ECN
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Current Profiles

at the Offshore Wind Farm Egmond aan Zee

J.W. Wagenaar

P.J. Eecen

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NoordzeeWind

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Abstract
NoordzeeWind carries out an extensive measurement and evaluation program as part of the Offshore Wind farm Egmond aan Zee (OWEZ) project. The technical part of the measurement and evaluation program considers topics as climate statistics, wind and wave loading, detailed performance monitoring of the wind turbines, etc. The datasets are available in the public domain.

The data considered in this report are taken from a 116m height meteorological mast, including the ADCP. The latter measures, among others, current speeds and directions at 7m and 11m depth. In this report current profiles are characterized and possible daily and yearly patterns are examined.

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Principal
NoordzeeWind
2e Havenstraat 5b
1976 CE IJmuiden

Project information
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d	Depth of the seabed	m
$Direction_7$	Current direction at 7m depth	degrees
$Direction_{11}$	Current direction at 11m depth	degrees
MSL	Mean Sea Level	m
smse	Square root of mean squared errors	m/s
v	Current speed	m/s
v_7	Current speed at 7m depth	m/s
v_{11}	Current speed at 11m depth	m/s
z	Height above MSL	m
Δv	Difference in current speed	m/s
ΔDirection	Difference in current direction	degrees

1. Introduction

NoordzeeWind (NZW) carries out an extensive measurement and evaluation program (NSW-MEP) as part of the OWEZ project. NoordzeeWind contracted Bouwcombinatie Egmond (BCE) to build and operate an offshore meteorological mast at the location of the OWEZ wind farm. BCE contracted Mierij Meteo to deliver and install the instrumentation in the meteorological mast. After the data have been validated, BCE delivers the measured 10-minute statistics data to NoordzeeWind. ECN created a database under assignment of NoordzeeWind and fills the database with the delivered data. NoordzeeWind contracted ECN to report the data.

The technical part of the measurement and evaluation program considers topics as climate statistics, wind and wave loading, detailed performance monitoring of the wind turbines, etc. A 116m high meteorological mast has been installed to measure the wind, water and wave conditions. This mast is in operation since the summer of 2005 and the measurements have been made available by NoordzeeWind. The requirements specified in the measurement and evaluation program [1]. This report deals with item 1.2.2 ad 7, which addresses current profiles.

The data used in this report come from a 116m high meteorological mast at the offshore wind farm location OWEZ, for which the instrumentation is described in [2]. More specifically, the current data are taken by the Acoustic Doppler Current Profiler (ADCP), attached to the J-tube of the mast –17m MSL. Seen from the monopile of the meteorological mast the ADCP is at a distance of about 15m in a direction of 280 degrees [2] (see also Figure 1.1). The ADCP measures the current speed and the current direction both at -7m and -11m [3].

Roughly, current data are available from May 2006 until November 2006 and October 2007 until November 2008, as was reported in [4]. From this period 80623 and 80684 valid data points are used for the current speeds and the current directions, respectively.

This report is organised as follows: section 2 contains a description of the current speeds and directions themselves and section 3 contains a description of the current profiles. Possible daily and yearly effects are examined in section 4 and the main conclusions are drawn in section 5.

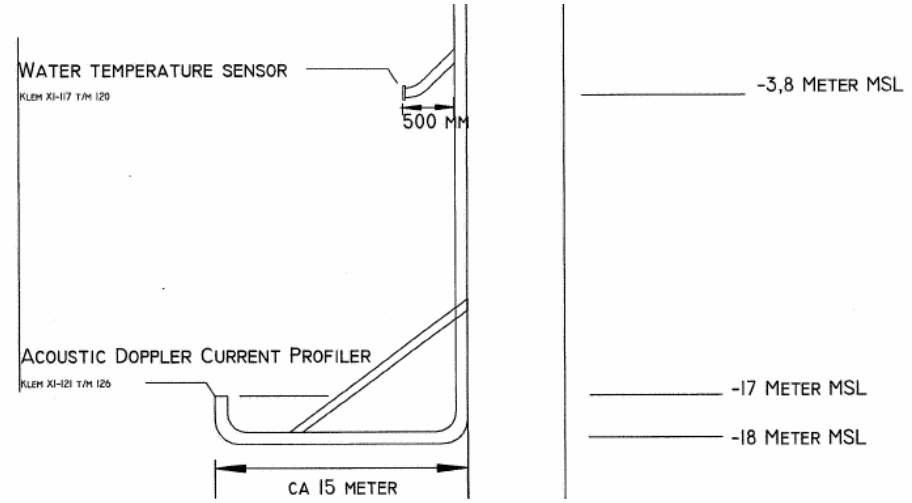

Figure 1.1 *Position of the ADCP on the monopile of the meteorological mast.*

2. Current speeds and directions

As mentioned in the Introduction (section 1) current measurements at OWEZ are performed by an ADCP for two depths: -7m and -11m MSL. In Figure 2.1 the distributions of the current direction and the current speed are given for both these depths. The upper plot in Figure 2.1 shows the distribution of the current directions. It is clearly seen that the mean current directions at both depths are North and South.

From the lower right plot, which shows the mean current speed per direction, it is seen that the mean current speed is for both depths highest around 105-135 degrees. At these directions the mean current speed at 11m depth is higher than the current speed at 7m depth. For all other directions the current speed at 7m depth is higher. We note here that seen from the ADCP, the monopile is at 100 degrees. Flow distortions from the monopile are however not examined in this report.

The distributions of the current speed are for both depths shown in the lower left plot of Figure 2.1. The distributions show that the maxima are for both depths at 0.5m/s. They also show that generally the current speed at 7m depth is a bit higher than the current speed at 11m depth. This can be seen from the distribution of the current speed at 11m depth, which indicates more lower current speeds (<= 0.5 m/s) and less higher current speeds (> 0.5m/s) as compared to the distribution of the current speed at 7m depth.

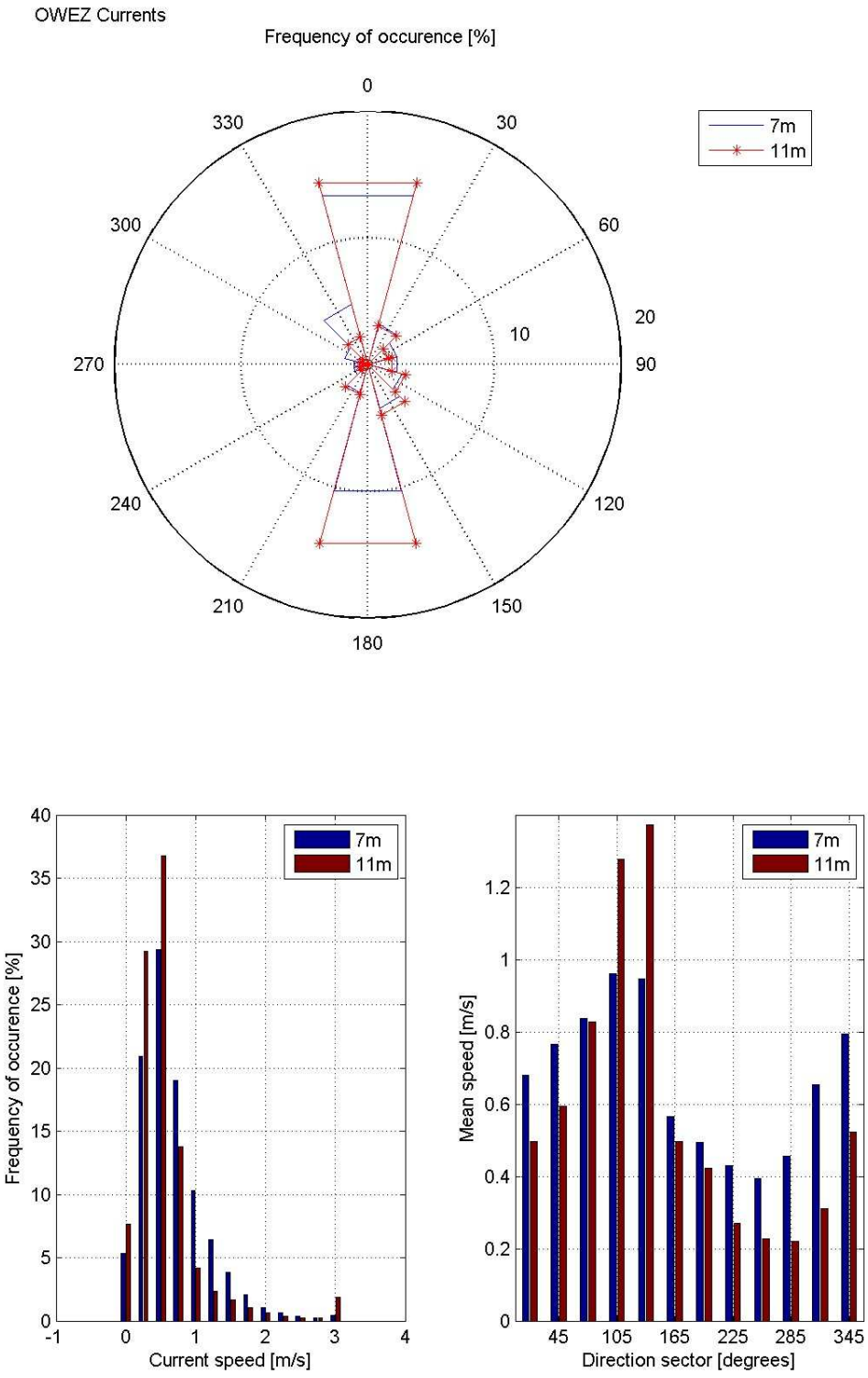

Figure 2.1 *Current direction distributions (upper plot), current speed distributions (lower left plot) and mean current speeds per direction (lower right plot).*

3. Current profiles

At OWEZ, the current direction and the current speed are measured at two different depths in the sea. It is therefore not a trivial task to determine a current profile. In order to quantify the current profile 3 profile indicators are determined. These are:

- The ratio of the current speeds: $Ratio = \frac{v_7}{v_{11}}$.
- The difference in the current speeds: $\Delta v = v_7 - v_{11}$.
- The difference in the current directions: $\Delta Direction = Direction_7 - Direction_{11}$

All three indicators are examined.

The distribution of the ratio of the current speeds is given in the upper plot of Figure 3.1. It is clearly seen that a ratio of 1, indicating that the current speeds are equal, occurs most frequently. In the lower left plot of Figure 3.1 is the mean ratio per direction sector given. The lowest mean ratio is seen around 195 degrees and the highest mean ratio is seen around 315 degrees. The lower right plot of Figure 3.1 gives a scatter plot of the differences in current speed as function of the current direction. Large deviations in the difference are seen in the sector around about 120 degrees; the smallest deviations in the difference are around 250 degrees.

Differences in current direction as well as differences in current speed are given in Figure 3.2. The upper left plot shows the frequency of occurrence of the difference in current direction. It can be seen that the distribution of the differences is symmetrical and sharply peaked at 0, indicating that the two directions are mostly aligned. Because the distribution drops off very fast large deviations in the directions occur very rarely.

The frequency of occurrence of the difference in current speed is shown in the lower left plot of Figure 3.2. It is sharply peaked at 0, indicating that the two speeds are mostly equal, which was already concluded. The distribution is not entirely symmetrical; it indicates that current speeds at 7m depth are generally a bit higher than the speeds at 11m depth. This, also, was already concluded.

The right plot of Figure 3.2 shows the frequency of occurrence as function of both the differences: the differences in current speed and the differences in current direction. It, basically, is a combination of both plots on the left. No new conclusions are drawn from this plot.

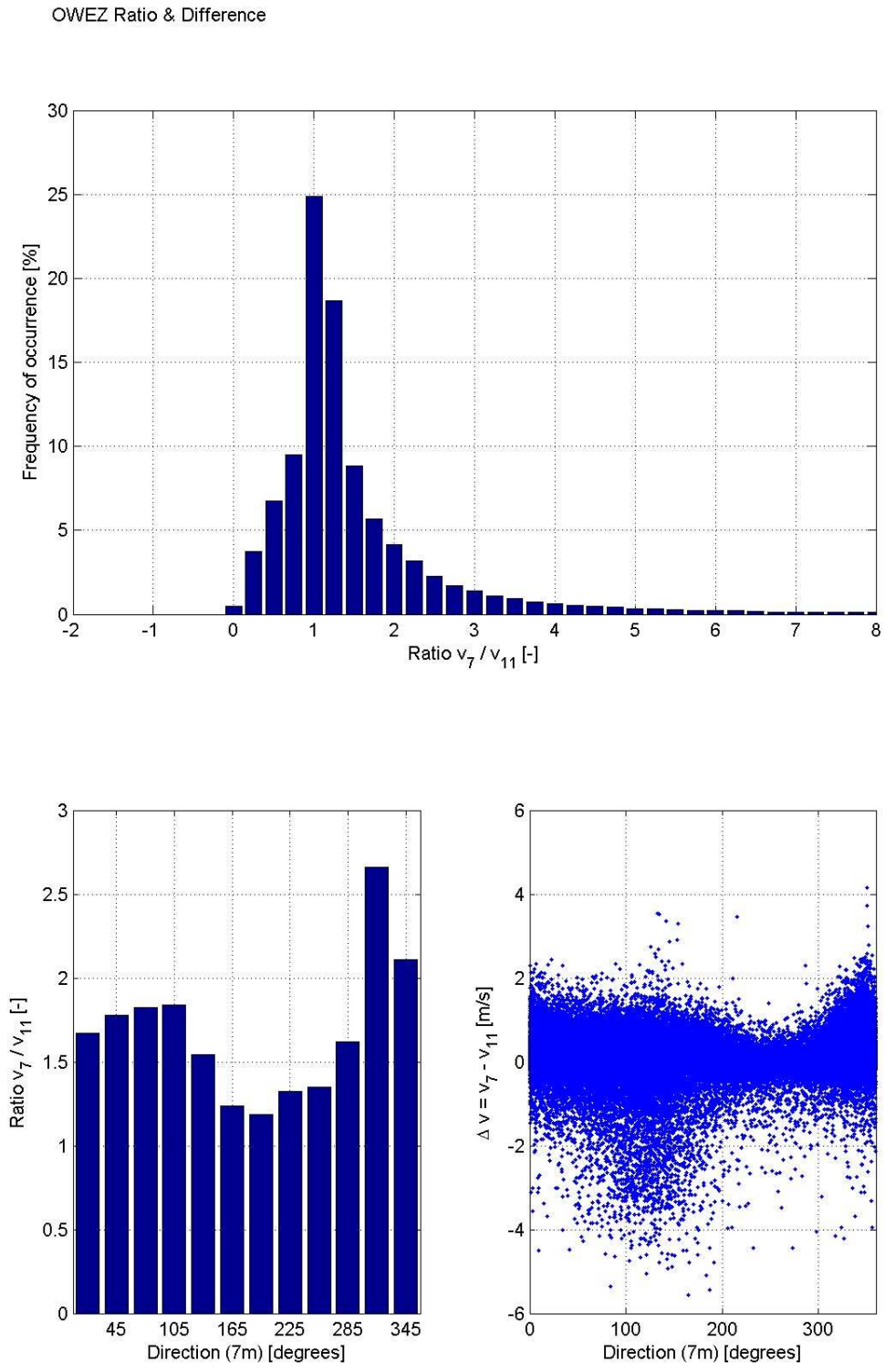

Figure 3.1 *Frequency of occurrence of the ratio of the current speeds (upper plot). Ratio as function of the direction at 7m depth (lower left plot). Difference of the current speeds as function of the direction at 7m depth (lower right plot).*

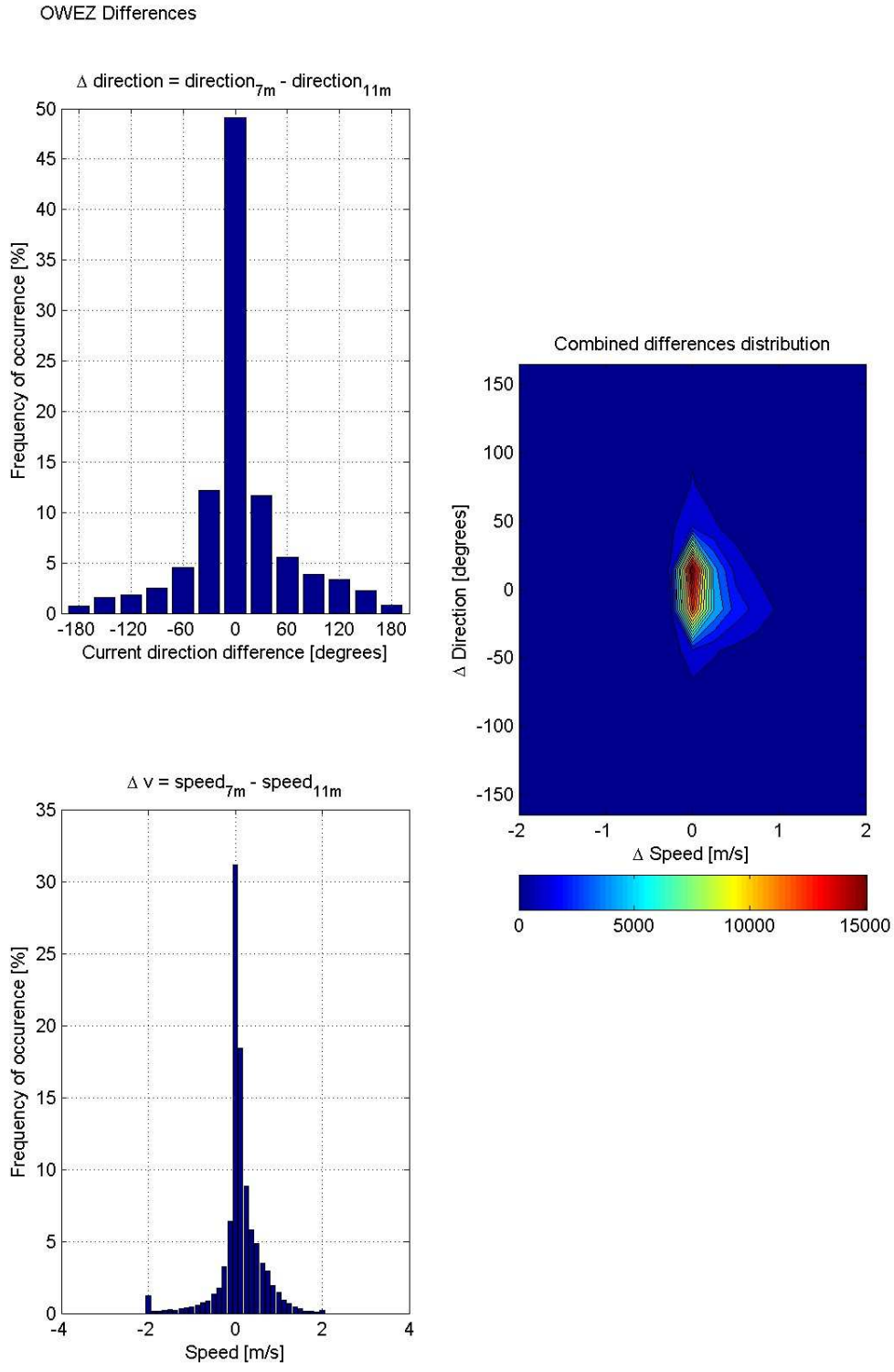

Figure 3.2 *Frequency of occurrence of the difference in current directions (upper left plot). Frequency of occurrence of the difference in current speeds (lower left plot). Frequency of occurrence of the difference in current directions and the difference in current speed (right plot).*

In the standards for design requirements for offshore wind turbines [5] a power law profile of the current speed as function of the depth is assumed

$$v(z) = v(0) \cdot \left(\frac{z+d}{d} \right)^{1/7} , \qquad (1)$$

where v(z) is the current speed at height z and z is the height above MSL (negative in downward direction). d is the depth (location of the seabed; taken as a positive number) and is 20m.

The current speed at the seabed is assumed to be zero. We therefore have 3 depths where the current speed is known and to which (1) can be fitted. v(0) is the fit parameter. The results of the fits are shown in Figure 3.3 as well as Table 3.1. In Figure 3.3 the current speeds at 7m and 11m depth are the mean current speeds of all available data. In the upper plots these involve the mean for all directions and in the remaining plots the mean current speeds per current direction. Current direction bins (based on both the current direction at 7m and 11m depth) of 30 degrees wide are considered; the centre values of these bins are indicated in the plots. In these plots *smse* means the square root of the mean squared errors:

$$smse = \sqrt{\frac{1}{n-1} \sum_{i=-20,-11,-7} \left(v(z_i) - v_i \right)^2} , \qquad (2)$$

where v_i is the measured value and $v(z_i)$ is the fitted value at depth i. n is the number of points (n=3).

We notice that the fit is the best for the direction 60 degrees – 90 degrees (centre value of 75 degrees) and the fit is the worst for the direction 120 degrees – 150 degrees (centre value of 135 degrees).

Table 3.1 *List of fit coefficients v(0) and smse for all directions and per direction bin.*

Directions [°]	Coefficients [m/s]	SMSE [m/s]
All	0.697	0.033
0-30	0.629	0.067
30-60	0.769	0.069
60-90	0.973	0.001
90-120	1.472	0.191
120-150	1.573	0.302
150-180	0.509	0.022
180-210	0.503	0.009
210-240	0.556	0.037
240-270	0.296	0.051
270-300	0.350	0.098
300-330	0.527	0.176
330-0	0.719	0.108

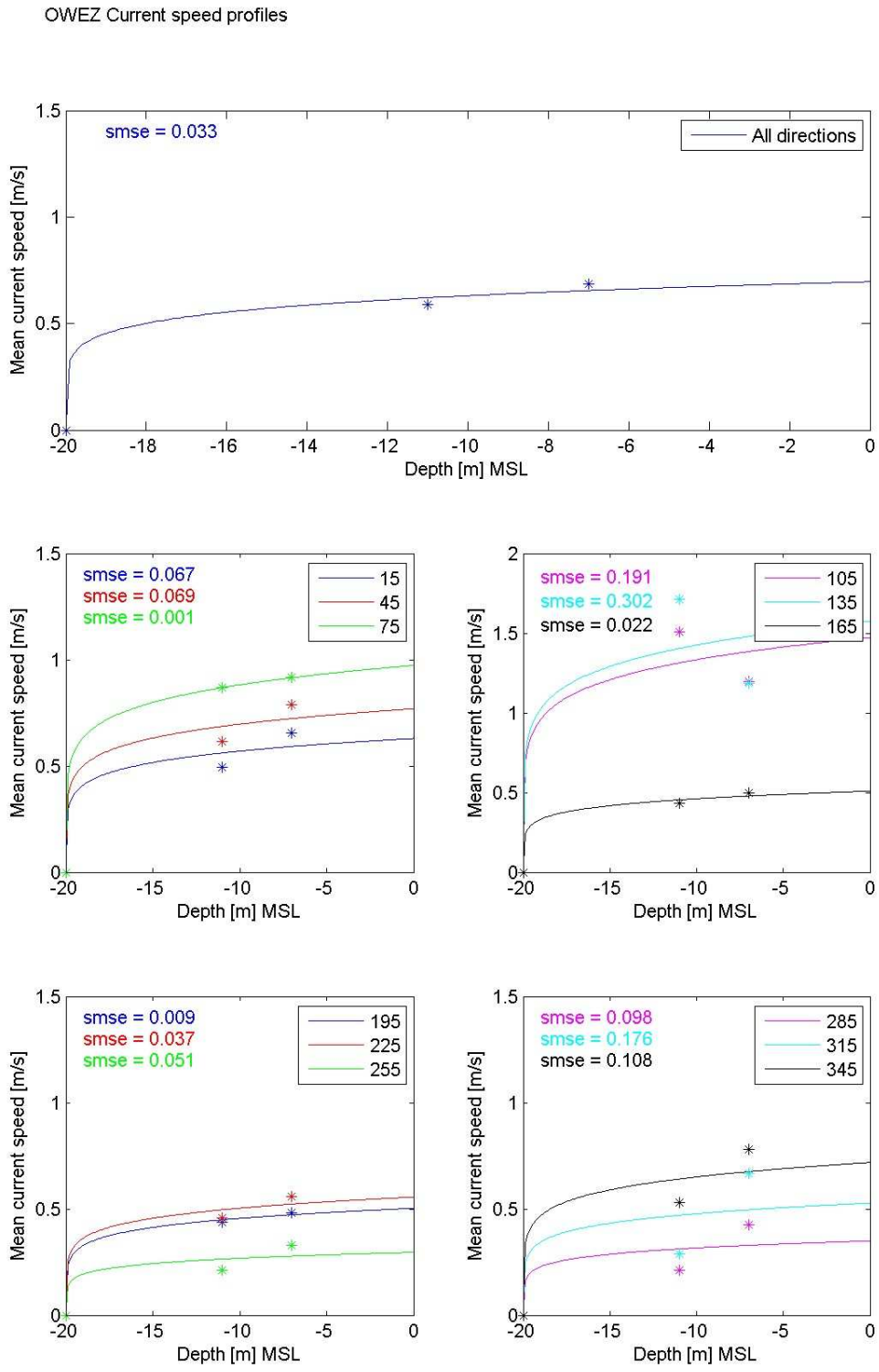

Figure 3.3 *Mean current speed as function of height for all directions (upper plot) and per direction sector (remaining plots). The stars indicated measured values and the lines indicate the fits.*

4. Daily and Yearly patterns

It is interesting to see whether there is a daily or yearly pattern in the current profiles. To this end Figure 4.1 shows various plots where data has been gathered per hour and per month.

The differences in current speed are shown in the upper plots of Figure 4.1. The left plot shows the differences as function of the hour of the day and the right scatter plot shows the differences as function of the month of the year. Besides the scatter plots also the means are given. From the left scatter plot we see that the deviation in the differences is highest during day time (6:00 hours – 17:00 hours) and from the right scatter plot we see that the deviation in the differences is highest around October. Although the mean values do not vary much, we see that the mean difference is highest in February and lowest in October.

The lower plots of Figure 4.1 show the mean ratio as function of the hour of the day (left plot) and as function of the month of the year (right plot). No real daily pattern can be seen in the left plot. However, in the right plot it can be seen that the mean ratio is highest around February and lowest around October. This pattern was also seen for the mean current speed differences.

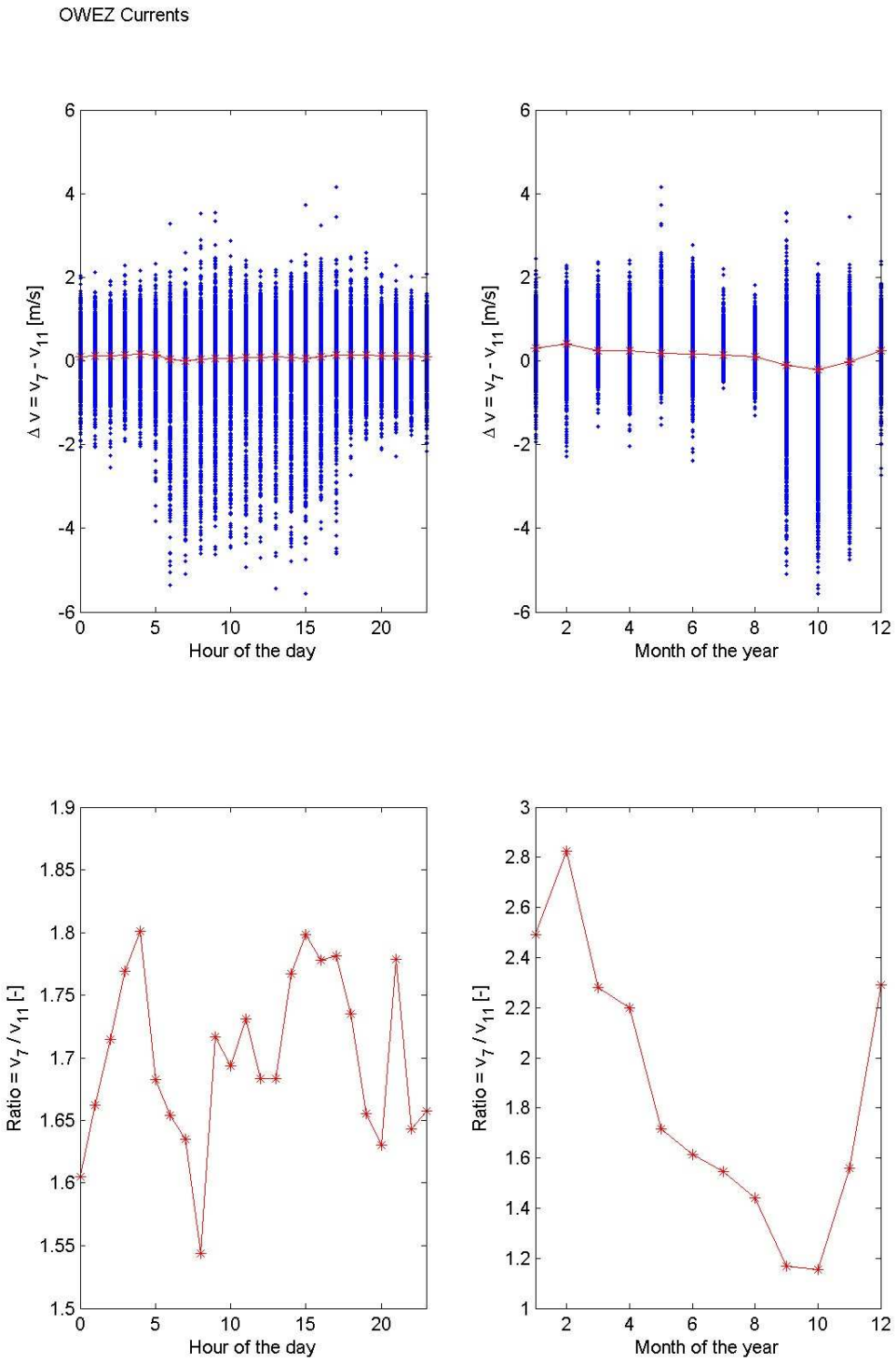

Figure 4.1 *Difference in current speeds as function of the hour of the day and the month of the year (upper plots). Ratio of the current speeds as function of the hour of the day and the month of the year (lower plots).*

5. Conclusions

The main conclusions about the currents themselves and the current profile indicators are summarised by subject:

- The main current speed is 0.5 m/s for both depths and generally the current speed at 7m depth is a bit higher than the current speed at 11m depth. A current speed ratio of 1 occurs most frequently.
- Directional effects:
    - The main current directions are North and South.
    - The current directions are mostly aligned. Large deviations in the current direction rarely occur.
    - Large deviations in the current speed differences are seen in the sector around about 120 degrees; the smallest deviations in the differences are around 250 degrees.
    - The lowest mean ratio of the current speeds is seen around 195 degrees and the highest mean ratio is seen around 315 degrees current direction.
    - Assuming a power law profile for the current speeds with a power 1/7 the best fit is for 75 degrees and the worst fit is for 135 degrees.
- Daily patterns:
    - The deviation in the current speed differences are largest during daytime (6:00 hours – 17:00 hours).
- Yearly patterns:
    - The deviation in the current speed differences is largest around October.
    - The mean current speed difference as well as the mean current speed ratio is highest around February and lowest around October.

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