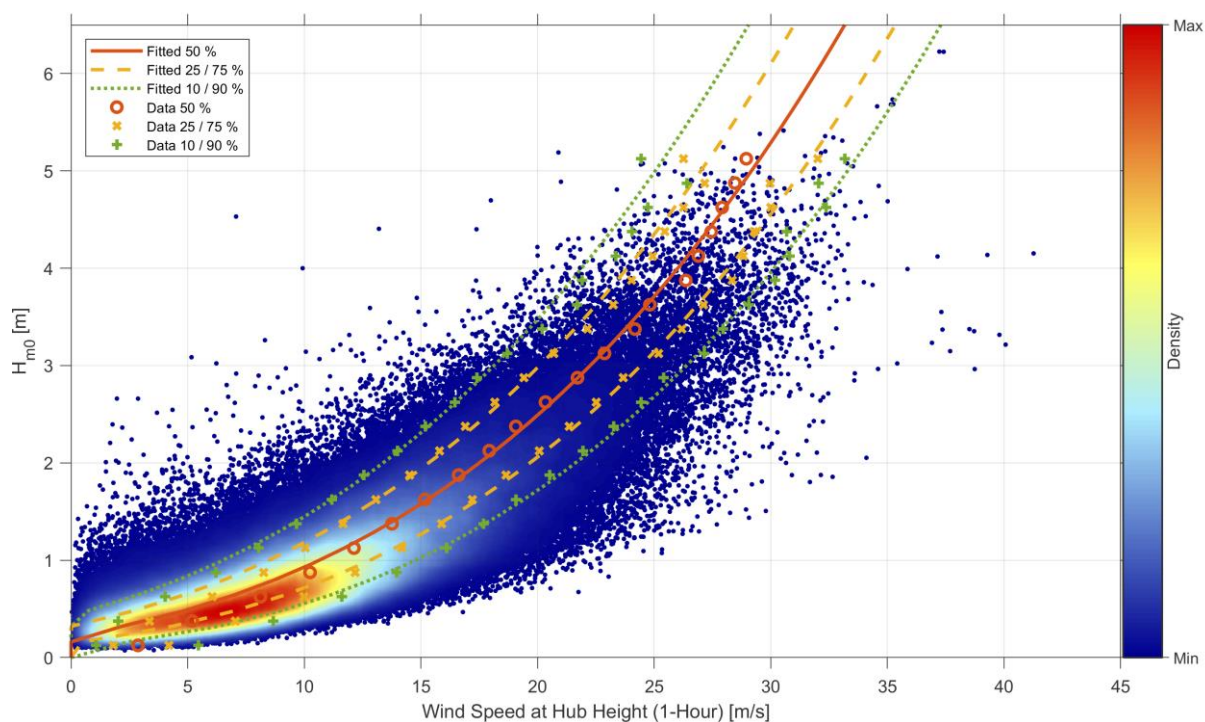


Figure 14.1: Percentiles of hub height wind speeds conditional on  $H_{m0}$ .

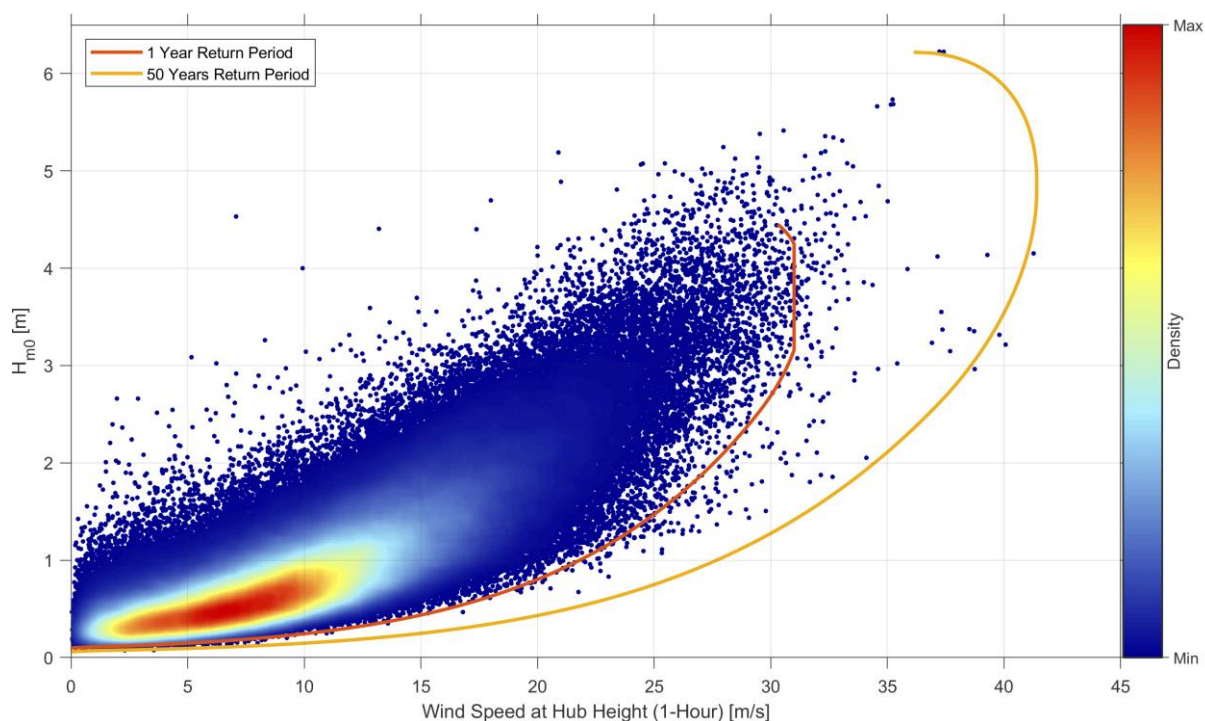


Figure 14.2: 1- and 50-year IFORM contours of hub height wind speeds conditional on  $H_{m0}$ .

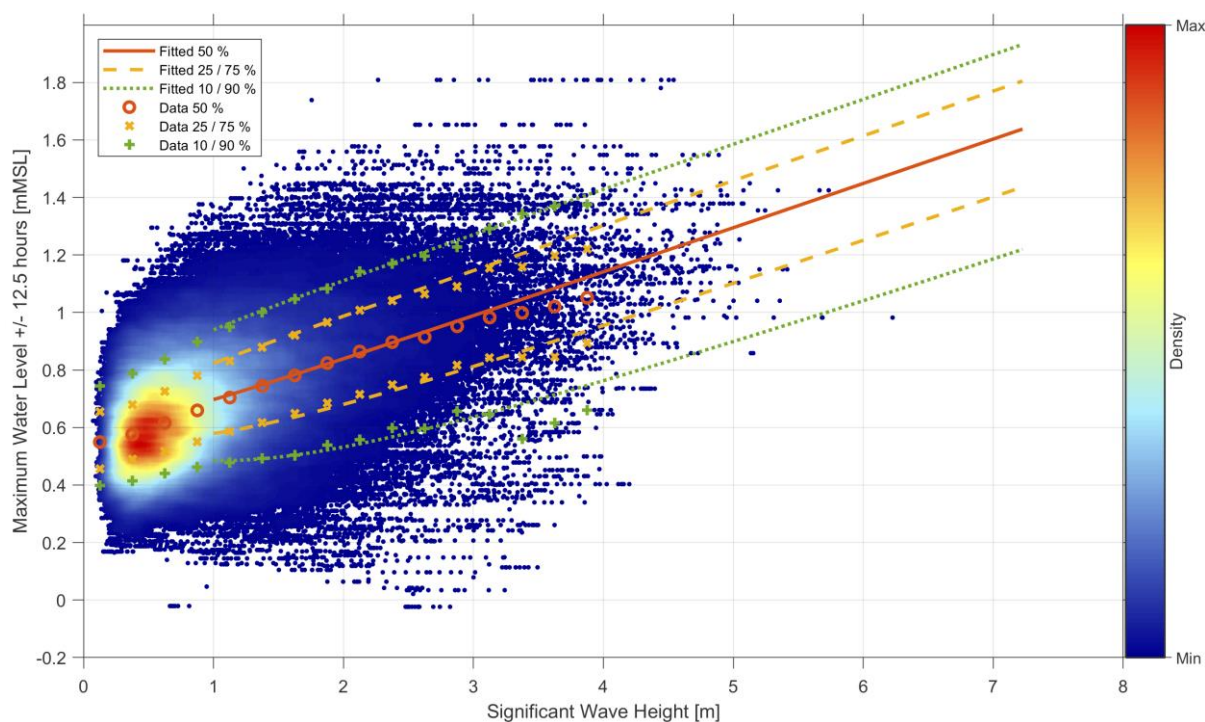


Figure 14.3: Percentiles of positive still water levels conditional on  $H_{m0}$ .

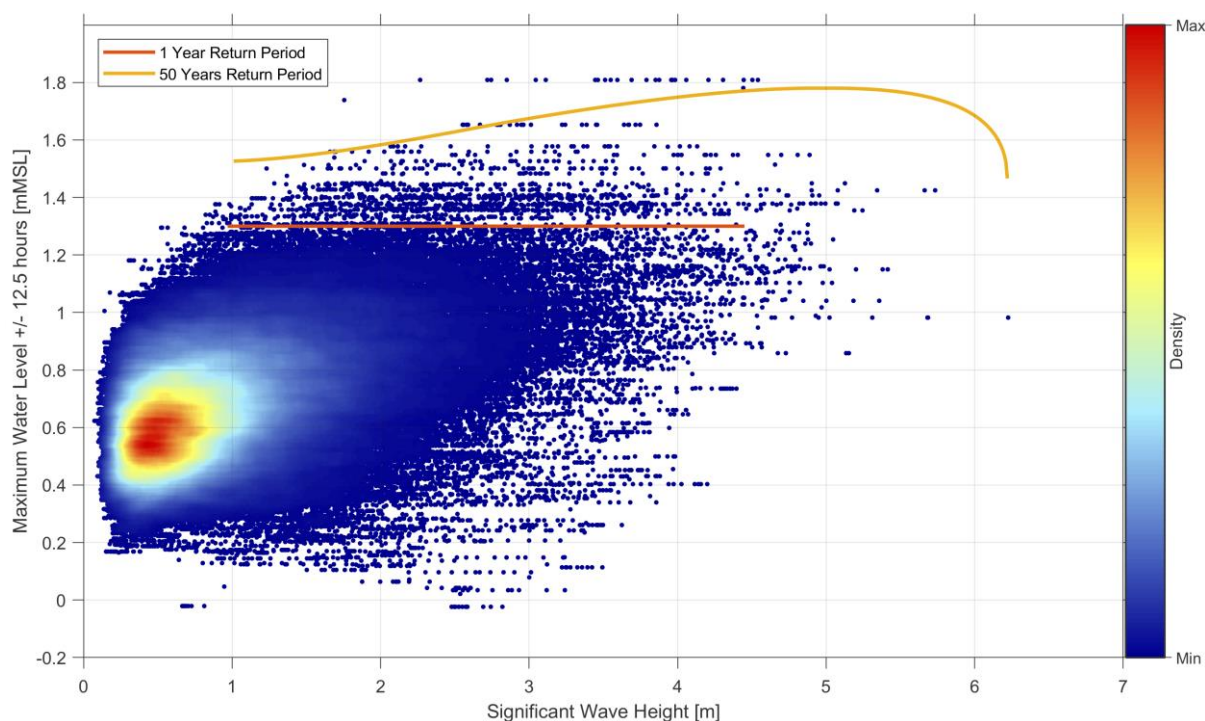


Figure 14.4: 1- and 50-year IFORM contours of positive water levels conditional on  $H_{m0}$ .

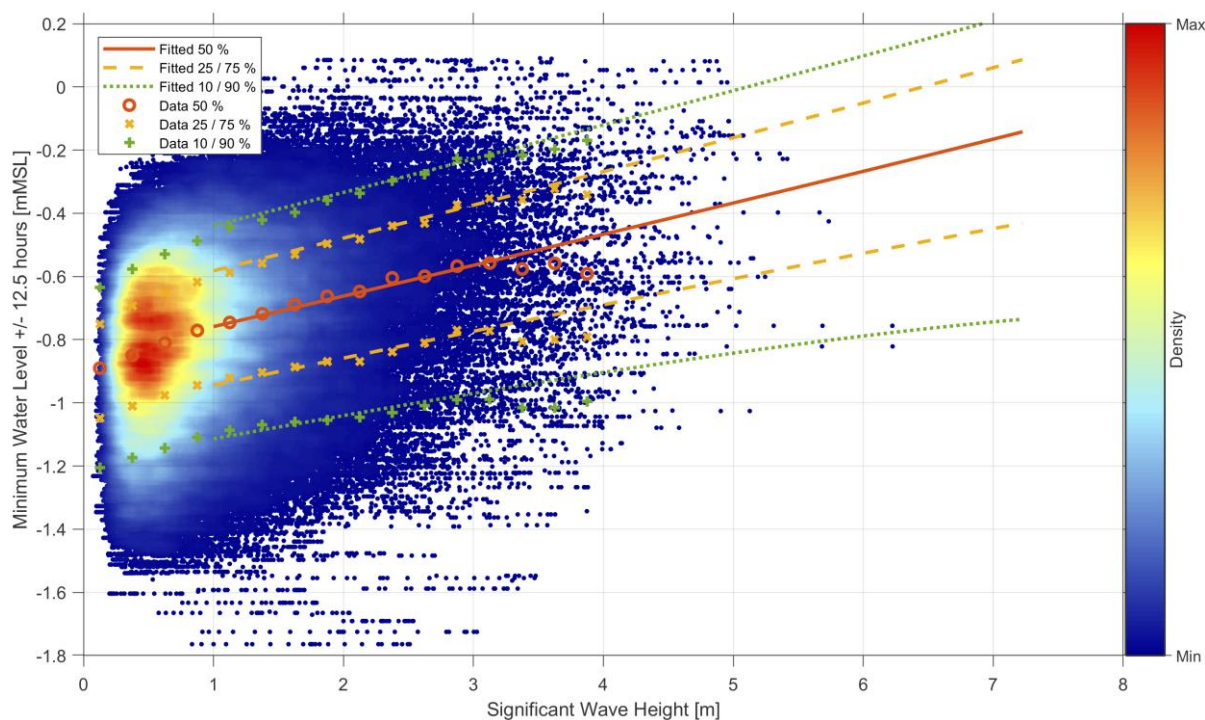


Figure 14.5: Percentiles of negative still water levels conditional on  $H_{m0}$ .

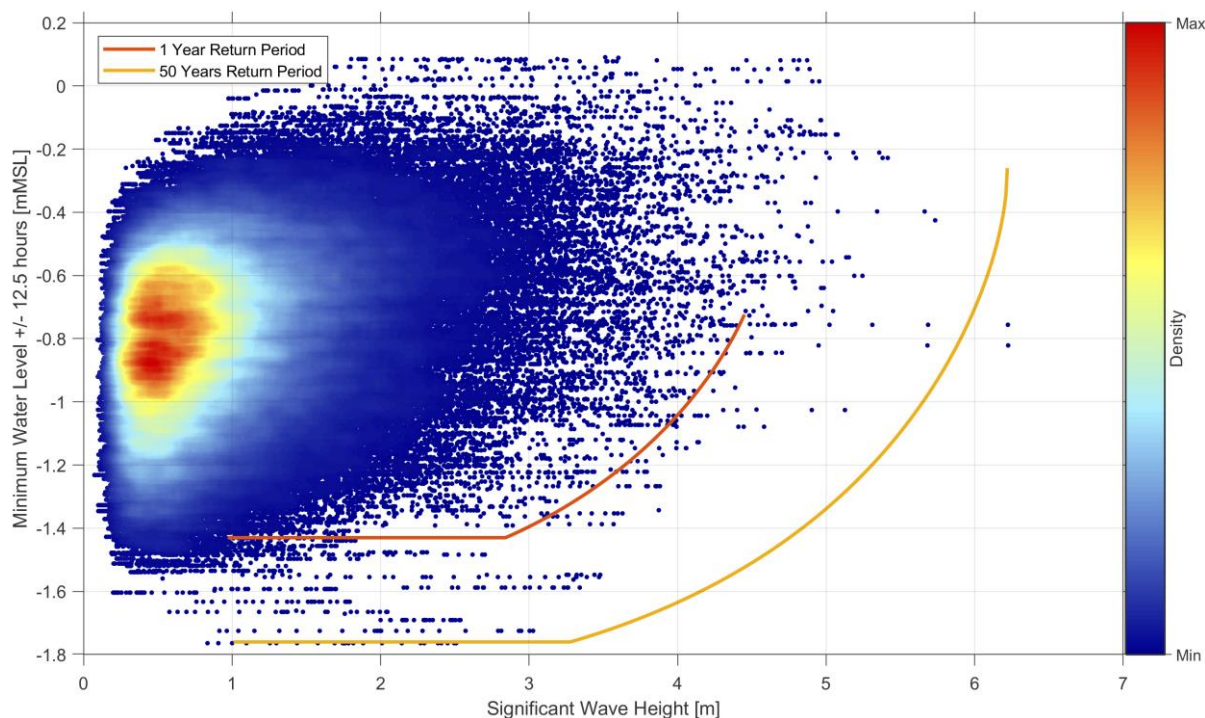


Figure 14.6: 1- and 50-year IFORM contours of negative water levels conditional on  $H_{m0}$ .



### 14.3 Parameters Associated with Hub Height Wind Speeds

Percentiles of  $H_{m0}$  conditional on 3-hour mean hub height wind speeds are shown in Figure 14.7 followed by 1- and 50-year IFORM contours in Figure 14.8. Thereafter, analogous figures for positive still water levels (Figure 14.9 and Figure 14.10) and negative still water levels (Figure 14.11 and Figure 14.12) are included. Again, only unconditional current speed statistics are used and as such, no model is fitted, nor diagnostic plots included herein.

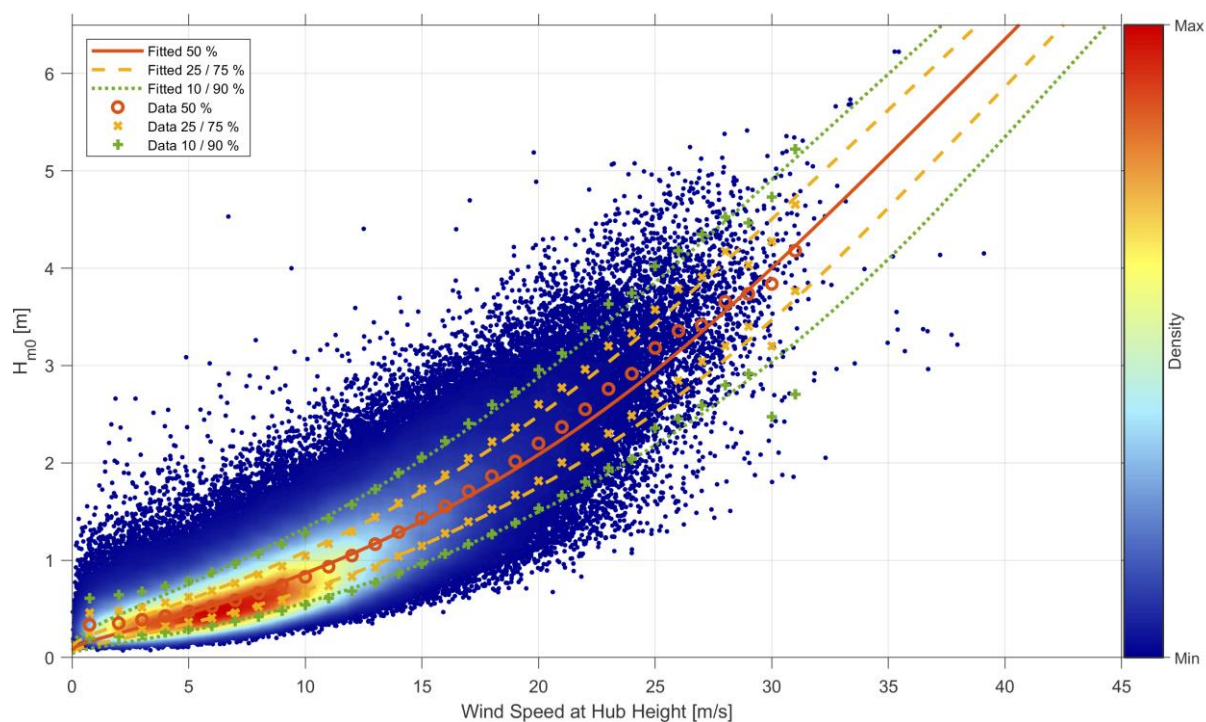


Figure 14.7: Percentiles of  $H_{m0}$  conditional on hub height wind speed.

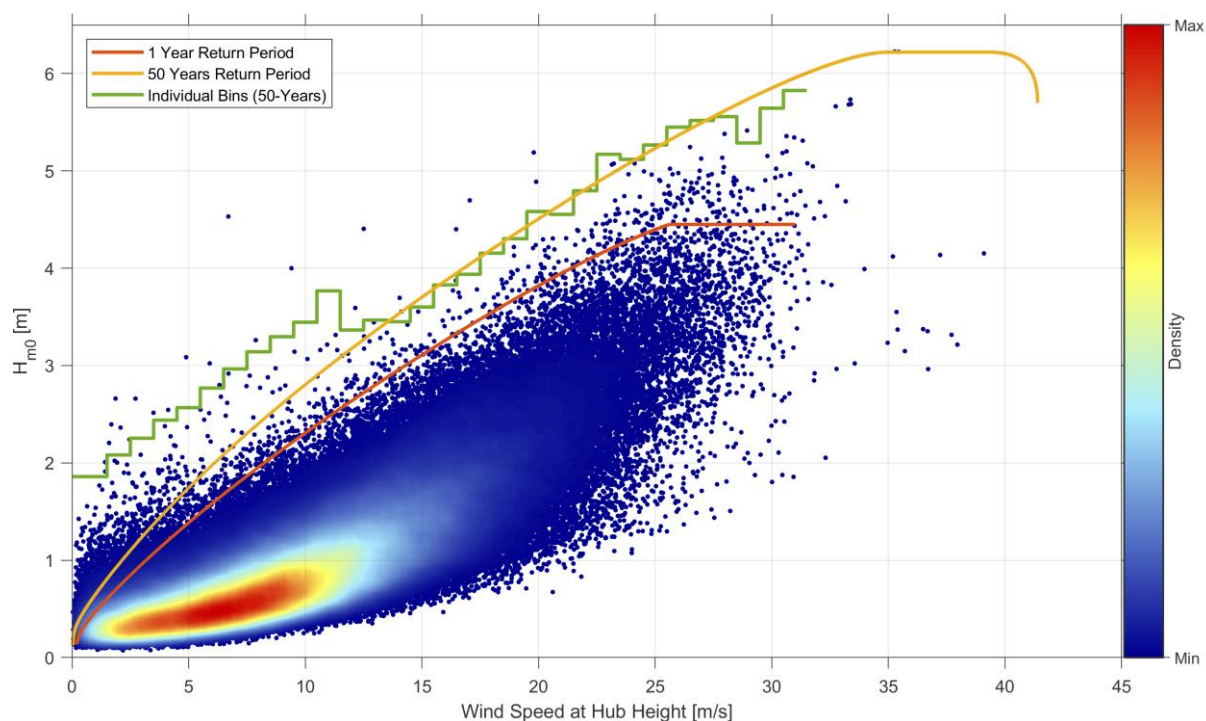


Figure 14.8: 1- and 50-year IFORM contours of  $H_{m0}$  conditional on hub height wind speed.

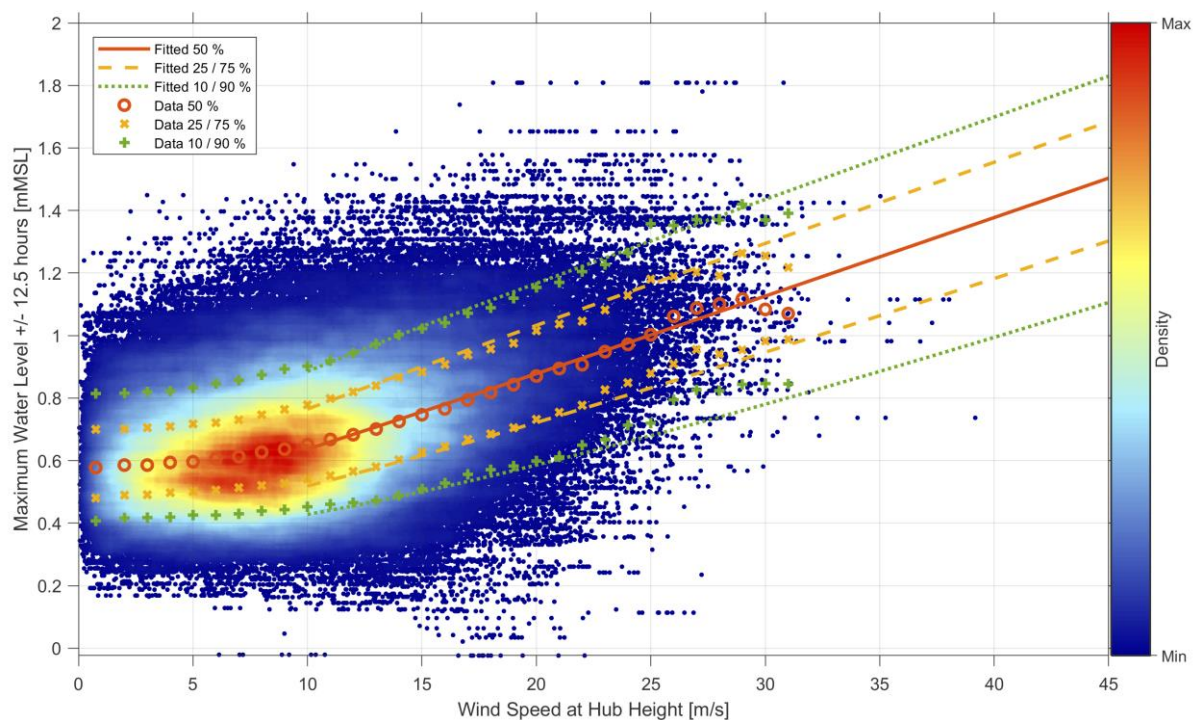


Figure 14.9: Percentiles of positive still water levels conditional on hub height wind speed.

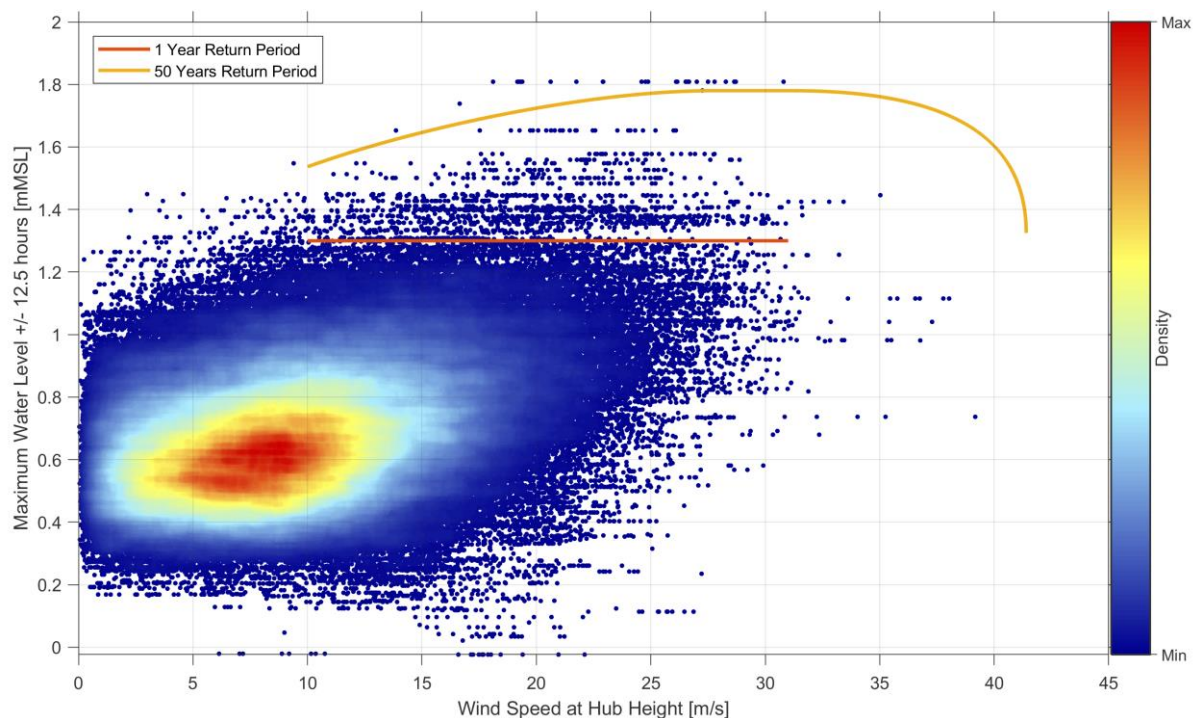


Figure 14.10: 1- and 50-year IFORM contours of positive water levels conditional on hub height wind speed.

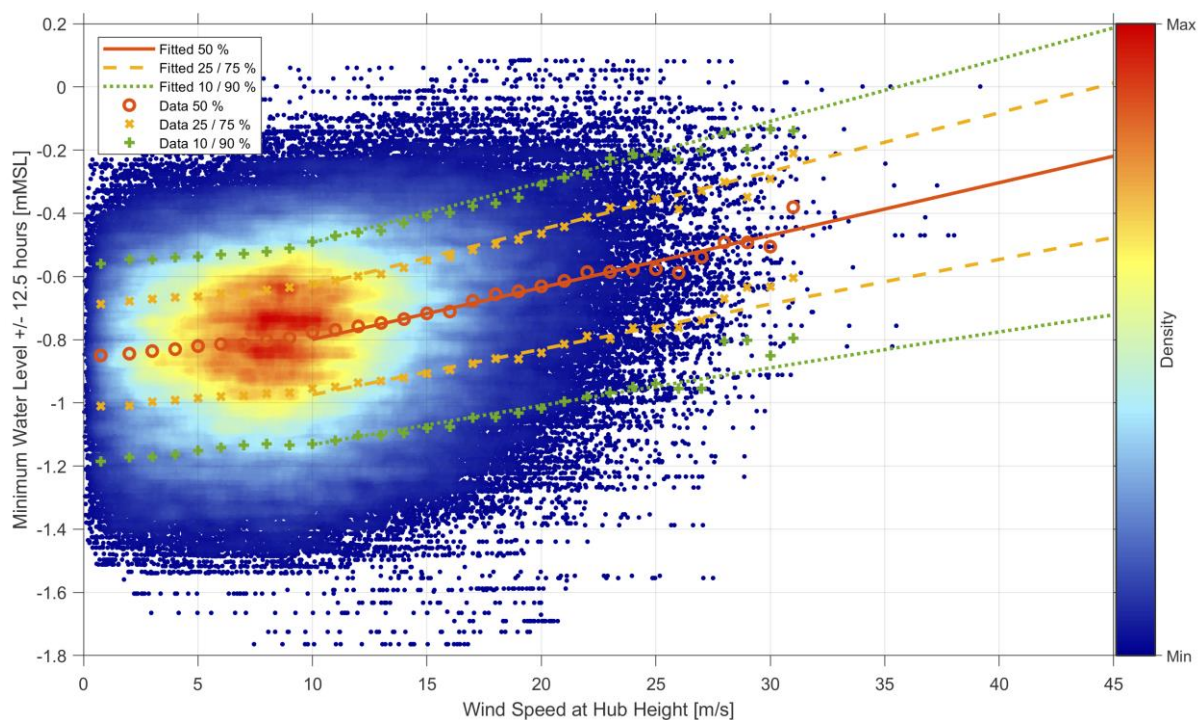


Figure 14.11: Percentiles of negative still water levels conditional on hub height wind speed.

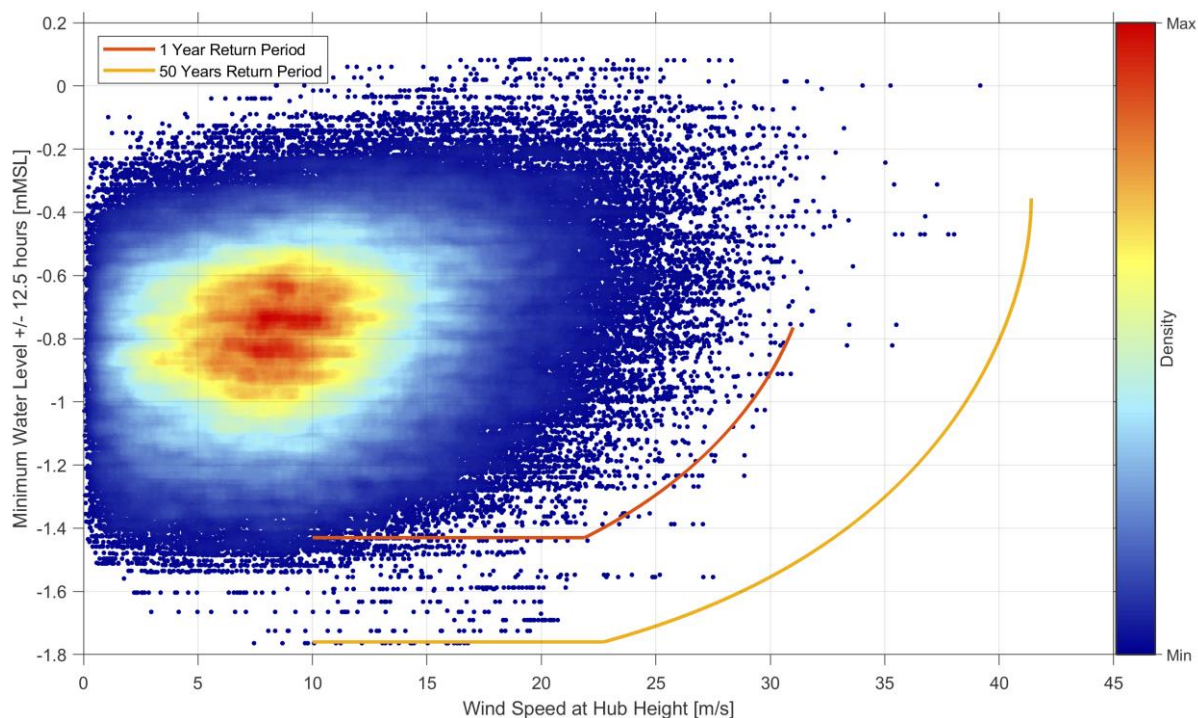


Figure 14.12: 1- and 50-year IFORM contours of negative water levels conditional on hub height wind speed.



## 15 Figure List

A number of additional plots are specified as being required to support analysis in the worksheet “10 – Figure list” of the Microsoft Excel Spreadsheet SSE\_C00004\_R05\_Metocean\_Input\_For\_Design\_East.xlsx. As requested therein, these are provided as separate .png files.



## 16References

- [1] MetOceanWorks, “Metocean Data Overview, Arklow Bank Offshore Wind Farm, SSE\_C00002\_R03\_Metocean\_Data\_Overview,” 2021.