

QA/QC procedure SC-ADCP data from the Egmond lander

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1. Overview and summary

The ADCP data is processed in four steps (ADCP internal process, and level 0 – 2) from the binary ADCP files into four standardized variables of the ADCP data for the various applications (velocity, backscatter, quality, details and deployment averaged). The processing is done for separate Matlab files corresponding to the separate binary ADCP files of the deployment periods, and only in the final processing step merged together into one time-series and separated per category. The levels of processing are:

ADCP internal data test (additional)

During the collection of the ADCP data a few procedures are applied within the instrument before saving the data to the internal memory card.

Level 0 – preprocess

This step is to prepare the files for processing in Matlab, the data remain unprocessed. The amount of parameters is reduced and some parameters are renamed for simplicity. The internal ADCP time is compared to the other instruments on the frame, and adjusted where necessary. An ADCP time field is added to the variable DAY; DAY.numadcp. This variable contains the differences between the ADCP-time and the 'frame-time' within the 10-minute burst interval.

Level 1 – Conversion and derivation of variables

Some first order conversion is applied, which involved converting the velocities of the 2011 data from beam to earth coordinates. In 2012 the data was recorded in earth coordinates. The water level is determined, and the quality of the water surface bins are analyzed. The depth to which the data is disturbed by the surface is 12%. This layer is removed from the data. The depth of the bins is converted from 'distance from the instrument' to 'distance from the seabed'. The z-layer approach is kept with the seabed as the reference level. All the other instruments on the lander are also referenced to the seabed. The water depth varies between the deployments, due to slight position changes (what done with it?).

In this level also the ADCP quality indicators are used to remove individual erroneous data and also entire time frames during lander motions.

Level2 – Quality of the data

“Typically, Level 2 processing entails advanced statistical methods such as variance spectra, empirical orthogonal function (EOF) analysis, and auto- and cross correlation analysis.”

But I have restricted this level of processing to analyzing the velocities and water levels by tidal component analysis. As this is also useful information for the paper. Other statistical methods do not seem to help understanding of the data.

The individual deployment data-files are merged together, and split into 4 ADCP variables. Tidal analysis is performed on the velocities at each height, also the ADV's on the lander frame are added to complete the overview. The water depth per deployment is analyzed and compared to the CTD. The calculated sea surface elevation (SSE) is subjected to the tidal analysis with UTide. Conversion of velocity in alongshore and cross-shore directions, with a conversion angle of 7 degrees calculated as the average between the upper water layer and the lower water layer (is appropriate in level 2 as the conversion needs an analysis of the velocity vectors). Ellipticity is not really analyzed in depth, just as a result of the tidal analysis (minor axis). But it is expected that the ellipticity varies over time.

2. RDI ADCP Collection processing

During the collection of the ADCP data a few procedures are applied within the instrument before saving the data to the internal memory card. The settings that have a quality control in them, which are used in the project set-up are:

- Allow 3-beam solutions
- Allow bin mapping
- Threshold maximum is at 50 counts. This is the maximum difference between echo intensity readings among the four profiling beams. For detecting fish.
- Ambiguity velocity = 175 cm/s radial.
- Pings per ensemble (averaging done) = 30.
- Correlation threshold = 64 (Default WC)

These tests can be names as 'global range data test'

3. Level 0 processing

3.1 L0 - ASCII to matlab

Script `rdradcp.m` by R.Pawlovic. No conversions are applied in this script. The data are only recursively read from a binary data file into a Matlab data file.

The amount of parameters is reduced and parameters are renamed for simplicity if necessary (if so shorter), and velocities are renamed to `vel1-vel4` if in 'beam' coordinate, else `vn, ve, vu, verr`.

Removed data obtained during lander recovery manoeuvre (comparing to `DAY.deploy` and `DAY.recov`)

Added `data.config.deploy_period`.

3.2 L0 - Date

ADCP Time is adjusted for UTC, winter time, summer time differences (`data.num`).

An offset in time is detected between the ADCP and the CTD, from comparison of timing of HW from smoothed pressure data (these smoothed data are not saved). This offset is due to various causes:

- Intermittent use of local (CTD) vs UTC times (sometimes ADCP).
 - Action: Both ADCP and CTD are adjusted by 1-2 hours for this inconsistency.
 - Also the CTD for period 11 is adjusted other than usual Summer time difference.
- Difference in start time of instruments at deployment. CTD starts always at 18:00 (local time), while ADCP between 00:00 for period 2-4 and start at programming time for period 5-18.
- Difference in internal clock of ADCP wrt 'lander-time' (other instruments on bottom frame). Maximum time difference is 9 minutes, which is almost the whole length of the interval.
 - Action: while working on data, flooring at 10min intervals. But also `DAY.numadcp` added to `DAY` variable.

In periods 2-4 there is no difference in start time of pings. All instrument were set to start at 18:00 of the deployment day. Thus the time difference in Figure 1 indicates an internal clock difference between the ADCP and lander-time, plus a difference in start time for periods 5 - 19. In the end the source of the difference is not important for further processing, as it needs to be accounted for in a similar way further in the analysis.

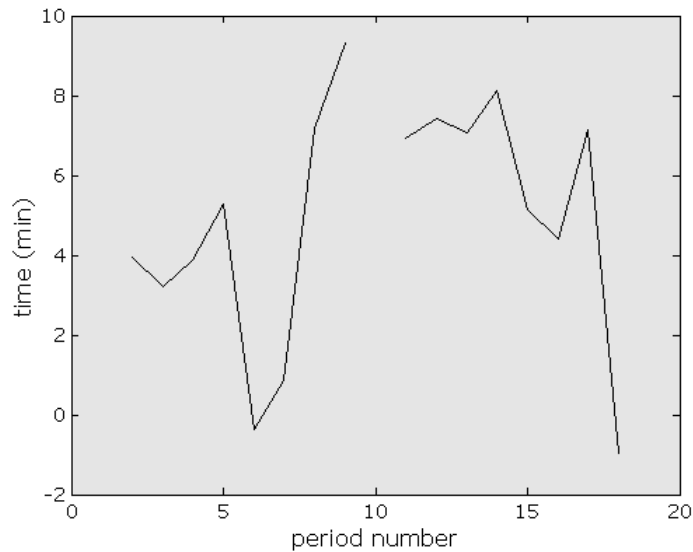


Figure 1. The average time differences between high waters of CTD and ADCP data.

4. Level 1 processing

4.1 L1 - Velocities Beam to earth

Convert BEAM to EARTH coordinates for 2011 data (periods 2-9). This has been done with the script `bm2geo` from the USGS ADCP Toolbox. The script has been adjusted to work without the netcdf file structure.

4.2 L1 – Correction speed of sound

Difference between observed and set salinities is [range].

This changes the level of the near-surface bin with how much?

	25	Salinity =30	32
5	1458.2	1464.5	1467.1
Temp			
18	1504.6	1510.3	1512.5

Max difference = $1512.5 - 1458.2 = 54$ m/s. Over 9 meter:

Is temperature taken into account? Yes, temperature sensor is used!

How about salinity? ES=30

Then, max error over series = 5 m/s. Over 9 meter gives only 3 cm difference in the upper bin! No need to correct for salinity difference over this short distance.

4.2 L1 - Surface affected bins

- Find surface and accordingly remove values above the surface (vel and bs; setNaN) .
- Account for side-lobe effect (Figure 3), with beam angle of 20 degrees. `Trimbin.m` (rewritten from `trimbins.m` from USGS ADCP Toolbox). Theory gives a percentage of 6%, but from backscatter intensities it was found that a higher percentage of 12% of surface removal should be applied. The test was performed on the 18th dataset of which a part is shown in

Figure 2. With stars (6%) and dots (12%) the flagged/removed datapoints are indicated on top of the backscatter signal of the first beam.

- After removal it appears that there are still timeframes for which the intensity increases in the upper bins (Figure 2b). These are most probably bubbles. These do not disturb the horizontal velocity record, as bubbles only move vertical. The intensity signal is affected by the bubbles, and thus will have an effect on the sediment concentration.

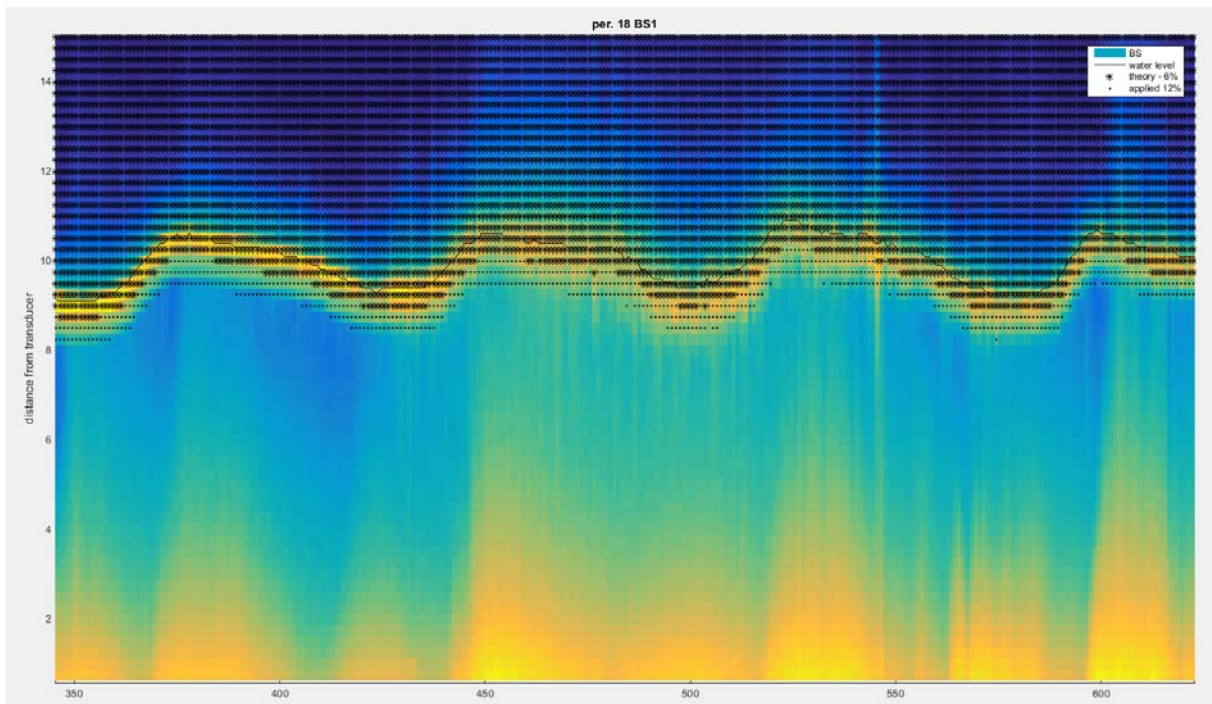


Figure 2a. BS (backscatter) in period 18. The difference in bs levels between the theoretical 6% and the applied 12% surface affected water layer is visually seen. Horizontal axis is time frame numbers.

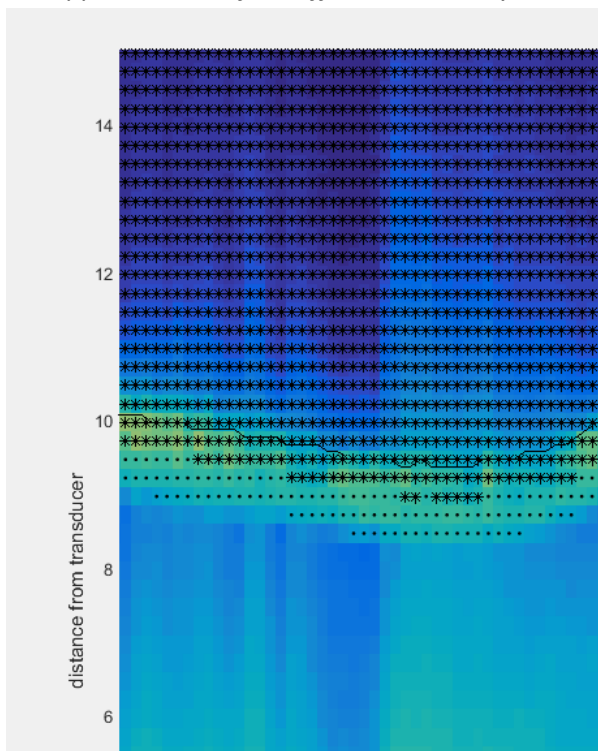


Figure 2b. BS3, increase in bs in non-deleted data!

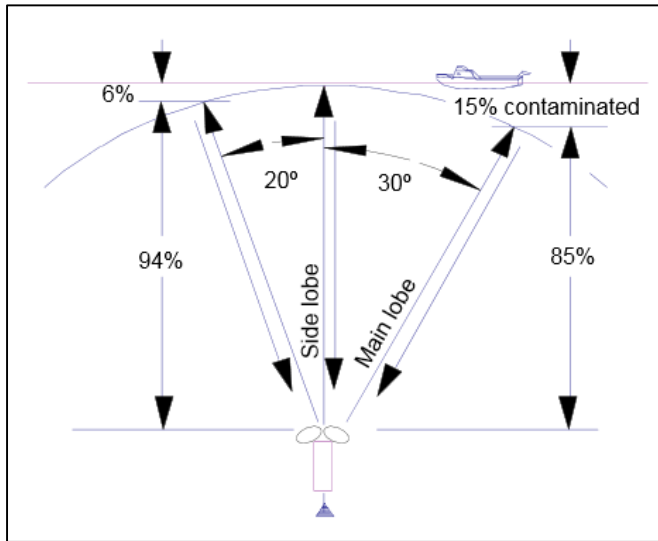


Figure 3. The side-lobe effect illustrated for two ADCP configurations. The beam angle of the SC-ADCP is 20 degrees, but the side lobe effect seems to be larger at our site. (Figure source: Broadband Primer by RDI)

4.3 L1 - First order quality check

Table 1. Settings for quality parameters

Parameter	Criterion	Per Beam, Bin or Ensemble
Echo intensity	< 46	Bin (velocities internally corrected)
Echo intensity difference	> 10	Bin
Pitch and roll	> 15 degrees	Ensemble
Heading difference	> 1 degree	Ensemble
Error velocity	> 0.1 m/s	Bin
Horizontal velocity	> 3 m/s	Bin
Vertical velocity	> 0.3 m/s	Bin
Relative vertical velocity	> 50%	Bin
Vertical difference v_{tot}	> 0.1 m/s	Bin
Correlation	< 64	Bin

The rejected data is removed from the dataset without interpolation or extrapolation. The list of tests is obtained from the IOOS Qartod Manual (version 1, 2013). The criteria are formed from a combination of recommendations and expert judgement.

The ADCP orientation and motion criteria remove timeframes, especially during high energetic events (when water levels also rise 2m for instance in period 17). These data gaps are not interpolated, as conditions are stochastic and non-predictable. Time-wise interpolation is not suited during turbulent, energetic conditions.

After the check, remarks that remain which may play a role later on:

- vertical velocity near transducer is larger in first 1-2 meters
- Period 17 has a large number of half-deleted profiles
- Decrease in intensity over the 2 years time? -> plot all merged data in lines in next section

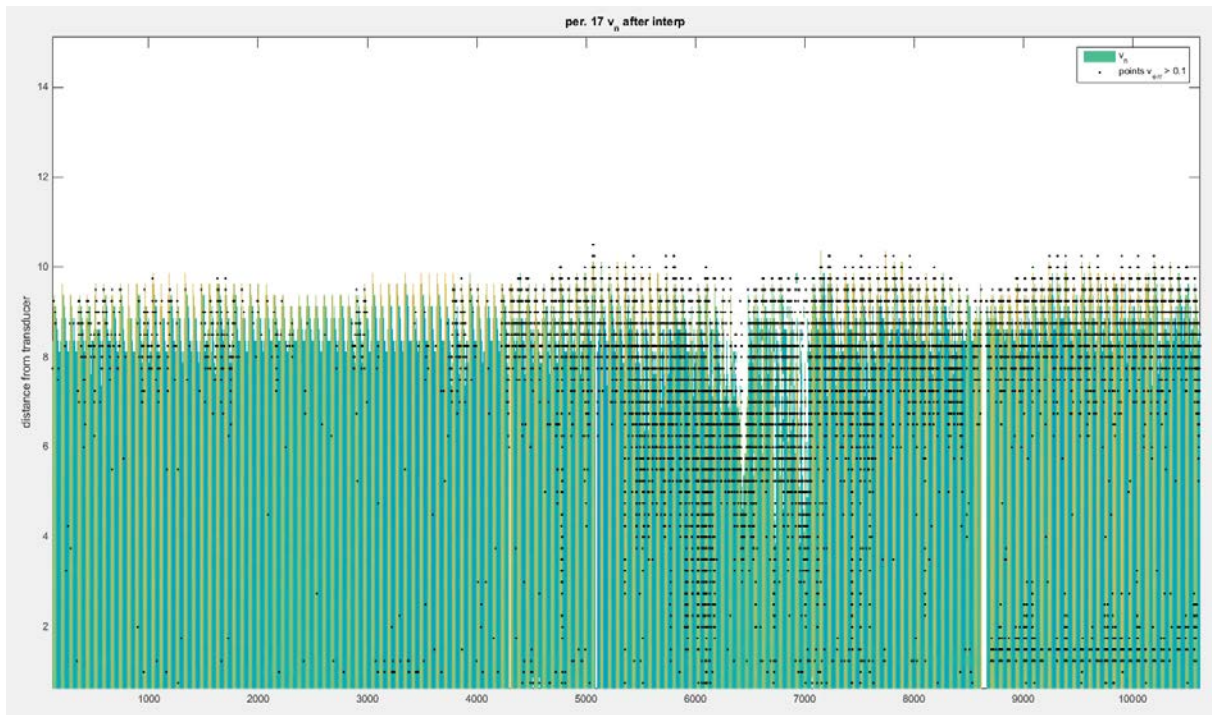


Figure 4. Indication of the error-velocity-criterion (black dots) on top of the northward velocity before the quality analysis. The white fields near the surface between 6000 and 7000 were removed by the ADCP internal quality check (section 2). The white timeframes were removed with the frame-motion-criterion.

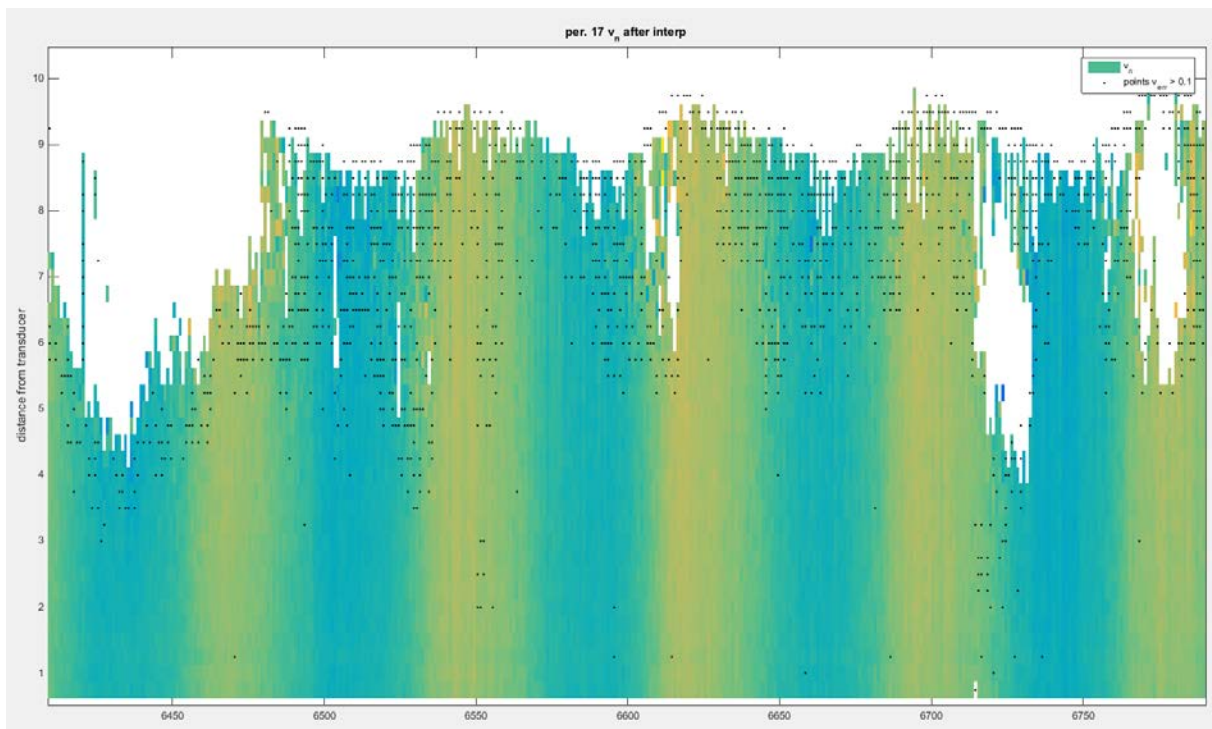


Figure 5. Zoom of the corrected velocity data (in a previous version the data were interpolated instead of removed), to see in detail that fields are set to NaN at the surface due to the error-velocity-criterion (white field with a black dot), that fields near the surface were already set to NaN by the ADCP internal criteria (white fields without dot), that individual fields with bright blue and yellow

colors (> 1.5 m/s) are present as single data points after this quality control (which should have been removed by the quality control, surrounding fields have been removed as well).

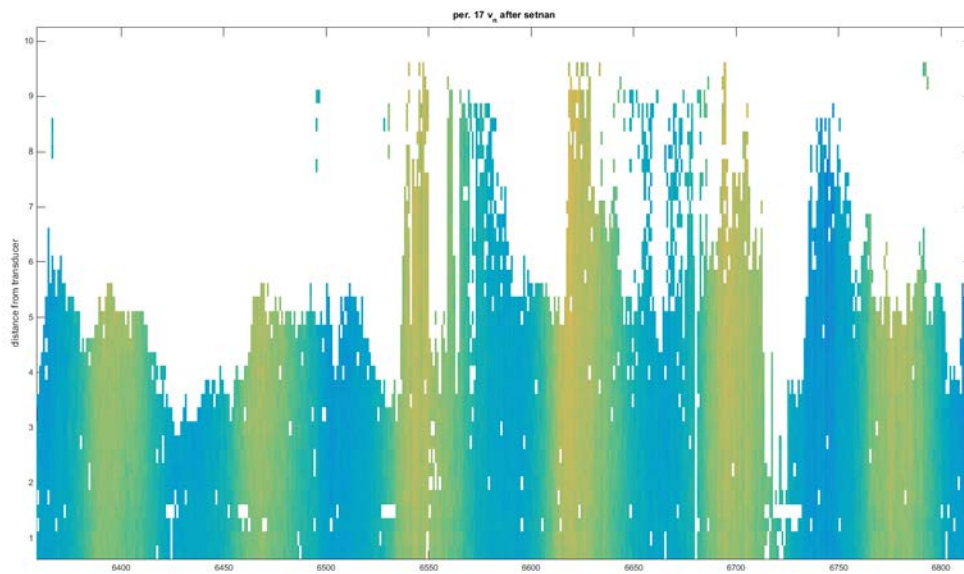


Figure 6. Zoom of the same data as in Figure 5, but now after the renewed quality analysis. More data have been removed, than was indicated with the error-velocity criterion (as was necessary). The 1st qa-analysis leaves barely a velocity profile useful for further analysis. The water level fluctuates between 10 and 11 m.

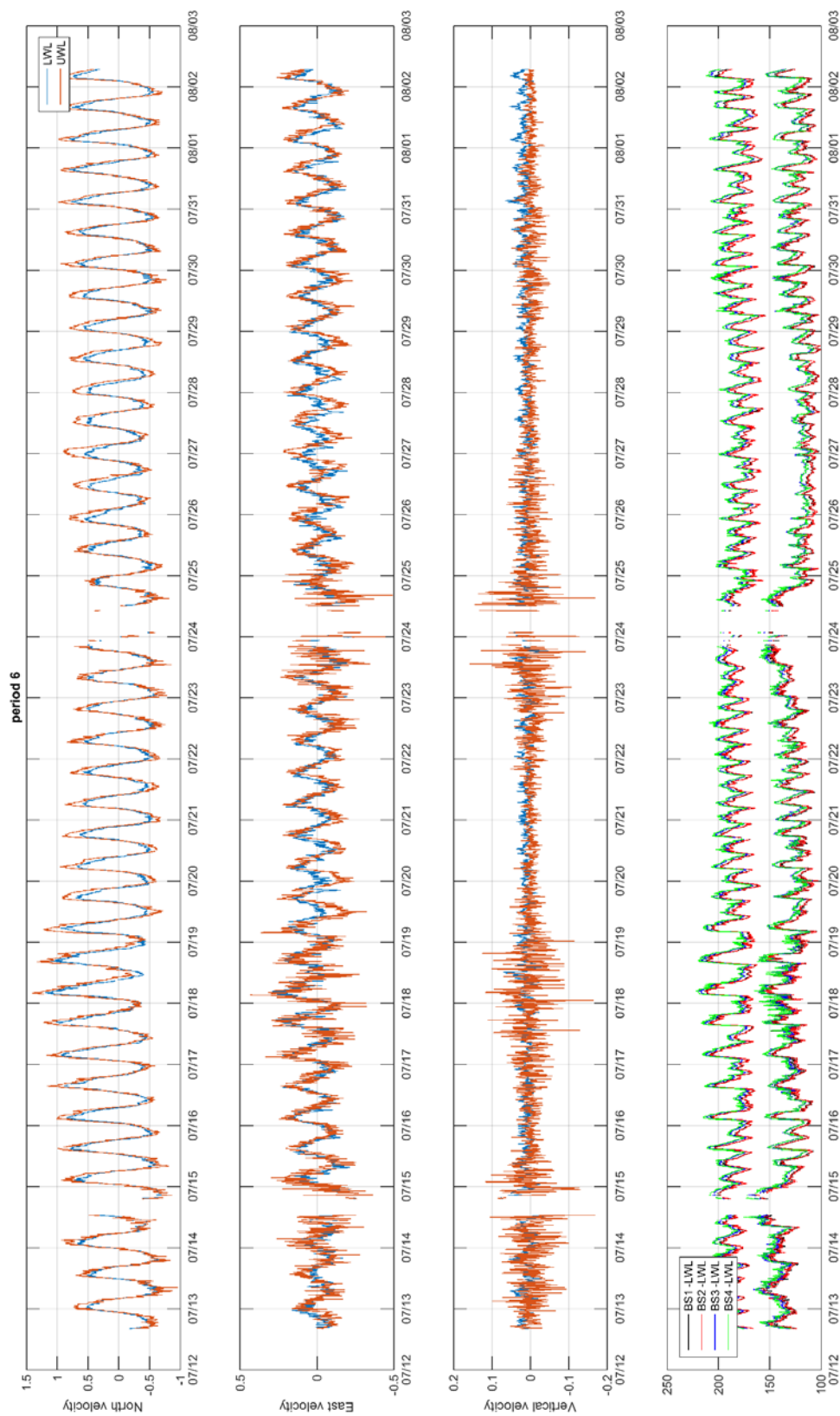


Figure 7. Data of the LWL and the UWL of period 6 after step L1 of the qa-analysis .

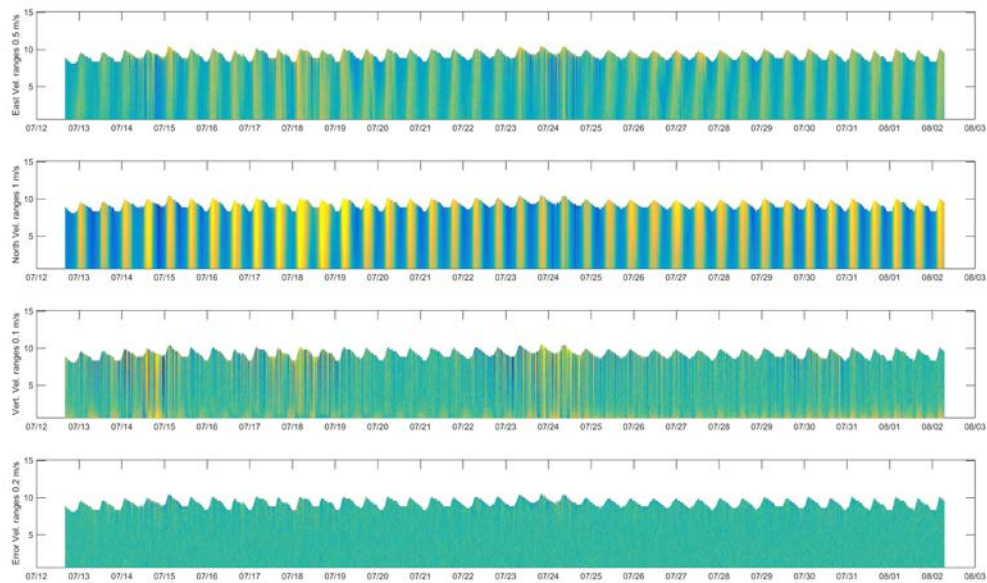


Figure 8. 2D velocity data of period 6 before the L1 step . Pay attention to the vertical velocity near the ADCP transducer.

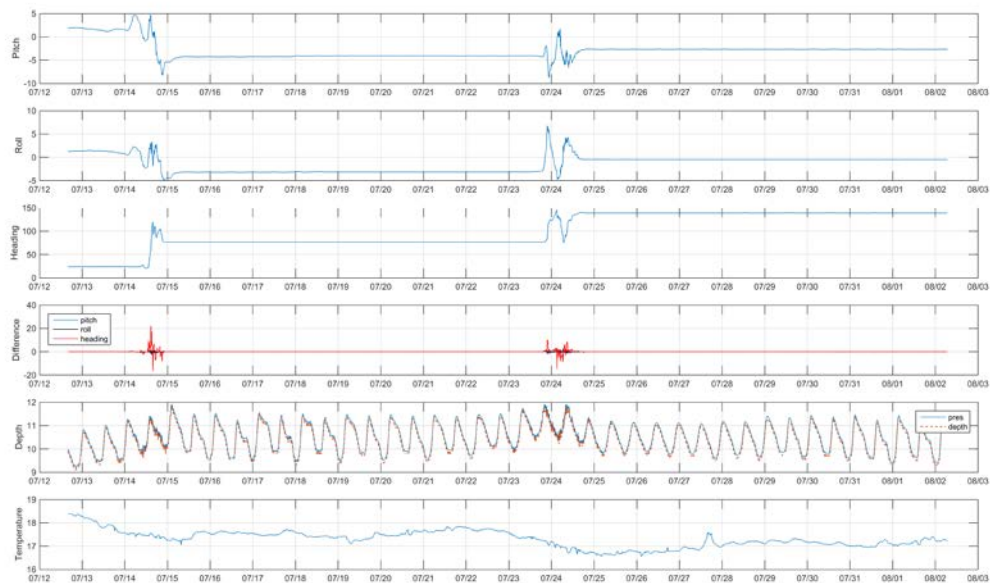


Figure 9. Environmental parameters (pitch, roll, heading, difference, depth and temperature) of period 6.

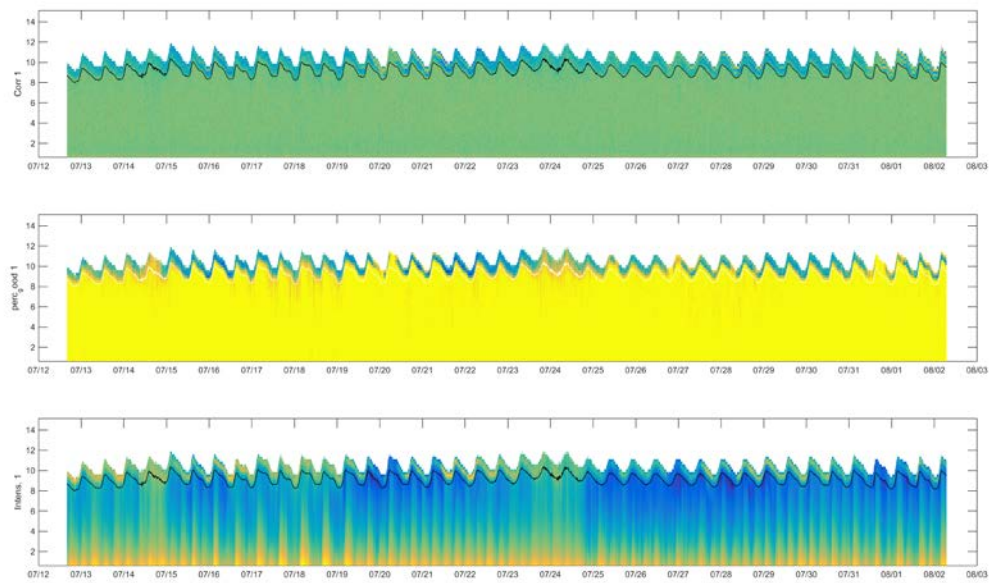


Figure 10 ADCP quality parameters (correlation magnitude, percentage good, intensity) of beam 1 of period 6. Data above the waterline are removed, the black line indicates the 12% surface affected bins. .

5. Level 2 Processing – Quality variables

Steps:

- Merge files
- Squeeze for NaN layers (42:59, but some depth indicated water level up to layer 50. Possibly these fields have been deleted in the process for the frame motions)
- Determine averages per deployment period
- Tidal components of both the velocities and the sea surface elevation (SSE)
- Velocity conversion North-East to along-cross shore.
- Analysis of the (frame) depth, and correction for this in variables.

5.1 L2 - Deployment details

Calculated averages per deployment period (Figure 11), if possible for the upper water layer (UWL, layer 25) and the lower water layer (LWL, layer 3). Also the 95% confidence interval is given, if functional. The parameters are:

- Tidal analysis of the M2 component per deployment with UTide, for UWL and LWL
- Residual velocities (north,east,up), both for LW and UWL. Calculated as deployment average (AVG), residual from UTide per period (Mean) and averaged over 24h tidal periods (24T).
- Backscatter; averaged over all sensors. Determined for both the LWL and the UWL.
- Depth, pitch, roll, heading, temperature

Interesting results (odds) from the averages:

- The depth difference between the shallowest and deepest deployment is 0.9 m.
- The angle of the M2 tidal current varies per deployment period, with values between 0 and 14 degrees wrt north.
- Pitch and roll have been quite severe in period 15.
- Residual northward and eastward velocities are quite large in period 18 (short period).
- East-velocity in UWL changes direction over the periods (but hardly possible to see due to the legend...).
- Upward velocities in LWL.
- Backscatter signal decreases over time, period 17 being extreme.

Missing data:

- Period 18 contains only 5 days before ADCP broke down
- Period 10 (2,5 month) and part of 9; in total 3 months

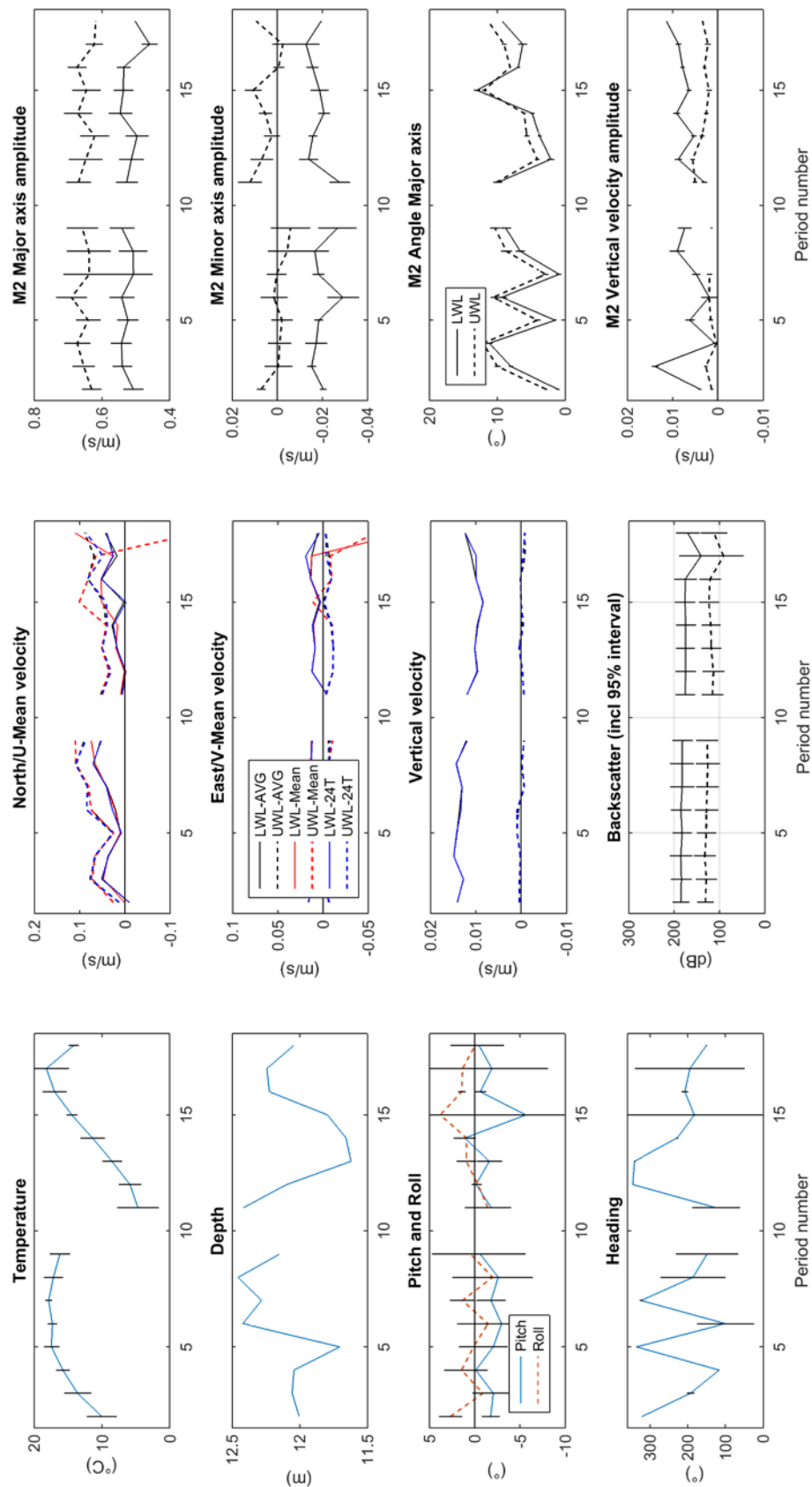
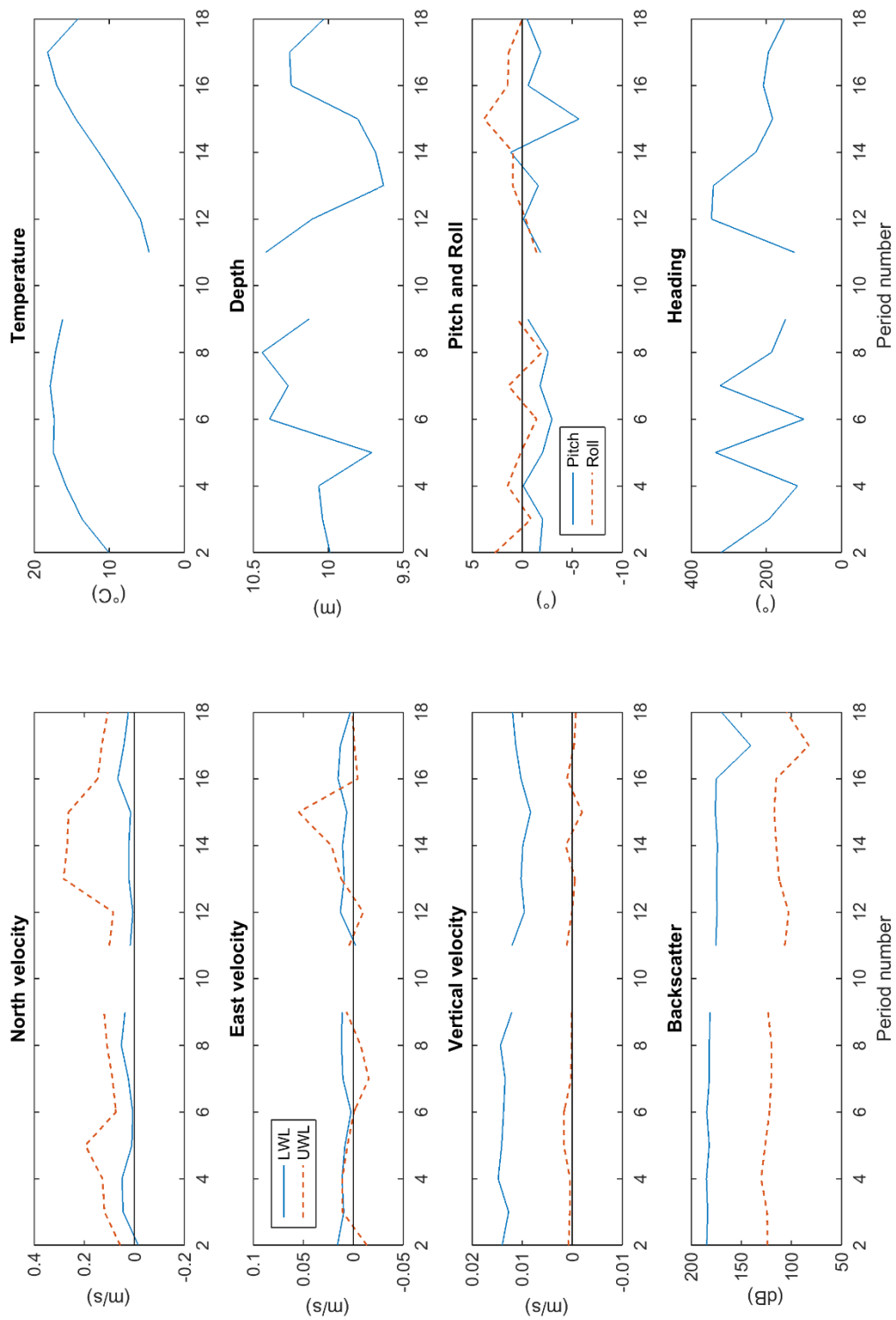


Figure 11. Deployment details (averages and tidal analysis). Values with their 95% confidence interval if shown. 'AVG' means the average of the data, 'Mean' means the calculated mean from the tidal analysis.



Figures 12. Deployment averages, first edition (for comparison of differences due to increased quality control parameters).

5.2 L2 - Merge files

Merge data-files together on basis of the DAY format (so NaNs between deployments, 70 MB file). Four separate files are created for the quality analysis, to limit the memory necessary in future analysis.

- | | |
|--|--------|
| • One for velocities; | ADCPV. |
| • One for backscatter; | ADCPS. |
| • One for quality items, rotation | ADCPQ. |
| • One for detailed items; env. params, and deployment averages | ADCPD. |

5.3 L2 - Tidal analysis

The Matlab toolbox *UTide* is applied to the north and east velocity data. The *UTide* toolbox is a Unified Tidal Analysis and Prediction based on harmonic analysis of Godin 1972, incorporated in Pawlowicz 2002, and which is further extended (especially for irregular spaced data) in Codiga 2011. Unfortunately the data gap in winter is too large to treat the dataset as one (error in *UTide* iteration), so we had to analyze the dataset in two separate periods (2-9 and 11-17) and average the results.

Tidal components (Table 2)

UWL – LWL differences & similarities:

- M2 is largest by far (87% percent of energy), then S2 and N2, and after that many other semi-diurnal and higher order components
- Diurnal components (O1 and K1) are weak (20+ on the list).
- UWL amplitudes are larger than LWL amplitudes

SSE – velocities: differences and similarities:

- M2 is largest for both, but thereafter different components follow up.
- M4 is quite strong (nr 4 and 2) for both variables.
- The contribution of other components to the M2 sse is larger than for the velocities. M2 has 72% percent of energy for SSE relative to 87% for velocities. This is reflected in the magnitude of the amplitudes.
- Diurnal component is more present in SSE than in velocities.

	LWL		UWL		SSE (ADCP)		SSE (CTD)	
1	M2	0.513	M2	0.644	M2	0.638	M2	0.625
2	S2	0.119	S2	0.147	M4	0.194	S2	0.194
3	N2	0.084	N2	0.102	S2	0.193	M4	0.192
4	M4	0.059	M4	0.064	MS4	0.112	MS4	0.115
5	L2	0.046	L2	0.061	O1	0.106	O1	0.102
6	MU2	0.042	MU2	0.055	MU2	0.103	MU2	0.099
7	K2	0.042	K2	0.052	2MS6	0.078	2MS6	0.079
8	M6	0.033	M6	0.046	N2	0.072	MSF	0.075
9	MS4	0.033	2MS6	0.039	M6	0.069	M6	0.068
10	2MS6	0.028	MS4	0.036	K1	0.068	N2	0.068
11	MN4	0.018	2MN6	0.023	MSF	0.062	K1	0.065
12	MM	0.017	MM	0.020	MN4	0.051	L2	0.050
13	2MN6	0.015	MKS2	0.020	L2	0.046	MN4	0.050
14	MSF	0.015	MF	0.018	2MN6	0.033	2MN6	0.035
15	MF	0.014	MN4	0.016	M8	0.033	M8	0.031
16	M8	0.014	M8	0.015	MM	0.032	2MK5	0.024
17	MKS2	0.013	MSF	0.015	2MK5	0.026	2SM6	0.021
18	SSA	0.013	2MK6	0.013	ETA2	0.022	Q1	0.020
19	MK4	0.011	EPS2	0.013	Q1	0.021	ETA2	0.019
20	EPS2	0.010	MSN2	0.012	2SM6	0.019	SN4	0.015
21	2MK6	0.010	SSA	0.011				
22	O1	0.009	O1	0.010				
...	K1	0.002	K1	0.004				

Table 2. Chronological order of the first 20 tidal components in the velocities from the LWL and the UWL and from the SSE (both from ADCP pressure sensor and CTD pressure sensor). The diurnal components O1 and K1 are added as well. Computed with UTide (Codiga, 2011). UWL is layer 25, and LWL is layer 3 of the ADCP profile.

5.4 L2 - North-East to along-cross

- The angle between the alongshore direction and the north is calculated from the tidal analysis of the M2 component. Averaged over both periods and over UWL and LWL this angle is 7 degrees (Table 3).
- Table 2 shows that there is a noticeable difference (4 cm) in the magnitude of the M2 tide between both periods. Also Figure 13 shows structural differences in the other components between the two periods. Is this important?
- Analysis of the split in periods of the ADV's on the lander shows that averaging over the periods is almost similar to using the whole period (Table 3). The difference is within 1 cm.

M2 details	LWL			UWL			Tot. Avg.	ADV 1.4 mab			
	per2-9	per11-17	avg.	per2-9	per11-17	avg.		per2-9	per11-17	avg.	per 2-17
Major (m)	0.523	0.502	0.513	0.651	0.637	0.644	0.578	0.369	0.376	0.3725	0.366
Minor (m)	-0.019	-0.014	-0.016	0.000	0.006	0.003	-0.007	-0.017	-0.017	-0.017	-0.015
Theta (deg)	6.0	6.6	6.3	7.8	7.8	7.8	7.1	9.0	5.7	7.33	7.7
phase lag (deg)	82	82	82	84	84	84	83	84	84	83.9	89

Table 3. Details of the M2 tidal component from the UTide analysis.

5.5 L2 - Vertical profile of M2 tide decomposition

In Figure 13.

Major axis: The amplitude decreases gradually from 0.6 m/s at the UWL to 0.2 m/s near the seabed. In the LWL the profile does not seem really logarithmic (Should the 'average' profile be logarithmic? test it some other time?)

Minor axis: Positive in the UWL (signal change at 8m depth) and negative in the LWL and going to zero near the seabed. The difference between both periods and some NaNs at some heights creates a wiggly signal of the average.

Theta: The angle (wrt the alongshore direction) is positive in the UWL and negative in the LWL (signal change at 4.5 m). The difference is about 2 degrees between UWL and LWL location (also Table 3).

The ADV at 1.4 mab has a large discrepancy between both periods, further analysis needed as this is too big. The ADV at 0.15 mab also seems an outlier. Should theta be calculated per deployment period, to understand the influence of the frame on the velocity observations?

Phase: the phase is fairly equal over depth, decreases towards the seabed. The ADVs at 1.4mab and 0.15mab are outliers.

Combination ADCP&ADV: From the profiles in Figure 13, I have my doubts whether the 1.4 mab ADV gives (frame) unbiased data. This is confirmed with the screenshot in Figure 14, of the northward velocities of the various instruments at the transition from one period to the next. The ADCP and the Vektor keep similar velocity amplitudes for both the flood and ebb velocities at both periods. The ADV at 1.4 mab appears to have relatively smaller ebb velocities than flood velocities in the first period, while the opposite occurs in the next period; relatively smaller flood velocities than ebb velocities.

Residual velocity profile per deployment period.

In Figure 15.

First of all, the residual velocity increases exponentially in the part where there is sometimes no water. All velocity directions show an (small) effect of the lander in the lowest bins; the upward velocity more than the north and east velocities.

- The northward residual velocity is slightly larger in the upper water column, than in the lower water column.
- The eastward residual velocity changes direction over the vertical. Eastward in the lower water layer and westward in the upper water layer.
- The vertical residual velocity is non-negative in the lower water column, directed in upward direction. This effect is measured up to 7 mab.

The values of Figure 15 of the LWL (layer 3, 3.12mab) and the UWL (layer 25, 8.62 mab) have been added to the deployment averages in Figure 11. The lines overlap with the period-averaged velocity and the UTide-residual velocity. The residual velocity per period is thus mostly an effect of the tidal current, and not affected by a residual due to an half measured tidal cycle.

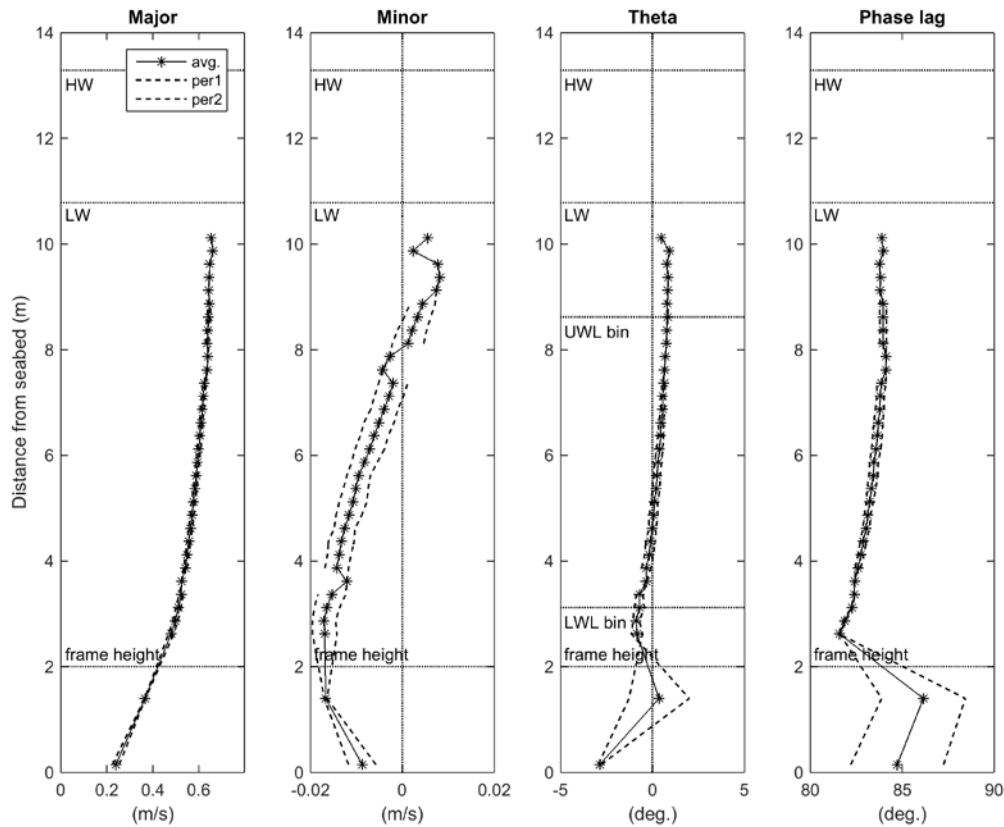


Figure 13. Decomposition of the M2 tide. Included are the results from the two ADV's mounted onto the lander (0.15mab and 1.4mab). Vertical profiles of the major and minor axis, the angle wrt longshore direction and the phase lag. HW and LW are defined as $MSL(min,max) \pm \text{amplitude}$ ($M2+M4$).

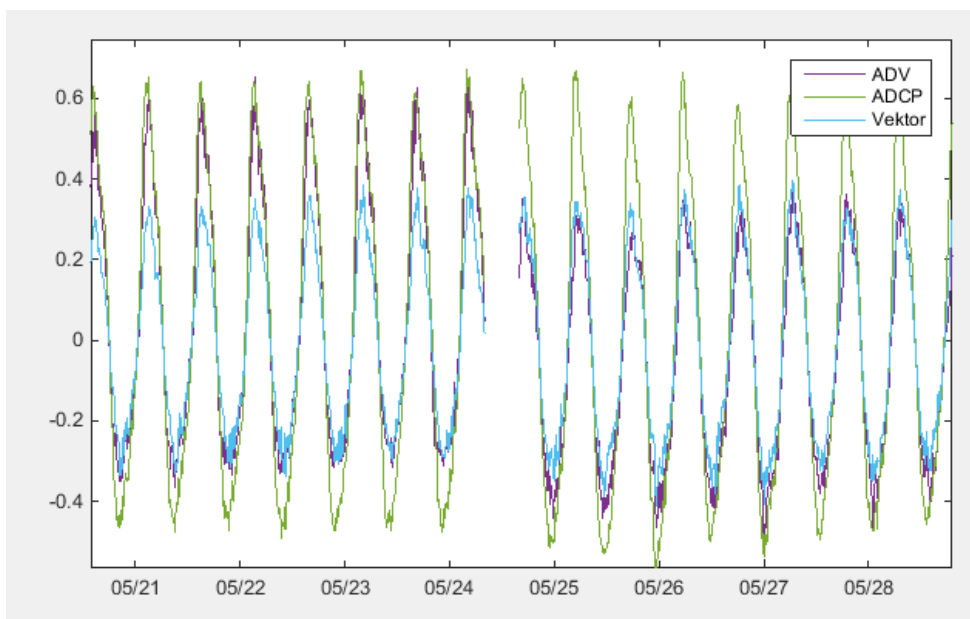


Figure 14. Example of the effect the ADV at 1.4mab experiences per deployment period; peaks are smaller either on the flood or on the ebb, depending on the deployment period. The Vektor at 0.3mab seems unaffected.

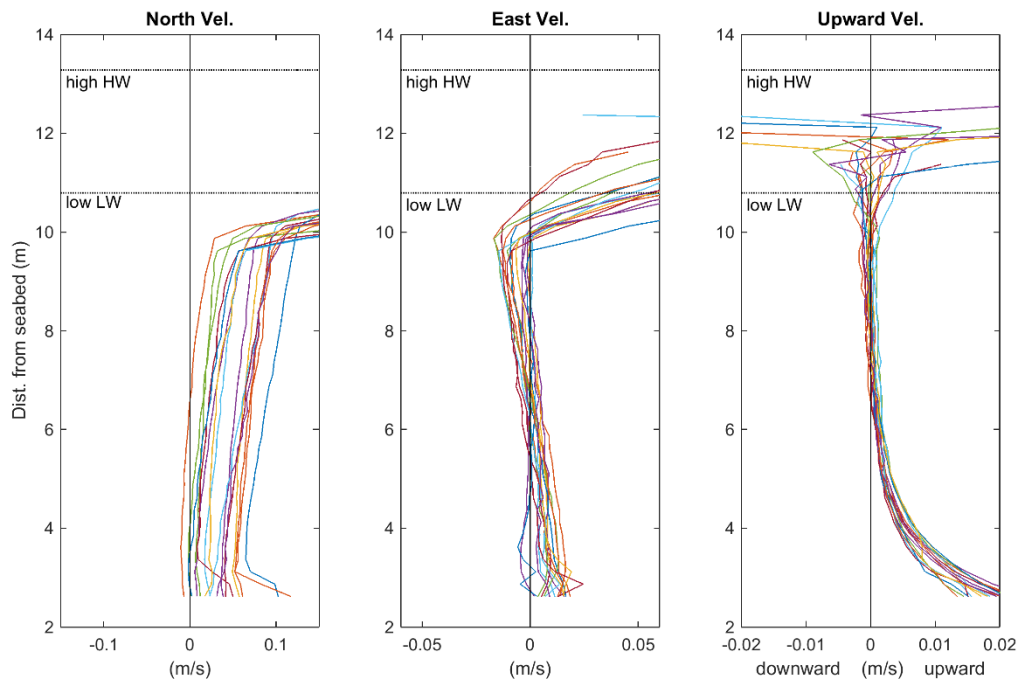


Figure 15. The residual velocity profiles per deployment period calculated from an exact number of 24h tidal cycles (2 times M2) within the deployments.

5.6 L2 - Depth definition and SSE variation

The heart of the transducers are at 2.20 meters above the seabed (when the frame has sunken into the bed up to the ballast pipes, which is about 0.13 m). This height is added to the config structure, with the name 'transducer_offset'. The ADCPD.dep and ADCPD.bin variables have been updated with this number, and are thus representative for the depth of the water column from the seabed to the sea surface. Also the variable ADCPD.binadv has been created in which the heights of both ADV's is added to the structure of the ADCP bin heights.

ADCPD.sse is made from ADCPD.dep by subtracting the average water level of the deployment period. From sse we can calculate the tidal components more accurately. Mostly the SA and the SSA components have a lower amplitude, the amplitudes and phases of the lunar, solar and diurnal tides remained similar. Table 1 has been updated with this new tidal component analysis of the SSE, and the SSE tidal analysis of the CTD signal has been added.

Actually kind of bizarre how little of the surface can be analyzed with the ADCP (for tidal analysis). In Figure 13 are the points plotted for which a solution was found by UTide. HW and LW are defined as $MSL(\min, \max) \pm \text{amplitude} (M2+M4)$. Possibly there are too many data gaps in the bins more towards the surface to solve the tidal analysis. The first two meters below the LW level are affected by lower water levels, differences in deployment depth, and mostly due to the surface affected bins (12% = 1.5 m).

Depth and SSE are well defined and analyzed. Figure 16 gives an impression of the variation of the sea surface elevation (SSE) over time, instead of seeing only tidal components. The spring-neap signal

is largely hidden due to the local set-up and set-down of the water level (which is seen in the blue graph of the composed tidal variation in the lower graph in Figure 16). Table 4 gives the deployment-averaged water depths recorded by the ADCP and the CTD. It appears that during deployments 2,4,6 and 8 the distance between both sensors was 10 cm or less. Possibly the CTD sensor of these deployments had an offset of about 0.45 m. This seems to have been solved in 2012 (periods 11+).

Table 4. Average water depth (m) of the ADCP and CTD sensors per deployment period.

period	ADCP	CTD	diff
1	0	0	0
2	9.9874	10.1054	0.118
3	10.0375	10.5386	0.5011
4	10.0631	10.1134	0.0503
5	9.7097	10.1856	0.4759
6	10.3915	10.4022	0.0107
7	10.2668	10.739	0.4722
8	10.4402	10.4635	0.0233
9	10.1284	10.6857	0.5573
10	NaN	10.3904	
11	10.4173	10.8848	0.4675
12	10.1065	10.6238	0.5173
13	9.6302	10.1078	0.4776
14	9.6845	10.2098	0.5253
15	9.8028	10.1337	0.3309
16	10.2464	10.6214	0.375
17	10.2579	10.7007	0.4428

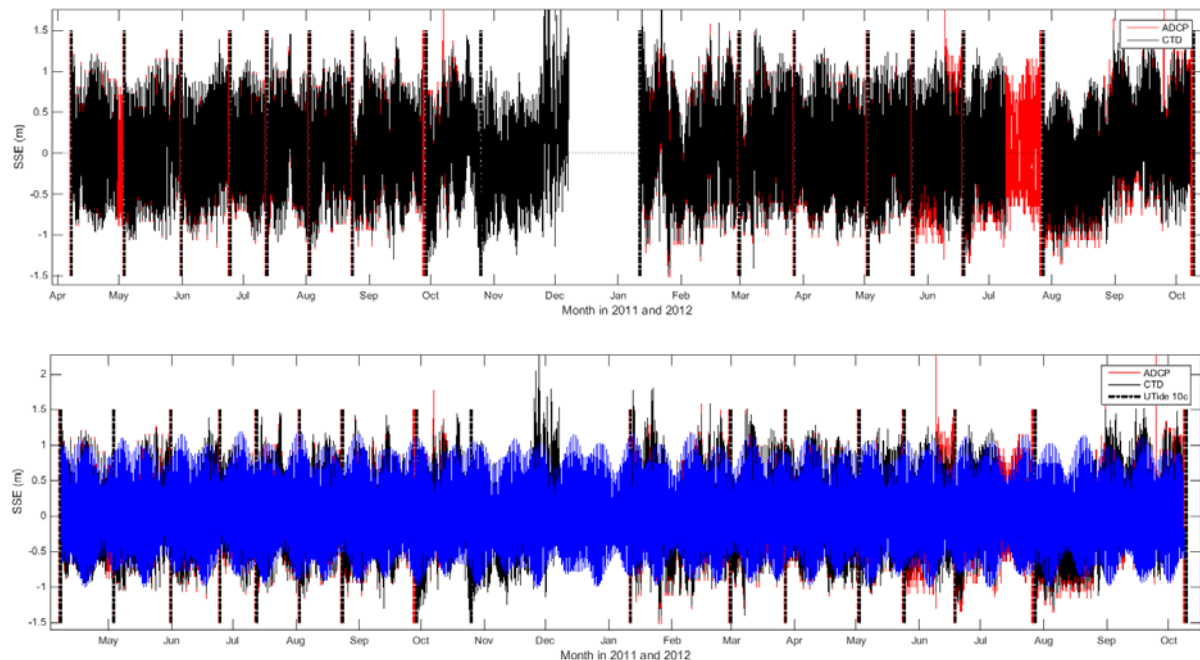


Figure 16. SSE of both the ADCP pressure sensor and the CTD pressure sensor. To give an impression of the variation of the sea surface over time. In blue the calculated tidal elevation is shown, calculated from the top 10 tidal components.

6. Conclusion

Available for use are the datasets:

- ~ ADCPD
- ~ ADCPV
- ~ ADCPS
- ~ (ADCPQ)
- ~ M2

Caution with, in further analyses:

- Upward velocities near frame, also some influence noted in the north and east velocities (the residuals)
- Backscatter in period 17 is oddly low.
- The backscatter signal decreases over time, period 17 being extreme.
- Velocities of the ADV: flood and ebb peaks may be reduced to the frame orientation (zero-crossings are still fine and used to determine the tidal periods)
- There are data gaps, sometimes of a few hours.
- In October to January missing 3 months of data consecutive.

Interesting conclusions:

- ~ The depth difference between the shallowest and deepest deployment is 0.9 m.
- ~ Residual velocities: There is a somewhat larger alongshore-northward residual in the upper water column than the lower water column. Cross-shore wise there is an onshore residual near the seabed and an offshore residual near the surface.
- ~ There is a small difference in the direction of the main current between the surface and bottom (1.5 degrees).
- ~ The water level and the velocity have a different tidal signal. M4 and the diurnal component have a larger contribution to the sea surface elevation (SSE) than to the velocity.