**Date** 02 February 2016
**Your reference** WOZ150011
**Our reference** ECN-WIND-2016-040

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THE NETHERLANDS

**Subject** Supply of Meteorological and Oceanographic data for Borssele Wind Farm Zone Period 14 Augustus - 14 September 2015

Dear Sir/Madam,

The following two Meteorological and Oceanographic data reports produced by Fugro OCEANOR AS have been reviewed by ECN Wind Energy:

1. Supply of Meteorological and Oceanographic data at Borssele Wind Farm Zone (BWFZ)
   Monthly Progress Report : 14 August – 14 September 2015.
   Reference No: C75339_MPR03_R2 (17 December 2015)
2. Supply of Meteorological and Oceanographic data at Borssele Wind Farm Zone (BWFZ)
   Validation report : 14 August – 14 September 2015.
   Reference No: C75339_VAL03_R1 (7 December 2015)

ECN has found that the above referenced reports provide a sufficient detail for potential users of the provided data to perform analysis.

Please note that the provided data can be retrieved via the website : www.WindOpZee.net. It should also be noted that in the documents it is mentioned that additional Water Level Sensor data will become available after retrieving the sensor. This data is at the present moment not available via the website and is also not part of this review. Additional actions need to be taken after the data becomes available.

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Yours sincerely,

Hans Verhoef
Project Leader Measurements

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THE NETHERLANDS ENTERPRISE AGENCY (RVO)

# Supply of Meteorological and Oceanographic data at Borssele Wind Farm Zone (BWFZ)
## Monthly Progress Report: 14 August - 14 September 2015

Reference No: C75339_MPR03_R2
17 December 2015

Fugro OCEANOR AS
Pirsenteret, P.O. Box 1224, Sluppen, N-7462 Trondheim, Norway
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| Supply of Meteorological and Oceanographic data at Borssele Wind Farm Zone (BWFZ): C75339_MPR03_R2 | | | | |
|---|---|---|---|---|
| **Rev** | **Date** | **Originator** | **Checked & Approved** | **Issue Purpose** |
| 0 | 24.11.2015 | Lasse Lønseth | Arve Berg | Final report. |
| 1 | 07.12.2015 | Lasse Lønseth | Arve Berg | Final report updated according to client's comments. |
| 2 | 17.12.2015 | Lasse Lønseth | Arve Berg | Final report with updated wind direction plots. |

| Rev 2 – 17 December 2015 | Originator | Checked & Approved |
|---|---|---|
| Signed: | Lasse Lønseth | Arve Berg |

This report is not to be used for contractual or engineering purposes unless the above is signed where indicated by both the originator of the report and the checker/approver and the report is designated 'FINAL'.

# TABLE OF CONTENT

# SUMMARY

The Seawatch Wind Lidar buoy is deployed at the Borssele Wind Farm Zone (BWFZ). The buoy was first deployed on 11 June 2015 at 15:55 UTC, and the bottom mounted tide gauge (WLR) was deployed at 16:15 UTC on the same day. The multicat type workboat M.P.R.3 was used for the operation.

There has been no service visits to the buoy during the third month of operation. However, the transmissions from the buoy stopped on 11 September 2015 and the buoy was recovered to shore on 6 October 2015 by the multicat type workboat Multrasalvor 3.

This third monthly report summarizes the activities and data collected during the period 14 August 2015 – 14 September 2015, and presents the data delivered by the buoy in time series plots.

# 1. INTRODUCTION

The Seawatch Wind Lidar buoy with serial no. WS149 is deployed at the Borssele Wind Farm Zone (BWFZ) in the Dutch sector of the North Sea. The buoy was first deployed on 11 June 2015 at 15:55 with the bottom mooring weight at position 51° 42.41388' N, 3° 2.07708' E. A bottom mounted water level recorder (WLR) at position 51° 42.4362' N, 3° 02.1030' E transmits data to the buoy in real time data via an acoustic link. The water depth at this location is approximately 30 m.

No service visits were carried out within the third month of operation. However, since the transmissions from the buoy stopped on 11 September 2015 at 16:00, the buoy was recovered to shore on 6 October 2015 for inspection and repair. The multicat type workboat Multrasalvor 3 was used for this operation.

This report presents project progress and results during the period 14 August – 14 September 2015, and the data which have been transmitted to shore via the Iridium satellite system in this period. From 11 September 2015 at 16:00 the buoy did not transmit data. However data from the Lidar wind profiler and the profiling current meter have been recovered later from their internal data stores and used to supplement the transmitted data. The data recovery percentages for this period are also presented.

The time reference used in this report is UTC.

# 2. Instrumentation and measurement configuration

The buoy is a Seawatch Wind Lidar Buoy based on the original Seawatch Wavescan buoy design with the following sensors:

- Wavesense: 3-directional wave sensor
- Xsens 3-axes motion sensor
- Gill Windsonic M acoustic wind sensor
- Vaisala PTB330A air pressure sensor
- Vaisala HMP155 air temperature and humidity sensor
- Nortek Aquadopp 600kHz current profiler.
- ZephIR 300S Lidar.

An independent self-recording Aanderaa SeaGuard WLR tide gauge is located on the bottom. The WLR transmits data to the buoy via an acoustic link.

The buoy with mooring as deployed is presented in Figure 2.1, including the mooring for the WLR.

The measurement setup is detailed in Table 2-1. Details of sensor types and serial number can be found in Appendix A.

**Table 2-1 Configuration of measurements by the Seawatch Wind Lidar buoy at Borssele Wind Farm Zone (BWFZ).**

| Instrument type | Sensor height (m) | Parameter measured | Sample height[2)] (m) | Sampling interval (s) | Averaging period (s) | Burst interval (s) | Trans-mitted? |
|---|---|---|---|---|---|---|---|
| Wavesense 3 | 0 | Heave, pitch, roll, heading | 0 | 0.5 | Time series duration: 1024 s | 600 | No |
| | | Sea state parameters (1) | 0 | 600 | 1024 | 600 | Yes |
| Xsens | | Heave,east,north acceleration, q0,q1,q2,q3 (attitude quaternion) | 0 | 0.5 | N/A | 3600 | No |
| Gill Windsonic M | 4.1 | Wind speed, wind direction | 4.1 | 1 | 600 | 600 | Yes |
| Vaisala PTB330A | 0.5 | Air pressure | 0.5 | 30 | 60 | 600 | Yes |
| Vaisala HMP155 | 4.1 | Air temperature<br>Air humidity | 4.1 | 5 | 60 | 600 | Yes |
| Nortek Aquadopp | -1 | Current speed and direction profile, water temperature (at 1 m depth) | -4<br>-6<br>…<br>-30<br>(14 levels) | N/A | 600 | 600 | Yes |
| ZephIR 300S Lidar | 2 | Wind speed and direction at 10 heights (The 11th level, the so called reference level which is not configurable, is also located at 40 m and referred to as 40.0 Ref.) | 30.0<br>40.0<br>40.0 ref<br>60.0<br>80.0<br>100.0<br>120.0<br>140.0<br>160.0<br>180.0<br>200.0 | ≈ 17.4 s[1)] | 600 | 600 | Yes |
| Aanderaa WLR (SeaGuard) via acoustic link | -30 | Water pressure<br>Temperature | -30 | 600 | 60 | 600 | Yes |

1) This is the approximate time between the beginning of one sweep of the profile and the next one, the interval may vary slightly. The ZephIR sweeps one level at a time beginning at the lowest one, and after the top level has been swept it uses some time for calculations and re-focusing back to the lowest level for a new sweep.

2) Height relative to actual sea surface. The depth of the WLR is an approximate number.

**Table 2.2 Definitions of wave parameters presented in this report**

| | |
|---|---|
| H | Individual wave height |
| Hmax | = Max(H): Height of the highest individual wave in the sample, measured from crest to trough |
| m0, m1, m2, m4, m-1, m-2 | Moments of the spectrum about the origin: $\int f^k S(f)df$ where $S(f)$ is the spectral density and the wave frequency, $f$, is in the range 0.04 - 0.50 Hz |
| Hm0 | Estimate of significant wave height, Hs, $Hm0 = 4\sqrt{m0}$ |
| Tp | Period of spectral peak = $1/f_p$, The frequency/period with the highest energy |
| Tm01 | Estimate of the average wave period; $Tm01 = m0/m1$ |
| Tm02 | Another estimate of the average wave period; $Tm02 = \sqrt{\frac{m0}{m2}}$ |
| ThTp | Mean wave direction at the spectral peak (“The direction of most energetic waves”) |
| Mdir | Wave direction averaged over the whole spectrum |
| | Directions are given in degrees clockwise from north, giving the direction the waves come from. (0° from north, 90° from east, etc.) |

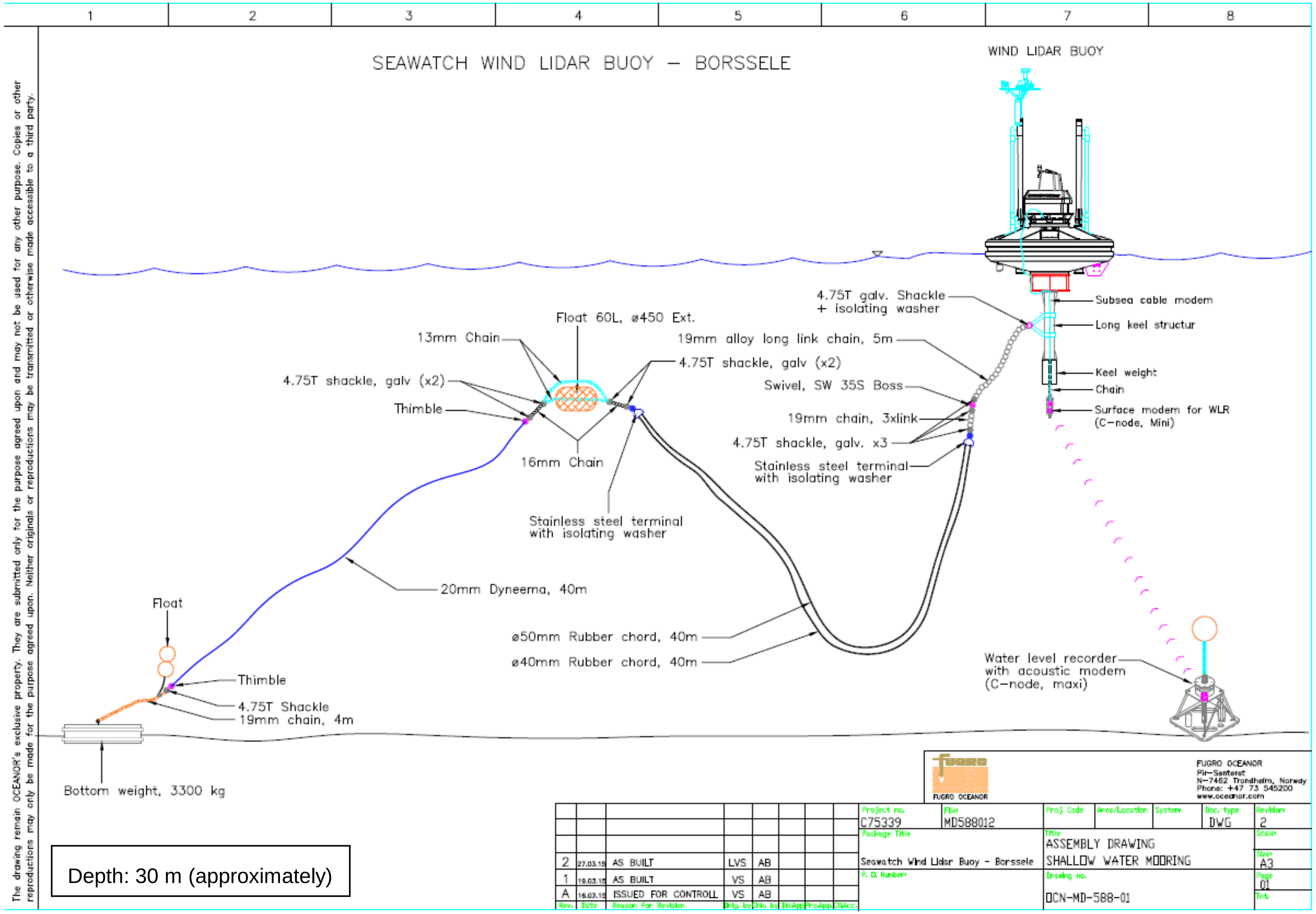


**Figure 2.1 Mooring design for the Wind Lidar Buoy as deployed at Borssele Wind Farm Zone (BWFZ).**

# 3. Summary of activities

## 3.1 Buoy operation

The Seawatch Wind Lidar buoy with serial no. WS149 and a bottom mounted Water Level Recorder (SeaGuard WLR) were deployed at the Borssele Wind Farm Zone in the Dutch sector of the North Sea on 11 June 2015. The buoy was deployed at 15:55 with the bottom mooring weight at position 51° 42.41388' N, 3° 2.07708' E. A bottom mounted WLR was deployed at position 51° 42.4362' N, 3° 02.1030' E. The WLR transmits data to the buoy in real time data via an acoustic link. The sounder depth was recorded as approximately 30 m.

During this third month after the deployment the buoy was in continuous good operation until 11 September 2015 at 15:50. After that time the buoy did transmit any data, and did not store data on its internal hard disk. Due to the failure of transmissions the buoy had to be recovered to shore for diagnosis and repair. The recovery was achieved on 6 October 2015 at 11:30 by the multicat type workboat Multrasalvor 3. Recovery of the water level recorder by means of the acoustic release unit was attempted, but although contact with the release unit was established the subsea floater was not released, and consequently the WLR unit remained on the bottom.

## 3.2 Health, Safety and Environment

There were no incidents, near misses or accidents in connection with the deployment and recovery operations.

29 August 2015 there was an incident when the survey vessel Breaker of Deep B.V. hooked onto something near the buoy when doing a survey. After recovery of the buoy we have confirmed that neither the buoy nor its mooring is damaged in any way. It could, however, very well be that it hooked on to the water level recorder at the bottom.

# 4. Results

## 4.1 Summary of results and data return

The buoy transmitted data continuously from all sensors until 11 September 2015 at 15:50, except for some gaps due to communication problems, which are discussed in the following. The wind data received in real time were supplemented by data stored in the ZephIR Lidar itself to achieve 30.5 days of actual wind measurements, which was obtained on the 14 September at 15:30. Also the current velocity profile time series was supplemented with data stored internally in the instruments. The other parameters measured by the buoy were not recorded after 11 September at 15:50.

The number of hours of good data compared to the total obtainable hours of data is presented in Table 4-1.

**Table 4-1 Data return during the period 14 August 2015 at 19:10– 14 September 2015 at 15:30.**

| Measurement device | Length of data period (days) | Length of data set (days) | Average availability (%) |
|---|---|---|---|
| Lidar wind profile sensor | 30.847 | 30.5 | 98.87 |
| Wave sensor | 30.847 | 27.826 | 90.21 |
| Current velocity and direction sensor | 30.847 | 30.813 | 99.89 |
| Atmospheric pressure sensor | 30.847 | 27.861 | 90.32 |
| Air temperature sensor | 30.847 | 27.861 | 90.32 |
| Water Level Sensor * | 30.847 | 0.000 | 0.00 |

* The real time transmitted water level data are unexpectedly lost due to breakdown of the acoustic link. However, the complete data series will be recovered if the instrument is recovered later.

## 4.2 Presentation of the received data

The following presentations show good data transmitted from the buoy via Iridium satellite during the period 14 August 2015 at 19:10 – 11 September 2015 at 15:50, combined with data stored in the Lidar and current profiler until 14 September at 15:30, giving a total wind profile data set of 30.5 days.

Two drop-outs are seen in the data due to buoy processor restarting; on 22 August at 08:40 and 3 September around 18:00.

### 4.2.1 Meteorological data

The following plots present the air pressure, air temperature, and sea surface temperature. The sensors have generally performed well.

The water temperature sensor is part of the current profile sensor, Aquadopp, and data recovery for water temperature is the same as for current profile data.


**Figure 4.1 Time series plots of air pressure (upper panel), air and water temperature (lower panel), 14 - 25 Aug 2015.**

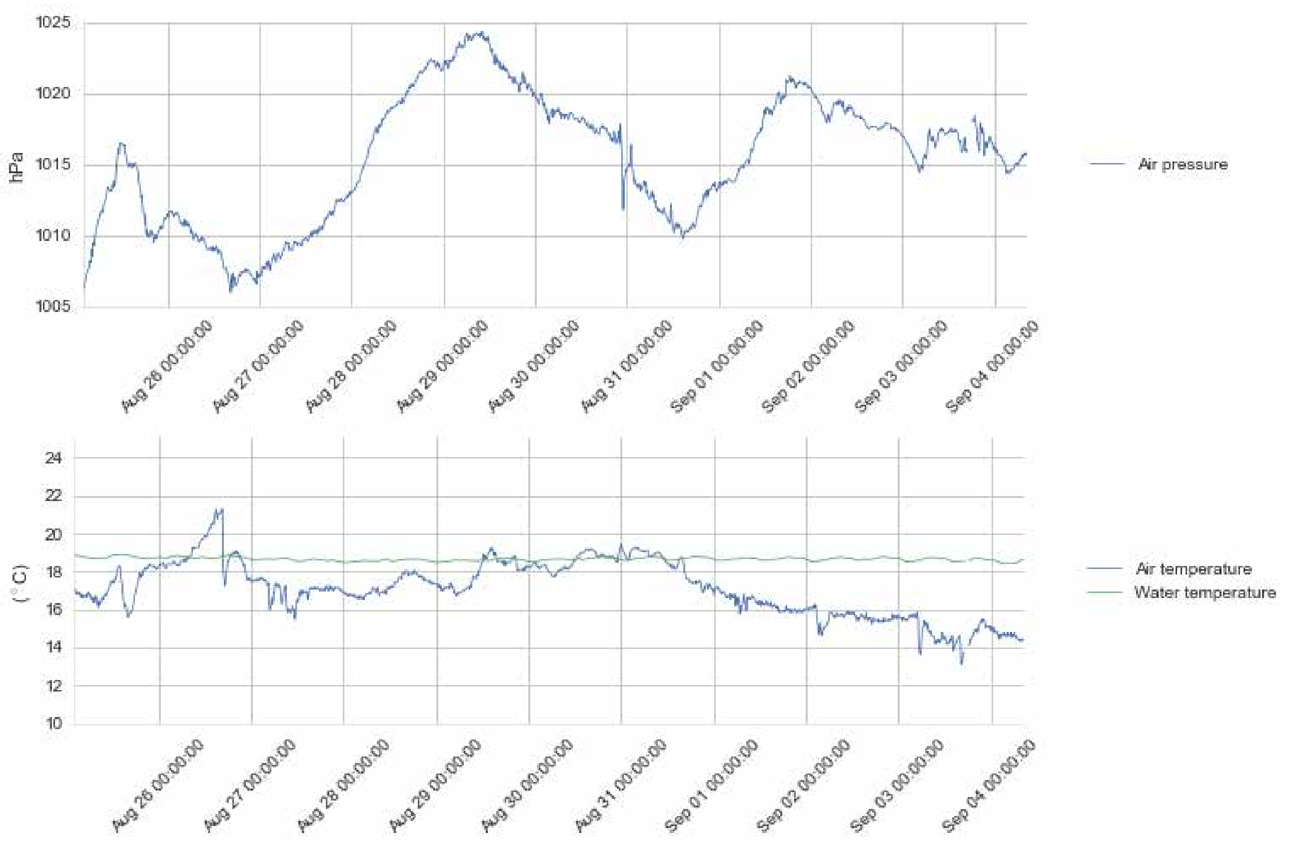


**Figure 4.2 Time series plots of air pressure (upper panel), air and water temperature (lower panel), 25 Aug – 4 Sep 2015.**

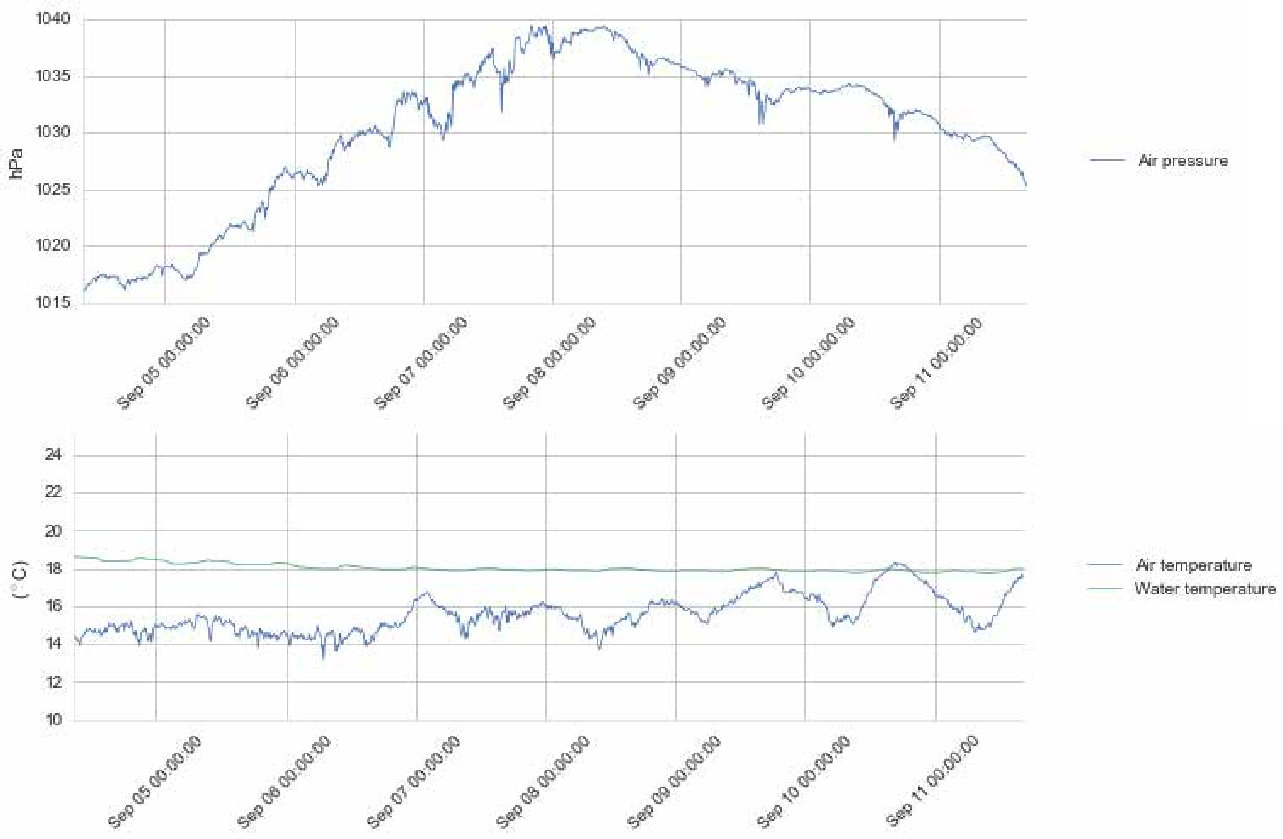


**Figure 4.3 Time series plots of air pressure (upper panel), air and water temperature (lower panel), 4 - 14 Sep 2015.**

### 4.2.2 Wave data

The next plots present wave height, period and direction. The wave sensor has generally functioned well. Some dropouts shown in the plots are due to loss of data within the first half hour after rebooting of the buoy.

The highest significant wave height (Hm0) measured in this period is 3.28 m from a north-northwesterly direction on 6 September at 03:20-03:30. The highest single wave was 5.13 m observed at the same time.

Variations in wave height agree well with the wind speeds in general. The average wave period parameters Tm01 and Tm02 show semidiurnal variations which can be explained by the shift in frequency when the waves are travelling along with or opposing the current direction, since the tidal current direction varies in a semi-diurnal pattern.

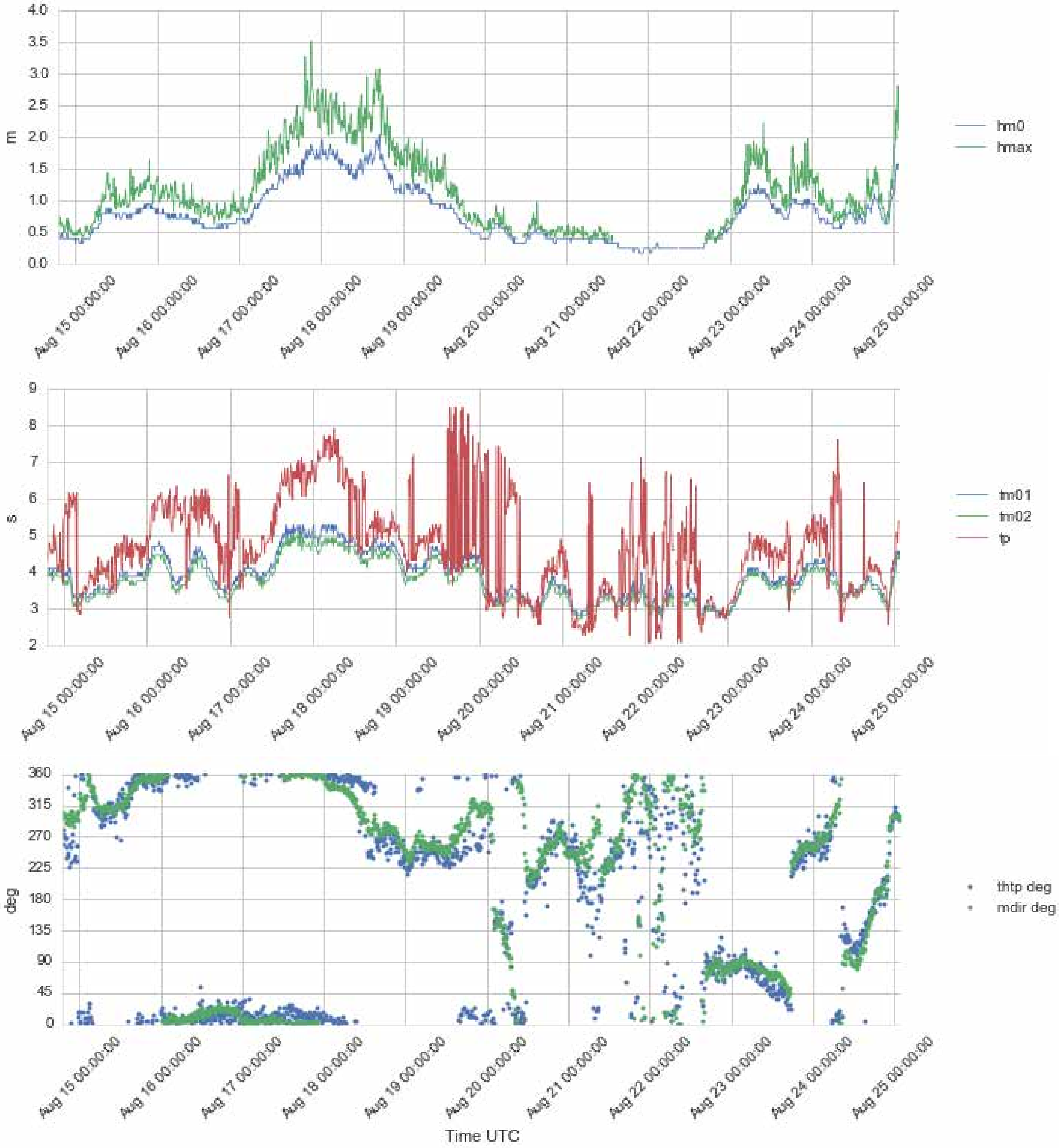


**Figure 4.4 Time series plots of wave height (Hm0 and Hmax) (upper panel), wave period (Tm01, Tm02 and Tp) (second panel), and wave direction (ThTp and Mdir) (lower panel), 14 – 25 Aug 2015.**

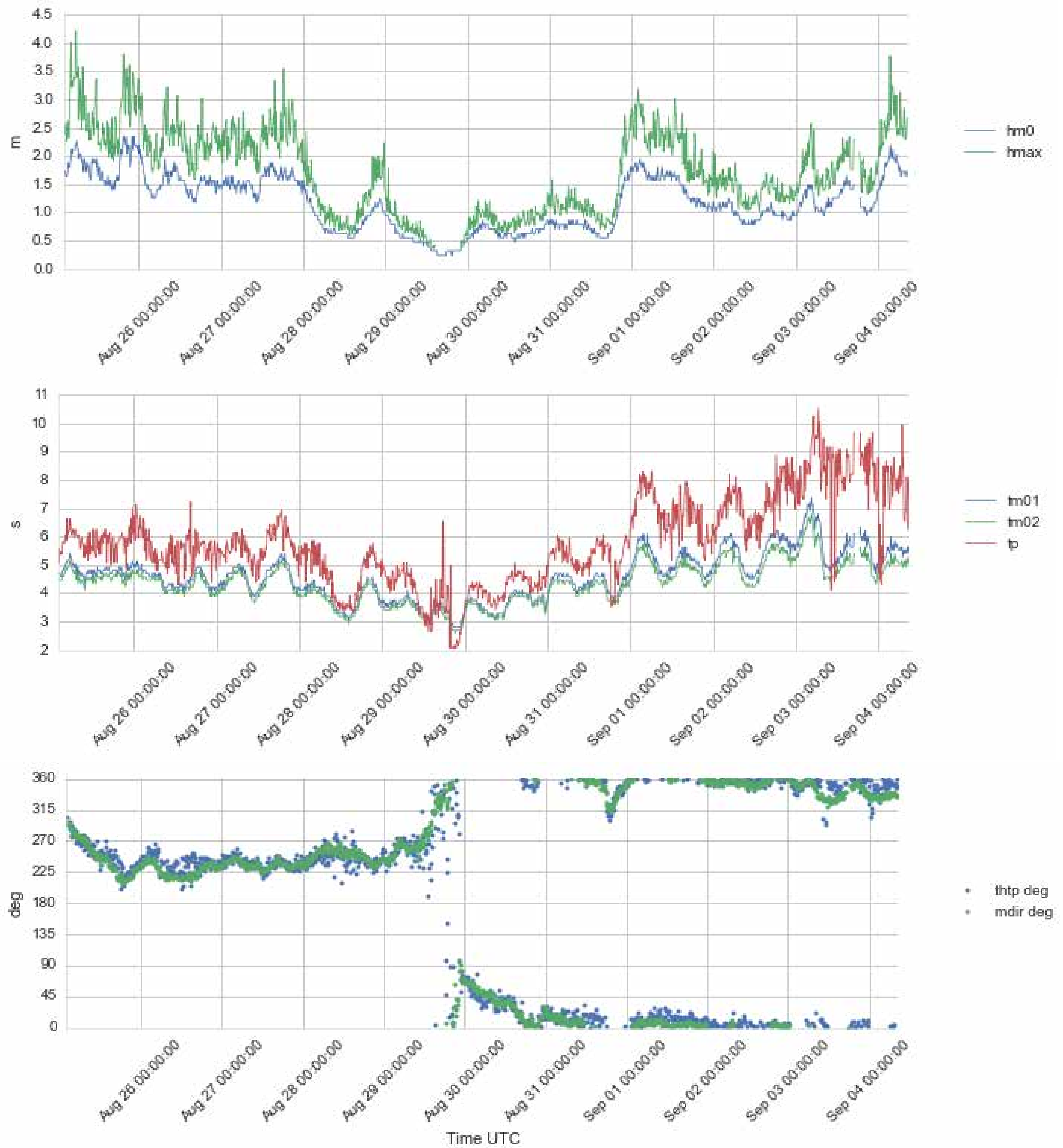


**Figure 4.5 Time series plots of wave height (Hm0 and Hmax) (upper panel), wave period (Tm01, Tm02 and Tp) (second panel), and wave direction (ThTp and Mdir) (lower panel), 25 Aug – 4 Sep 2015.**

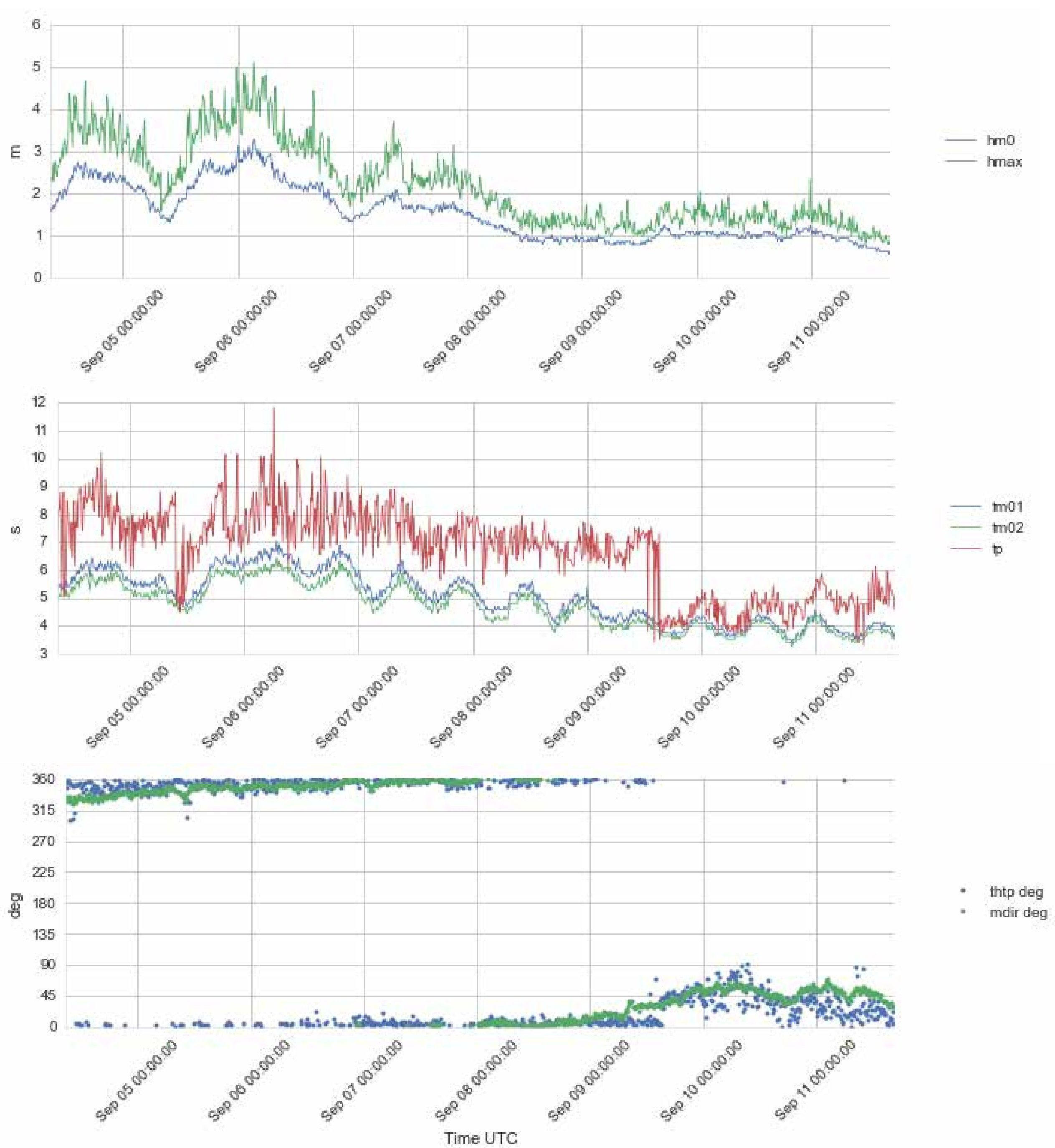


**Figure 4.6 Time series plots of wave height (Hm0 and Hmax) (upper panel), wave period (Tm01, Tm02 and Tp) (second panel), and wave direction (ThTp and Mdir) (lower panel), 4 - 14 Sep 2015.**

### 4.2.3 Wind profile data

In the wind and wave direction plots 0° and 360° indicate direction from the north.

The following plots show the wind speed and direction data from the Gill wind sensor mounted at 4 m height on the buoy mast. The data from the Gill sensor are generally good without dropouts, except for those associated with restarting of the whole buoy system, but the Gill wind data end when the buoy transmissions stopped on 11 September. In this periods wind speeds up to 14.4 m/s and gusts up to 18.2 m/s were measured at 4 m above the sea surface.

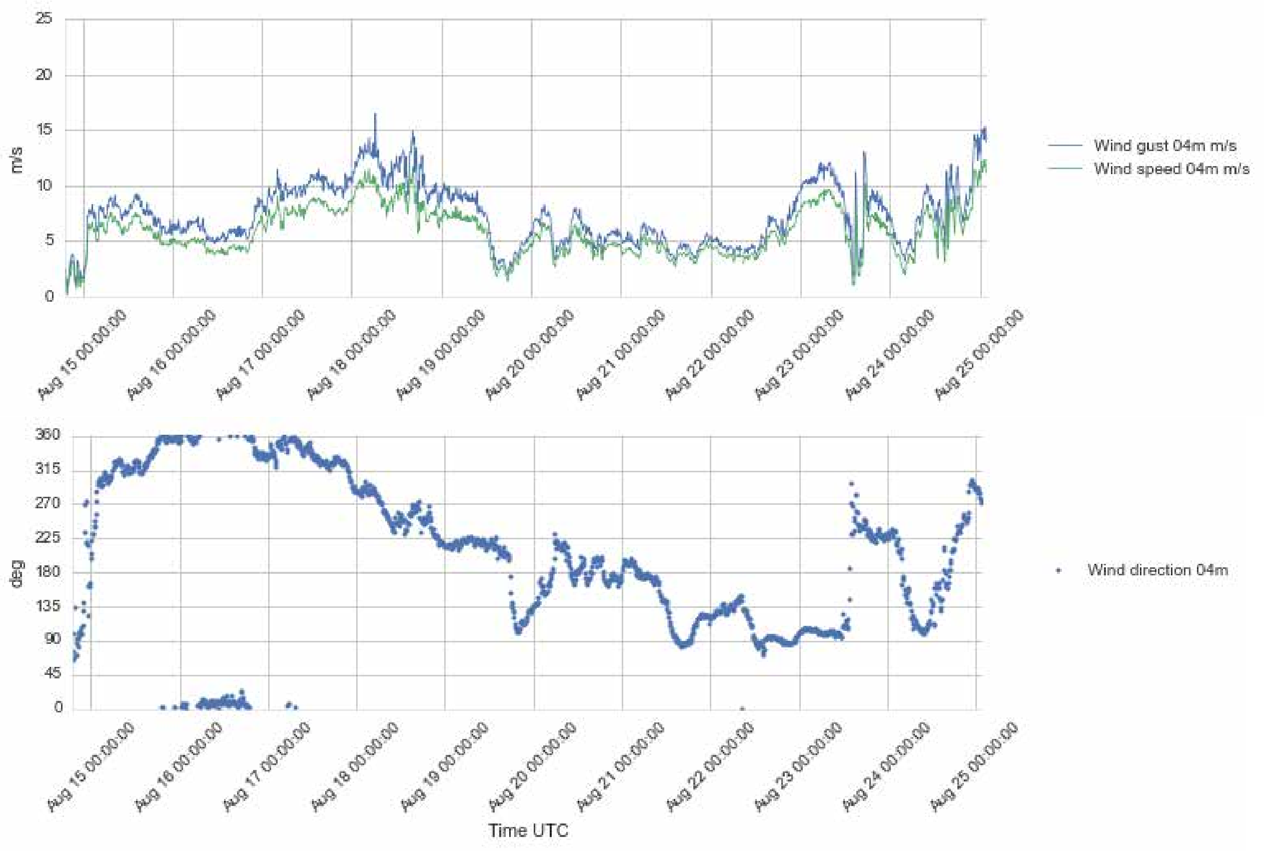


**Figure 4.7 Plots of wind speed and gust (upper), and wind direction (lower) at 4 m a.s.l., 14 - 25 Aug 2015.**

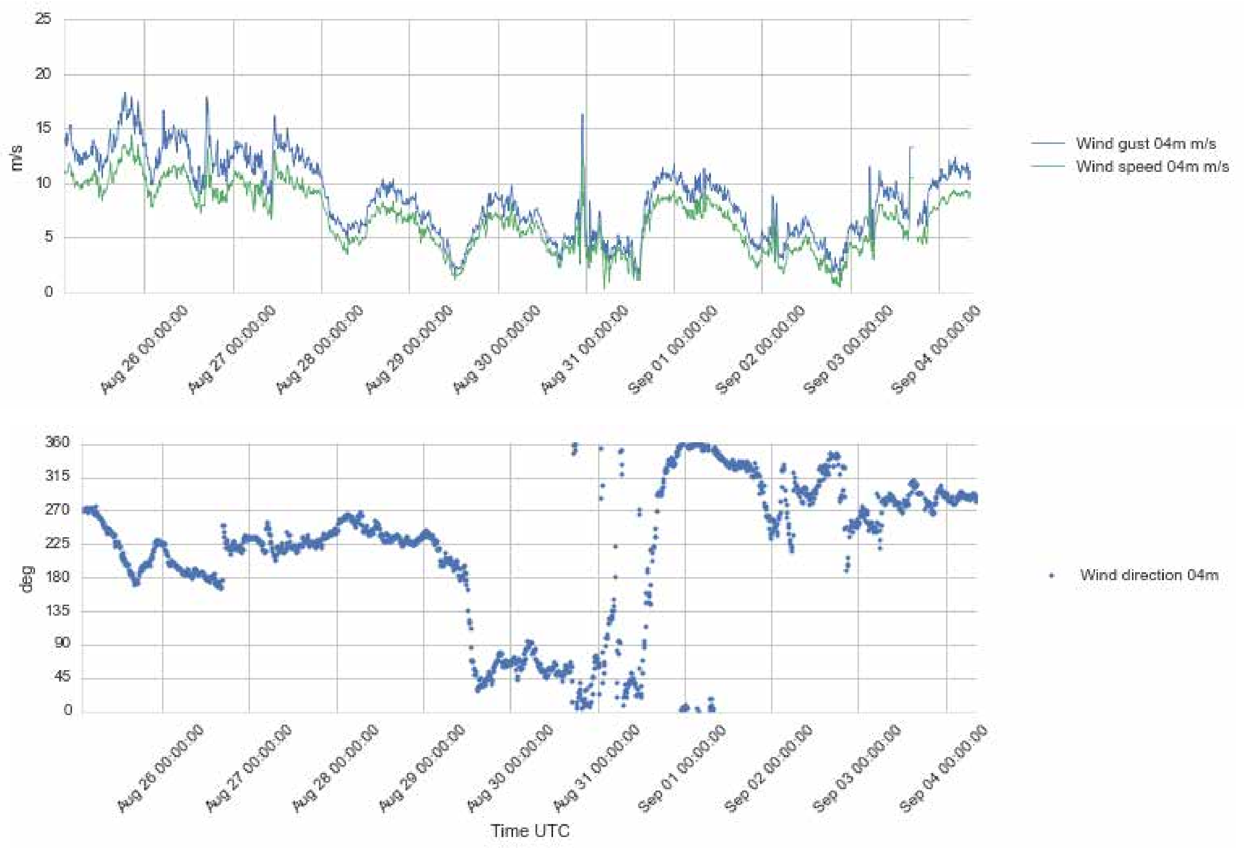


**Figure 4.8 Plots of wind speed and gust (upper), and wind direction (lower) at 4 m a.s.l., 25 Aug – 4 Sep 2015.**

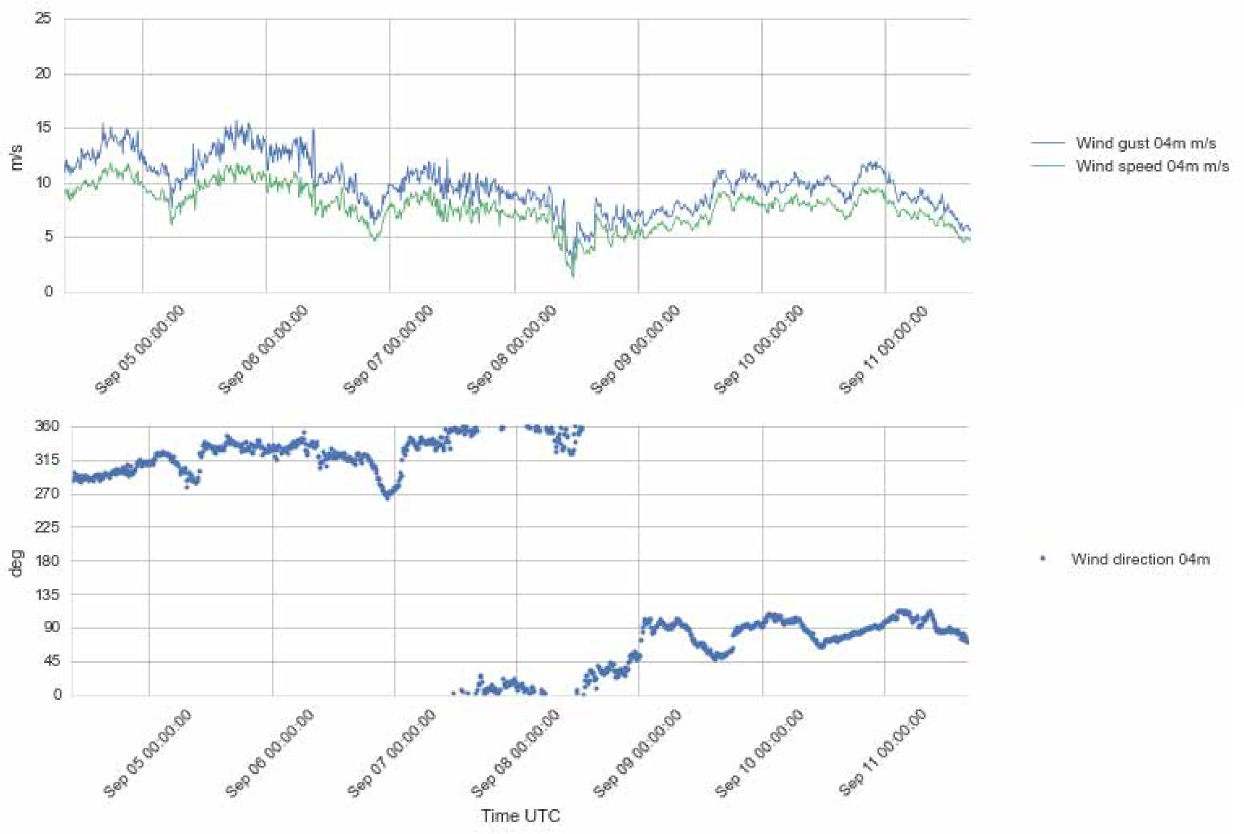


**Figure 4.9 Plots of wind speed and gust (upper), and wind direction (lower) at 4 m a.s.l., 4 – 11 Sep 2015.**

The wind profiling data from the Lidar are presented in the following plots showing the time series of 10 min. mean wind for each individual level. Plots of the derived parameters Inflow Angle and Turbulence Intensity are also presented[1].

The Inflow Angle (IA) is the angle of the 3-dimensional wind vector based on the ten minute averaged values of the horizontal and vertical wind velocity components. IA can be positive or negative; a positive IA means that the wind vector has an upward directed vertical component. The Turbulence Intensity (TI) is defined as TI = $\sigma/\bar{u}$ where $\sigma$ is the standard deviation and $\bar{u}$ is the mean of the wind speed for a 10-min period. Note that this definition frequently gives relatively high values in situations with low mean wind speed, which is noticeable in the plots.

The 180° directional ambiguity in the Lidar wind directions has largely been resolved using a correction with directions from the Gill wind sensor as ground truth. From 11th September at 16:00 UTC data from the Gill sensor were no longer available, as explained above, and a correction using data from the wind mast at Vlakte van Raan has been applied. Due to the distance to the reference station, 27.6 km, this correction is obviously not as accurate as the correction based on the buoy mounted sensor.

The highest observed horizontal mean wind speed during this month varies from 18.6 m/s at 30m to 22.4 m/s at 200 m above the surface. These maxima were measured on 25 August at 20:20 - 20:30.

[1] TI is not included in the regular Iridium transmissions, and only received through the dialup connection. Consequently, TI is missing for some periods when the dialup connection failed.

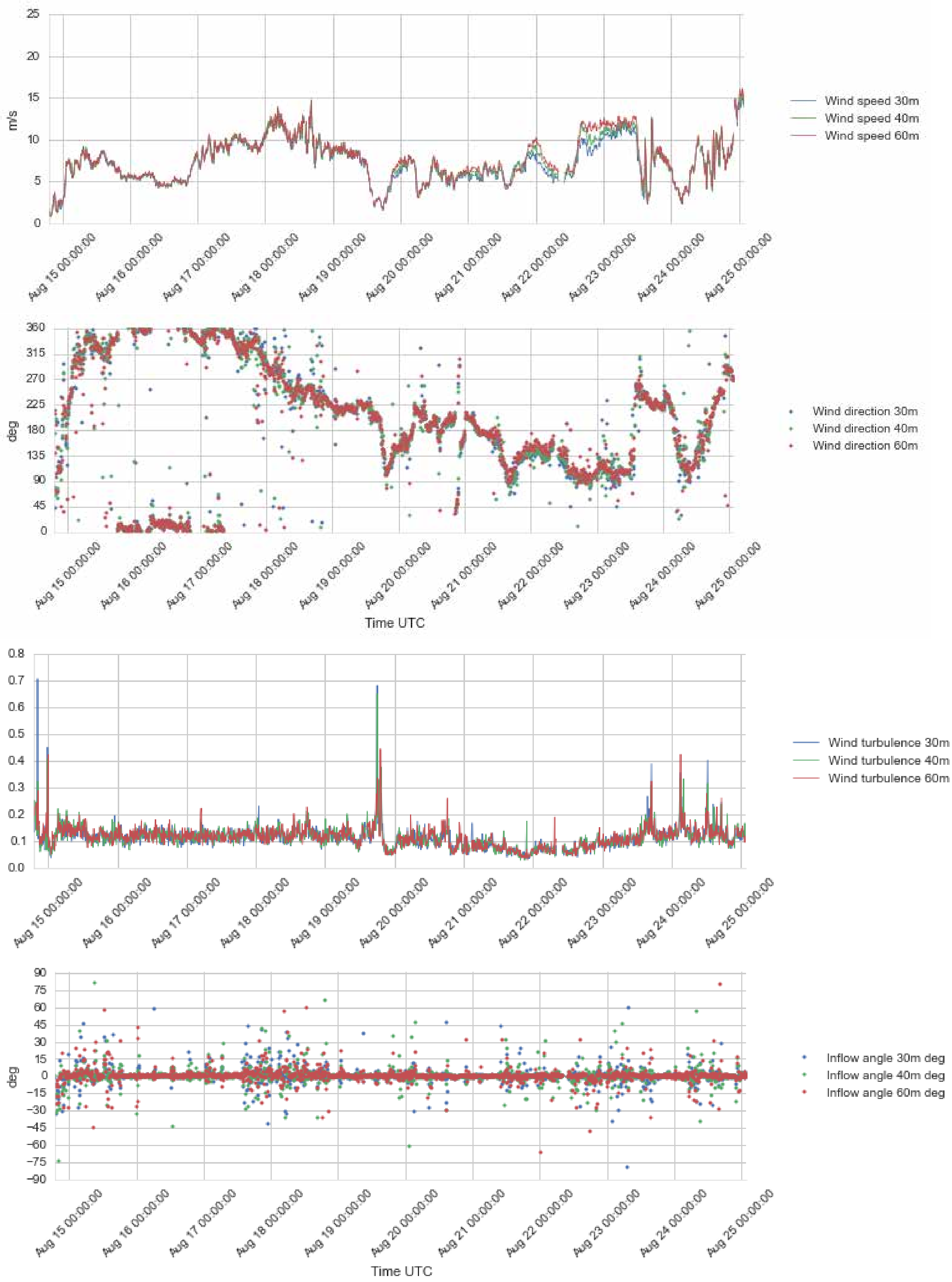


**Figure 4.10 Plots of wind profile data, 30 – 60 m a.s.l., 14 - 25 Aug 2015.**

**From top to bottom: Wind speed, Wind direction, Turbulence Intensity, and Inflow Angle.**

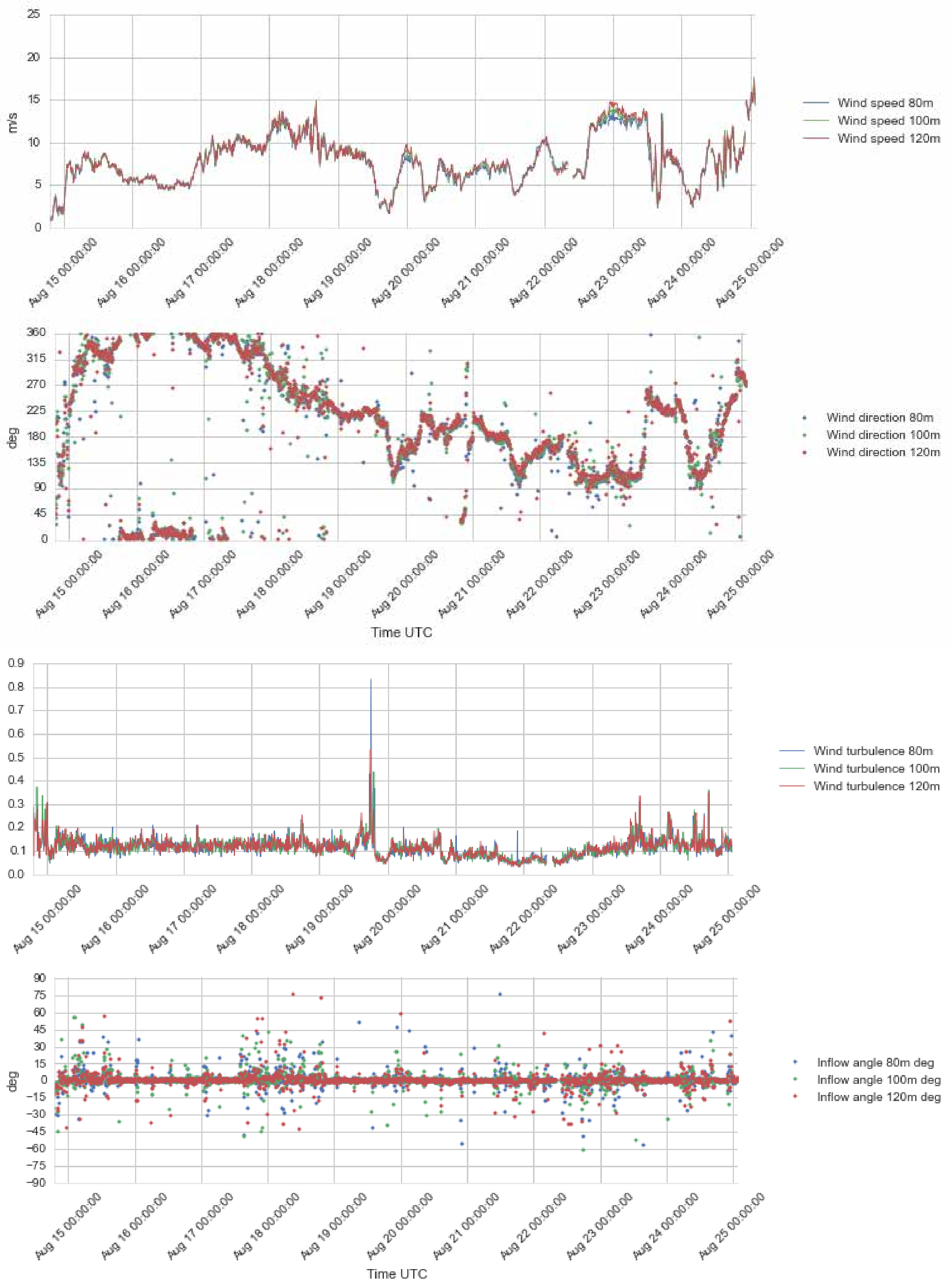


**Figure 4.11 Plots of wind profile data, 80 – 120 m a.s.l., 14 - 25 Aug 2015.**

**From top to bottom: Wind speed, Wind direction, Turbulence Intensity, and Inflow Angle.**

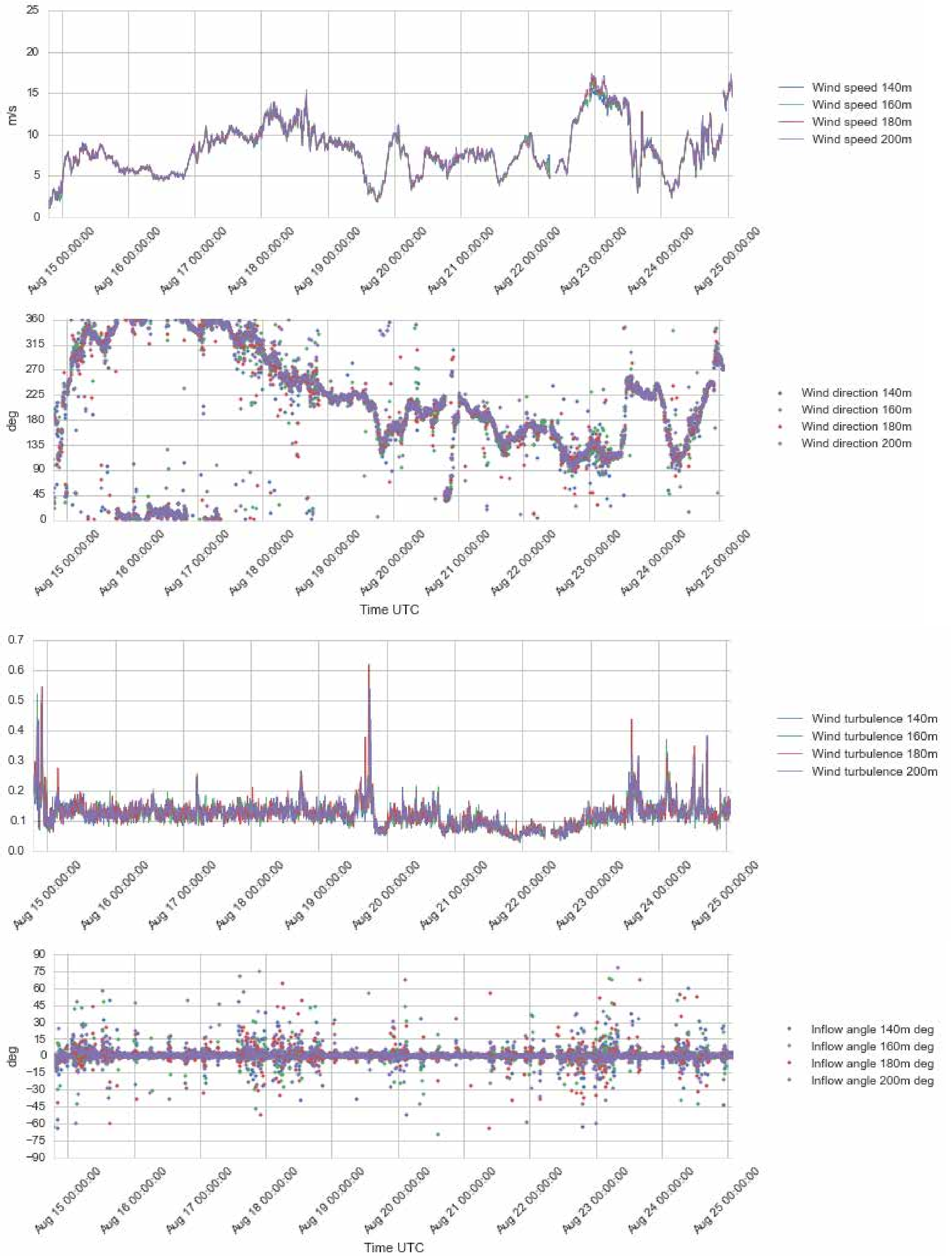


**Figure 4.12 Plots of wind profile data, 140 – 200 m a.s.l., 14 - 25 Aug 2015.**

**From top to bottom: Wind speed, Wind direction, Turbulence Intensity, and Inflow Angle.**

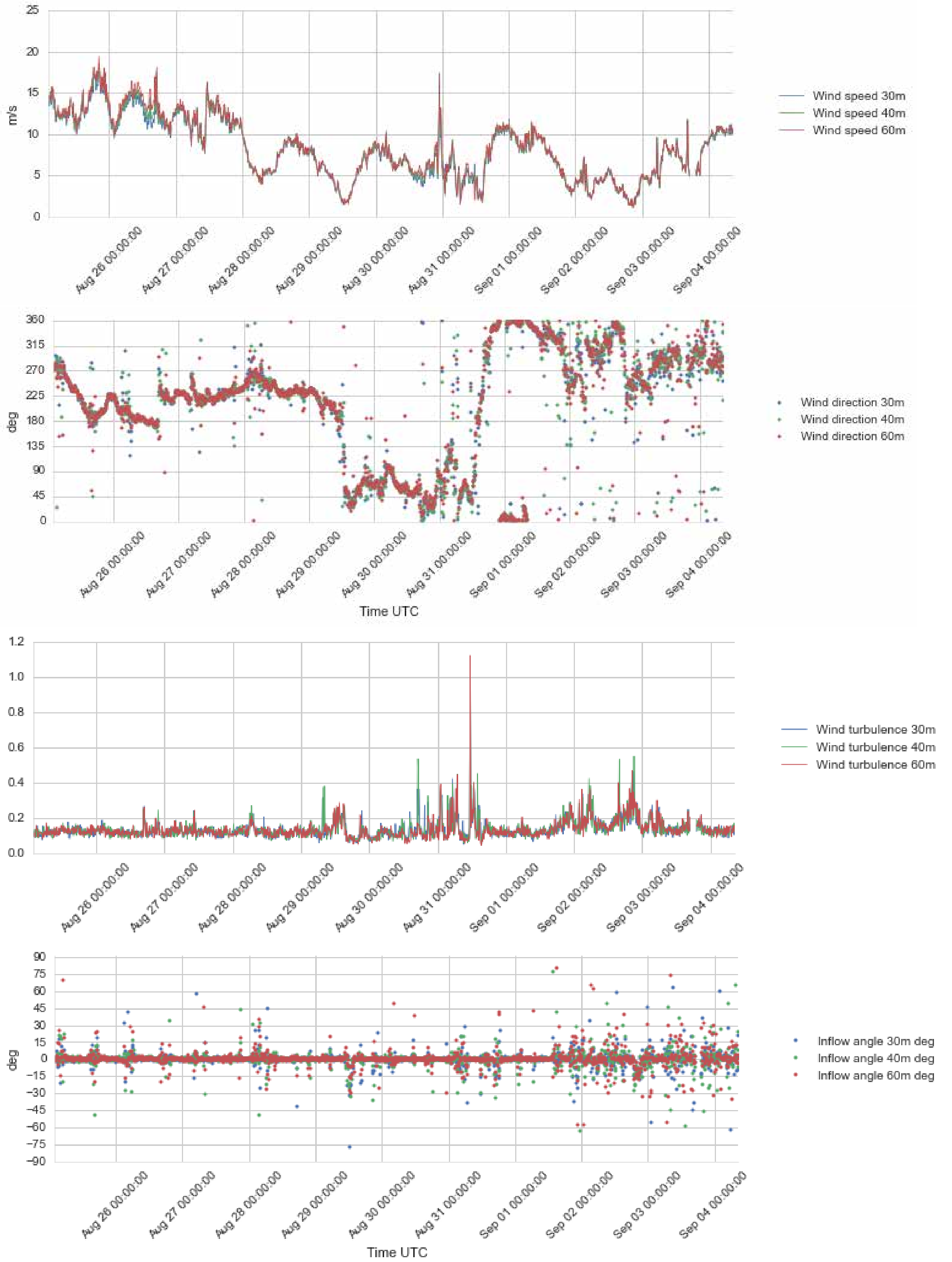


**Figure 4.13 Plots of wind profile data, 30 – 60 m a.s.l., 25 Aug – 4 Sep 2015.**

**From top to bottom: Wind speed, Wind direction, Turbulence Intensity, and Inflow Angle.**

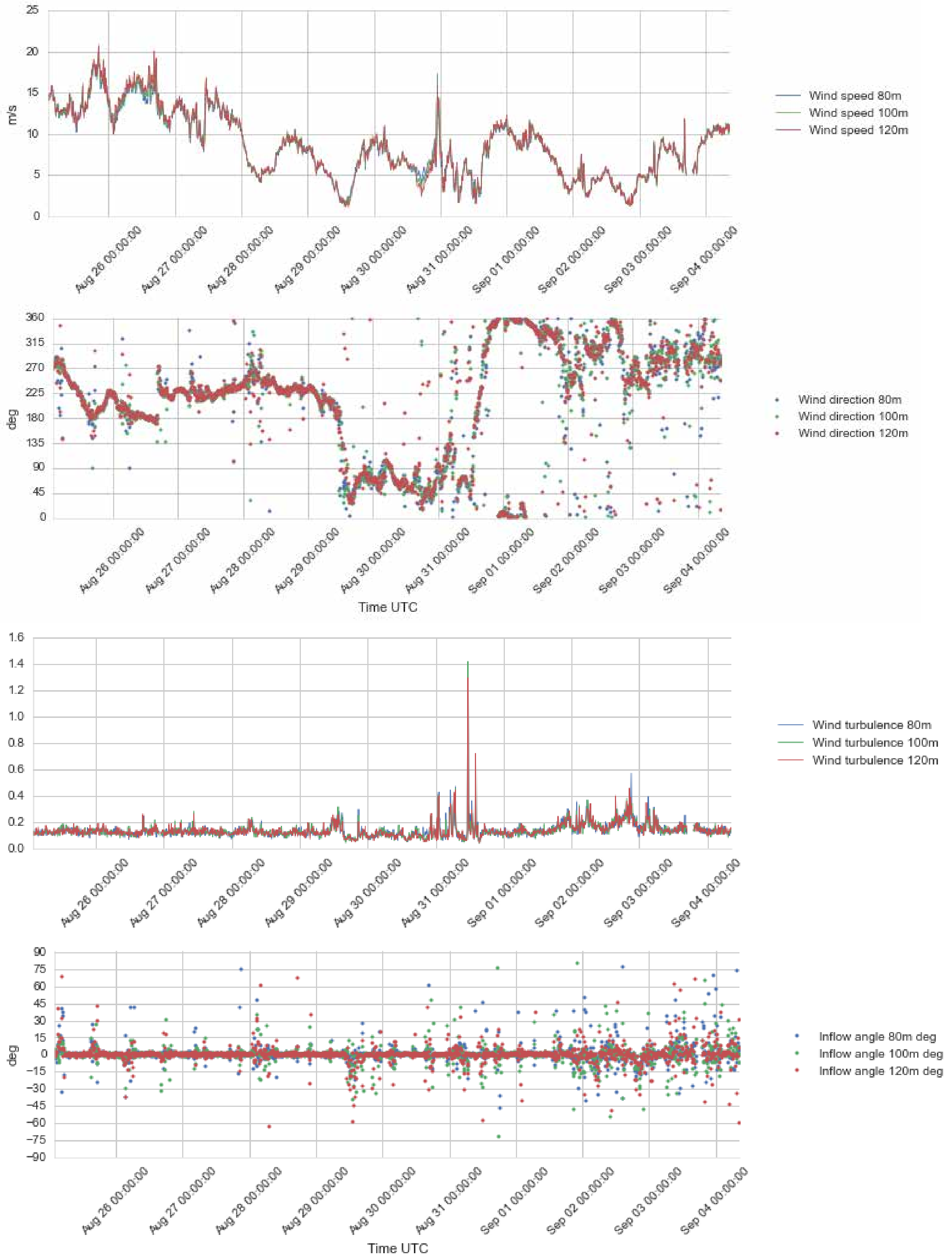


**Figure 4.14 Plots of wind profile data, 80 – 120 m a.s.l., 25 Aug – 4 Sep 2015.**

**From top to bottom: Wind speed, Wind direction, Turbulence Intensity, and Inflow Angle.**

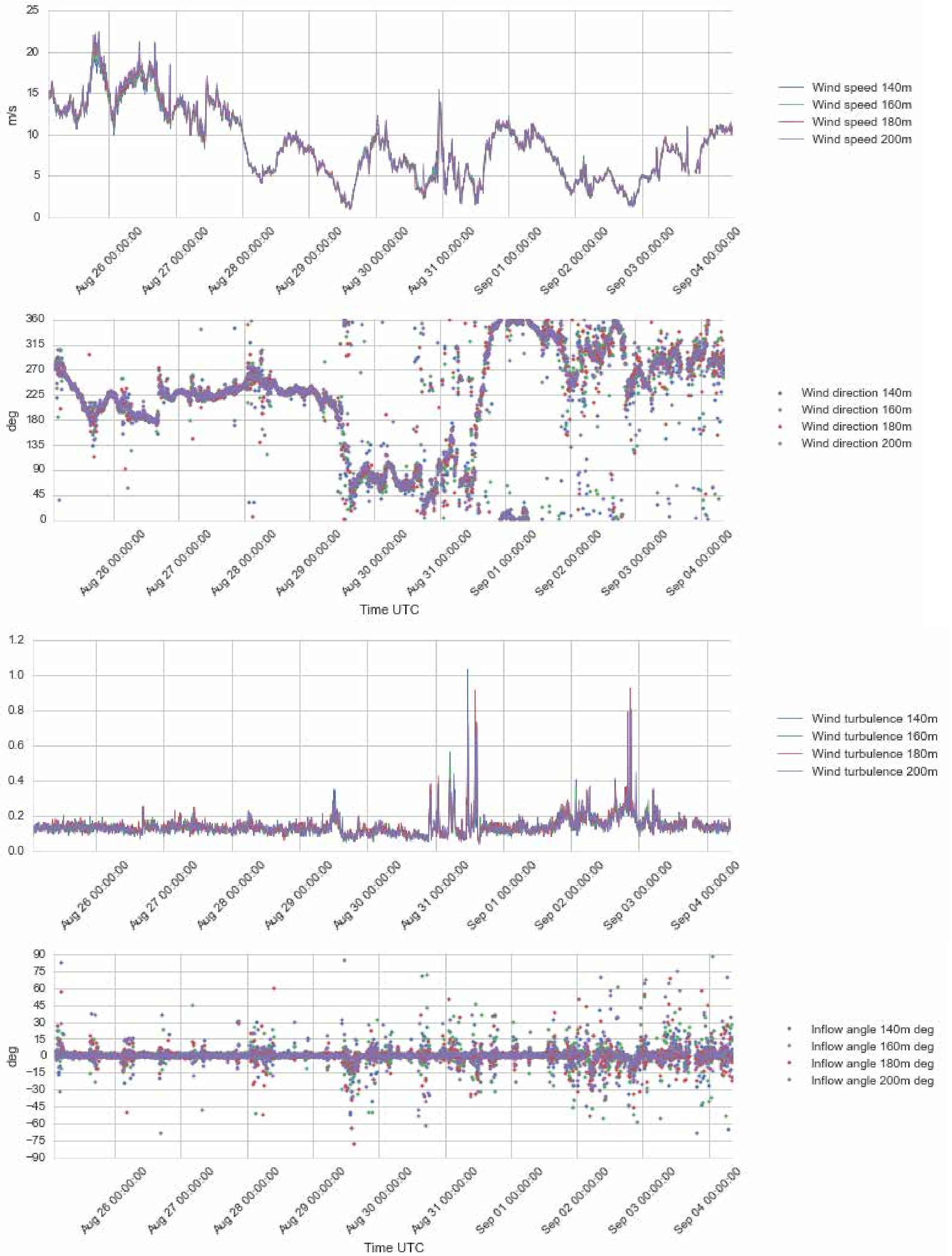


**Figure 4.15 Plots of wind profile data, 140 – 200 m a.s.l., 25 Aug – 4 Sep 2015.**

**From top to bottom: Wind speed, Wind direction, Turbulence Intensity, and Inflow Angle.**

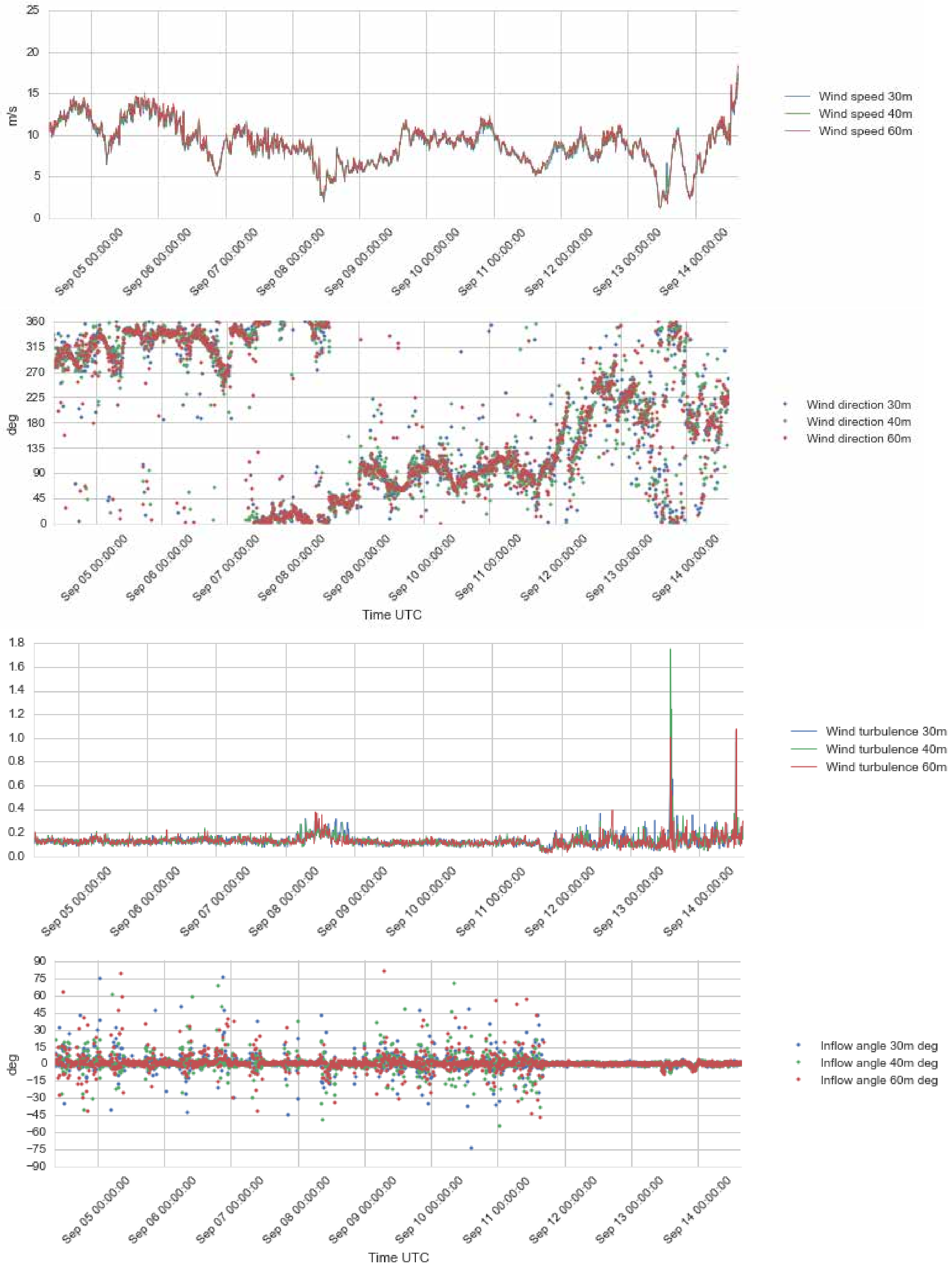


**Figure 4.16 Plots of wind profile data, 30 – 60 m a.s.l., 4 – 14 Sep 2015.**

**From top to bottom: Wind speed, Wind direction, Turbulence Intensity, and Inflow Angle.**

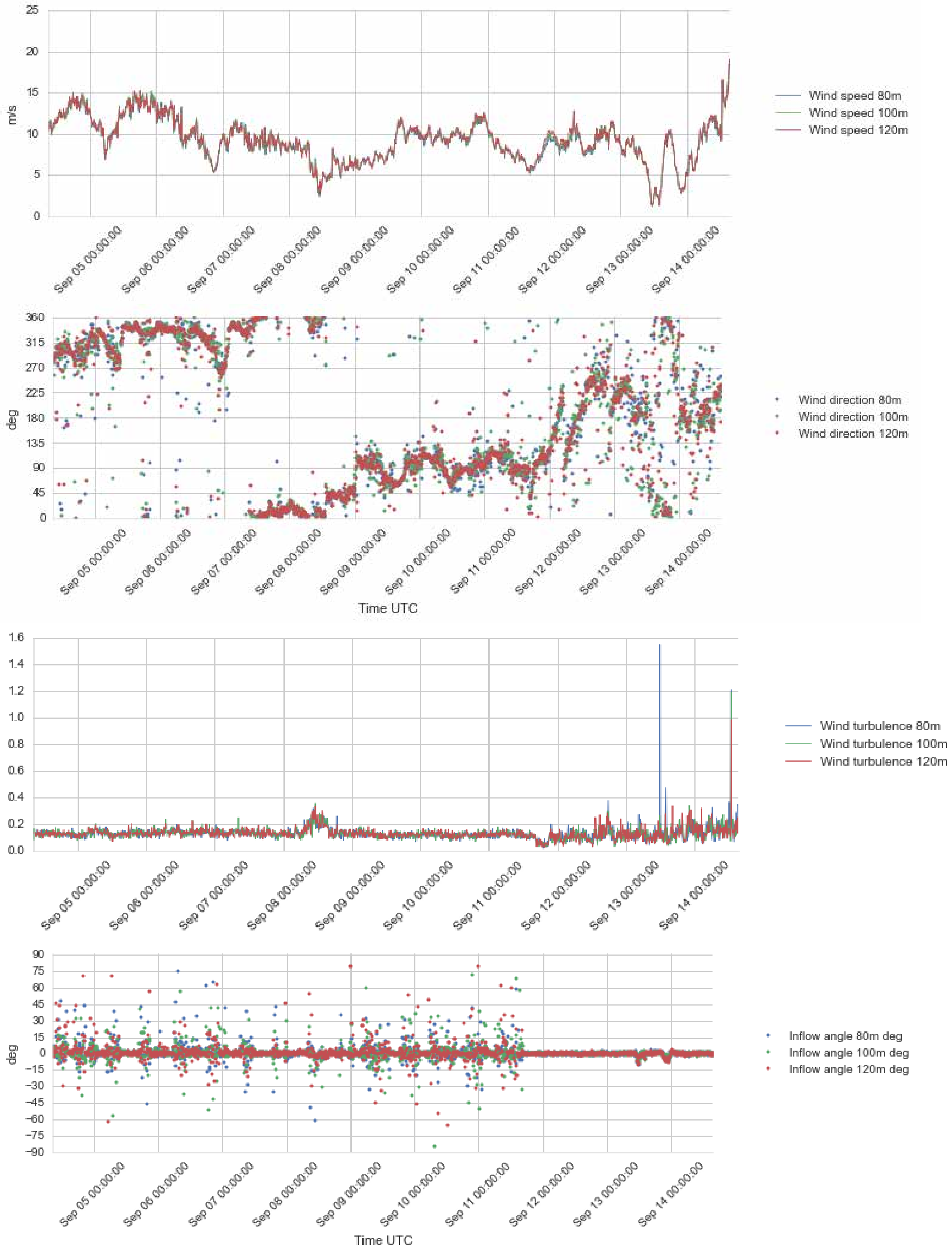


**Figure 4.17 Plots of wind profile data, 80 – 120 m a.s.l., 4 – 14 Sep 2015.**

**From top to bottom: Wind speed, Wind direction, Turbulence Intensity, and Inflow Angle.**

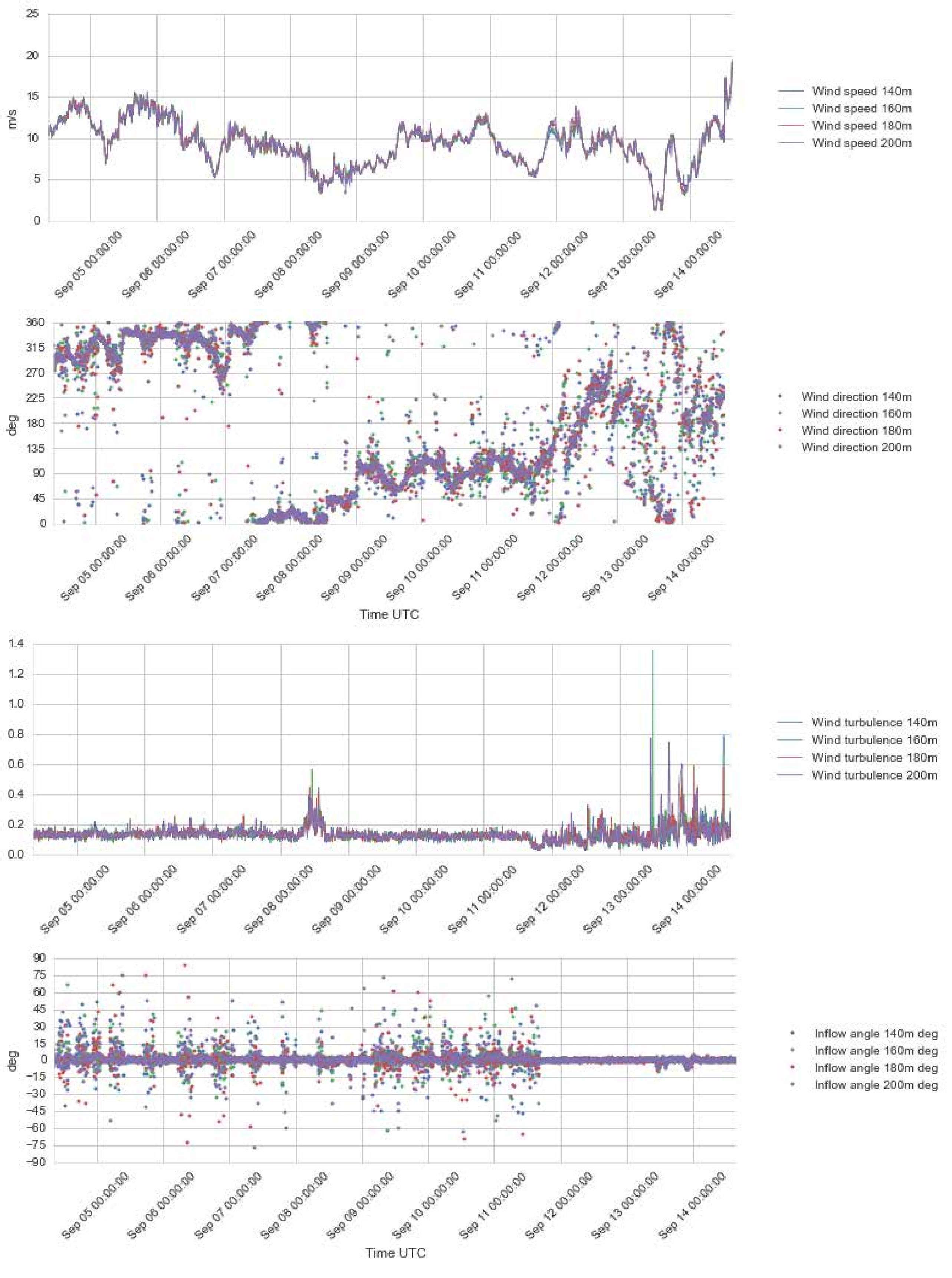


**Figure 4.18 Plots of wind profile data, 140 – 200 m a.s.l., 4 – 14 Sep 2015.**

**From top to bottom: Wind speed, Wind direction, Turbulence Intensity, and Inflow Angle.**

### 4.2.4 Current velocity profile data

The following plots show the current velocity profile time series. In these plots current direction 0° or 360° means that the current flows toward north, 90° indicates flow toward east etc. In general the current profiler has worked well, just a few data points were lost due to buoy restarting, but otherwise the series is continuous

As expected for this location the current velocity data show a very strong and consistent semi-diurnal tidal current pattern, completing two full rotations of the current vector per day, and four tidal current maxima; two toward south-southwest and two toward north-east. The quarter-diurnal peaks in the current speed vary between 60 – 100 cm/s over the month, depending on the phases of the moon.

At the lowest level, 30 m depth, the current speeds are reduced when the profiling beam hits the bottom. This usually occurs at every other peak in the current speed; that is when the strong current coincides with relatively low water level.

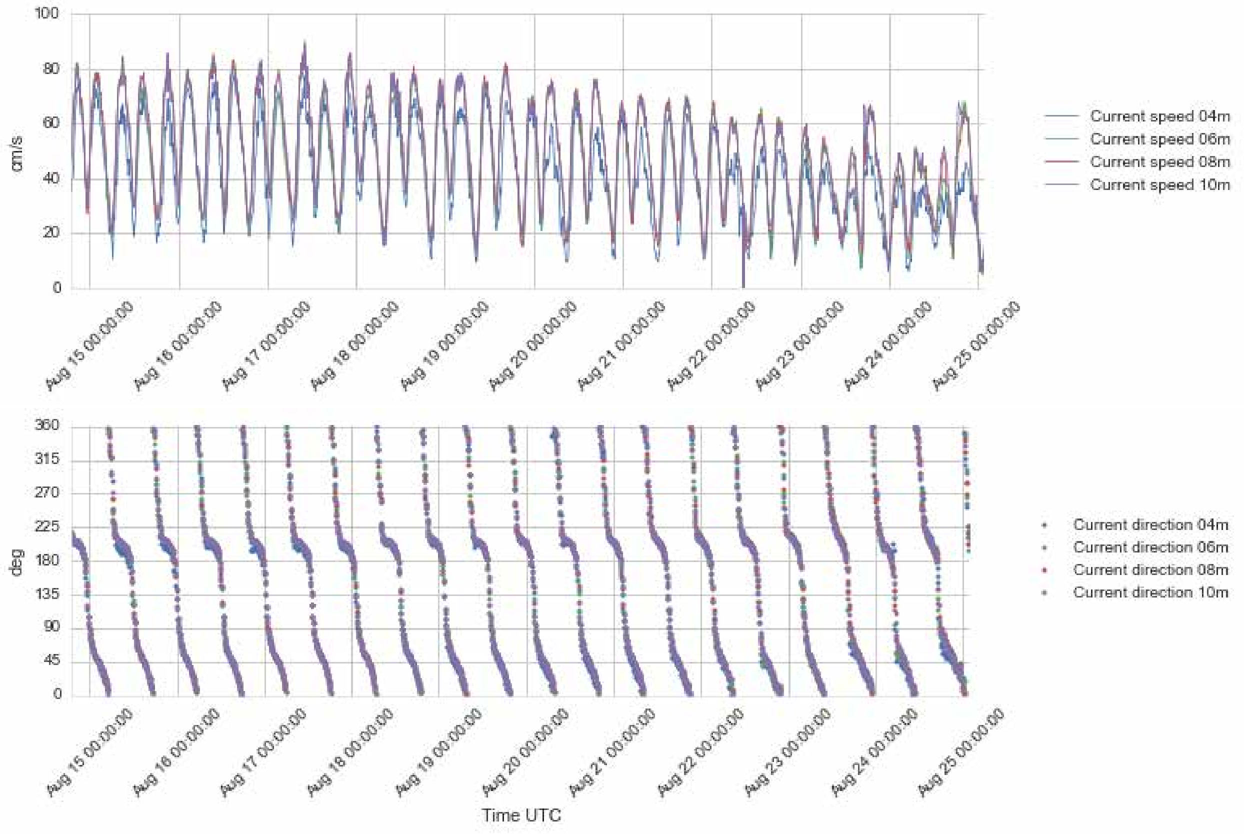


**Figure 4.19 Time series plots of current speed (upper) and direction (lower panel), 4 - 10 m depth, 14 - 25 Aug 2015**

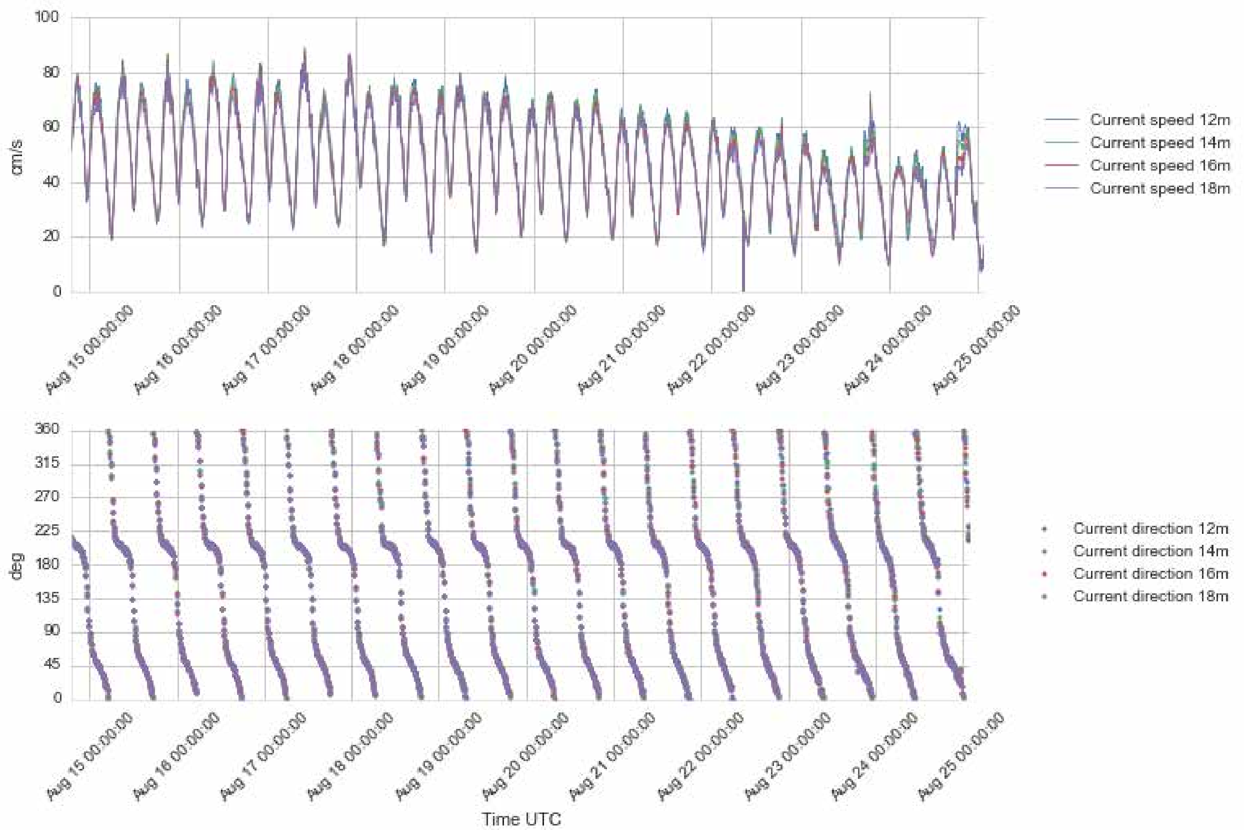


**Figure 4.20 Time series plots of current speed (upper) and direction (lower panel), 12 - 18 m depth, 14 - 25 Aug 2015**

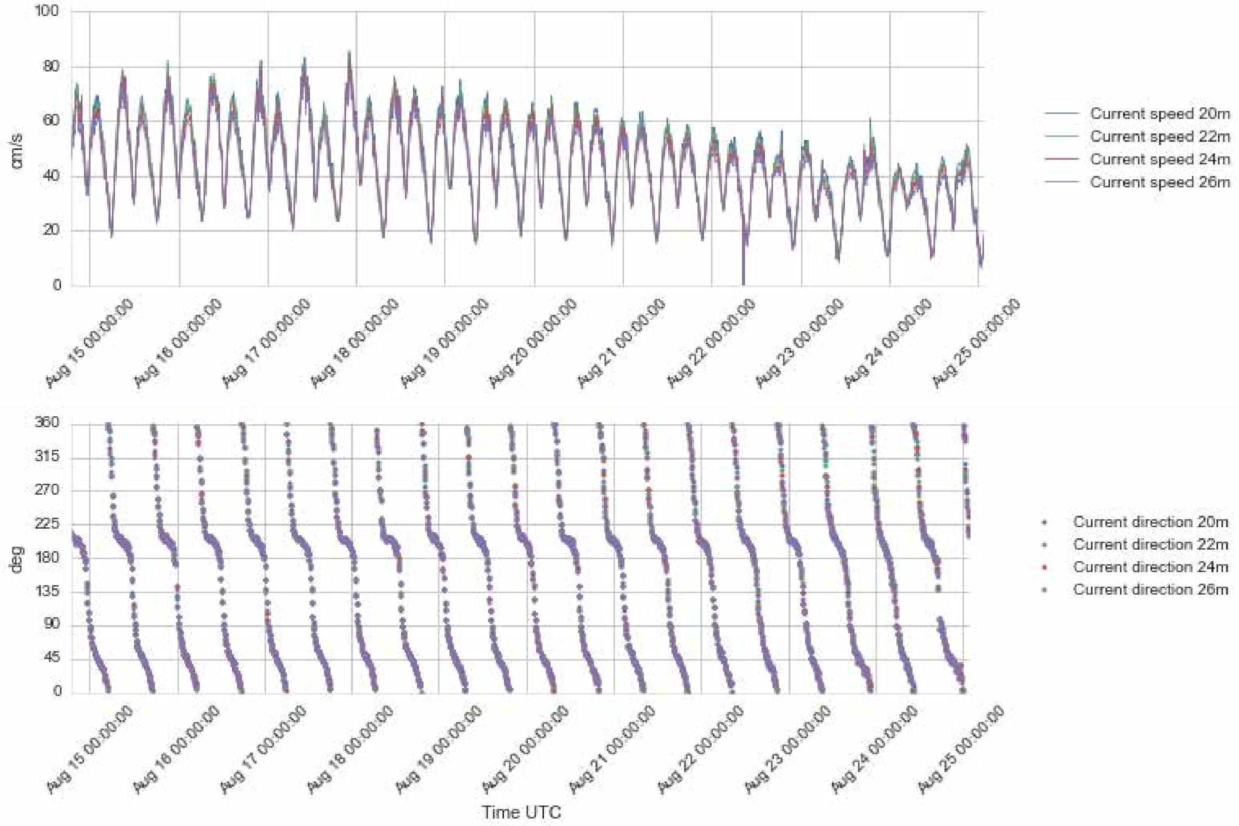


**Figure 4.21 Time series plots of current speed (upper) and direction (lower panel), 20 - 26 m depth, 14 - 25 Aug 2015**

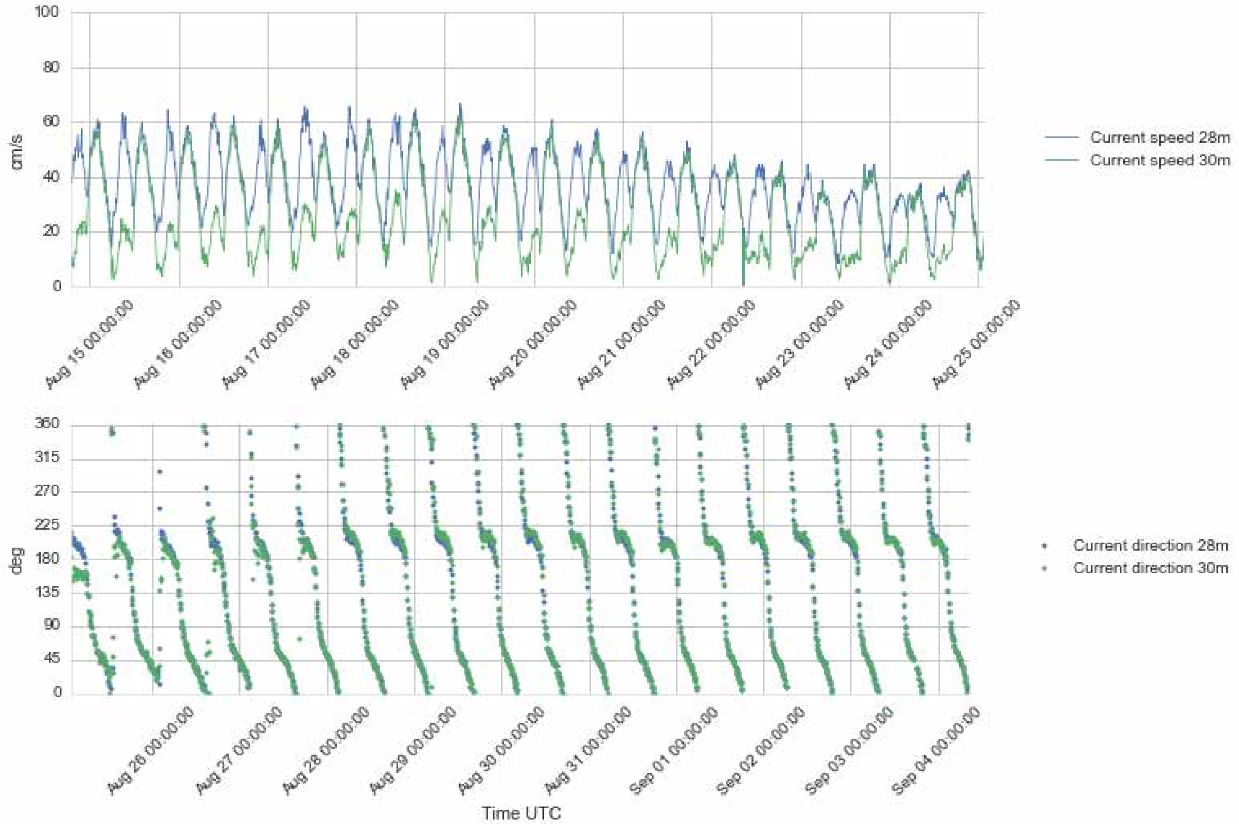


**Figure 4.22 Time series plots of current speed (upper) and direction (lower panel), 28 - 30 m depth, 14 - 25 Aug 2015**

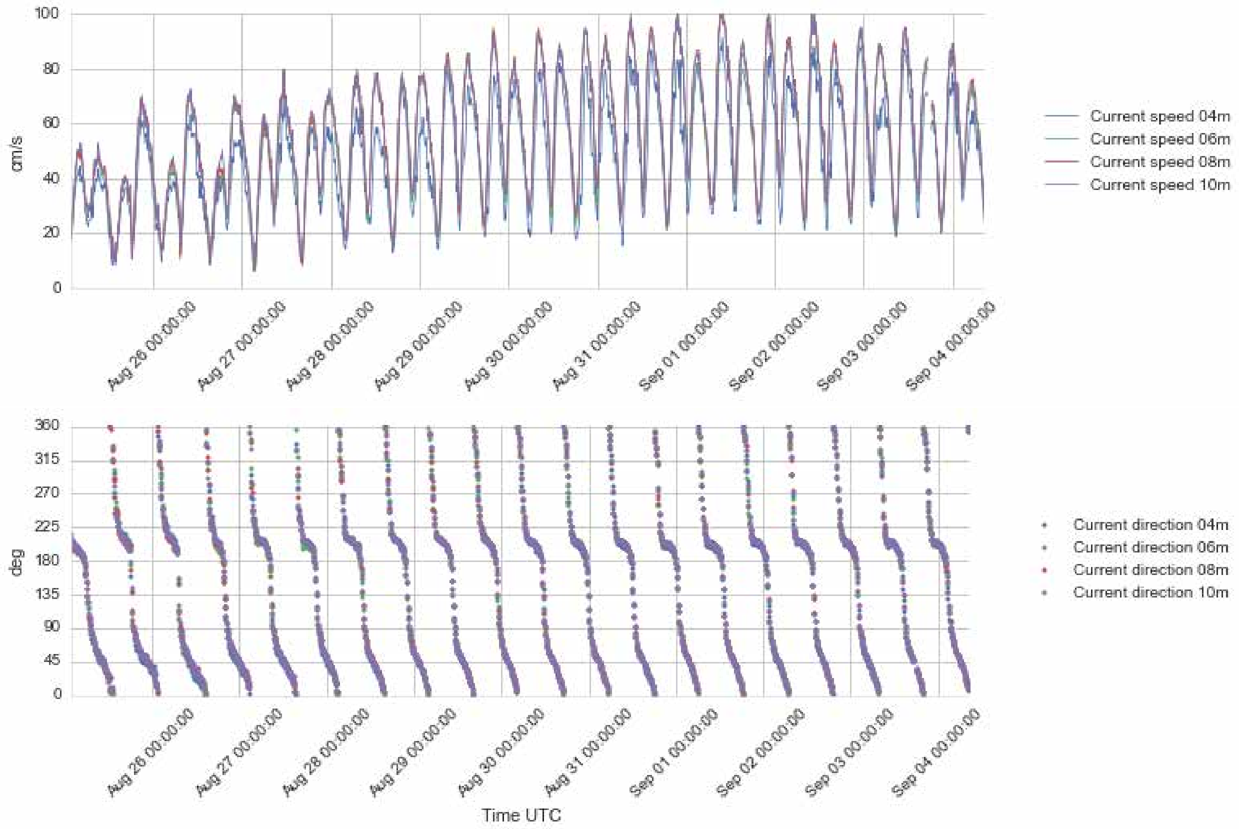


**Figure 4.23 Time series plots of current speed (upper) and direction (lower panel), 4 - 10 m depth, 25 Aug – 4 Sep 2015**

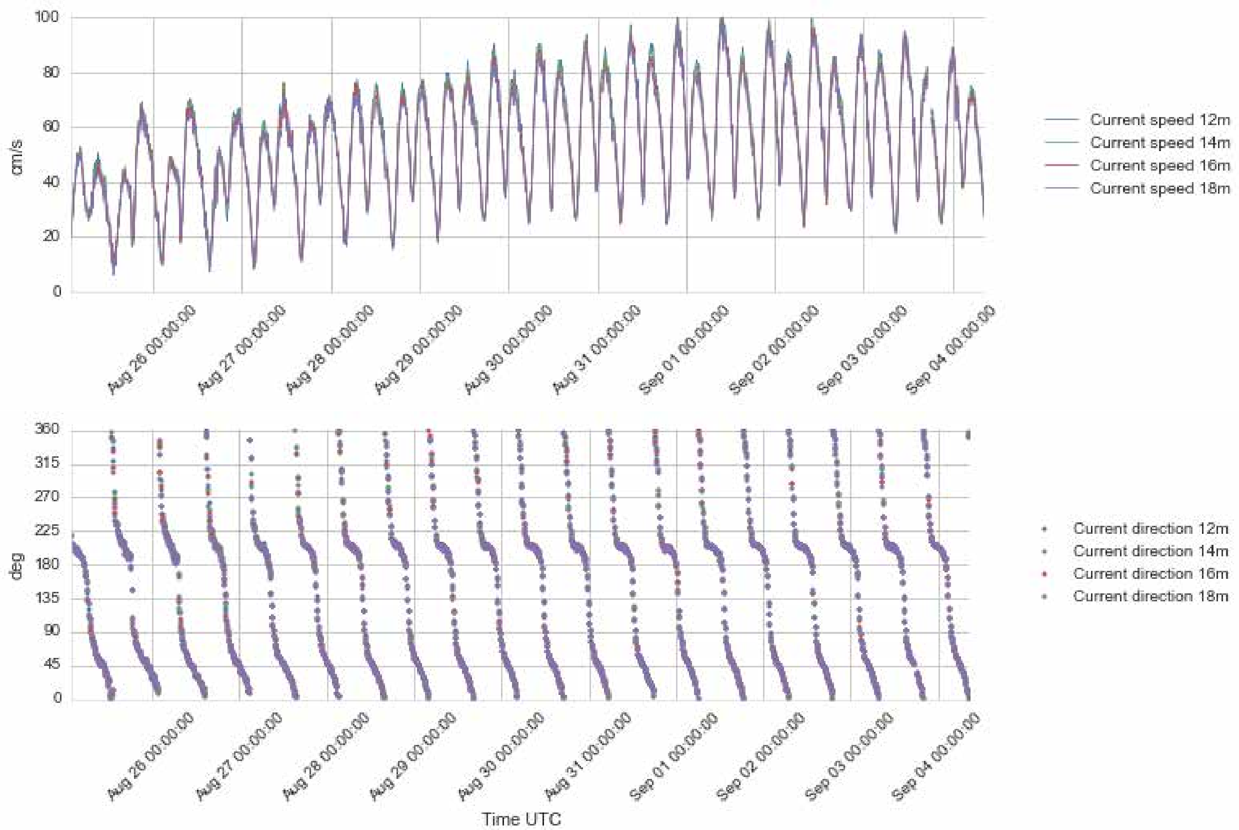


**Figure 4.24 Time series plots of current speed (upper) and direction (lower panel), 12 -18 m depth, 25 Aug – 4 Sep 2015**

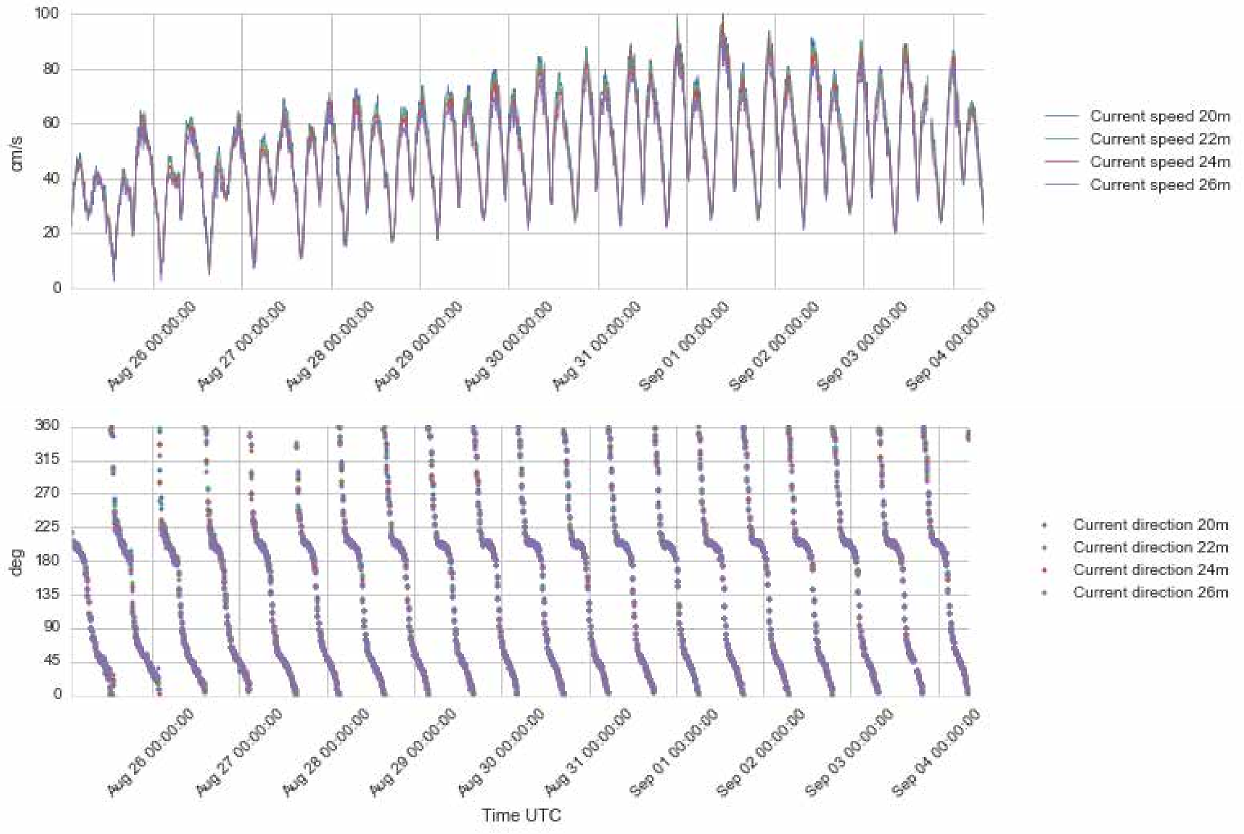


**Figure 4.25 Time series plots of current speed (upper) and direction (lower panel), 20 – 26 m depth, 25 Aug – 4 Sep 2015**

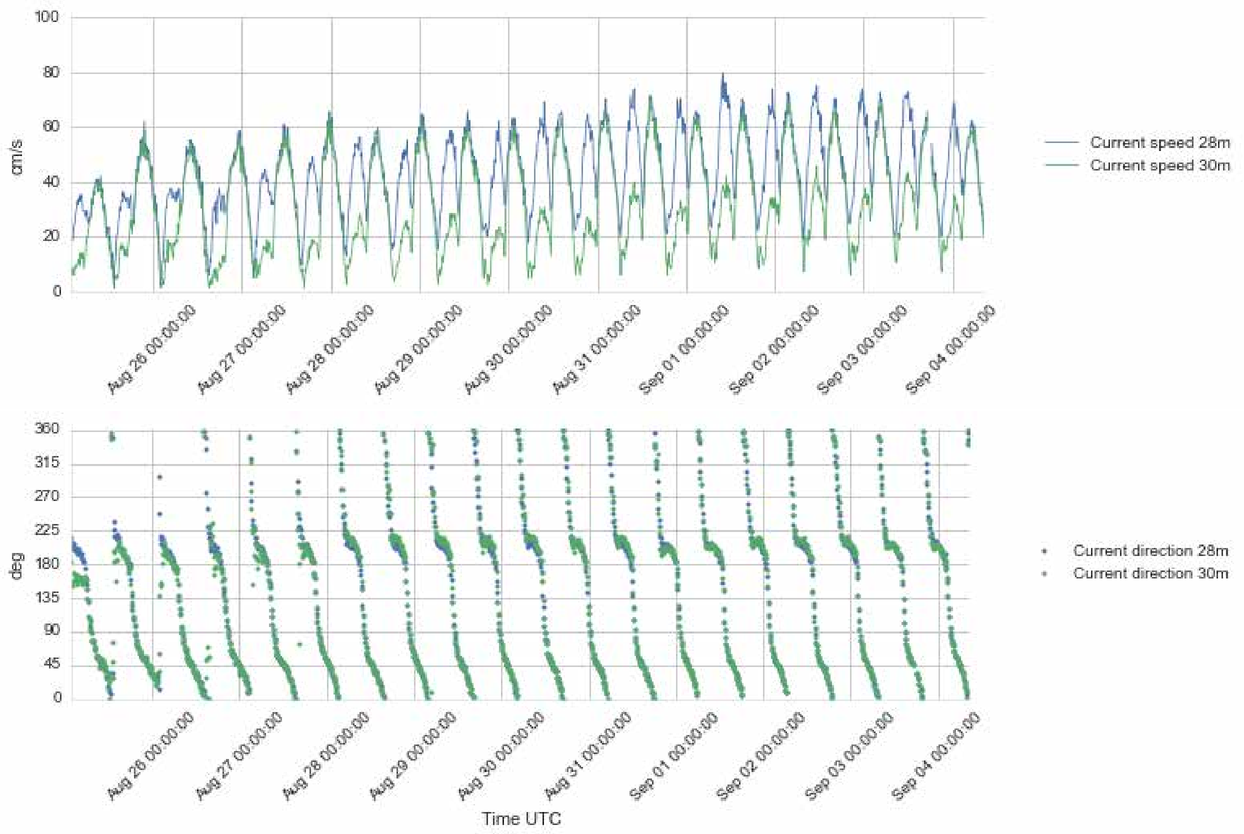


**Figure 4.26 Time series plots of current speed (upper) and direction (lower panel), 28 – 30 m depth, 25 Aug – 4 Sep 2015**

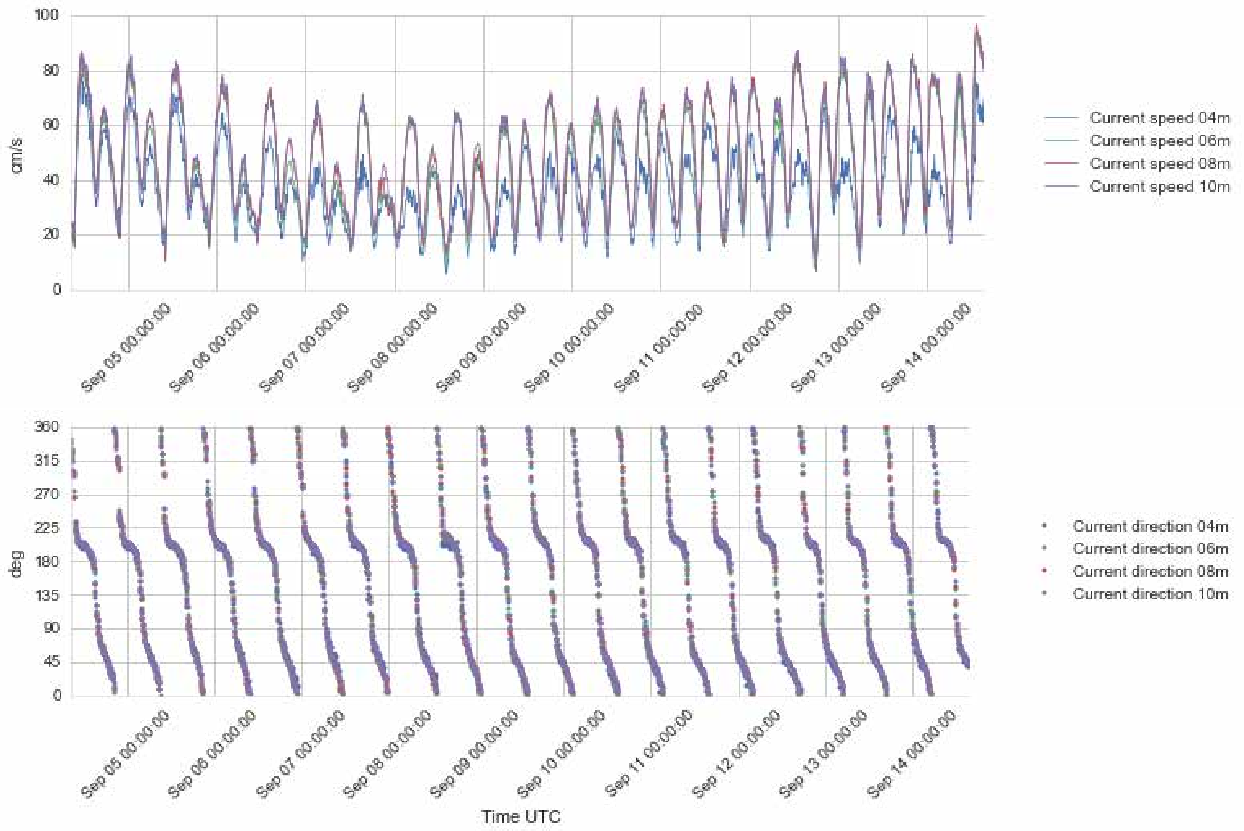


**Figure 4.27 Time series plots of current speed (upper) and direction (lower panel), 4 - 10 m depth, 4 – 14 Sep 2015**

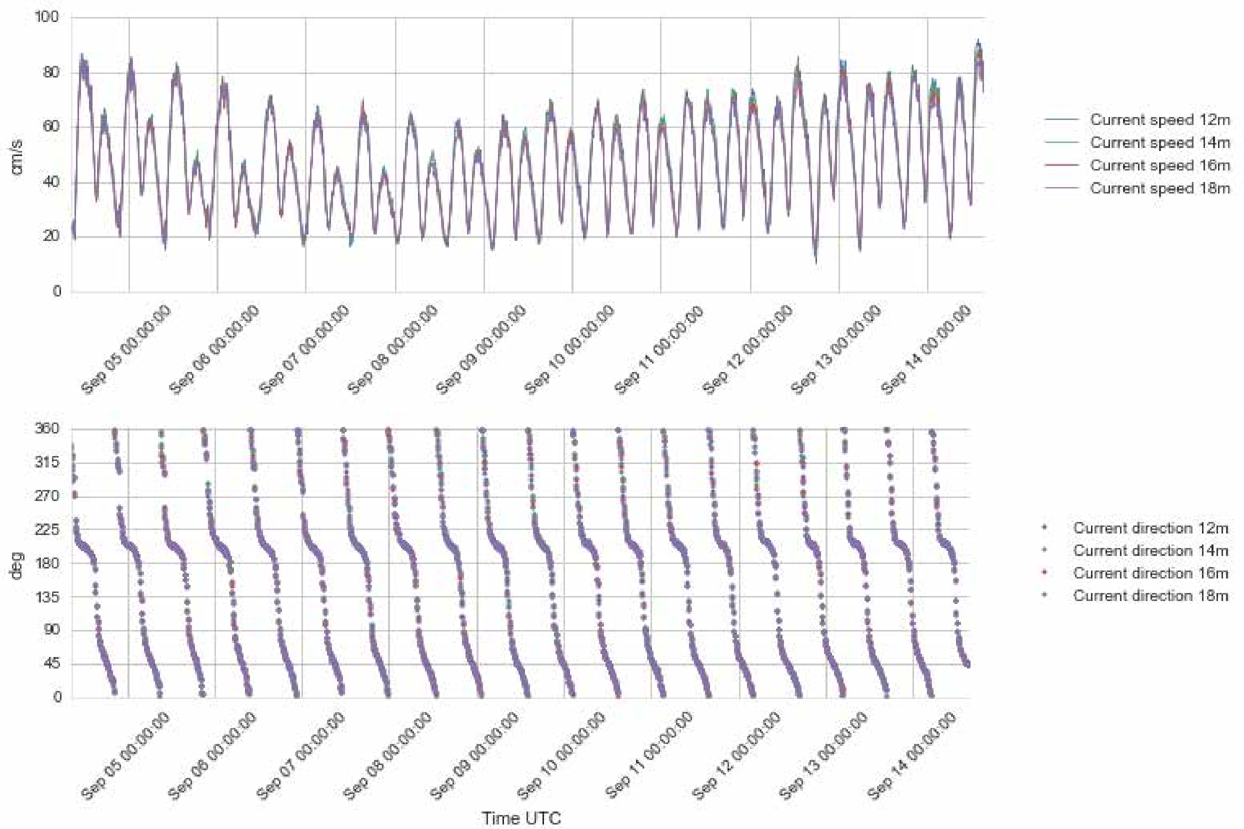


**Figure 4.28 Time series plots of current speed (upper) and direction (lower panel), 12 - 18 m depth, 4 – 14 August 2015**

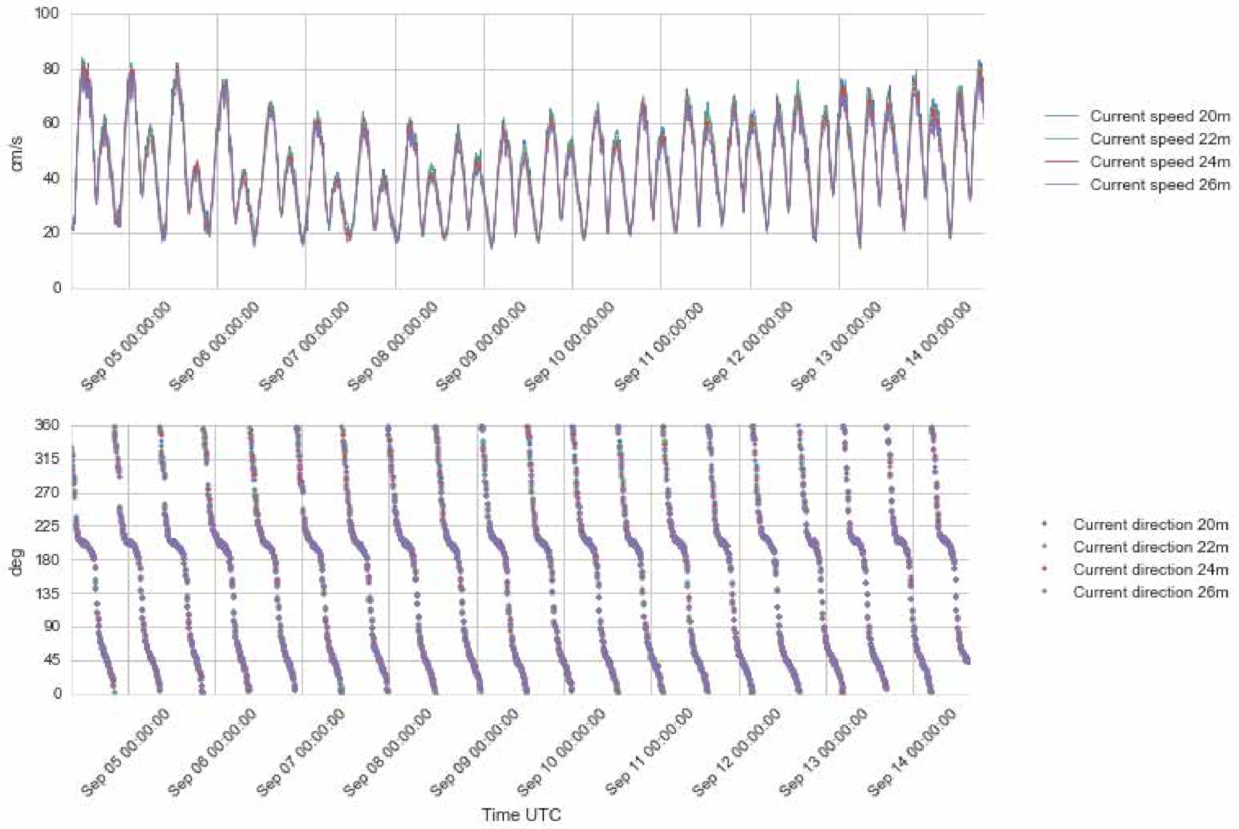


**Figure 4.29 Time series plots of current speed (upper) and direction (lower panel), 20 - 28 m depth, 4 – 14 Sep 2015**

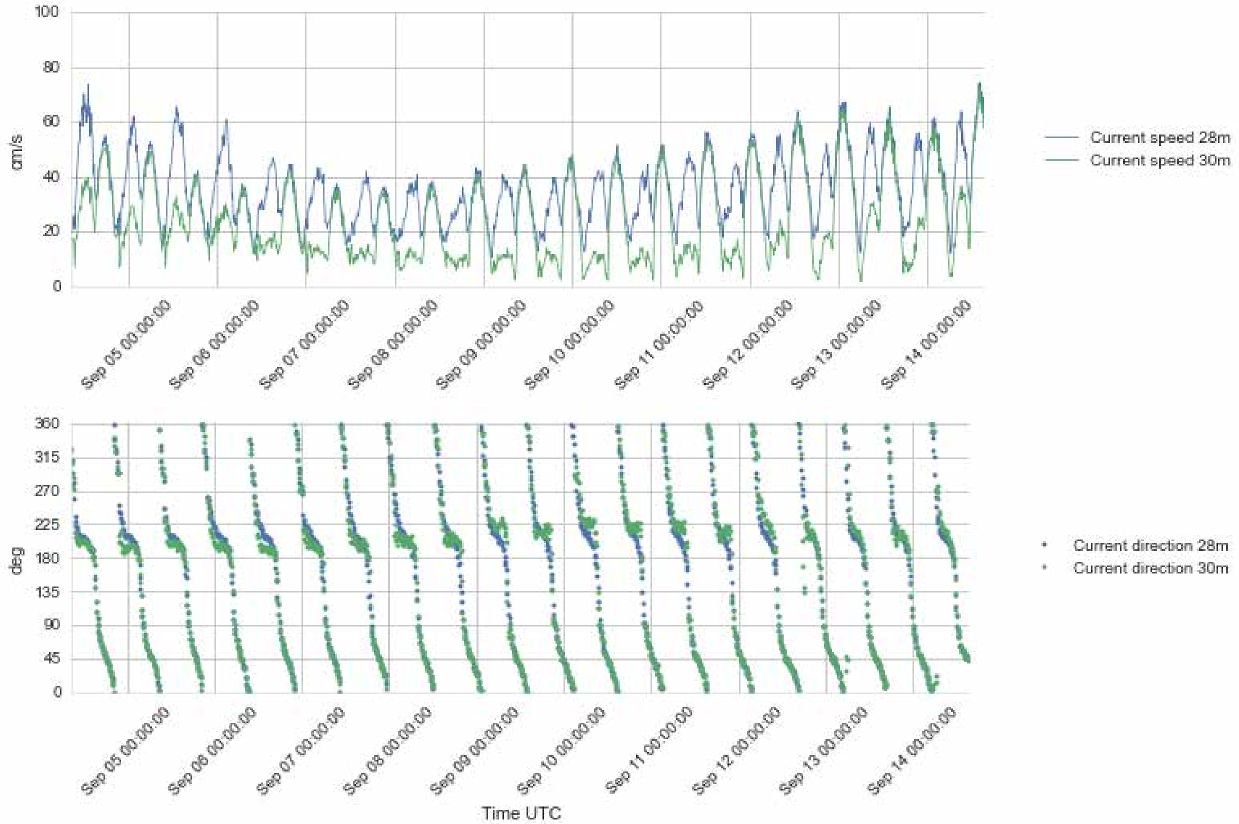


**Figure 4.30 Time series plots of current speed (upper) and direction (lower panel), 28 - 30 m depth, 4 – 14 Sep 2015**

### 4.2.5 Water level and bottom temperature data

The buoy received no data from the bottom mounted Seaguard WLR via the acoustic data link during this month. The received data indicate that the communication link between the sensor and the buoy was broken on 8 July 2015. It is expected that the data can be recovered from the internal storage in the WLR when it is recovered from the seabed.

# Appendix A

# Buoy deployment record

## BUOY DEPLOYMENT SHEET

| | | | |
|---|---|---|---|
| Project Name: | **WS Lidar buoy to Borssele, Nederland** | | |
| Project no: | C75339 | Latitude: | 51°42.41388'N (x=502392) |
| Station name: | Borssele | Longitude: | 3°2.07708'E (y=5728440) |
| WS buoy no: | WS149 | Approx. depth: | 30m |
| PFF numbers: | 33900 – 33904, 33909 | Buoy marking: | |

| **Buoy module/sensor** | **Serial number/ID** |
|---|---|
| Wavesense 3 data logger | 276 |
| XSense | 077003A0 |
| PMU | 333 |
| Vaisala PTB330 | J4010005 |
| Compass | 1035375 |
| Iridium modem | IMEI: 300125010219460<br>SIM: 8988169514001092357 |
| UHF service radio<br>Adeunis ARF7940BA | B134300547 |
| L3 AIS | S.n: 000990022<br>MMSI. 992572057 |
| Gill wind sensor | 13220063 |
| Vaisala air HMP155 temperature/humidity | J1130019 |
| Buoytracker | 736565 |
| ZephIR 300S Lidar | 428 |
| Flashlight | |
| Nortek Current meter | AQP7355 |
| Fuel Cell 1 | efoy : 302303-1407-32524<br>stack: 151010084—00501 |
| Fuel Cell 2 | efoy : 302302-1324-30871<br>stack: 151010084- |
| Fuel Cell 3 | efoy : 302303-1407-32516<br>stack: 151010084—00491 |
| Fuel Cell 4 | efoy : 302303-1407-32515<br>stack: 151010084--00492 |
| Seaguard<br>w/sensor 5217A | 1620<br>222 |

### CONFIGURATION

| | |
|---|---|
| Data transmission interval: | Continuous mode. ‘ |
| Listening window | NA |

### POWER OPTIONS

| | |
|---|---|
| Lead batteries type | **4 x 62Ah** |
| Lithium batteries: | **6 x 272Ah** |
| Fuel cells | **4 fuel cells with 10 methanol cartridges 28 litres** |

| | |
|---|---|
| | **each.** |

**DEPLOYMENT HISTORY**

| | **YEAR** | **MONTH** | **DATE** | **Local time** |
|---|---|---|---|---|
| First measurement | 2015 | 06 | 11 | 1655 |
| First measurement in position | 2015 | 06 | 11 | 1814 |
| Out of measuring position | | | | |
| Last measurement | | | | |

**Comments:**

**WLR deployment position:**

**51° 42.4362N, 3° 02.1030E, Depth: 30m**

**Time reference: CET (DST) (UTC + 2 hours)**

| | |
|---|---|
| Deployment vessel: MPR3 | Recovery vessel: |
| Deployed by: EME & OKH | Recovered by: |

**THE NETHERLANDS ENTERPRISE AGENCY (RVO)**

**Supply of Meteorological and Oceanographic data at Borssele Wind Farm Zone (BWFZ)**
**Validation report: 14 August - 14 September 2015**

**Reference No: C75339_VAL03_R1**
**7 December 2015**

**Fugro OCEANOR AS**
**Pirsenteret, P.O. Box 1224, Sluppen, N-7462 Trondheim, Norway**
**Tel: +47 73545200 Fax: +47 73545201, e-mail: trondheim@oceanor.com**

| Supply of Meteorological and Oceanographic data at Borssele Wind Farm Zone (BWFZ): C75339_VAL03_R1 | | | | |
|---|---|---|---|---|
| **Rev** | **Date** | **Originator** | **Checked & Approved** | **Issue Purpose** |
| 0 | 24.11.2015 | Lasse Lønseth | Arve Berg | Final report. |
| 1 | 07.12.2015 | Lasse Lønseth | Arve Berg | Final report updated according to client's comments. |

| **Rev 1 – 7 December 2015** | **Originator** | **Checked & Approved** |
|---|---|---|
| Signed: | Lasse Lønseth | Arve Berg |

This report is not to be used for contractual or engineering purposes unless the above is signed where indicated by both the originator of the report and the checker/approver and the report is designated 'FINAL'.

# TABLE OF CONTENT

# SUMMARY

The Seawatch Wind Lidar buoy is in operation at the Borssele Wind Farm Zone (BWFZ). The buoy was first deployed on 11 June 2015 at 15:55 UTC, and the bottom mounted tide gauge (WLR) was deployed at 16:15 UTC on the same day.

This evaluation report presents an evaluation of the wind and wave data collected during the period 14 August – 14 September 2015, comparing the buoy data to data from two fixed measurement stations in the region. The reference stations are a Waverider buoy at Schouwenbank (station SCHB) and a platform with a wind sensor at Vlakte van de Raan (VR).

Although the reference stations are some 20 – 30 km away from the buoy location we see good agreement between the buoy and references.

# 1. INTRODUCTION

The Seawatch Wind Lidar buoy with serial no. WS149 is deployed at the Borssele Wind Farm Zone (BWFZ) in the Dutch sector of the North Sea. The buoy was first deployed on 11 June 2015 at 15:55 UTC with the bottom mooring weight at position 51° 42.41388' N, 3° 2.07708' E. A bottom mounted water level recorder (WLR) at position 51° 42.4362' N, 3° 02.1030' E transmits data to the buoy in real time data via an acoustic link. The water depth at this location is approximately 30 m.

The wind and wave data collected during the period 14 August – 14 September 2015 are presented in the data presentation report ref. C75339_MPR03_R1. This report presents an evaluation of the wind and wave data, comparing the buoy data to data from fixed measurement stations in the area. The reference stations are the Waverider buoy at Schouwenbank (station SCHB) and a platform with a wind sensor at Vlakte van de Raan (VR).

The wave data are compared to measurements from SCHB, and the wind data are compared to data from VR. The comparisons are shown in time series and scatter plots.

The time reference used in this report is UTC.

# 2. Instrumentation and measurement configuration

The buoy is a Seawatch Wind Lidar Buoy based on the original Seawatch Wavescan buoy design with the following sensors:

- Wavesense: 3-directional wave sensor
- Xsens 3-axes motion sensor
- Gill Windsonic M acoustic wind sensor
- Vaisala PTB330A air pressure sensor
- Vaisala HMP155 air temperature and humidity sensor
- Nortek Aquadopp 600kHz current profiler.
- ZephIR 300S Lidar.

An independent self-recording Aanderaa SeaGuard WLR tide gauge is located on the bottom. The WLR transmits data to the buoy via an acoustic link.

The buoy with mooring as deployed is presented in Figure 2.1, including the mooring for the WLR.

The measurement setup is detailed in Table 2.1. Detail information such as sensor types and serial numbers can be found in the deployment record in Appendix A.

**Table 2.1 Configuration of measurements by the Seawatch Wind Lidar buoy at Borssele Borssele Wind Farm Zone (BWFZ).**

| Instrument type | Sensor height (m) | Parameter measured | Sample height[2)] (m) | Sampling interval (s) | Averaging period (s) | Burst interval (s) | Trans-mitted? |
|---|---|---|---|---|---|---|---|
| Wavesense 3 | 0 | Heave, pitch, roll, heading | 0 | 0.5 | Time series duration: 1024 s | 600 | No |
| | | Sea state parameters (1) | 0 | 600 | 1024 | 600 | Yes |
| Xsens | | Heave,east,north acceleration, q0,q1,q2,q3 (attitude quaternion) | 0 | 0.5 | N/A | 3600 | No |
| Gill Windsonic M | 4.1 | Wind speed, wind direction | 4.1 | 1 | 600 | 600 | Yes |
| Vaisala PTB330A | 0.5 | Air pressure | 0.5 | 30 | 60 | 600 | Yes |
| Vaisala HMP155 | 4.1 | Air temperature Air humidity | 4.1 | 5 | 60 | 600 | Yes |
| Nortek Aquadopp | -1 | Current speed and direction profile, water temperature (at 1 m depth) | -4<br>-6<br>…<br>-30<br>(14 levels) | N/A | 600 | 600 | Yes |
| ZephIR 300S Lidar | 2 | Wind speed and direction at 10 heights (The 11th level, the so called reference level which is not configurable, is also located at 40 m and referred to as 40.0 Ref.) | 30.0<br>40.0<br>40.0 ref<br>60.0<br>80.0<br>100.0<br>120.0<br>140.0<br>160.0<br>180.0<br>200.0 | ≈ 17.4 s[1)] | 600 | 600 | Yes |
| Aanderaa WLR (SeaGuard) via acoustic link | -30 | Water pressure Temperature | -30 | 600 | 60 | 600 | Yes |

1) This is the approximate time between the beginning of one sweep of the profile and the next one, the interval may vary slightly. The ZephIR sweeps one level at a time beginning at the lowest one, and after the top level has been swept it uses some time for calculations and re-focusing back to the lowest level for a new sweep.

2) Height relative to actual sea surface. The depth of the WLR is an approximate number.

**Table 2.2 Definitions of wave parameters presented in this report**

| | |
|---|---|
| H | Individual wave height |
| Hmax | = Max(H): Height of the highest individual wave in the sample, measured from crest to trough |
| m0, m1, m2, m4, m-1, m-2 | Moments of the spectrum about the origin: $\int f^k S(f)df$ where $S(f)$ is the spectral density and the wave frequency, $f$, is in the range 0.04 - 0.50 Hz |
| Hm0 | Estimate of significant wave height, Hs, $Hm0 = 4\sqrt{m0}$ |
| Tp | Period of spectral peak = $1/f_p$, The frequency/period with the highest energy |
| Tm01 | Estimate of the average wave period; *Tm01 = m0/m1* |
| Tm02 | Another estimate of the average wave period; $Tm02 = \sqrt{\frac{m0}{m2}}$ |
| ThTp | Mean wave direction at the spectral peak (“The direction of most energetic waves”) |
| Mdir | Wave direction averaged over the whole spectrum |
| | Directions are given in degrees clockwise from north, giving the direction the waves come from. (0° from north, 90° from east, etc.) |

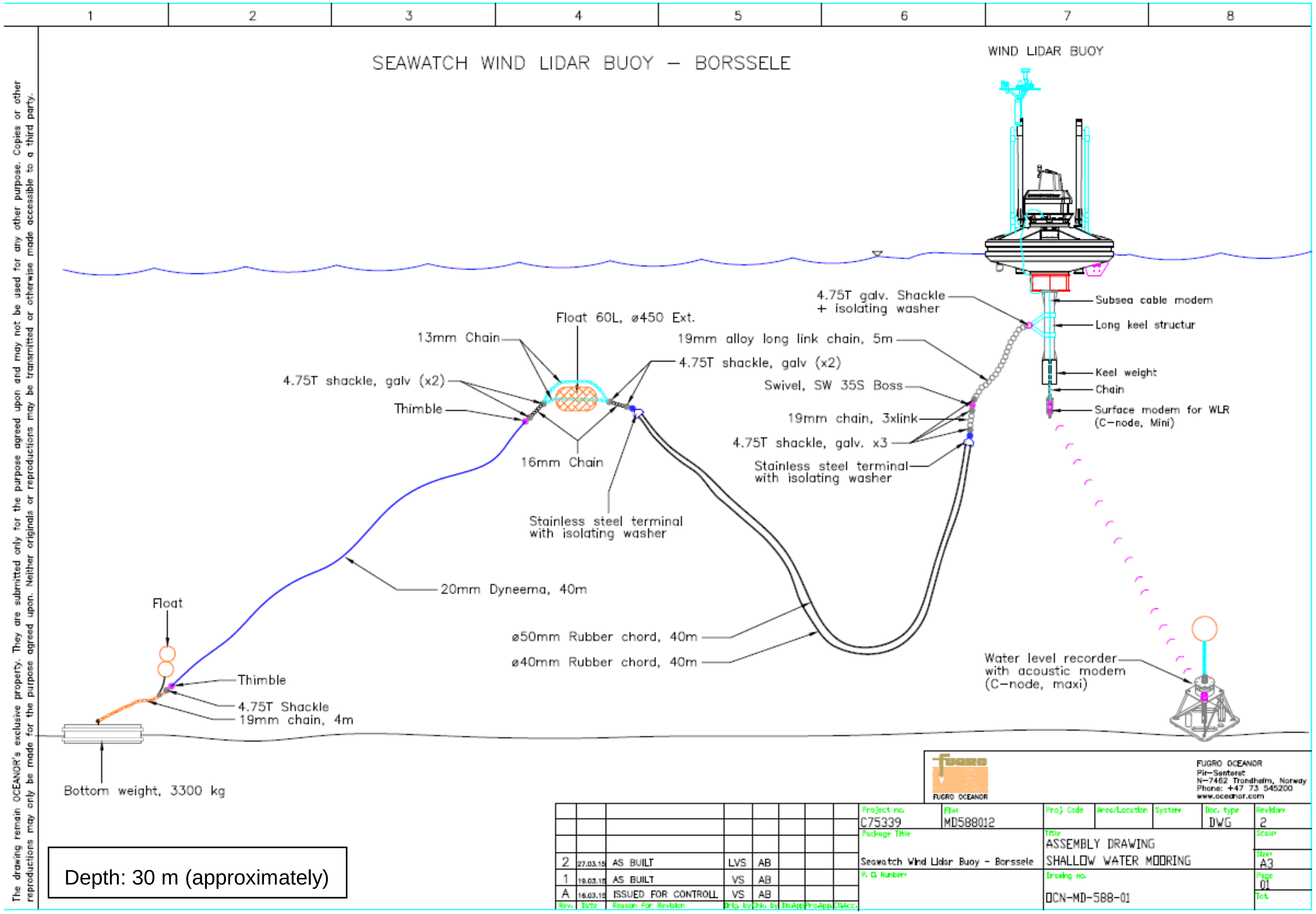


**Figure 2.1 Mooring design for the Wind Lidar Buoy as deployed at Borssele Wind Farm Zone (BWFZ).**

# 3. Results

## 3.1 Data recovery

The number of days of good data compared to the total length of the data collection period presented in Table 3.1, which is copied from the data presentation report (ref. C75339_MPR03_R1). The data recovery is high for all parameter except for the water level and bottom temperature from the Seaguard WLR. The WLR data are missing in real time due to the failure of the acoustic data link. The buoy transmitted data continuously from all sensors until 11 September 2015 at 15:50, and then transmissions stopped. However, the Lidar and the Aquadopp continued recording internally, and those data have been recovered and used as supplement to achieve 30.5 days of wind and current measurements, which was obtained on the 14 September at 15:30. The other parameters measured by the buoy were not recorded after 11 September at 15:50.

**Table 3.1 Data return during the period 14 August 2015 at 19:10 UTC – 14 September 2015 at 15:30 UTC**

| Measurement device | Length of data period (days) | Length of data set (days) | Average availability (%) |
|---|---|---|---|
| Lidar wind profile sensor | 30.847 | 30.5 | 98.87 |
| Wave sensor | 30.847 | 27.826 | 90.21 |
| Current velocity sensor | 30.847 | 30.813 | 99.89 |
| Atmospheric pressure sensor | 30.847 | 27.861 | 90.32 |
| Air temperature sensor | 30.847 | 27.861 | 90.32 |
| Water Level Sensor * | 30.847 | 0.000 | 0.00 |

* The real time transmitted water level data are partly lost due to disturbances of the acoustic link. However, the complete data series will be recovered from the instrument later during the service visits.

## 3.2 Reference stations

### 3.2.1 Positions and distances

Two public reference stations are used in the validation of the data; a Waverider buoy at Schouwenbank and a weather station at a small platform on the Vlakte van de Raan. The positions of the stations are given in Table 3.2, which gives an overview of the location and distances.

**Table 3.2 Postitions of the Lidar buoy and the reference stations used in the evaluation of the buoy data.**

| Station | Latitude | Longitude | Distance from the Lidar buoy | Shortest distance from land |
|---|---|---|---|---|
| Borssele Lidar buoy | 51° 42.41’ N | 3° 2.08’ E | | 32.5 km |
| Schouwenbank Waverider buoy (SCHB) | 51° 44.8’ N | 3° 18.3’ E | 19.3 km | 22.0 km |
| Vlakte van de Raan (VR) | 51° 30’ N | 3° 15’ E | 27.6 km | 12.2 km |

### 3.2.2 Schouwenbank

The wave measuring buoy at Schouwenbank (SCHB station) is a directional ("2D") Datawell Waverider buoy. This buoy measures the wave height and directional spectrum using 3-axis accelerometers.

The SCHB station should be expected to have lower heights of wind sea than the Borssele Lidar buoy location in southerly to north-easterly winds due to the more limited fetch distance in those directions. In situations with wind sea from north-east to north-west, and situations dominated by northerly swells the two buoy should be exposed to approximately the same wave heights.


**Figure 3.1 Google Earth image with indication of the Lidar buoy position and reference stations.**

### 3.2.3 Vlakte van de Raan

The Vlakte van de Raan (VR) station is measuring wind speed and wind direction. Figure 3.2 shows a photo of the wind mast. Wind speed is measured with the KNMI cup-anemometer. Cup diameter is 105 mm and the distance between the centre of the cups to the rotation axis is 100 mm. Wind direction is measured with the KNMI wind vane. Distance between axis and the outer side of the vane is 535 mm. The anemometer and wind vane are located 13.9 m above the mean sea level. The azimuth of the wind vane plugs at the tip of the booms are determined with a camera relative to distant objects at close to the horizon. The instruments are logged with the KNMI wind SIAM. Wind gusts are determined from a running 3 sec mean value.

Calibration of the cup anemometers is done in the wind tunnel of KNMI. Wind vanes are balanced and the direction of the vane is tested. Sensors are replaced after 26 month. The cup anemometer contains a photo-chopper with 32 slits. The accuracy is 0.5 m/s. The treshold velocity is 0.5 m/s. The resolution is 0.1 m/s. The response length is 2.5 m. The wind vane contains a code disk. Accuracy is 3°. Resolution is 1°. [ref. Chapter 5 “Handbook for the Meteorological Observation. Koninklijk Nederlands Meteorologisch Instituut KNMI, De Bilt September 2000.]

The VR station is located only 12 km from the coast and much closer to land than the Lidar buoy, and that is expected to have some effect on the winds, both speed and direction, especially for wind with direction from shore; directions from south-southwest to east-northeast in particular. This means that there can be considerable differences in wind speed and direction at any given time, while the long term overall averages are expected to be approximately the same.

**Figure 3.2 The wind measuring station at Vlakte van de Raan.**

## 3.3 Evaluation of the collected data

### 3.3.1 Wave data

The wave data from the Lidar buoy are compared to data from the Waverider at Schouwenbank in time series and scatter plots. The distance of about 20 km between the two locations and the different distance from shore is expected to cause some differences in these shallow waters.

The time series plot in Figure 3.3 and scatter plot in Figure 3.4 compares the significant wave height (Hm0). All peaks in the time series occur at almost exactly the same time, showing good coherence. The average Hm0 values are 1.11 m at the Lidar buoy compared to 1.00 m at Schouwenbank. The difference as well as the scatter with $R^2 = 0.955$ may be attributed to differences in location, depth and distance from the shore line at the two locations.

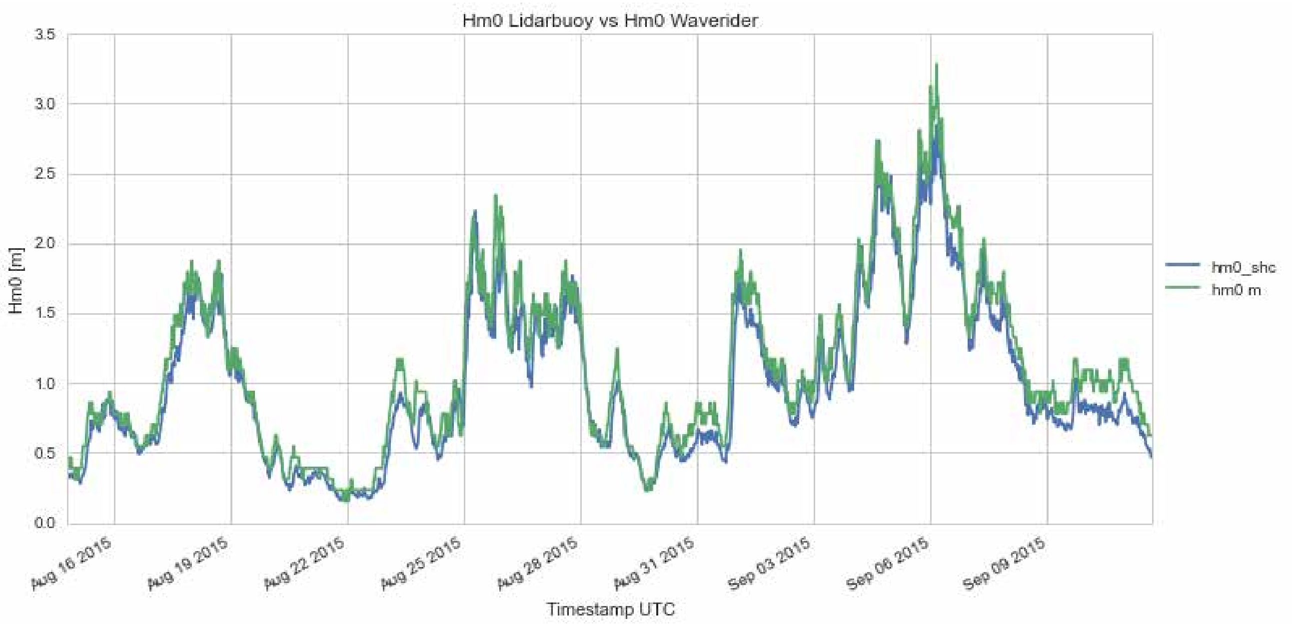


**Figure 3.3 Time series plot of significant wave height (Hm0) from the Lidar buoy (green curve) and the Schouwenbank Waverider buoy (blue).**

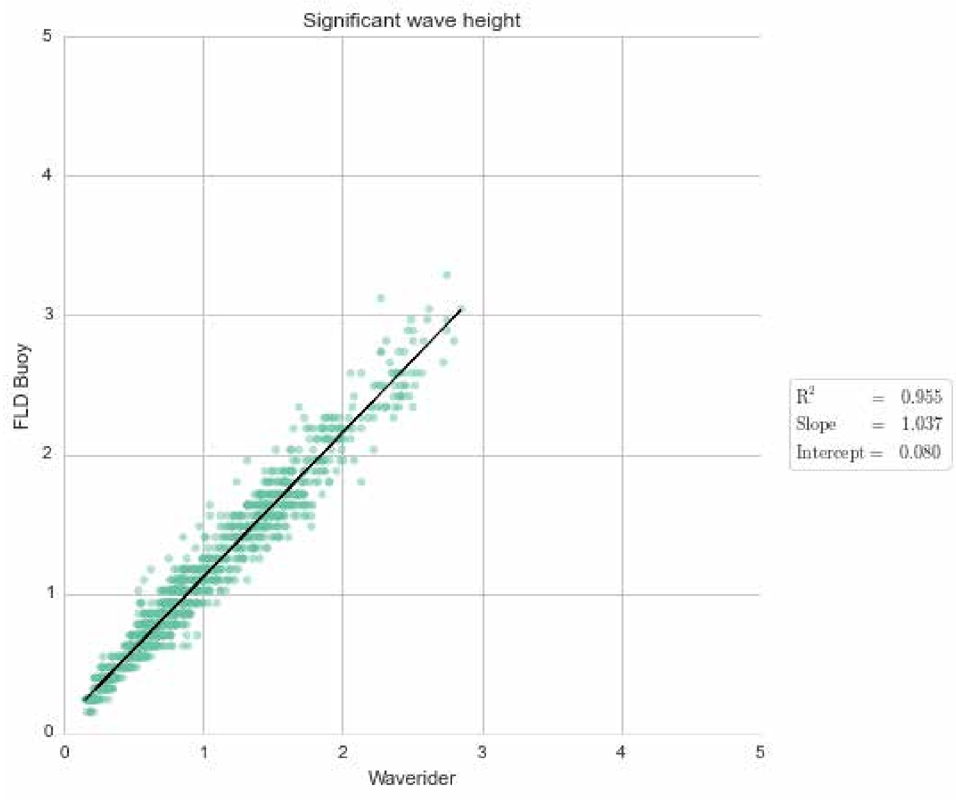


**Figure 3.4 Scatter plot comparing Hm0 measured by the Lidar buoy toHm0 from the Schouwenbank Waverider buoy.**

The mean wave period (Tm02) from the Lidar buoy is compared to the Waverider Tm02 in the time series plot in Figure 3.5 and the scatter plot in Figure 3.6. The time series plot shows good coherence and the values appear very similar. The scatter plot shows $R^2$ = 0.913. Some scatter must be expected due to the distance between the stations. The average values of Tm02 are 4.19 s at the Lidar buoy compared to 4.12 s at the Waverider.

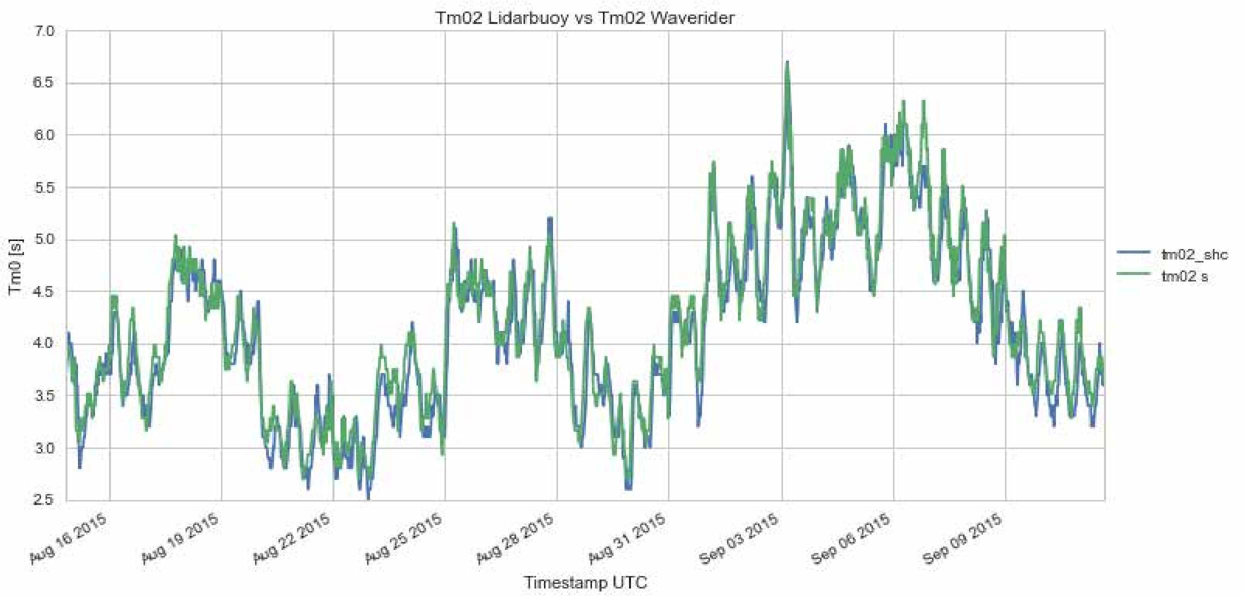


**Figure 3.5 Time series plot of mean wave period (Tm02) from the Lidar buoy (green curve) and the Schouwenbank Waverider buoy (blue).**

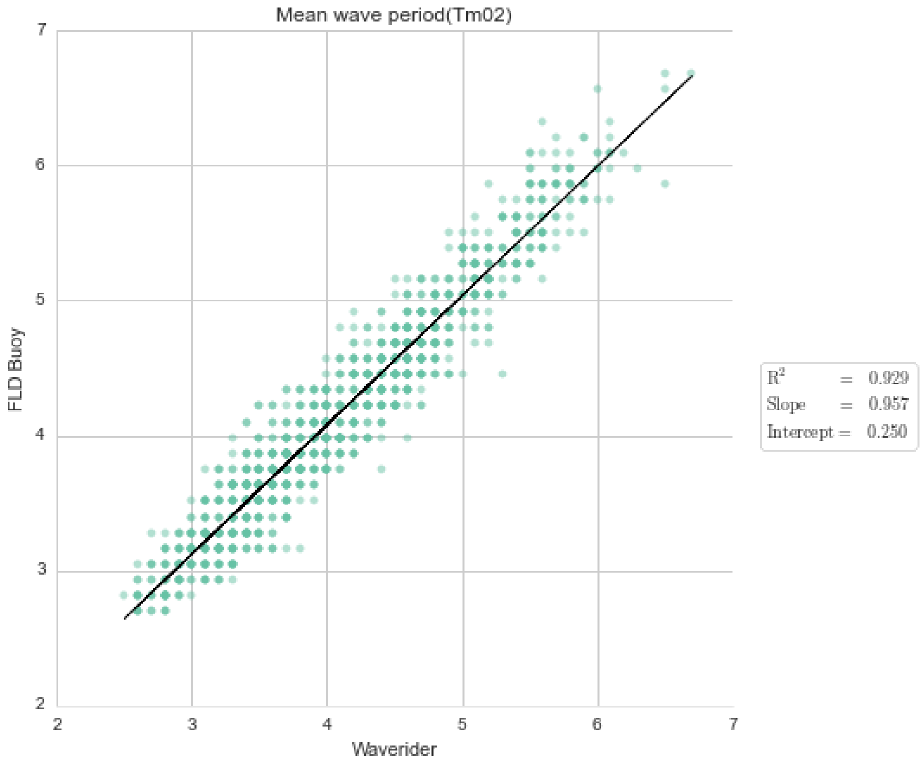


**Figure 3.6 Scatter plot comparing Tm02 measured by the Lidar buoy toTm02 from the Schouwenbank Waverider buoy.**

### 3.3.2 Wind data

The Vlakte van de Raan (VR) wind station is located about 28 km away from the Lidar buoy and closer to shore. The VR station is about 12 km from the nearest shore, while the buoy is 33 km from land. The wind speeds measured at anemometer height, 13.9 m above the mean sea level, have been reduced to 10 m above mean sea level by a factor of 0.95. The horizontal Lidar wind speed data from the lowest cell, at 30 m above the sea surface, have been compared to the wind data from VR adjusted from 10 m to 30 m height by a factor of 1.15. The data series presented in Figure 3.7 show good agreement in general terms; the maxima in wind speed at both locations appear at the same time, showing good coherence. In average the data compare well with a 30 m average speed of 8.16 m/s at the buoy compared to 8.27 m/s in average at the VR station.

The scatter plot in Figure 3.8 compares the wind speeds when the VR station speeds exceed 2 m/s. The correlation is seen clearly, although the scatter is quite large due to the distance between the stations and the differences in the way land effects influence the local wind. This confirms that there is no reason to suspect that the Lidar has not measured the wind speed correctly.

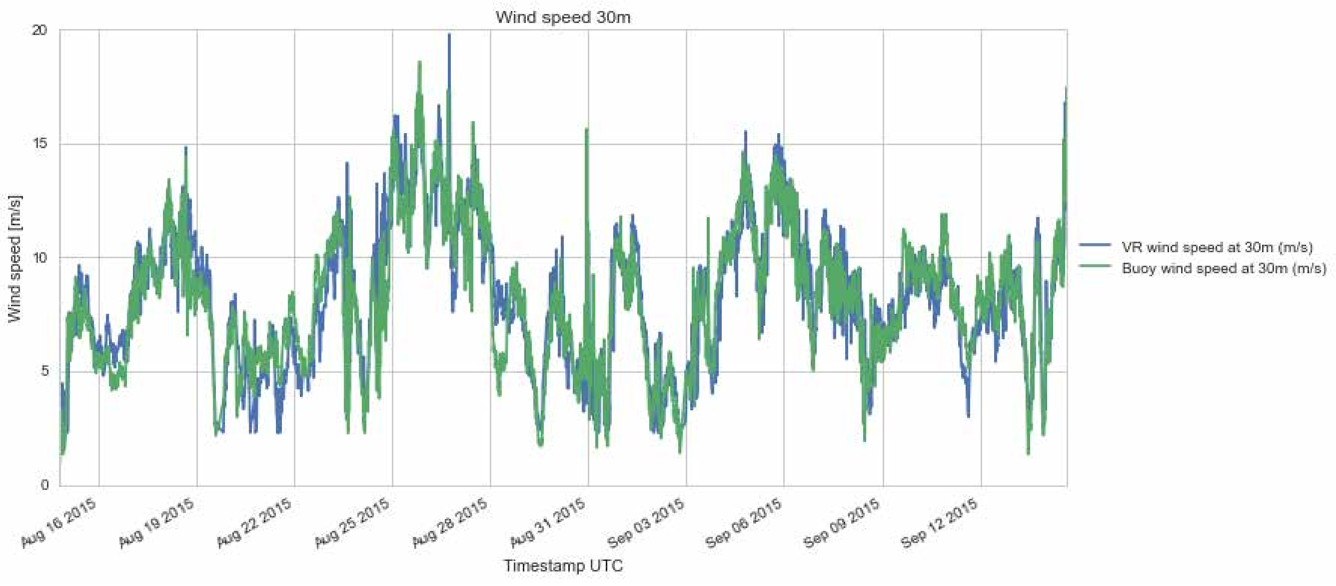


**Figure 3.7 Wind speed at 30 m above sea level measured by the Lidar buoy (green curve) compared to wind speed at Vlakte van de Raan adjusted to 30 m (blue).**

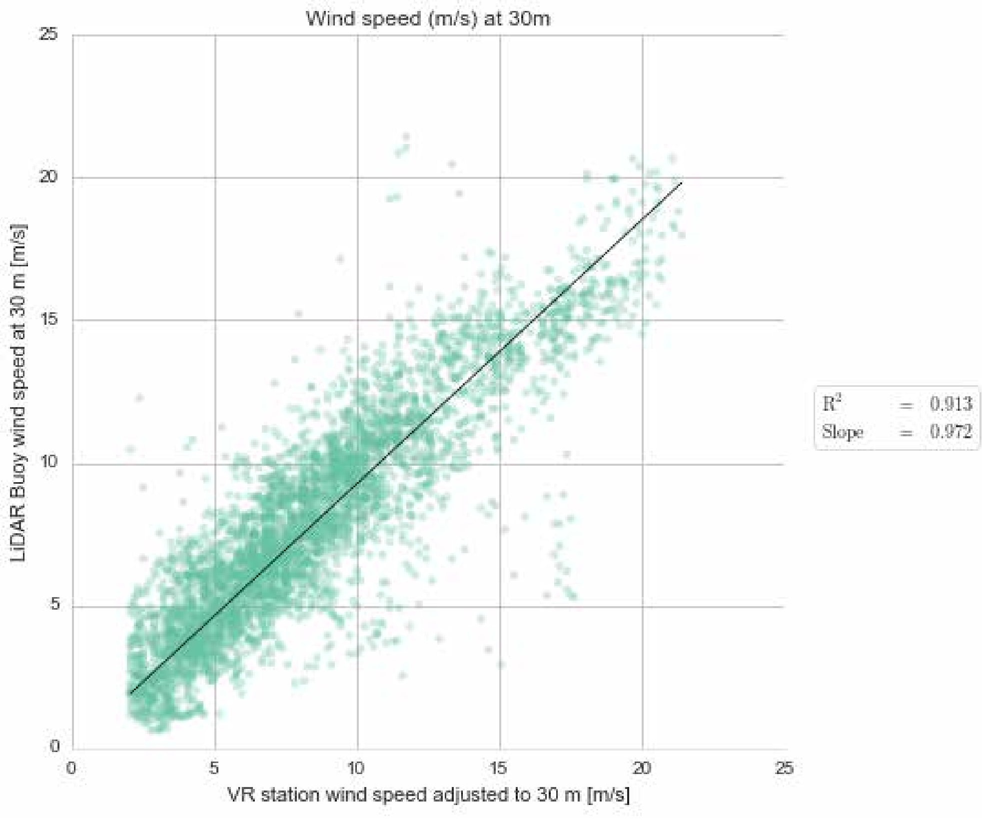


**Figure 3.8 Scatter plot comparing the wind speed at 30 m above sea level measured by the Lidar buoy compared to the wind speed at Vlakte van de Raan adjusted to 30 m a.s.l. (Regression formula: y = Slope * x)**

The time series of wind direction are compared in Figure 3.9, which also shows the wind speed at Vlakte van de Raan. Samples with speed less than 2 m/s are excluded. Again we see that there is a general agreement between the measurements, and this is seen also in the scatter plot in Figure 3.10. Control of the buoy after recovery showed that the Lidar was misaligned by 15° from the designated position, which gives a fixed offset in the original data. After correction for this, there is practically no offset between the wind directions. The offset is calculated as the average of the difference between the wind directions. It was expected that the wind directions would differ at any given time due to the distance between the locations, and this may explain the scatter seen in the plot.

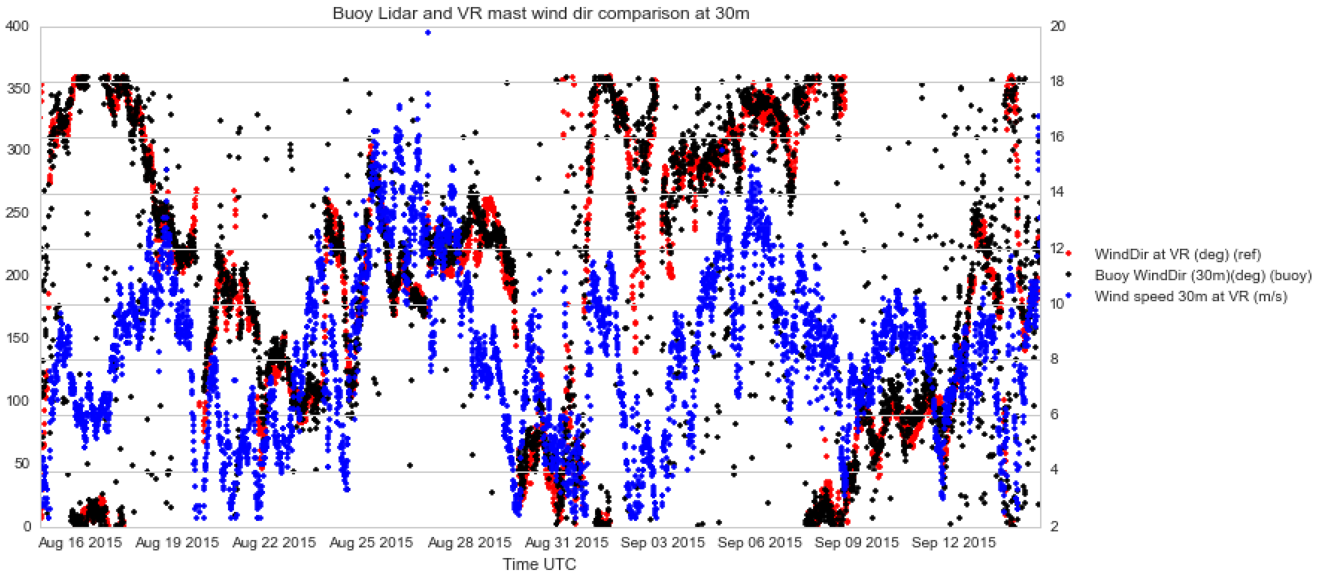


**Figure 3.9 Wind direction at 30 m above sea level measured by the Lidar buoy (black dots) compared to wind direction at Vlakte van de Raan (red). The blue dots show the VR station 10m wind speeds. (Samples with VR wind speed less than 2 m/s are excluded.)**

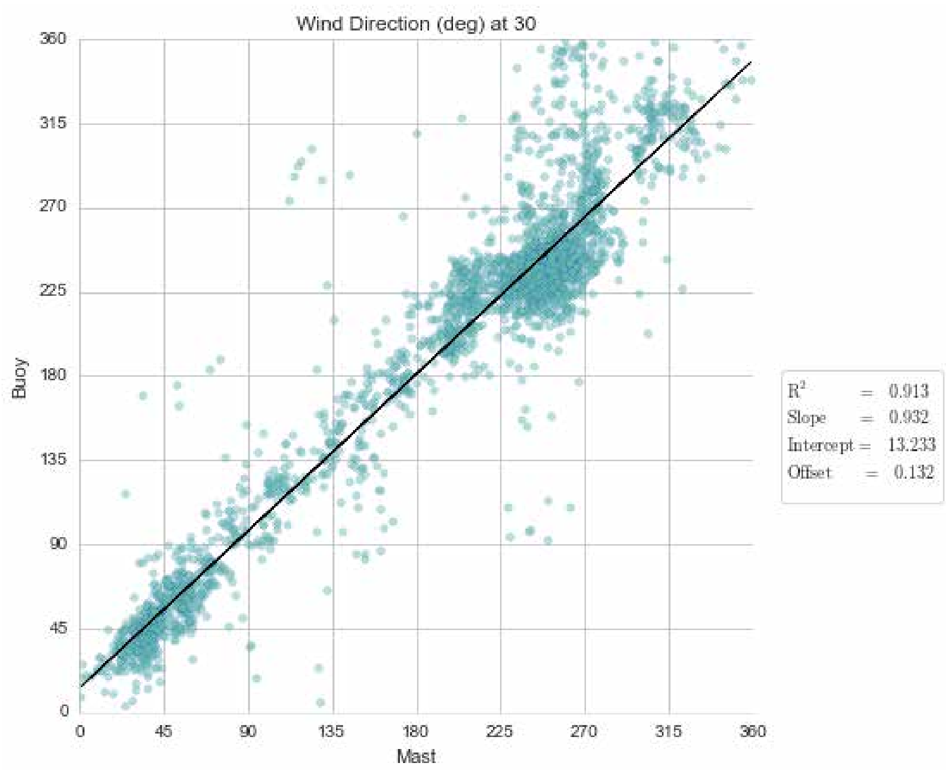


**Figure 3.10 Wind direction at 30 m above sea level measured by the Lidar buoy compared to wind direction at Vlakte van de Raan. (Samples with VR wind speed less than 2 m/s are excluded.) ("Offset" is the average difference of directions.)**

## 3.4 Conclusions

The Lidar buoy has transmitted data continuously during the month. The comparisons to the reference station data presented above indicate that the buoy has collected data of good quality for winds and waves. There were only short gaps in the wind data, and as a result 30.847 days were required to acquire 30.5 days of actual good wind measurements.

# Appendix A

# Buoy deployment record

## BUOY DEPLOYMENT SHEET

| | | | |
|---|---|---|---|
| Project Name: | **WS Lidar buoy to Borssele, Nederland** | | |
| Project no: | C75339 | Latitude: | 51°42.41388'N (x=502392) |
| Station name: | Borssele | Longitude: | 3°2.07708'E (y=5728440) |
| WS buoy no: | WS149 | Approx. depth: | 30m |
| PFF numbers: | 33900 – 33904, 33909 | Buoy marking: | |

| **Buoy module/sensor** | **Serial number/ID** |
|---|---|
| Wavesense 3 data logger | 276 |
| XSense | 077003A0 |
| PMU | 333 |
| Vaisala PTB330 | J4010005 |
| Compass | 1035375 |
| Iridium modem | IMEI: 300125010219460<br>SIM: 8988169514001092357 |
| UHF service radio<br>Adeunis ARF7940BA | B134300547 |
| L3 AIS | S.n: 000990022<br>MMSI. 992572057 |
| Gill wind sensor | 13220063 |
| Vaisala air HMP155 temperature/humidity | J1130019 |
| Buoytracker | 736565 |
| LIDAR ZephIR300 | 428 |
| Flashlight | |
| Nortek Current meter | AQP7355 |
| Fuel Cell 1 | efoy : 302303-1407-32524<br>stack: 151010084—00501 |
| Fuel Cell 2 | efoy : 302302-1324-30871<br>stack: 151010084- |
| Fuel Cell 3 | efoy : 302303-1407-32516<br>stack: 151010084—00491 |
| Fuel Cell 4 | efoy : 302303-1407-32515<br>stack: 151010084--00492 |
| Seaguard<br>w/sensor 5217A | 1620<br>222 |

### CONFIGURATION

| | |
|---|---|
| Data transmission interval: | Continuous mode. ‘ |
| Listening window | NA |

### POWER OPTIONS

| | |
|---|---|
| Lead batteries type | **4 x 62Ah** |
| Lithium batteries: | **6 x 272Ah** |
| Fuel cells | **4 fuel cells with 10 methanol cartridges 28 litres** |

| | |
|---|---|
| | **each.** |

**DEPLOYMENT HISTORY**

| | YEAR | MONTH | DATE | Local time |
|---|---|---|---|---|
| First measurement | 2015 | 06 | 11 | 1655 |
| First measurement in position | 2015 | 06 | 11 | 1814 |
| Out of measuring position | | | | |
| Last measurement | | | | |

**Comments:**

**WLR deployment position:**

**51° 42.4362N, 3° 02.1030E, Depth: 30m**

**Time reference: CET (DST) (UTC + 2 hours)**

| | |
|---|---|
| Deployment vessel: MPR3 | Recovery vessel: |
| Deployed by: EME & OKH | Recovered by: |