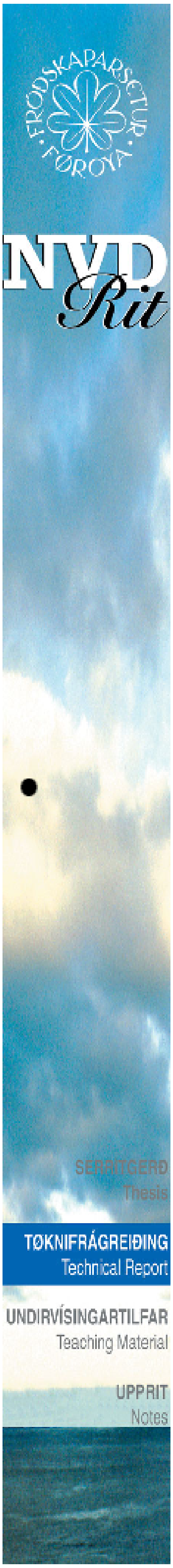

Technical Report

Current measurements Nólsoyarfjørður 2007

Data report, tidal analysis and power estimates

Niclasen, B.A. and Simonsen, K.

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Introduction

The project 'mapping of the Tidal Stream Energy Potential', hence labelled TSEP, started 01.03.2009, and will according to plan be completed 01.03.2011. The purpose of this project is to map the power available in the tidal currents on the Faroese Shelf by conducting current measurements and running high resolution current models (dx 500-50m) for the area. The project is conducted by the University of the Faroe Islands (Department of Science and Technology) and is funded by the Faroese Research Council (Granskingarráði) and the faroese power production company SEV. This report documents a previous deployment in Nólsoyarfjørður done in 2007, but using the report type used in the TSEP project.The report describes the instrumentation, setup, deployment, data inspections, tidal harmonic analysis and finally statistics of current speed and tidal current power.

Location and instrumentation setup

The measurements are conducted with an Aanderaa RDCP600 current profiler. Information on the mooring and frame can be fond in a separate report. The instrument was deployed on the bottom, looking upwards. Data only exist for the first month after deployment due to full memory.

Site information

Latitude and longitude position of the site is from the ship Magnus Heinason GPS, depth is based on the RDCP pressure sensor. Depth is calculated as average absolute pressure in kPa minus 101,3 kPa (1 atm) divided by $\varrho \times g$ ($g = 9.82$ m/s^2 and $\varrho = 1027$ kg/m^3). The site details are given in Table 1, and a depth chart of the area is given in Figure 1.

Table 1: Deployment information

Longitude:	6°41.50' West
Latitude:	62°0.67' North
Depth (pressure sensor):	35.4 m
Time of deployment	8/3-2007 ??:?? UTC
Time of recovery	29/5-2007 ??:?? UTC

Instrument information

According to the datasheet, p. 46 in Aanderaa (2006), the RDCP600 can measure up to a distance of 35-70 m in 'Low power-mode', which is used here, and can measure horizontal speeds in the range 0-500 cm/s. The main RDCP setup features are listed in the Table 2.

In the following all references to speeds will be to horizontal current-speed if nothing else is stated.

Data quality control

This section gives a review on how the data have been quality checked. The MATLAB functions used to check the data are given in the Appendix, and contain some more specific details.

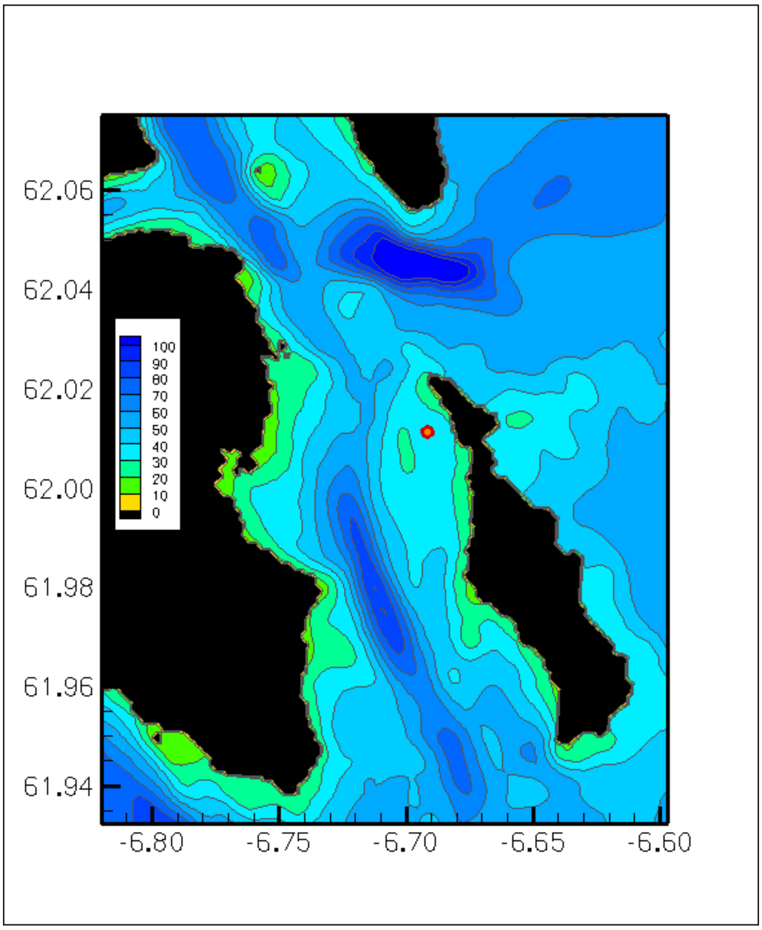

Figure 1: Depth in deployment area. Red dot indicates deployment position of the RDCP

Calibration: The part of the transceiver-head that measures current-speed does not have to be recalibrated (Minken, 2000). Other sensors are expected to remain stable for several years, but if the aim is maximum accuracy, it is advised to check the calibrations once a year (Aanderaa, 2006). Sensors on this RDCP:

- compass-tilt sensor (no calibration data given)
- pressure sensor (no calibration data given)
- current-speed sensor (no calibration needed)
- temperature sensor (calibration date is 18/5-2004)

Clock drift: Due to overfull memory i.e. clock drift chcck could not been made.

Valid duration: All data seem to be recorded at deployment location and valid duration is therefore set to be the whole measurement interval.

- First valid measurement: 07/03-2007 21:21 UTC (measurement no. 0)
- Last valid measurement: 19/4-2007 11:01 UTC (measurement no. 3065)

Valid vertical range: RDCP vertical measurement range is limited by surface effects, quoting Aanderaa (2006) p. 36, good measurement range is limited by $d\cos(\theta)$. In this deployment transducer depth d is 36.3 m, transducer inclination θ is 25° (Aanderaa, 2006) which gives a valid

Table 2: Instrument setup

Instrument type:	Aanderaa RDCP600
Parameters:	Current speed/direction, Pressure, Temperature
Instrument no.:	0035
Instrument frequency:	600 Hz
Height above bottom:	1 m
Depth:	36.3 m
Time of first data:	07/03-2007 21:21 UTC
Time of last data:	19/04-2007 11:01 UTC
Sample interval:	20 min
No. of ensembles:	3066
Pings per ensemble:	300
Pulse and cell length:	2 m
Depth of first cell:	33 m (36 - 3)
No. of bins:	20
Sound speed:	set to 1500 m/s
Sampling type:	Burst mode
Ping interval:	0.640 s
Sampling duration:	192 s (300*0.640)
Pulse type:	Auto
Cell overlap:	0%

vertical range of 33 m. This means that all cells above cell 15, which spans the interval 30-32 m above the transducer head, are discarded.

Sound-speed related uncertainties Distances reported by the RDCP are measured time intervals multiplied by the deployment fixed sound-speed (see Table 2). There are uncertainties connected to difference between the used fixed sound speed and the actual value. These uncertainties are relatively small (Niclasen and Simonsen, 2009) and no adjustment has been made to the data.

Automatic instrument specific quality checks: Soft flags[1] were added to the data, according to recommendation from instrument manufacturer.

- Cells which had signal strength less than -45 dB were flagged (157 in total).
- Cells with single ping standard deviation larger than 20 cm/s were flagged (3 in total).
- Cells with recorded speeds or tilt above instrument specifications would be flagged, but none were found.

Additional automatic quality check: 4 beam speeds are given for each cell[2]. As only 3 beam speeds are needed in order to determine the current velocity, the extra information can be used to test consistency of the data. Here we have used the beam speeds to calculate error-velocity[3]. There are no clear limits defined for acceptable levels of error velocity, and here we ended up

[1] data flagged but not rejected automatically
[2] one from each of the 4 transducers
[3] difference in measured vertical velocity from two orthogonal-pairs of transducers

using $0.07 + 0.00 * Speed$ as a limit as this seemed to capture the most extreme outliers (127 in total) in the data (see red line in Figure 2). Again only soft flags were added to data.

Correction from Magnetic- to Geographic-North: The RDCP measures direction relative to a compass sensor in the transducer head. In order to convert from a time varying magnetic reference fame to a static geographic reference frame current directions have been corrected according to the 'Magnetic Declination Calculator' at
http://www.ngdc.noaa.gov/geomagmodels/struts/calcDeclination
which gives 6°56'W at center time of data series (1/1-2010). Direction according to Geographic-North is thus recorded direction according to Magnetic-North minus 7°27'. No test was made of magnetic offset of the RDCP compass prior to or after the deployment, but as we use a deployment with external batteries and a plastic/stainless-steel frame, this deviation is expected to be small.

Manual inspection of current speed: The last quality test was to browse trough current speed data (speed and direction, east and north components of the speed), with special attention given to flagged values. The manual investigation was done using MATLAB plots described in the appendix. Main emphasis was given to detecting spikes in cell time series or along the vertical profile. Overall the 2D-series (profile vs. time) seemed smooth with a moderate level of random noise. The smoothness is most likely caused by the large ping number per ensemble used in this deployment (measured values are ensemble averages). There are several passages which seem to contain spiky time-behavior, but as the behavior seemed periodic and consistent in depth, none of the 'spiky' data have been discarded. Cell 15 which is the highest cell most remote from the RDCP showed a to abrupt change in characteristics relative to the underlying cells and was therefore removed.

In other words all data within valid-duration and range less than 31 m (cell 14 and below) have been accepted as is. Time- or cell-averaging could be conducted in order to reduce "random" noise, but as the subsequent tidal harmonic analysis isn't affected by random error no averaging has been conducted. Average profiles related to data quality of the accepted data are shown in Figure 3. Generally data in the uppermost cells contain relative more suspicious data, and should be interpreted with care.

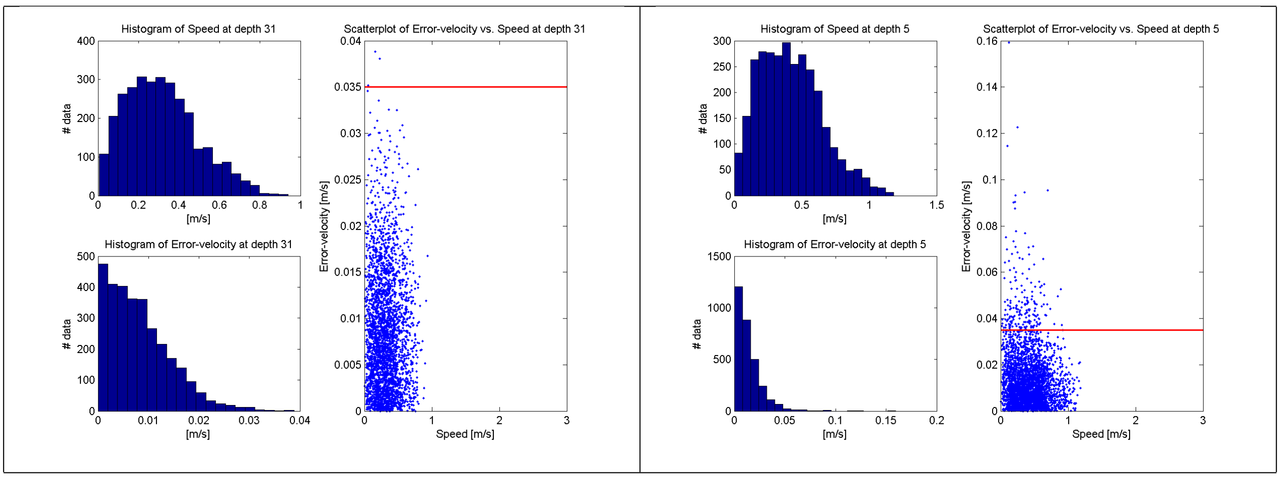

Figure 2: Scatter plot of error-velocity. The plot to the left is from the cell closest to the instrument (range 3 m), and the plot to the right is from the last valid cell (range 31 m). Red line indicates flagging threshold

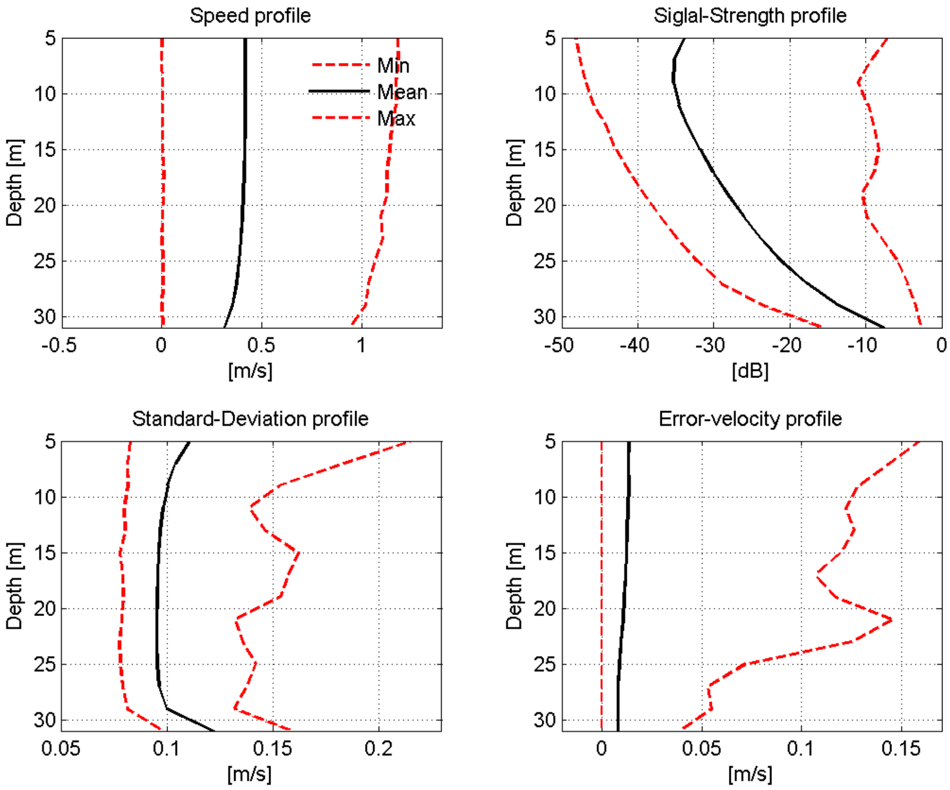

Figure 3: Average profiles of data-quality related parameters

Assessment of data quality

The measured data cannot be compared with independent data, as this is the first current profile measurement in this part of the fjord. On the other hand the measured data are clearly within its measuring range of the instrument, and the measured data quality parameters (signal-strength and standard-deviation) also indicate that the data are valid.

Valid data

In the following the general properties of the accepted data are presented in figures and tables. The current profile in this deployment is composed of 14 valid cells, and in order to reduce the number of plots only 3 cells/depths will be displayed. These are:

- The cell/depth closest to the ocean surface (cell 14, depth 7 m)
- The cell/depth with strongest current speed (cell 10, depth 15 m)
- The cell/depth closest to the ocean bottom (cell 1, depth 33 m).

Figure 5 gives a scatter plot of data at the specified depths. Figure 7 gives current profile along major and minor axis, and gives the main direction at the specified depths. Figure 8 gives the profile of the residual in each cell.
Table 3 gives number of data in the speed intervals used in the subsequent error-flag-tables. Table 4 gives number of data flagged due to low signal-strength, Table 5 gives the number of data flagged

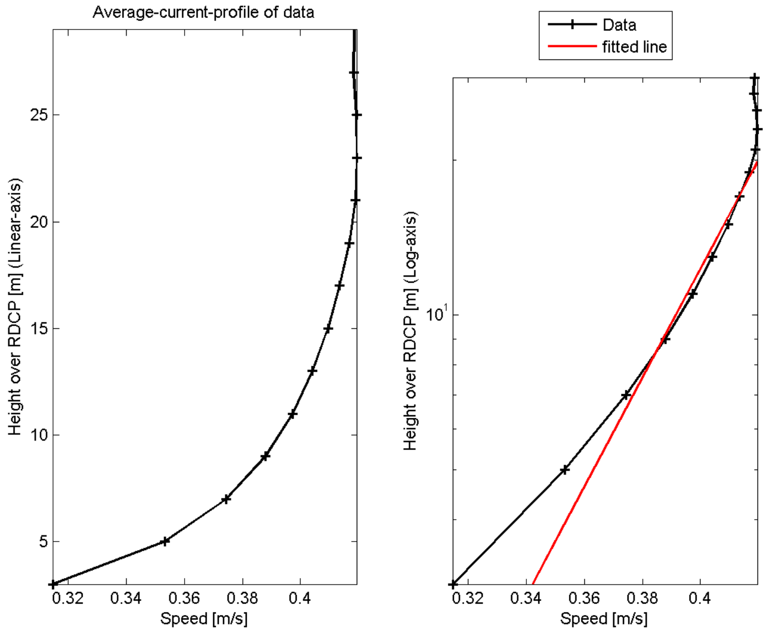

Figure 4: Average current profile in linear and logarithmic depth-axis. The red line gives the best fit to cells 3-9

due to large standard-deviation and finally Table 6 gives the number of data flagged due to high error-speed.

The measured temperature time series is given in Figure 6

Tidal analysis

Here we use the software T-Tide (version 1.1) to do the tidal harmonic analyses of the measured time series in every bin. The set of Matlab functions composing T-Tide written by Rich Pawlowicz (Pawlowitcz et al., 2002) are based on the widely used FORTRAN code developed by M. G. G. Forman[4].

Here are a few comments of the main features of T-Tide:

- Given start time and latitude, T-Tide is able to handle nodal corrections[5].
- If a nearby time series is available that resolves more tidal constituents than the actual time series under investigation, is possible to approximate/resolve equivalent tidal coefficients in the shorter series by using a method called 'inference'. This has not been conducted in this investigation.
- By default T-Tide picks only the resolvable frequencies according to the Rayleigh criterion, from a database of 69 standard frequencies (see T-Tide documentation).

[4]Institute of Ocean Sciences, Sidney British-Columbia, Canada.

[5]Small adjustments to the amplitudes and phases of resolved harmonic constituents to compensate for unresolved overlapping frequencies.

Table 3: Number of measured data in 0.5 m/s intervals

m | m/s	0.0-0.5	0.5-1.0	1.0-1.5	1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5
07	1997	1030	39	0	0	0	0
09	2003	1026	37	0	0	0	0
11	1984	1045	37	0	0	0	0
13	1988	1040	38	0	0	0	0
15	1983	1048	35	0	0	0	0
17	1998	1034	34	0	0	0	0
19	2023	1013	30	0	0	0	0
21	2041	997	28	0	0	0	0
23	2070	973	23	0	0	0	0
25	2104	949	13	0	0	0	0
27	2149	907	10	0	0	0	0
29	2242	819	5	0	0	0	0
31	2380	685	1	0	0	0	0
33	2596	470	0	0	0	0	0

Table 4: Data flagged due to low signal-strength

m | m/s	0.0-0.5	0.5-1.0	1.0-1.5	1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5
07	74	2	0	0	0	0	0
09	60	2	0	0	0	0	0
11	18	0	0	0	0	0	0
13	1	0	0	0	0	0	0
15	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0
29	0	0	0	0	0	0	0
31	0	0	0	0	0	0	0
33	0	0	0	0	0	0	0

Table 5: Data flagged due to high standard-deviation

m | m/s	0.0-0.5	0.5-1.0	1.0-1.5	1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5
07	1	1	1	0	0	0	0
09	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0
29	0	0	0	0	0	0	0
31	0	0	0	0	0	0	0
33	0	0	0	0	0	0	0

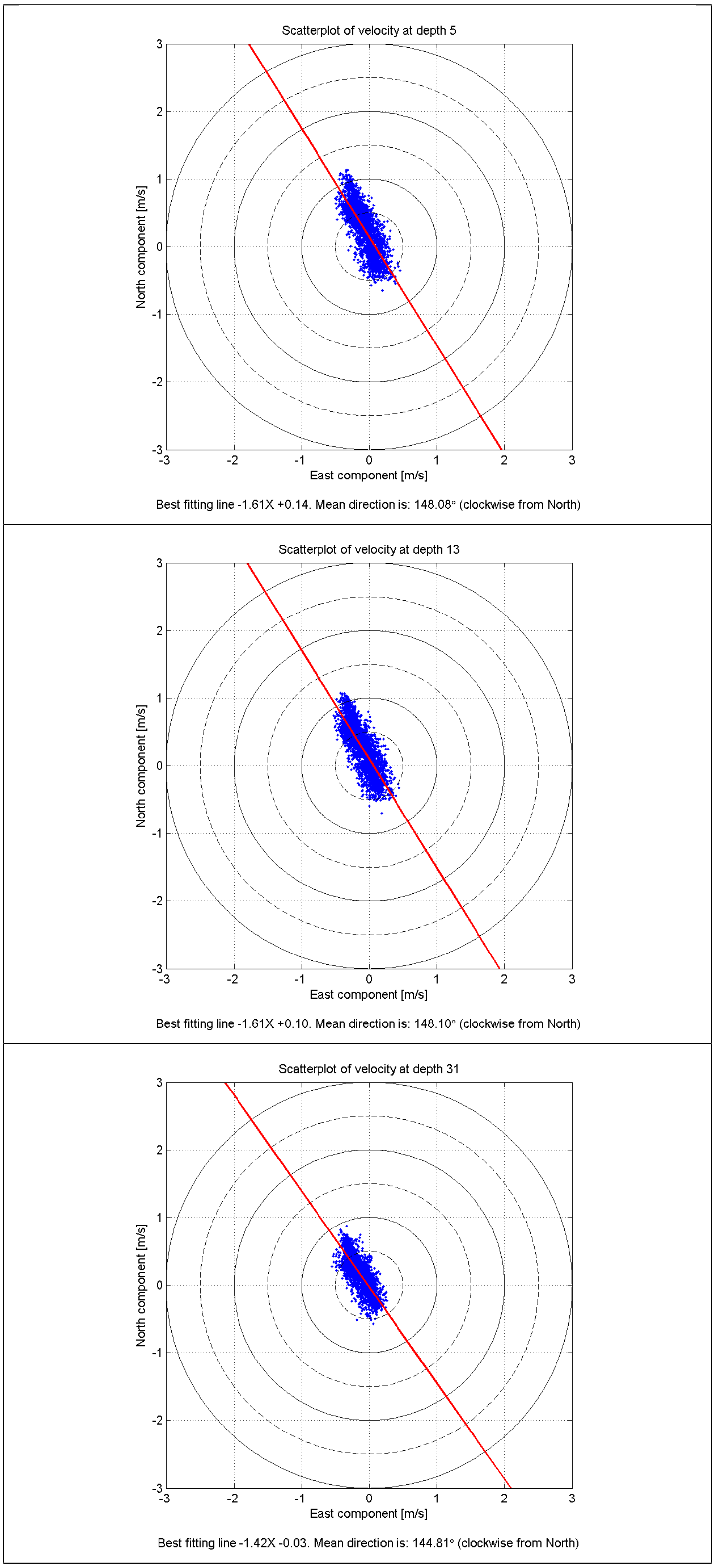

Figure 5: Scatter plot of measured velocity in North and East directions. Red line indicates best fitting mean direction

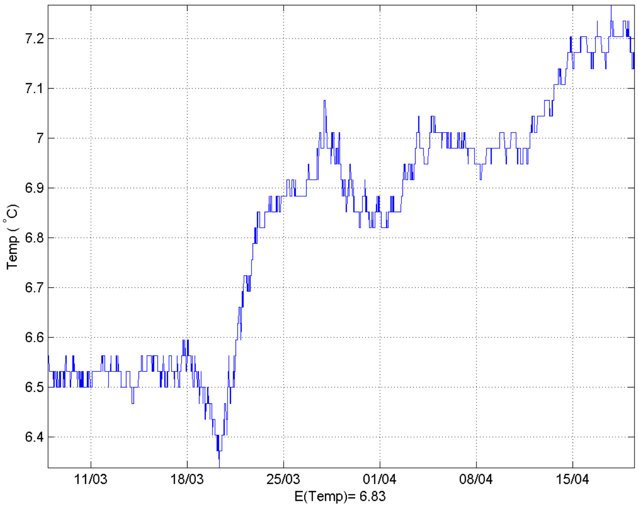

Figure 6: Measured temperature

- In order to see how well the tidal harmonics are removed, amplitude spectral plots of the measured time series and the residual time series[6] time series are given in Figure 9.
- It is possible in T-Tide to force a fit to shallow water constituents, but this did not seem necessary for these data as there were no energetic 'spikes' in the high frequency part of the Amplitude-spectra in Figure 9(only frequencies up to 0.35 hour^{-}1 are shown in the plots, but the rest was not shown as the spectra remained flat).
- For each analyzed cell a table is generated with the resolved tidal constituents along with a confidence-intervals signal-to-noise-ratios for each individual constituent. These additional information is strictly-speaking only reliable if the coordinate-system is rotated so that the tidal major-axes are along one of the coordinate axes (see T-Tide documentation). These tables are given in the Appendix.

In Figure 10 measured current speed time series is given along with a predicted series. The predicted time series spans a whole year with a sampling period of 5 minutes so derived tidal-current-speed statistics will be more representative. The tidal prediction is based on all resolved tidal constituents i.e. not only those which have signal-to-noise-ratios larger than 2, which is standard setting in T-Tide. Also the average residual current speed is added to the T-Tide prediction, which also is not standard in T-Tide.

In Figure 11 the measured and tidally predicted speed distribution are plotted for the specified depths.

In Table 8 a normalized distribution of the measured speed at all cell depths is given. Table 7 gives the same distribution based on the tidal prediction.

[6]measured time series minus tidally predicted time series

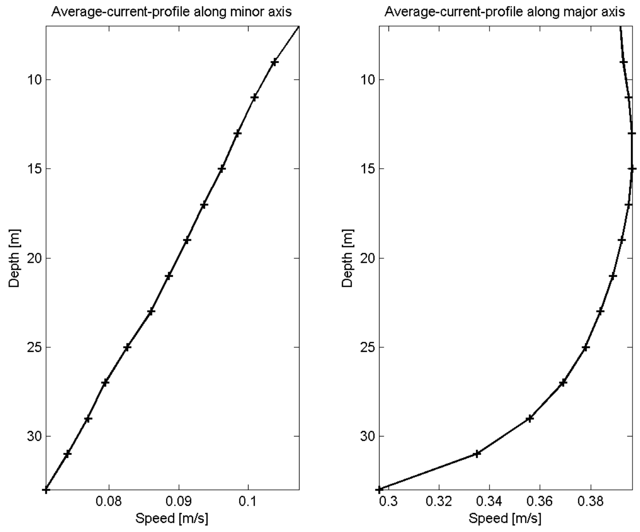

Figure 7: Average current profile along major and minor axis

Table 6: Data flagged due to high error-speed

m | m/s	0.0-0.5	0.5-1.0	1.0-1.5	1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5
07	15	1	0	0	0	0	0
09	12	1	0	0	0	0	0
11	21	2	0	0	0	0	0
13	16	2	0	0	0	0	0
15	14	2	0	0	0	0	0
17	13	1	0	0	0	0	0
19	6	1	0	0	0	0	0
21	6	0	0	0	0	0	0
23	8	0	0	0	0	0	0
25	5	0	0	0	0	0	0
27	1	0	0	0	0	0	0
29	0	0	0	0	0	0	0
31	0	0	0	0	0	0	0
33	0	0	0	0	0	0	0

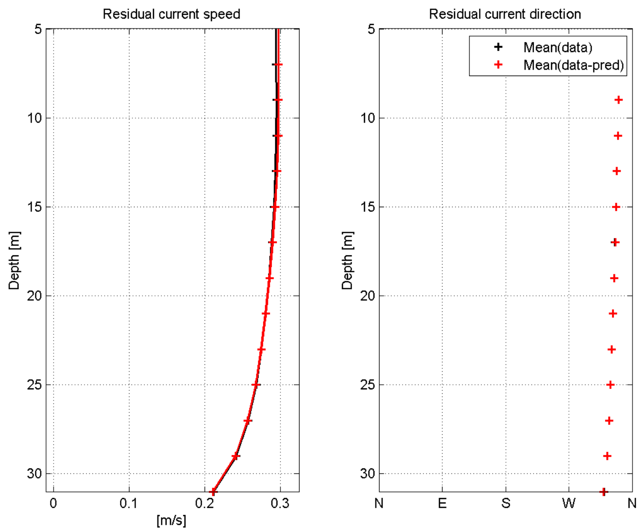

Figure 8: Profile of residual current

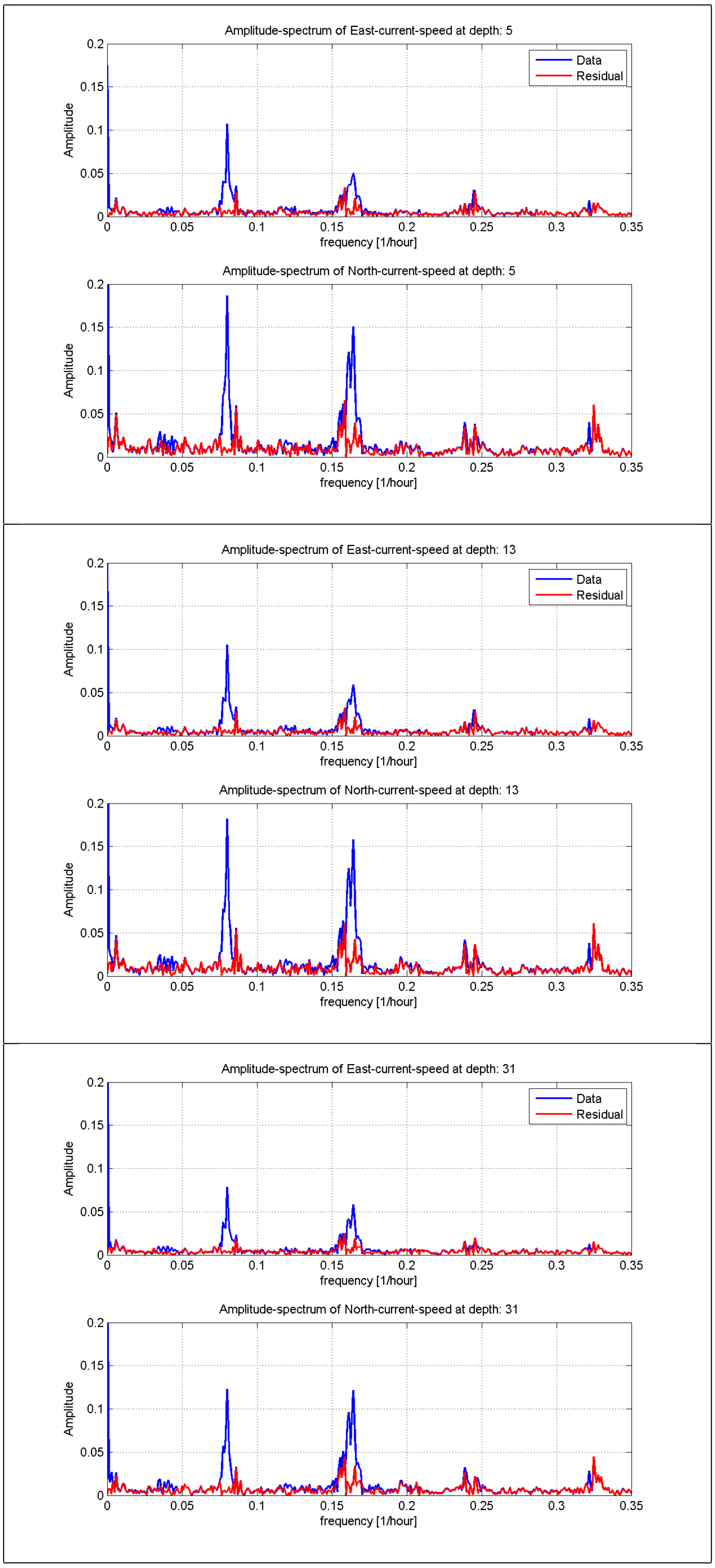

Figure 9: Amplitude spectrum at the uppermost cell (top-plot), the cell with strongest tidal current (middle-plot) and the lowermost cell (lowest-plot)

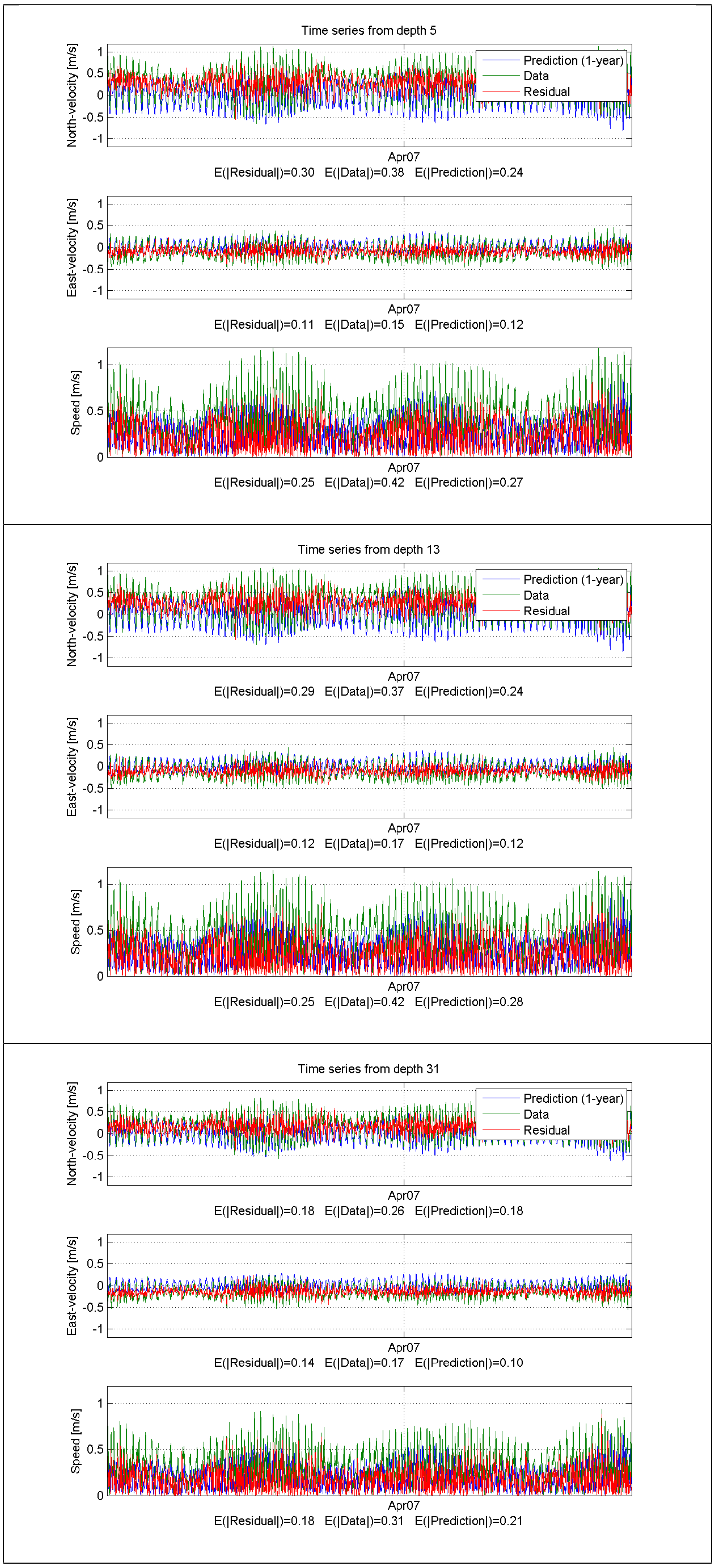

Figure 10: Time series of measured and predicted current speed

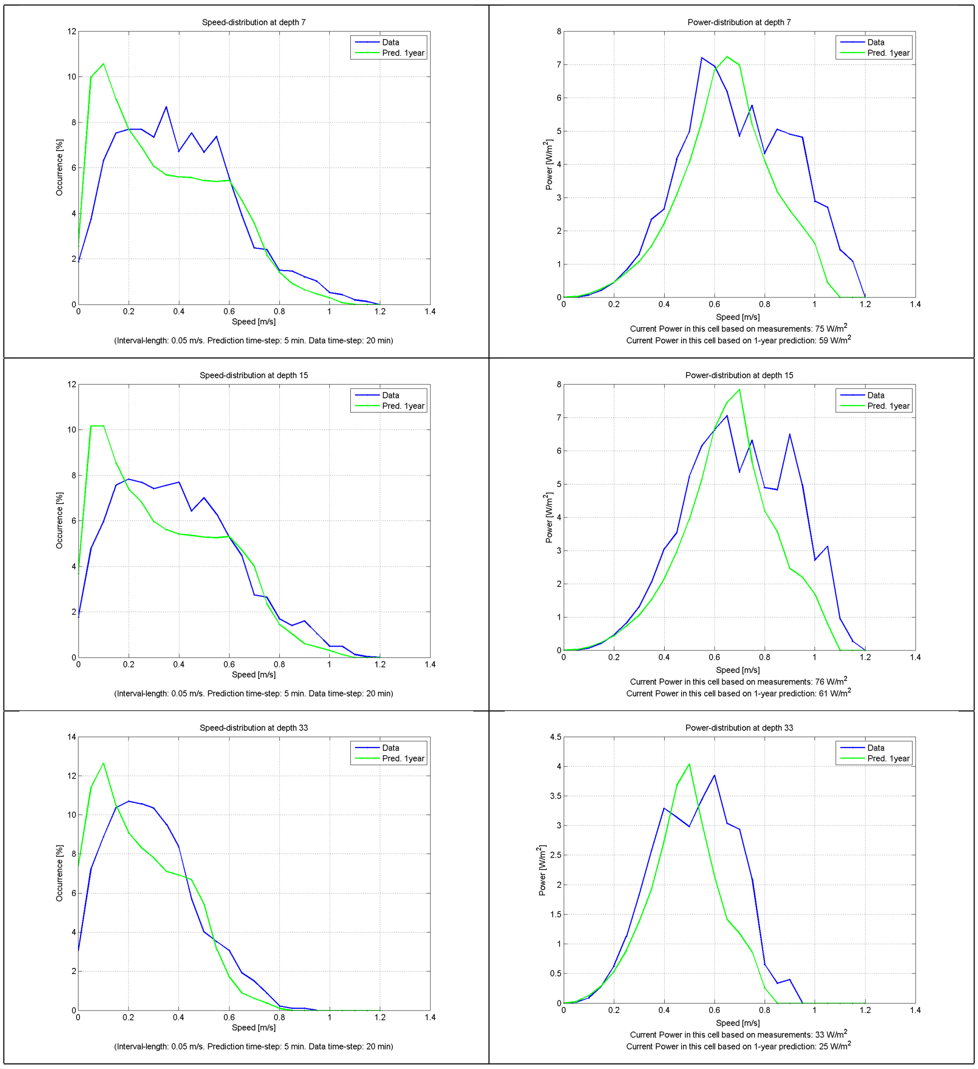

Figure 11: Distribution of measured and predicted current speed to the left, and distribution of measured and predicted power as a function of current speed

The depth profiles of major-axis, minor-axis, inclination and phase of the tidal constituents M2, S2, N2, O1 and K1 are given in Figure12

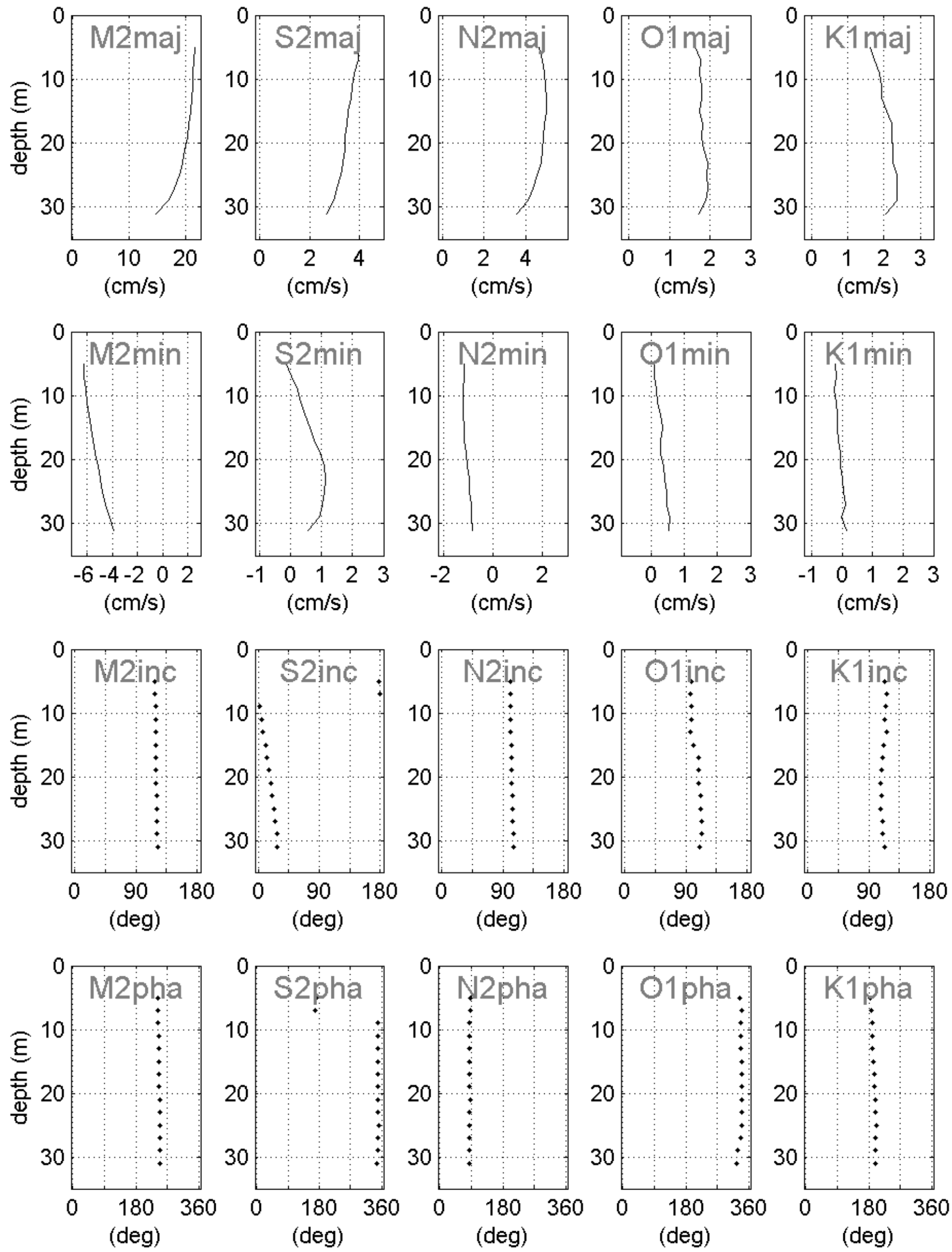

Figure 12: Profile of residual current

Table 7: Distribution of predicted current speeds in 0.5 m/s intervals (1-year tidal prediction)

m | m/s	0.0-0.5	0.5-1.0	1.0-1.5	1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5
07	0.6961	0.3003	0.0036	0.0000	0.0000	0.0000	0.0000
09	0.6936	0.3023	0.0041	0.0000	0.0000	0.0000	0.0000
11	0.6914	0.3043	0.0043	0.0000	0.0000	0.0000	0.0000
13	0.6907	0.3048	0.0045	0.0000	0.0000	0.0000	0.0000
15	0.6908	0.3049	0.0043	0.0000	0.0000	0.0000	0.0000
17	0.6935	0.3025	0.0040	0.0000	0.0000	0.0000	0.0000
19	0.6976	0.2990	0.0033	0.0000	0.0000	0.0000	0.0000
21	0.7028	0.2945	0.0027	0.0000	0.0000	0.0000	0.0000
23	0.7105	0.2877	0.0019	0.0000	0.0000	0.0000	0.0000
25	0.7213	0.2776	0.0011	0.0000	0.0000	0.0000	0.0000
27	0.7348	0.2649	0.0003	0.0000	0.0000	0.0000	0.0000
29	0.7581	0.2419	0.0000	0.0000	0.0000	0.0000	0.0000
31	0.7977	0.2023	0.0000	0.0000	0.0000	0.0000	0.0000
33	0.8778	0.1222	0.0000	0.0000	0.0000	0.0000	0.0000

Table 8: Distribution of measured current speeds in 0.5 m/s intervals

m | m/s	0.0-0.5	0.5-1.0	1.0-1.5	1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5
07	0.6513	0.3359	0.0127	0.0000	0.0000	0.0000	0.0000
09	0.6533	0.3346	0.0121	0.0000	0.0000	0.0000	0.0000
11	0.6471	0.3408	0.0121	0.0000	0.0000	0.0000	0.0000
13	0.6484	0.3392	0.0124	0.0000	0.0000	0.0000	0.0000
15	0.6468	0.3418	0.0114	0.0000	0.0000	0.0000	0.0000
17	0.6517	0.3372	0.0111	0.0000	0.0000	0.0000	0.0000
19	0.6598	0.3304	0.0098	0.0000	0.0000	0.0000	0.0000
21	0.6657	0.3252	0.0091	0.0000	0.0000	0.0000	0.0000
23	0.6751	0.3174	0.0075	0.0000	0.0000	0.0000	0.0000
25	0.6862	0.3095	0.0042	0.0000	0.0000	0.0000	0.0000
27	0.7009	0.2958	0.0033	0.0000	0.0000	0.0000	0.0000
29	0.7312	0.2671	0.0016	0.0000	0.0000	0.0000	0.0000
31	0.7763	0.2234	0.0003	0.0000	0.0000	0.0000	0.0000
33	0.8467	0.1533	0.0000	0.0000	0.0000	0.0000	0.0000

Surface height measurements

The RDCP pressure sensor measures absolute pressure P_{data} in kPa. The height h to the surface was found by the following equation:

$$h = \frac{P_{data} - P_{atm}}{\varrho g} \tag{1}$$

where P_{atm} is the atmospheric pressure (constant value of one atmosphere used i.e. 101.3 kPa), sea water density $\varrho = 1027$ kg/m^3 and acceleration of gravity $g = 9.82$ m/s^2.

The surface height time series was analyzed using T-Tide and the measured and predicted series, along with difference are given in Figure 13

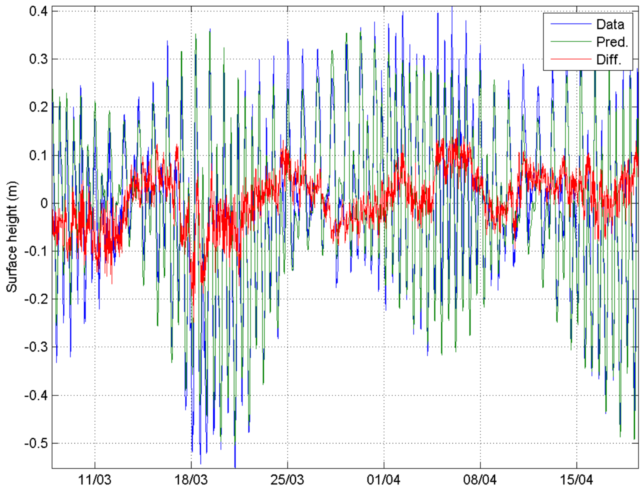

Figure 13: Time series of surface variation measured, predicted and difference.

The tidal constituents derived by T-Tide are given as the first entry in Appendix A.

Power estimates

The available power P per m^2 is given by the following formula:

$$P = \frac{1}{2}\rho V^3 \tag{2}$$

where ρ is the density of sea water (we use $\rho = 1027$ kg/m^3) and V is the current speed in m/s. Using this formula it is now possible to convert the measured speeds and tidal predictions of the current speed into time series of the power present at the different depths. Right column of Figure 11 gives the distribution of power present at the given depths. These plots are included as an illustration of how large a role the short time periods with high current speeds play for the total power available.

Figure 14 gives the available-power time series of the specified depths.

Figure 15 shows the average power profile.

Discussion and concluding remarks

This report documents the data from the current measurement conducted in Nólsoyarfjørður 2007. Tidal analysis is preformed and available power estimates are derived. It is important to note that the listed power estimates refer to the available resource (kinetic energy) per square meter, and that only one part of this quantity can be converted into mechanical and subsequently into electrical power.

Acknowledgements

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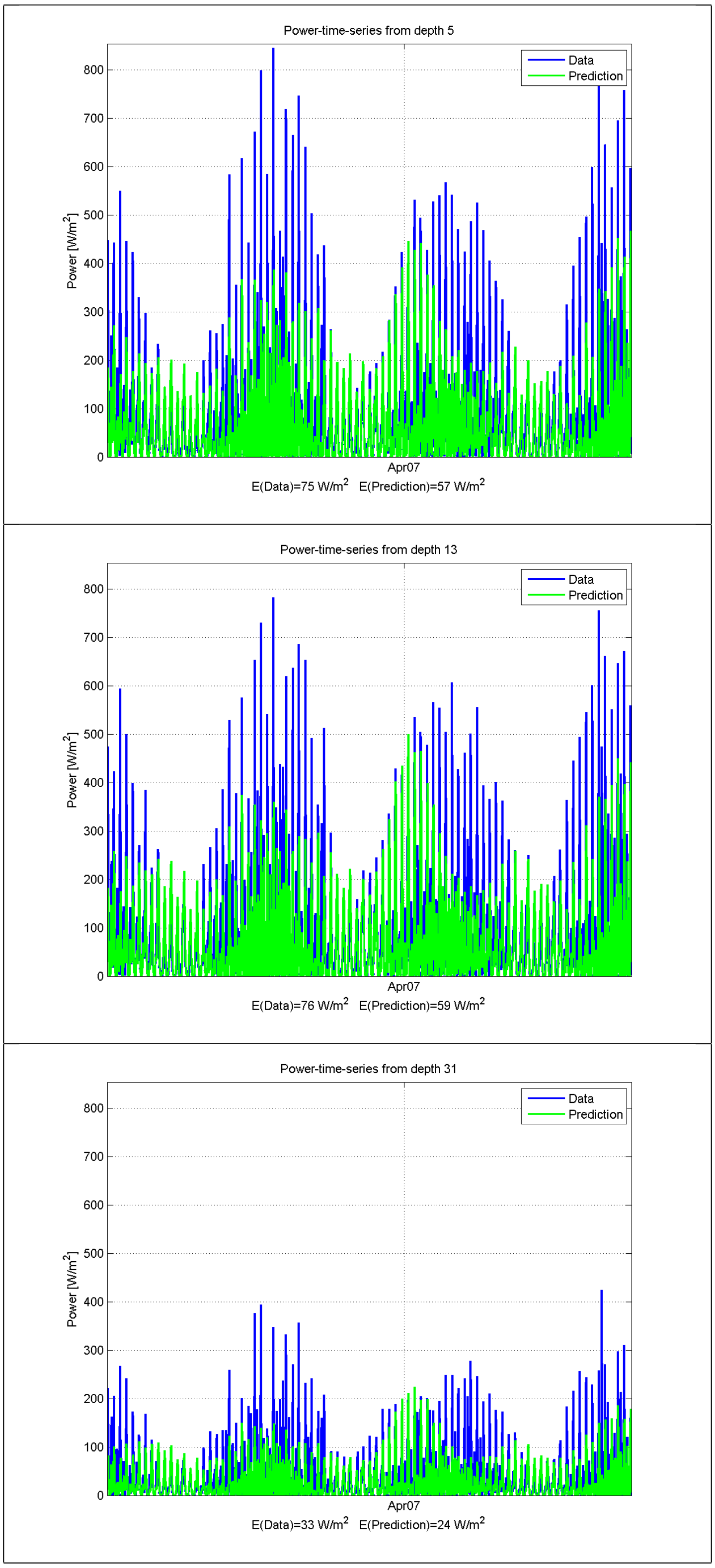

Figure 14: Time series of the available power at the specified depths, over the measurement period

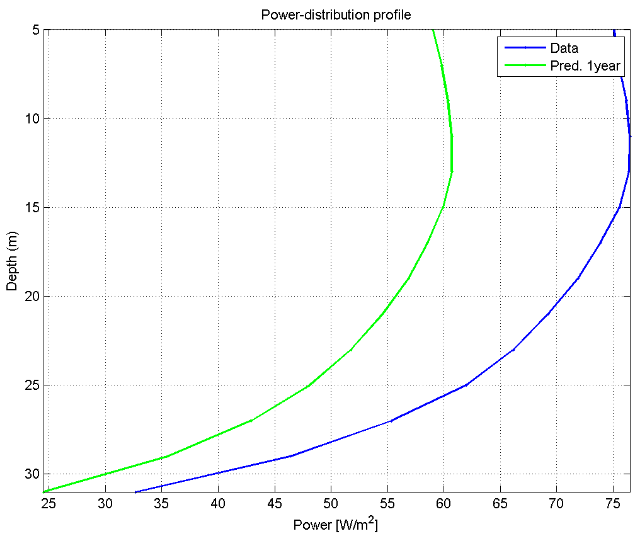

Figure 15: Average-power profile