ECN

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THE NETHERLANDS

Subject Supply of Meteorological and Oceanographic data for Borssele Wind Farm Zone Period 11 June -14 July 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 : 11 June – 14 July 2015.
   Reference No: C75339_MPR01_R3 (20 November 2015)
2. Supply of Meteorological and Oceanographic data at Borssele Wind Farm Zone (BWFZ)
   Validation report : 11 June – 14 July 2015.
   Reference No: C75339_VAL01_R2 (20 November 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.

It should also be noted that the earlier observed offset in the wind direction data is corrected in this version and that a new data set is available via the website.

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: 11 June - 14 July 2015

Reference No: C75339_MPR01_R3
20 November 2015

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Supply of Meteorological and Oceanographic data at Borssele Wind Farm Zone (BWFZ):
C75339_MPR01_R3

Rev	Date	Originator	Checked & Approved	Issue Purpose
0	22.07.2015	Ola K. Storås	Lasse Lønseth	Final report.
1	27.08.2015	Lasse Lønseth	Arve Berg	Final report with extended data period.
2	11.09.2015	Lasse Lønseth	Arve Berg	Final report updated according to comments from client.
3	20.11.2015	Lasse Lønseth	Arve Berg	Final report updated with revision of direction data due to offset correction.

Rev 3 – 20 November 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 11th 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 this first month of operation.

This first monthly report summarizes the activities and data collected during the period 11th June – 14th July 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 11th 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.

No service visits have been carried out within the first month of operation.

This report presents project progress and results during the period 11th June – 14th July 2015, and the data which have been transmitted to shore via the Iridium satellite system in this period. The overall period data recovery percentages are also presented.

In this revision 3 of the report the data have been corrected for 15° misalignment of the Lidar relative to the buoy hull.

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 total length of the mooring line is approximately 91 m which allows for circle of motion with a radius of 86 m. However, with the rubber cords stretched due to current drag the actual radius as shown by the GPS position data is 113 m.

The measurement setup is detailed in Table 2.1. Definitions of the presented wave parameter are given in Table 2.2.

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 Air humidity	4.1	5	60	600	Yes
Nortek Aquadopp	-1	Current speed and direction profile, water temperature (at 1 m depth)	-4 -6 … -30 (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 40.0 40.0 ref 60.0 80.0 100.0 120.0 140.0 160.0 180.0 200.0	≈ 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.)

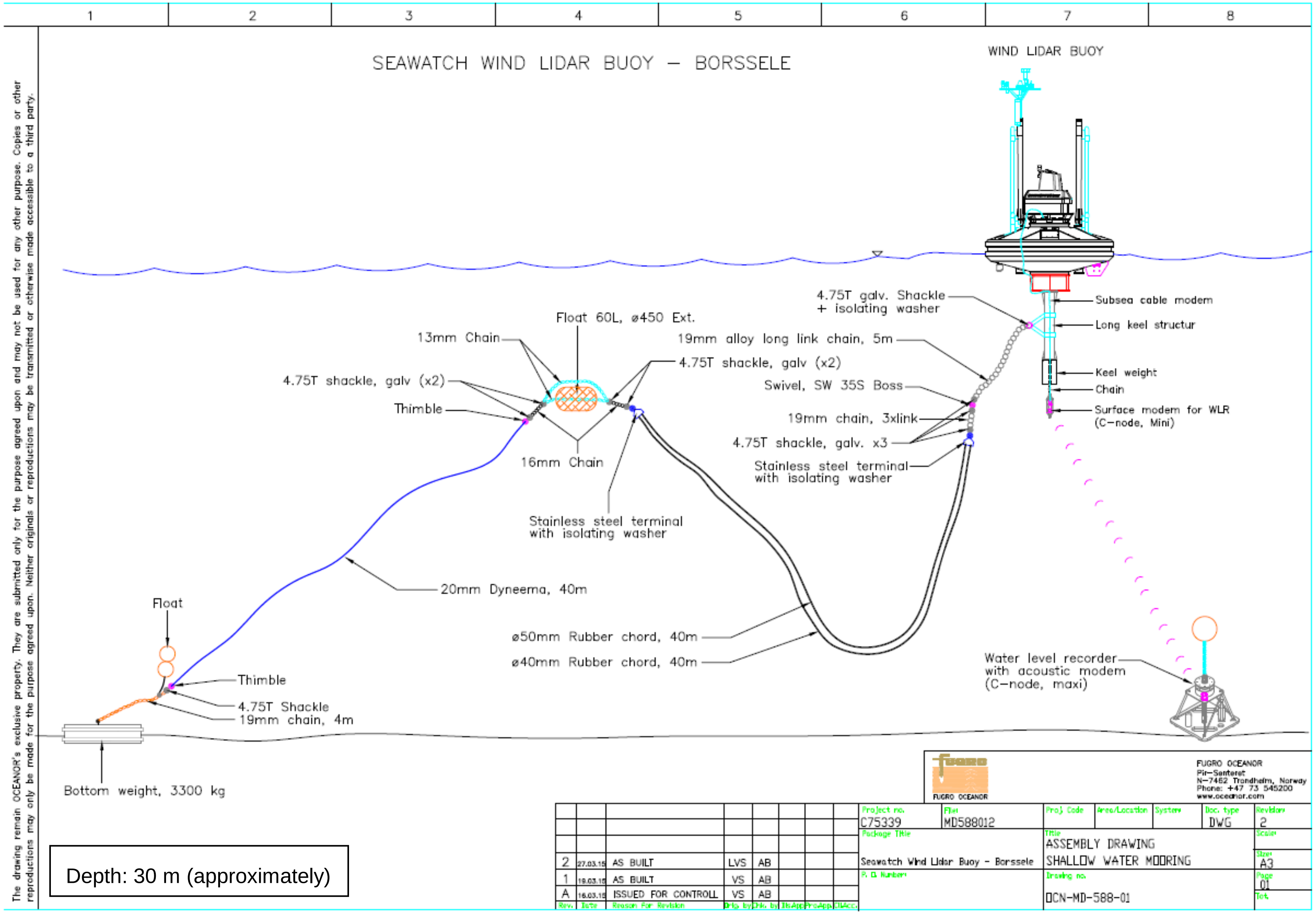

Figure 2.1 Mooring design for the Wind Lidar Buoy as deployed at Borssele Wind Farm Zone (BWFZ).

3. 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 (BWFZ) in the Dutch sector of the North Sea on 11th June 2015. The buoy was deployed at 15:55 UTC 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.

The multicat type work vessel MPR3 was used for the deployment. The equipment was mobilised to the vessel in Schiedam. The detailed cruise log is included in Appendix A. The vessel was mobilized on 8th June 2015, with intended deployment on the following day. However, the weather and wave conditions on 9th and 10th June were not workable, so the operation was postponed to 11th June.

The buoy has been in continuous good operation during the first month after the deployment. No service activities have been carried out.

3.2 Health, Safety and Environment

There were no incidents, near misses or accidents in connection with the deployment operation.

As the buoy has been in autonomous operation without intervention during the whole period until 14th July 2015 there were no HSE related events in this period. No vessels or third parties have interfered with the buoy.

4. Results

4.1 Summary of results and data return

The buoy has transmitted data continuously from all sensors during the month, but there are some gaps due to communication problems, which are discussed in the following.

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 period11th June 2015 at 18:20 UTC – 14th July 2015 at 21:10 UTC

Measurement device	Length of data period (days)	Length of data set (days)	Average availability (%)
LiDAR wind profile sensor	33.097	30.5	92.15
Wave sensor	33.097	32.993	99.69
Current velocity and direction sensor	33.097	33.001	99.73
Atmospheric pressure sensor	33.097	33.035	99.81
Air temperature sensor	33.097	33.035	99.81
Water Level Sensor *	33.097	4.542	13.72

* 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.

4.2 Presentation of the received data

The following presentations show good data transmitted from the buoy via Iridium satellite during the period 11th June 2015 at 18:20 UTC – 14th July 2015 at 21:10 UTC. Within this period 30.5 days of actual wind data were collected, and this took totally 33.097 days to collect due to some wind measuring system outages.

Some drop-outs seen in water temperature and waves have occurred due to buoy restarting. Gaps in wind profile data, from 30 m up to 200 m, have occurred due to loss of communication between the LiDAR and the central Geni processor, and data from these periods may be recovered later from the LiDAR's internal data store. One 37.5 hour long gap in the LiDAR wind profile caused by this communication problem lasting from 13th June at 21:30 to 15th June 11:00 (UTC) accounts for about 60% of the total loss of data in this period.

4.2.1 Meteorological data

The time series plots in Figure 4.1 - Figure 4.3 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 dropouts in water temperature have occurred after reboots of the buoy central Geni processor, because an empty data sample was transmitted before the sensor had time to complete the measurement cycle.

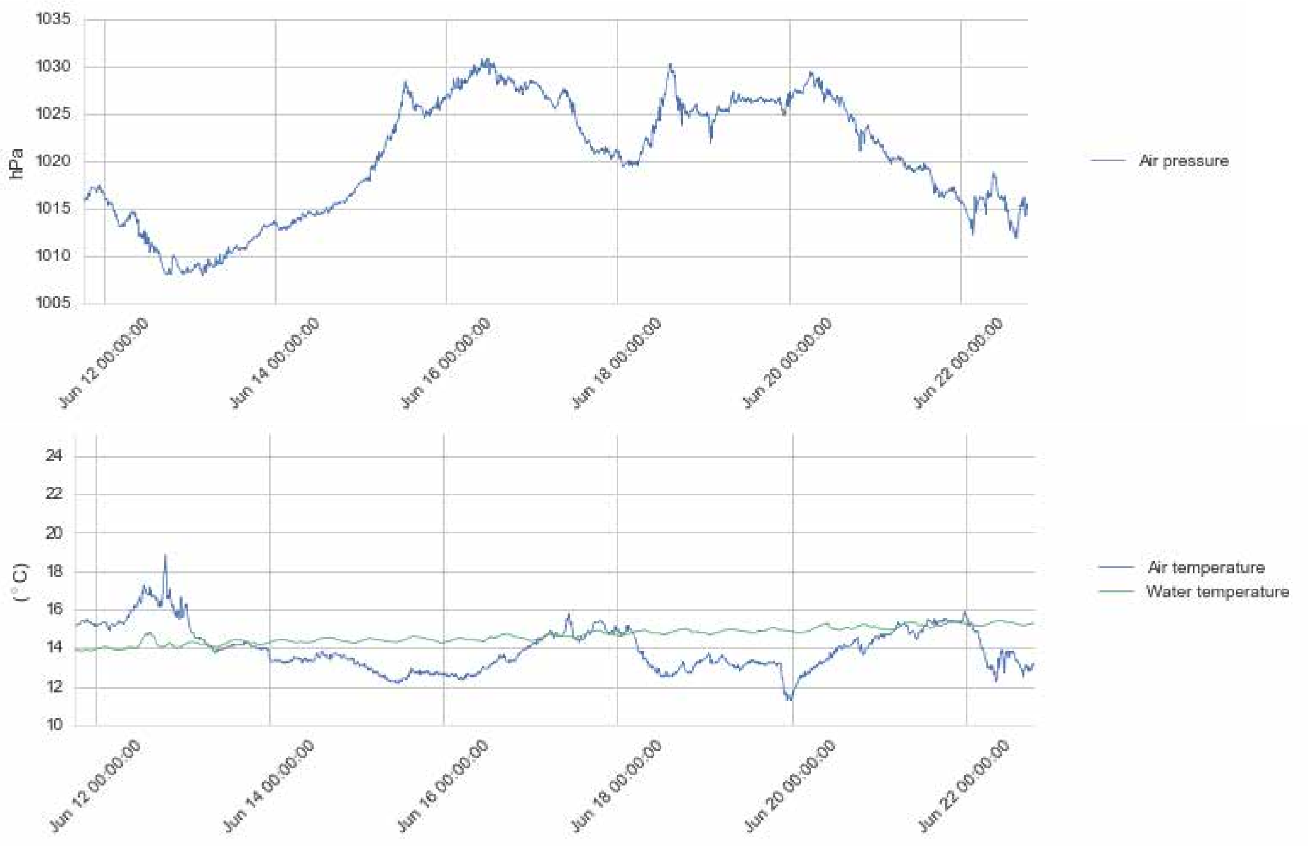

Figure 4.1 Time series plots of air pressure (upper panel), air and water temperature (lower panel), 11-22 June 2015.

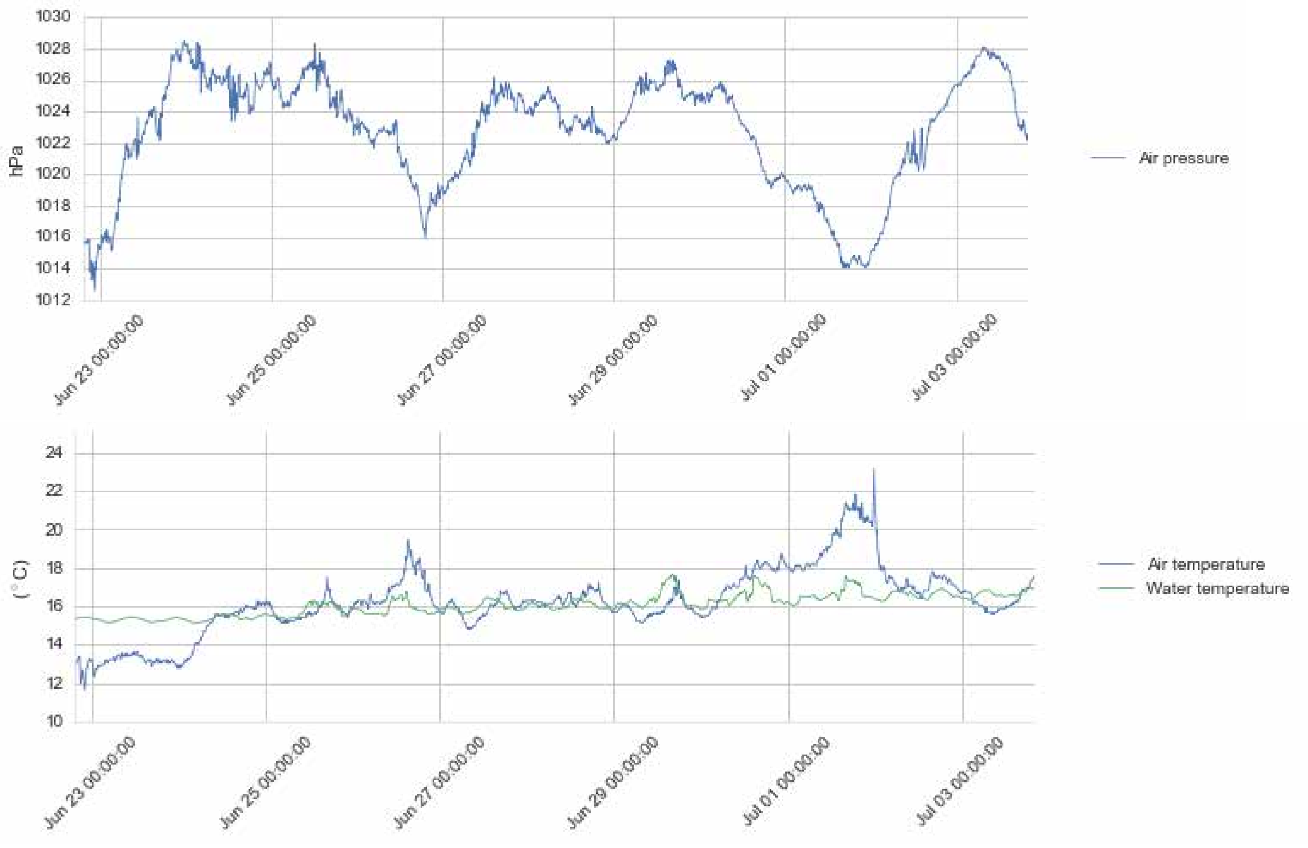

Figure 4.2 Time series plots of air pressure (upper panel), air and water temperature (lower panel), 22 June – 3 July 2015.

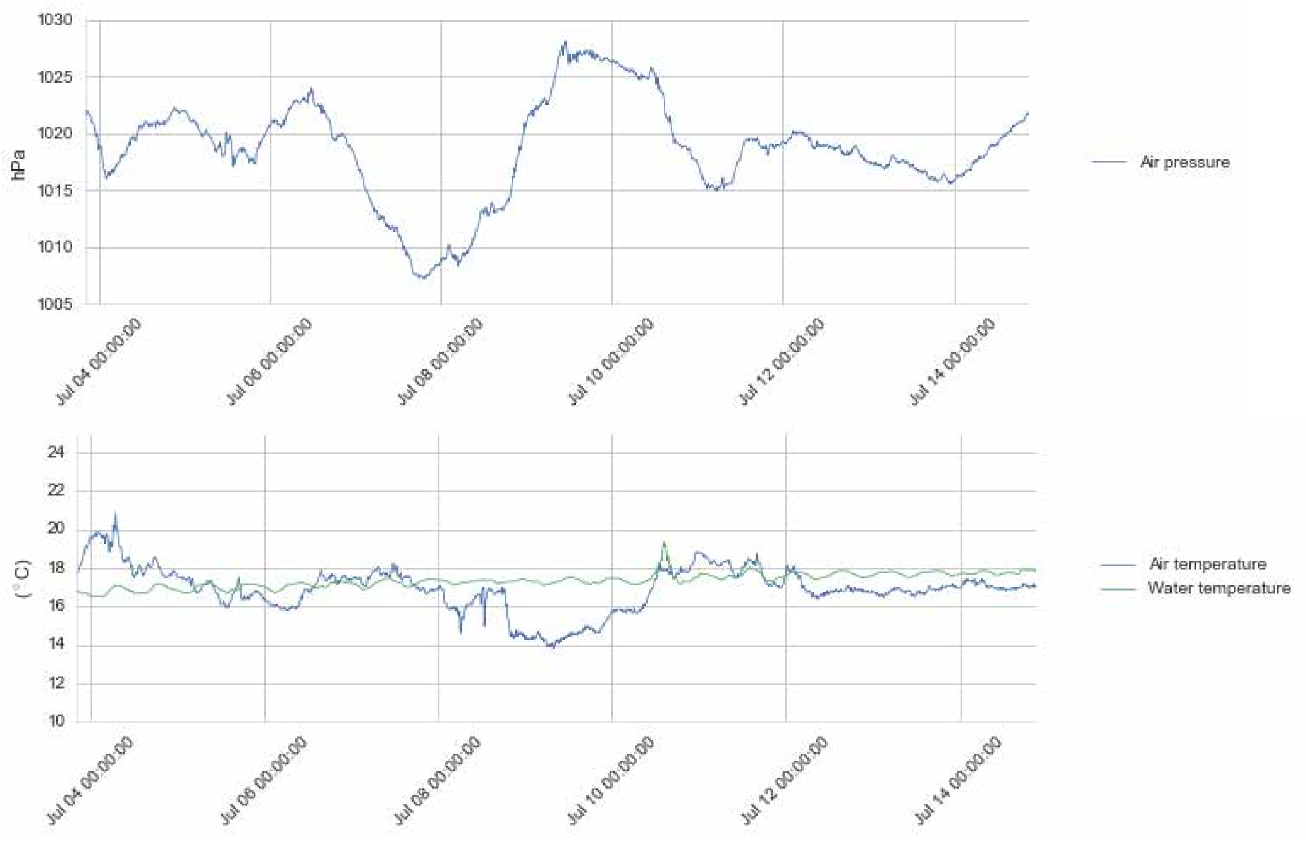

Figure 4.3 Time series plots of air pressure (upper panel), air and water temperature (lower panel), 3 – 14 July 2015.

4.2.2 Wave data

Figure 4.4 - Figure 4.6 present plots of 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 2.5 m from a southwesterly direction on 13th June at 12:00 UTC. The highest single wave was 4.37 m observed on 13th June at 09:30 UTC. 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.

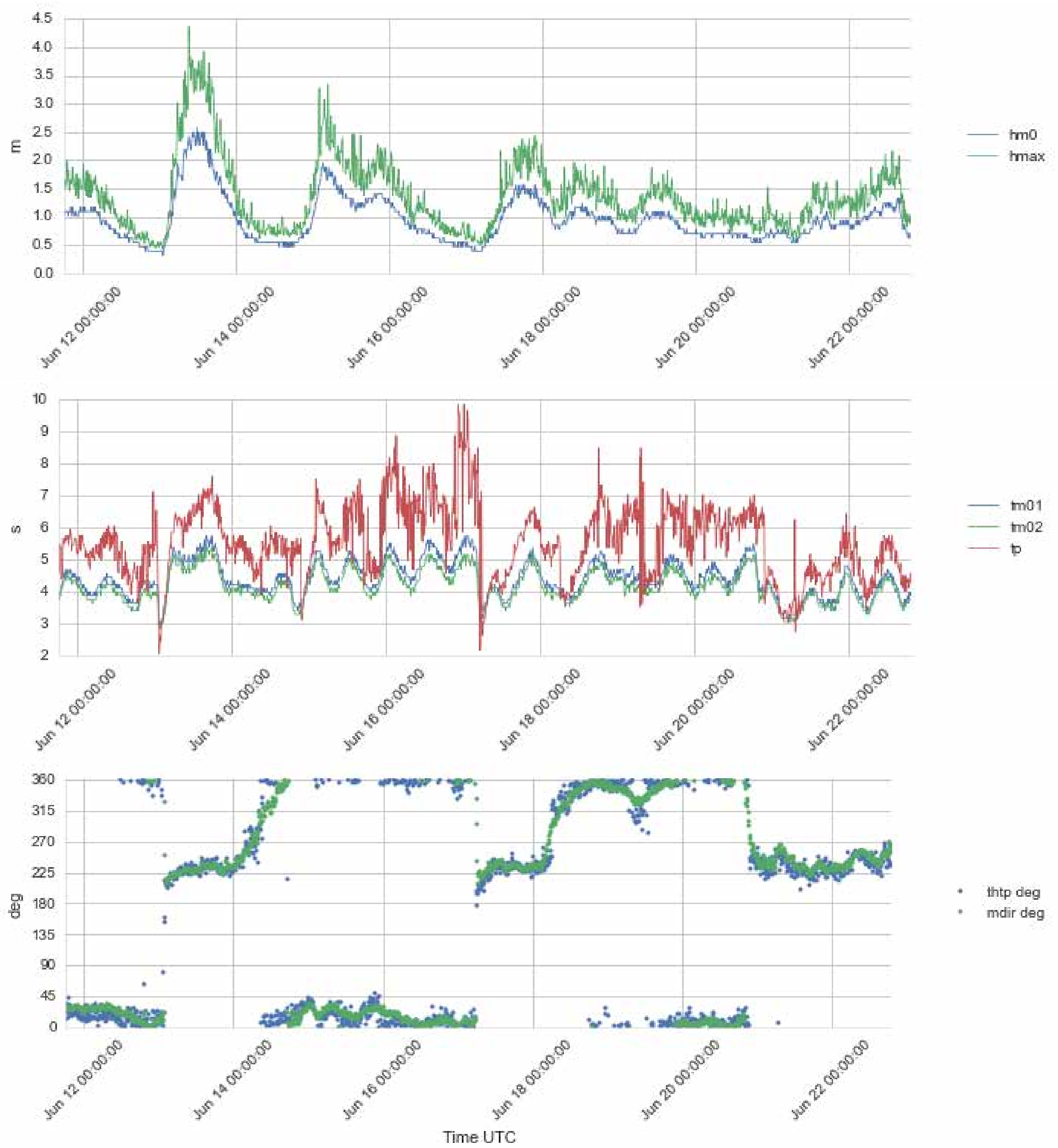

Figure 4.4 Time series plots of wave height (Hm0 and Hmax) (upper panel), wave period (Tm01, Tm02 and Tp) (second panel), and wave direction (ThTp and Mdir) (lower panel), 11 – 22 June 2015.

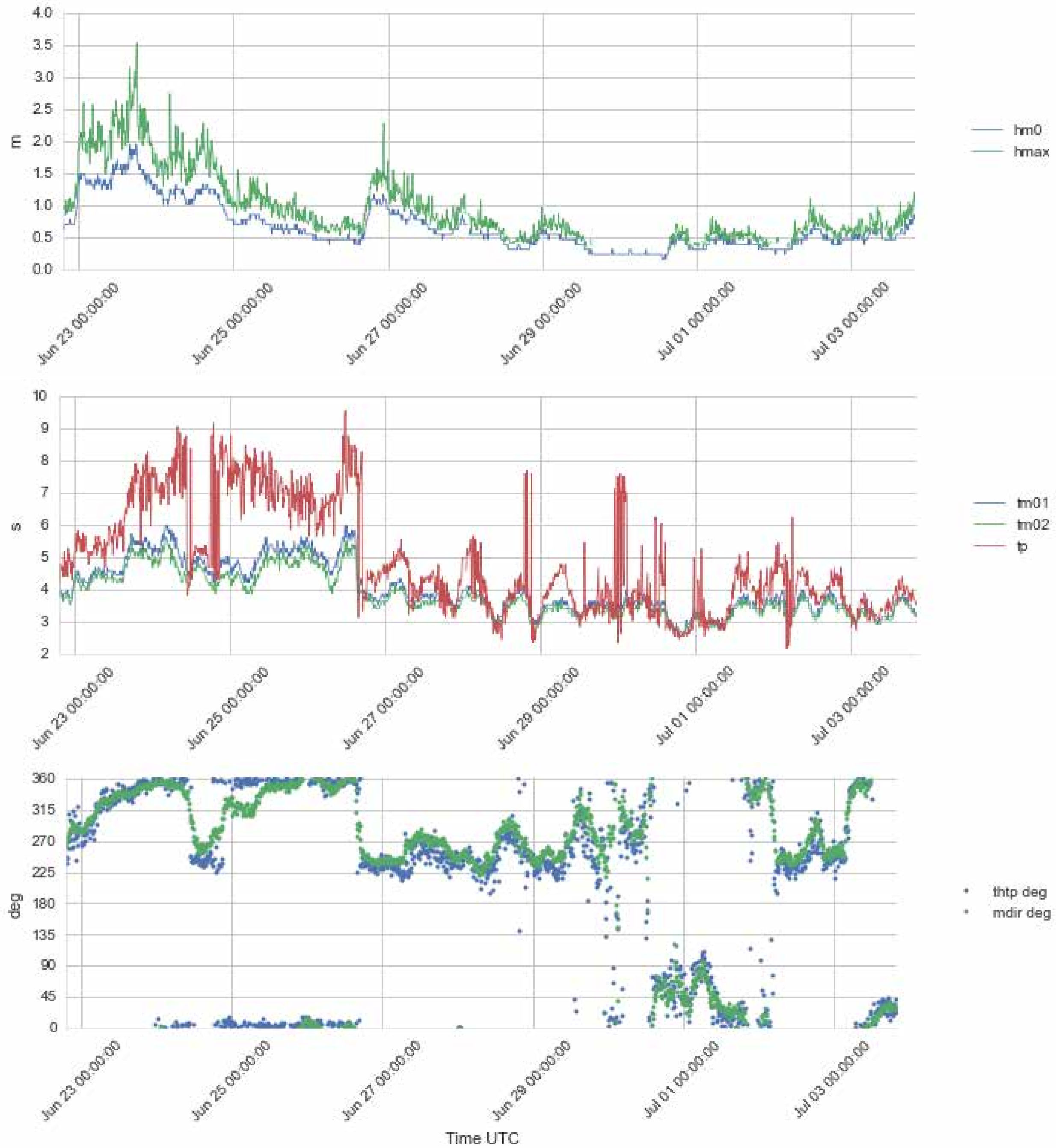

Figure 4.5 Time series plots of wave height (Hm0 and Hmax) (upper panel), wave period (Tm01, Tm02 and Tp) (second panel), and wave direction (ThTp and Mdir) (lower panel), 22 June – 3 July 2015.

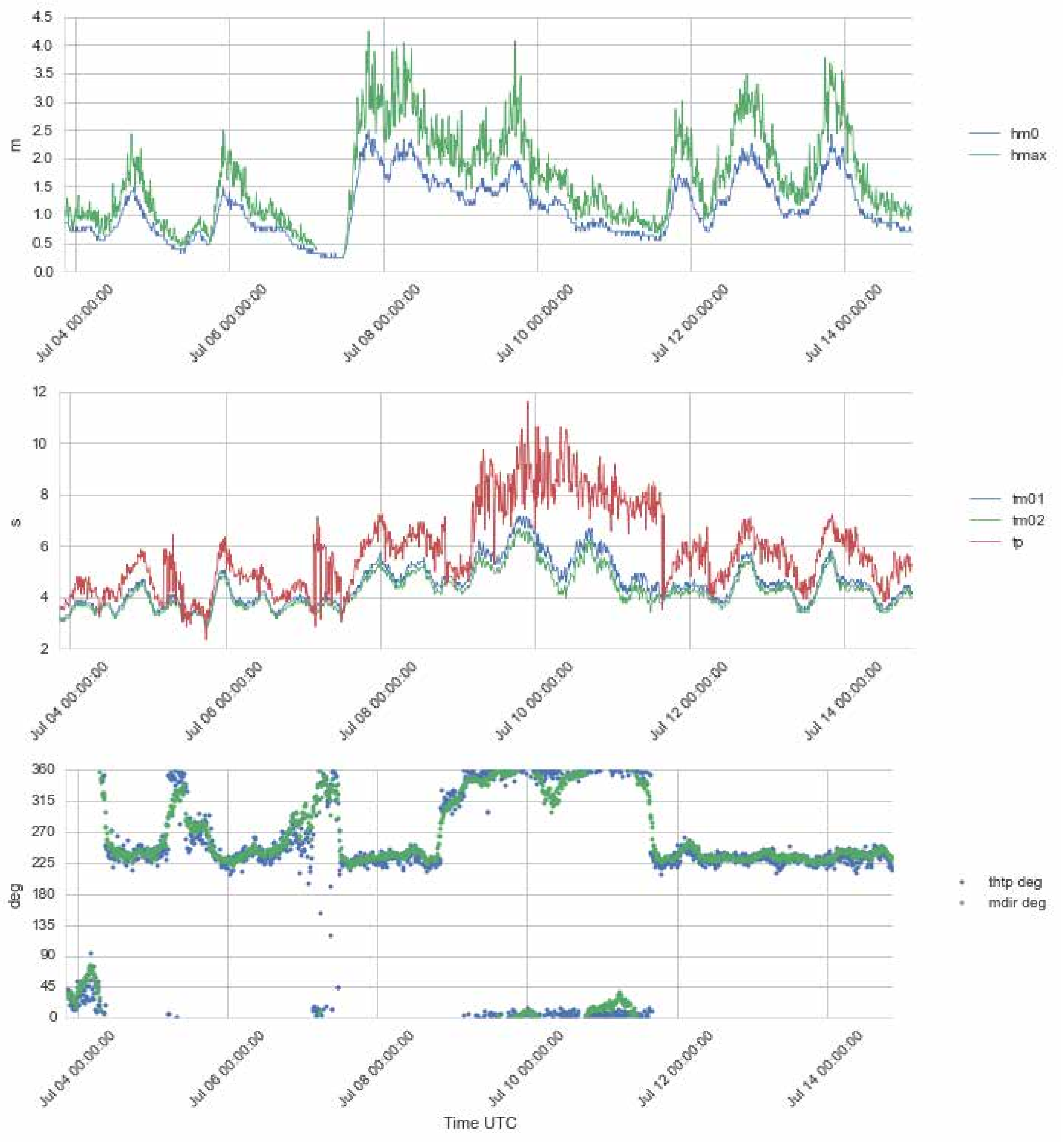

Figure 4.6 Time series plots of wave height (Hm0 and Hmax) (upper panel), wave period (Tm01, Tm02 and Tp) (second panel), and wave direction (ThTp and Mdir) (lower panel), 3 – 14 July 2015.

4.2.3 Wind profile data

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

The wind speed and direction data from the Gill wind sensor at 4 m height on the buoy are plotted in Figure 4.7 - Figure 4.9. The data from the Gill sensor are generally good without dropouts, except for those associated with restarting of the whole buoy system. Wind speeds up to 13.3 m/s and gusts up to 17.5 m/s have been observed at 4 m above the sea surface.

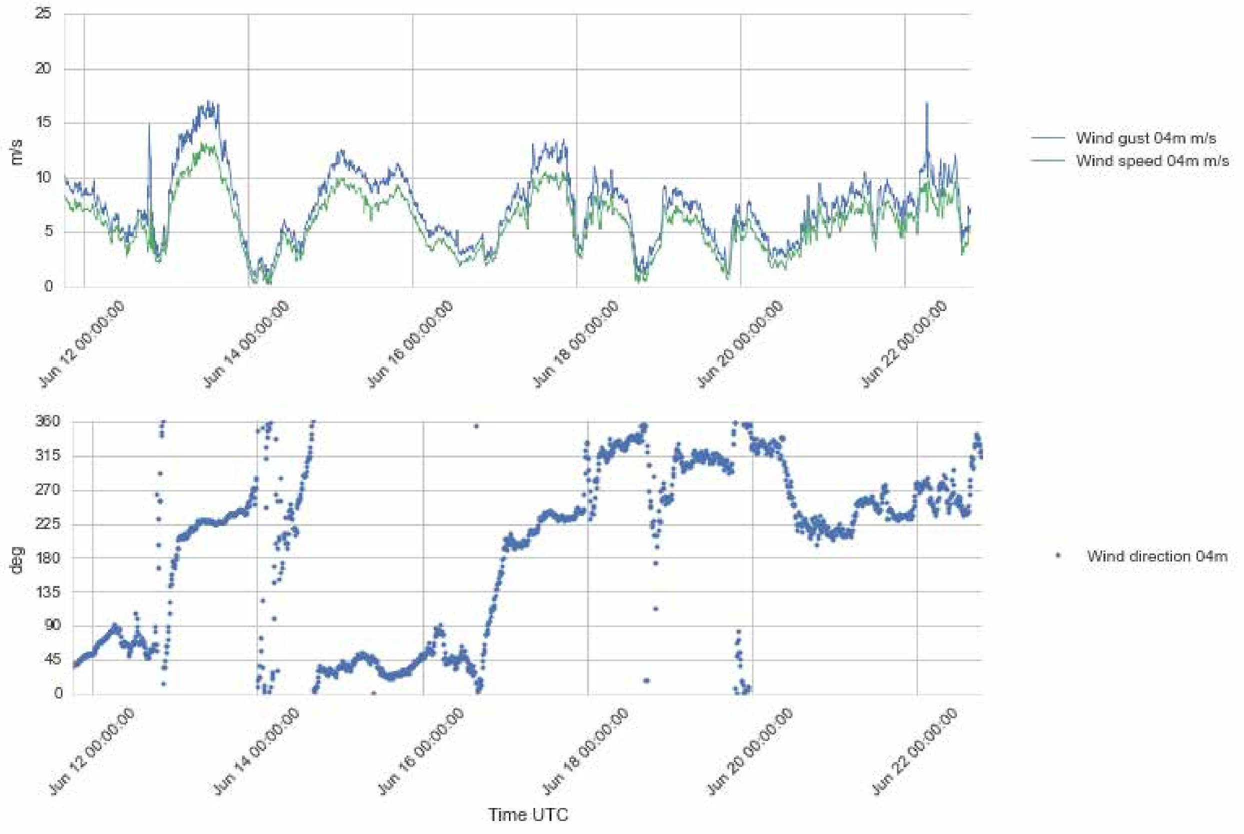

Figure 4.7 Plots of wind speed and gust (upper), and wind direction (lower) at 4 m a.s.l., 11 - 22 June 2015.

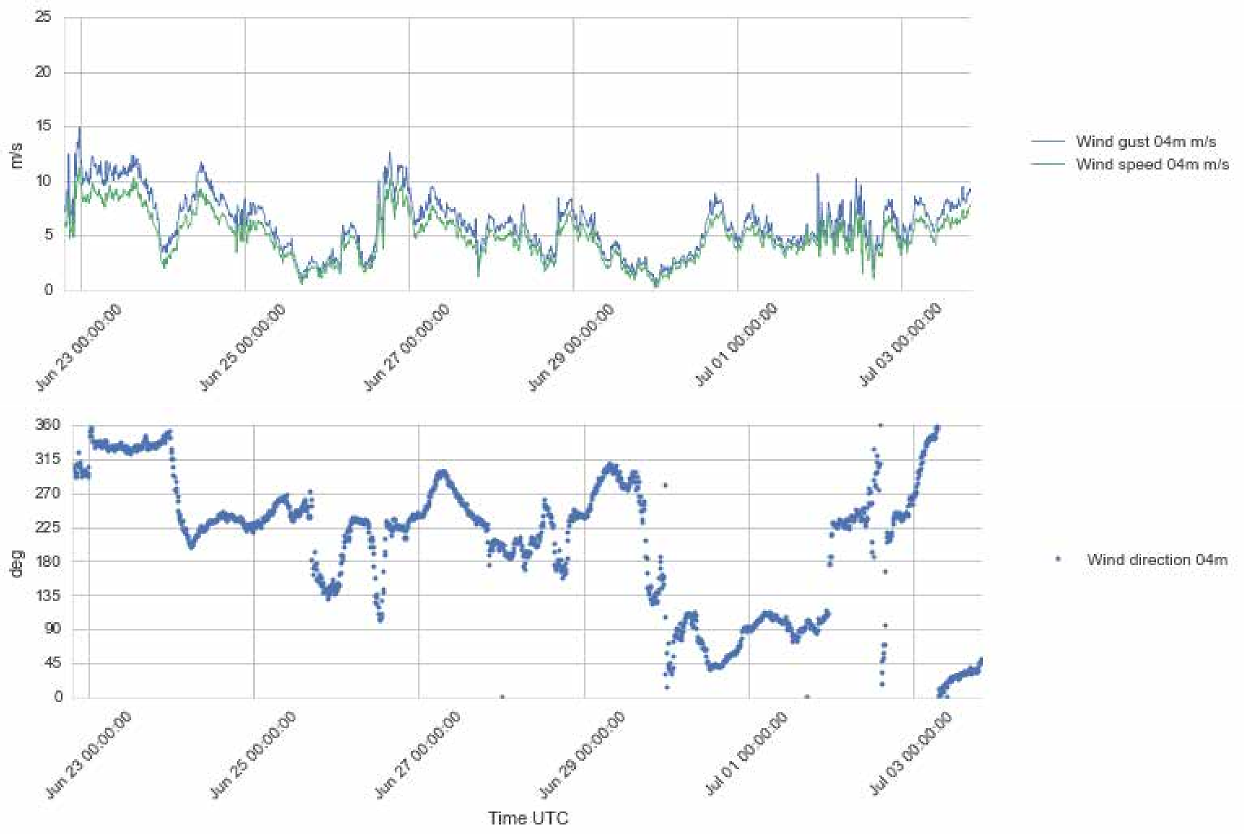

Figure 4.8 Plots of wind speed and gust (upper), and wind direction (lower) at 4 m a.s.l., 22 June – 3 July 2015.

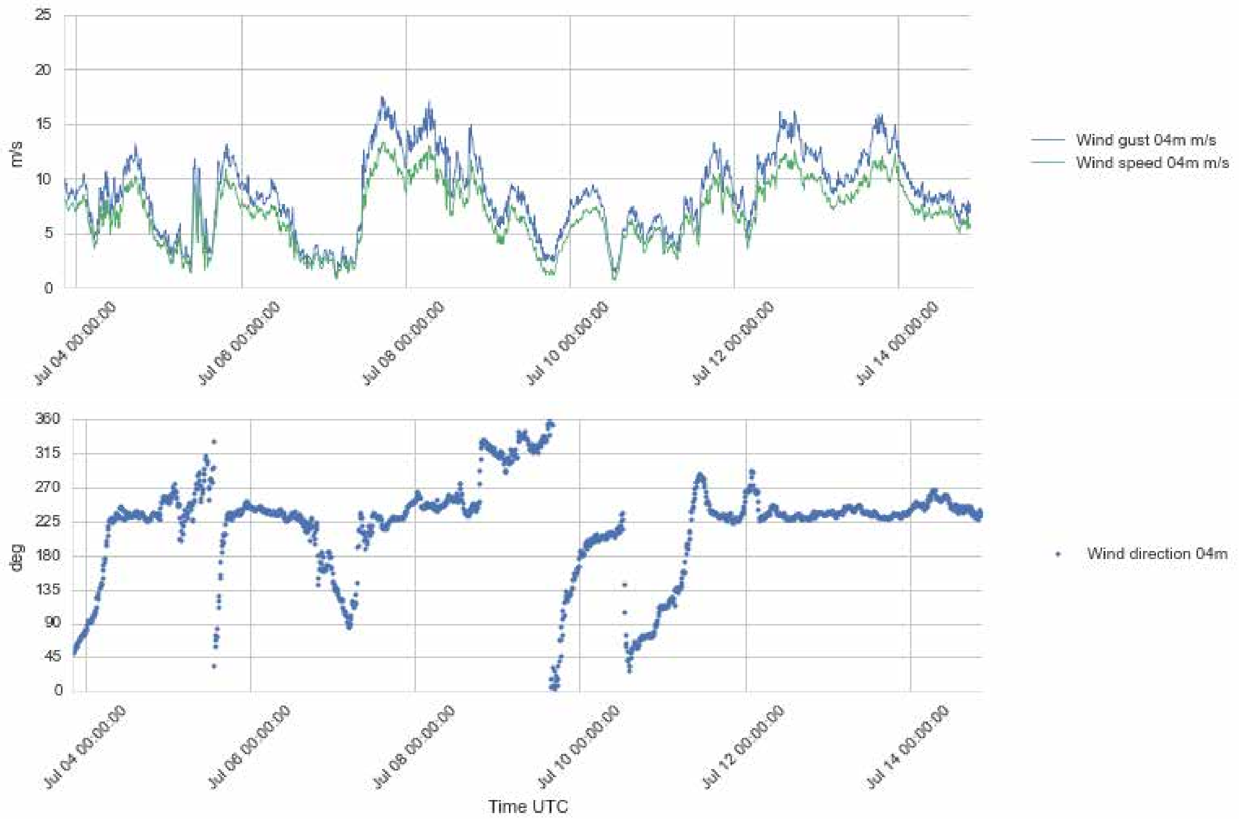

Figure 4.9 Plots of wind speed and gust (upper), and wind direction (lower) at 4 m a.s.l., 3 - 14 July 2015.

The wind profiling data from the LiDAR are presented in Figure 4.10 - Figure 4.18 showing time series plots of 10 min. mean wind for each individual level. Plots of the derived parameters Inflow Angle and Turbulence Intensity are also presented.

The vertical wind component is defined positive upwards. The Inflow Angle (IA) is the angle of the 3-dimensional wind vector relative to the horizontal, and can be positive or negative. IA is computed from 10 minute mean vertical and horizontal wind components, and is positive when the vertical wind component is positive.

The Turbulence Intensity is defined as $TI = \sigma/\bar{u}$ where σ is the standard deviation and $\bar{u}$ is the mean of the wind speed for a 10-min period. TI is a dimensionless number. Note that this definition frequently gives relatively high values in situations with low mean wind speed, which is noticeable in the plots. This is computed by the buoy's Geni processor based on raw data extracted from the LiDAR.

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.

The highest observed mean speed of the horizontal wind during this month varies from 17.3 m/s at 30m to 22.6 m/s at 200 m above the surface.

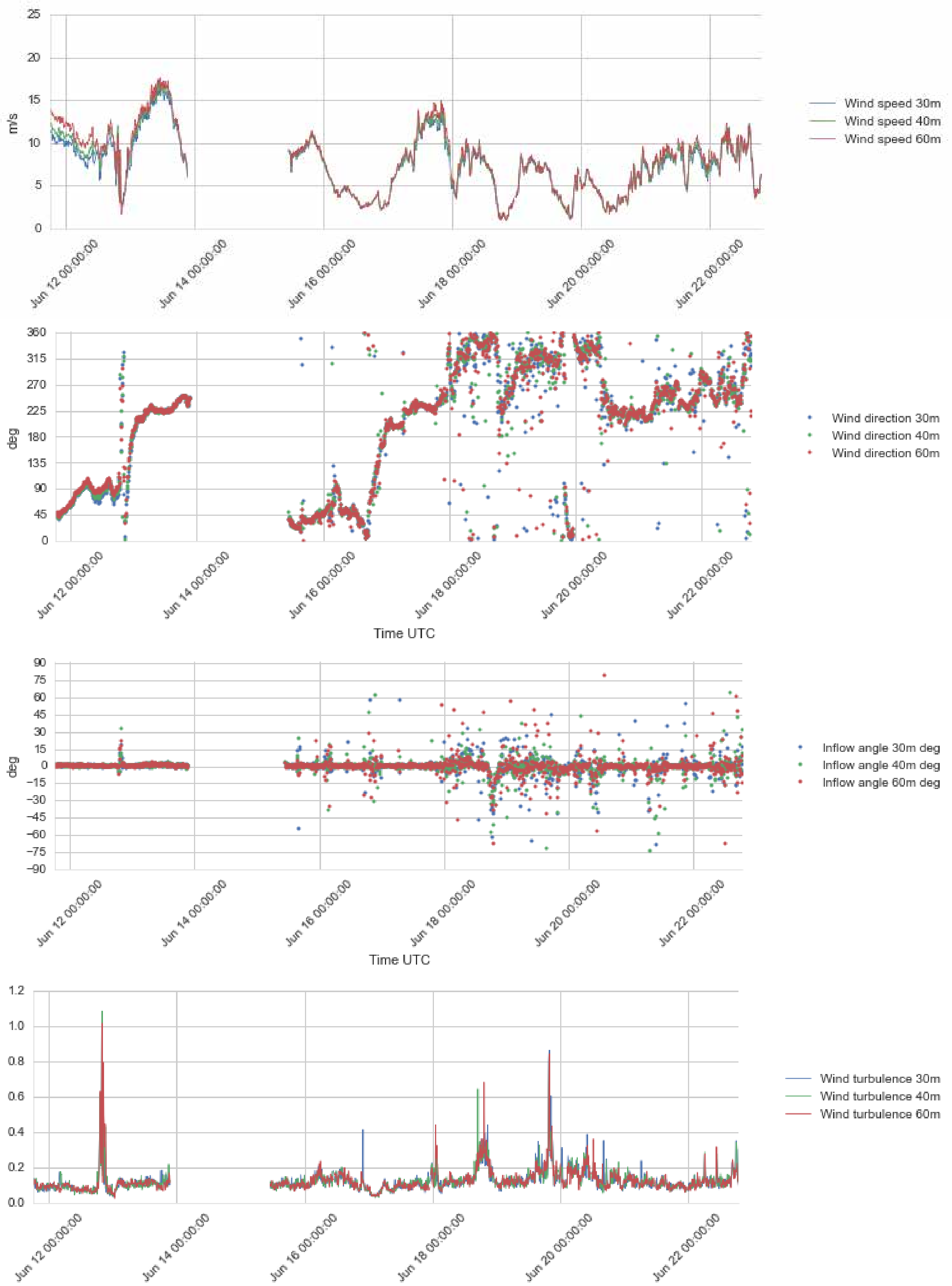

Figure 4.10 Plots of wind profile data, 30 – 60 m a.s.l., 11 - 22 June 2015.

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

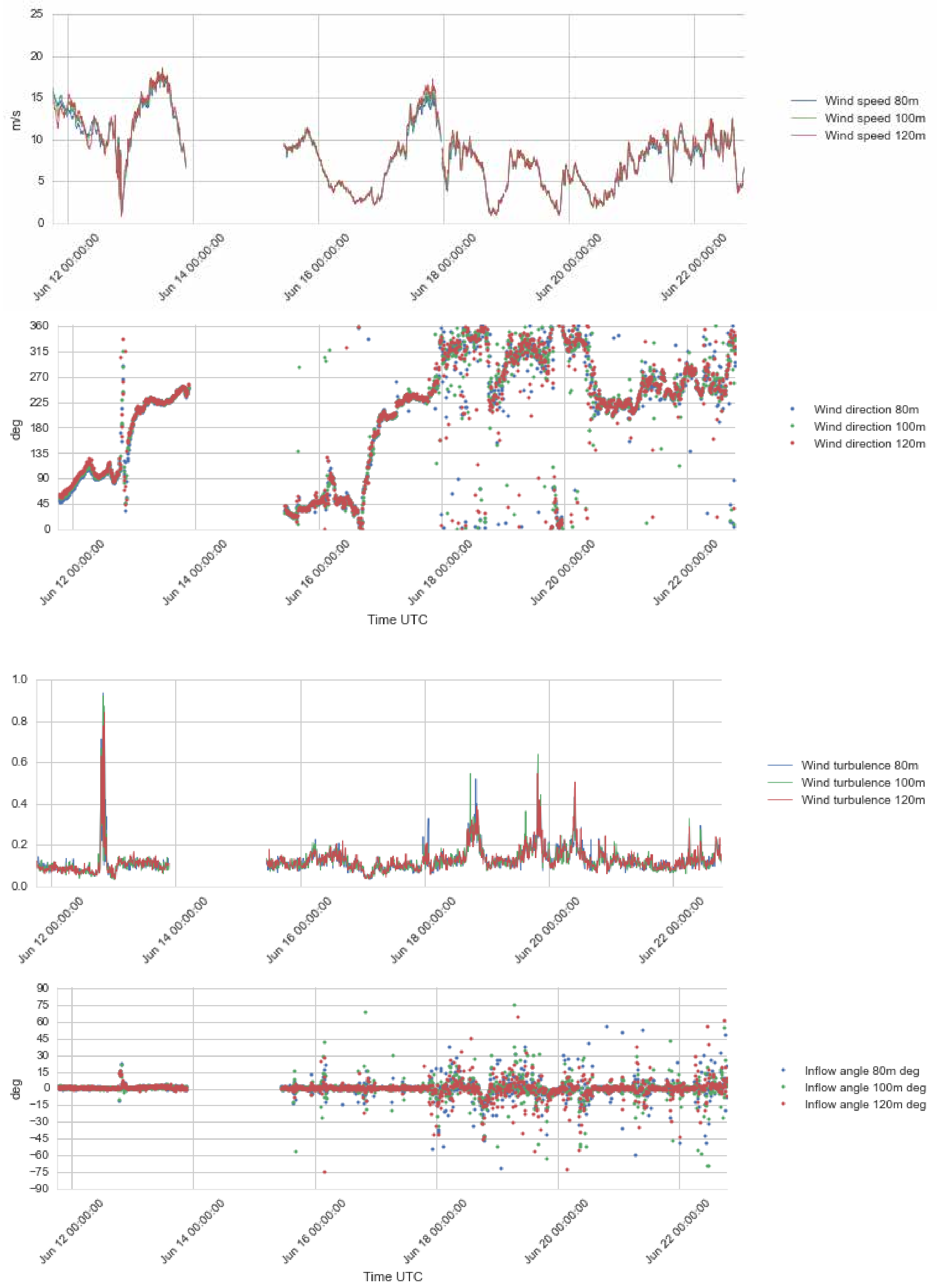

Figure 4.11 Plots of wind profile data, 80 – 120 m a.s.l., 11 - 22 June 2015.

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

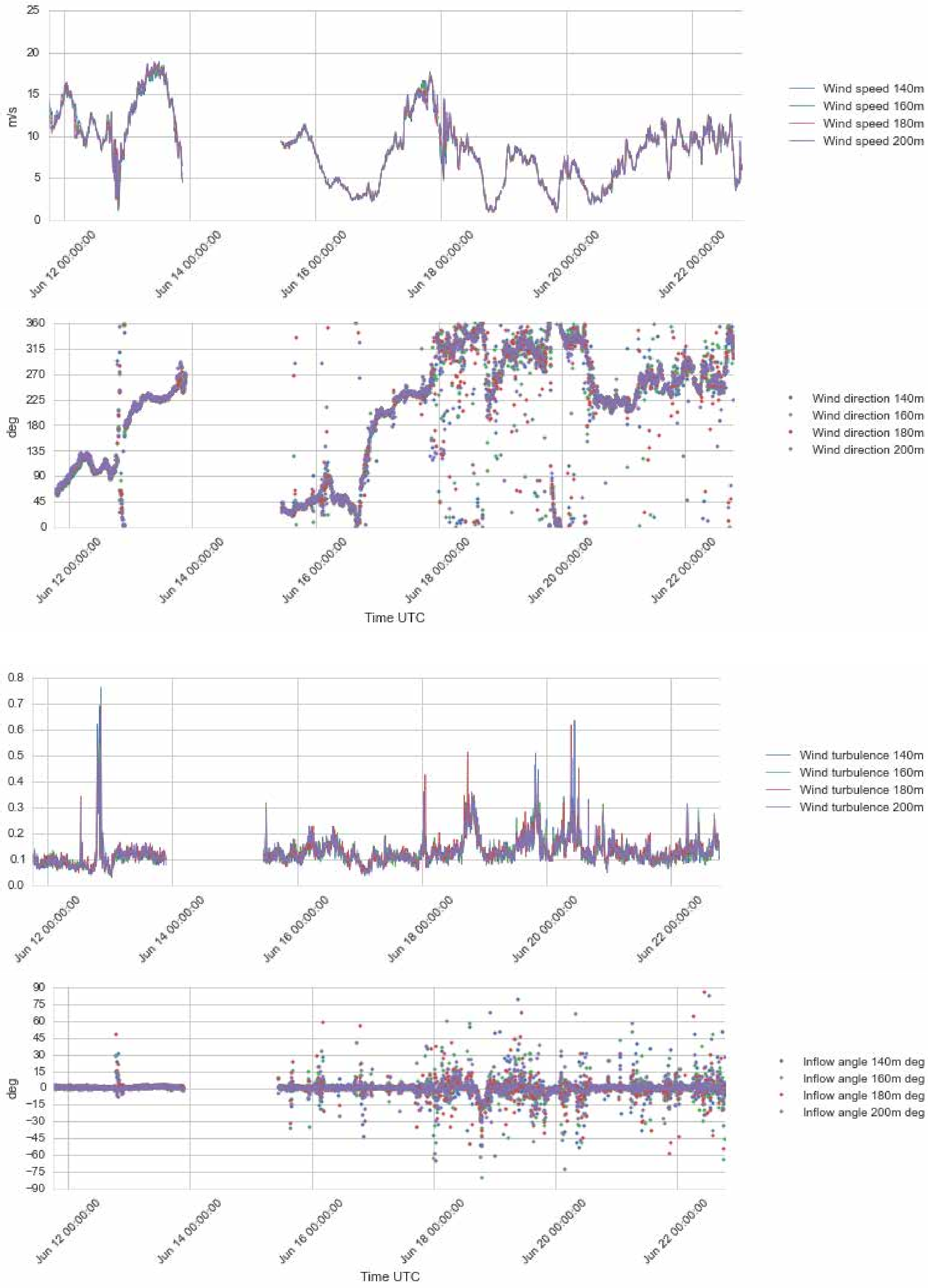

Figure 4.12 Plots of wind profile data, 140 – 200 m a.s.l., 11 - 22 June 2015.

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

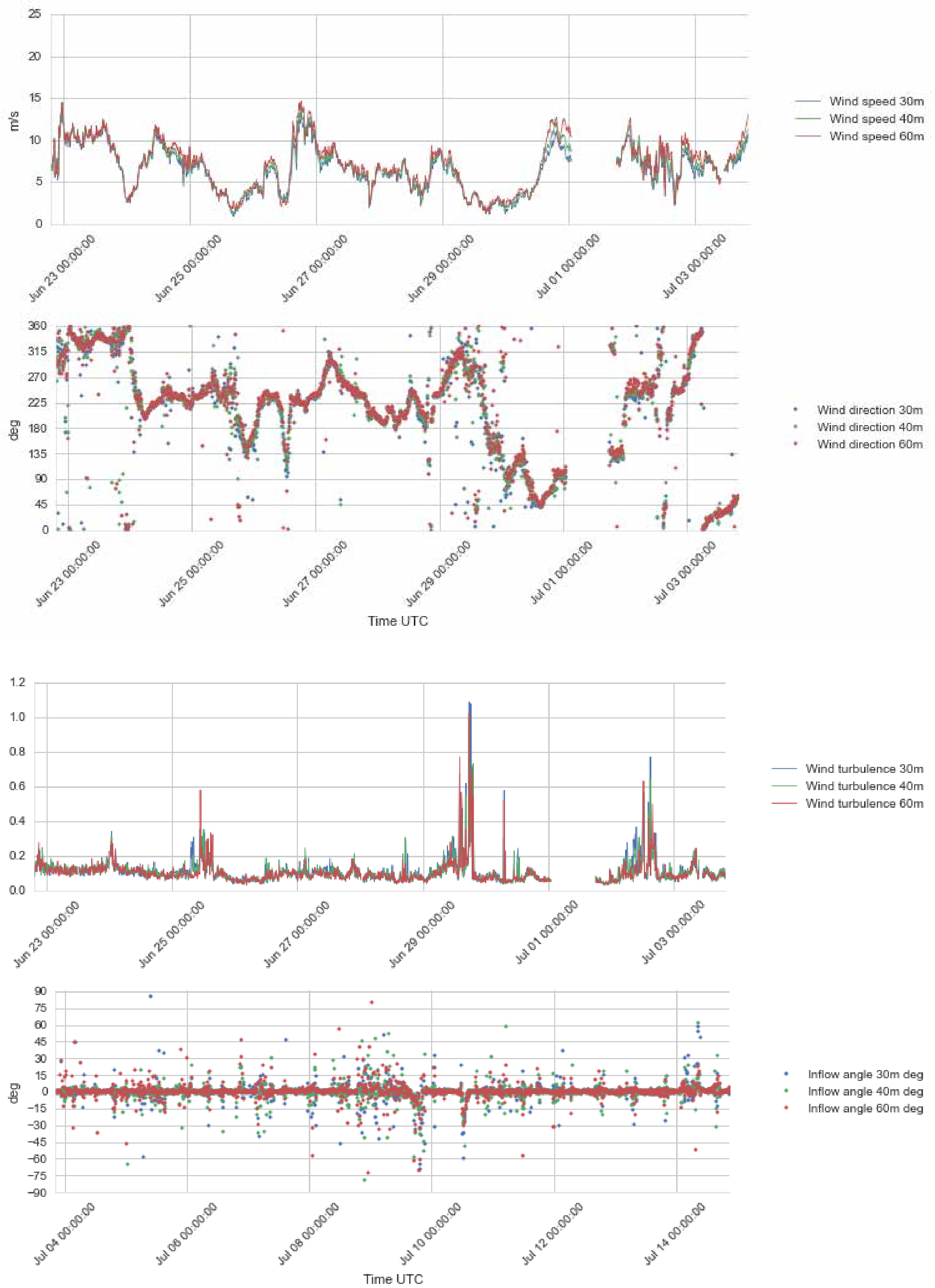

Figure 4.13 Plots of wind profile data, 30 – 60 m a.s.l., 22 June – 3 July 2015.

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

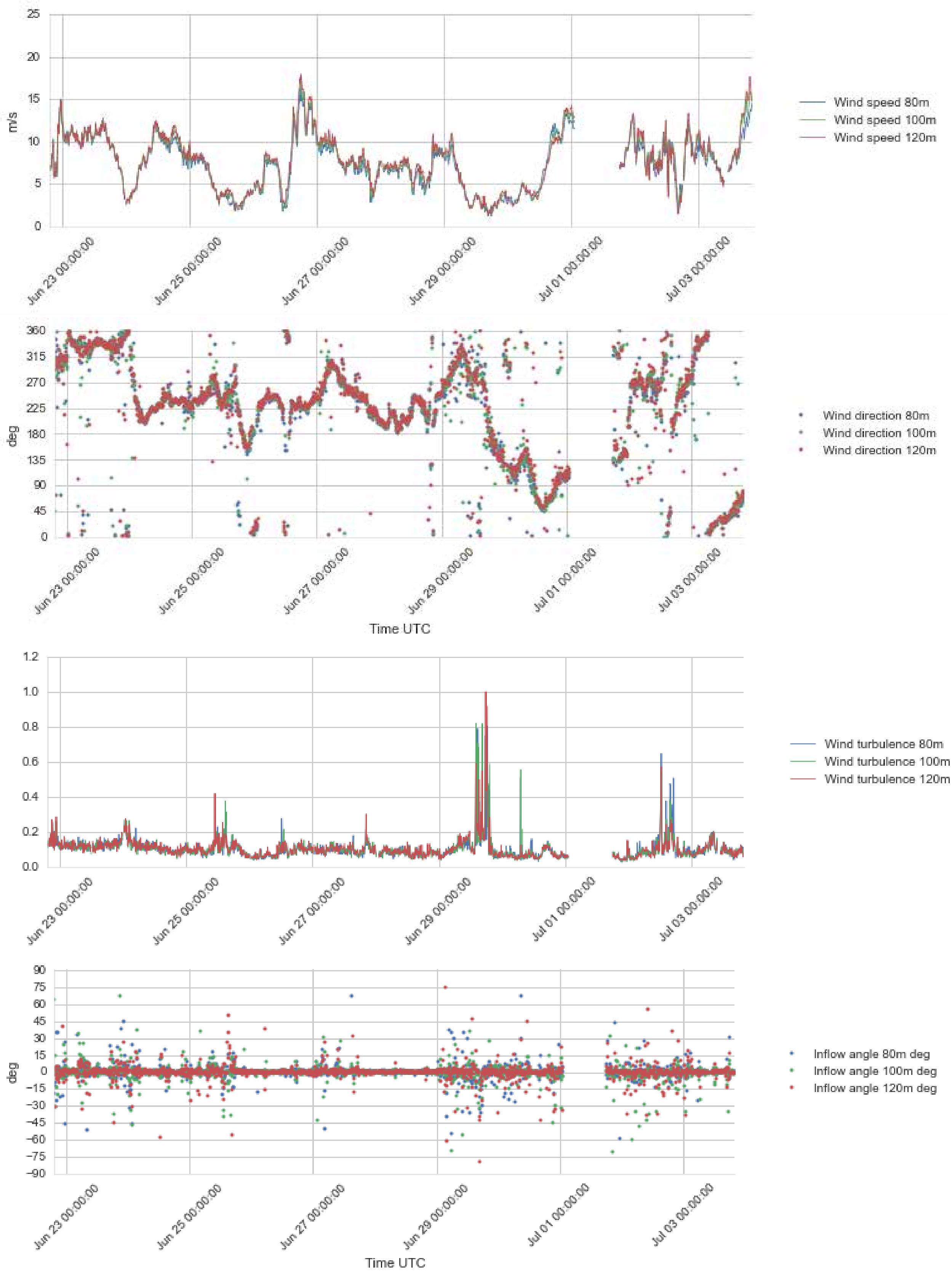

Figure 4.14 Plots of wind profile data, 80 – 120 m a.s.l., 22 June – 3 July 2015.

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

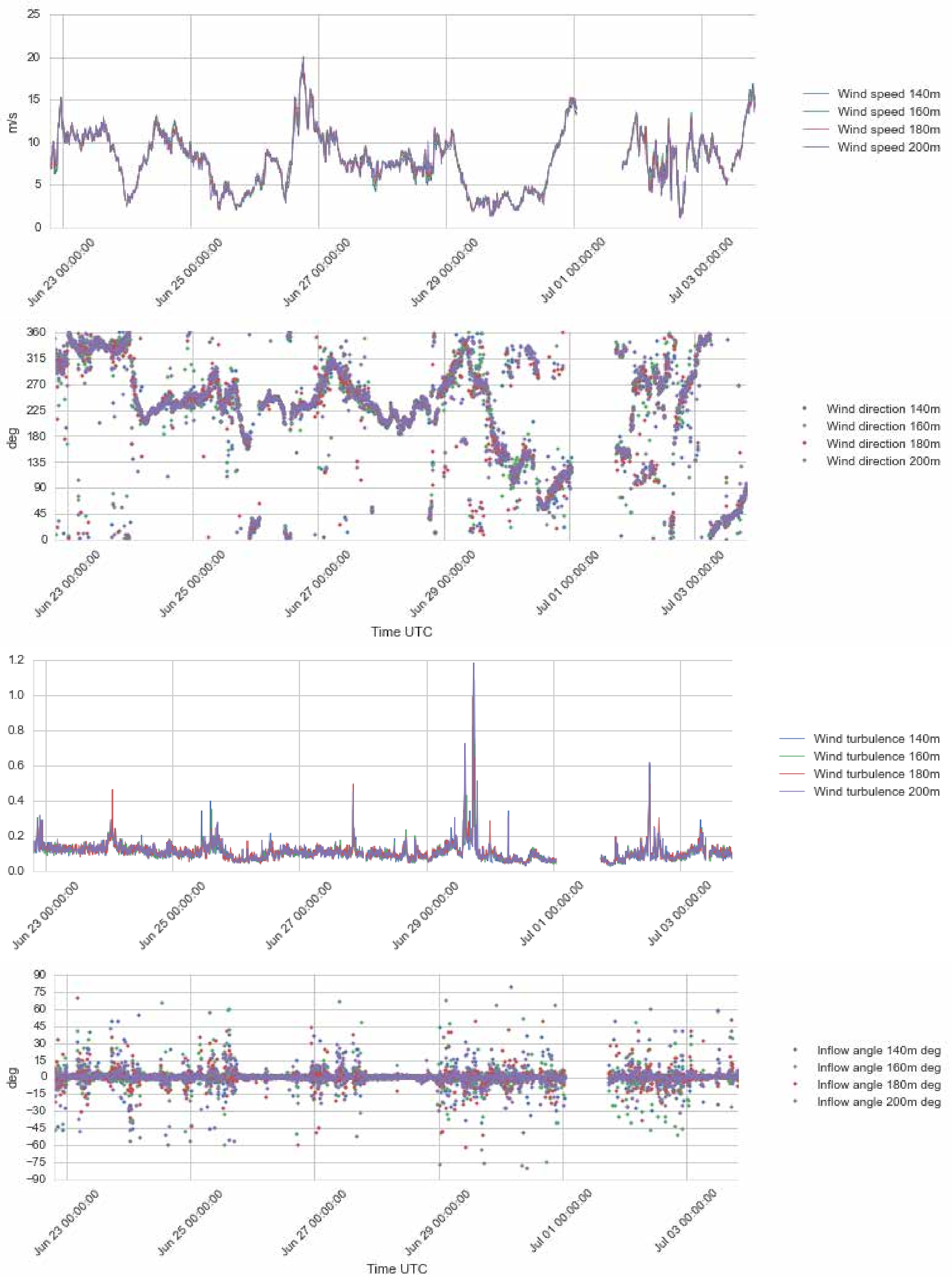

Figure 4.15 Plots of wind profile data, 140 – 200 m a.s.l., 22 June – 3 July 2015.

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

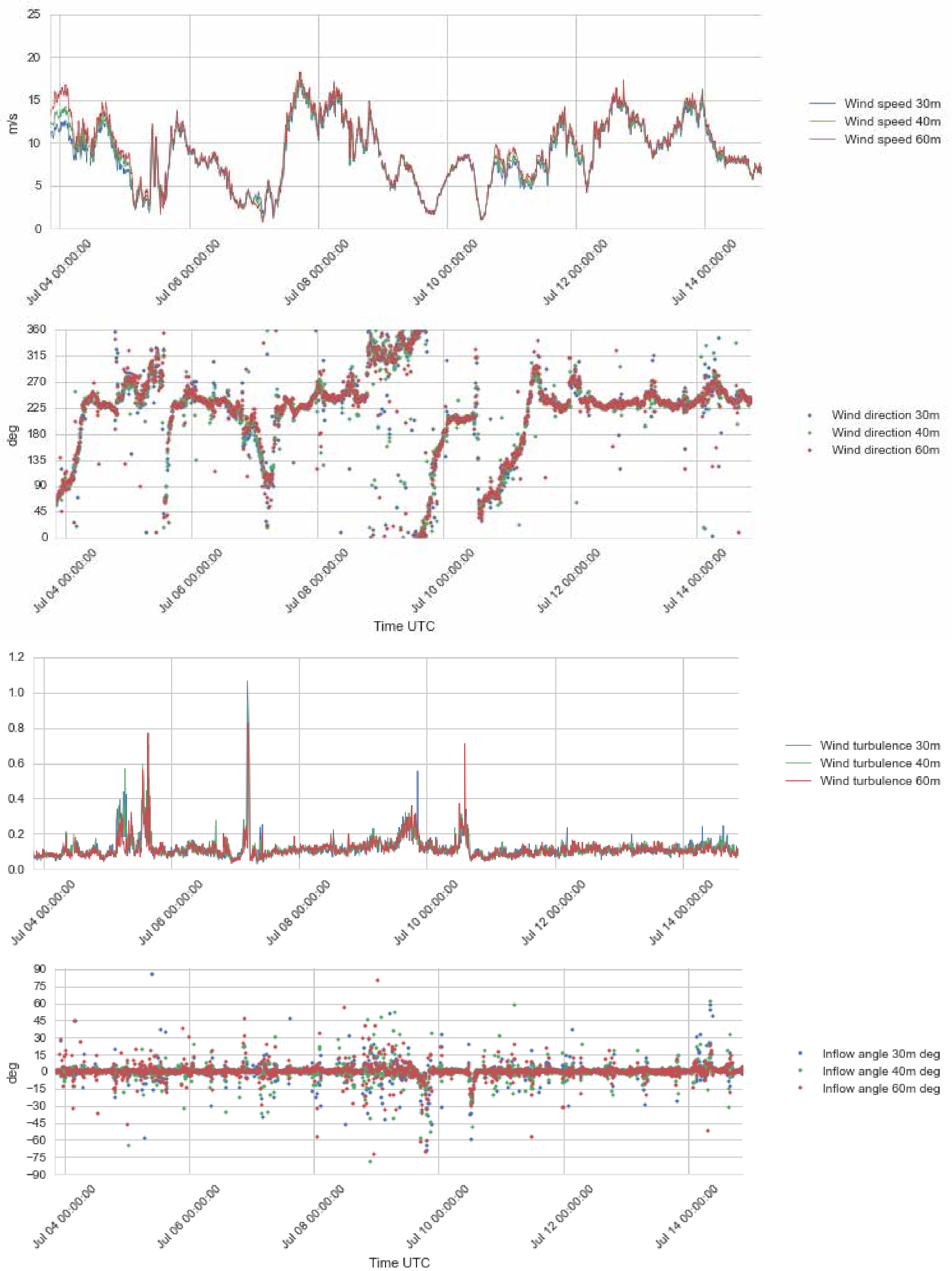

Figure 4.16 Plots of wind profile data, 30 – 60 m a.s.l., 3 – 14 July 2015.

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

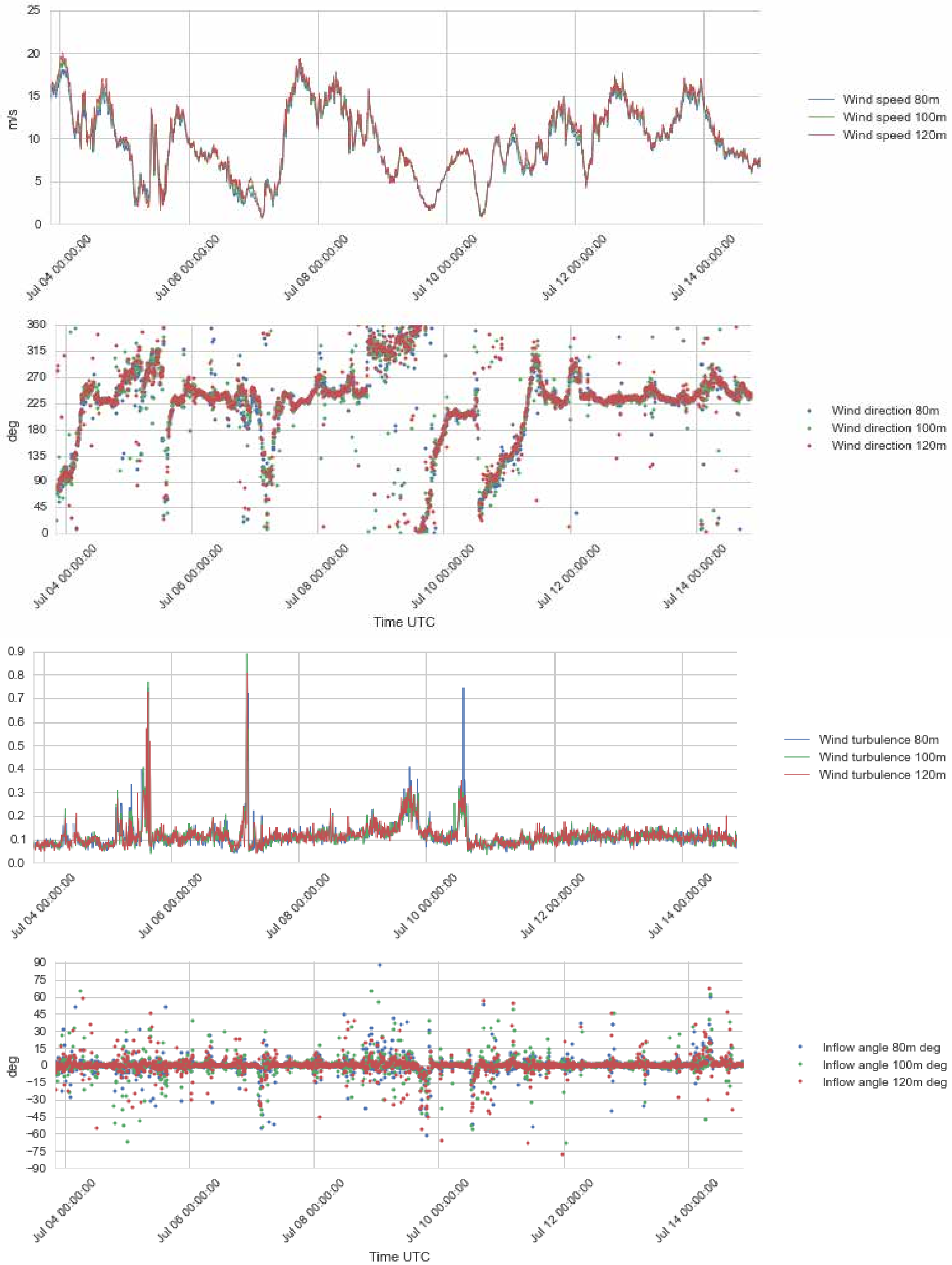

Figure 4.17 Plots of wind profile data, 80 – 120 m a.s.l., 3 – 14 July 2015.

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

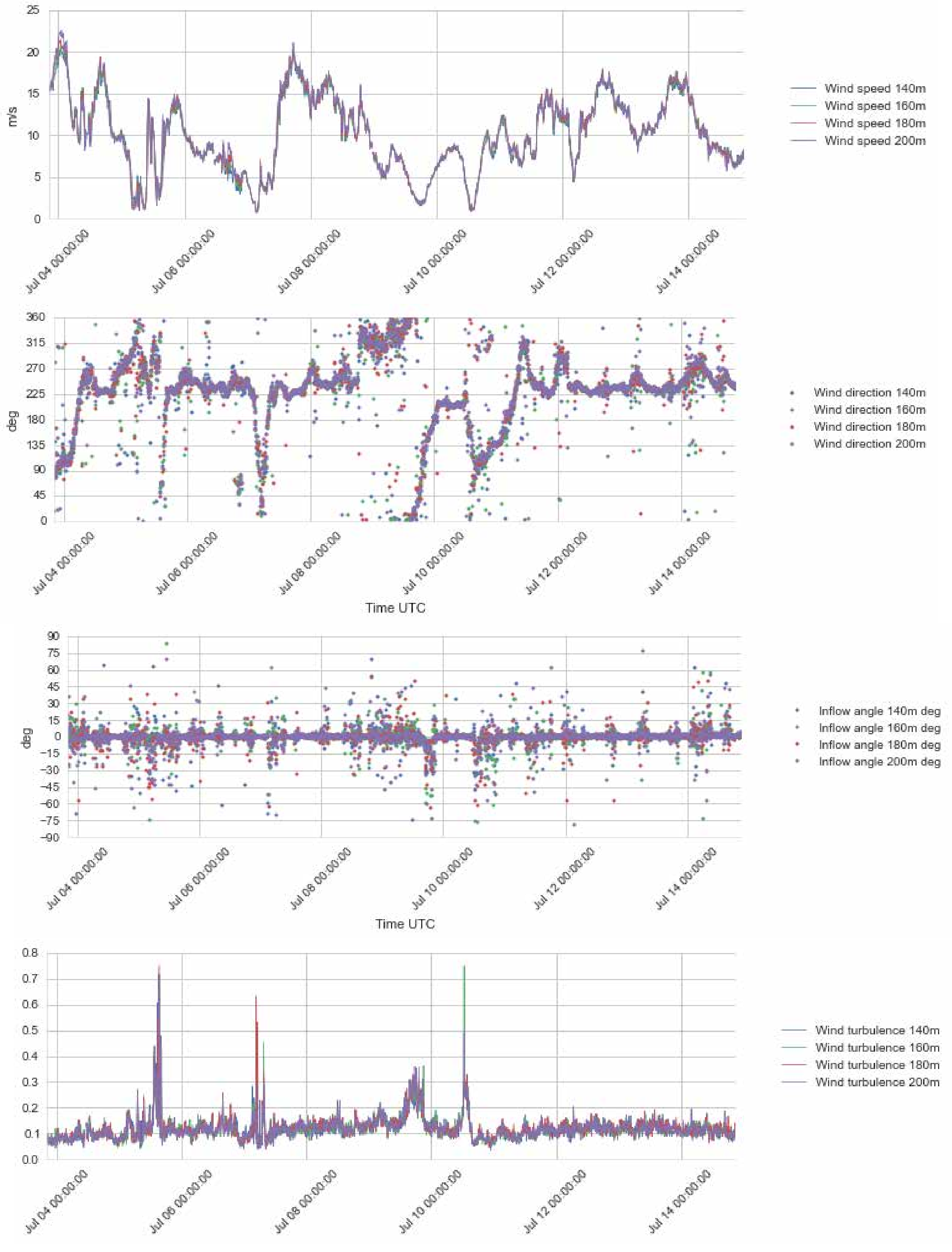

Figure 4.18 Plots of wind profile data, 140 – 200 m a.s.l., 3 – 14 July 2015.

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

4.2.4 Current velocity profile data

Figure 4.19 - Figure 4.30 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.

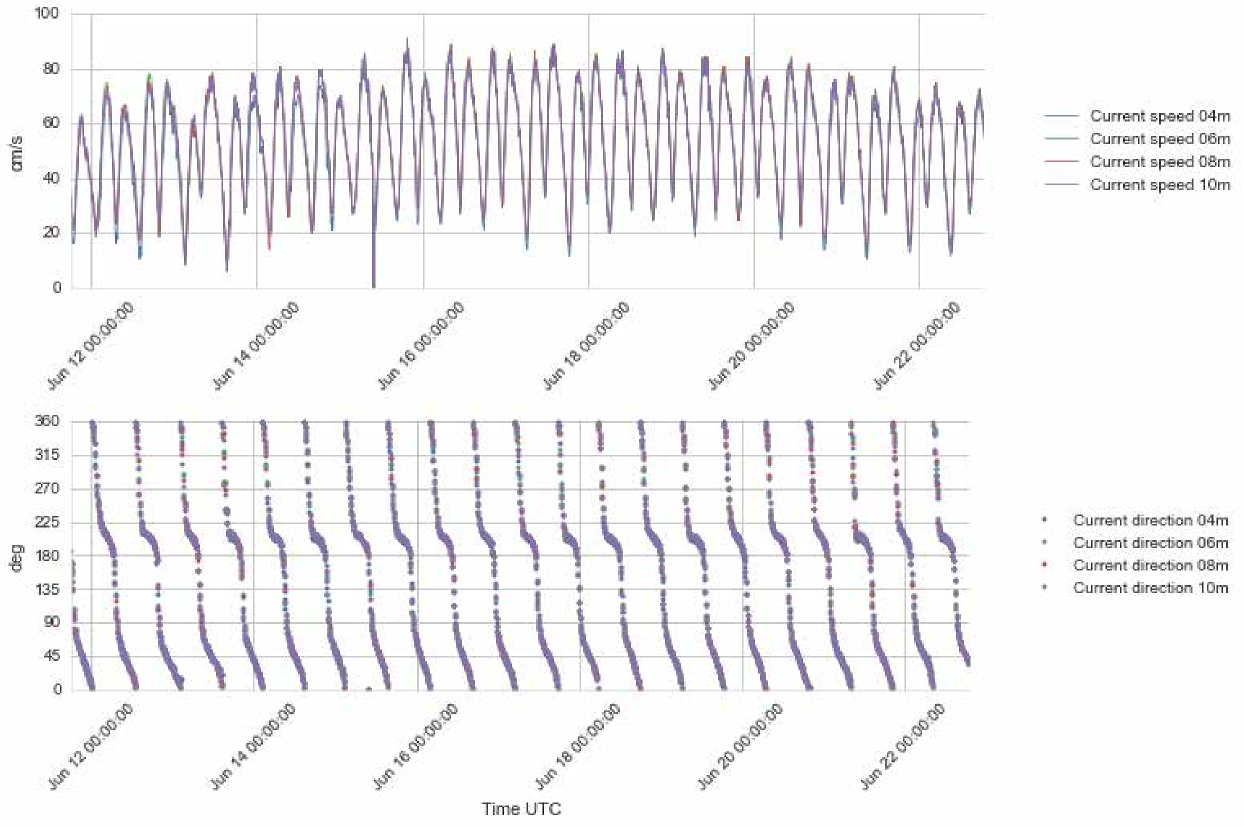

Figure 4.19 Time series plots of current speed (upper) and direction (lower panel), 4 - 10 m depth, 11 - 22 June 2015

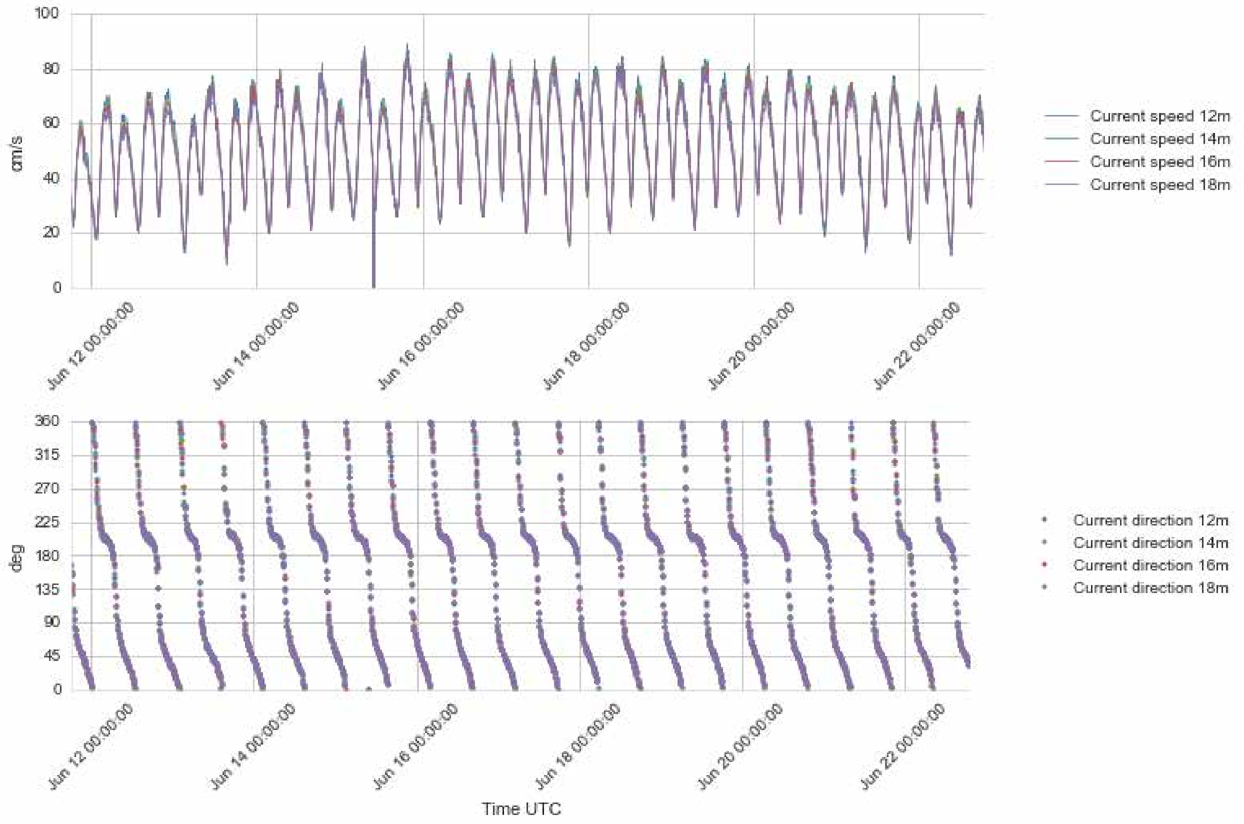

Figure 4.20 Time series plots of current speed (upper) and direction (lower panel), 12 - 18 m depth, 11 - 22 June 2015

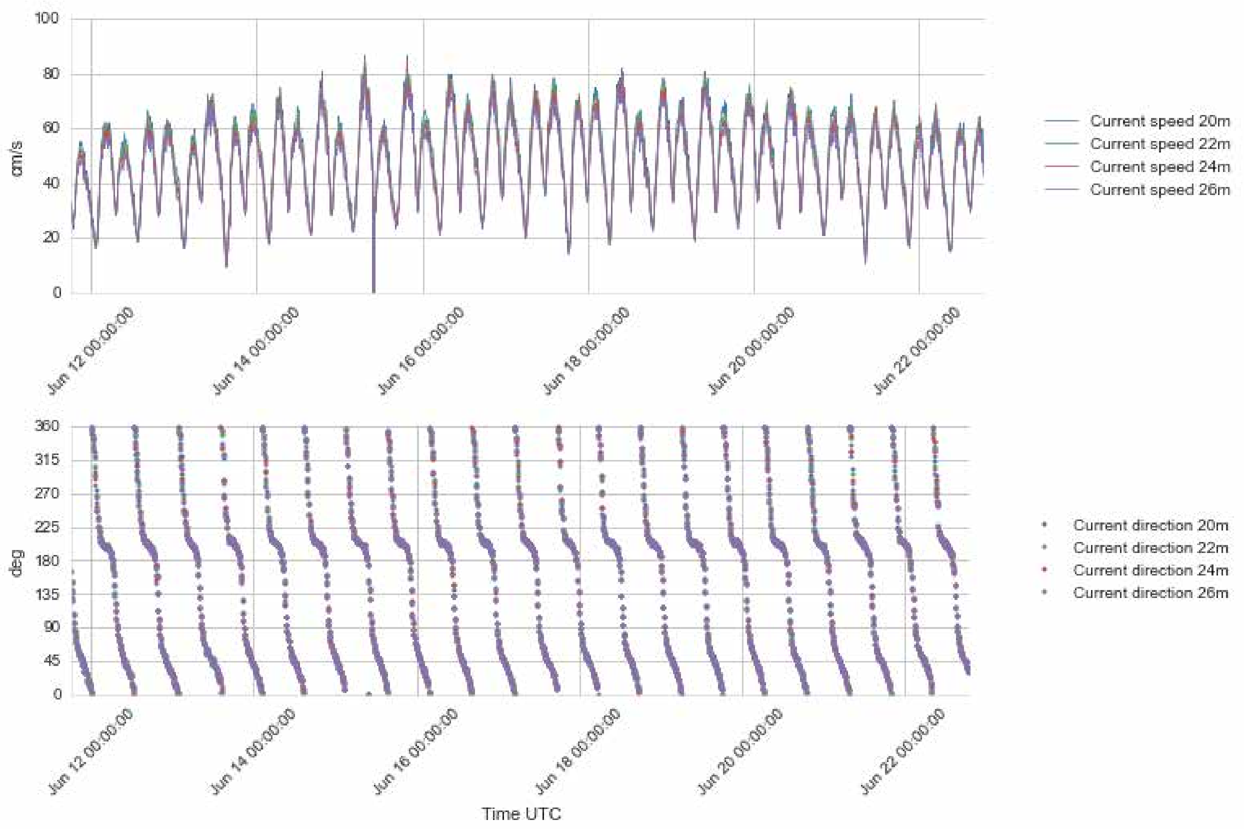

Figure 4.21 Time series plots of current speed (upper) and direction (lower panel), 20 - 26 m depth, 11 - 22 June 2015

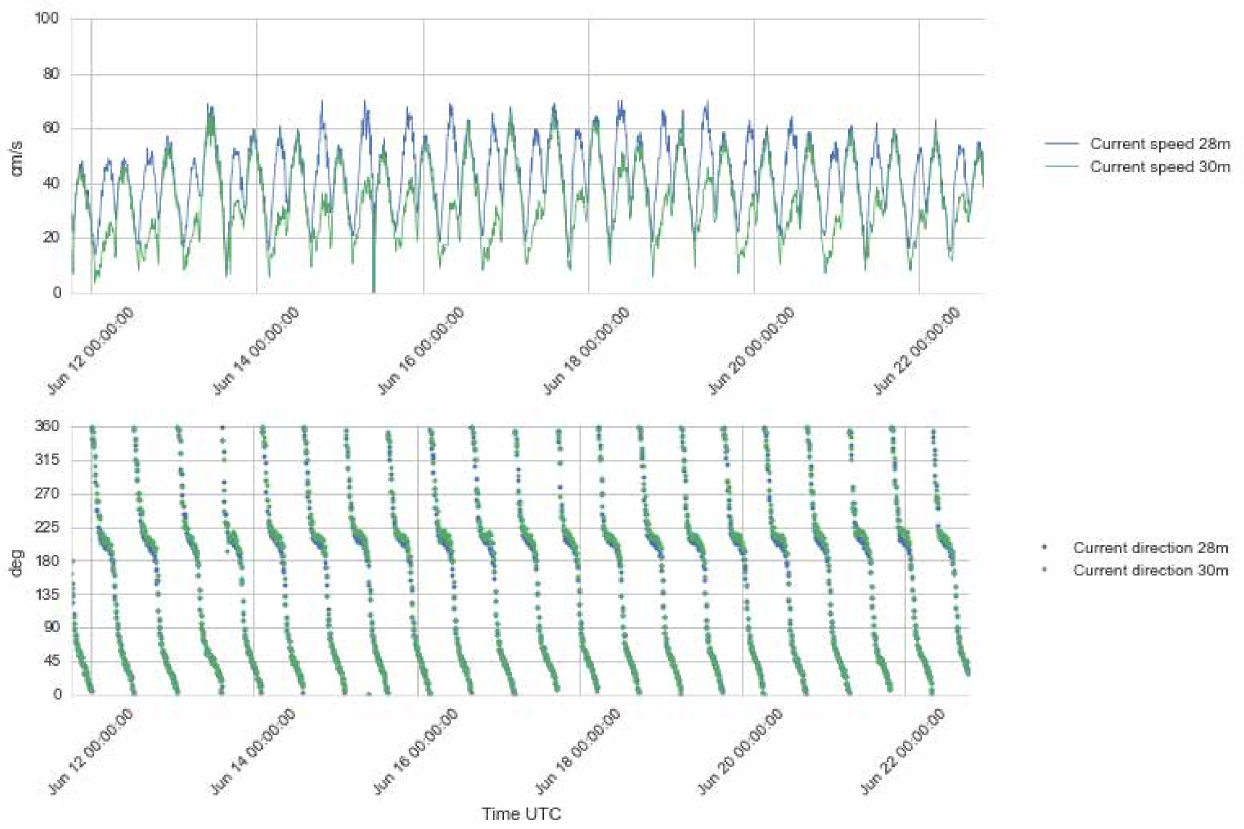

Figure 4.22 Time series plots of current speed (upper) and direction (lower panel), 28 - 30 m depth, 11 - 22 June 2015

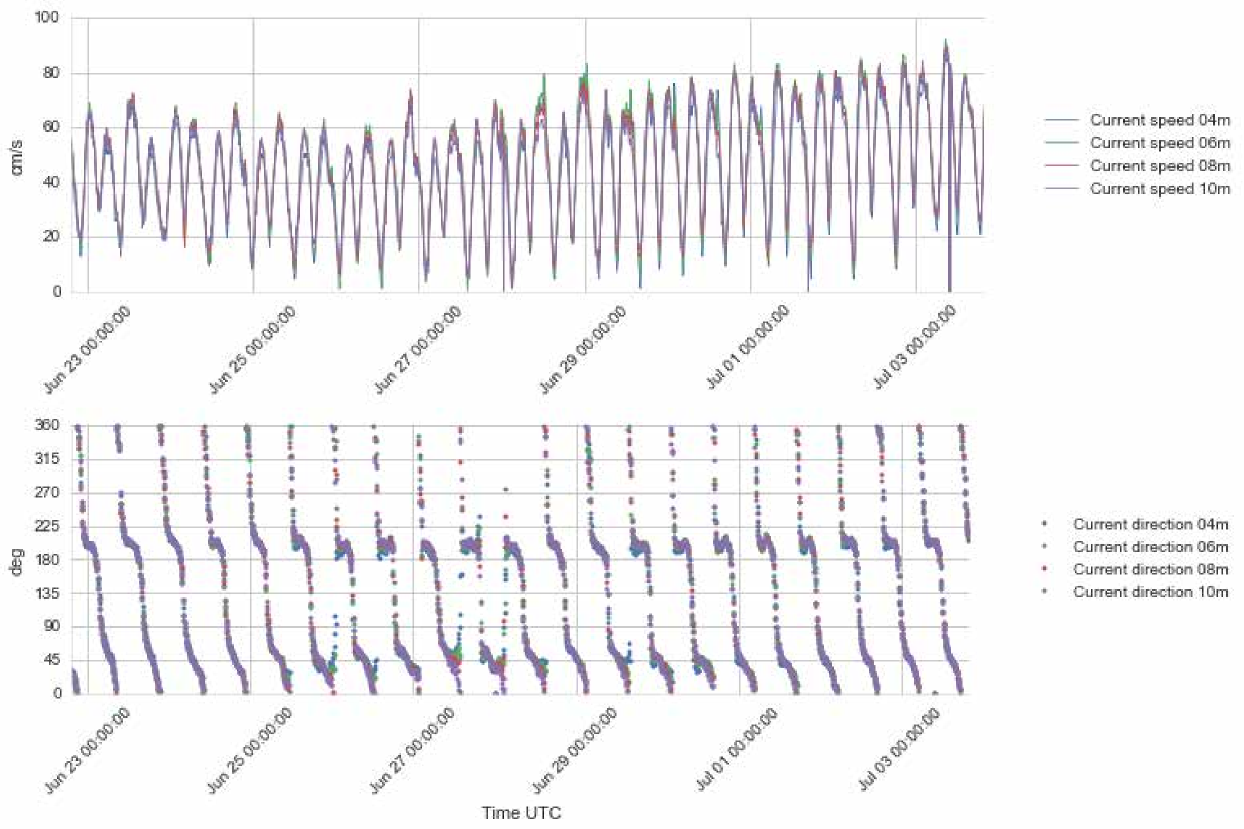

Figure 4.23 Time series plots of current speed (upper) and direction (lower panel), 4 - 10 m depth, 22 June – 3 July 2015

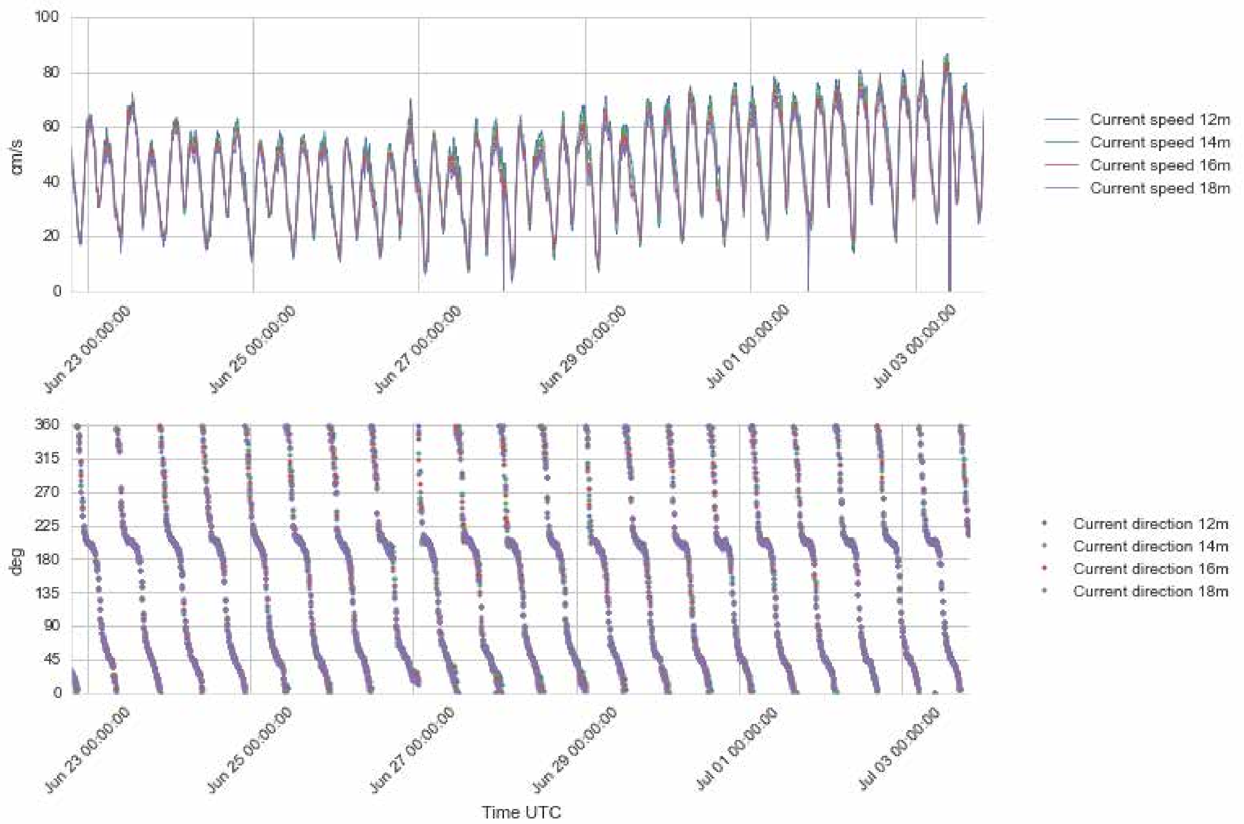

Figure 4.24 Time series plots of current speed (upper) and direction (lower panel), 12 - 18 m depth, 22 June – 3 July 2015

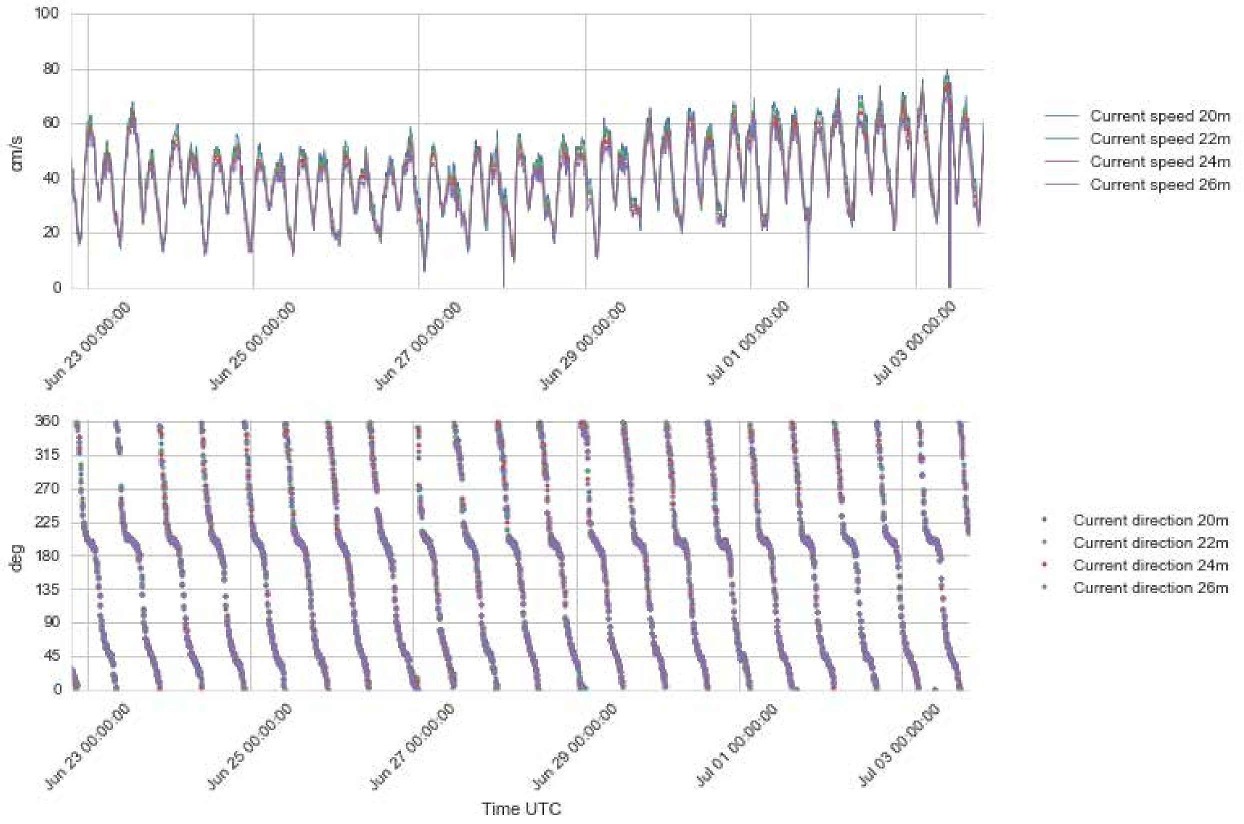

Figure 4.25 Time series plots of current speed (upper) and direction (lower panel), 20 - 28 m depth22 June – 3 July 2015

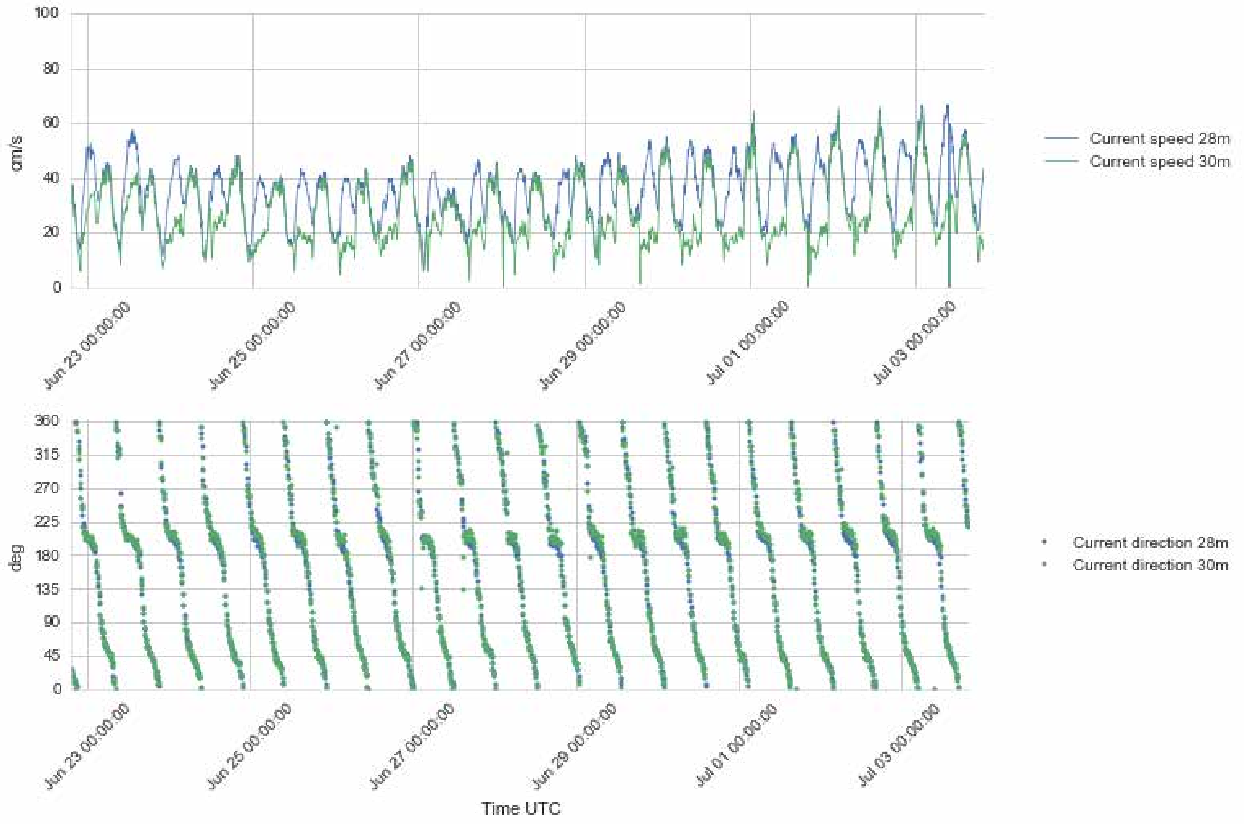

Figure 4.26 Time series plots of current speed (upper) and direction (lower panel), 28 - 30 m depth, 22 June – 3 July 2015

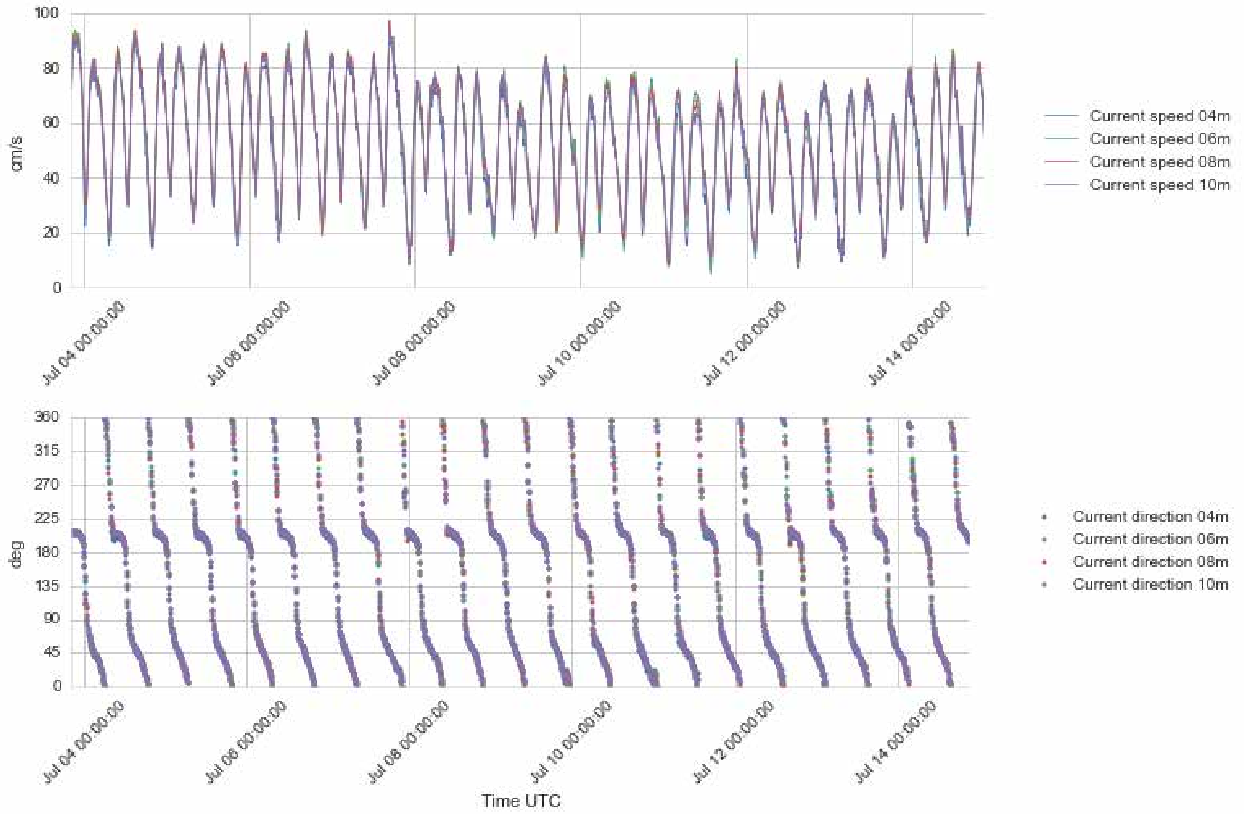

Figure 4.27 Time series plots of current speed (upper) and direction (lower panel), 4 - 10 m depth, 3 – 14 July 2015

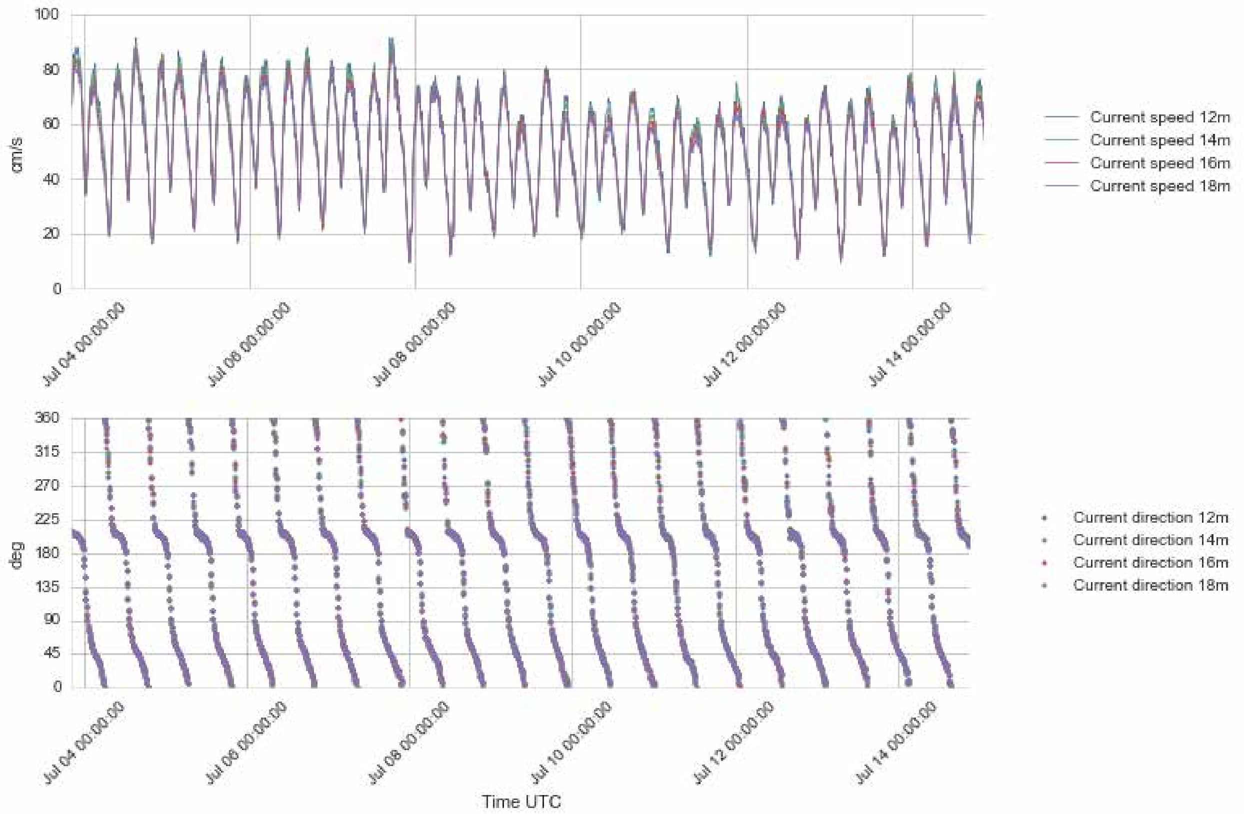

Figure 4.28 Time series plots of current speed (upper) and direction (lower panel), 12 - 18 m depth, 3 – 14 July 2015

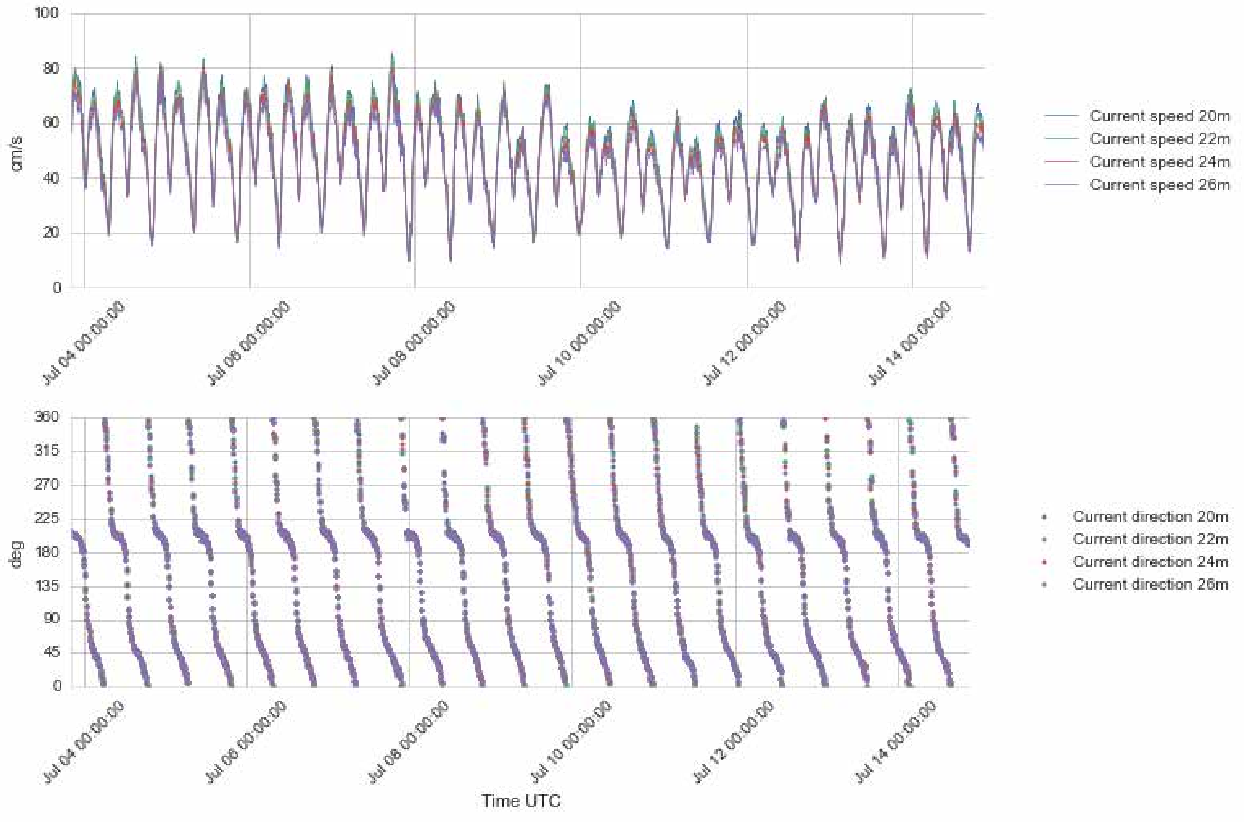

Figure 4.29 Time series plots of current speed (upper) and direction (lower panel), 20 - 26 m depth, 3 – 14 July 2015

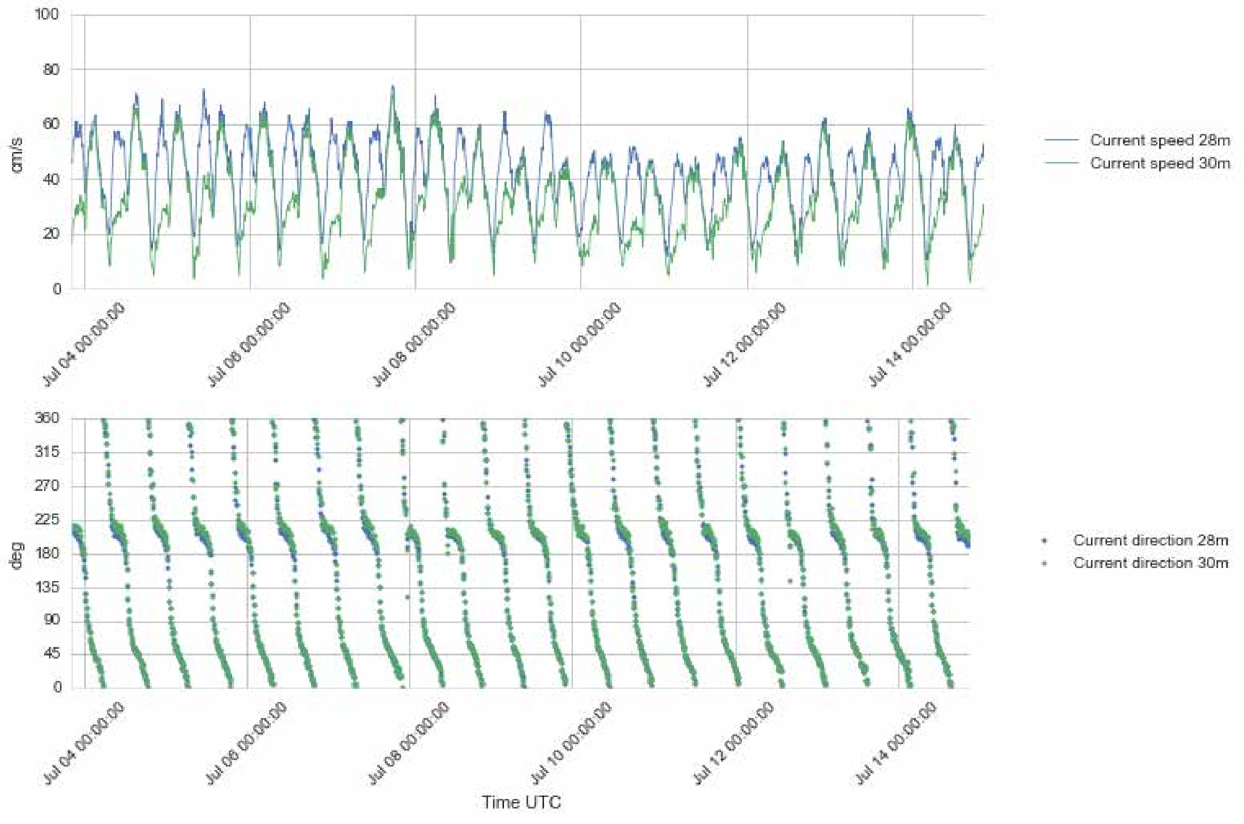

Figure 4.30 Time series plots of current speed (upper) and direction (lower panel), 28 - 30 m depth, 3 – 14 July 2015

4.2.5 Water level and bottom temperature data

The water level and bottom temperature data received from the bottom mounted Seaguard WLR are presented in Figure 4.31 - Figure 4.33.

There has been problems with the acoustic communication link between the bottom mounted instrument and the acoustic receiving modem in the buoy, resulting in loss of data in real time. When a data sample is not received the previous data sample is re-transmitted via satellite, consequently data gaps are identified as straight horizontal lines in the plots. No data have been received from the WLR after 8th July 2015. It is expected that the complete data series can be recovered from the internal storage in the WLR when it is recovered from the seabed.

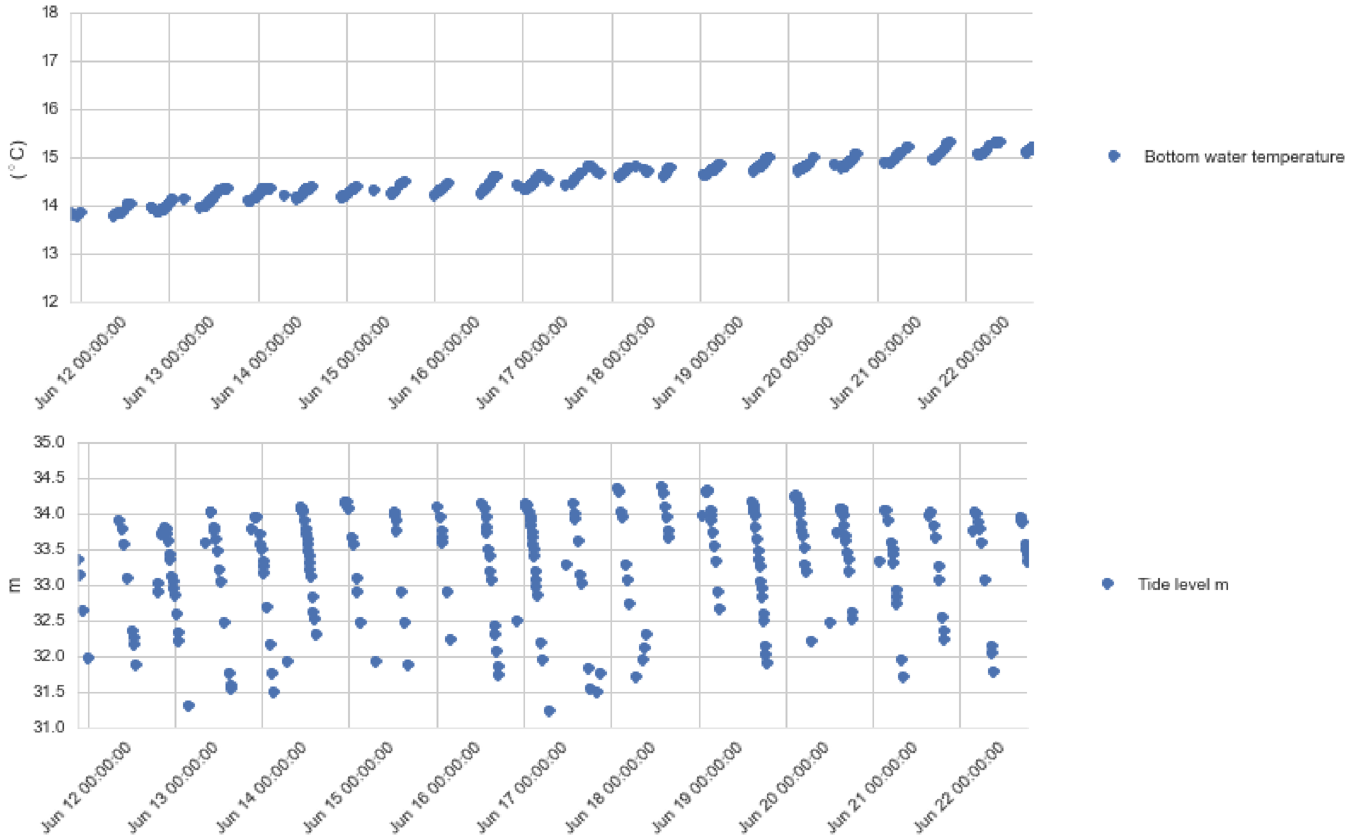

Figure 4.31 Time series plots of bottom water temperature (upper) and water level (lower panel), 11 – 22 June 2015

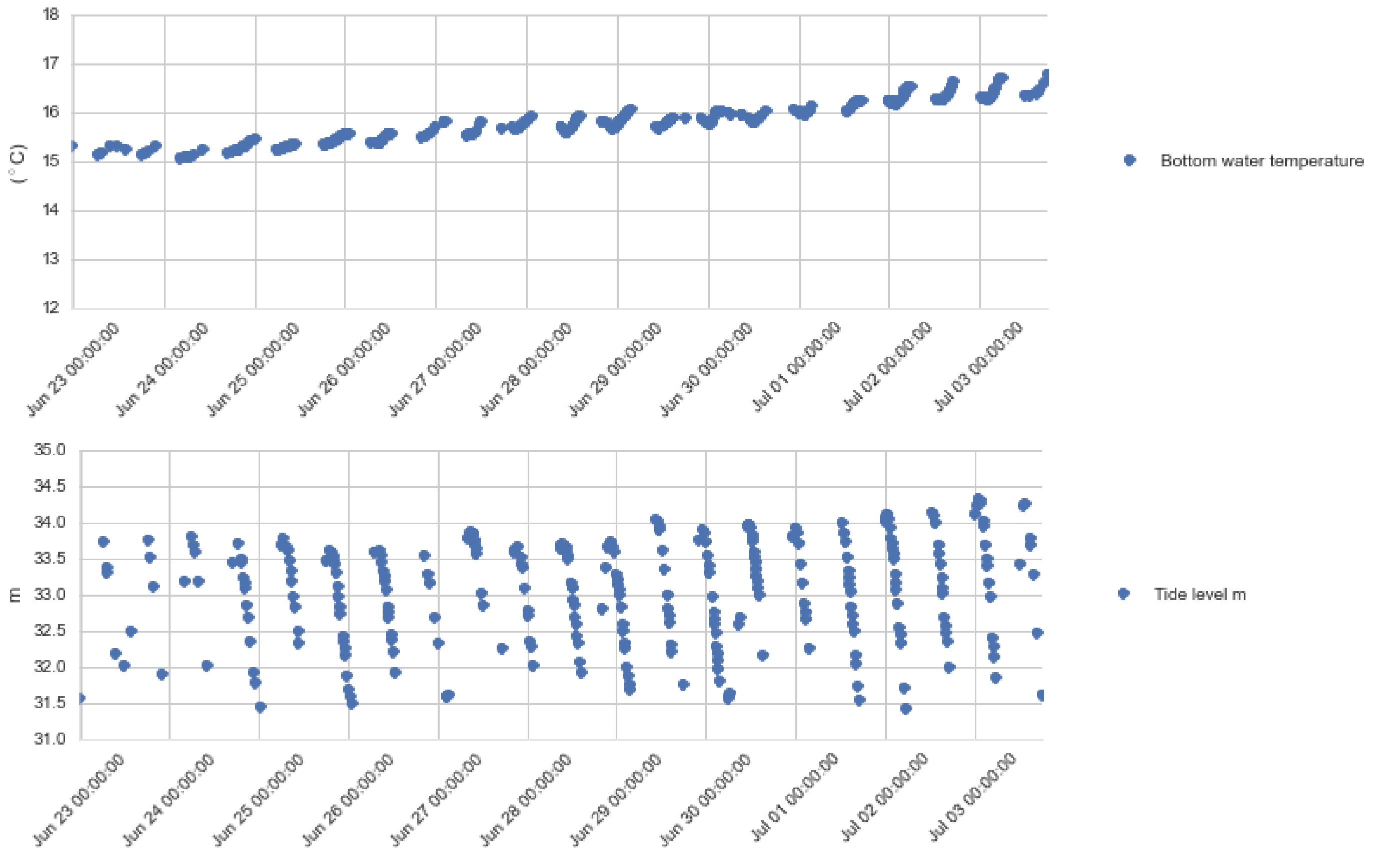

Figure 4.32 Time series plots of bottom water temperature (upper) and water level (lower panel), 22 June – 3 July 2015

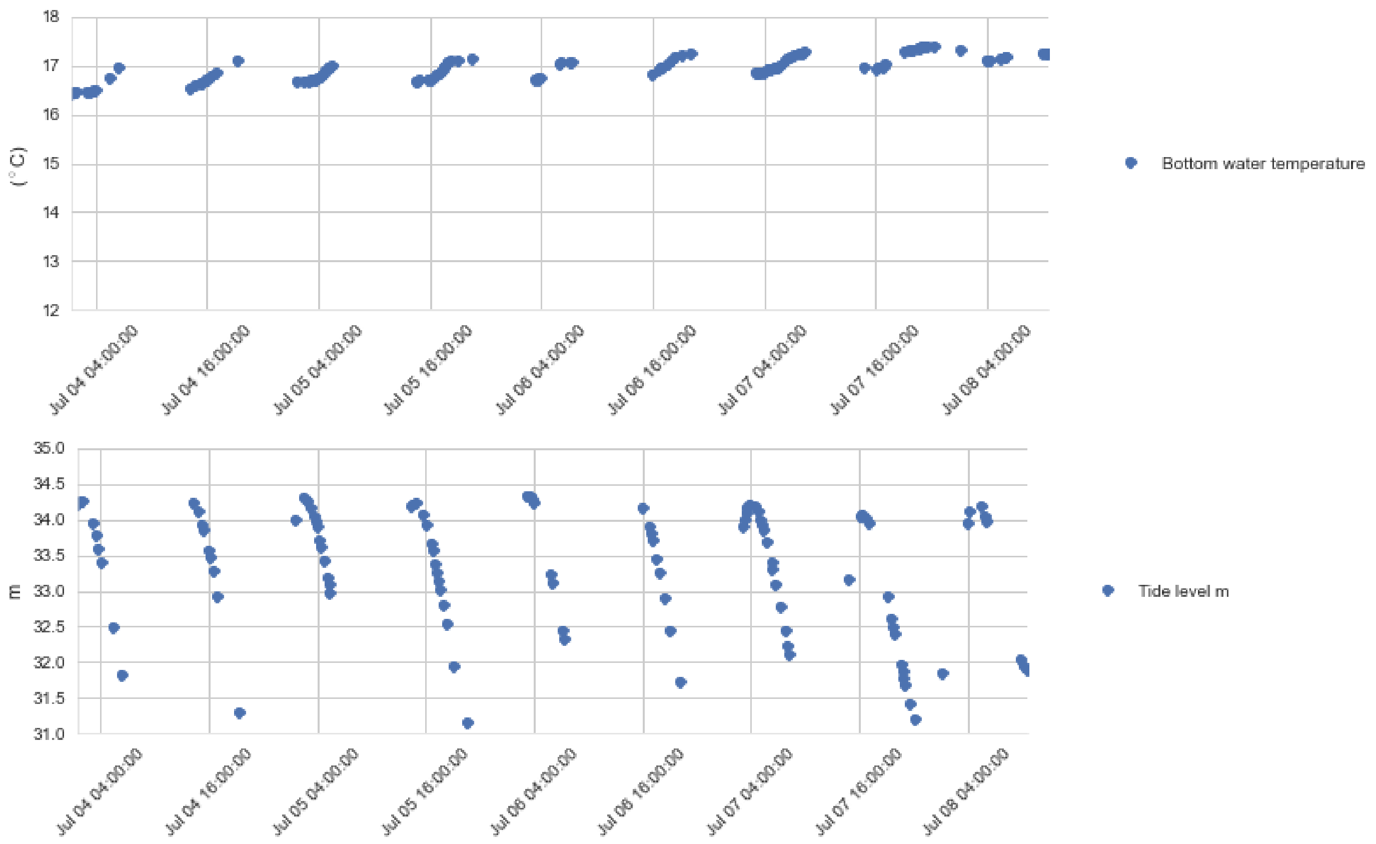

Figure 4.33 Time series plots of bottom water temperature (upper) and water level (lower panel), 3 – 8 July 2015

Appendix A

Cruise report for buoy deployment

DAILY SURVEY REPORT

CONTRACT NAME: WS lidar buoy to Borssele-nederland	**LOCATION/VESSEL: MPR3**
CONTRACT NO: C75339	**PERSONNEL: EME, OKH**
DATE: 2015-06-08	**TIME: UTC+2**

TIME (UTC+2)	OPERATIONS
0830	At MPR3
	Making buoy ready for deployment.
	Installed 3 new methanol cartridges.
	Mounting keel weight.
	Connecting together mooring.
	Making tide sensor ready for deployment. Attached floater on top.
2000	Finished for today

WORK COMPLETED TO DATE

Changed Methanol cartridges that was not full.

Attached keel weight to buoy.

Mooring connected together and connected to buoy.

Prepaired tide sensor for deployment

SAFETY

COMMENTS

19:30 Client Rep + K.V.O Project manager visited the vessel

WEATHER REPORT N/A → in Port

Wind.......

Sea.......

Weather.......

SIGNED Edvard M. Clyde....... (Fugro OCEANOR)

SIGNED [signature] Julian Scholten....... (Client's Representative)

DAILY SURVEY REPORT

CONTRACT NAME: WS lidar buoy to Borssele-nederland	**LOCATION/VESSEL: MPR3**
CONTRACT NO: C75339	**PERSONNEL: EME, OKH**
DATE: 2015-06-09	**TIME: UTC+2**

TIME (UTC+2)	OPERATIONS
0730	Onboard MPR3
0850	Departure. Heading for Borssele Vindfarm to deploy the buoy and WLR.
1125	Stopping after coming to open sea to evaluate the weather condition. Got information from a rig nearby that significant wave height was 1.6m.
1138	Deciding in agreement with client and captain that the weather condition is too bad for deploying the buoy. Aborting and returning to port.
1500	Back in port.
1900	Checking the latest forecast for Wednesday, which doesn't look better than today's forecast. Deciding that it is not worth trying again on Wednesday.

WORK COMPLETED TO DATE

SAFETY

COMMENTS

Good decision to head back to port

WEATHER REPORT

Wind >10m/s

Sea 1.6m

Weather Cloudy. Some rain showers.

SIGNED Edvard M. Elgsæther
(Fugro OCEANOR)

SIGNED Jurrian Scholten
(Client's Representative)

DAILY SURVEY REPORT

CONTRACT NAME: WS lidar buoy to Borssele-nederland	**LOCATION/VESSEL: MPR3**
CONTRACT NO: C75339	**PERSONNEL: EME, OKH**
DATE: 2015-06-10	**TIME: UTC+2**

TIME (UTC+2)	**OPERATIONS**
0830	Checking the latest weather forecast for Thursday. Looks OK
	Waiting for weather
1900	Checking the latest forecast. It still looks OK.

WORK COMPLETED TO DATE

SAFETY

COMMENTS

Weather too bad for deploying buoy.

WEATHER REPORT

Wind: >10m/s at site

Sea: ~1.5m waves at site

Weather: Fine

SIGNED Edvard M. Elgsæther
(Fugro OCEANOR)

SIGNED [signature]
(Client's Representative)

DAILY SURVEY REPORT

CONTRACT NAME: WS lidar buoy to Borssele-nederland	**LOCATION/VESSEL: MPR3**
CONTRACT NO: C75339	**PERSONNEL: EME, OKH**
DATE: 2015-06-11	**TIME: UTC+2**

TIME (UTC+2)	OPERATIONS
0735	Boarding MPR3. Client's representative had already arrived
0750	Leaving port and heading for deployment position. Weather looks much better than on Tuesday.
1530	Toolbox talk with crew.
1550	At position
1655	Buoy at sea
1708	Giving out mooring and checked that all sensors except WLR is working Waiting to verify that Iridium sending is working.
1745	Verified that all sensors and data transmission is working. Moving to buoy position.
1755	Dropping bottom weight at position: 51° 42.41388'N, 3° 2.07708'E, Depth: 30m
1814	Dropping WLR at position: 51° 42.4362N, 3° 02.1030E, Depth: 30m
	Received no data from WLR.
	Called Kongsberg who delivers the cNode acoustic modems that are used with the WLR to check if there is something that can be done to find out where the problem is and possibly fix it, but the conclusion was that there is nothing to be done except taking up the bottom unit again and check it. We were considering taking up the bottom unit, but after discussing it with client representative Jurian Scholten and project manager Arve Berg, it was agreed not to do it. The crew have had a long day already. There is also not made a job description and safe job analysis for this operation.
2048	Heading back.
0400	At quay

WORK COMPLETED TO DATE

Deployed buoy and Water Level Recorder

SAFETY

COMMENTS

No data from Water Level Recorder before we left the site.

WEATHER REPORT Wind: 7m/s Sea:1m Weather: Fine	SIGNED Edvard M. Elgsaether (Fugro OCEANOR) SIGNED [signature] (Client's Representative)

DAILY SURVEY REPORT

CONTRACT NAME: WS lidar buoy to Borssele-nederland	**LOCATION/VESSEL: MPR3**
CONTRACT NO: C75339	**PERSONNEL: EME, OKH**
DATE: 2015-06-12	**TIME: UTC+2**

TIME (UTC+2)	OPERATIONS
0400	At quay
0900	Got message from Fugro Oceanor Office that data from Water Level Recorder has started to come in.

WORK COMPLETED TO DATE

SAFETY

COMMENTS

WEATHER REPORT	
Wind: 7m/s	SIGNED Edvard M. Elysether (Fugro OCEANOR)
Sea:1m	
Weather: Fine	SIGNED [signature] (Client's Representative)

DEPLOYMENT/RECOVERY 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 SIM: 8988169514001092357
UHF service radio Adeunis ARF7940BA	B134300547
L3 AIS	S.n: 000990022 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 stack: 151010084—00501
Fuel Cell 2	efoy : 302302-1324-30871 stack: 151010084-
Fuel Cell 3	efoy : 302303-1407-32516 stack: 151010084—00491
Fuel Cell 4	efoy : 302303-1407-32515 stack: 151010084--00492
Seaguard w/sensor 5217A	1620 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	GMT
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
Alle tider er i UTC+2

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: 11 June - 14 July 2015

Reference No: C75339_VAL01_R2
20 November 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_VAL01_R2				
Rev	**Date**	**Originator**	**Checked & Approved**	**Issue Purpose**
0	28.08.2015	Lasse Lønseth	Arve Berg	Final report.
1	15.09.2015	Lasse Lønseth	Arve Berg	Final report updated in response to comments from client.
2	20.11.2015	Lasse Lønseth	Arve Berg	Final report updated due to correction of wind direction.

Rev 2 – 20 November 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 11th 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 11th June – 14th July 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 11th 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.

This report presents an evaluation of the wind and wave data collected during the period 11th June – 14th July 2015, 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.

In this revision 2 of the report the data have been corrected for 15° misalignment of the Lidar relative to the buoy hull.

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 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 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 -6 … -30 (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 40.0 40.0 ref 60.0 80.0 100.0 120.0 140.0 160.0 180.0 200.0	≈ 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.)

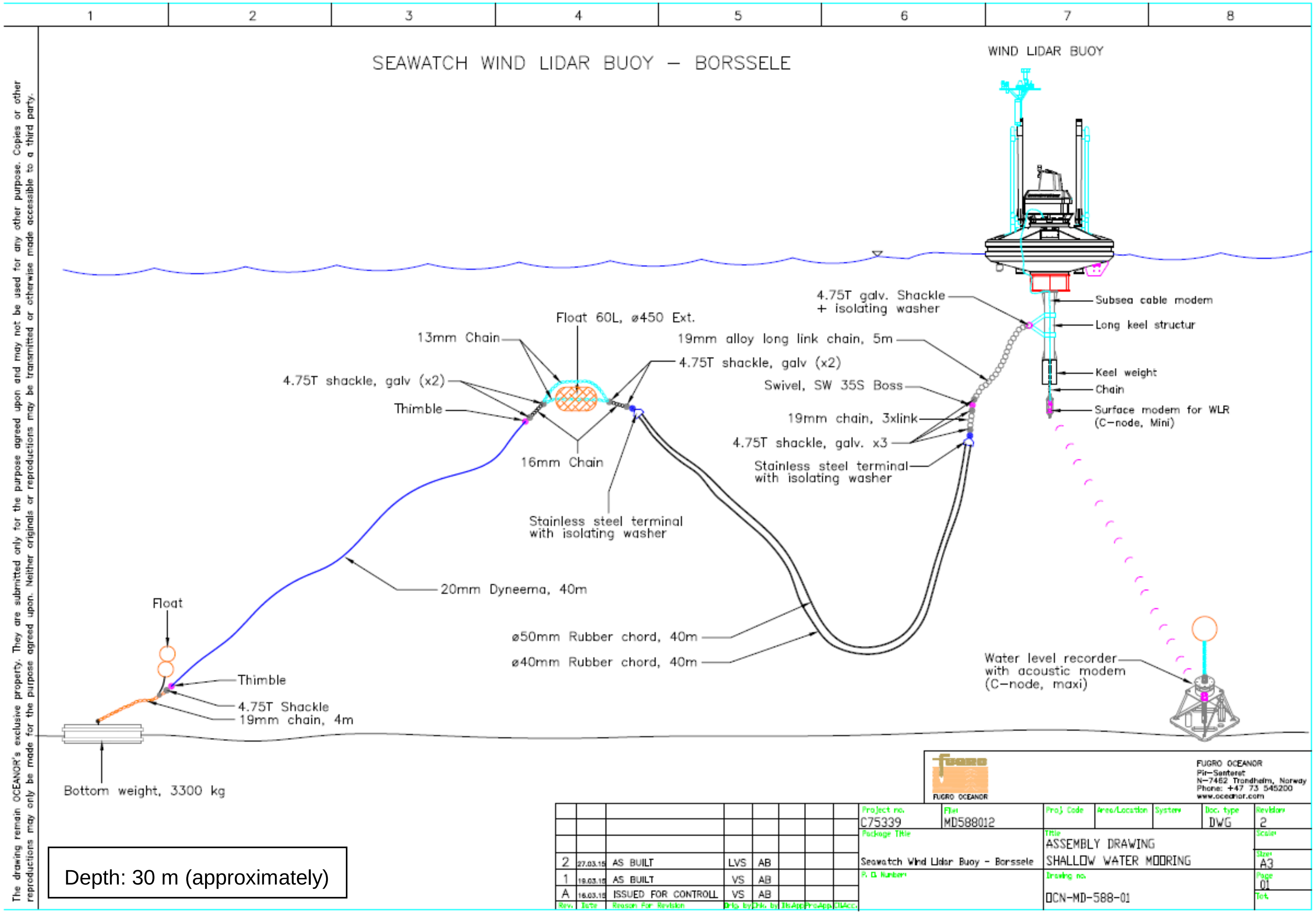

Figure 2.1 Mooring design for the Wind Lidar Buoy as deployed at Borssele Wind Farm Zone (BWFZ).

3. Results

3.1 Data recovery

The number of days of good data compared to the total obtainable hours of data is presented in Table 3.1 which is copied from the data presentation report (ref. C75339_MPR01_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.

Table 3.1 Data return during the period11th June 2015 at 18:20 UTC – 14th July 2015 at 21:10 UTC

Measurement device	Length of data period (days)	Length of data set (days)	Average availability (%)
LIDAR wind profile sensor	33.097	30.5	92.15
Wave sensor	33.097	32.993	99.69
Current velocity sensor	33.097	33.001	99.73
Atmospheric pressure sensor	33.097	33.035	99.81
Air temperature sensor	33.097	33.035	99.81
Water Level Sensor *	33.097	4.542	13.72

* 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

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 3.1, 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
Borssele Lidar buoy	51° 42.41' N	3° 2.08' E	
Schouwenbank Waverider buoy (SCHB)	51° 44.8' N	3° 18.3' E	19.3 km
Vlakte van de Raan (VR)	51° 30' N	3° 15' E	27.6 km

3.2.1 Schouwenbank

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

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

3.2.2 Vlakte van de Raan

The Vlakte van de Raan 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 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]

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

3.3 Evaluation of 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 in these shallow waters is expected to cause some differences.

The time series plot in Figure 3.1 compares the significant wave height (Hm0). All peaks in the time series occur at almost exactly the same time, showing good coherence. The Lidar buoy shows slightly higher Hm0 values than the Waverider, which may be attributed to different location, depth and distance from the shore line. The average Hm0 values are 0.91 m at the Lidar buoy compared to 0.82 m at Schouwenbank. The scatter plot in Figure 3.2 confirms the results. The scatter with R^2 = 0.928 is not unexpected due to the distance between stations. Apart from that the scatter plot also confirms the observed difference in Hm0 values.

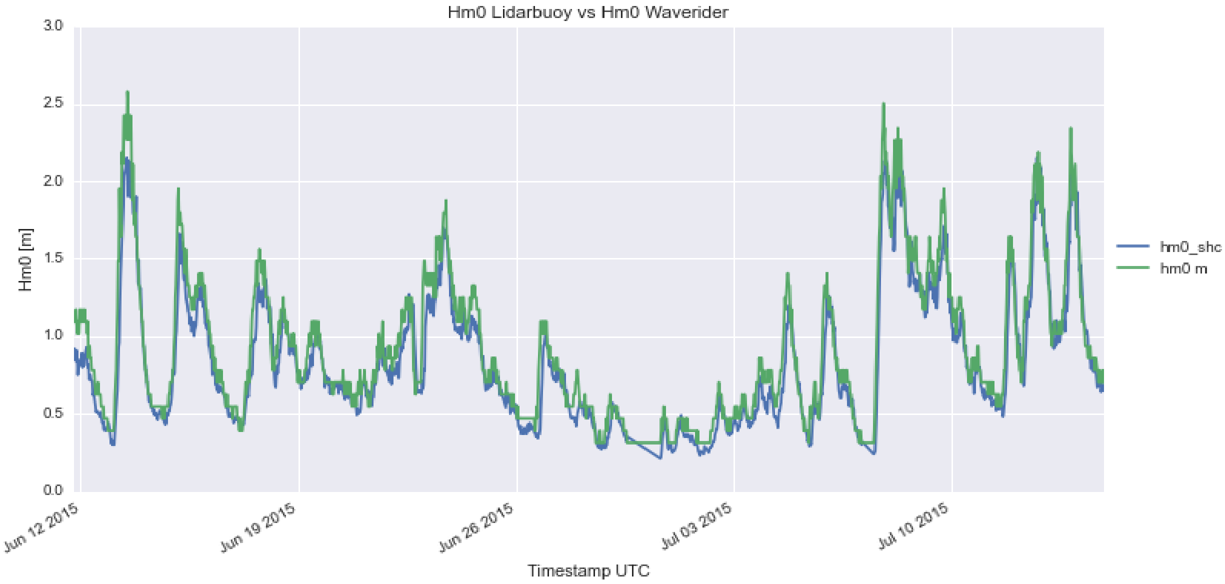

Figure 3.3 Time series plot of significant wave height (Hm0) from the Lidar buoy (green curve) and the Schouwenbank Waverider buoy (blue).

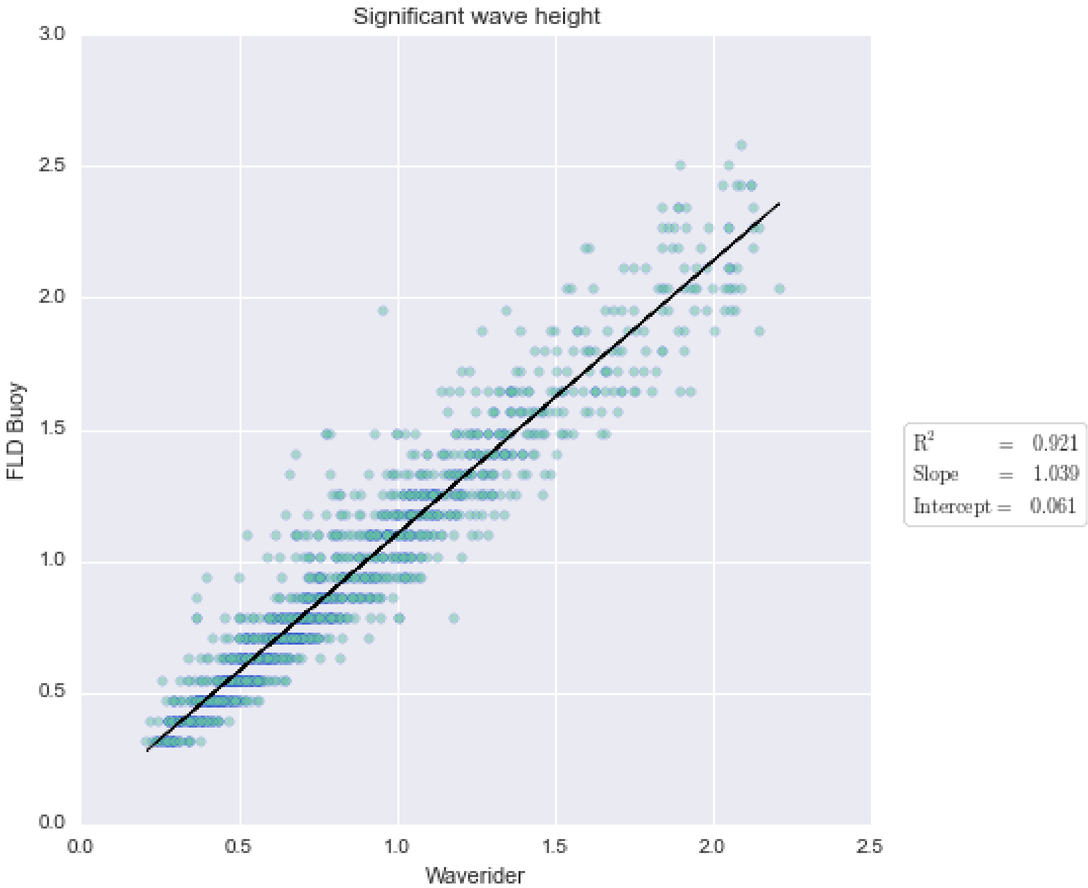

Figure 3.4 Scatter plot comparing Hm0 measured by the Lidar buoy to Hm0 from the Schouwenbank Waverider buoy.

The mean wave period (Tm02) from the Lidar buoy is compared to the Waverider Tm02 in the time series plot in Figure 3.3 and the scatter plot in Figure 3.4. The time series plot shows good coherence and the values appear very similar. The scatter plot shows R^2 = 0.852. Some scatter must be expected due to the distance between the stations. The average values of Tm02 are 4.07 s at the Lidar buoy compared to 4.02 s at the Waverider.

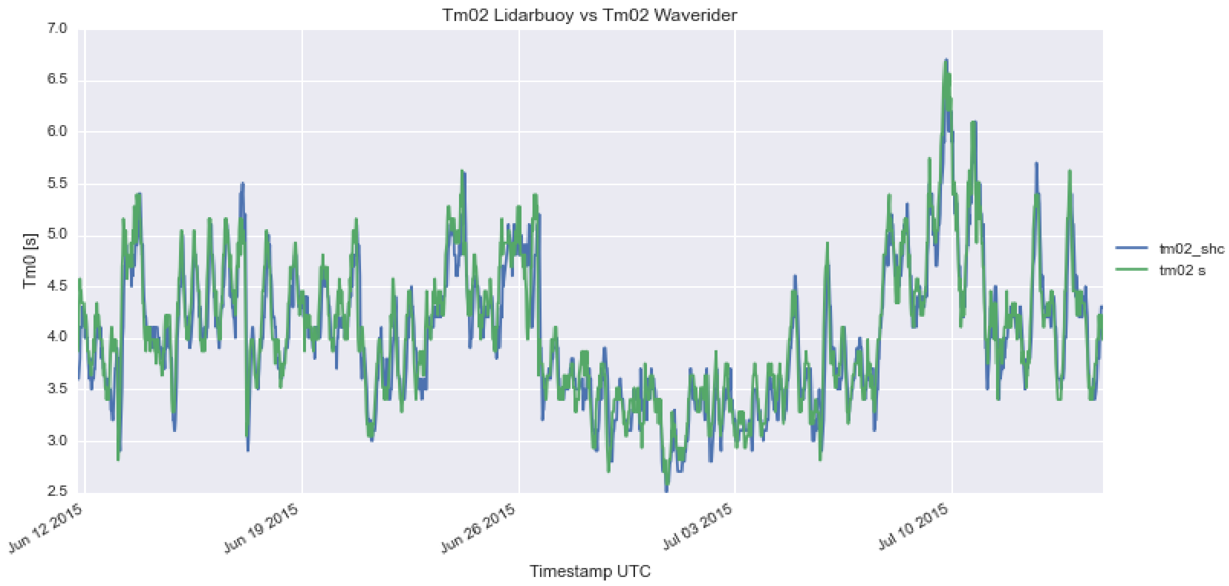

Figure 3.5 Time series plot of mean wave period (Tm02) from the Lidar buoy (green curve) and the Schouwenbank Waverider buoy (blue).

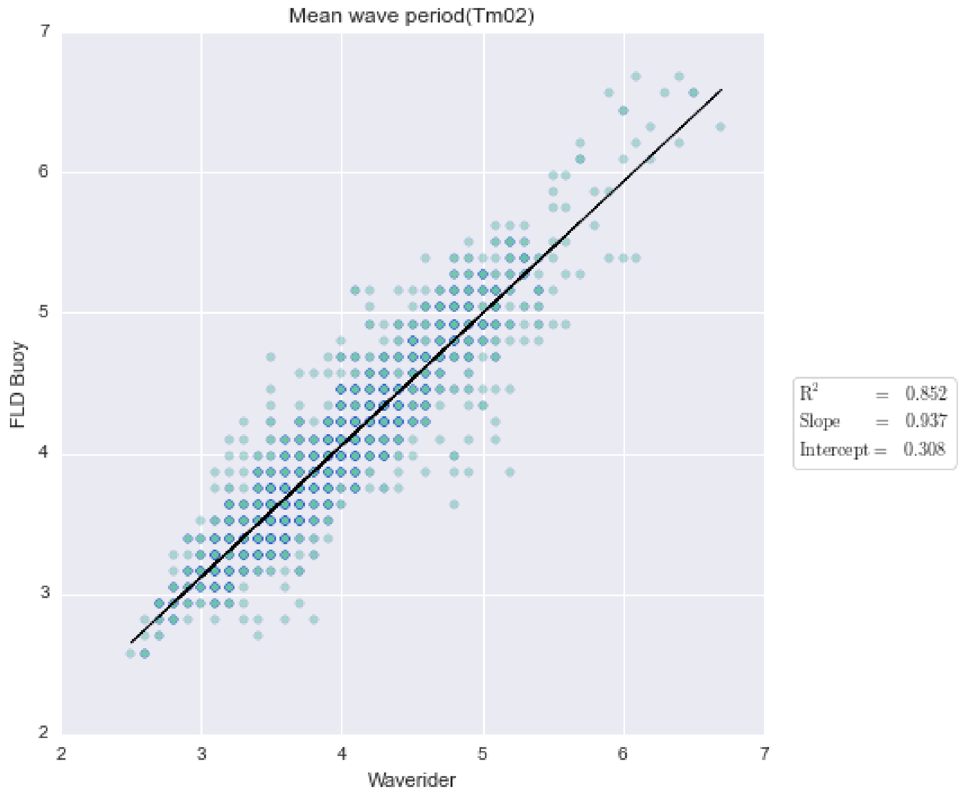

Figure 3.6 Scatter plot comparing Tm02 measured by the Lidar buoy toTm02 from the Schouwenbank Waverider buoy.

3.4 Evaluation of 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 13 km from the nearest shore, while the buoy is 33 km from land. The wind speeds measured at anemometer height have been reduced to 10m above 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 for 10 m height at VR in Figure 3.6. The data show a general good agreement as the maxima in wind speed at both locations appear at the same time, showing good coherence. In the storm of 13th June (in the beginning of the plot) it is noticed that the buoy gives considerably higher speed than the VR station. In this case the winds are south-westerly and the VR station measurement would be more affected by land effects when the wind has a component from land.

The scatter plot in Figure 3.7 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 station 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.

The time series of wind direction are compared in Figure 3.8, which also shows the wind speed. 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 3.9. The differences between the data from the two sources can easily be explained by the distance and different influence from the terrain, and give no reason to suspect that the buoy is not measuring correctly.

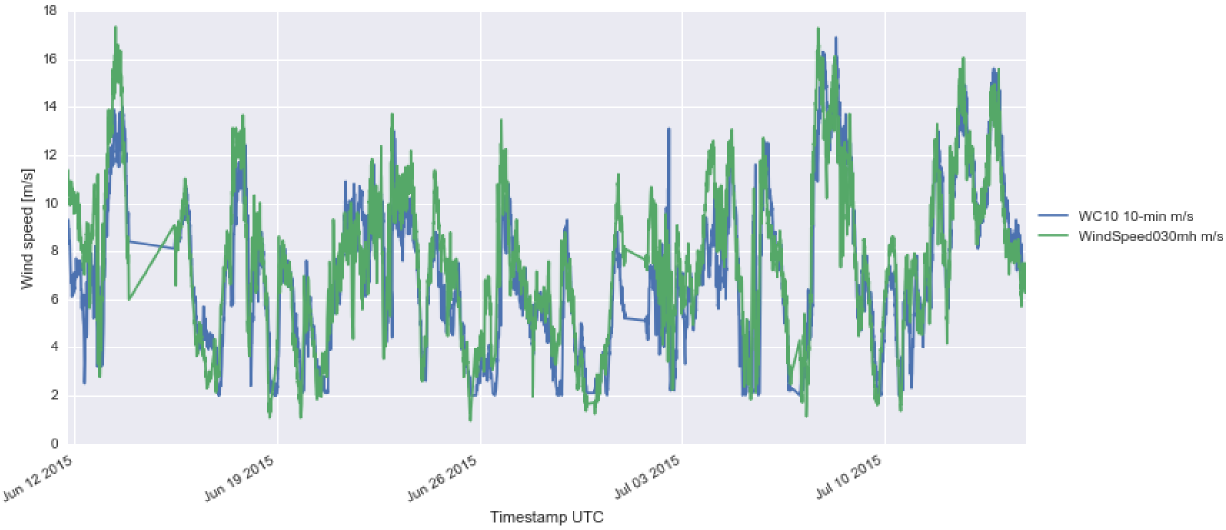

Figure 3.7 Wind speed at 30 m above sea level measured by the Lidar buoy (green curve) compared to 10 m wind speed at Vlakte van de Raan (blue).

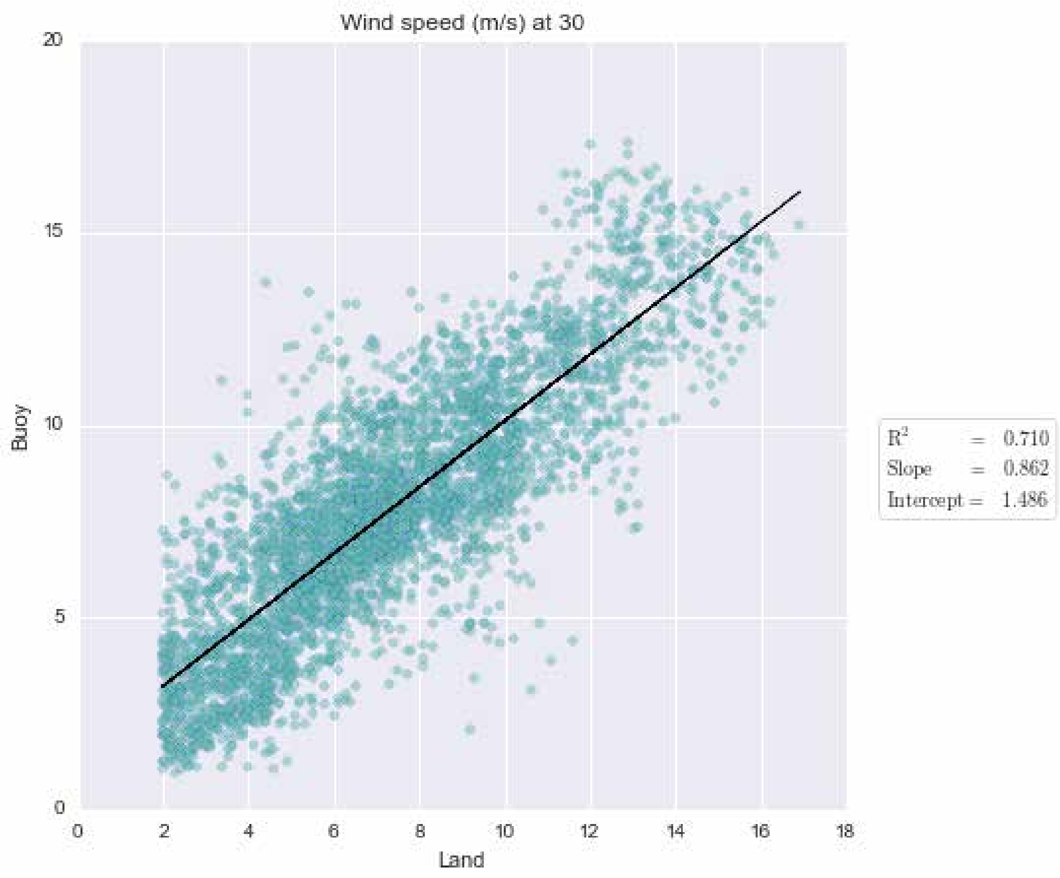

Figure 3.8 Scatter plot comparing the wind speed at 30 m above sea level measured by the Lidar buoy compared to the 10 m wind speed at Vlakte van de Raan.

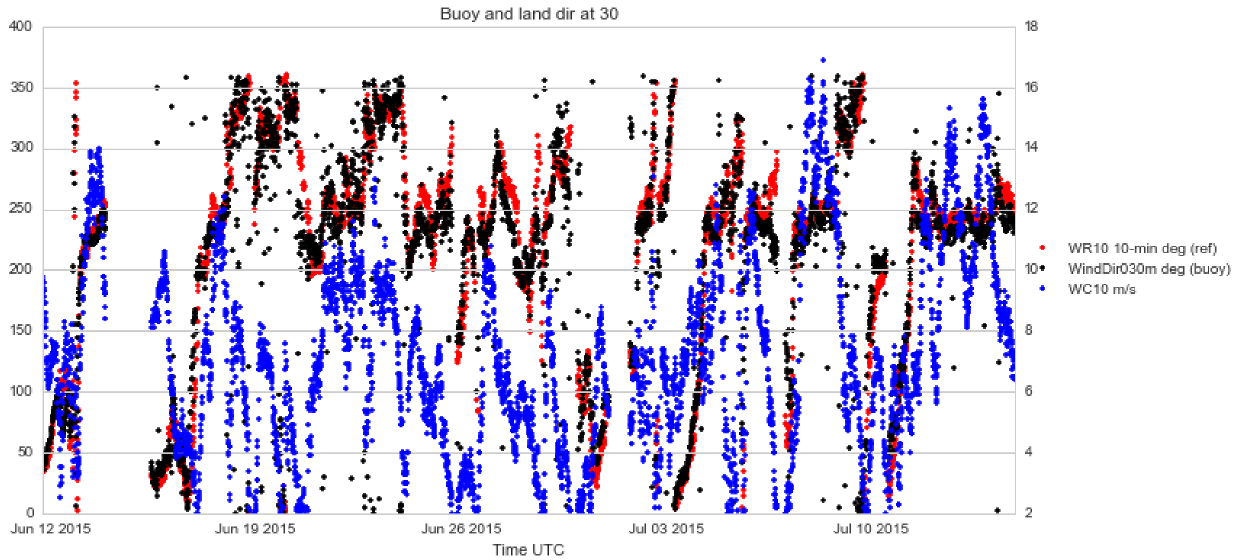

Figure 3.9 Wind direction at 30 m above sea level measured by the Lidar buoy (black dots) compared to wind direction at Vlakte van de Raan (red). The blue dots show the VR station 10m wind speeds. (Samples with VR wind speed less than 2 m/s are excluded.)

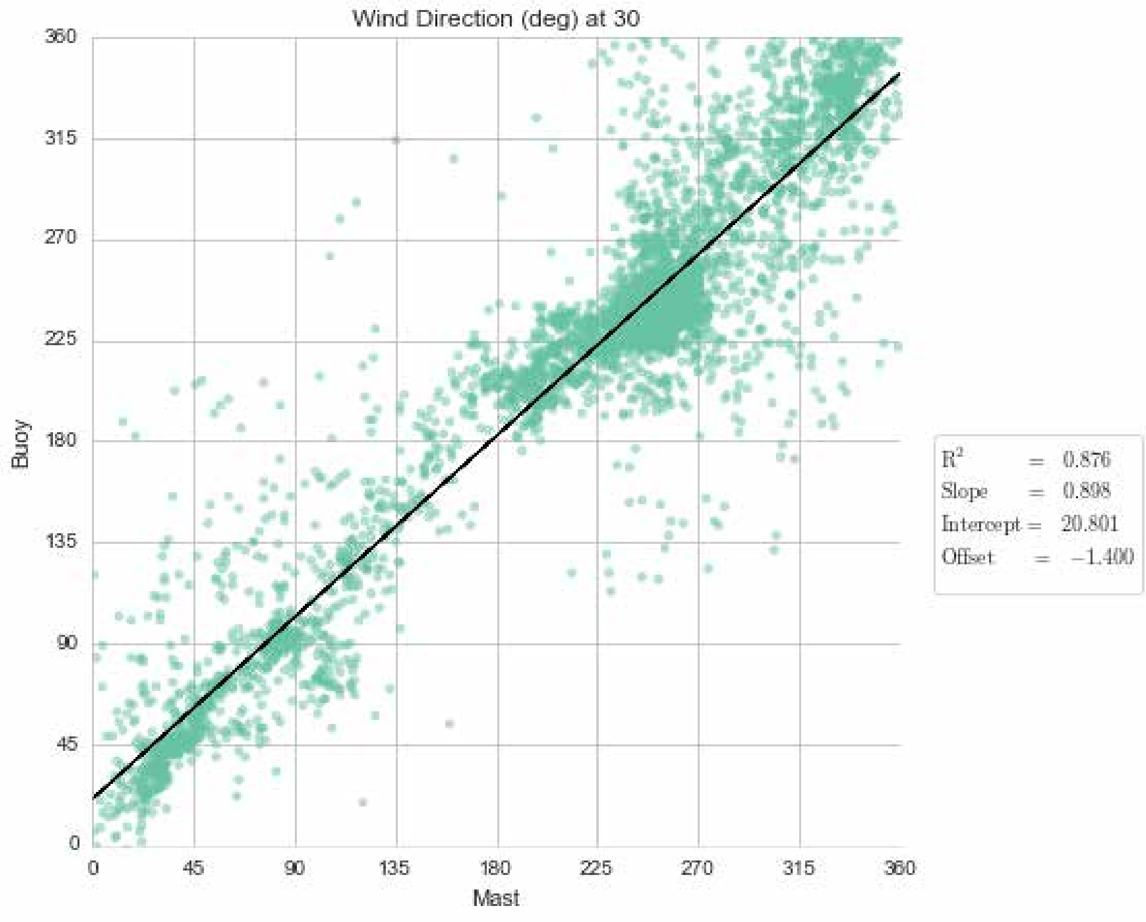

Figure 3.10 Scatter plot showing the wind direction at 30 m above sea level measured by the Lidar buoy compared to the wind direction at Vlakte van de Raan. The black line is located by standard y on x regression. Offset is the average difference between the directions. (Samples with VR wind speed less than 2 m/s are excluded.)

3.4.1 Other parameters

The data for current velocity, atmospheric pressure and air temperature have not been compared to a reference, but by inspection of the time series presented in the data presentation report (ref. C75339_MPR01_R2) it is seen that the data are good and agree with expected local conditions.

3.5 Conclusions

The 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 some gaps in the data due to communication problems, and as a result 33.097 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 SIM: 8988169514001092357
UHF service radio Adeunis ARF7940BA	B134300547
L3 AIS	S.n: 000990022 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 stack: 151010084—00501
Fuel Cell 2	efoy : 302302-1324-30871 stack: 151010084-
Fuel Cell 3	efoy : 302303-1407-32516 stack: 151010084—00491
Fuel Cell 4	efoy : 302303-1407-32515 stack: 151010084--00492
Seaguard w/sensor 5217A	1620 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**	**GMT**
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

Alle tider er i UTC+2

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