

**Date** 24 March 2016  
**Your reference** WOZ150011  
**Our reference** ECN-WIND-2016-049

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THE NETHERLANDS

**Subject** Supply of Meteorological and Oceanographic data for Borssele Wind Farm Zone Period 12 November - 14 December 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 : 12 November – 14 December 2015.  
Reference No: C75339\_MPR04\_R1 (14 March 2016)
2. Supply of Meteorological and Oceanographic data at Borssele Wind Farm Zone (BWFZ)  
Validation report : 12 November – 14 December 2015.  
Reference No: C75339\_VAL04\_R1 (14 March 2016)

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 dataset (Period 4 , Version 2 dd. 20160314) can be retrieved via the website : [www.WindOpZee.net](http://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.

Yours sincerely,

A handwritten signature in blue ink, appearing to read 'H. Verhoef', is written over a horizontal line.

Hans Verhoef  
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**THE NETHERLANDS ENTERPRISE AGENCY (RVO)**

**Supply of Meteorological and Oceanographic data at Borssele Wind Farm Zone (BWFZ)  
Monthly Progress Report: 12 November - 14 December 2015**



**Reference No: C75339\_MPR04\_R1  
14 March 2016**

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**Supply of Meteorological and Oceanographic data at Borssele Wind Farm Zone (BWFZ):  
C75339\_MPR04\_R1**

Rev	Date	Originator	Checked & Approved	Issue Purpose
0	10.02.2016	Lasse Lønseth	Arve Berg	Final report.
1	14.03.2016	Lasse Lønseth	Arve Berg	Final report.

Rev 1 – 14 March 2016	Originator	Checked & Approved
Signed:		

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'.

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Appendix A: Buoy deployment record

## **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.

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 Multirasalvor 3. After repair on shore the buoy was redeployed on 12 November 2015.

This fourth monthly report summarizes the activities and data collected during the period 12 November – 14 December 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.

Following the stop in the transmissions from the buoy on 11 September 2015 at 16:00, the buoy was recovered to shore on 6 October 2015 for inspection and repair. It was redeployed after repair on 12 November 2015 at 14:00. The multicat type workboat Multirasalvor 3 was used for this operation.

This report presents project progress and results during the period 12 November – 14 December 2015, and the data which have been transmitted to shore via the Iridium satellite system in this period. The data recovery percentages for this period are also presented. Due to some gaps in the data it took 32.375 days to collect 30.5 days of good wind profile data from the Lidar buoy.

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 <sup>2)</sup> (m)	Sampling interval (s)	Averaging period (s)	Burst interval (s)	Transmitted?
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 11 <sup>th</sup> 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	$\approx 17.4 \text{ s}^{1)}$	600	600	Yes
Aanderaa WLR (SeaGuard) via acoustic link	-30	Water pressure Temperature	-30	600	60	600	Yes

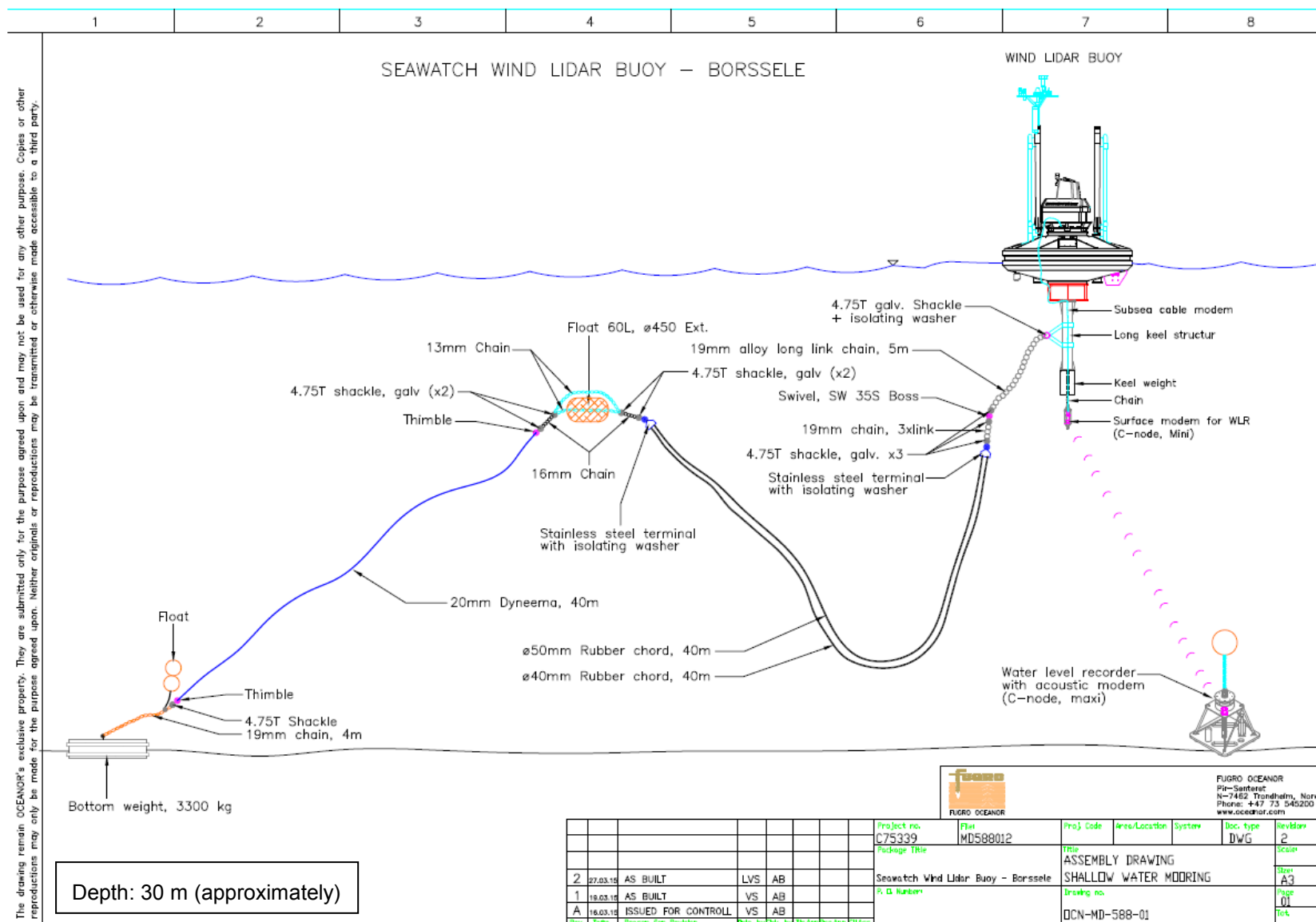
<sup>1)</sup> This is the approximate time between the beginning of one sweep of the profile and the next one, the interval may vary slightly. The ZephIR sweeps one level at a time beginning at the lowest one, and after the top level has been swept it uses some time for calculations and re-focusing back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

<sup>2)</sup> 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, $H_s$ , $Hm0 = 4\sqrt{m0}$
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.

After approximately 3 months of continuous good operation the transmissions from the buoy ended on 11 September 2015 at 15:50. Therefore 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, while the WLR unit remained on the bottom.

The buoy was redeployed by the Multrasalvor 3 on 12 November 2015 at 14:00, and good data were received from 14:20. This reporting period extends to 14 December 2015 at 23:10 when 30.5 days of wind profile data had been collected.

#### **3.2 Health, Safety and Environment**

There were no incidents, near misses or accidents in connection with the deployment operation on 12 November 2015.

## 4. Results

### 4.1 Summary of results and data return

The buoy transmitted data continuously from all sensors from 12 November 2015 at 14:20 until 14 December 2015 at 23:10, except for a gap of 33 hours 50 min in the Lidar data from 22 November at 05:30 to 15:00 on 23 November, and a 6 hour gap in all data from 00:30 to 06:00 on 6 December 2015. There are also a number of single profile dropouts in the Lidar data. Due to these gaps it took 32.375 days to collect 30.5 days of good wind profile data from the Lidar buoy.

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 12 November 2015 at 14:20– 14 December 2015 at 23:10.**

Measurement device	Length of data period (days)	Length of data set (days)	Average availability (%)
Lidar wind profile sensor	32.375	30.500	94.21
Wave sensor	32.375	32.090	99.12
Current velocity and direction sensor	32.375	32.090	99.12
Atmospheric pressure sensor	32.375	32.090	99.12
Air temperature sensor	32.375	32.090	99.12
Water Level Sensor *	32.375	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 12 November 2015 at 14:20 – 14 December 2015 at 23:10, giving a total wind profile data set of 30.5 days.

#### 4.2.1 Meteorological data

The following plots present the air pressure, air temperature, and sea surface temperature. The sensors performed well in this period.

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.

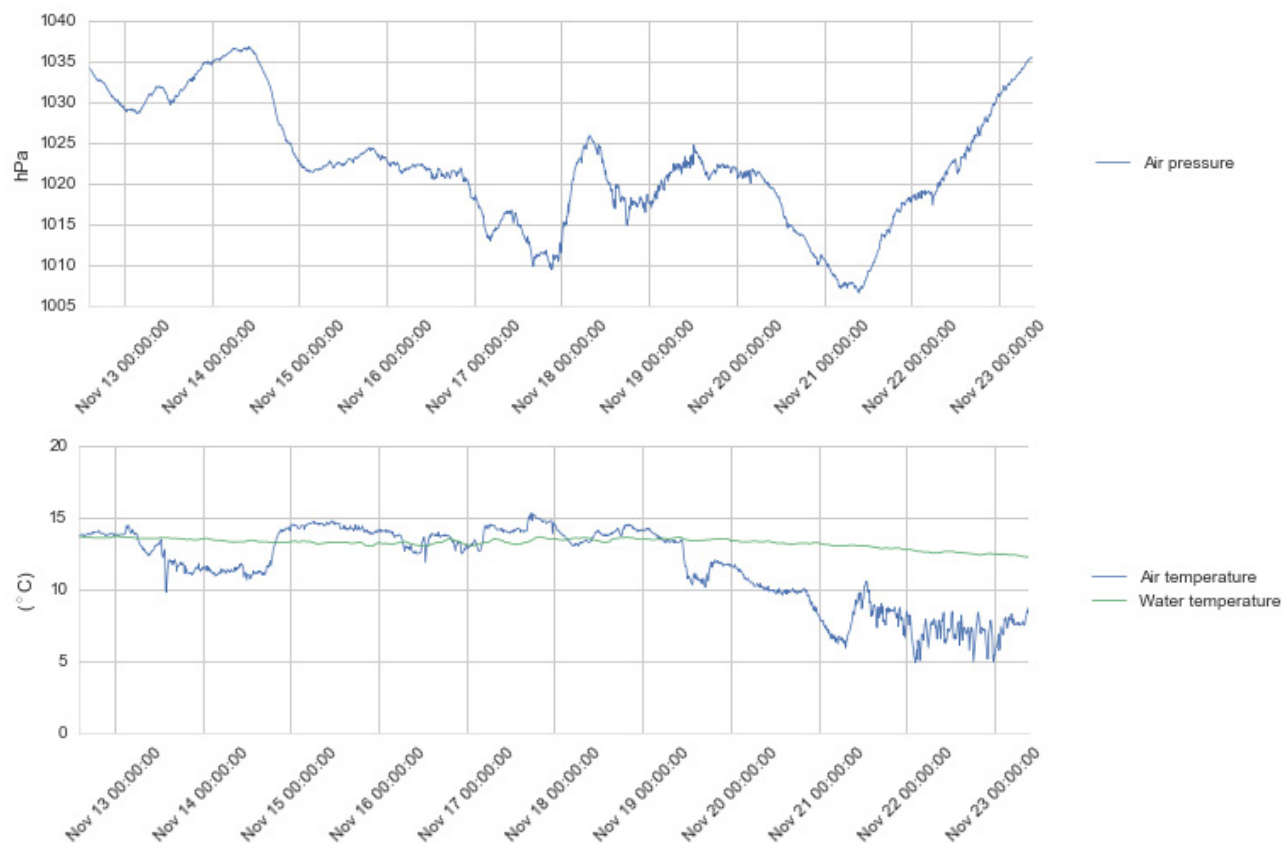


Figure 4.1 Time series plots of air pressure (upper panel), air and water temperature (lower panel), 12 - 23 Nov 2015.

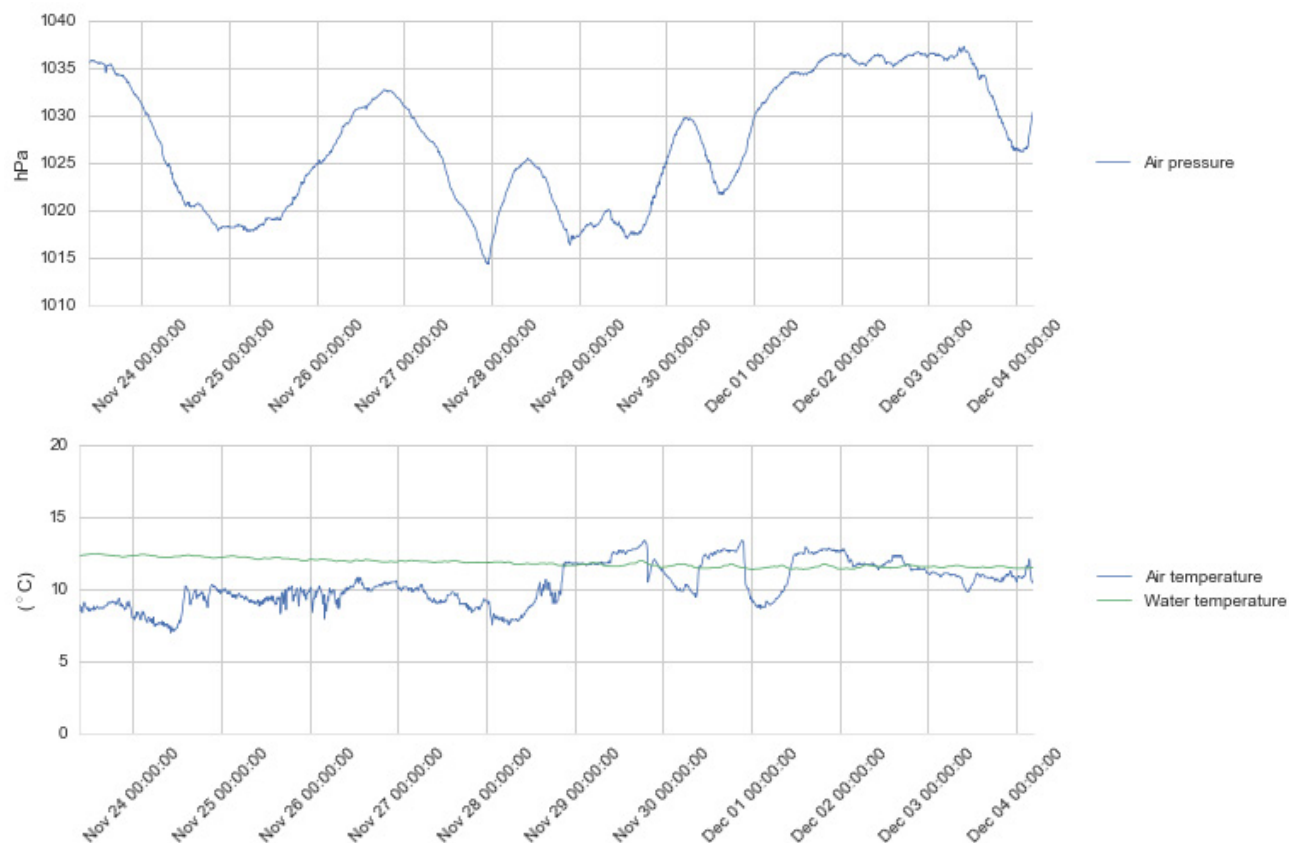


Figure 4.2 Time series plots of air pressure (upper panel), air and water temperature (lower panel), 23 Nov – 4 Dec 2015.



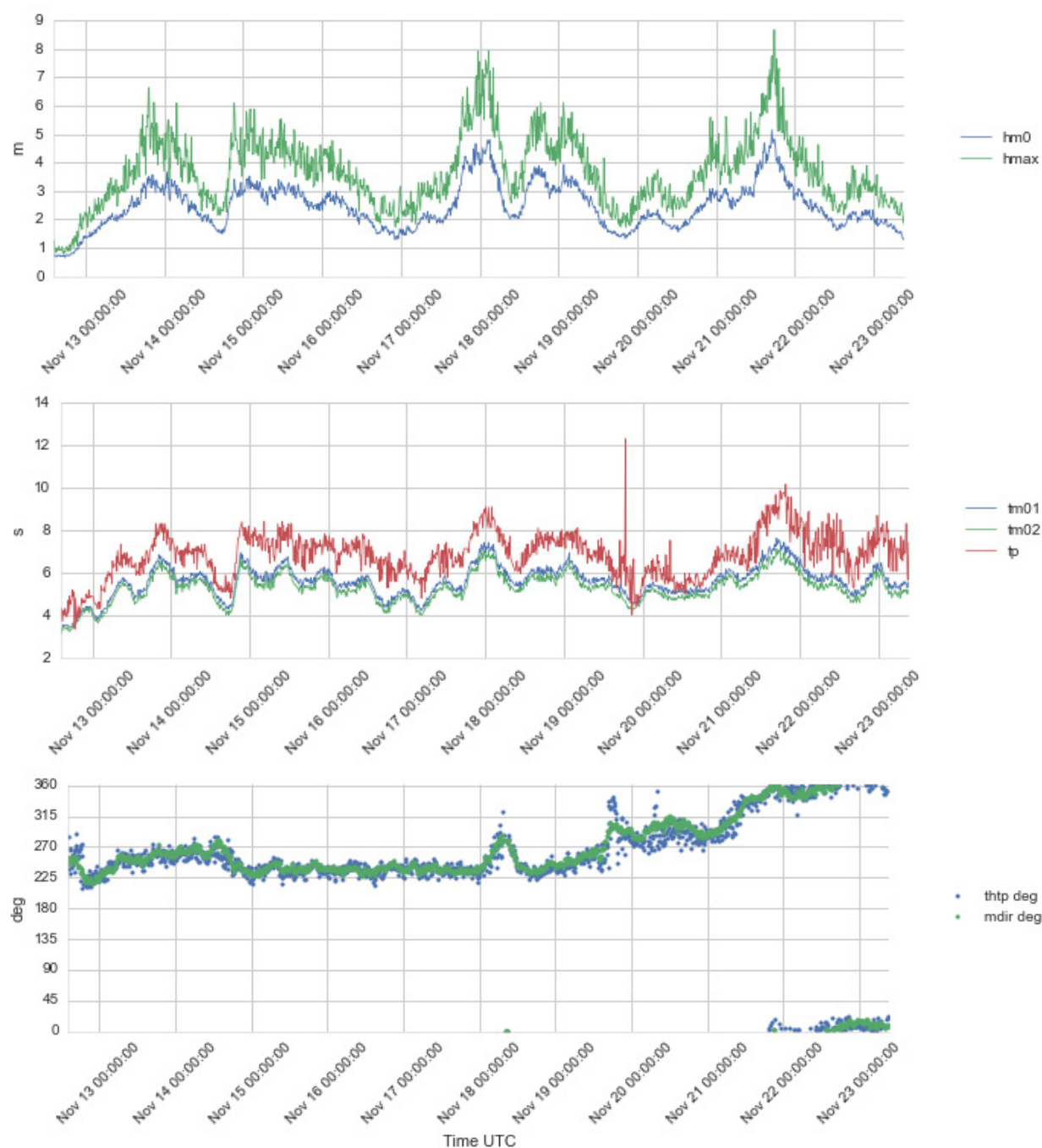
Figure 4.3 Time series plots of air pressure (upper panel), air and water temperature (lower panel), 4 - 14 Dec 2015.

#### 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 ( $H_{m0}$ ) measured in this period is 5.16 m from a north-northwesterly direction on 21 November at 17:00. The highest single wave with a height of 8.67 m was observed on the same day at 17:40.

The variations in wave height agree well with the wind speeds in general. The average wave period parameters  $T_{m01}$  and  $T_{m02}$  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 ( $H_{m0}$  and  $H_{max}$ ) (upper panel), wave period ( $T_{m01}$ ,  $T_{m02}$  and  $T_p$ ) (second panel), and wave direction ( $ThTp$  and  $Mdir$ ) (lower panel), 12 - 23 Nov 2015.

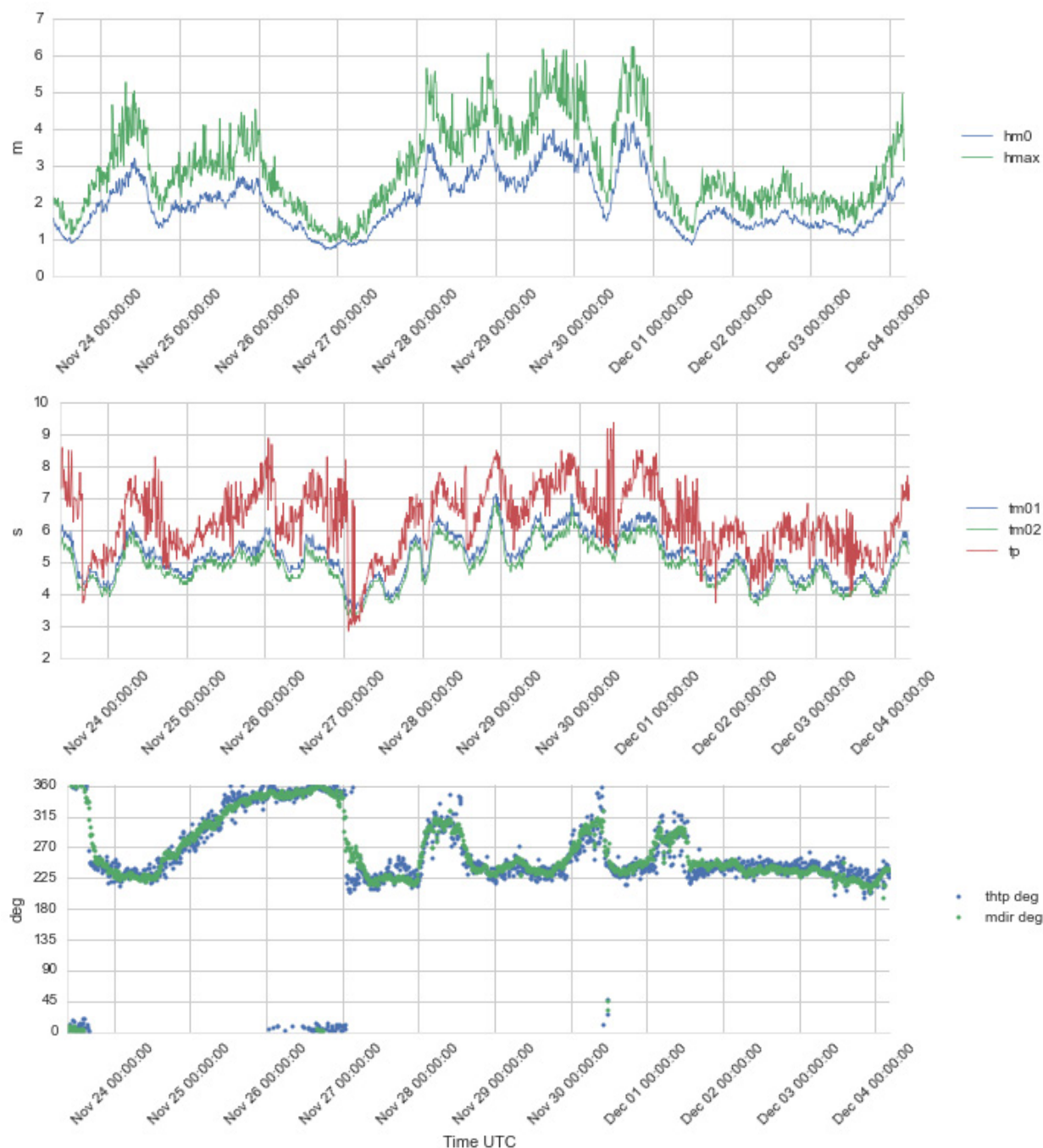


Figure 4.5 Time series plots of wave height ( $H_{m0}$  and  $H_{max}$ ) (upper panel), wave period ( $T_{m01}$ ,  $T_{m02}$  and  $T_p$ ) (second panel), and wave direction ( $ThTp$  and  $Mdir$ ) (lower panel), 23 Nov – 4 Dec 2015.



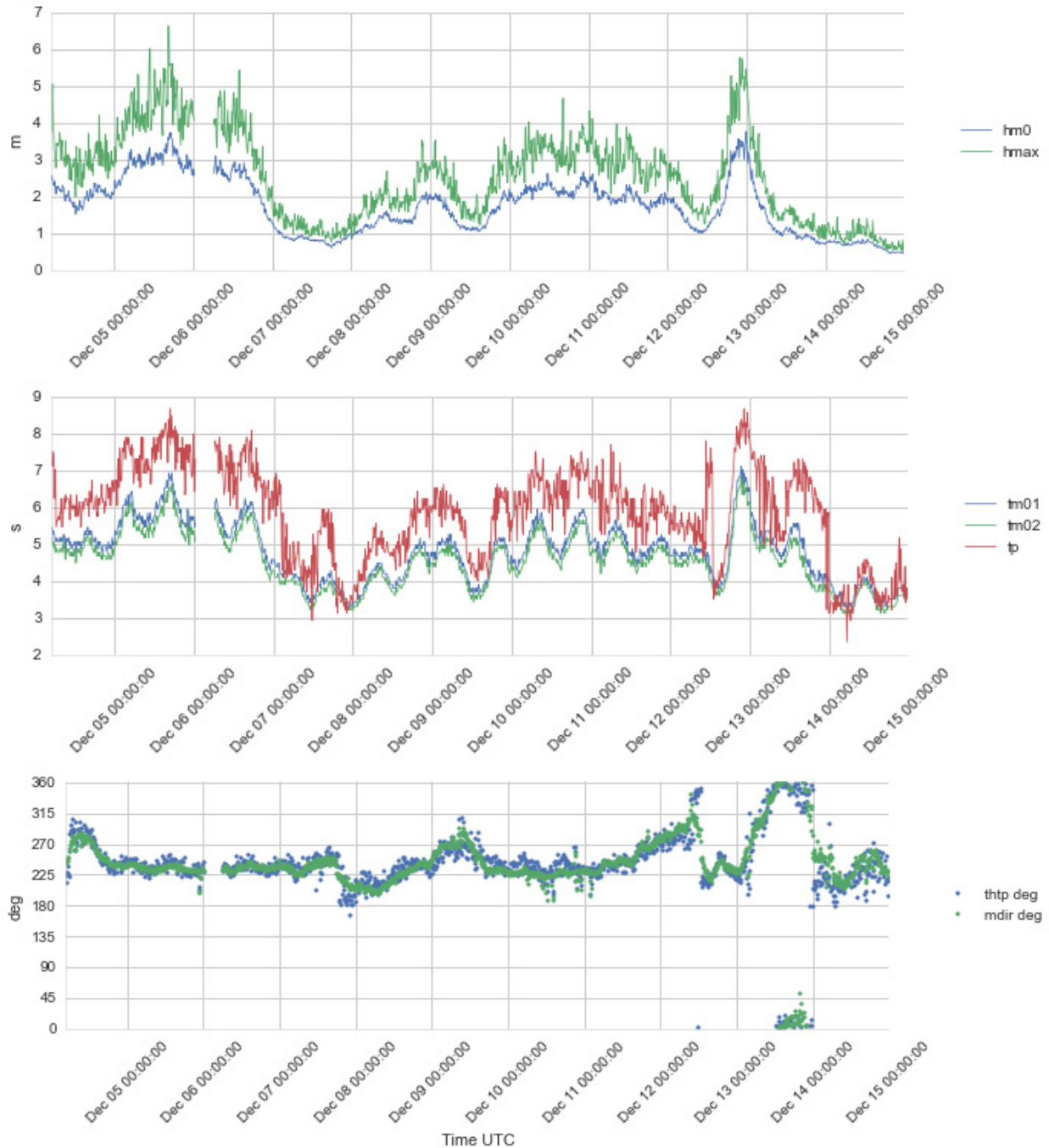


Figure 4.6 Time series plots of wave height (Hm0 and Hmax) (upper panel), wave period (Tm01, Tm02 and Tp) (second panel), and wave direction (ThTp and Mdir) (lower panel), 4 - 14 Dec 2015.

#### 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. In this period 10 min mean wind speeds up to 20.2 m/s and gusts up to 25.7 m/s were measured at 4 m above the sea surface. The average wind speed at this height was 10.6 m/s.

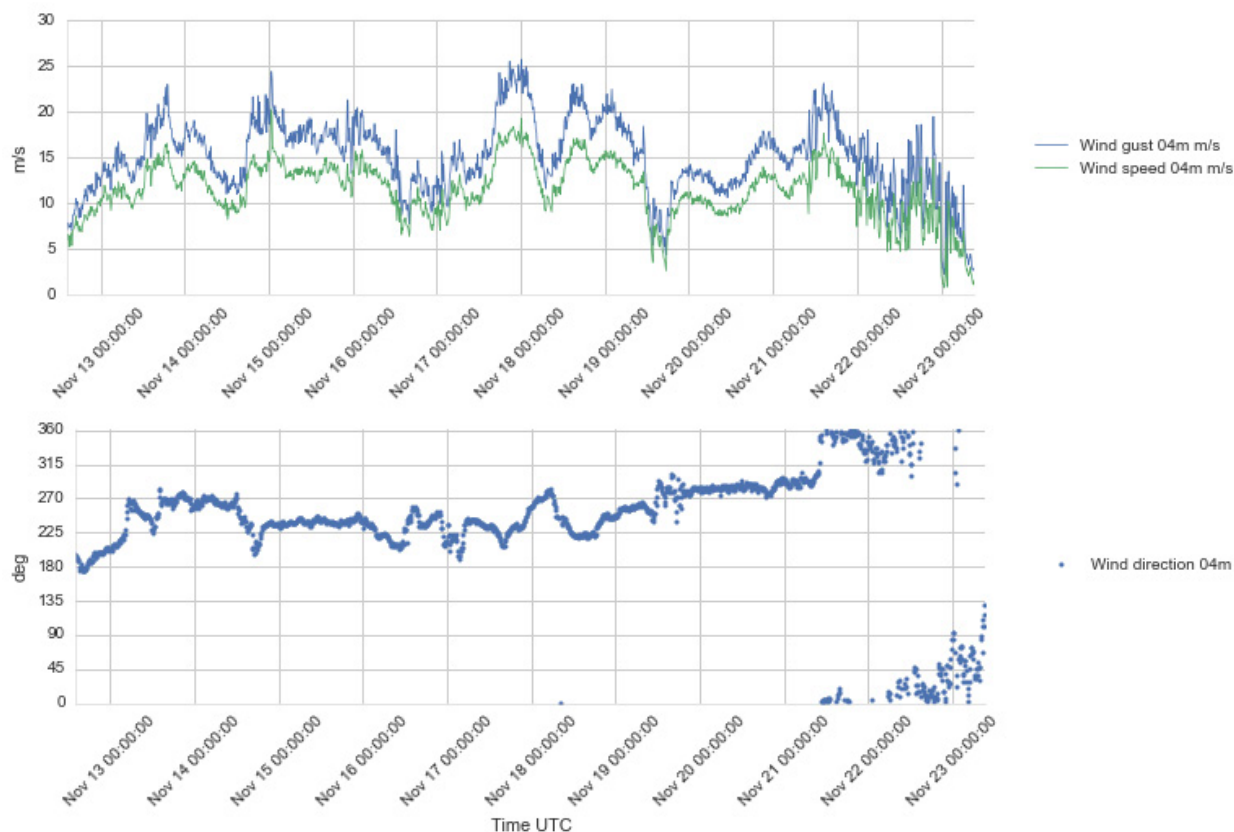


Figure 4.7 Plots of wind speed and gust (upper), and wind direction (lower) at 4 m a.s.l., 12 - 23 Nov 2015.

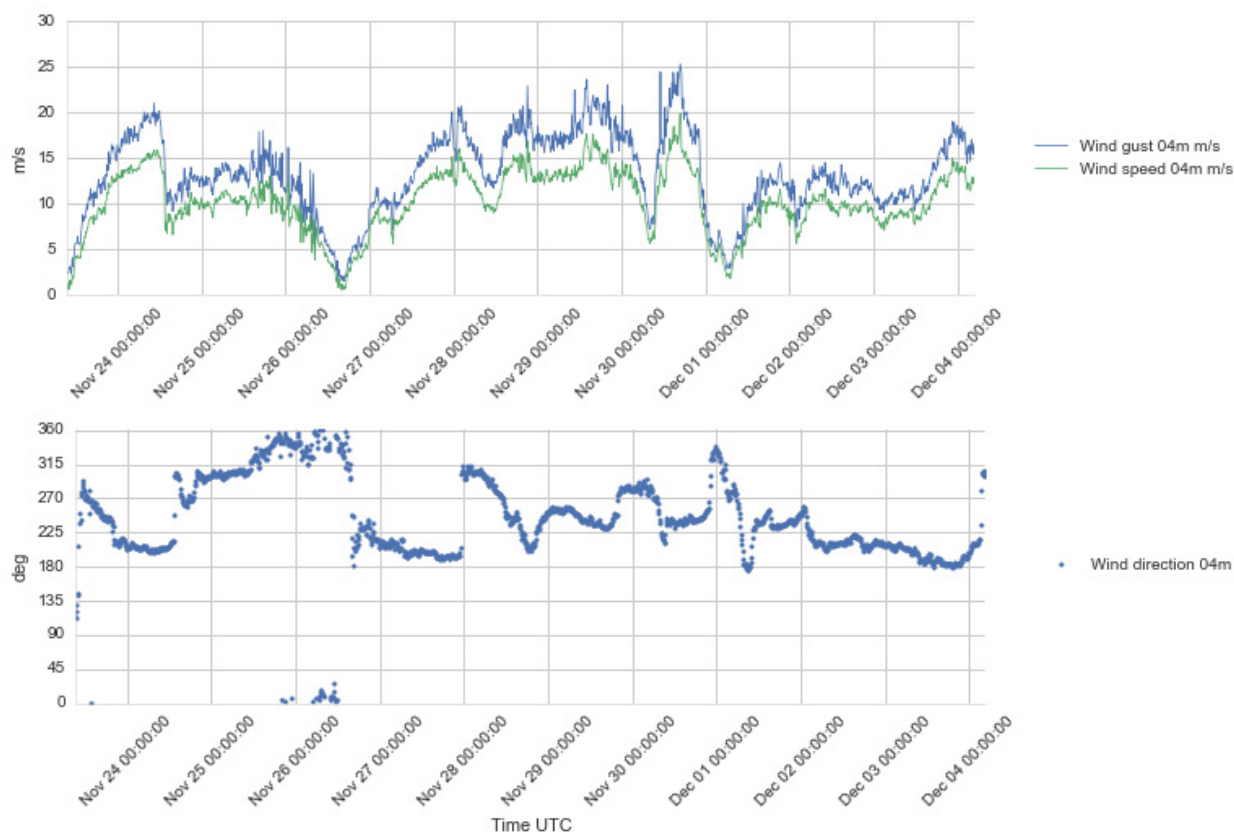
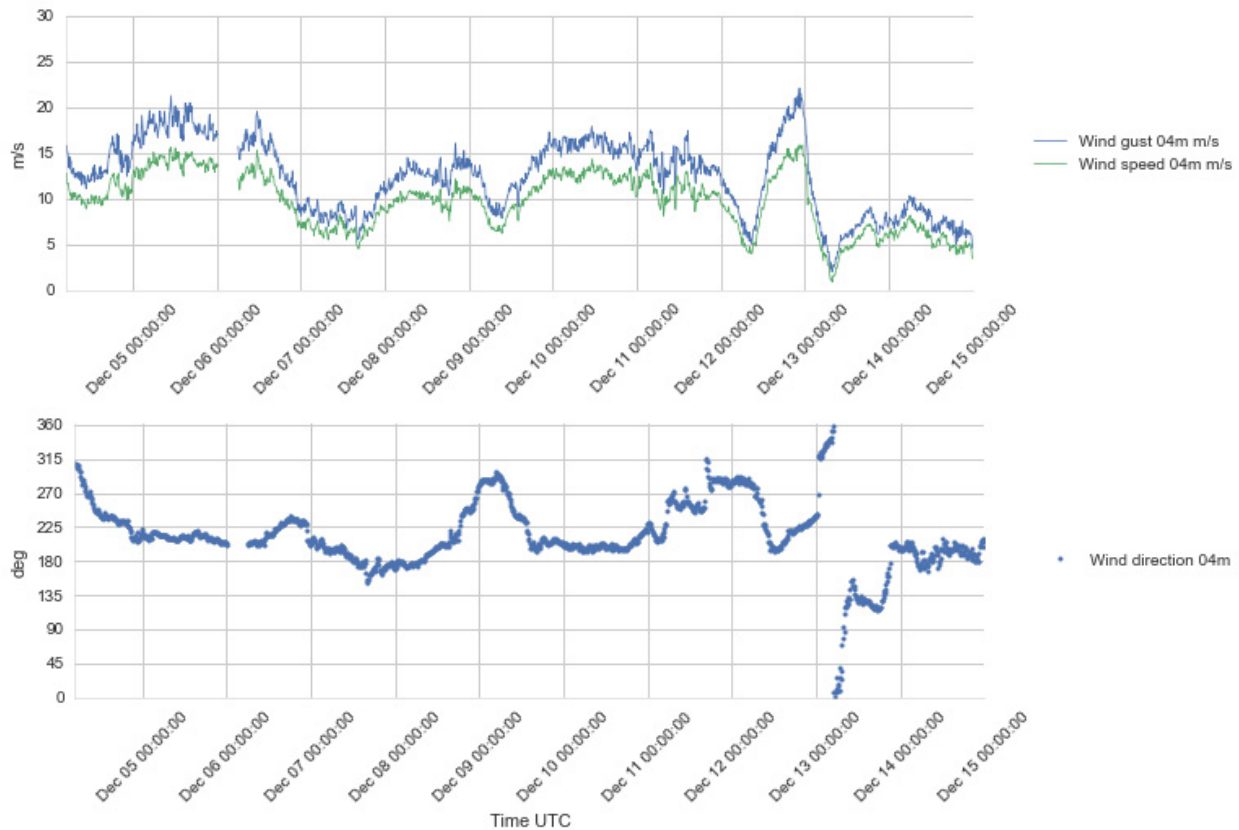


Figure 4.8 Plots of wind speed and gust (upper), and wind direction (lower) at 4 m a.s.l., 23 Nov – 4 Dec 2015.



**Figure 4.9 Plots of wind speed and gust (upper), and wind direction (lower) at 4 m a.s.l., 4 – 14 Dec 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<sup>1</sup>.

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.

The highest observed horizontal mean wind speed during this month varies from 24.3 m/s at 30 m to 29.5 m/s at 200 m above the surface. These maxima were measured on 17 November 2015 at 21:50 - 22:00. The wind direction was around 240° at that time.

<sup>1</sup> 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., 12 - 23 Nov 2015.

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

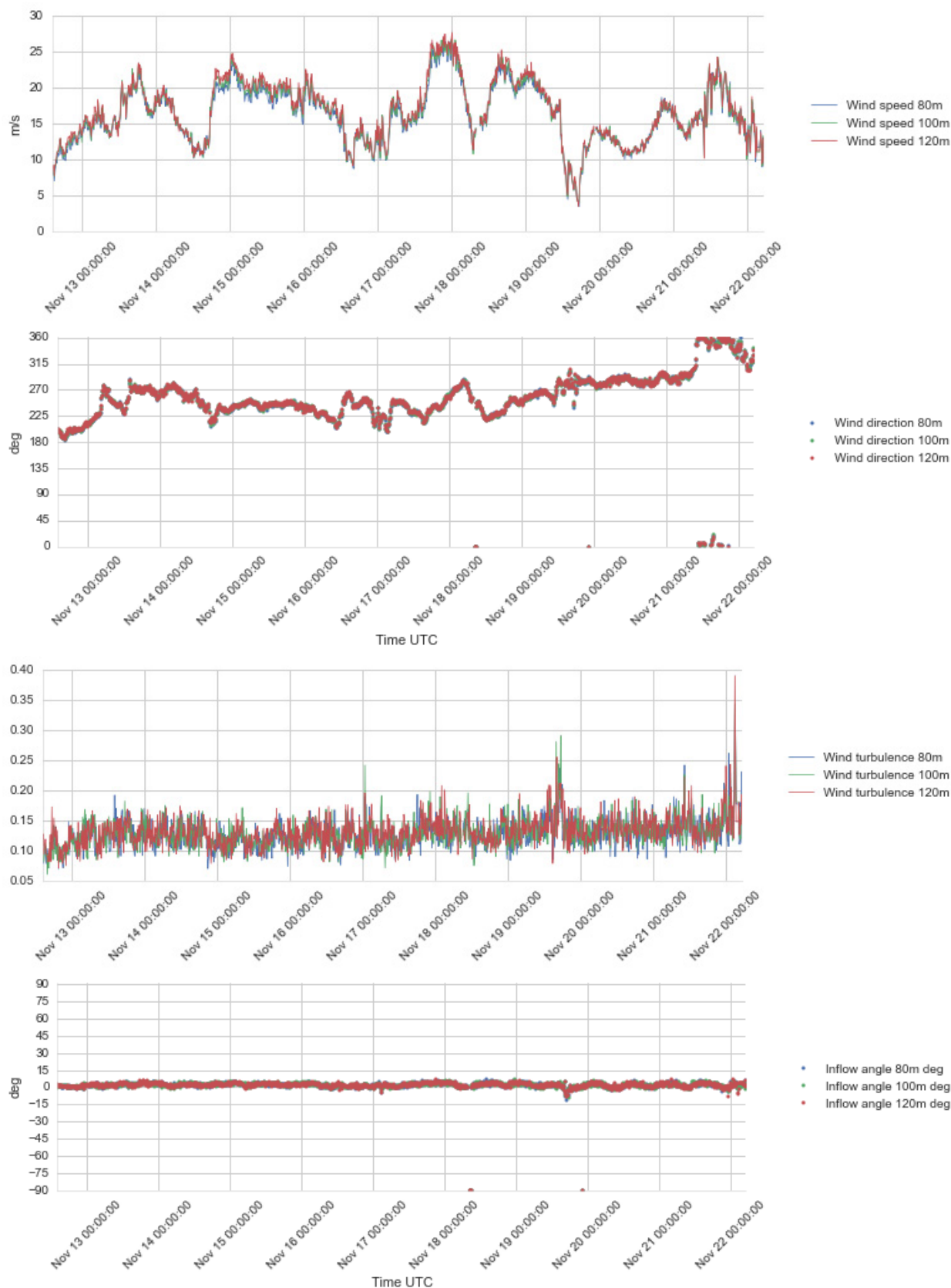


Figure 4.11 Plots of wind profile data, 80 – 120 m a.s.l., 12 - 23 Nov 2015.

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



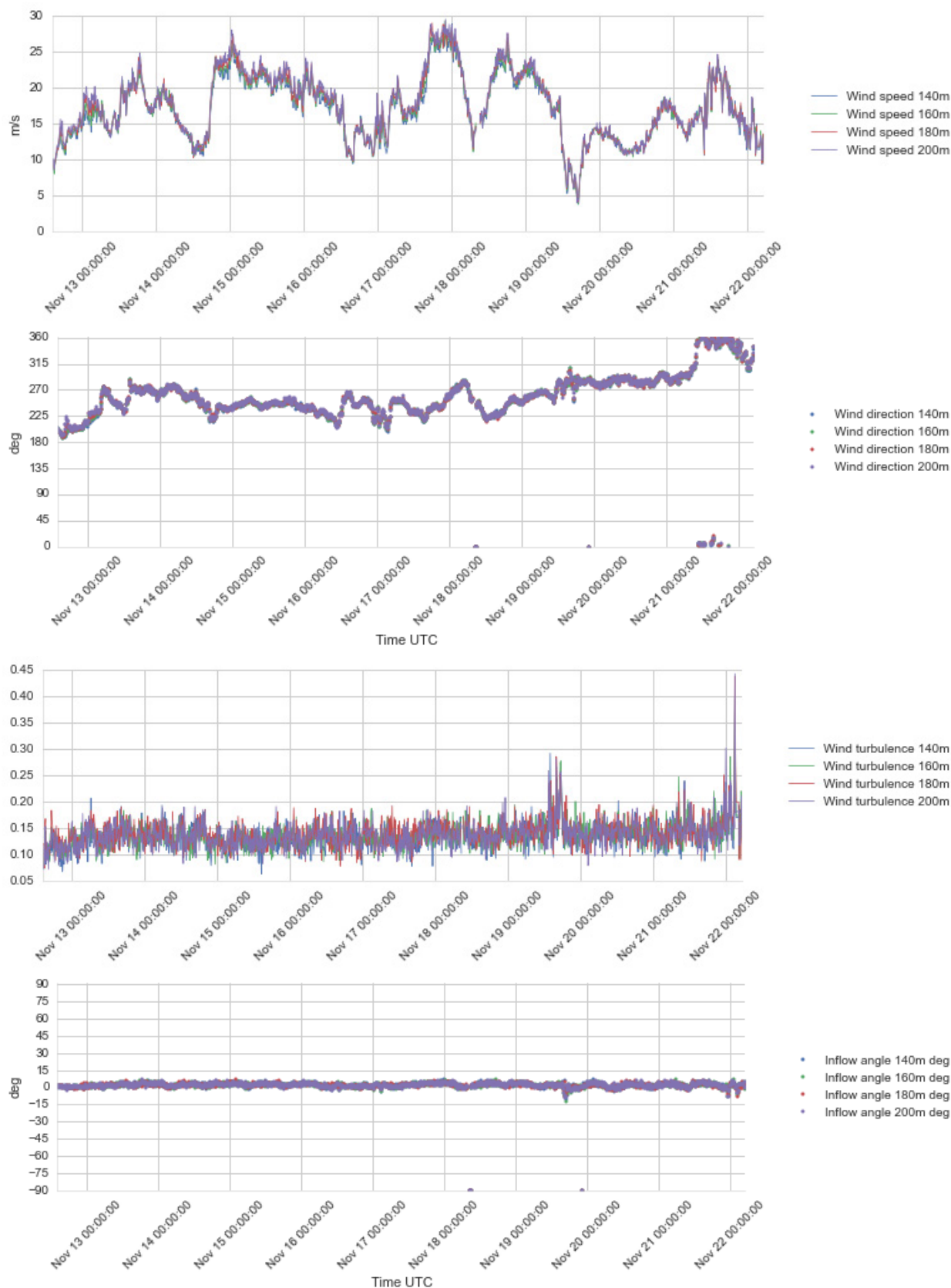


Figure 4.12 Plots of wind profile data, 140 – 200 m a.s.l., 12 - 23 Nov 2015.

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

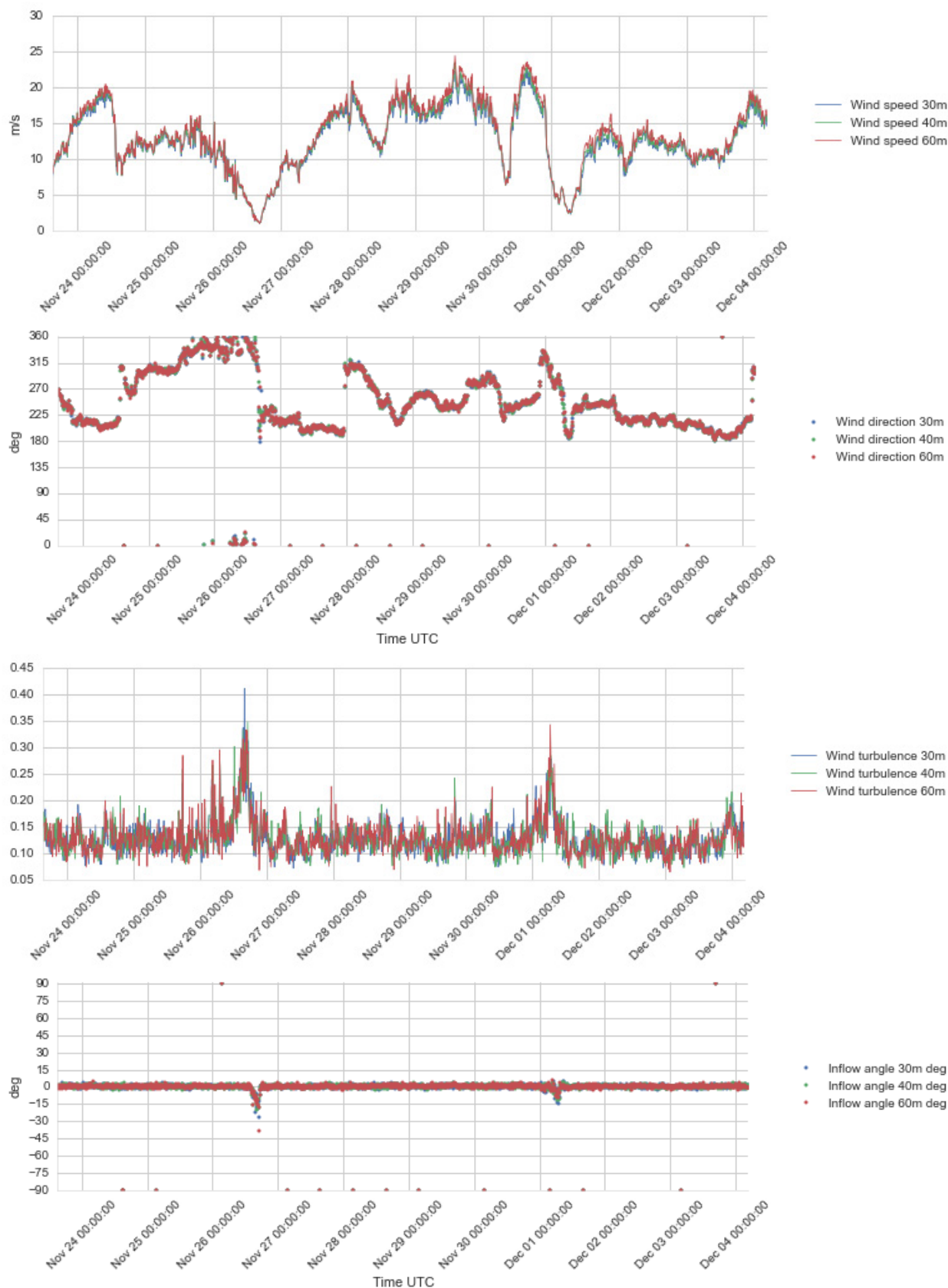


Figure 4.13 Plots of wind profile data, 30 – 60 m a.s.l., 23 Nov – 4 Dec 2015.

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., 23 Nov – 4 Dec 2015.

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

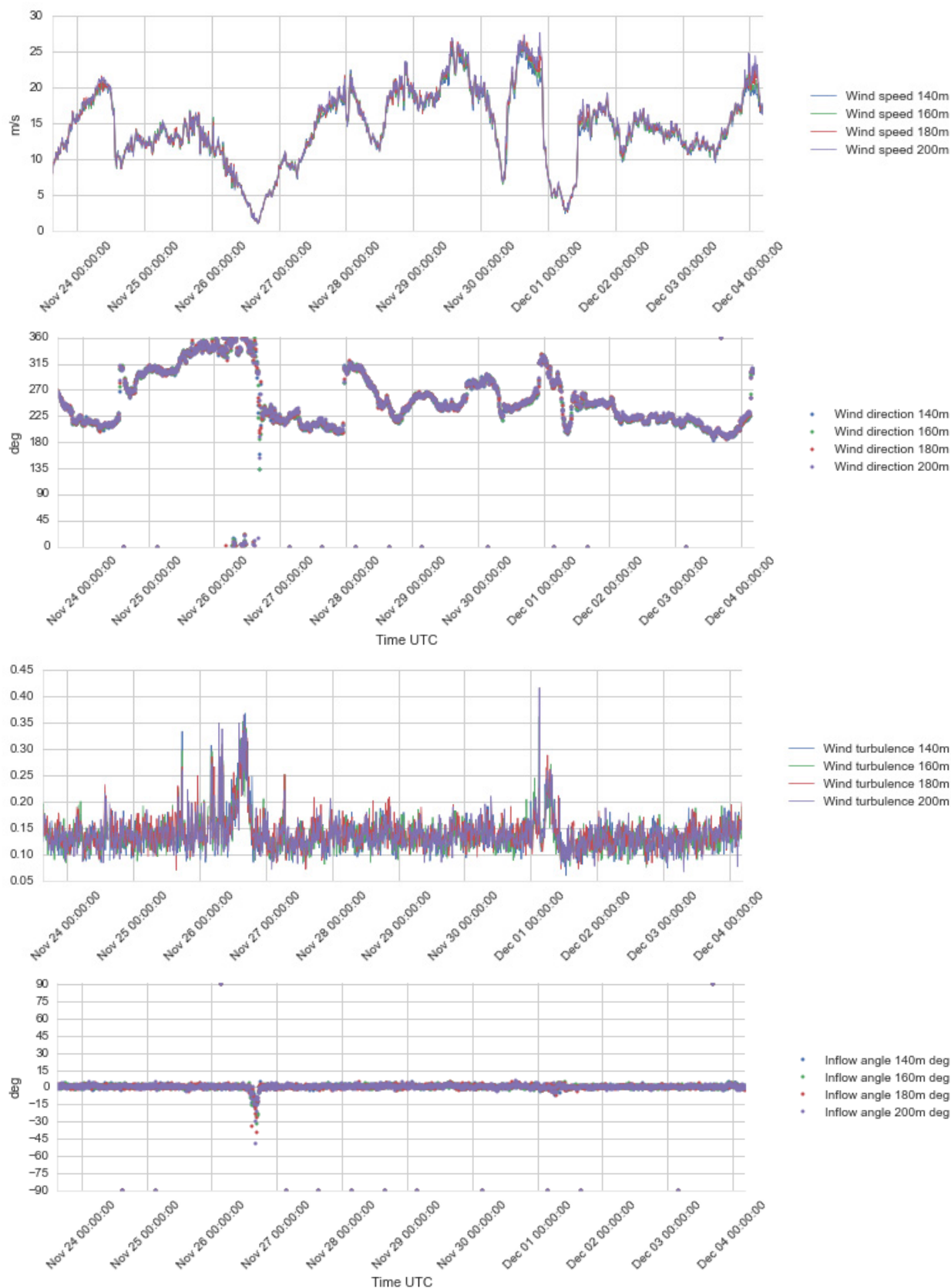


Figure 4.15 Plots of wind profile data, 140 – 200 m a.s.l., 23 Nov – 4 Dec 2015.

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

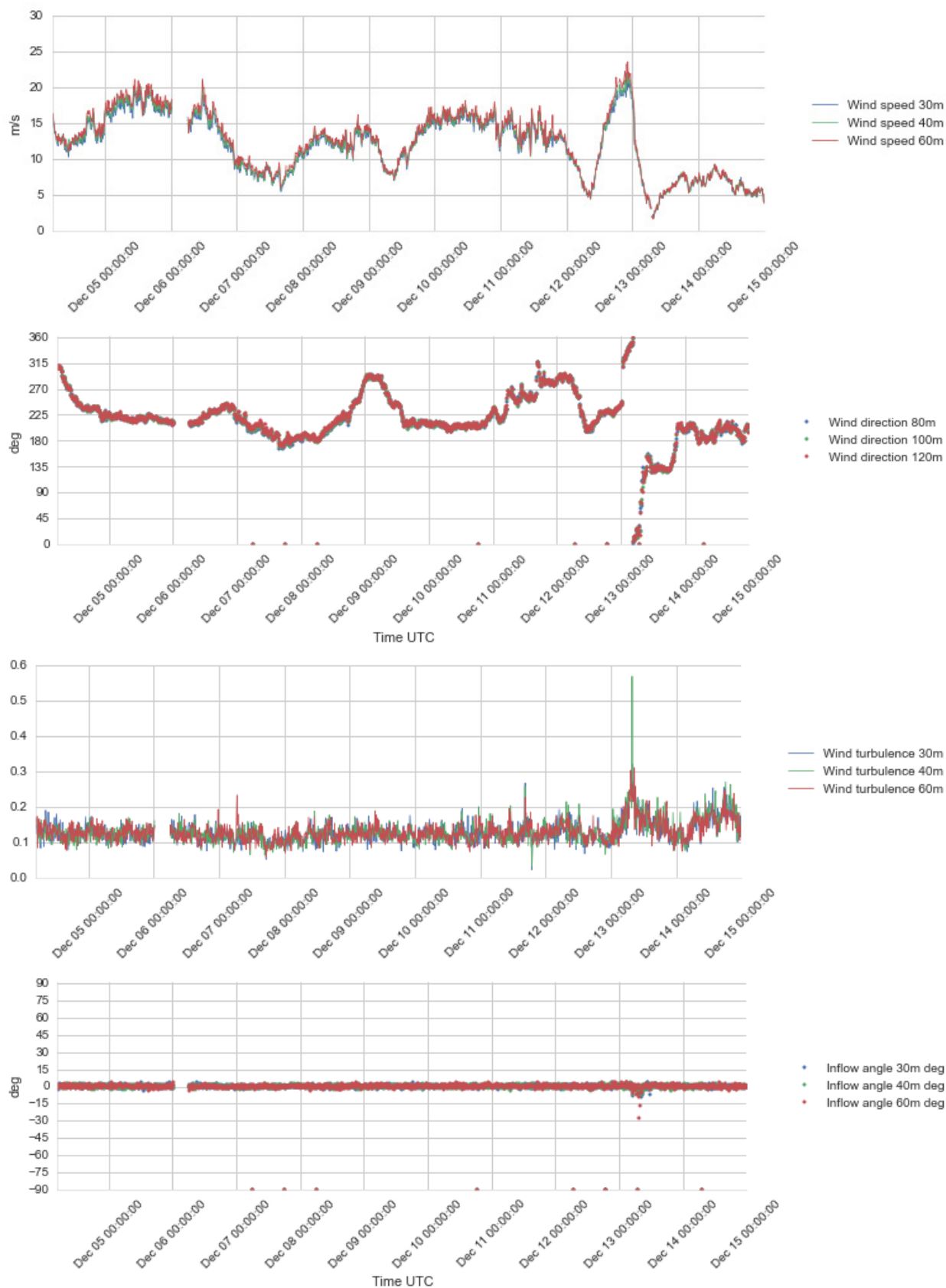


Figure 4.16 Plots of wind profile data, 30 – 60 m a.s.l., 4 – 14 Dec 2015.

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

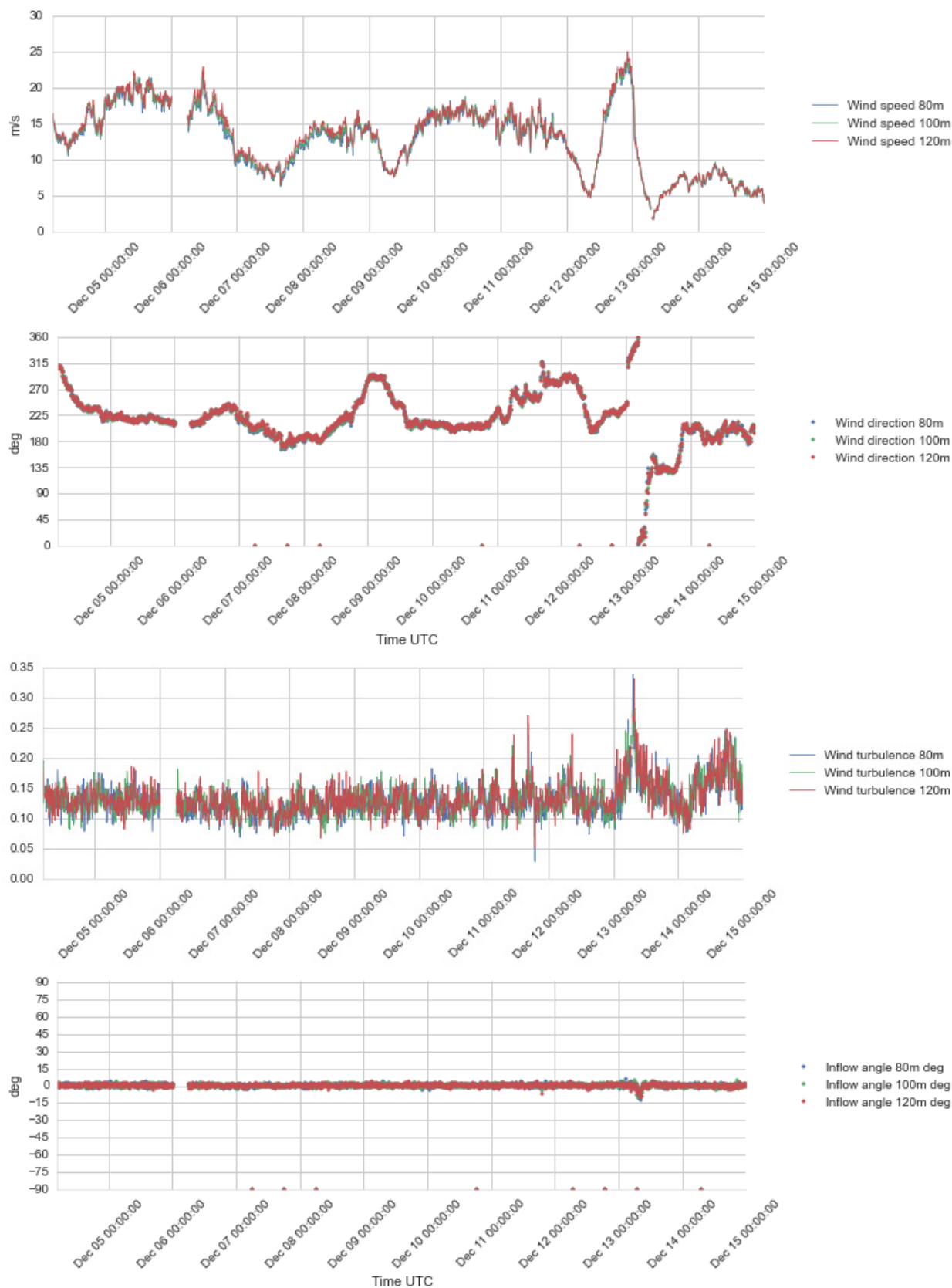


Figure 4.17 Plots of wind profile data, 80 – 120 m a.s.l., 4 – 14 Dec 2015.

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

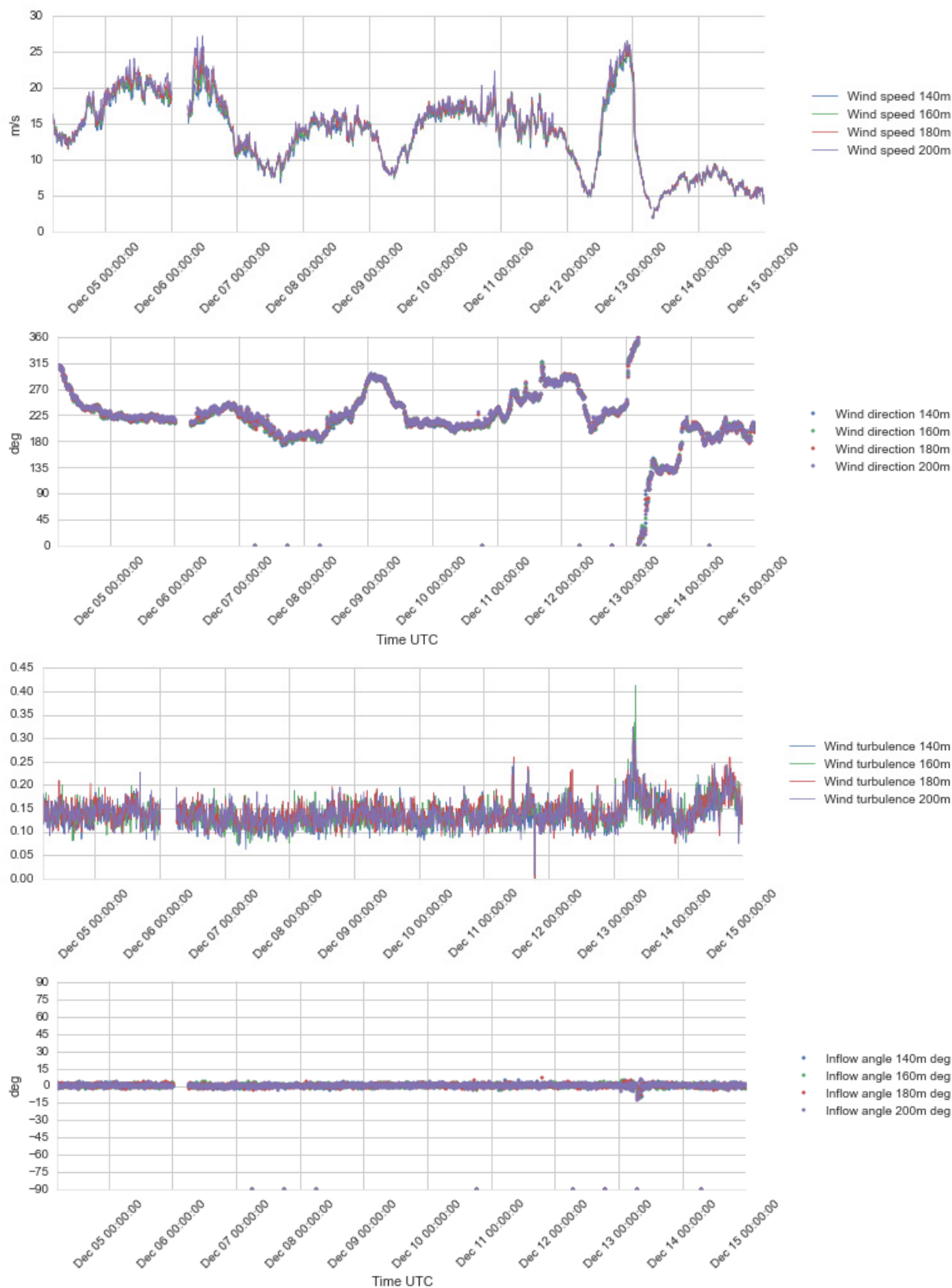


Figure 4.18 Plots of wind profile data, 140 – 200 m a.s.l., 4 – 14 Dec 2015.

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

#### **4.2.4 Current velocity profile data**

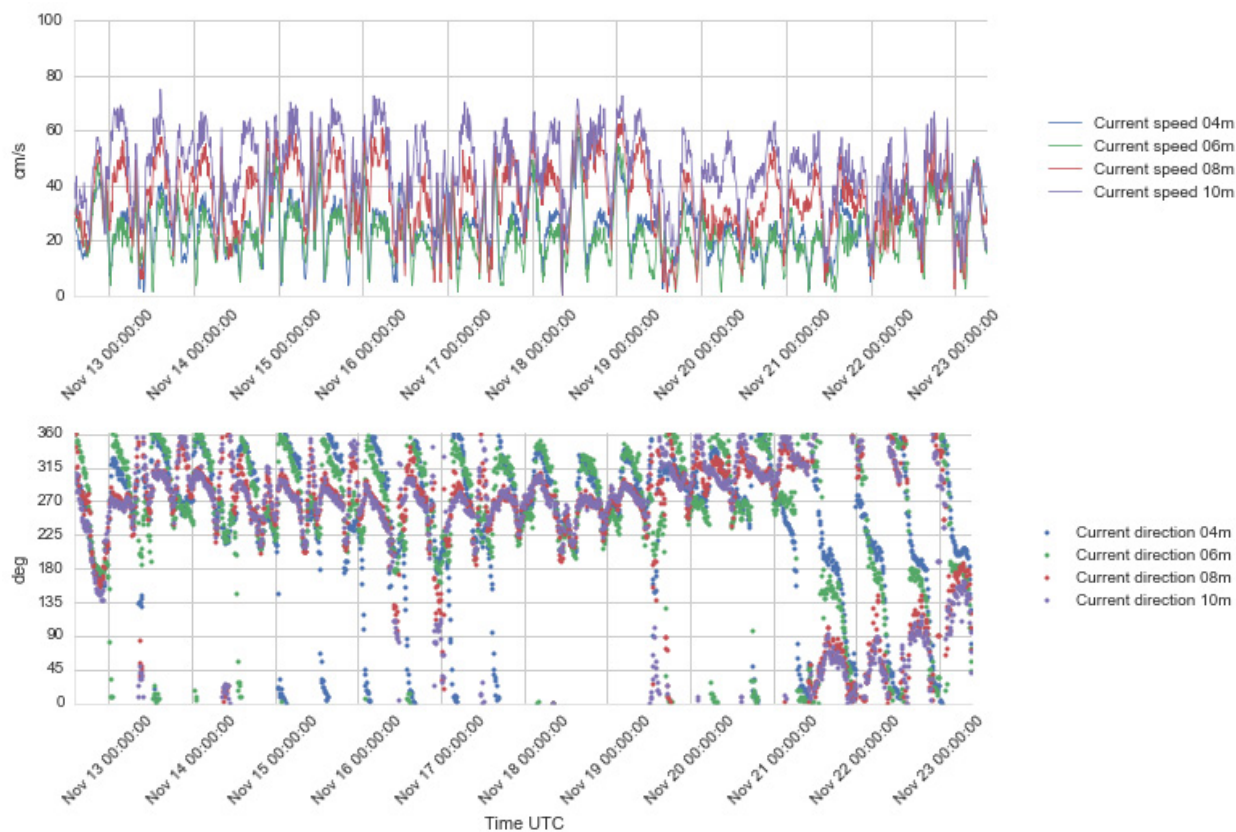
The following plots show the current velocity profile time series. In these plots current direction 0° or 360° means that the current flows toward north, 90° indicates flow toward east etc. In general the current profiler has worked well, just a few data points were lost due to buoy restarting, but otherwise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

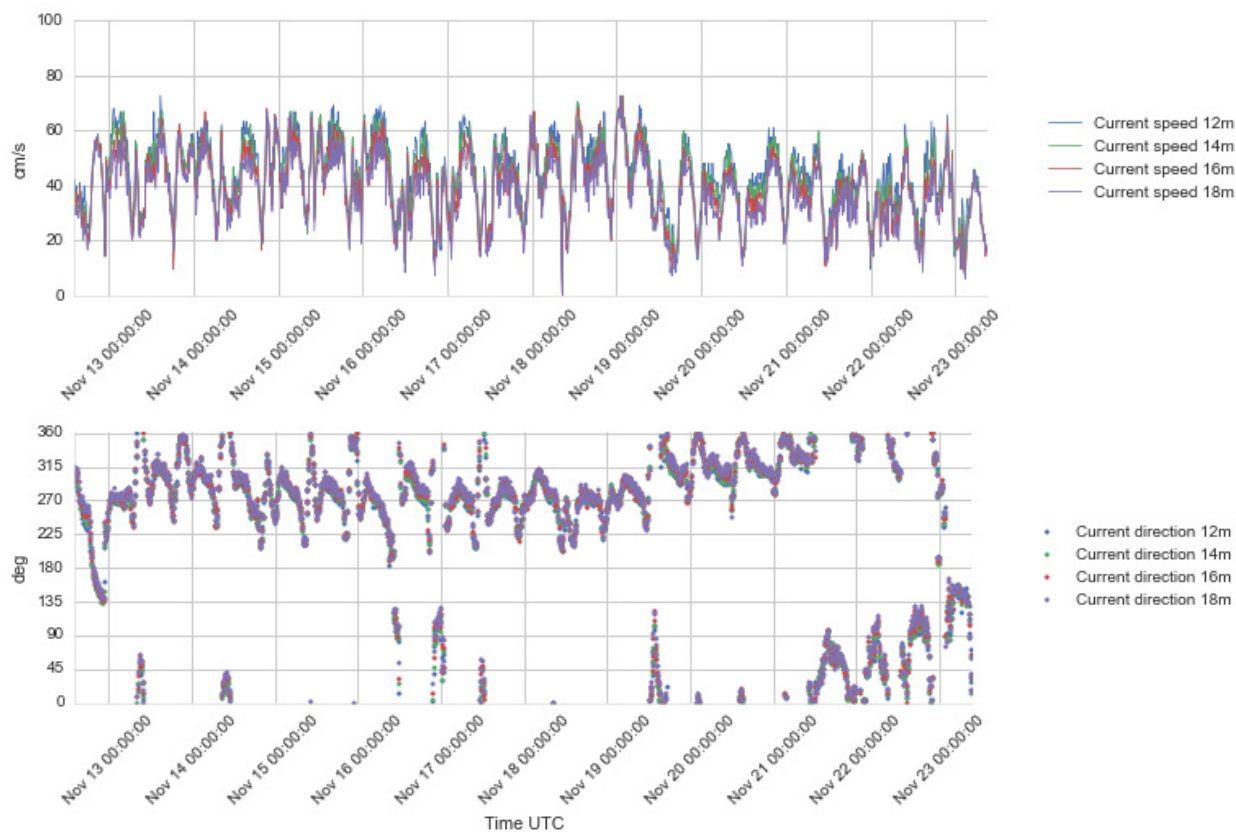
The current measurements at 4 – 8 m depth appear too low in general compared to the measurements at middle depths. This is probably caused by disturbances in the upper layer due to wake effects on the leeward side of the buoy where the sensor was placed. (The sensor is placed on the opposite side compared to where the mooring is connected.)

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, 12 - 23 Nov 2015**



**Figure 4.20 Time series plots of current speed (upper) and direction (lower panel), 12 - 18 m depth, 12 - 23 Nov 2015**



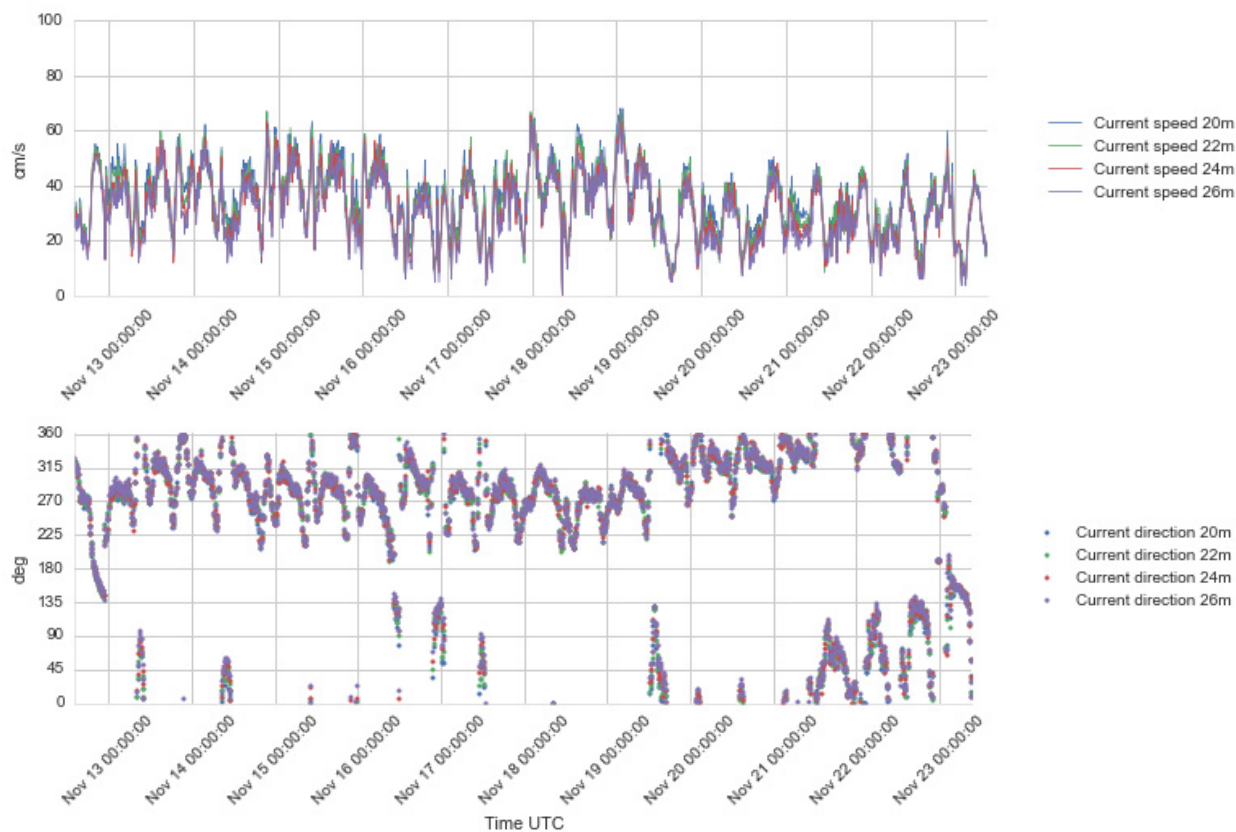


Figure 4.21 Time series plots of current speed (upper) and direction (lower panel), 20 - 26 m depth, 12 - 23 Nov 2015

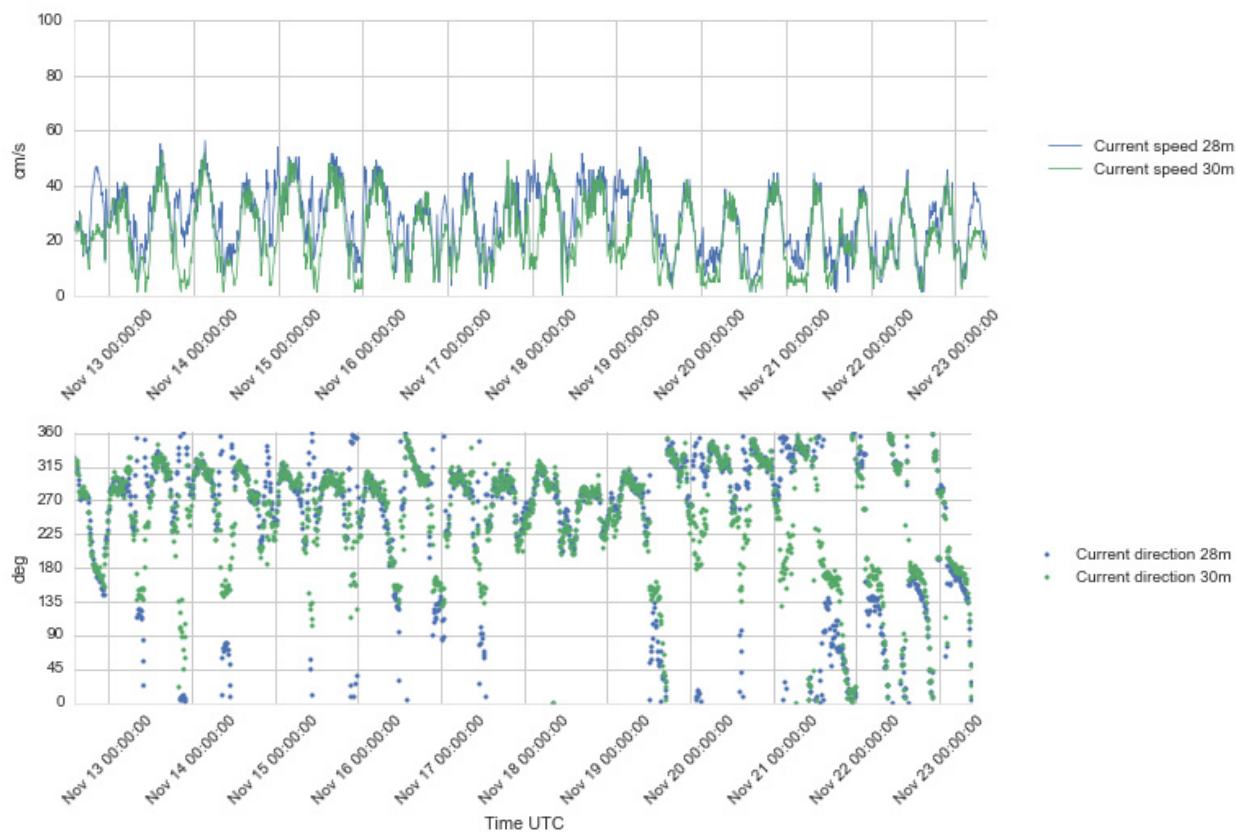


Figure 4.22 Time series plots of current speed (upper) and direction (lower panel), 28 - 30 m depth, 12 - 23 Nov 2015

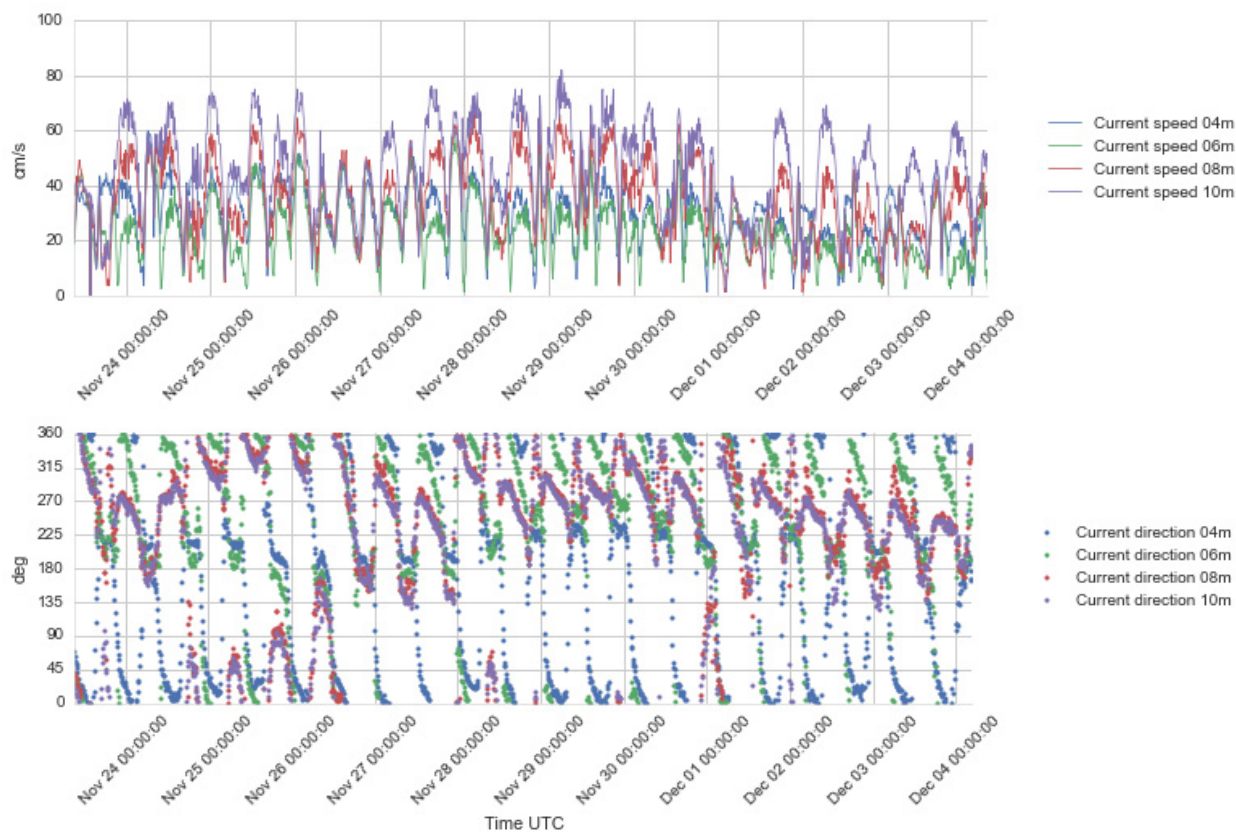


Figure 4.23 Time series plots of current speed (upper) and direction (lower panel), 4 - 10 m depth, 23 Nov – 4 Dec 2015

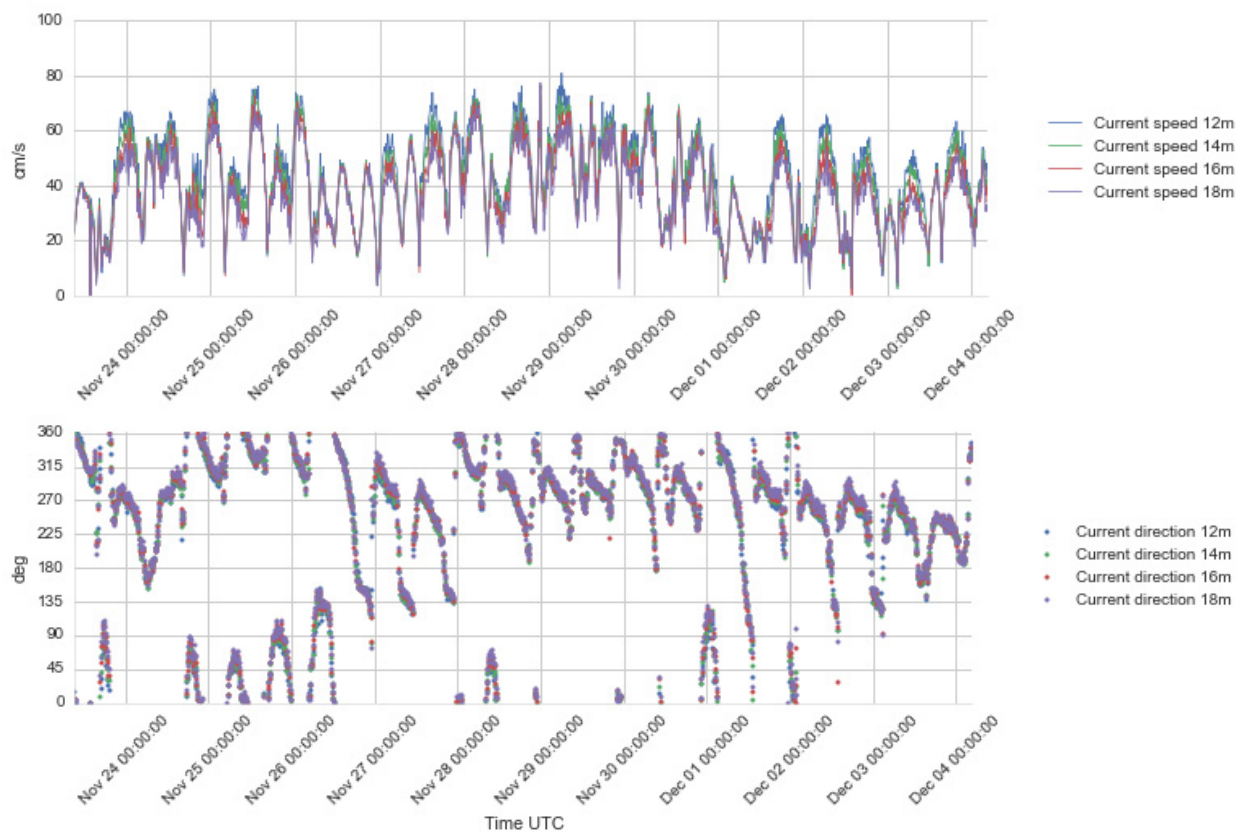


Figure 4.24 Time series plots of current speed (upper) and direction (lower panel), 12 -18 m depth, 23 Nov – 4 Dec 2015

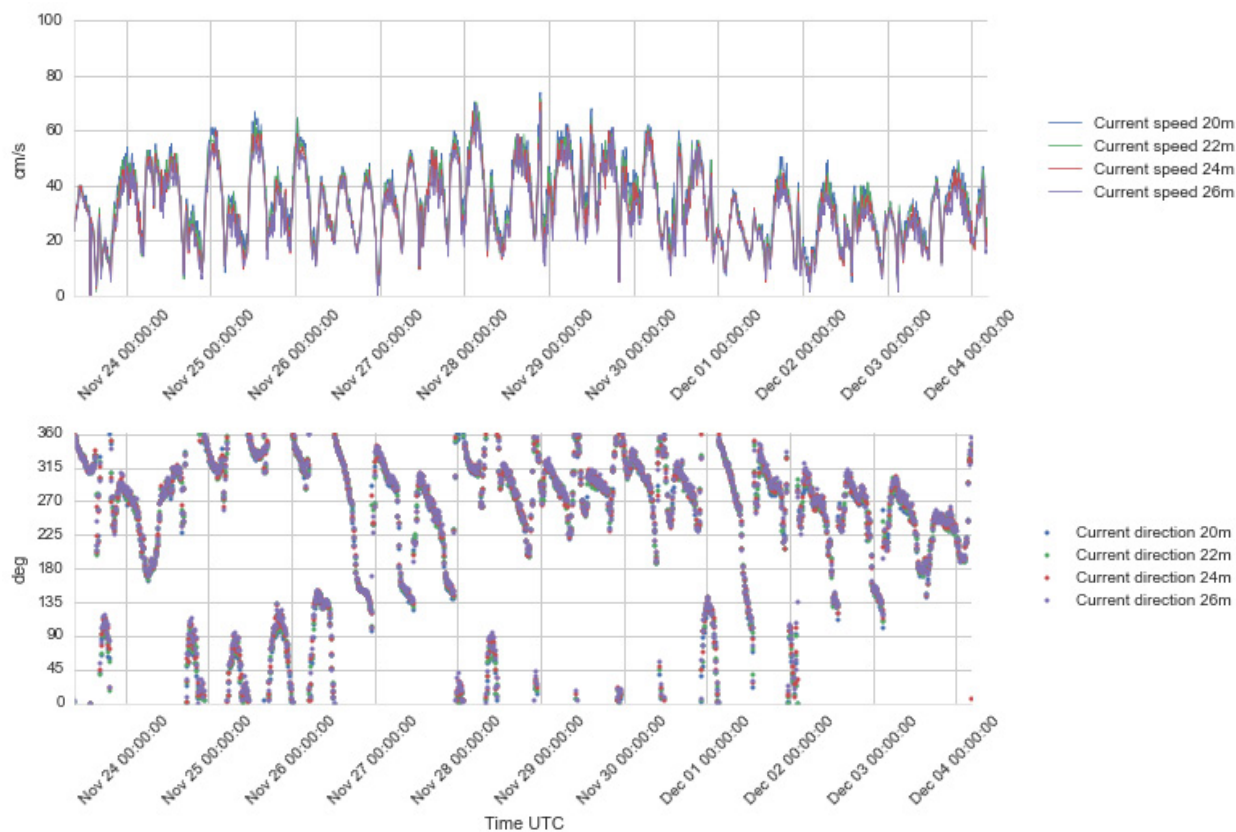


Figure 4.25 Time series plots of current speed (upper) and direction (lower panel), 20 – 26 m depth, 23 Nov – 4 Dec 2015

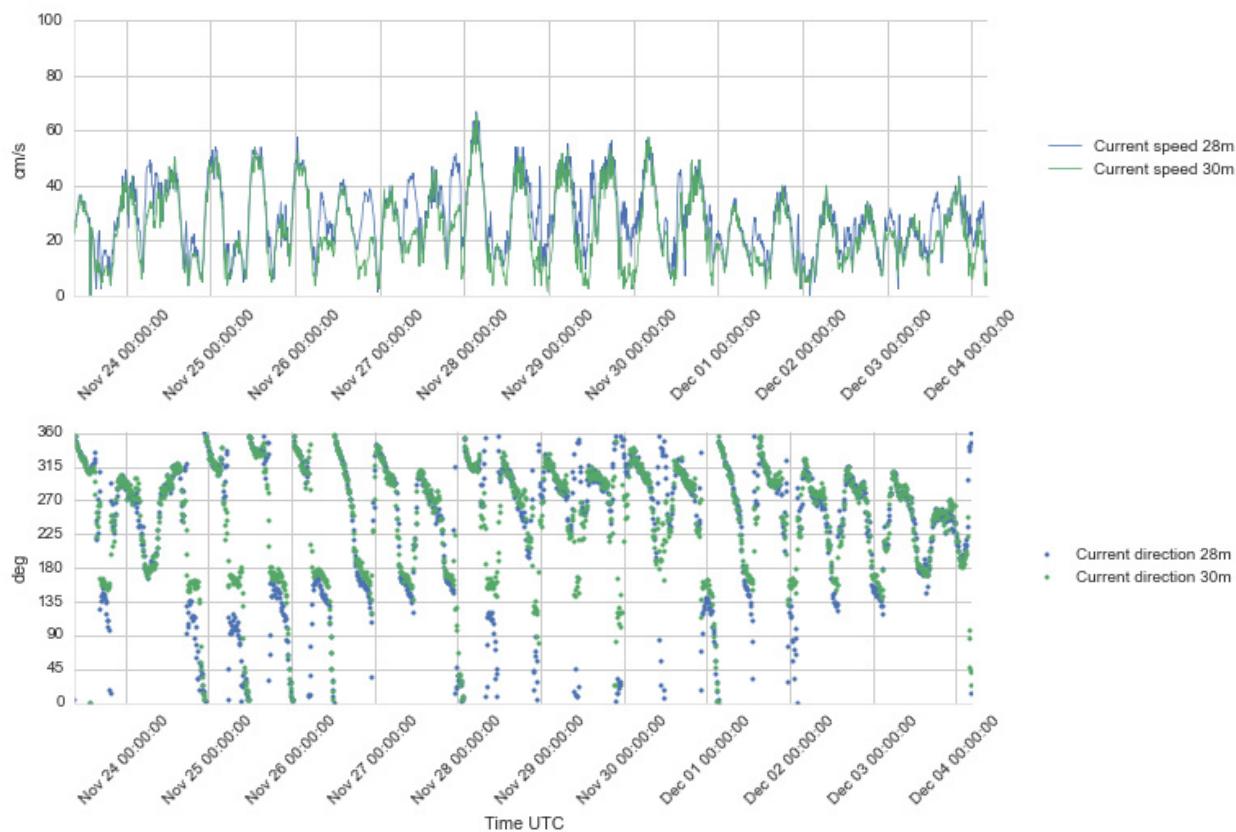
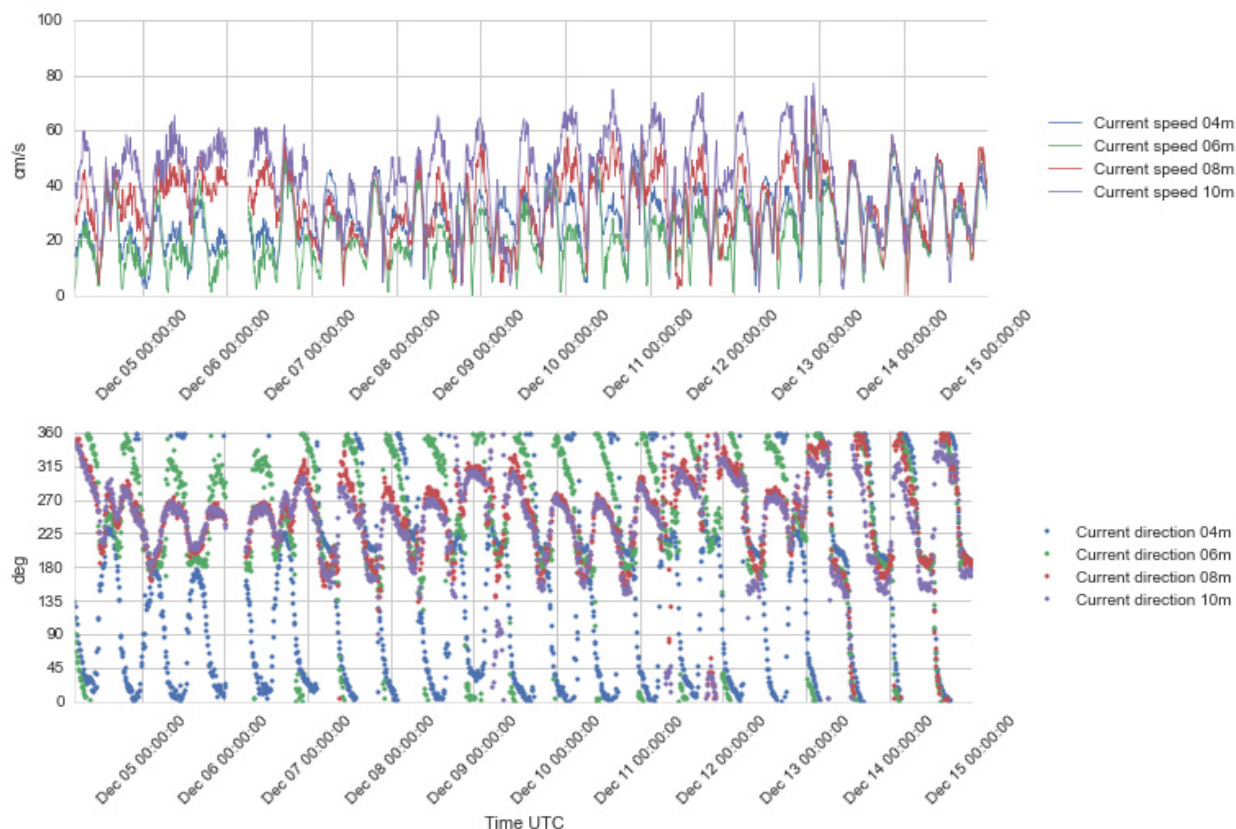
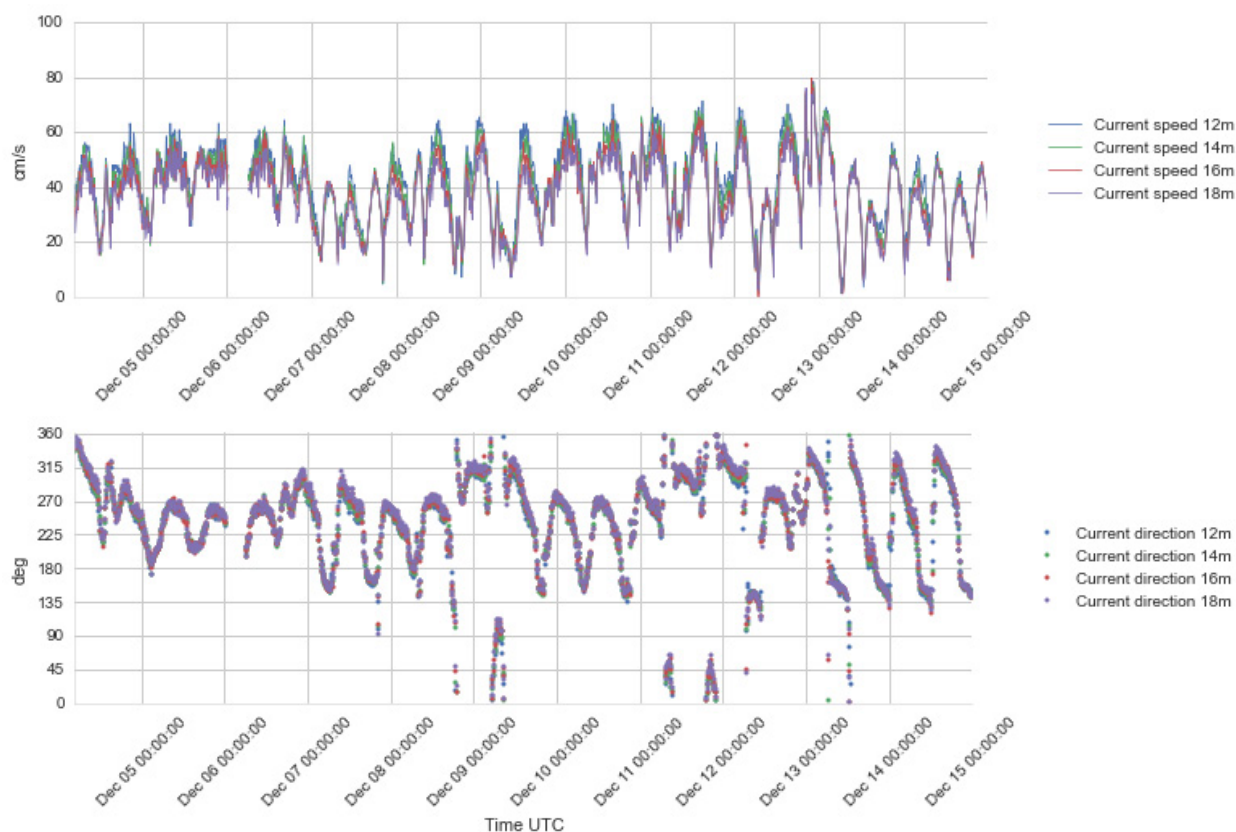


Figure 4.26 Time series plots of current speed (upper) and direction (lower panel), 28 – 30 m depth, 23 Nov – 4 Dec 2015

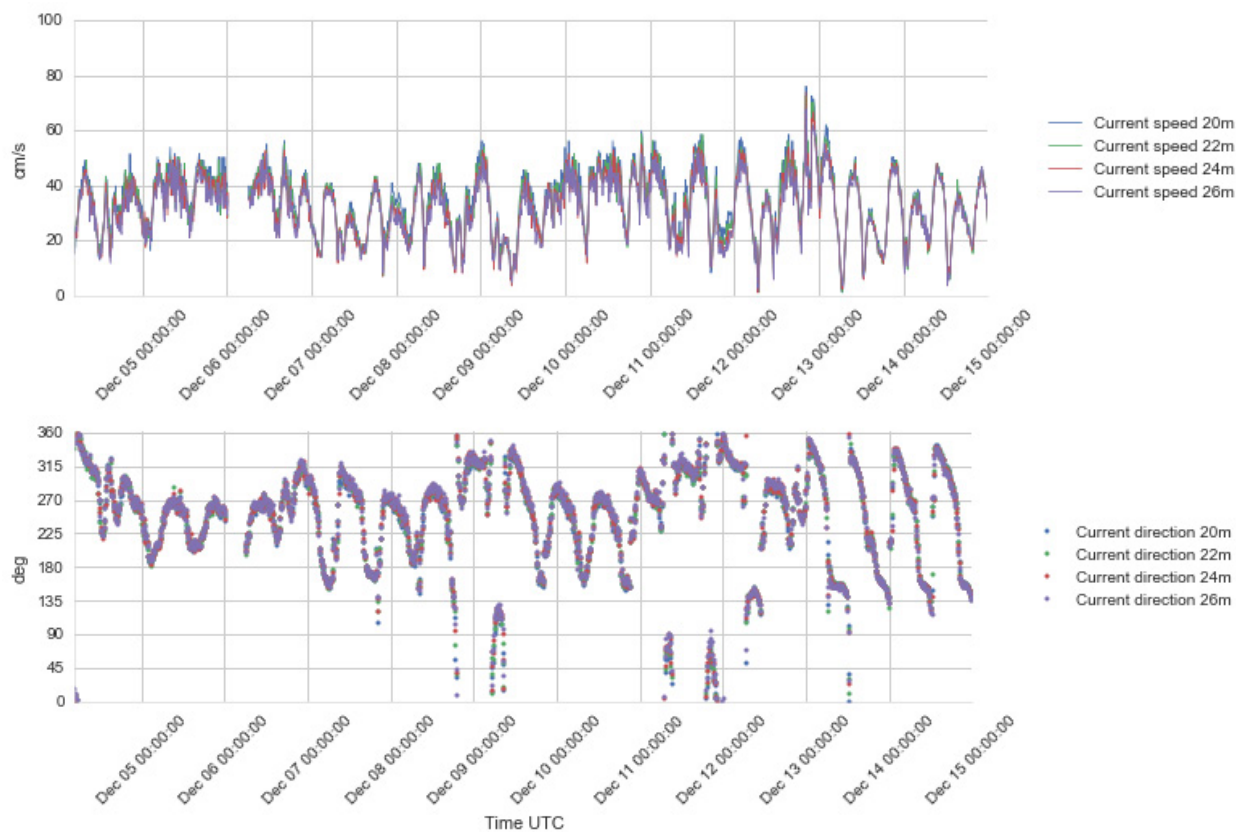




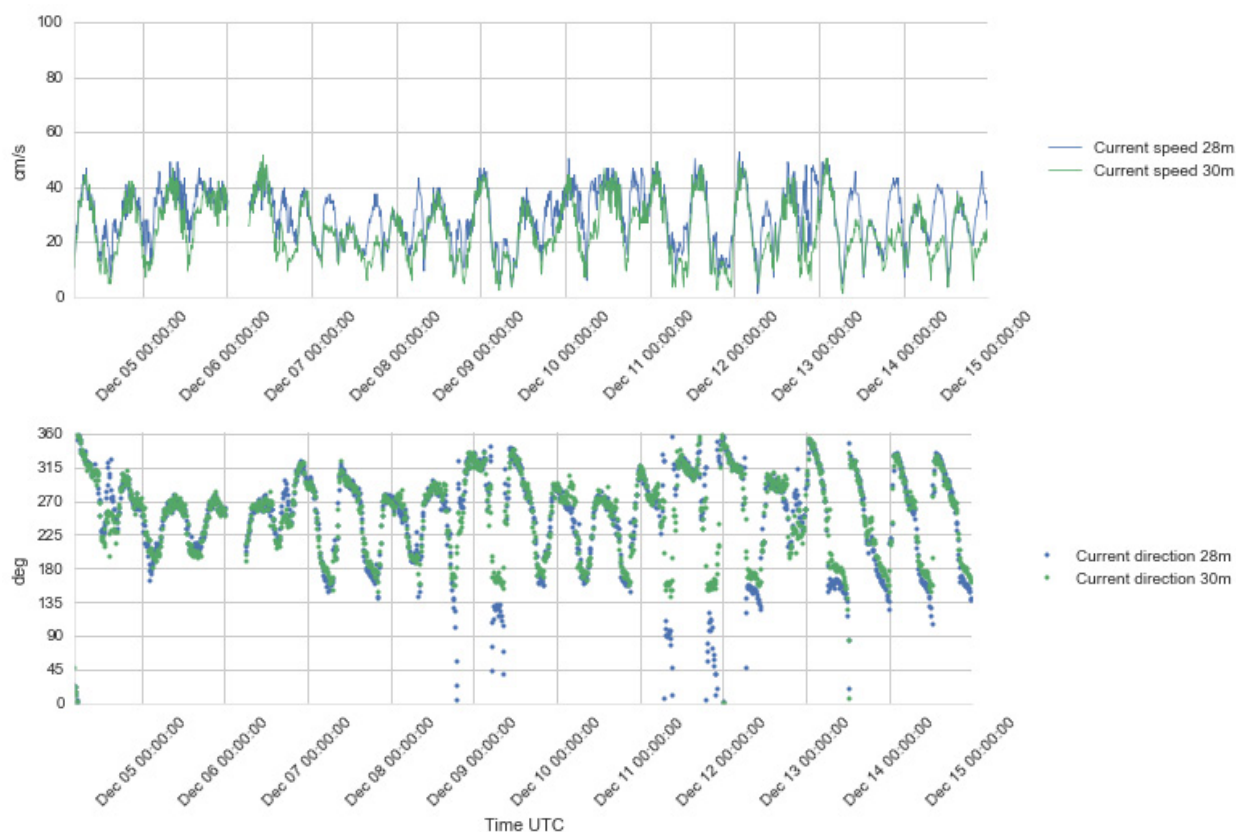
**Figure 4.27 Time series plots of current speed (upper) and direction (lower panel), 4 - 10 m depth, 4 – 14 Dec 2015**



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



**Figure 4.29 Time series plots of current speed (upper) and direction (lower panel), 20 - 26 m depth, 4 – 14 Dec 2015**



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

Several attempts to recover the WLR have been performed without success. It is thus decided to postpone further attempts until better weather and lighter days come in the spring.

Because of this a new WLR recorder without acoustic communication was deployed on 18 December 2015 together with the buoy. It is believed that at least one of the WLR units will record data that later can be 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:	
<b>Buoy module/sensor</b>		<b>Serial number/ID</b>	
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	
ZephIR 300S Lidar		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	Local time
First measurement	2015	06	11	1655
First measurement in position	2015	06	11	1814
Out of measuring position	2015	10	06	11:30
Last measurement				
<b>Comments:</b> <b>WLR deployment position:</b> <b>51° 42.4362N, 3° 02.1030E, Depth: 30m</b> <b>Time reference: CET (DST) (UTC + 2 hours)</b>				
Deployment vessel: MPR3	Recovery vessel: Multirasalvor 3			
Deployed by: EME & OKH	Recovered by:			

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:	33910 – 33914, 33919	Buoy marking:	
<b>Buoy module/sensor</b>		<b>Serial number/ID</b>	
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	
ZephIR 300S Lidar		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.			
<b>DEPLOYMENT HISTORY</b>				
	<b>YEAR</b>	<b>MONTH</b>	<b>DATE</b>	<b>Time (UTC)</b>
First measurement	2015	11	12	14:00
First measurement in position	2015	11	12	14:20
Out of measuring position				
Last measurement				
<b>Comments:</b> <b>WLR deployment position:</b> <b>51° 42.4362N, 3° 02.1030E, Depth: 30m</b> <b>Time reference: UTC</b>				
Deployment vessel: Multisalvor 3		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: 12 November - 14 December 2015**



**Reference No: C75339\_VAL04\_R1**  
**14 March 2016**

**Fugro OCEANOR AS**  
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**Supply of Meteorological and Oceanographic data at Borssele Wind Farm Zone (BWFZ):**  
**C75339\_VAL04\_R1**

Rev	Date	Originator	Checked & Approved	Issue Purpose
0	11.02.2016	Lasse Lønseth	Arve Berg	Final report.
1	14.03.2016	Lasse Lønseth	Arve Berg	Final report.

Rev 1 – 14 March 2016	Originator	Checked & Approved
Signed:		

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'.



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Appendix A: Buoy deployment record

## **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. The buoy was recovered to shore for repair on 6 October 2015 and redeployed on 12 November 2015 at 14:00.

This report presents an evaluation of the wind and wave data collected during the period 12 November – 14 December 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.

Following the stop in the transmissions from the buoy on 11 September 2015 at 16:00, the buoy was recovered to shore on 6 October 2015 for inspection and repair. It was redeployed after repair on 12 November 2015 at 14:00.

The wind and wave data collected during the period 12 November – 14 December 2015 are presented in the data presentation report ref. C75339\_MPR04\_R0. 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 Vlake 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).**

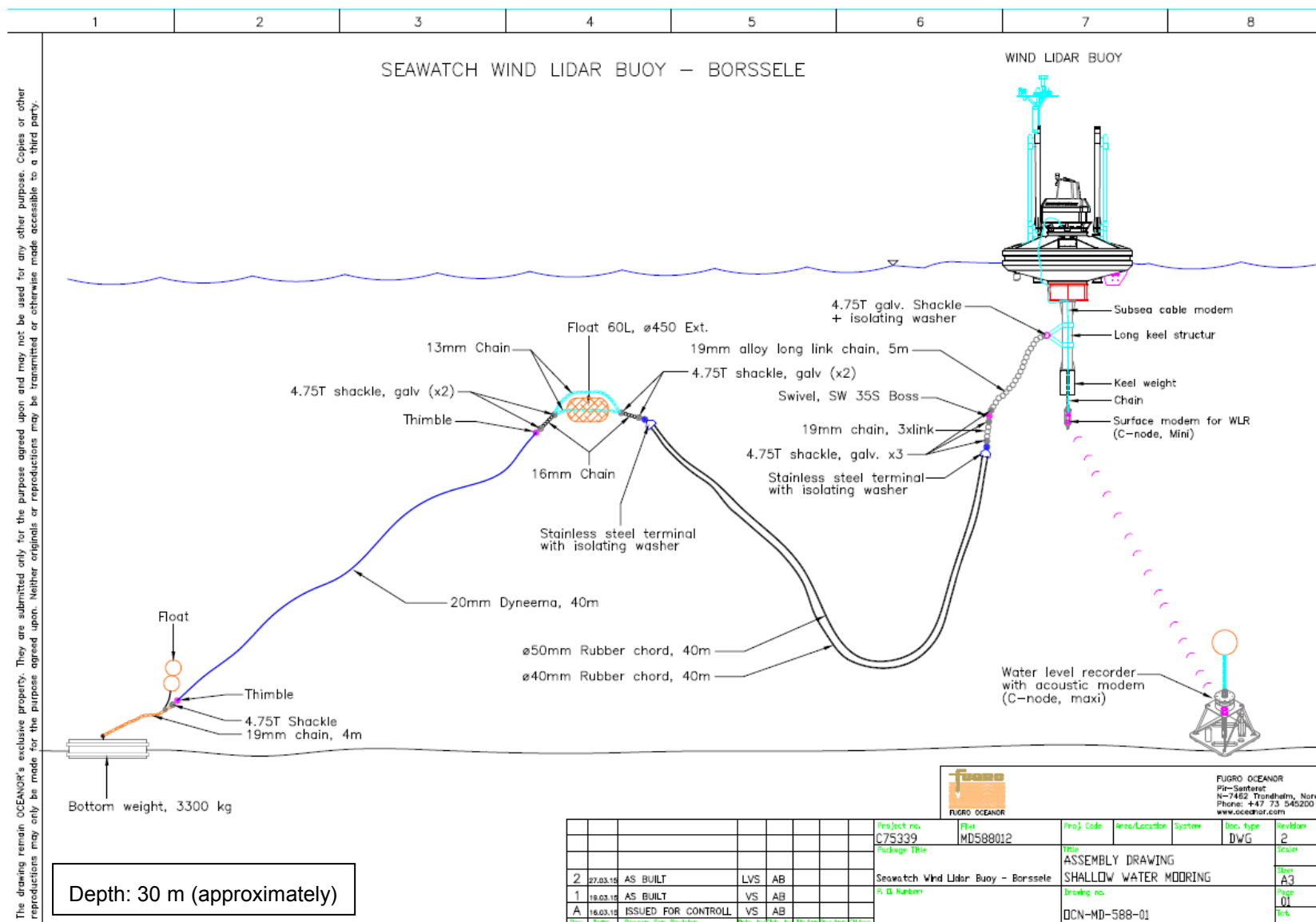
Instrument type	Sensor height (m)	Parameter measured	Sample height <sup>2)</sup> (m)	Sampling interval (s)	Averaging period (s)	Burst interval (s)	Transmitted?
Wavesense 3	0	Heave, pitch, roll, heading	0	0.5	Time series duration: 1024 s	600	No
		Sea state parameters (1)	0	600	1024	600	Yes
Xsens		Heave, 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 11 <sup>th</sup> 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	$\approx 17.4 \text{ s}^{1)}$	600	600	Yes
Aanderaa WLR (SeaGuard) via acoustic link	-30	Water pressure Temperature	-30	600	60	600	Yes

<sup>1)</sup> 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.

<sup>2)</sup> 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, $H_s$ , $Hm0 = 4\sqrt{m0}$
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\_MPR04\_R0). 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 from 12 November 2015 at 14:20 until 14 December 2015 at 23:10, except for a gap of 33 hours 50 min in the Lidar data from 22 November at 05:30 to 15:00 on 23 November, and a 6 hour gap in all data from 00:30 to 06:00 on 6 December 2015. There are also a number of single profile dropouts in the Lidar data. Due to these gaps it took 32.375 days to collect 30.5 days of good wind profile data from the Lidar buoy.

**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	32.375	30.500	94.21
Wave sensor	32.375	32.090	99.12
Current velocity sensor	32.375	32.090	99.12
Atmospheric pressure sensor	32.375	32.090	99.12
Air temperature sensor	32.375	32.090	99.12
Water Level Sensor *	32.375	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. While the recovery attempts so far have been unsuccessful, a second WLR was deployed 18 December 2015 without real time acoustic data transfer for redundancy. Further information is given in the data presentation report, ref. C75339\_MPR04\_R1.

#### 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 Positions 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 threshold 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 Vlake 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 2.06 m at the Lidar buoy compared to 1.82 m at Schouwenbank. The difference as well as the scatter with  $R^2 = 0.913$  may be attributed to differences in location, depth and distance from the shore line at the two locations.

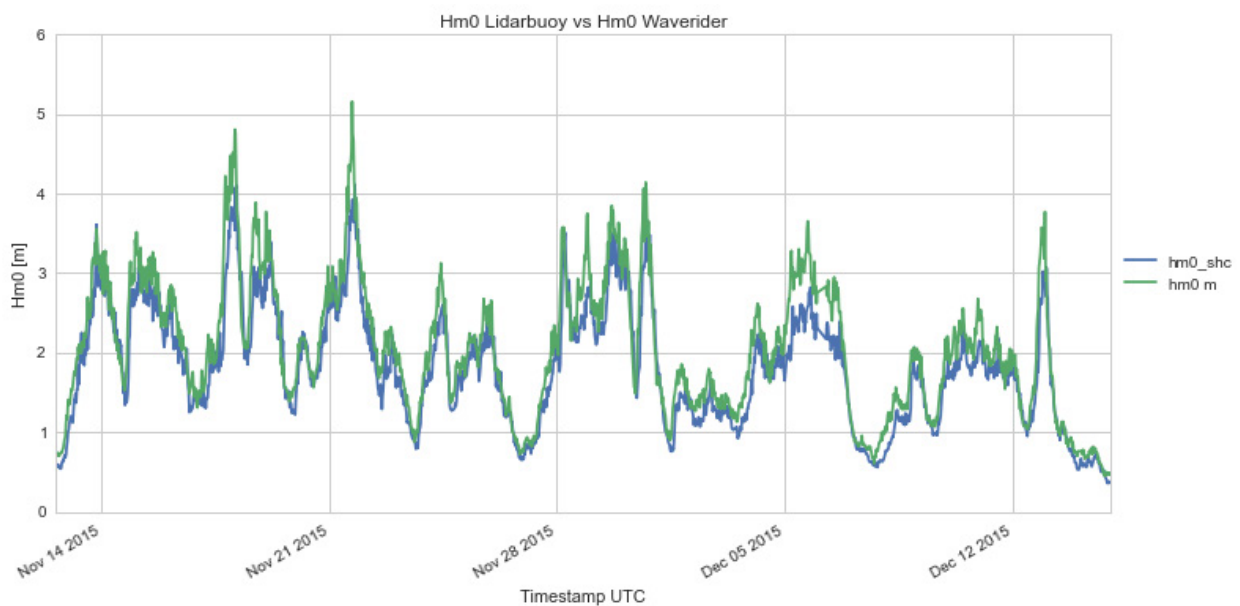
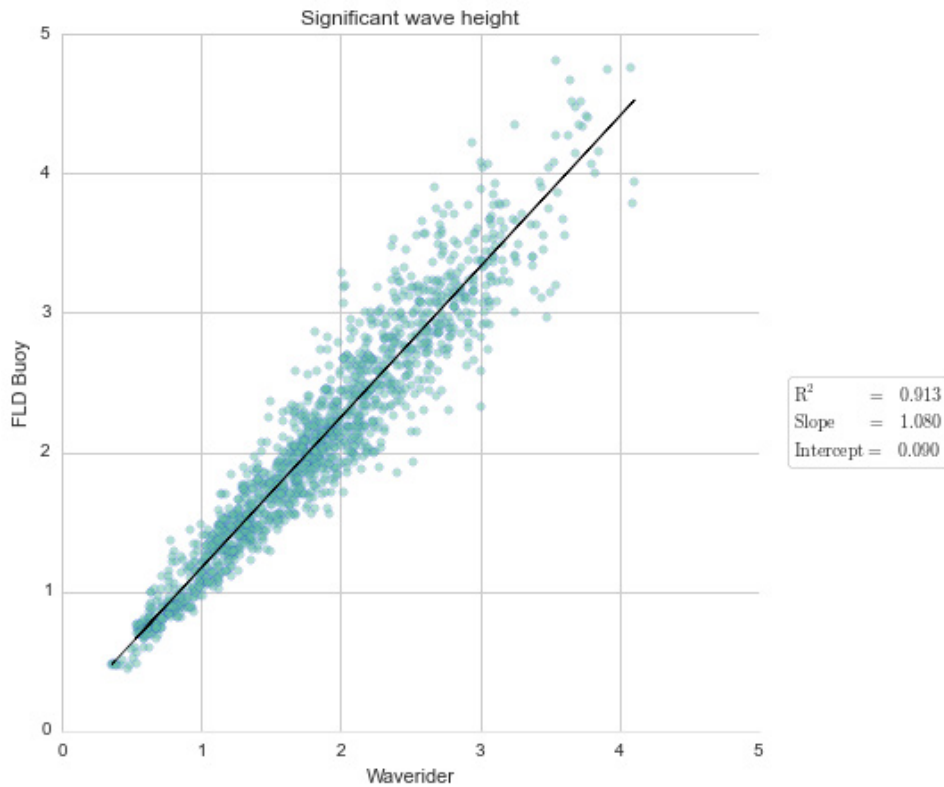
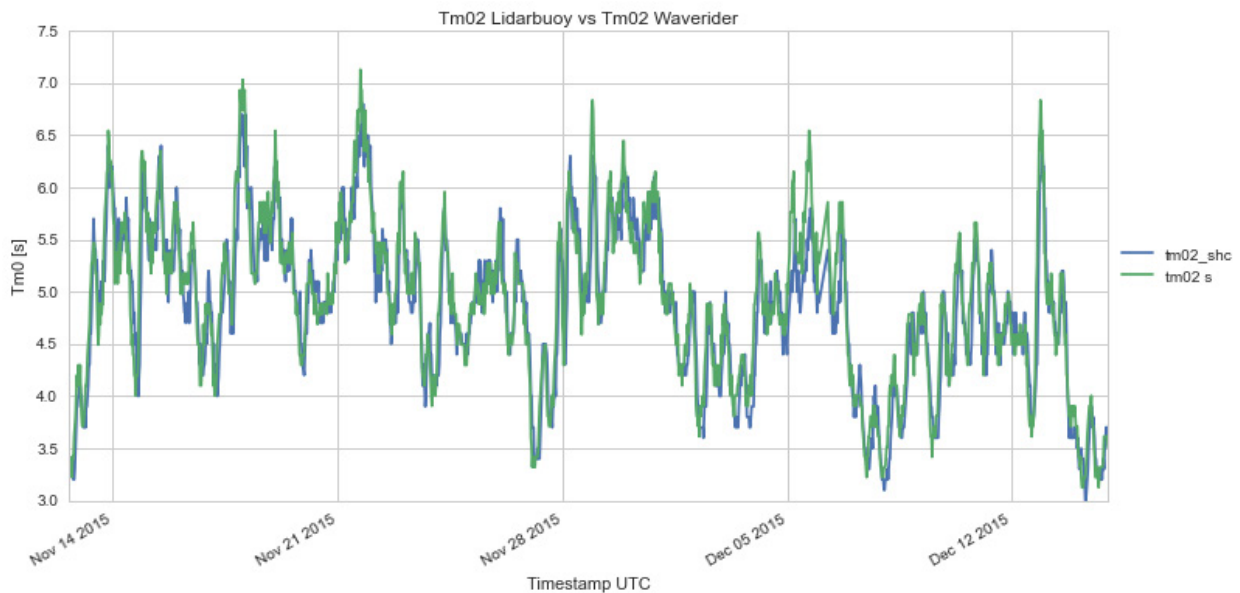


Figure 3.3 Time series plot of significant wave height (Hm0) from the Lidar buoy (green curve) and the Schouwenbank Waverider buoy (blue).



**Figure 3.4 Scatter plot comparing Hm0 measured by the Lidar buoy 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 3.5 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  $R^2 = 0.866$ . Some scatter must be expected due to the distance between the stations. The average values of Tm02 are 4.91 s at the Lidar buoy compared to 4.84 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).**



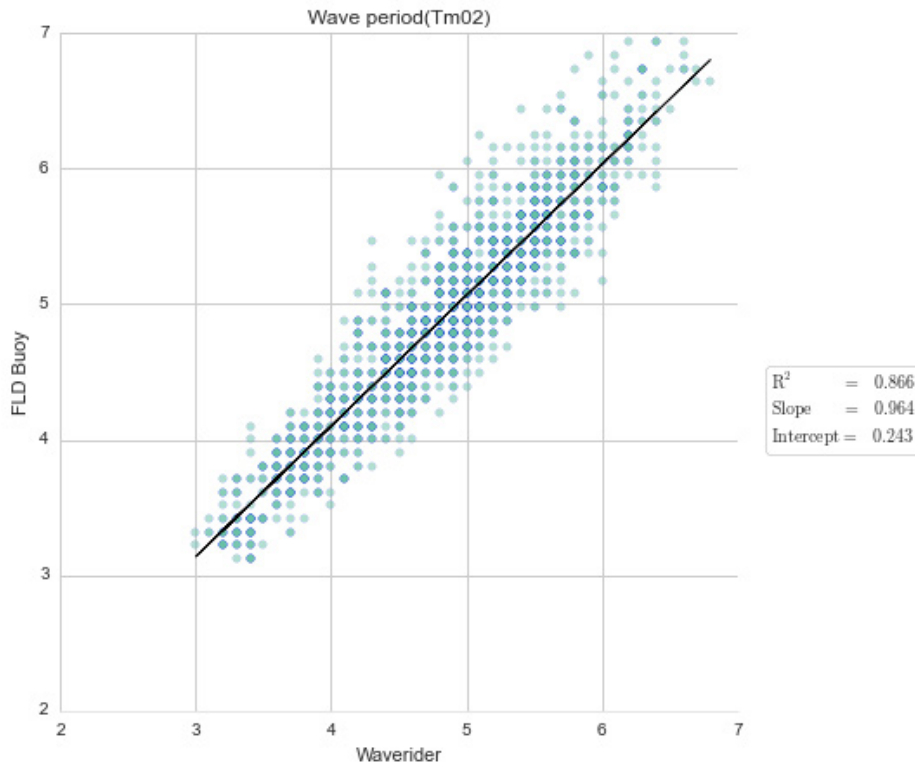
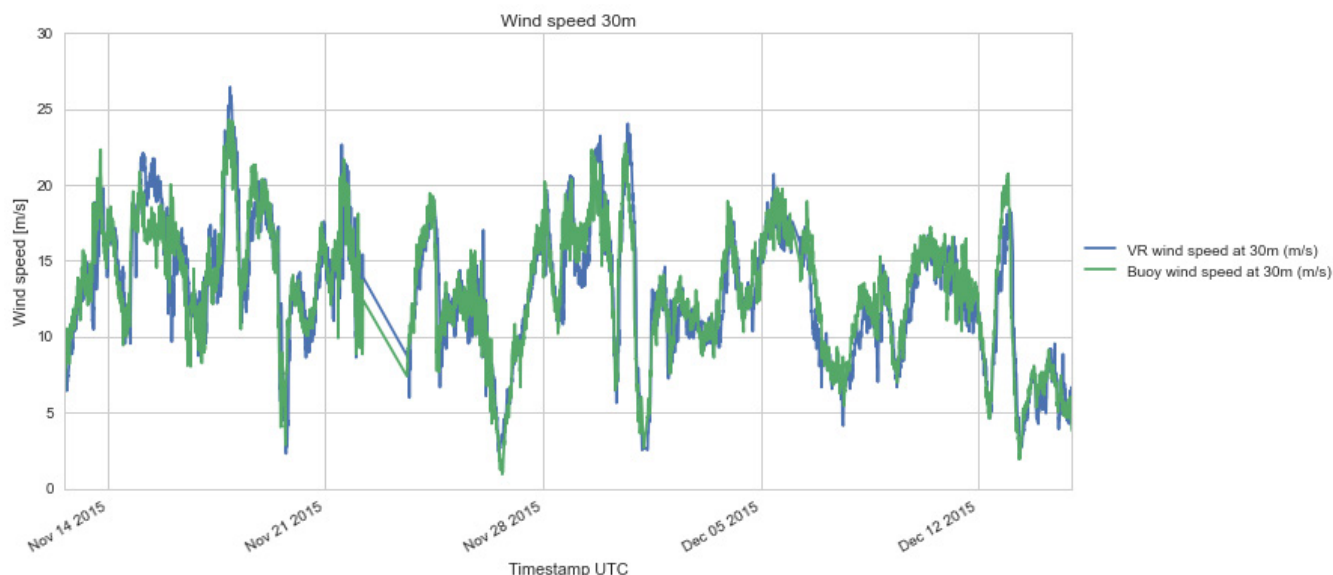


Figure 3.6 Scatter plot comparing Tm02 measured by the Lidar buoy to Tm02 from the Schouwenbank Waverider buoy.

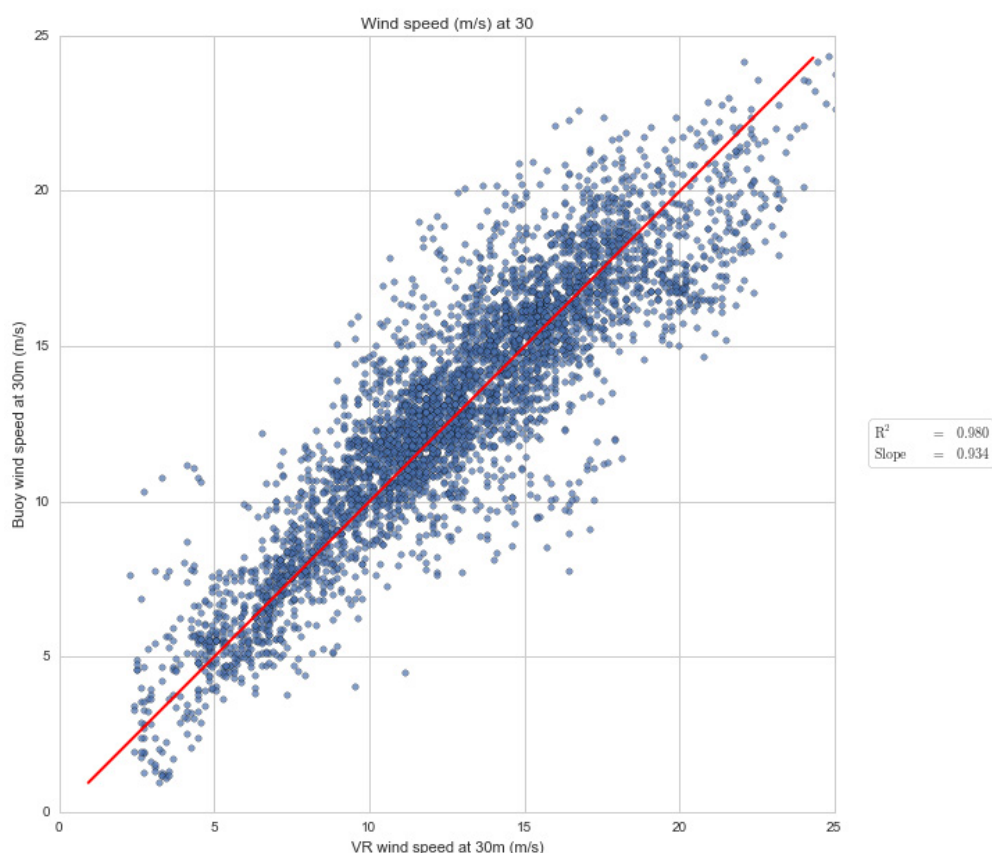
### 3.3.2 Wind data

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 13.07 m/s at the buoy compared to 12.71 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.



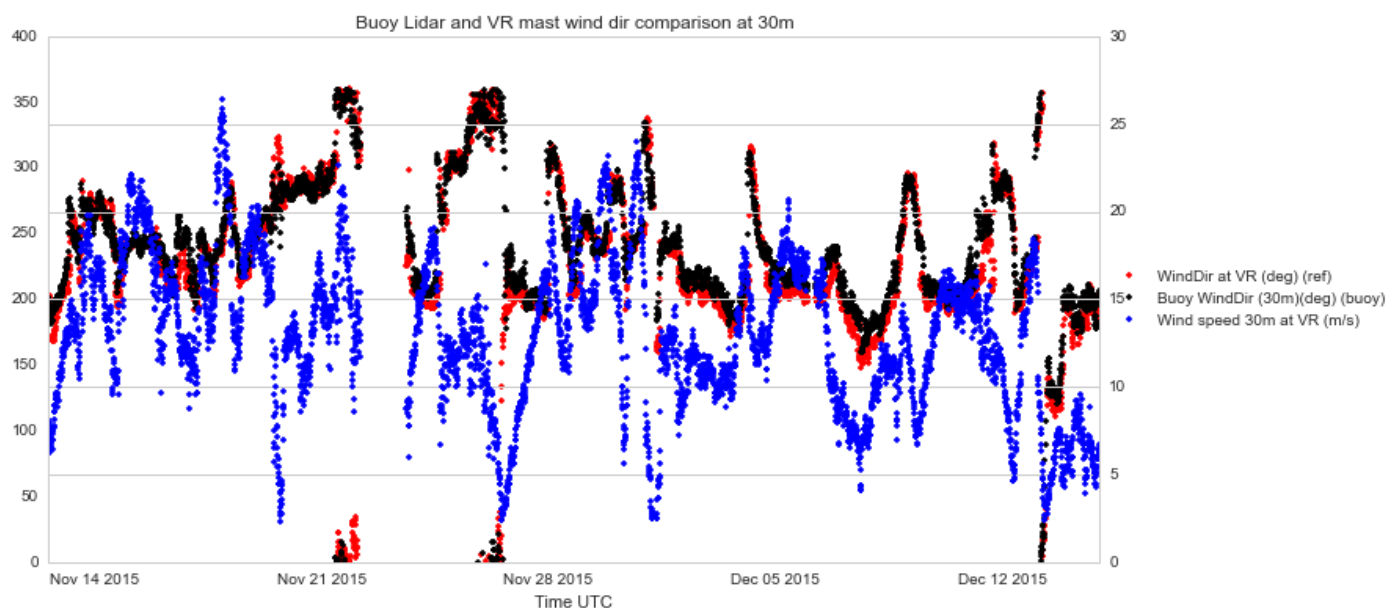
**Figure 3.7** Wind speed at 30 m above sea level measured by the Lidar buoy (green curve) compared to wind speed at Vlakte van de Raan adjusted to 30 m (blue).



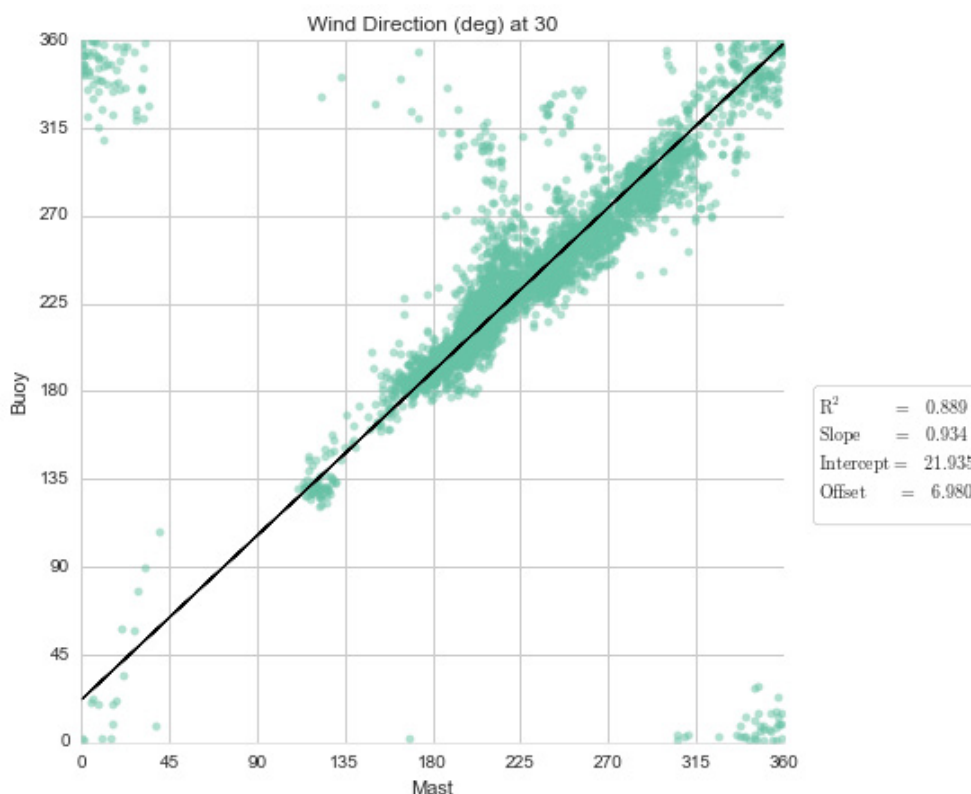
**Figure 3.8** Scatter plot comparing the wind speed at 30 m above sea level measured by the Lidar buoy compared to the wind speed at Vlakte van de Raan adjusted to 30 m a.s.l. (Regression formula:  $y = \text{Slope} \times x$ )

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. 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 Vlake 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 Vlake 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 comparisons to the reference station data presented above indicate that the buoy has collected data of good quality for winds and waves. The Lidar buoy has transmitted data continuously during the month, but there were two outages in the communication with the Lidar unit that caused gaps in the wind data. As a result 32.375 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:	
<b>Buoy module/sensor</b>		<b>Serial number/ID</b>	
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	
ZephIR 300S Lidar		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	Local time
First measurement	2015	06	11	1655
First measurement in position	2015	06	11	1814
Out of measuring position	2015	10	06	11:30
Last measurement				
<b>Comments:</b> <b>WLR deployment position:</b> <b>51° 42.4362N, 3° 02.1030E, Depth: 30m</b> <b>Time reference: CET (DST) (UTC + 2 hours)</b>				
Deployment vessel: MPR3	Recovery vessel: Multirasalvor 3			
Deployed by: EME & OKH	Recovered by:			

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:	33910 – 33914, 33919	Buoy marking:	
<b>Buoy module/sensor</b>		<b>Serial number/ID</b>	
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	Local time
First measurement	2015	11	12	14:00
First measurement in position	2015	11	12	14:20
Out of measuring position				
Last measurement				
<b>Comments:</b> <b>WLR deployment position:</b> <b>51° 42.4362N, 3° 02.1030E, Depth: 30m</b> <b>Time reference: UTC</b>				
Deployment vessel: MPR3		Recovery vessel:		
Deployed by: EME & OKH		Recovered by:		