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Hydrodynamics and Sediment Dynamics in the Schelde Estuary

Sub report 10
Factual data report for measurements at
Drempel van Hansweert in May/June 2016

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Agenda for the future – Mesoscale hydro- and sediment dynamics in the Schelde estuary

Sub report 10 – Factual data report for measurements at Drempel van Hansweert in April/May 2016

Vandebroek, E.; Claeys, S.; Plancke, Y.; Verwaest, T.; Mostaert, F.

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Abstract

Within the framework of the cross-border Flemish-Dutch research program, Agenda for the Future (Agenda voor de Toekomst), field measurements were collected and calibrated at a number of strategic locations along the Schelde. This report describes a April and May 2016 field campaign to measure hydrodynamics and sediment transport near the sill of Hansweert (Drempel van Hansweert).

Four up-looking ADCPs were placed on the bed and left to measure currents and acoustic backscatter over a period of one month. Due to the dynamic nature of the location, all four ADCPs were buried in sand by the end of the campaign, but were able to collect between 5 and 28 days of data. In order to estimate sediment transport rates using the acoustic backscatter of the ADCPs, two 6-hour calibration campaigns were conducted on May 9th and 10th, respectively. During the calibration, currents, suspended sediment concentration, sediment transport, and grain size were measured using an ADCP, LISST, two Delft bottles, and by collecting water and sediment samples for lab analysis. One of the ADCPs was already covered with sand at the time of the calibration campaign, but the other three ADCPs were calibrated to produce a time series of currents and sediment transport.

This report presents the measurement techniques, calibration methods, and summary of results (including ambient conditions). Accompanying this report are time series of hydrodynamic and sediment transport measurements from the four bed-mounted ADCPs. The results from this campaign (and others) are being used to calibrate and validate numerical models, the results of which will be described in a later report.

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1 Introduction

One component of the 4-year collaborative research program “Agenda for the Future,” between Belgium and the Netherlands, is to improve hydrodynamic and sediment transport numerical models. Within the “mesoscale morphology” project, numerical models will be used to reproduce both sedimentation patterns at dredging locations (“sills”) and sediment transport patterns of disposed sediments at deeper parts of the navigation channels. Field measurements are necessary in order to calibrate and validate the improved models. Two field measurement campaigns were conducted in 2015-2016 at strategic locations in order to validate the numerical models.

This report describes measurements collected at Drempel van Hansweert in April and May 2016, including the data collection methods, post-processing, and brief write-up of the results. Vandebroek et al. (2017) reports similar measurements carried out at Drempel van Frederik in December 2015 and January 2016.

1.1 Report Organization

Section 2 provides and overview of the data and methods used to describe ambient conditions (2.1), for the long-term frame measurements (2.2) and during the calibration campaigns (2.3). Section 3 describes how the data were post-processed, including how the 6-hour campaigns were used to calibrate the frame data. Section 4 presents time-series of the post-processed data collected during the 6-hour calibration campaigns. Section 5 presents the resulting time series of data from the measurement frames.

1.2 Acknowledgements

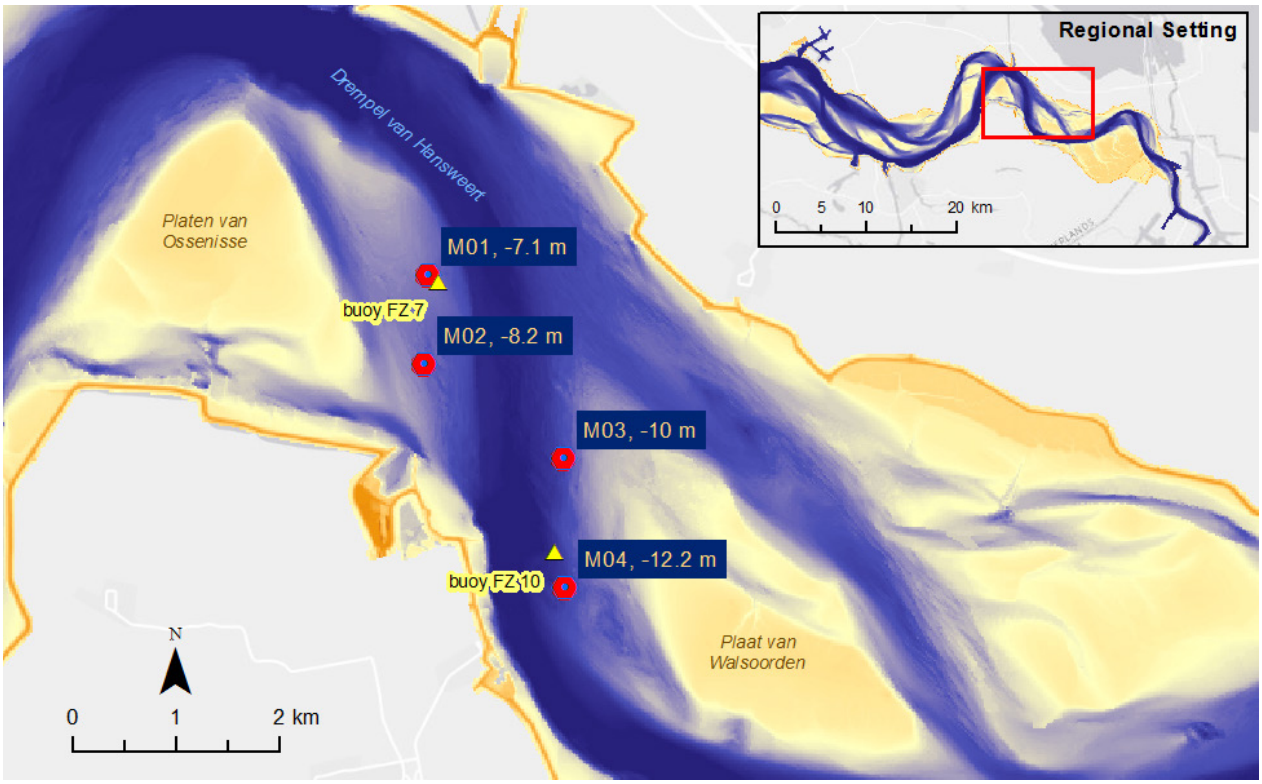
The authors and reviewers would like to thank the following contributors to this project:

- Rijkswaterstaat for deploying the long-term measurement frames
- Captain and crew of the MS Hondius who assisted during the calibration campaigns
- Field technicians who collected the calibration data
- Sediment lab for analyzing sediment samples.

2 Measurement campaigns

The measurement campaign included month-long measurement frames and two 6-hour calibration campaigns. Locations are shown in Figure 1. This section describes the various datasets used to describe ambient conditions (section 2.1), and the instruments/methods used during the long-term frame deployment (section 2.2) and the two 6-hour calibration campaigns (section 2.3).

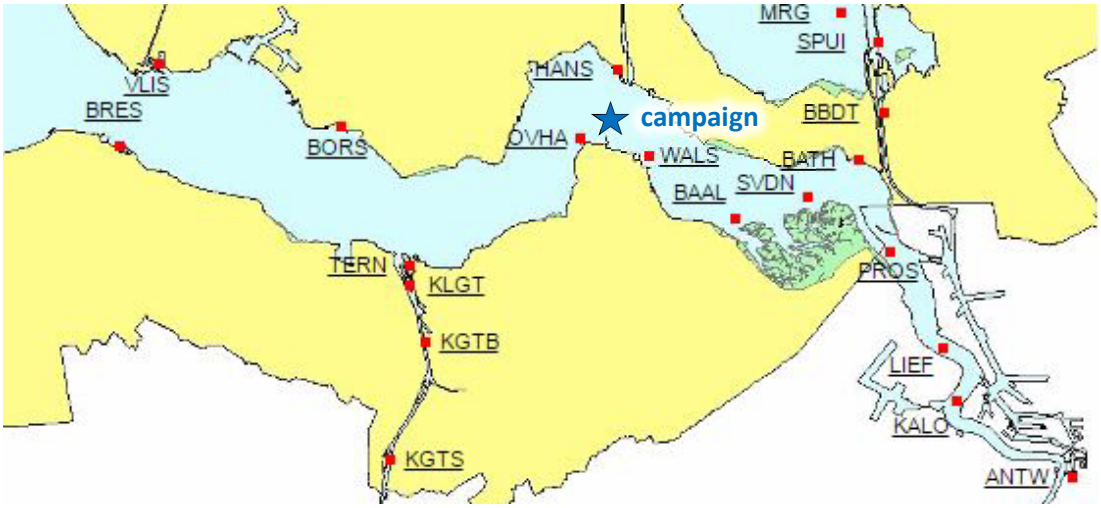
Figure 1 – Map of measurement frame locations at Drempel van Hansweert.
Buoys are approximate locations of the two days of calibration measurements. Elevations are in m NAP.



2.1 Ambient Conditions

Water levels, wind, and waves are measured by Rijkswaterstaat at many locations in Zeeland and are available for download from the Hydro Meteo Centrum Zeeland[1]. The water levels are measured using a Digital Level Meter and an analog Metrawatt. Wind and water level data are available in 10-minute increments while wave data is available every 30-minutes. Water levels were downloaded from the Walsoorden (WALS) and Hansweert (HANS) stations. Wind data was downloaded from the Hansweert (HAWI) station (not shown on the map below, but close to the HANS station). Wave data were downloaded from the HANS station.

Figure 2 – Rijkswaterstaat water level monitoring locations in the Westerschelde.



For comparison, 10-year tidal datums HANS are reported in Table 1, including mean high water (MHW), mean low water (MLW), mean sea level (MSL), mean tide rage (MTR), and the mean spring tide range and mean neap tide range. This long-term data is not available at the WALS station.

Table 1 – Tidal datums for the Hansweert (HANS) station[2]

Water Level (cm NAP)	Hansweert
Mean High Water Spring	277
Mean High Water	242
Mean High Water Neap	195
Mean Sea Level	8
Mean Low Water Neap	-170
Mean Low Water	-206
Mean Low Water Spring	-228
Spring Tide Range (m)	5.05
Average Tide Range (m)	3.65
Neap Tide Range (m)	4.48

[1] http://waterberichtgeving.rws.nl/nl/water-en-weer_dataleveringen_ophalen-opgetreden-data.htm
[2] https://staticresources.rijkswaterstaat.nl/binaries/Referentiewaarden%20waterstanden_tcm174-326696_tcm21-24223.pdf

2.2 Measurement Frames

2.2.1 Frame Locations and Set-up

Four measurement frames with ADCPs were installed by Rijkswaterstaat on the bed in the vicinity of Drempel Hansweert. The locations of the monitoring frames are shown in Figure 1. Table 2 reports the coordinates, durations, and corresponding calibration campaign for each of the frames.

Four measurement frames were deployed by Rijkswaterstaat, each containing one upward-facing ADCP, as described in the next section. A photo of a typical frame setup is shown in Figure 3. The ADCP is located above the bed and has an additional blanking distance of 0.8 m, so it does not measure the complete vertical velocity profile.

Table 2 – Summary of monitoring equipment at Drempel van Hansweert

	Measurement Frame			
	M01	**M02**	**M03**	**M04**
Adjacent to	Platen van Ossenisse	Platen van Ossenisse	Plaat van Walsoorden	Plaat van Walsoorden
Northing (m RD)	381685	380828	379912	378667
Easting (m RD)	60130	60095	61444	61457
Bed Elevation (m NAP - reported)	-6.6	-8.2	-8.8	-12.2
Bed Elevation (m NAP – new DEM)	-7.1	-8.2	-10.0	-13.1
File Name	DRHW1000.000	DRHW2000.000	DRHW3000.000	DRHW4000.000
Start Time	28/04/2016 12:00	28/04/2016 12:00	28/04/2016 12:00	28/04/2016 12:00
Last Readable Ensemble	4019	1707	710	1901
Time of Last Readable Ensemble	26/05/2016 09:40	10/05/2016 08:20	03/05/2016 10:10	11/05/2016 16:40
Duration (days)	27.5	11.5	4.9	13.2
Date of Corresponding Calibration Measurements	09/05/2016	09/05/2016	10/05/2016 (no overlap)	10/05/2016

2.2.2 Acoustic Doppler Current Profiler (ADCP)

Acoustic Doppler current profilers (ADCPs) measure the current profile on the basis of acoustic Doppler technology. Each of the four monitoring frames was equipped with an 1200 kHz RDI Workhorse Monitor ADCP manufactured by RDI (Teledyne). The instrument is capable of being deployed for long timeframes using an internal battery and datalogger with sufficient data capacity. The dimensions and technical specifications of the RDI Workhorse Monitor are shown in Table 3 and in Appendix A (section 0), respectively.

ADCPs use the Doppler effect to measure current velocities by sending out a short sound wave and listening to the echo that returns when soundwaves reflect off particles in the water. The ADCP measures the difference in frequency between the two signals (sent/detected). This principle can be expressed as:

$$V = \frac{F_{Doppler}}{F_{source}} \cdot \frac{C}{2}$$

Where:

V = current velocity in one direction (along the axis of the sound wave)

$F_{Doppler}$ = difference in frequency, also known as the Doppler shift

F_{Source} = frequency of the sent signal

C = speed of sound

The RDI Workhorse Monitor measures the current velocity along 3 axes, but reports the data in East, North, and Up coordinates (ENU coordinates). The measured data are converted to XYZ coordinates. Then, the instrument uses an internal fluxgate compass and tilt measurement to convert the XYZ coordinates to ENU coordinates. The profiler can be configured to be “upward facing” or “downward facing”. During this campaign, the profiler was set up in the “upward facing” configuration.

Figure 3 – Example of an ADCP measurement frame deployed by Rijkswaterstaat.

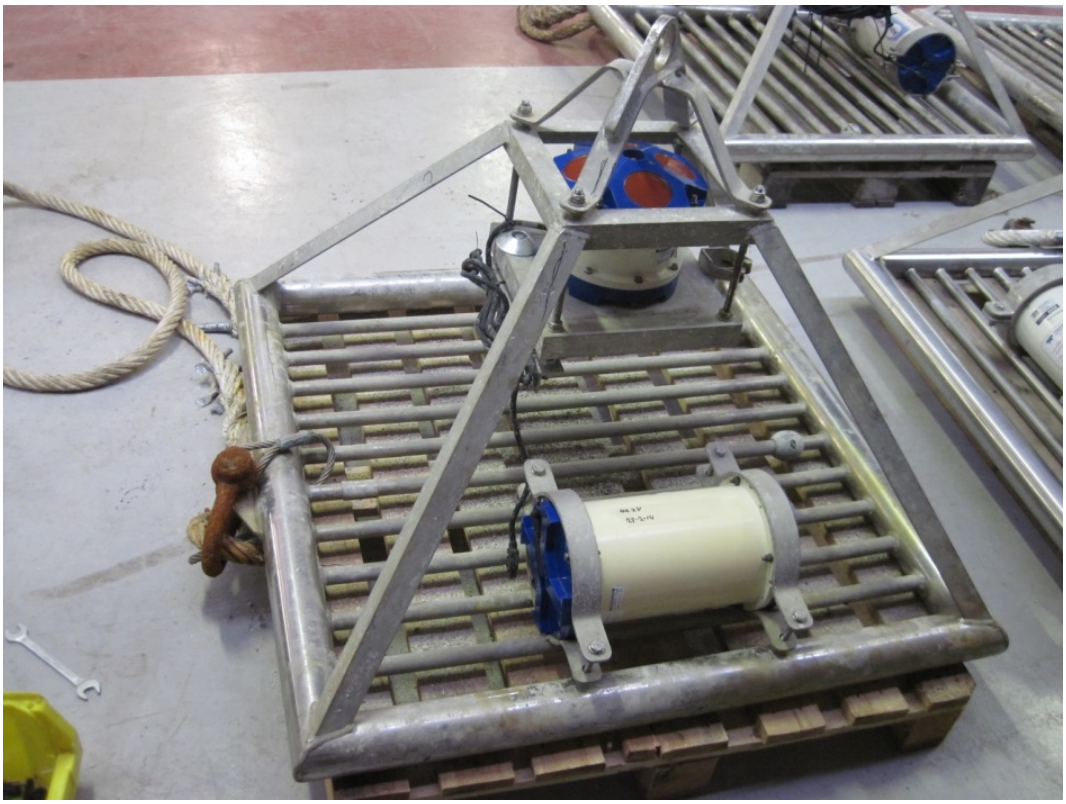


Table 3 – Workhorse Monitor Acoustic Doppler Current Profiler (ADCP) technical specifications from the manufacturer (Teledyne RD Instruments)

Water velocity measurement	
Acoustic frequency	1200 kHz
Maximum profiling range	11–15 m
Cell size	0.25–8 m
Beam angle	20°
Number of beams	4
Maximum number of cells	128
Velocity range	±5 m/s
Velocity resolution	0,1 cm/s
Accuracy	0,3% of measured value ±0,3cm/s
Maximum sampling rate:	2Hz (typical)
Standard sensors	
Temperature	*Mounted on transducer*
Range	–5°C to 45°C
Precision/resolution	0,4°C/0,01°C
Compass	*Fluxgate type*
Accuracy/resolution	2°/0,01° for tilt <15°
Tilt	
Accuracy/resolution	0,5°/0,01°
Maximum tilt	15°

2.2.3 Programming of the instruments

The ADCPs on the bed were programmed to collect 10-minute averaged velocity data as follows:

Bin size	0.25 m
First bin (blanking distance)	0.8 m
Ensemble interval	600 sec (10 minutes)
Pings per ensemble	50

2.3 Stationary 6-Hour Calibration Measurements

Two 6-hour calibration measurements took place at Drempel van Hansweert. Both measurement days used the vessel MS Hondius. The first was on May 9th near Plaat van Ossenisse, to correspond with measurement frames M1 and M2. The second was on May 10th near Plaat van Walsoorden, to correspond with measurement frames M3 and M4. Frame M03 stopped measuring on May 3rd 2016, so the calibration measurements do not overlap with the measurements collected near this frame. The other three frames, however, were successfully collecting data while the calibration measurements were being collected.

The following measurements were carried out during the 6-hour calibration campaigns:

- **Currents**
  - Downward facing velocity profile measured using the same type of ***ADCP*** as on the measurement frames (RDI Workhorse Monitor).
- **Suspended sediment concentrations**
  - Sediment volume concentrations measured using the ***LISST***.
  - ***Water samples*** were collected intermittently and analyzed for suspended sediment concentration.
  - The acoustic backscatter measured by the ***ADCP*** is an indicator of sediment concentration in the water column.
- **Sediment transport rates**
  - A ***Delft bottle*** was used to measure sediment transport rates at a bed-mounted frame (May 9th only) and in a suspended operation modus (both days).
  - The ***ADCP*** currents and suspended sediment concentrations were combined to estimate total sediment transport over the water column.
- **Grain size distributions**
  - Grain size distribution was measured using optical methods with the ***LISST***.
  - ***Sediment samples*** were collected from the Delft bottle and analyzed for grain size distribution.
  - ***Water samples*** were collected intermittently and analyzed for grain size distribution.

The methods associated with each of these measurements are described in the following sections.

2.3.1 Currents

A 1200 kHz RDI Workhorse Monitor ADCP was installed in the moonpool of the vessel for the duration of both calibration campaigns. See section 2.2.2 for background and specifications of this instrument. The downward facing ADCPs were programmed to collect 4-second averaged velocity data as follows:

Bin size	0.25 m
Middle of bin 1 (blanking distance)	0.53 m
Ensemble interval	4 sec
Pings per ensemble	4

2.3.2 Suspended sediment concentrations (SSC)

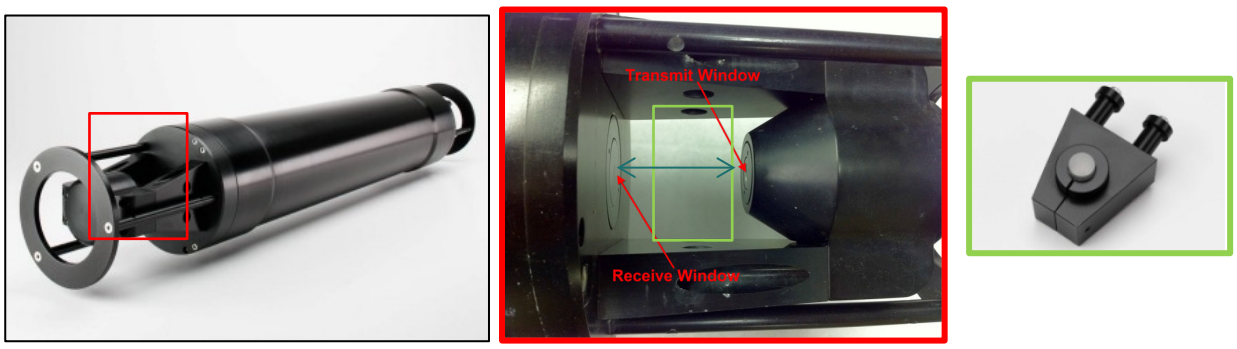
Water samples

Water samples (55 total) were collected intermittently at the same location as the LISST and sent to the lab to be analysed for suspended sediment concentration (SSC). Samples were filtered through 0.45µm filter paper, dried, and weighed to estimate the suspended sediment concentration.

LISST

A Laser In-Situ Scattering and Transmissometery (LISST) instrument was used to measure in-situ sediment volume concentrations and particle size. The LISST-100X uses laser diffraction (forward scattering) to measure the size of suspended sediment particles at one point in the water column (Figure 4). The manufacturer technical specifications are reported in Appendix B. A set of ring detectors, each of a different width and representing a different range of scattering angles, detect scattering from different angles. There are 32 detector rings covering 32 different angles over which light scattering is measured. When multiple grain sizes are present, the detected scattering is reflective of the combined scattering of all particles in suspension. From this combined scattering pattern it is possible to derive the concentrations of particles in 32 different size classes. This method is not dependent on sediment colour, composition, or size, and has been shown to have accuracies on the order of 20%[3]. The exact shape of the light scattering off a spherical particle of any size, colour, or composition can be computed, and conversely, the size of the particle can be derived from light scattering pattern. No two particles of different size or composition will have the same scattering patterns. The result is a detailed time series (1 to 2 second interval) of volume concentration (µl/l) by grain size, a total volume concentration, and a D50 estimate. The volume concentration is an indicator of sediment concentration, and can be calibrated using water samples assuming that the sediment density is constant. See section 3.1 for a description and the nuances of this post-processing step.

Figure 4 – Overview LISST-100x (left) | detail of the transmit and receive windows for the light beam (middle) | example of a PRM (right)



the double blue arrow indicates the length of the optical path
the green box indicates the place where a PRM should be installed if needed

[3] http://www.coastalwiki.org/wiki/Measuring_instruments_for_particle_size_and_fall_velocity#Particle_size_and_concentration_by_Laser_Diffraction_.28LISST.2C_COULTER.2C_PARTEC.29

ADCP

Another indicator of sediment concentration in the water column is the acoustic backscatter (ABS) measured by the ADCP. Each flow velocity measurement by the ADCP is accompanied by the ABS (also known as the Echo Amplitude) measured along each of the 4 ADCP beams. The higher the sediment concentration, the higher the ABS, except when the concentration is too high, causing multiple scattering of the acoustic signal. Section 3.2 describes how the ADCP ABS can be corrected and calibrated using water samples.

2.3.3 Sediment transport

Delft bottle

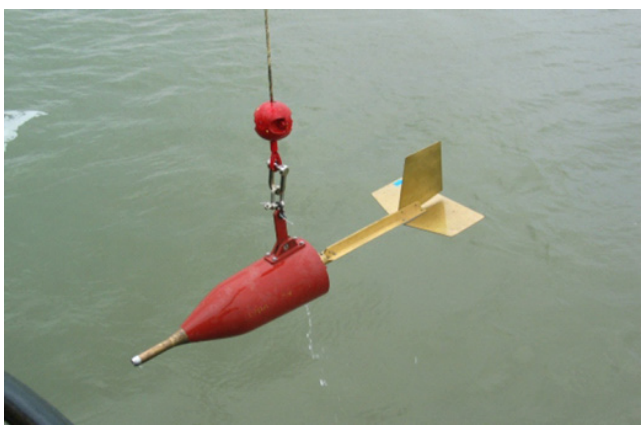
A Delft bottle was used to measure sediment transport (primarily by sand) during the calibration campaigns. The Delft bottle is a bronze casing with a small inlet at the front (faces upstream), where the water flows in, and four openings in the back (downstream) where the water flows out. Two different inlet diameters are available: 1.9 and 3.8 mm and correspond with either 2 or 4 openings at the outlet. The flared shape of the instrument results in a pressure difference such that headlosses are comparable for a range of flowrates. Inside, water passes through a maze, resulting in reduction in speed. Sediment with grainsize greater than 50 µm settles out inside the bottle. The duration of submersion should be based on the current velocity and the sediment concentrations such that the collected sample contains sufficient material.

The instrument is then retrieved and emptied onboard into a bucket. The bucket is then poured into a funnel which empties into a measuring tube. The sediment is allowed to settle for ~3 minutes, at which point the volume of settled sediments is read from the side of the tube. Assuming a fixed porosity and density of the sediment, and knowing the size of the inlet and duration of sampling, it's possible to deduce a sediment transport rate. The additional sediment collected when the instrument is being raised/lowered is assumed to be negligible. The sediment is put in a jar that is saved for further analysis (see next section).

The Delft bottle was developed to be used close to (about 10 cm above) the bed. For measurements within 50 cm of the bed, the bottle is placed on a frame (Figure 5) that is allowed to settle on the bottom. However, it can also be used to measure suspended sediment higher in the water column. A tail is mounted to the back of the bottle to ensure it faces into the direction of flow, and it is lowered by a cable to the desired depth.

The 9/5/2016 calibration campaign used a bed-mounted Delft bottle on a frame at 36 cm above the bed and a suspended Delft bottle which was kept 2 to 2.5 m above the bed. The 10/5/2016 calibration campaign only used a suspended Delft bottle, also 2 to 2.5 m above the bed.

Figure 5 – The Delft Bottle on bed-mounted frame (left) and moored (right).



ADCP

While the ADCP does not directly measure sediment transport like the Delft bottle, it measures currents (section 2.3.1) and an indicator of suspended sediment concentration (section 3.2). These can be combined in a post-processing step, described further in section 3.3, to estimate the sediment transport profile and total transport in the water column.

2.3.4 Grain size distribution

LISST

The grain size was measured in-situ using the LISST, as described in section 2.3.2. The result is a detailed time series (1 to 2 second interval) of volume concentration by grain size, total volume concentration, and a D50 estimate.

Sediment samples

Additionally, sediment samples from most of the Delft bottle deployments (43 in total) and water samples collected near the LISST (16 in total) were sent to the lab to be analysed for grain size distributions. The grain size is analysed in the lab using a Malvern Mastersizer 2000 (Figure 6), which uses laser diffraction to analyse samples up to 2000 µm in diameter. The samples are first filtered through a sieve with a mesh size of 2000 µm. The device can be used to analyse very small sediment samples (e.g. volumes of 1 cm^3). The analysis results in a complete grain size distribution, and the D10, D20, D35, D50, D65, D80, and D90 grainsize is reported. Fractions of sand is also derived using a grain size cut-off of 63 µm. However, pre-treatment (sonication, mixing, pumping) of the samples can alter the original (in-situ) grain size (flocs, organo-mineral structures…). Additionally, the sediment can flocculate, consolidate, or otherwise change during transit time between sampling and analysis, resulting in a different grain size. Therefore, results must be interpreted with this in mind.

Figure 6 – Malvern Mastersizer 2000

Water samples

The water samples were first filtered and then incinerated to remove the filter paper before being analysed using the same techniques as the Delft bottle sediment samples.

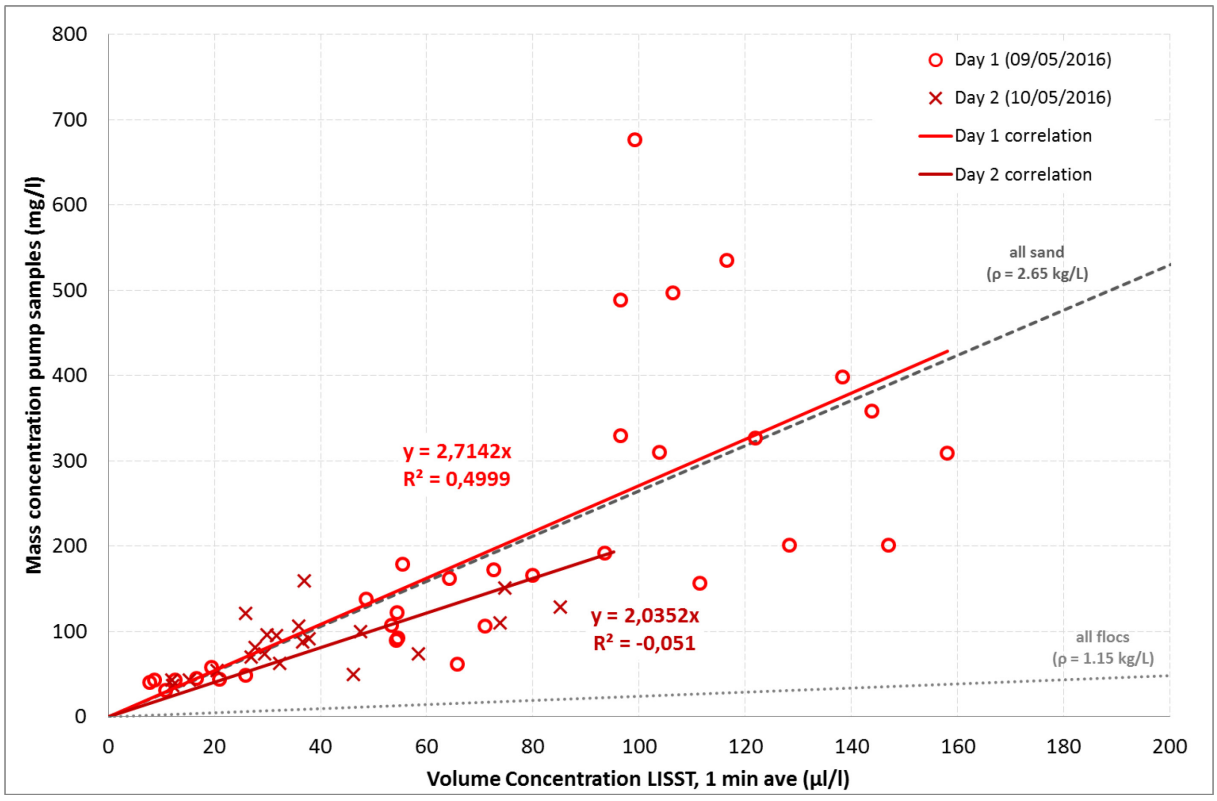
3 Calibration procedure

LISST and ADCP measure sediment concentration in an indirect way. The measured signal has to be converted into a sediment concentration using results from pump samples taken at the same moment and position. The following paragraphs describe the calibration for the different devices.

3.1 Sediment Concentration from LISST Volume Concentration

The volume concentrations reported by the LISST (in µg/L) were converted to suspended sediment mass concentration (SSC in mg/L) using a calibration curve developed by comparing the LISST concentration to water samples collected over the courses of both survey days. Figure 7 presents a scatterplot of the SSC in the water samples versus the coincident (1-minute averaged) LISST volume concentration. A linear fit (with a zero-intercept) was applied to each measurement day separately, and applied to the LISST volume concentration to develop a continuous time series of SSC over the full 6-hour measurement campaign (see Plancke and Paridaens 2012 for similar analysis). The results are presented in section 4.3.

Figure 7 – Calibration fit for LISST volume concentration to sample suspended sediment concentrations.



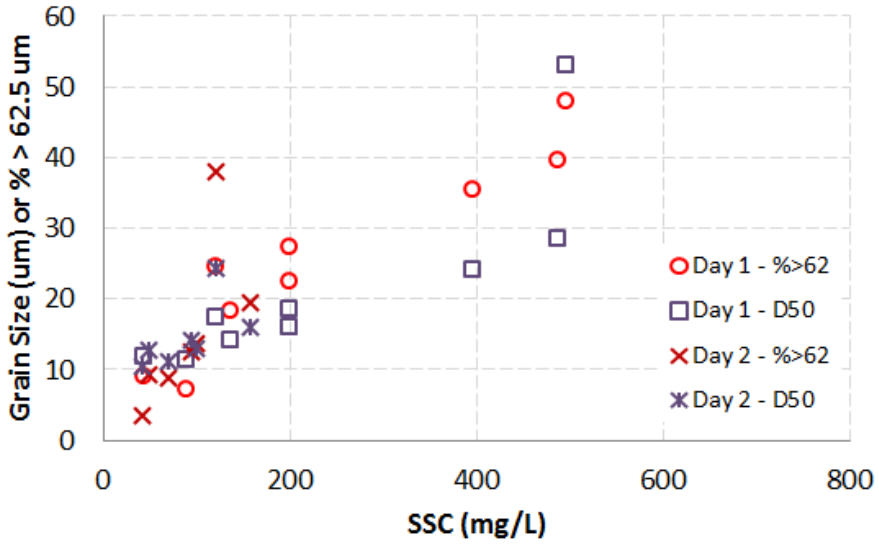
The link between volume concentration and suspended sediment concentration (a.k.a. “mass concentration”) is the density of the suspended particles. Two dashed grey lines are added to Figure 7 to show what the fit would be if the material was perfectly sandy (with a particle density of 2.65 kg/l) or floc-dominated (with a representative “floc” density of 1.15 kg/l, Gartner et al 2001, IMDC & WL 2007). The SSC was calculated by multiplying the volume concentration by assumed particle density:

$$SSC\left(\frac{mg}{l}\right) = VC\left(\frac{\mu l}{l}\right) * \rho_{sediment}\left(\frac{kg}{l}\right) * \frac{1l}{10^6 \mu l} * \frac{10^6 mg}{1kg} * \left(1 - \frac{\rho_{sediment} - \rho_{floc}}{\rho_{sediment} - \rho_{water}}\right)$$

In addition to water samples for SSC, a few water samples were collected for grain size analysis on each day. It should be noted that collecting water samples and transport of the samples will disturb the in situ sediment, especially if flocs occur. The resulting grain size characteristics should be seen as the result of the individual sediment particles, including broken-up flocs.

Figure 8 shows the resulting relationship between suspended sediment concentration and grain size. Grain size (D50 and % of sediment that is considered sand) and SSC are directly correlated.

Figure 8 – Suspended sediment grain size and concentration.



3.2 Sediment Concentration from Acoustic Backscatter

Acoustic backscatter (ABS) intensities can be used to estimate sediment concentration in the water column (e.g. Lohrmann 2001, Gartner 2004, Aardoom 2005). The following steps, based on Lohrmann 2001, can be taken to make this conversion:

1. Convert internal units (counts) to a linear or log scale (dB)
2. Range normalization - correct backscatter intensity (dB) for sound absorption in water
3. Develop calibration curve relating ABS (dB) to measured SSC (mg/l)
4. Convert ABS (dB) to SSC (mg/l)

Each step is described in the following four sections.

3.2.1 Step 1: Convert internal units to a linear or log scale

According to Lohrmann 2001, the internal units (counts) can be converted to decibels (dB) linearly over a range of 70 dB. Inside this range the scaling factor is approximately K_c = 0.43 counts/dB (range 0.40 to 0.47). Beyond the linear range (which corresponds to roughly 1 to 10,000 mg/L), the conversion is non-linear and values should not be used for sediment analysis.

$$K_c = 0.43\ dB/count$$

3.2.2 Step 2: Range normalization

The second step involves correcting the ABS for acoustic loss terms, which increase with distance from the sensor and is independent of sediment in the water column. The three terms to correct for include acoustic

spreading, water absorption, and particle attenuation. More explanation of each of these terms can be found in Lohrmann 2001.

$$acoustic\ spreading = 20\ \log_{10} R$$

$$water\ absorption = 2\alpha_w R \quad \left(\alpha_w = water\ absorption\ in \frac{dB}{m}\right)$$

$$particle\ attenuation = 20R \int \alpha_P dr \quad \left(\alpha_P = particle\ attenuation\ in \frac{dB}{m}\right)$$

$$R = range = z/\cos(beam\ angle)$$

The water absorption is dependent on the water density, pressure, and the transmitted frequency. Figure 9 shows how absorption in water varies with frequency and salinity.

Figure 9 – Absorption in water vs. frequency for fresh and salt water. Source: Lohrmann 2001.

Frequency (MHz)	α (dB / meter) Salinity = 0 ppt	α (dB / meter) Salinity = 35 ppt
10	26.9	26.9
3.0	2.4	2.9
1.5	0.6	0.7
0.50	0.07	0.14

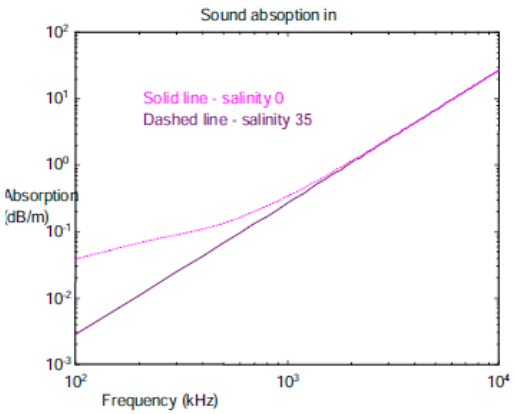


Figure 11 estimates the absorption for the 1.2 MHz ADCP (hollow points) for low and high salinity conditions based on the rates reported in Figure 9 (solid points) using a second order polynomial. Absorption in 0 and 35 ppt salinity is 0.383 dB/m and 0.543 dB/m, respectively. Drempel van Hansweert is in the brackish zone of the Schelde. The average salinity at the Baalhoek (BAAL) station (the nearest salinity monitoring station to the campaign) was 14.5 ppt for the duration of the campaign (Figure 10). Interpolating a salinity of 14.5 between the fresh and saline absorptions results in an absorption of 0.449 dB/m, which was applied in the absorption term.

Figure 10 – Salinity as measured at the BAAL station (location in Figure 2).

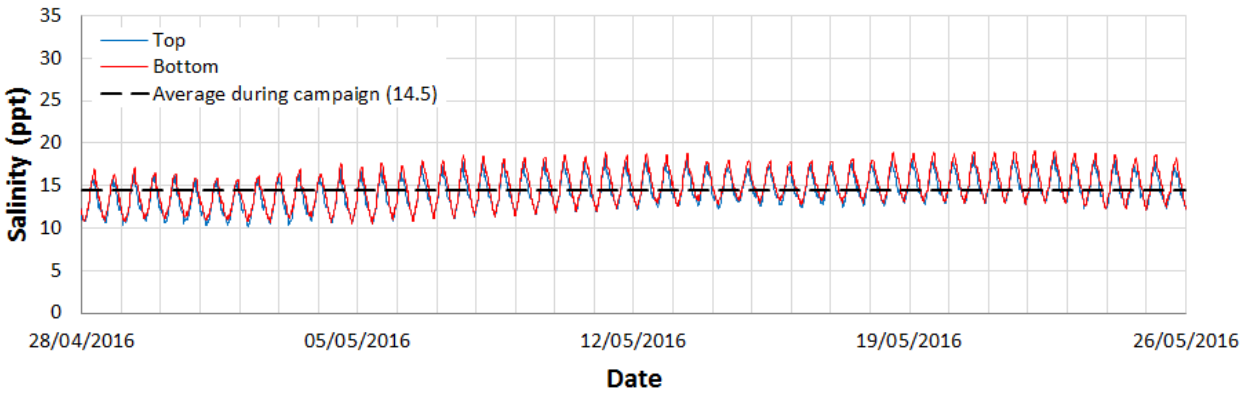
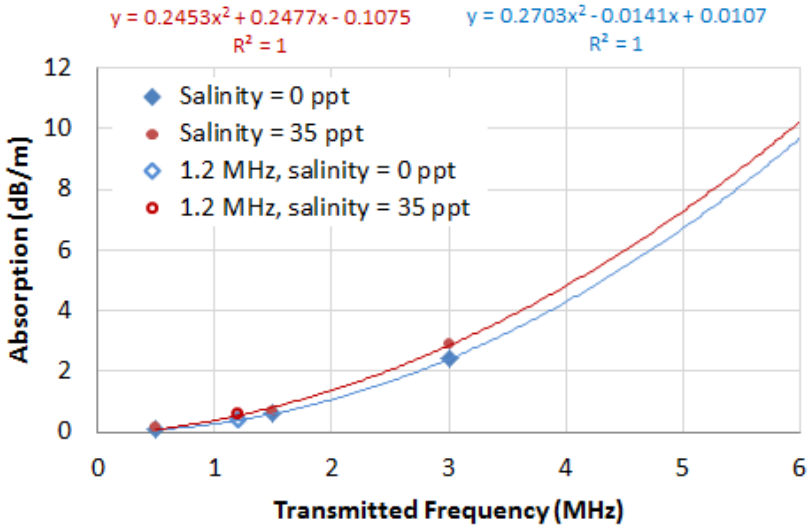


Figure 11 – Absorption of sound in the water column for various frequencies.



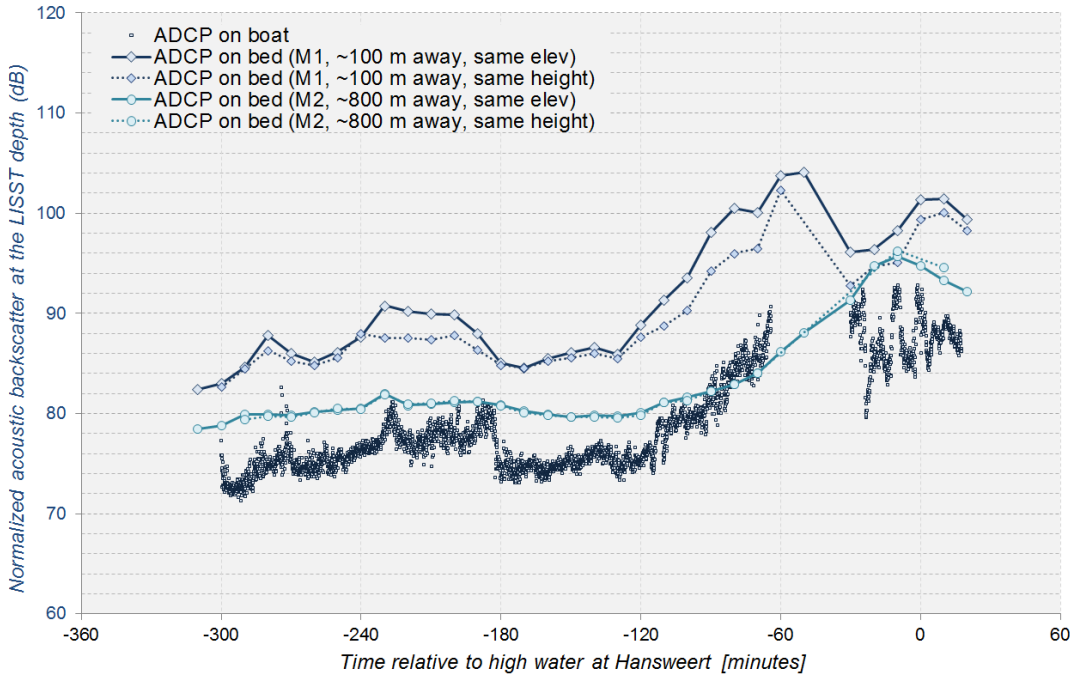
The last term, particle attenuation, is small at low concentrations and can be ignored. The present method ignores particle attenuation. The resulting complete equation (which already takes into account that the correction must be made twice, since the signal passes through the water column twice) is:

$$ABS_{norm} = Amp * K_c + acoustic\ spreading + water\ absorption + particle\ attentuation\ (assumed\ 0)$$

Figure 12 and Figure 13 plot the normalized acoustic backscatter measured near the LISST instrument (since this is where the SSC samples were collected for calibration purposes) for day 1 (9/5/2016) and day 2 (10/5/2016), respectively. The ABS measured by the bed-mounted ADCPs are also plotted. The corresponding ADCP backscatter was selected in two ways for each ADCP: once for the same absolute elevation and once for the same height above the bed. The reason for this is that the bed elevation differs between the calibration and bed frame locations (see Table 2 for frame elevations). Since SSC is expected to vary over the vertical profile, with the highest SSC near the bed, the “same height” data are expected to have the best agreement when compared with the bed-mounted ADCPs.

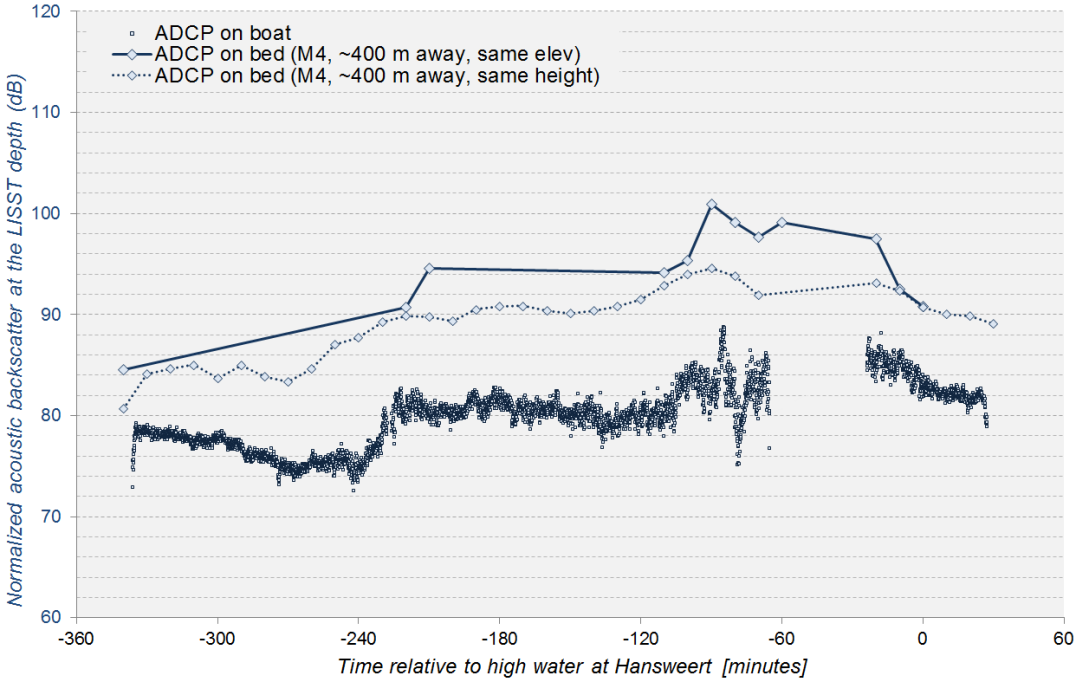
The backscatter at the same absolute elevation of the LISST is plotted in a solid line, and the backscatter at the same height above the bed is plotted in a dotted line. The calibration campaign on day 2 (10/5/2016) took place where the bed elevation was lower than the M4 frame. Therefore, most of the SSC samples were collected at an elevation below cell 1 of the M4 ADCP and cannot be linked to the SSC samples (hence the solid line with very few points). When measurements at the same height of the bed are compared (dotted line), the backscatter follows the same general pattern but appears to have a ~10 dB offset, as is also seen on day 1 (9/5/2016).

Figure 12 – Normalized acoustic backscatter (in dB) during day 1 (9/5/2016) of the calibration campaign, near Platen van Ossenisse.



The plotted ABS is that corresponding to the ADCP cell containing the LISST (varies over time).
The normalized ABS from the two nearby ADCPs (M1 and M2) are also plotted here.

Figure 13 – Normalized acoustic backscatter (in dB) during day 2 (10/5/2016) of the calibration campaign, near Plaat van Walsoorden.



The plotted ABS is that corresponding to the ADCP cell containing the LISST (varies over time).
The normalized ABS from one of the nearby ADCPs (M4) are also plotted here. Frame M3 was already covered in sand by this date.

3.2.3 Step 3: Develop calibration curve relating ABS to SSC

The next step is to correlate the range-normalized ABS with measured SSC. Over the course of the 6-hour calibration campaigns, 55 water samples were collected and analysed for SSC. These samples were used to calibrate the ABS with SSC. The samples were taken via tube/pump from the moored LISST frame.

6-hour calibration campaign

The SSC from the water samples can be compared to the acoustic backscatter measured in the corresponding bin of the ADCP. Since the ADCP is hull-mounted on the boat, the corresponding bin must be calculated based on the distance between the ADCP sensors and the intake tube for SSC samples, which varies over time. Figure 14 and Figure 15 illustrate how the various measurement instruments were located relatively (vertically) to each other over the course of the day 1 (9/5/2016) and day 2 (10/5/2016) calibration campaigns, respectively. It is possible to use the relative distance between the ADCP and LISST in order to assign the correct ADCP bin to each SSC sample:

$$Bin = \frac{Dist_{LISST\ to\ ADCP} - blanking\ distance}{bin\ size}$$

Figure 14 – Instrument locations relative to each other on day 1 (9/5/2016) calibration campaign near Platen van Ossenisse.

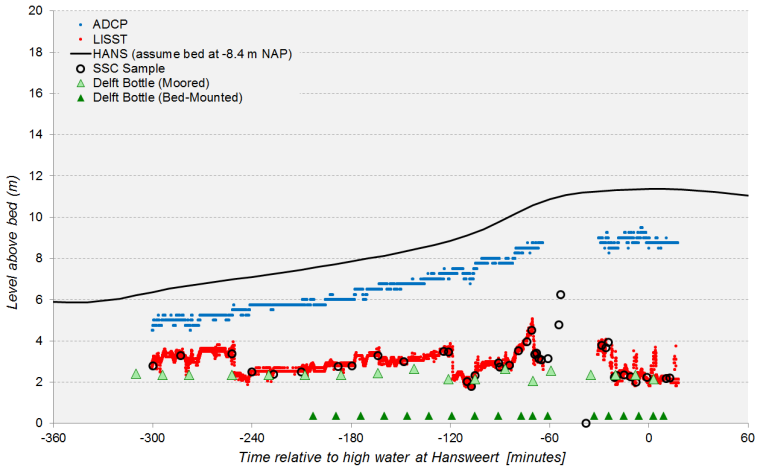
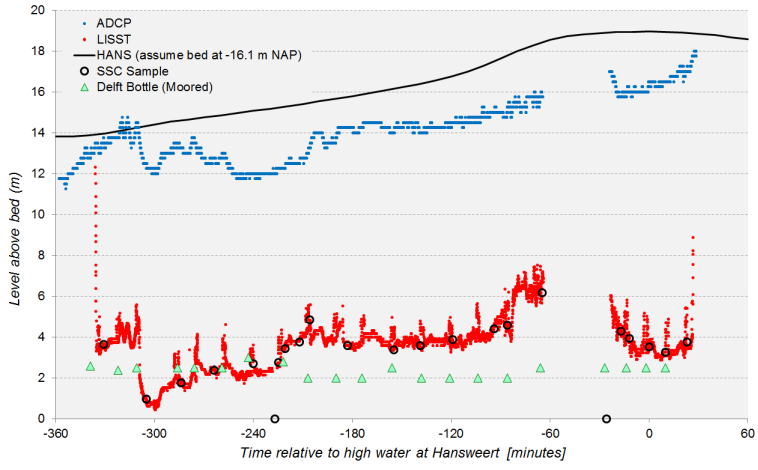
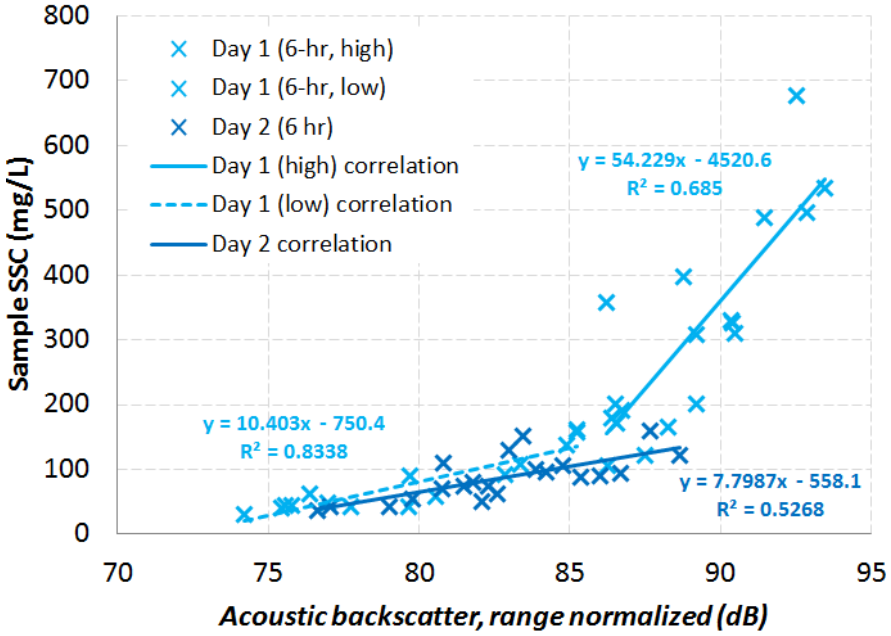


Figure 15 – Instrument locations relative to each other on day 2 (10/5/2016) calibration campaign near Plaat van Walsoorden.



Ideally, only the backscatter from the beam nearest to the water sample would be used. However, the precise orientation of the ADCP relative to the sampling tube is not known, so an average ABS_{norm} of all four beams is used instead. The beam angle of the ADCP used during the calibration campaign was 20 degrees. Figure 16 plots the SSC versus the range-normalized ADCP backscatter for day 1 (light blue) and day 2 (dark blue) of the calibration campaign. The day 1 data shows a clear discontinuity around 95 dB, so two linear fits were assigned to this data. Day 2, on the other hand, does not show this discontinuity, but that is likely largely because lower SSC concentrations were measured on day 2.

Figure 16 – ADCP acoustic backscatter calibration to suspended sediment concentration.



Long-term measurement frames

In order to check whether the calibrations developed using the boat-mounted ADCP can be applied to the ADCPs on the monitoring frames, we can look at the ABS that was being measured by the monitoring frames concurrently with the calibration campaign. Since we don't know exactly which ADCP beam pointed in the direction of the frames on the bottom, the average ABS_{norm} for all four ADCP beams is used. The beam angle of the ADCP on the bed was 20 degrees.

Figure 12 and Figure 13 overlay the normalized ABS measured by the moored and bed-mounted ADCPs at the elevation of the LISST. Frame M1, located approximately 100 m from the calibration campaign, measured higher backscatter than the ADCP on the boat (mean of 10 dB, σ = 2.1 dB), but measured the same signal of gradually increasing ABS, peaking when the current was the highest. Frame M2 also measured the same trend, but seemingly with a delay and matching the boat-mounted ABS values more closely, mean difference of 3.8 dB, σ = 2.1 dB). Frame M3 was no longer measuring at the time of the calibration campaign (it was covered in sand). Frame M4 was located at a higher elevation (roughly 4m higher) than the bed at the calibration campaign, so for most of day 2 (10/5/2016) the LISST was not in vertical range of the M4 ADCP, when comparing ADCP cells at the same elevation (rather than height above the bed). When comparing ADCP cells at the same height above the bed, the trends tend to agree, but there is again a constant offset (mean of 9.5 dB, σ = 2 dB).

3.2.4 Step 4: Apply the calibration curve to the long-term measurement frames

The next step is to apply the calibration curves developed during the 6-hour campaigns to the long-term measurement frames on the bed. The calibration derived from the moored ADCP during the first 6-hour campaign (9/5/2016) was used for frames M01 and M02. The calibration from the moored ADCP on day 2 (10/5/2016) was used for frame M04. No calibration curve could be created for frame M03 because the ADCP on frame M03 was not collecting data anymore by May 10th, due to a layer of sand covering the transponders.

As described in 3.2.3, there was a systematic difference in ABS when comparing the bed-mounted and moored ADCPs, with the bed-mounted ADCPs measuring a normalized ABS between 3.8 and 10 dB greater than the moored ADCPs. Therefore, applying the calibration curve (Figure 16) derived based on the ABS measured by the moored ADCPs would result in significantly overestimating the SSC, especially when applying the Day 1 calibration. Since the exact reason for the difference between the ADCPs could not be identified (possibly due to different instruments), the long-term ABS measurements from the bed-mounted ADCPs were reduced according to the average difference found during the calibration campaigns (e.g. the normalized ABS from frame M01 was reduced by 10 dB before applying the calibration to derive a time series of SSC).

3.3 Total Sediment Transport

The total sediment transport was estimated following these steps:

1. Applying the SSC-ABS calibration curves to the bed-mounted ADCP backscatter measurements (shifted as described in section 3.2.4), resulting in a vertical profile of SSC over time (i.e. a SSC for each bin for each moment in time).
2. Calculate the sediment transport rate within each bin (in g/m^2/s) by multiplying the SSC by the velocity magnitude.
3. Estimate a time series of total sediment transport rates by summing the sediment transport rates over all ADCP cells over the vertical profile and multiplying by the bin height.

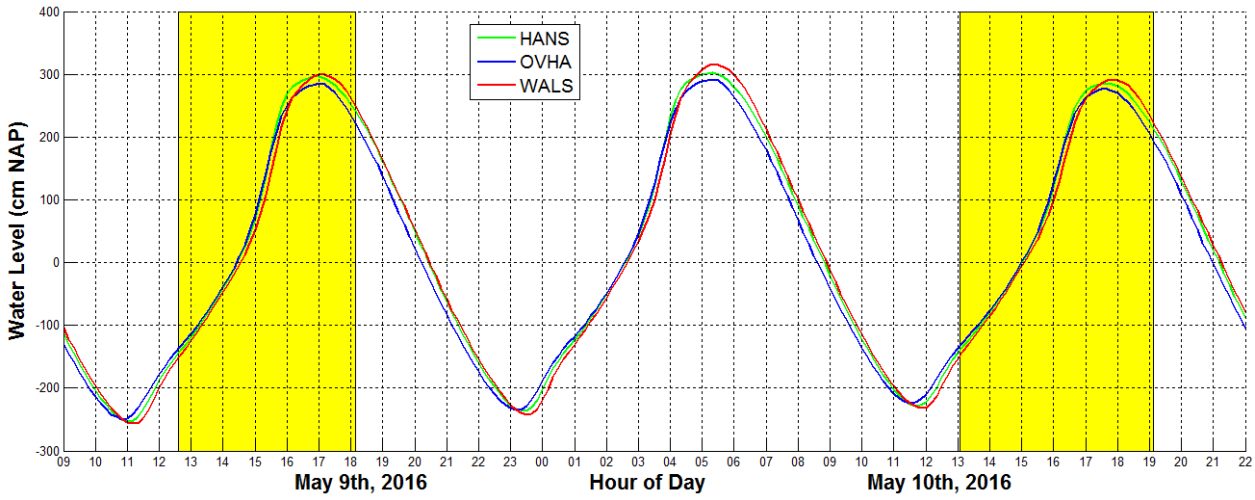
4 Results: calibration measurements

This section presents the data collected during the 6-hour calibration campaigns. For information about the methods used during these calibration campaigns, see section 2. Section 3 describes post-processing steps that were taken in developing the results below.

4.1 Water Levels

Figure 17 describes the tidal conditions during the 6-hour measurements. For average tidal datums, please refer to Table 1. Both of the 6-hour measurements started just after low tide, and ended just after high tide, covering the flood period. The high tide (HW) was 2.96 m NAP and 2.86 m NAP at the Hansweert (HANS) tide gage on day 1 and day 2, respectively.

Figure 17 – Water levels during the two days of 6-hour measurements (yellow shading indicates duration of the campaigns).



4.2 Currents

Figure 18 and Figure 19 present the depth-averaged currents as measured by the ADCP during the stationary 6-hour measurements at Hansweert on day 1 (May 9th, 2016) and day 2 (May 10th, 2016), respectively. Figure 20 and Figure 21 show the complete current profile (magnitude and direction). The gaps in both days that occur between approximately HW – 60 and HW – 30 minutes is when the anchor had to be re-set due to movement of the ship in the strong current, causing all instruments to be brought onboard during manoeuvers.

On day 1, the strongest currents (~1.6 m/s) were measured during the flood-phase of the tide, just before high water. The currents peaked during the data gap, so the actual strongest current was not measured. The lowest currents (about 0.2 m/s) were measured immediately at the start of the campaign, about 5 hours before high water (around slack low water). From the start of the measurement campaign, the direction slowly turned, starting around 210 degrees and decreasing steadily to about 100 degrees. Then, just before high water, it turned sharply and rotates about 230 degrees to a direction of 330 just after high water.

On day 2, the strongest currents were measured during the flood-phase of the tide, just before high water. The measured speeds reached 1.6 m/s while the instrument was recording. However, about 45 minutes of data was not collected just prior to high water, so it's possible the currents were even greater. The lowest

currents measured were approximately 0.2 m/s, about 5 hours before high water. During these low flows, the measured current direction is quite variable, due to difficulty of estimating the mean flow direction at such low flows. About 4.5 hours before high water the direction stabilizes around 140 degrees. However, it shifts again, for about one hour to hover around 180 degrees before returning to 140 degrees up until and during high tide.

Figure 18 – Currents as measured by the ADCP (depth-averaged) during measurements on day 1 near Platen van Ossenisse.

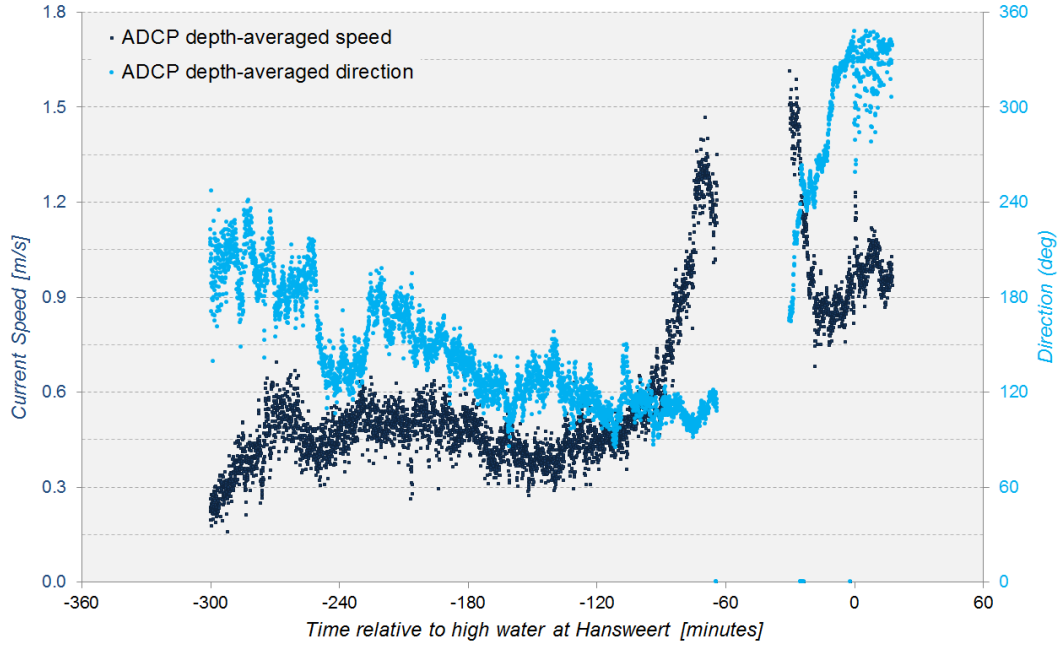


Figure 19 – Currents as measured by the ADCP (depth-averaged) during measurements on day 2 near Plaat van Walsoorden.

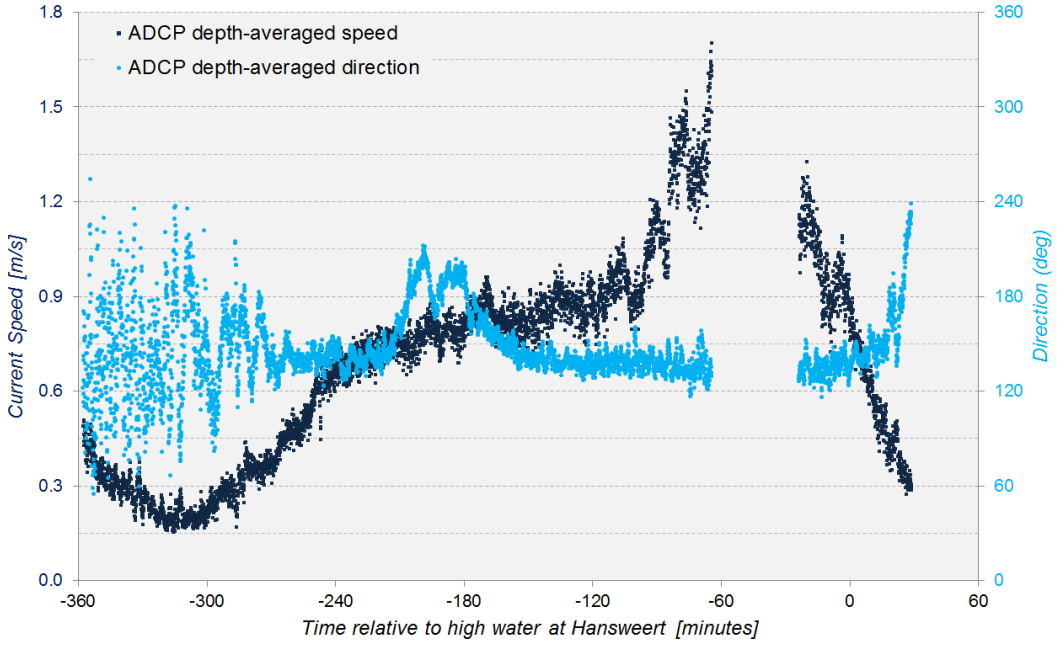


Figure 20 – Current magnitude (top) and direction (bottom) as measured by the boat-mounted ADCP on day 1 near Platen van Ossenisse. Gap is when boat was moved by strong current.

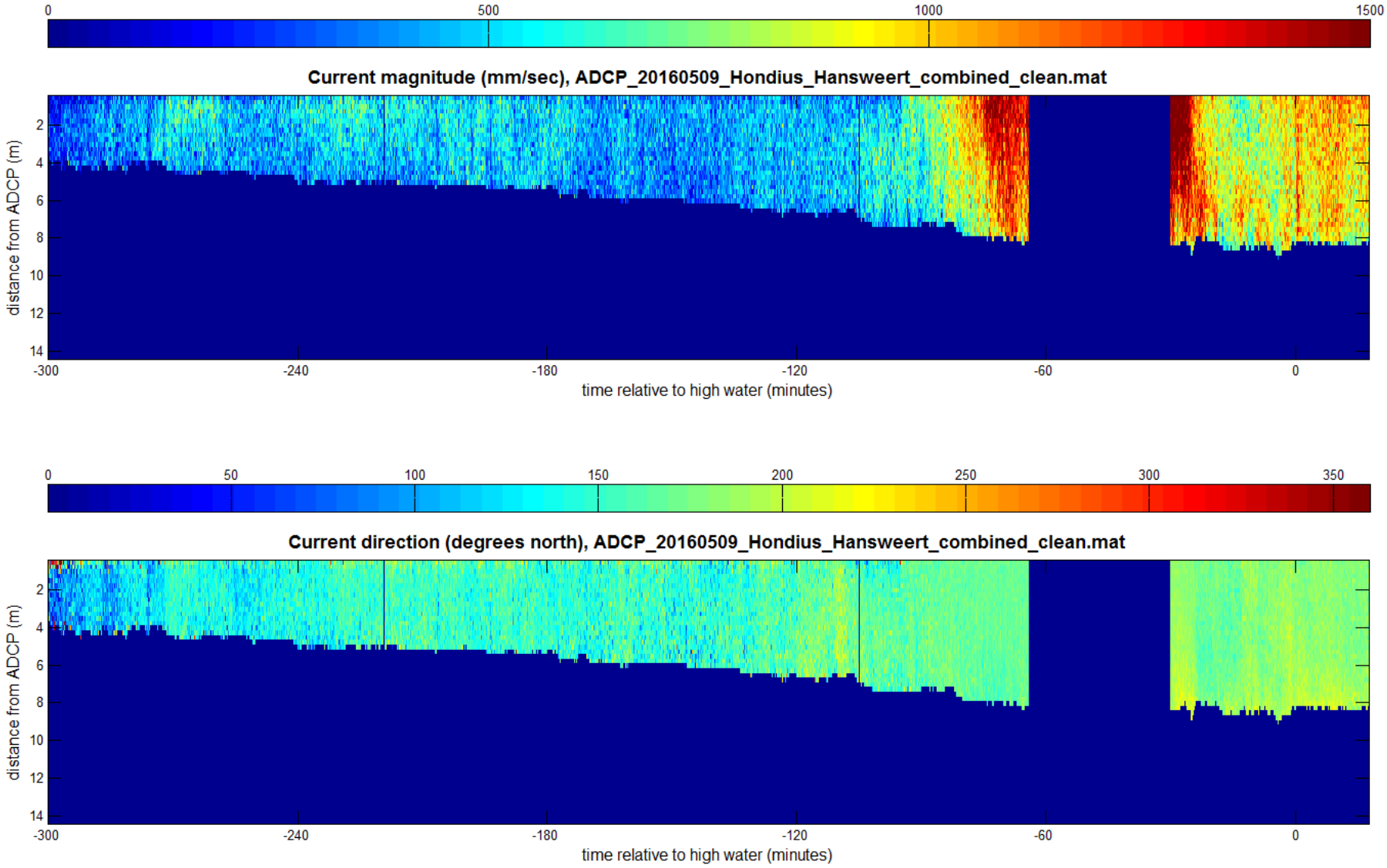
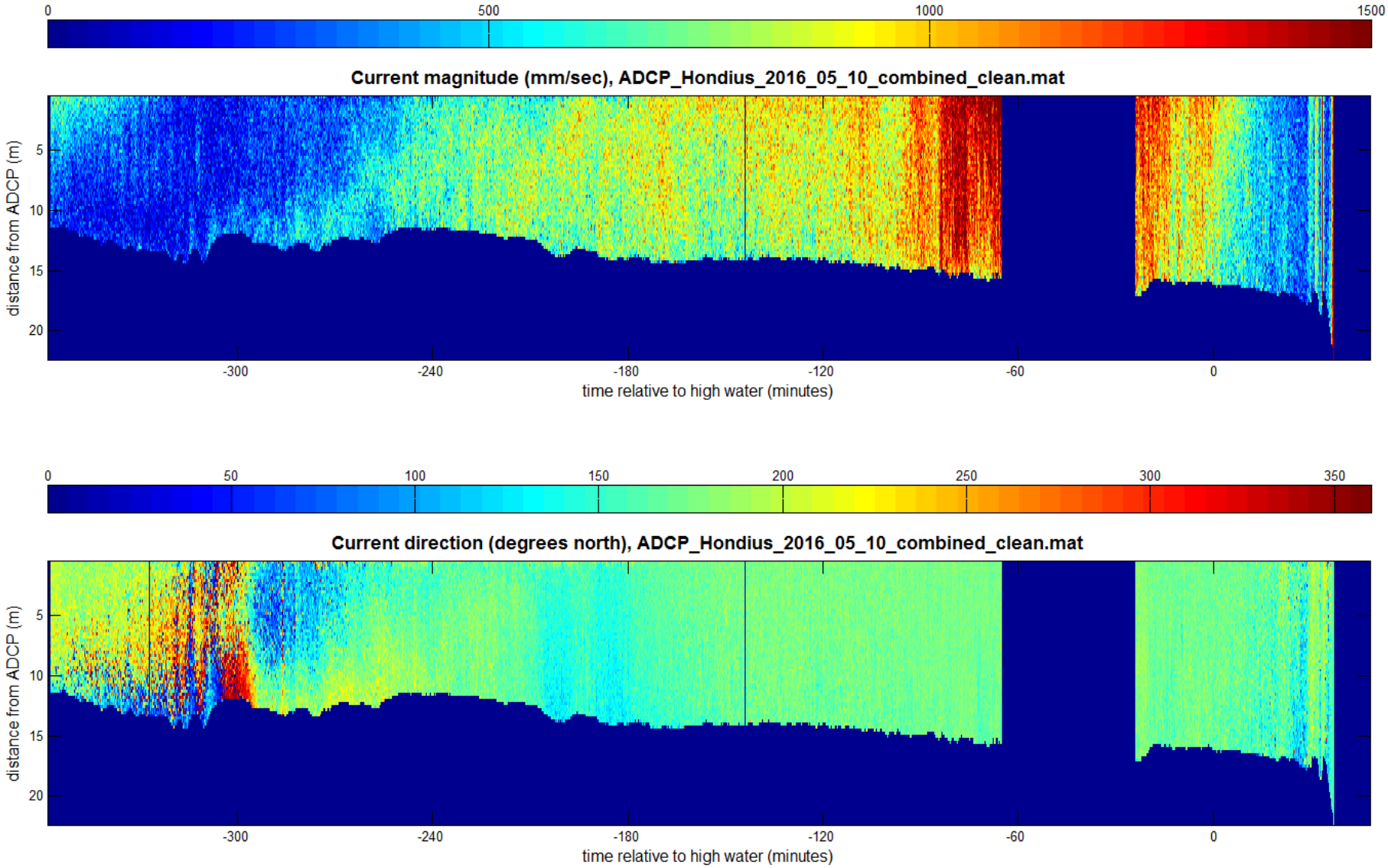


Figure 21 – Current magnitude (top) and direction (bottom) as measured by the boat-mounted ADCP on day 2 near Plaat van Walsoorden. Gap is when boat was moved by strong current.



4.3 Suspended sediment concentration (SSC)

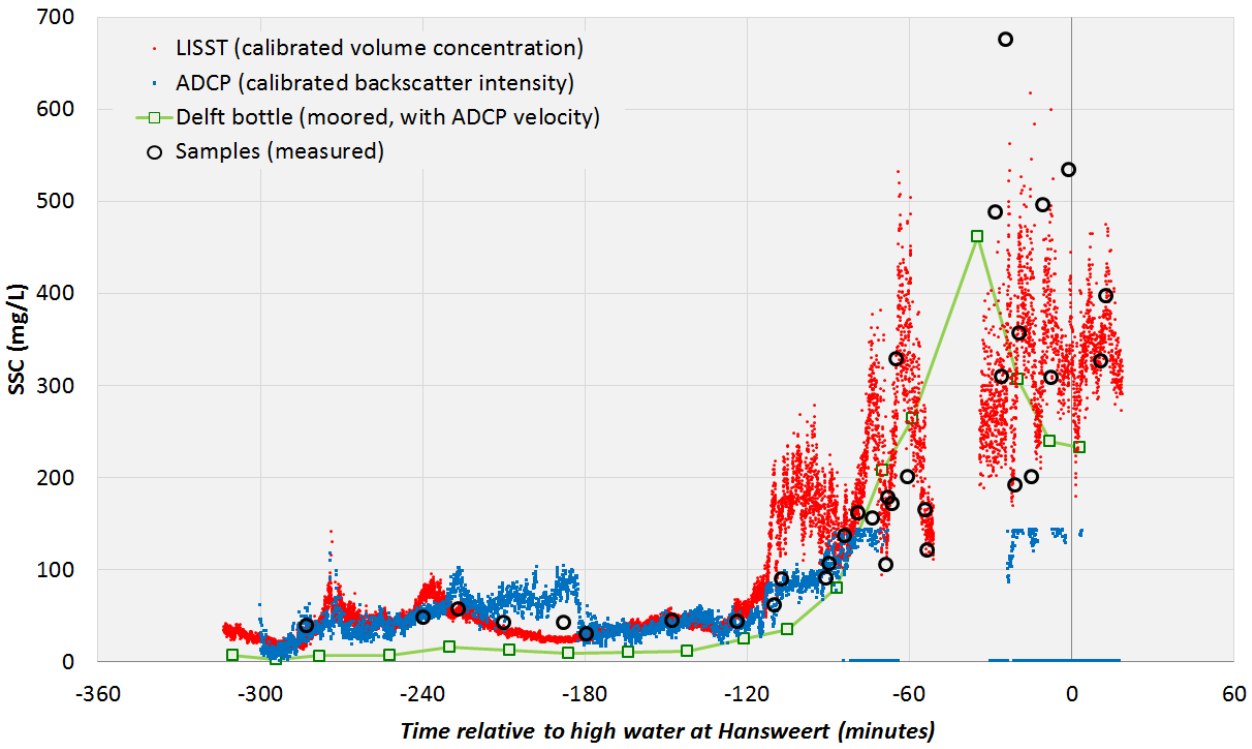
The suspended sediment concentration (or an indicator thereof) was measured by the LISST (as volume concentration), ADCP (as acoustic backscatter), and as water samples during the 6-hour calibration campaigns, as described in section 0. The volume concentration and acoustic backscatter were calibrated as described in sections 3.1 and 3.2, respectively. The SSC was estimated from the Delft bottle by dividing the sediment transport rate measured by the Delft bottle by the flow velocity (measured by the ADCP at the height of the Delft bottle):

$$SSC\left(\frac{mg}{L}\right) = \frac{transport\ rate\left(\frac{g}{m^2 s}\right)}{velocity\left(\frac{m}{s}\right)} * \frac{1m^3}{1000L} * \frac{1000mg}{1g}$$

The resulting 6-hour time series of SSC from all techniques are shown in Figure 22 and Figure 23 for day 1 and day 2, respectively.

On day 1, the SSC hovers around 50 mg/L, until about 2 hours before high tide, at which point it increases more or less linearly to 300 – 400 mg/L at high tide. Both the LISST and ADCP measurements show similar trends. Both become quite noisy during the hour before high tide, when current velocities peak. The estimates from the Delft bottle are lower, hovering around 10 mg/L. It would be expected that the Delft bottle would have a lower SSC, because generally only coarse material (sand fraction) falls out of suspension and is captured in the "bottle" during measurements, while fines (silt, clay) pass through the bottle and back into system. Additionally, the Delft bottle SSC can't be directly compared to the LISST/ADCP/Samples SSC, since the Delft bottle is not always moored at the same height above the bed as the LISST (see Figure 14 and Figure 15 for their locations relative to each other in time).

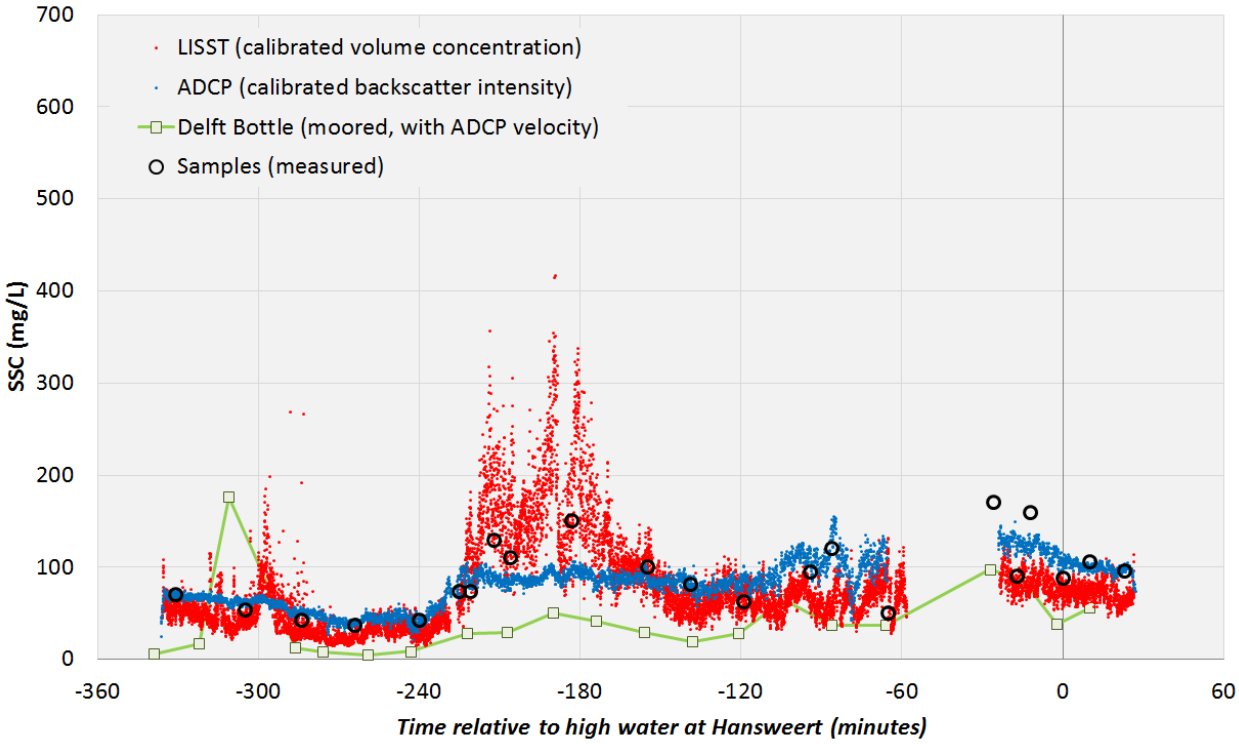
Figure 22 – Suspended sediment concentrations as measured by the LISST and ADCP during day 1 (9/5/2016) near Platen van Ossenisse, calibrated using the intermittent water samples (black circles)



ADCP measurements are for the ADCP cell corresponding to the location of the LISST (varies).

The SSC on day 2 near Plaat van Walsoorden stays relatively stable for the duration of the measurements. The ADCP and LISST agree on this, though the LISST measures an increase in SSC between 4 and 3 hours before high tide. This increase is also reflected in the water samples, so it appears that the volume concentration from the LISST is a better indicator of trends in SSC than the ABS from the ADCP, which does not seem to follow this trend. The Delft bottle registers lower SSC over the course of the day, which can partially be explained by the fact that only coarse material is captured.

Figure 23 – Suspended sediment concentrations as measured by the LISST and ADCP during day 2 (10/5/2016) near Plaat van Walsoorden, calibrated using the intermittent water samples (black circles)



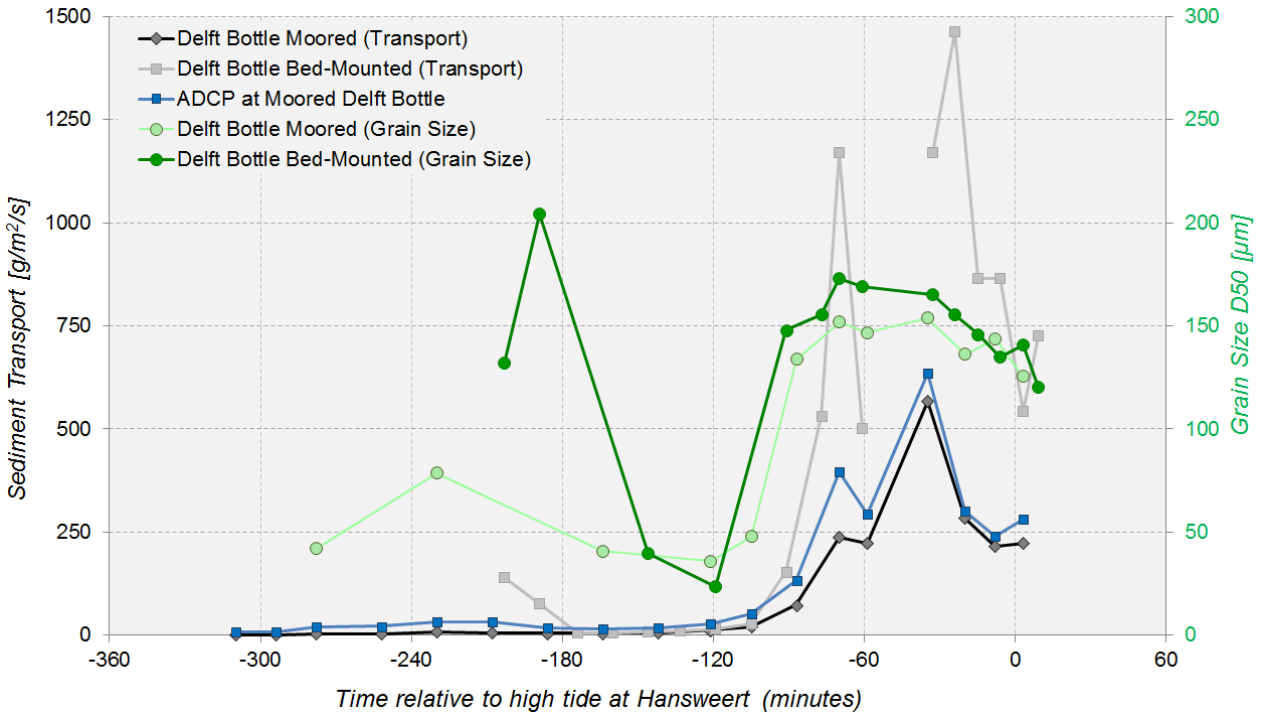
ADCP measurements are for the ADCP cell corresponding to the location of the LISST (varies).

4.4 Sediment transport

The Delft bottle and ADCP were used to measure sediment transport rates, as described in section 2.3.3. Figure 24 and Figure 25 show the sediment transport rates measured by the Delft bottle during day 1 and day 2, respectively. Up to approximately 120 minutes before high water, the Delft bottles measured essentially no transport. Then, transport increased up to a max that occurred between about 60 and 30 minutes before high water, in concert with peak flow velocities. The magnitude of the increase was significantly greater on day 1 than on day 2. As would be expected, the moored (suspended) Delft bottle measured less transport than the bed-mounted Delft bottle (less than 50% in some cases), since it is kept much higher in the water column. For a discussion of the grain size trends, see section 4.5.

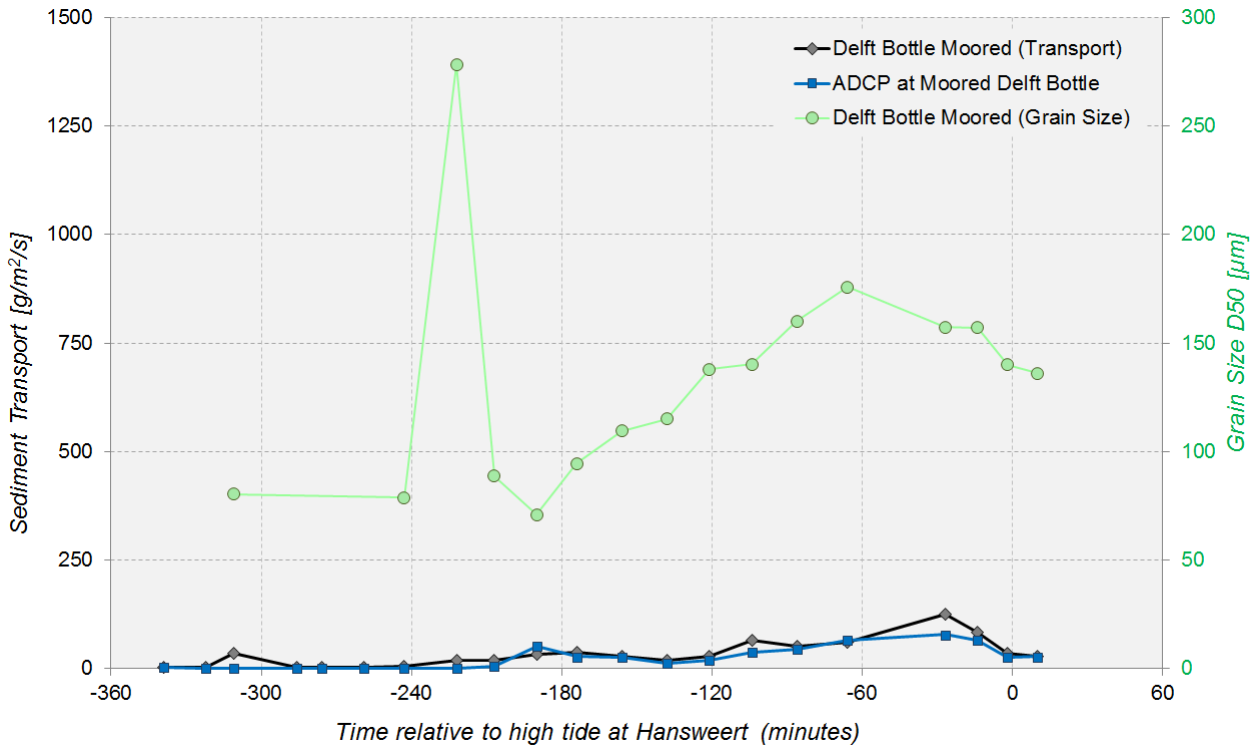
The results of estimating the suspended sediment concentration and total sediment transport from ADCP acoustic backscatter are shown for day 1 and day 2 in Figure 26 and Figure 27, respectively.

Figure 24 – Sediment transport rate and grain size measured by the Delft bottle and ADCP during day 1 (9/5/2016) near Platen van Ossenisse.



ADCP measurements are for the ADCP cell corresponding to the location of the moored Delft bottle.

Figure 25 – Sediment transport rate and grain size measured by the Delft bottle and ADCP during day 2 (10/5/2016) near Plaat van Walsoorden.



ADCP measurements are for the ADCP cell corresponding to the location of the moored Delft bottle.

Figure 26 – Suspended sediment concentration and total sediment transport rate estimated from the boat-mounted ADCP during day 1 (9/5/2016) near Platen van Ossenisse.

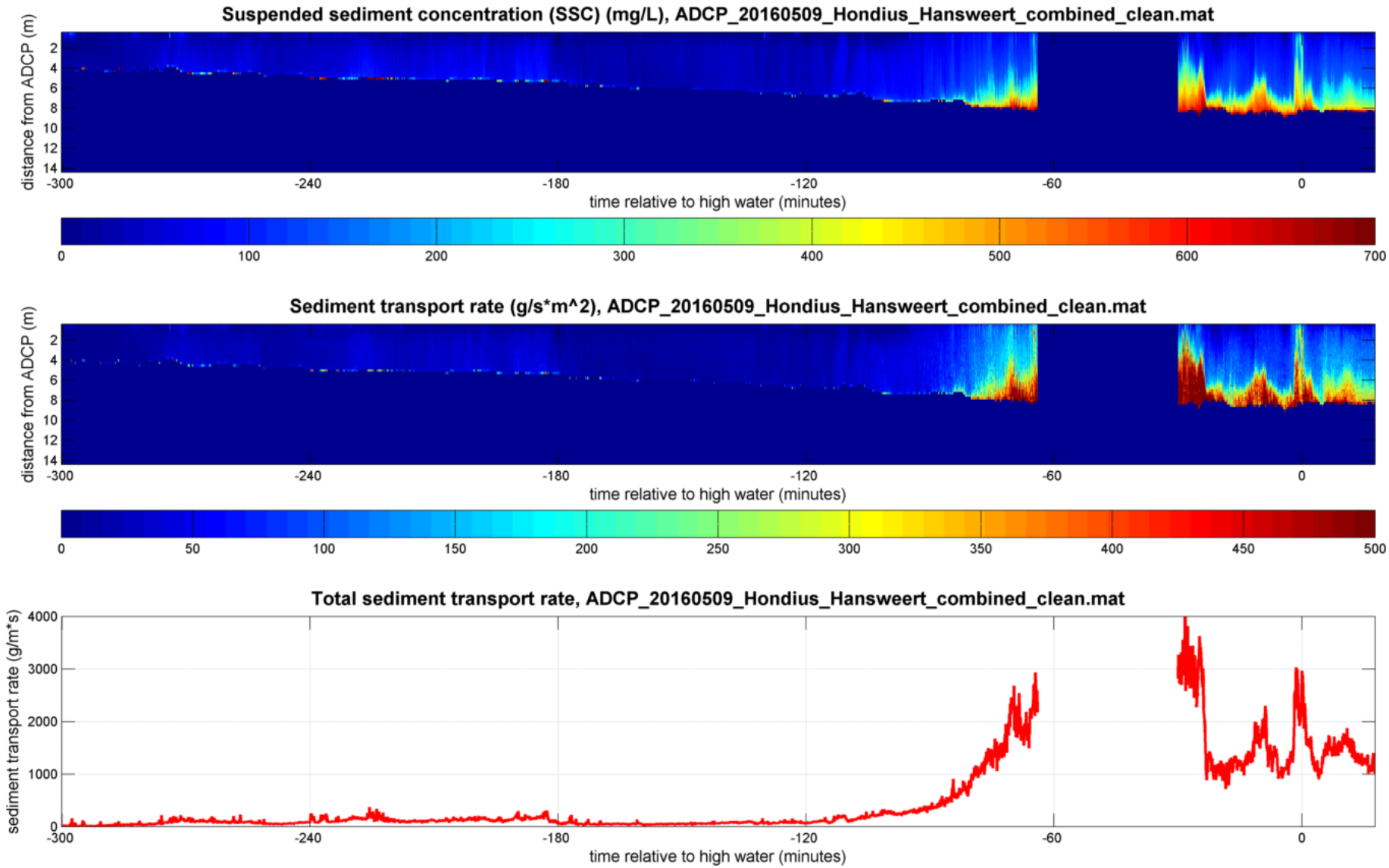
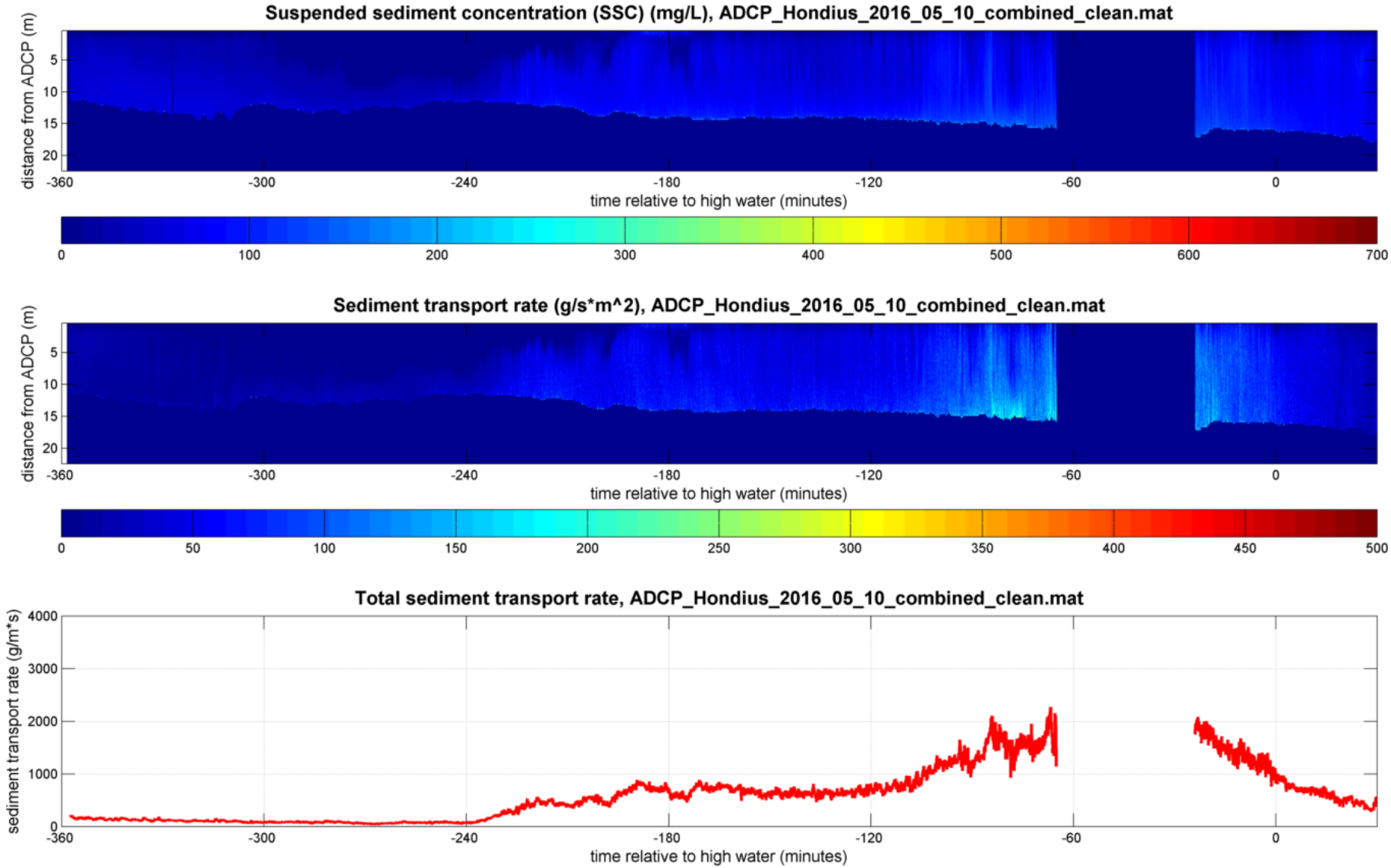


Figure 27 – Suspended sediment concentration and total sediment transport rate estimated from the boat-mounted ADCP during day 2 (10/5/2016) near Plaat van Walsoorden.



4.5 Grain Size

The grain size (D50) and sediment volume concentrations, as measured by the LISST, are plotted in Figure 28 for day 1 and Figure 29 for day 2 of the calibration campaign. Overlaid are the grain size (D50) of the samples collected from the Delft bottle measurements. Similarly, Figure 30 and Figure 31 show the fraction of sediment with a grain size greater than 62.5 µm (an indicator of the amount of sand in suspension) for day 1 and day 2, respectively. Figure 14 and Figure 15 show the vertical sampling locations of the Delft bottle samples relative to the LISST (i.e. above or below).

Day 1 and day 2 show different trends. On day 1, between 300 and 220 minutes before high tide, the grain size (D50) shows two small peaks. These peaks can also be seen clearly in the % of sediment with grain size greater than 62.5 µm, with up to 50% of suspended sediment being sandy. Then, the suspended grain size drops again until about 180 minutes before high tide, when it starts increasing gradually and peaks in the 30 minutes before high water. With the exception of a few outliers in the beginning of the day, the grain size of the moored Delft bottle follows a similar trend. The grain sizes from the two Delft bottles agree well with eachother, except around 200 minutes before high tide, where the bed-mounted Delft bottle measures higher grain size (and nearly 100% sand) than the moored one. The suspended grain size stays high (and relatively sandy) between about 100 minutes before to 20 minutes after high tide (when the measurements stopped).

On day 2, on the other hand, the LISST measured relatively consistent and low (D50 of 30 – 70 µm) grain sizes for the duration of the measurement. The fraction of sandy material measured by the LISST was also relatively consistent, ranging from 40 to 60%, with the exception of a drop between 300 and 240 minutes to high water. This day the Delft bottle measurements do not follow the same trend. The Delft bottle (there was only a moored one on day 2) samples showed grain size and suspended sand fraction gradually increasing from about 180 minutes before high tide to about 30 minutes before high tide, at which point it began to drop again. This clearly diverges from the grain size and sand fraction measured by the LISST. The differences between the Delft bottle and the LISST can largely be explained by the fact that much of the fine sediment flushes through the Delft bottle, distorting the sand fraction and D50. The difference increases as the current speed increases and leads to increased flushing through the Delft bottles.

Figure 28 – Grain size (D50) and suspended sediment concentration measured by the LISST and Delft bottle during day 1 (9/5/2016) near Platen van Ossenisse.

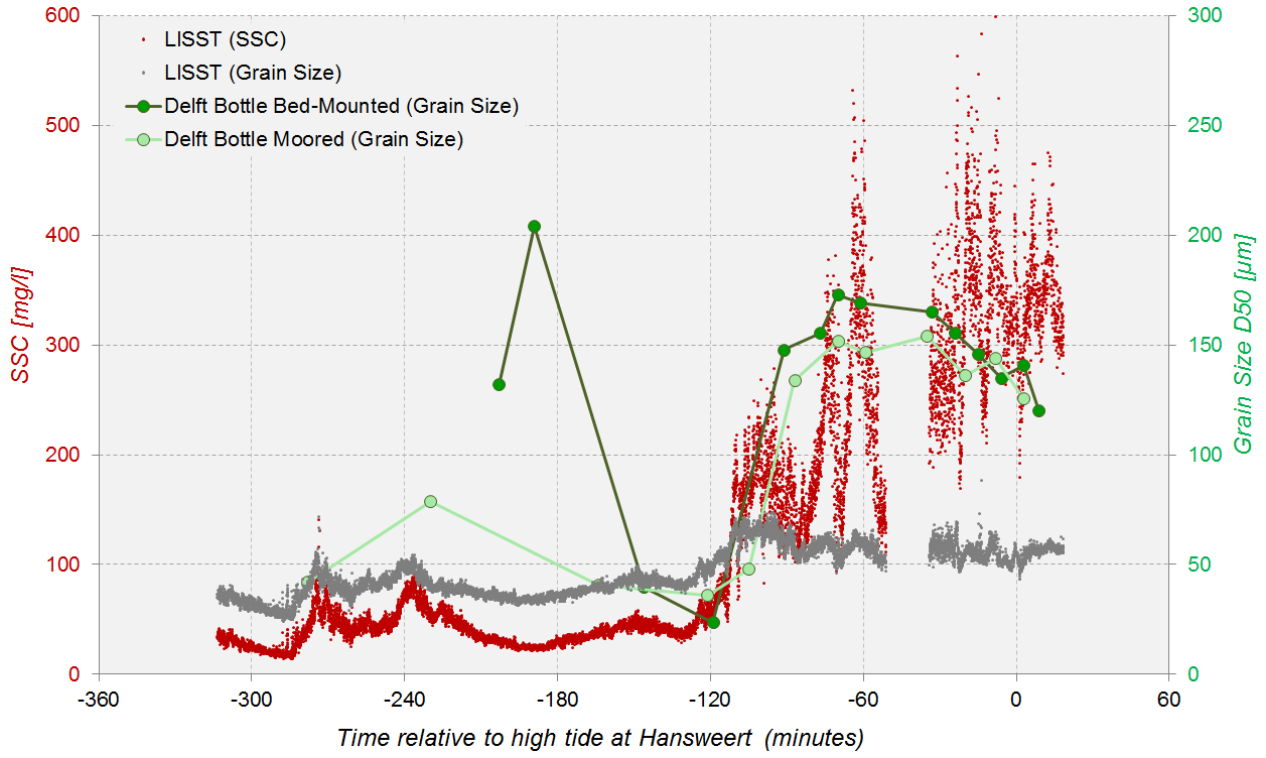


Figure 29 – Grain size (D50) and suspended sediment concentration measured by the LISST and Delft bottle during day 2 (10/5/2016) near Plaat van Walsoorden.

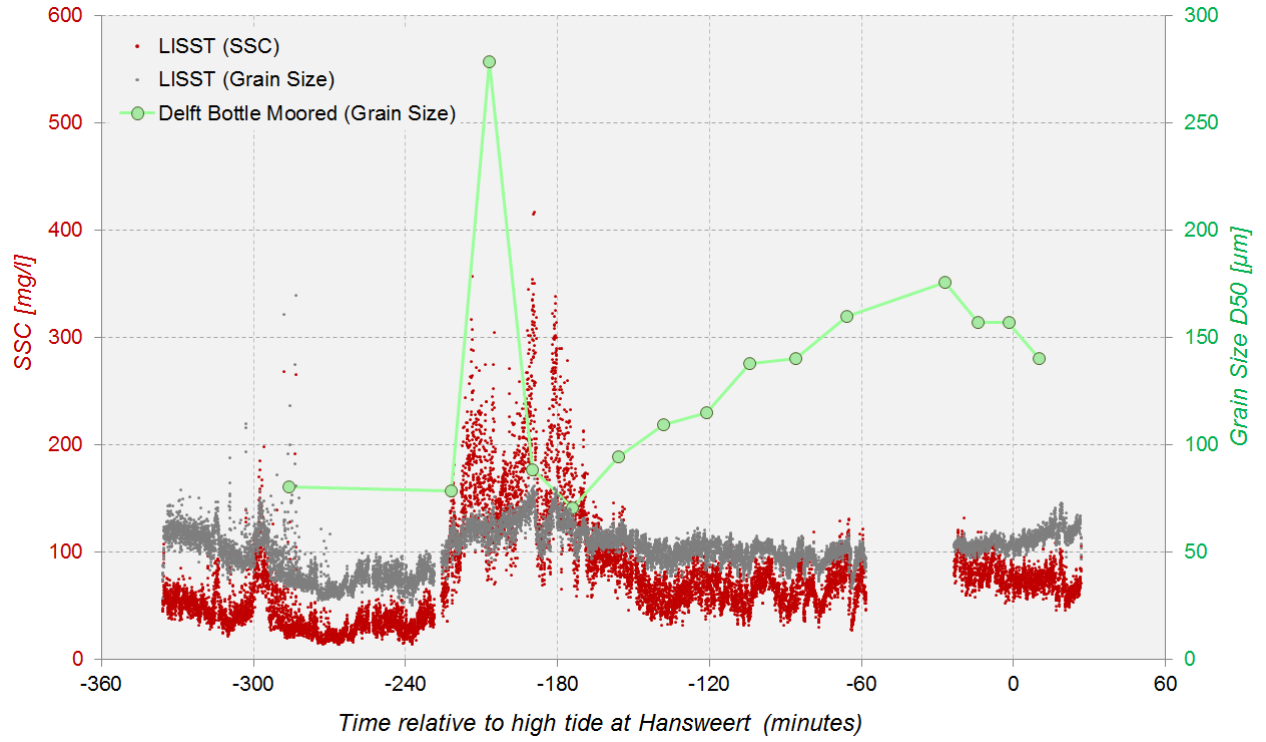


Figure 30 – Grain size (% volume > 62.5 um) and suspended sediment concentration measured by the LISST and Delft bottle during day 1 (9/5/2016) near Platen van Ossenisse.

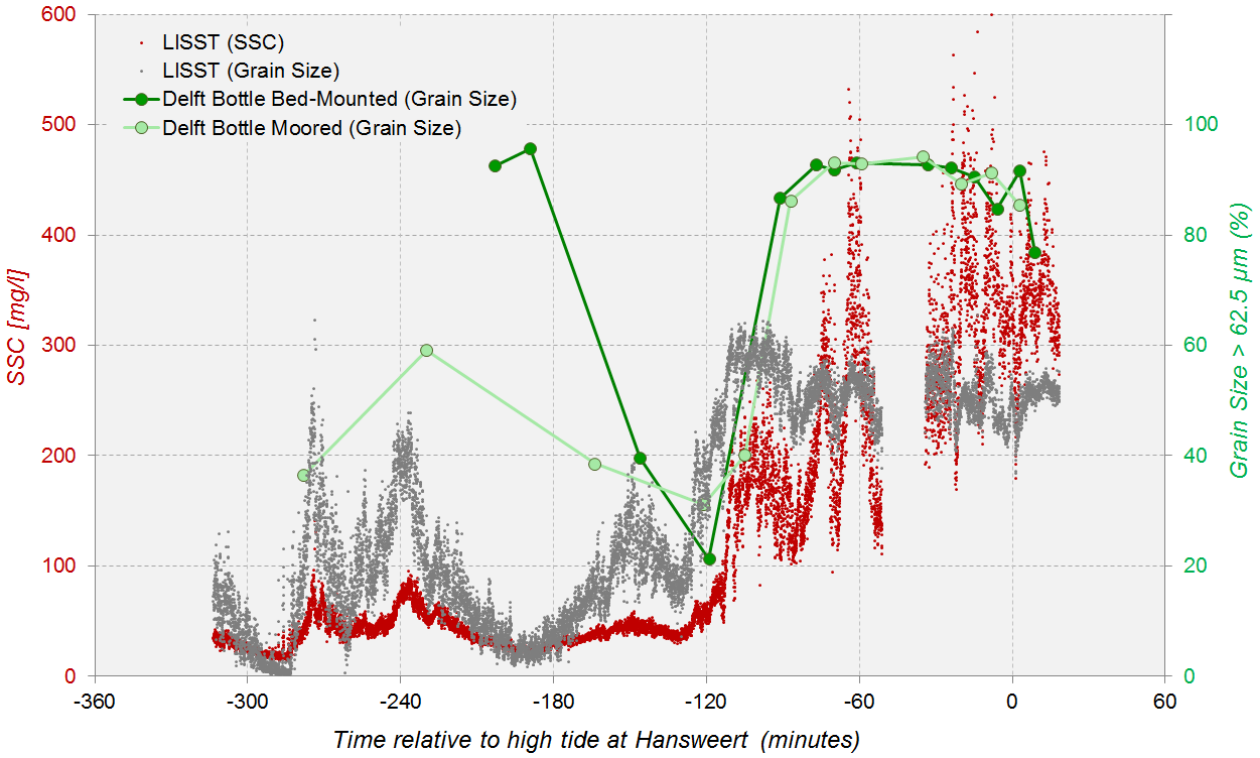
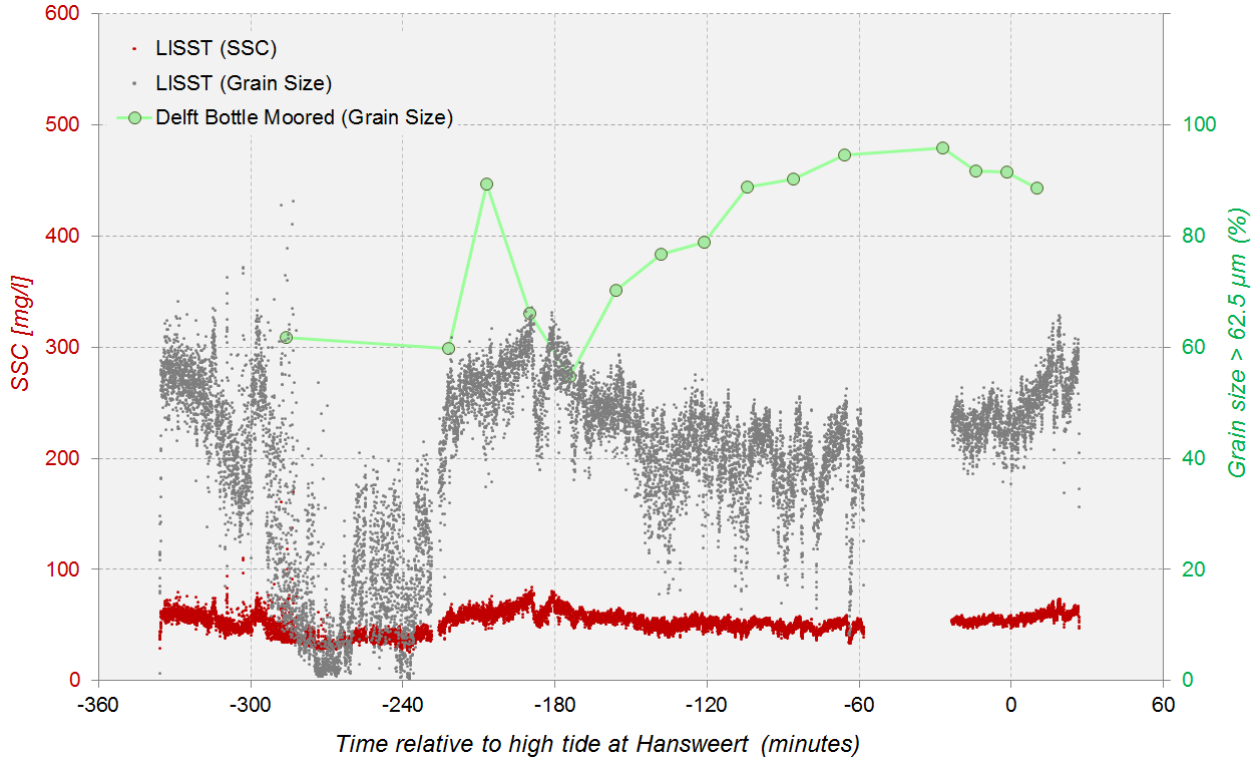


Figure 31 – Grain size (% volume > 62.5 um) and suspended sediment concentration measured by the LISST and Delft bottle during day 2 (10/5/2016) near Plaat van Walsoorden.



5 Results: long term frame measurements

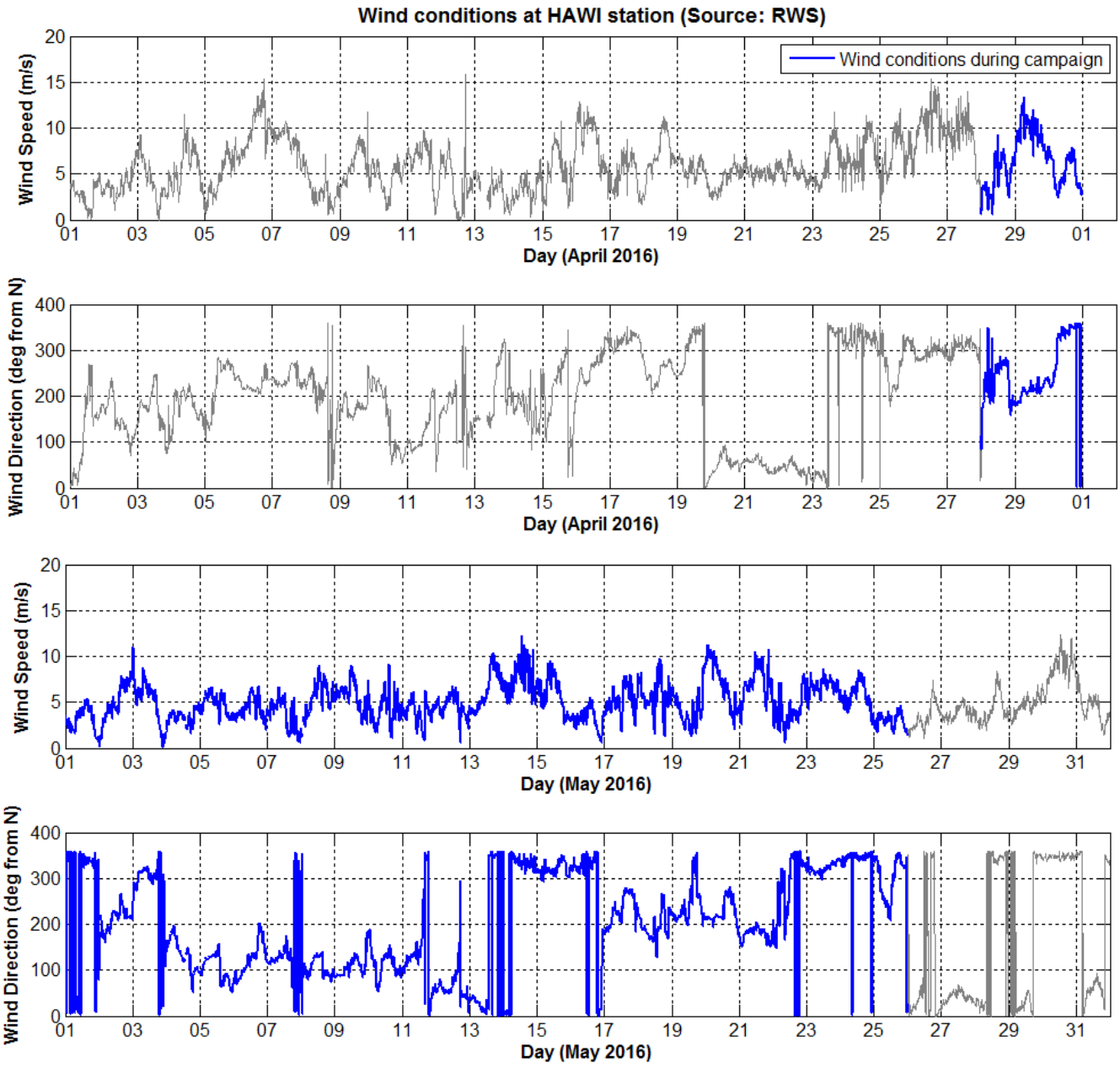
5.1 Ambient Conditions

The following sections present ambient conditions (wind, water levels, and waves) observed for the duration of the monitoring frame deployment.

5.1.1 Wind

Wind conditions (speed and direction) at the HAWI station are plotted in Figure 32 for the duration of the campaign. The windiest conditions occurred at the very beginning of the campaign, on April 29th, 2016.

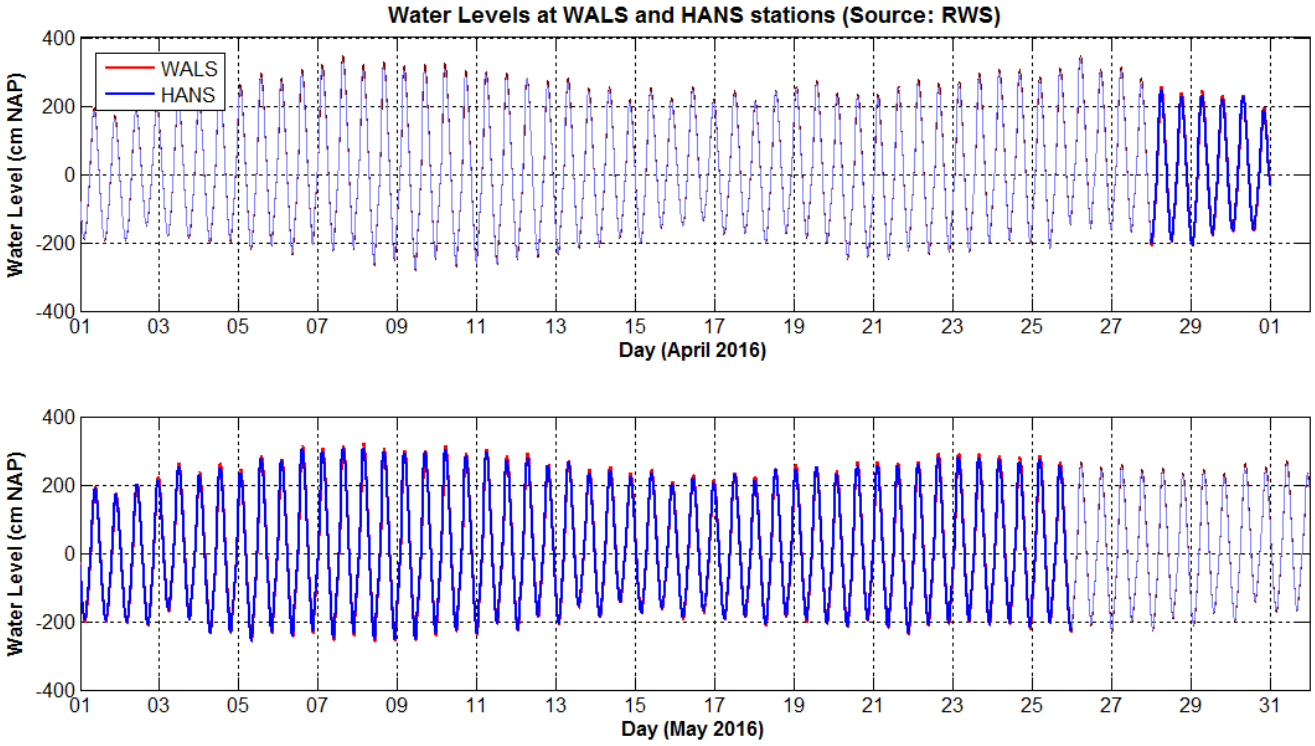
Figure 32 – Wind conditions at the HAWI station during campaign #2 at Drempel van Hansweert (top: April 2016, bottom: May 2016)



5.1.2 Water Levels

Figure 33 presents the measured water levels at the WALS station (nearest campaign #2) for the duration of the campaign. The highest and lowest water levels occurred around May 8th.

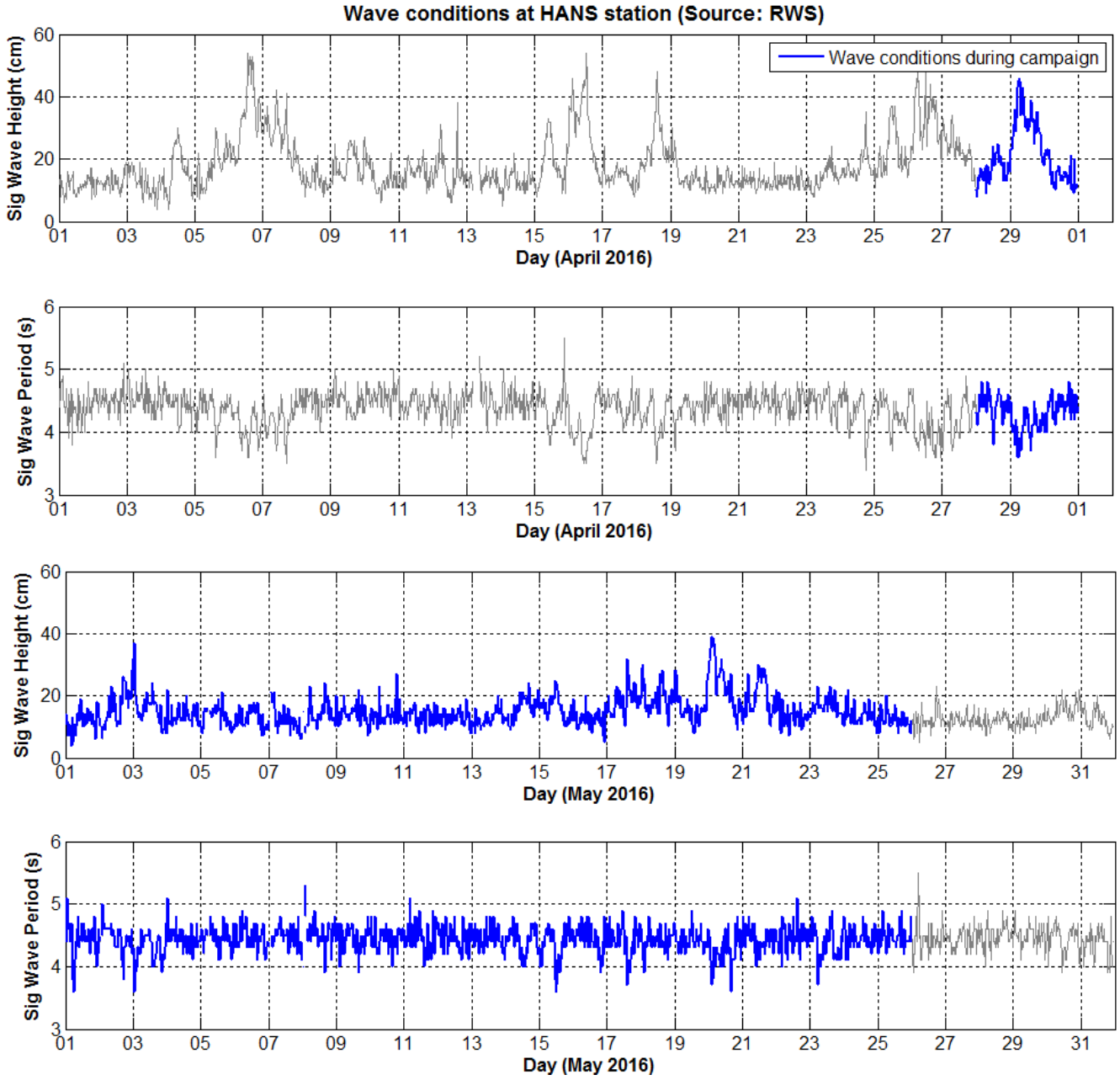
Figure 33 – Water levels at the WALS station during campaign #2 at Drempel van Hansweert (top: April 2016, bottom: May 2016)



5.1.3 Waves

Wave conditions (significant wave height and period) measured at the HANS station are plotted in Figure 34 (week by week) for the duration of campaign 2. The highest significant wave heights of 46 cm were reached on April 29, 2016, just after the start of the campaign.

Figure 34 – Wave conditions at HANS station during campaign #2 (top: April 2016, bottom: May 2016).

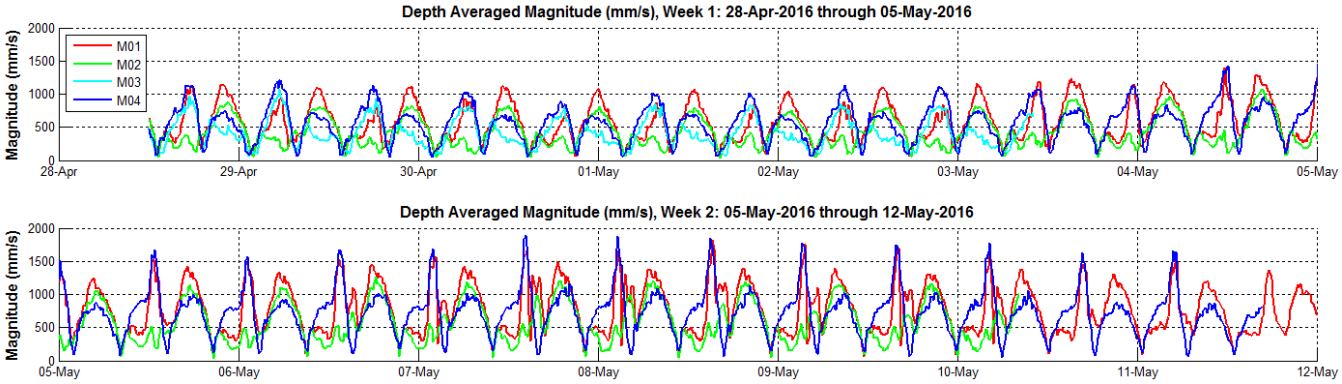


5.2 Currents

Figure 36 through Figure 40 show the depth averaged velocity overlaid with the measured water level at the WALS station for the M01, M02, M03, and M04 frames, respectively. Figure 41 through Figure 45 show the complete current profile over time. Figure 35 shows the depth averaged velocity for all 4 locations.

The depth time series collected by the ADCP was used to remove data beyond the water surface. Since frames M02 and M04 did not collect any depth data, the depth from frame M01 (the longest time series) was used to remove data beyond the water surface at frames M02 and M04[4]. The duration of data collected at each frame varies, as some were covered in sand earlier than others (see Table 2).

Figure 35 – Depth averaged current magnitude for all four frames, weeks 1 and 2.



[4] The depth was corrected by adding 1.55 m for M02 and 5.59 m for M04, based on the reported elevations of each frame provided by Rijkswaterstaat.

Figure 36 – Depth averaged magnitude and direction with water levels (as measured by the ADCP) for frame M01, weeks 1 and 2.

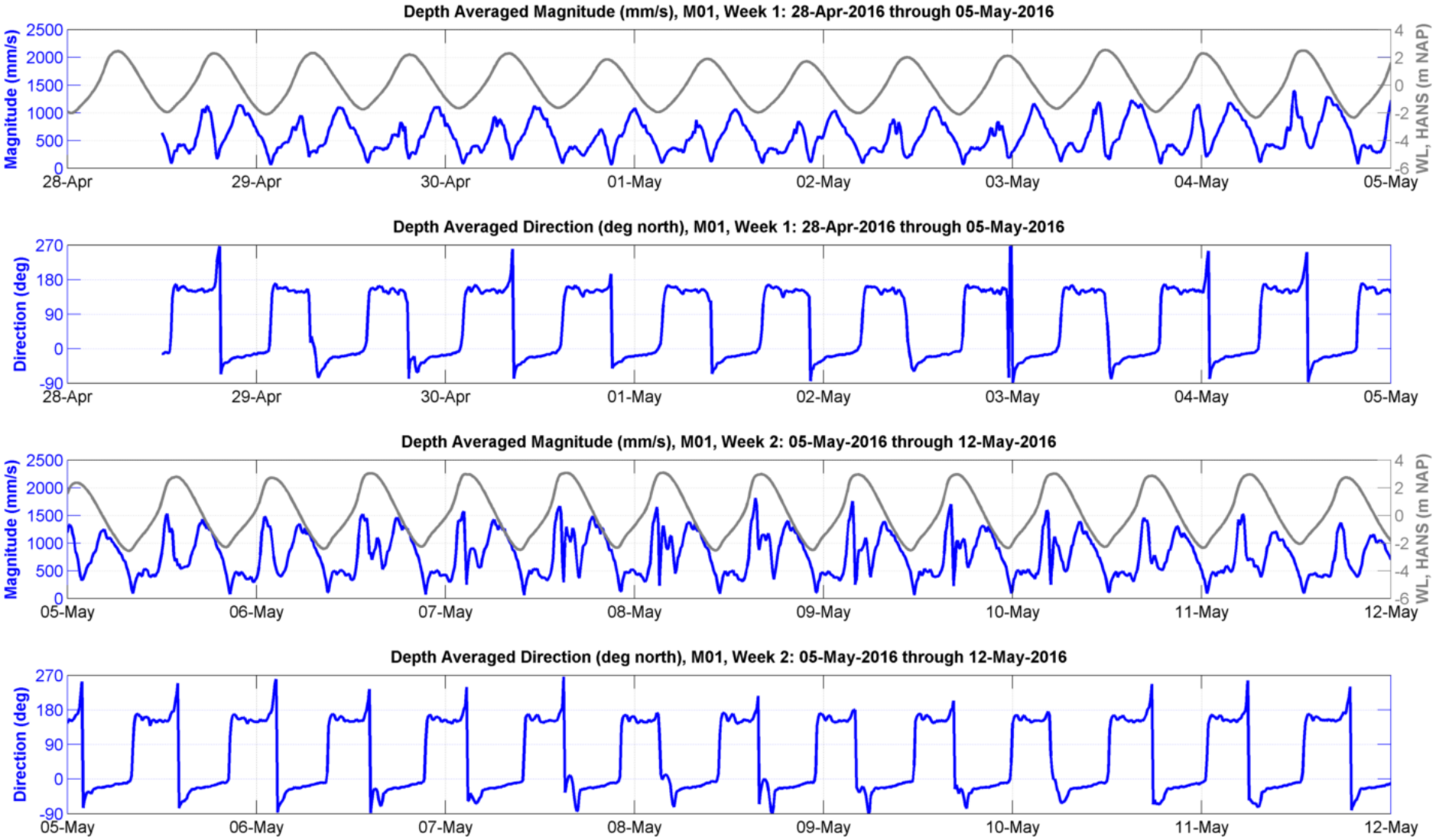


Figure 37 – Depth averaged magnitude and direction with water levels (as measured by the ADCP) for frame M01, weeks 3 and 4.

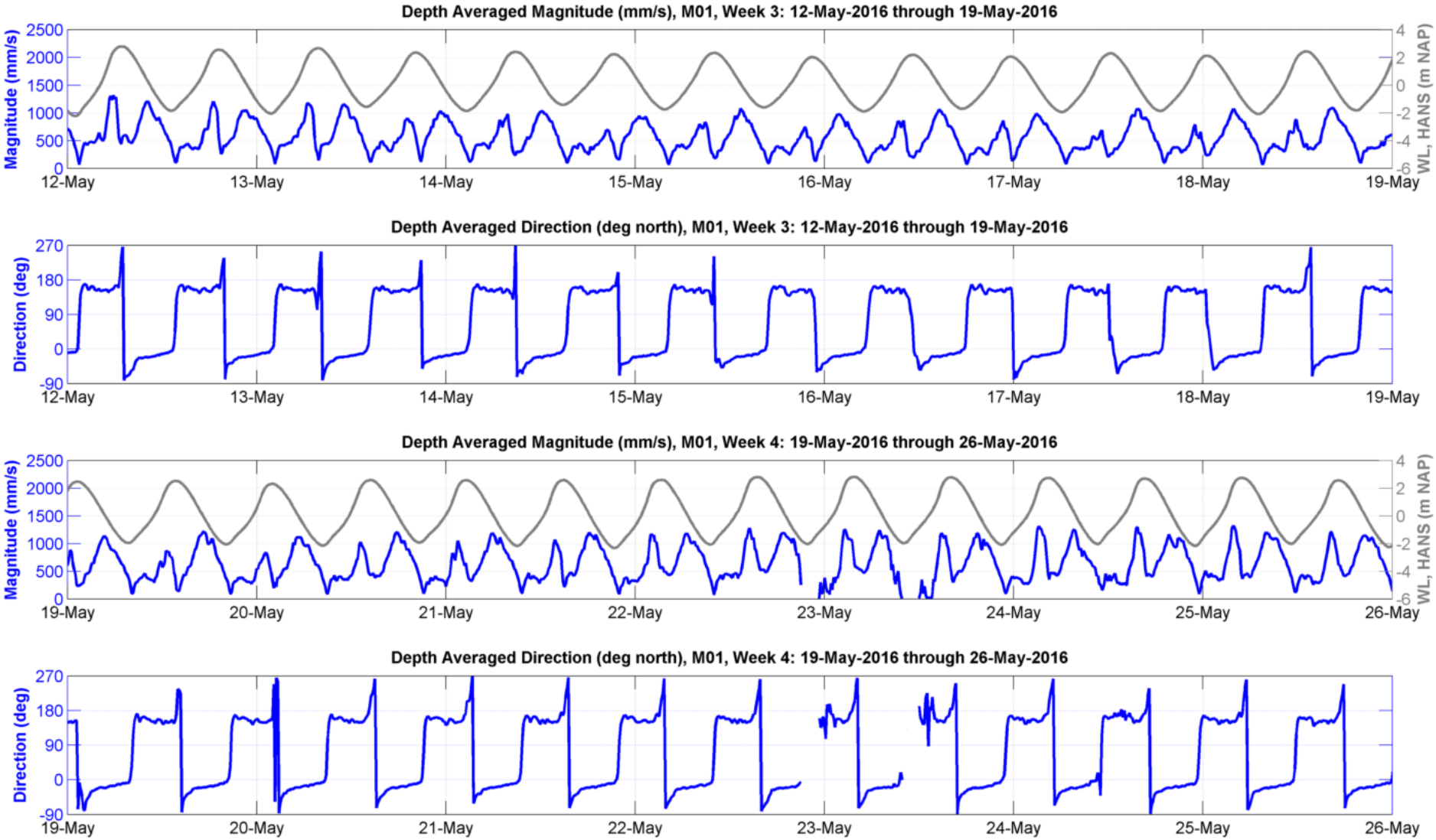


Figure 38 – Depth averaged magnitude and direction with water levels (at WALS) for frame M02, weeks 1 and 2.

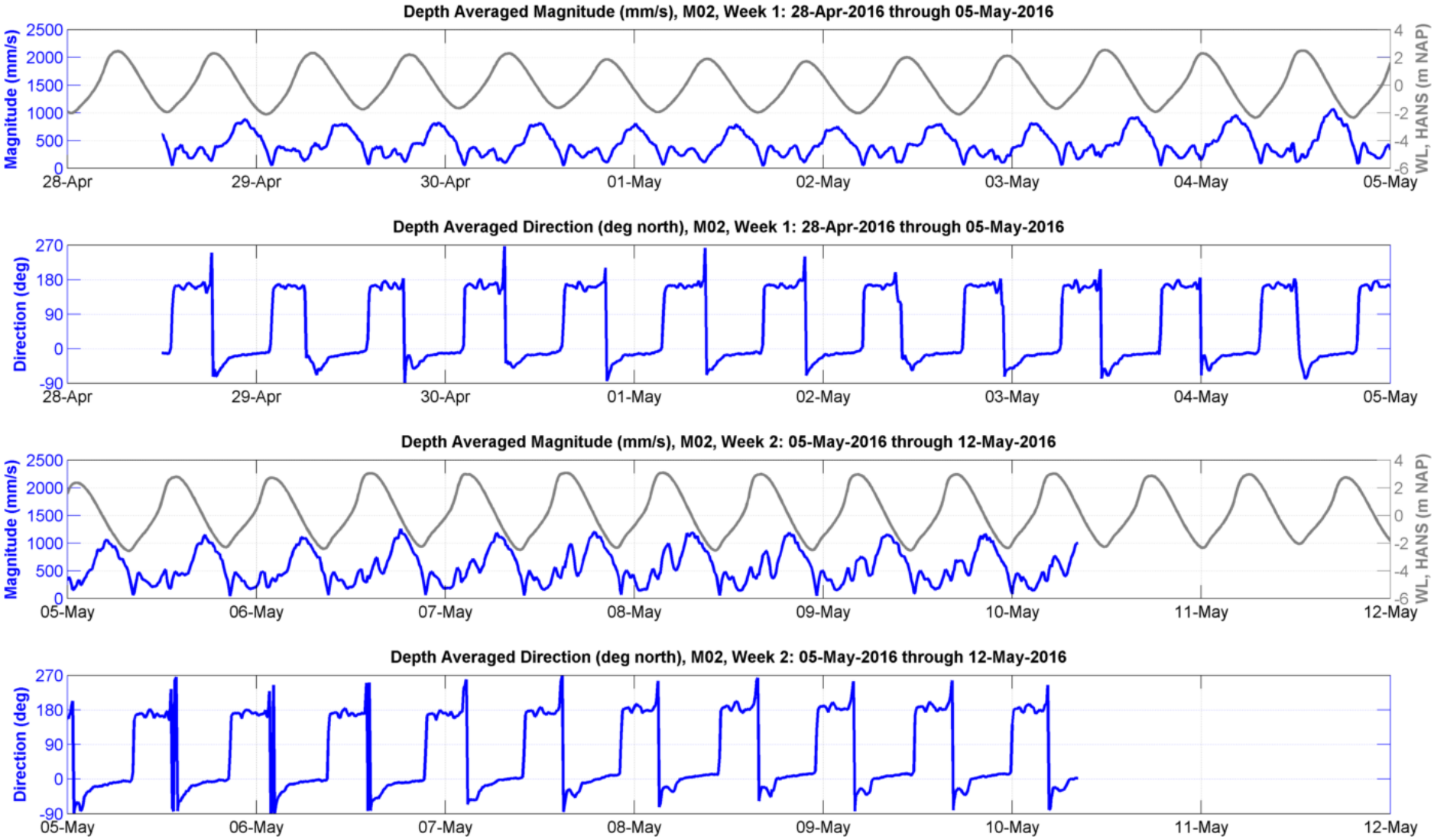


Figure 39 – Depth averaged magnitude and direction with water levels (at WALS) for frame M03, week 1.

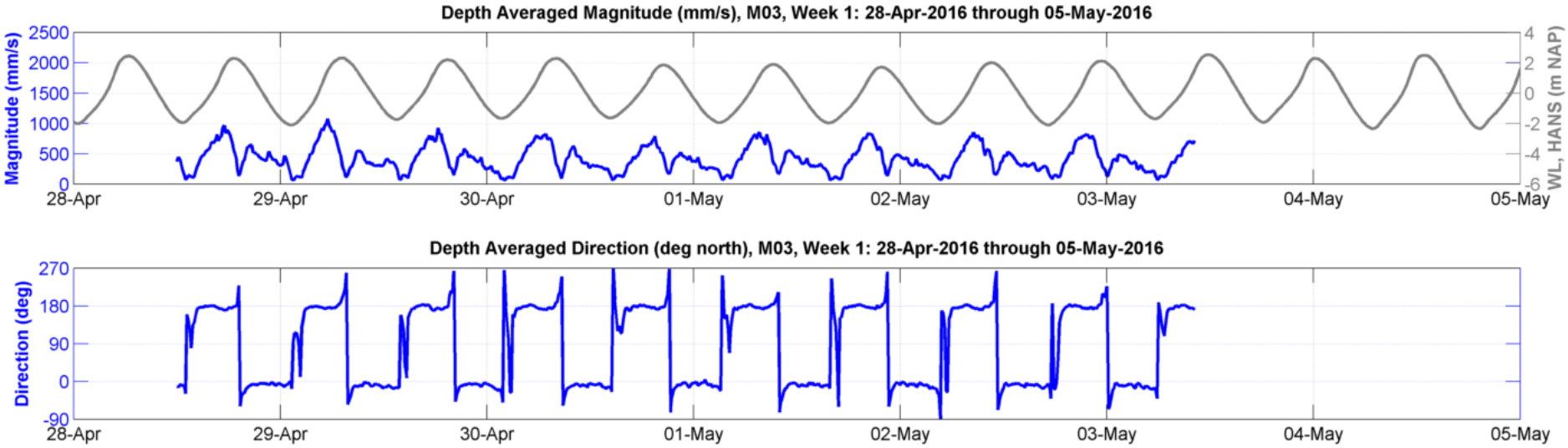


Figure 40 – Depth averaged magnitude and direction with water levels (at WALS) for frame M04, weeks 1 and 2.

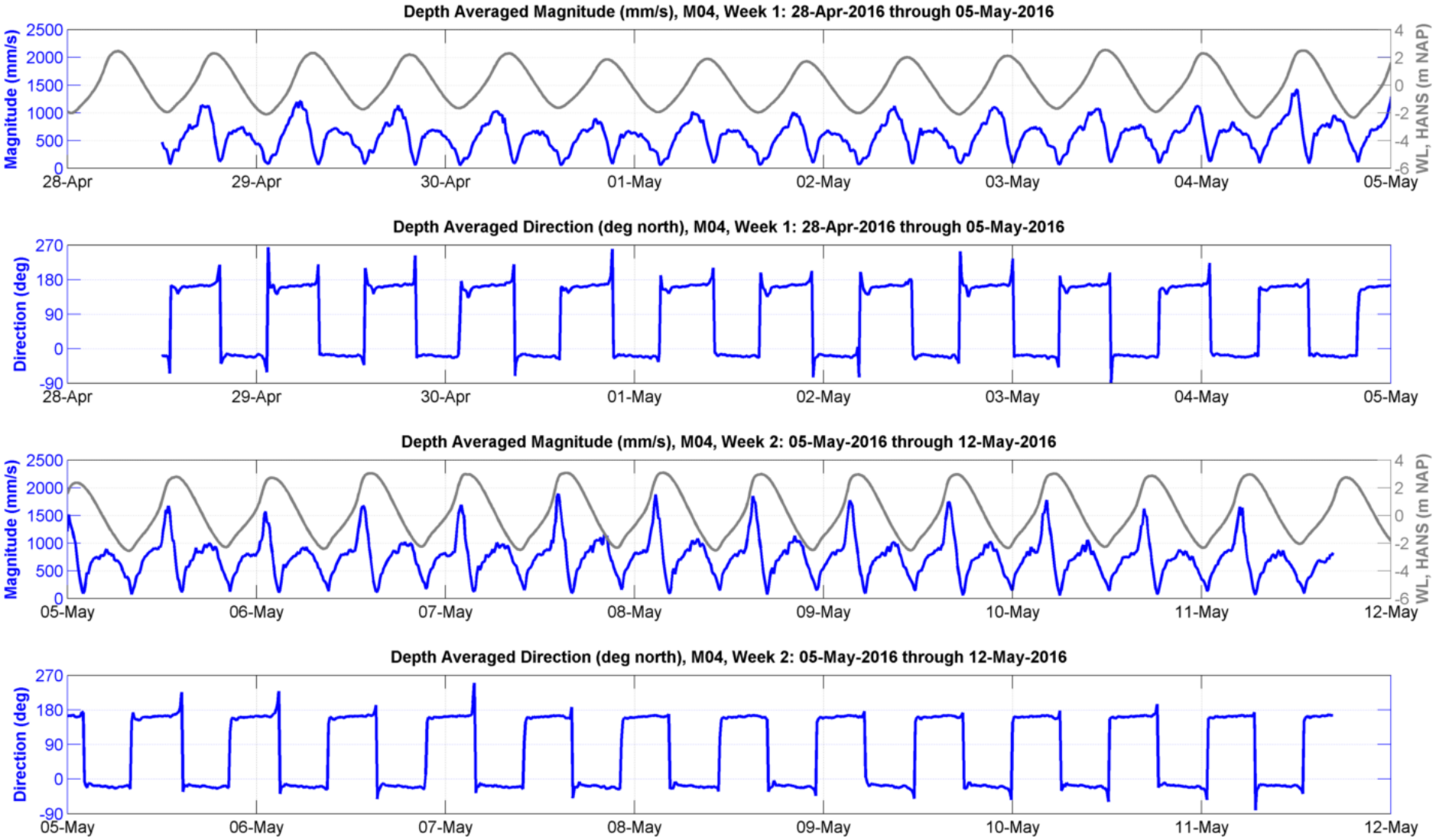


Figure 41 – Current magnitude and direction for frame M01, weeks 1 and 2.

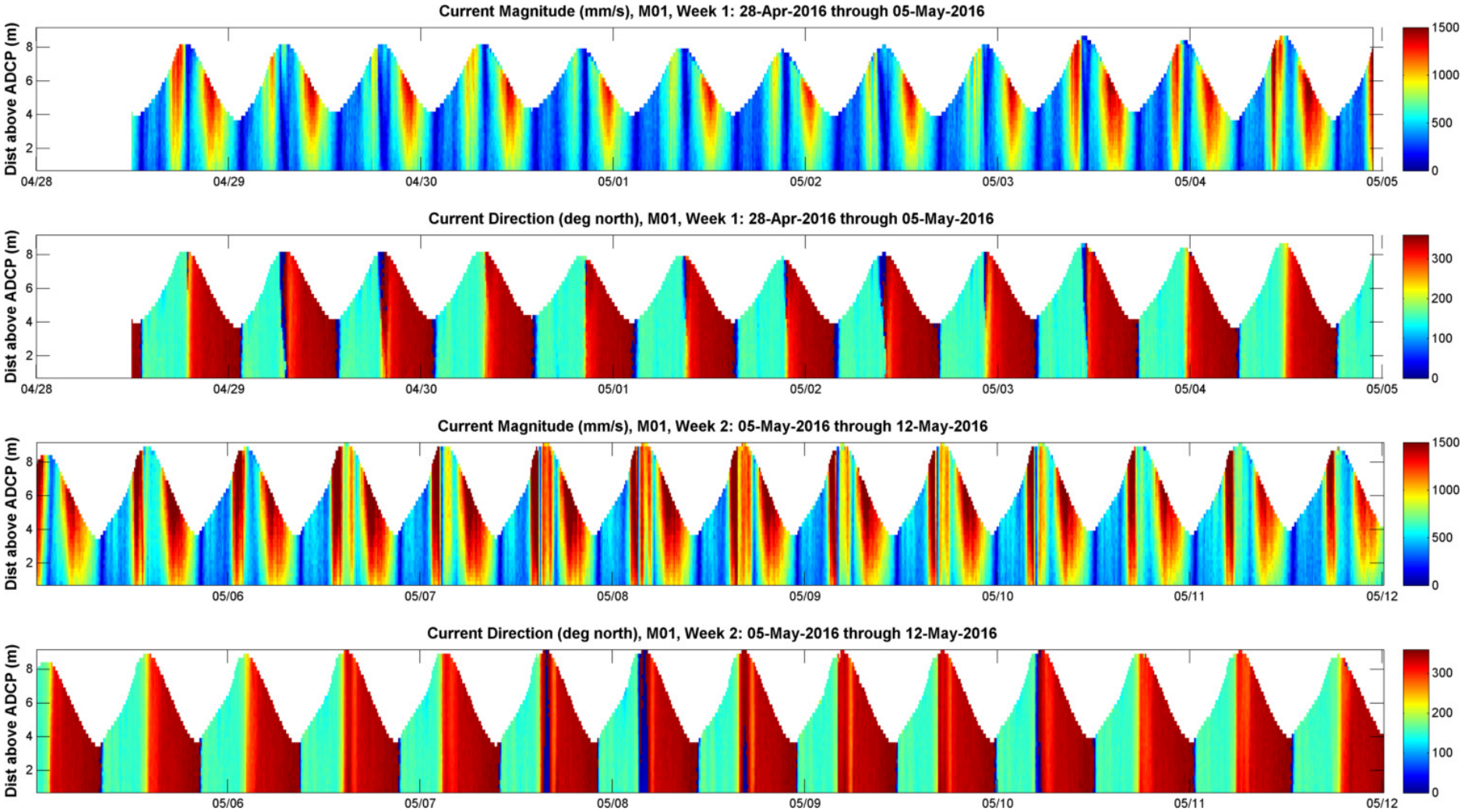


Figure 42 – Current magnitude and direction for frame M01, weeks 3 and 4.

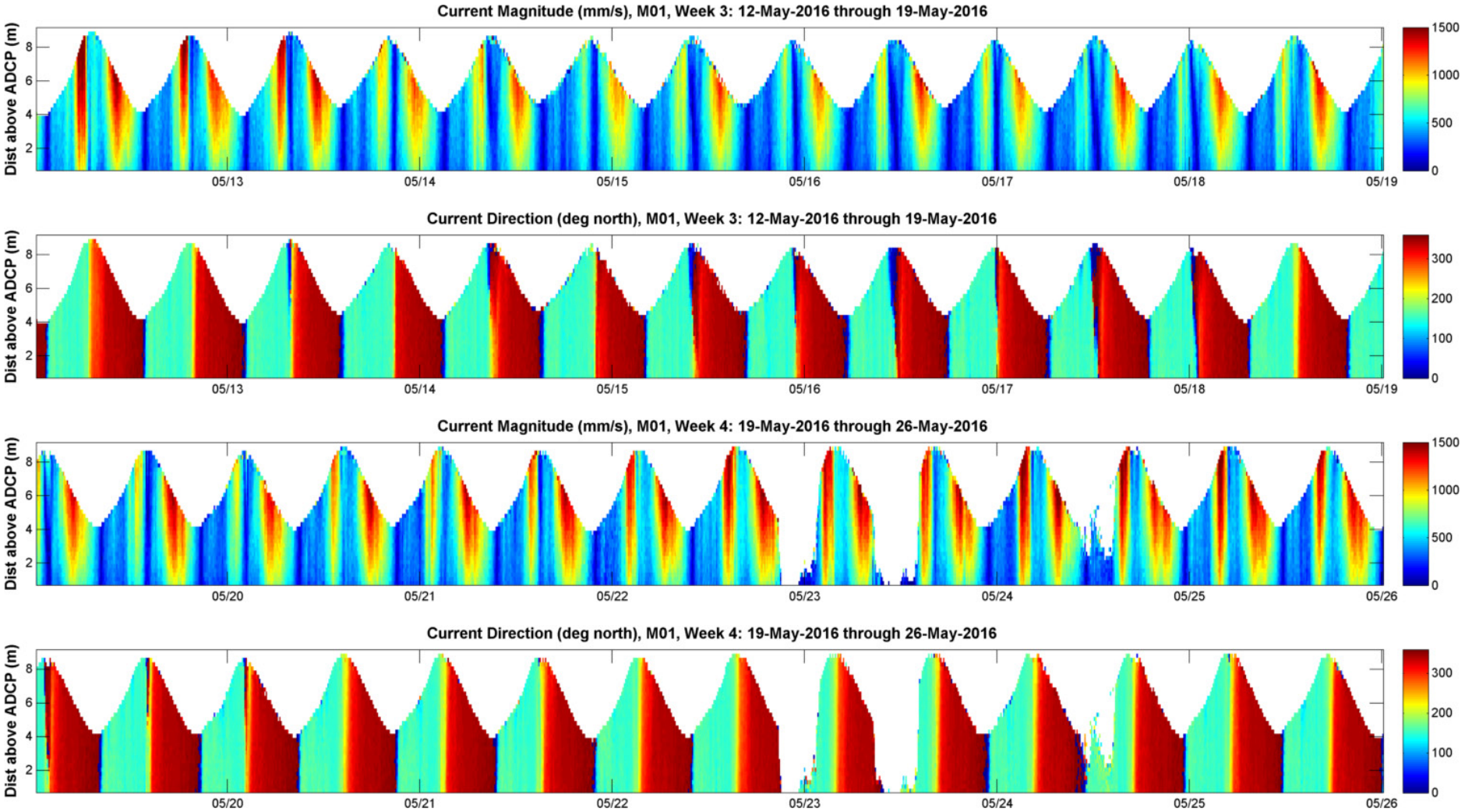


Figure 43 – Current magnitude and direction for frame M02.

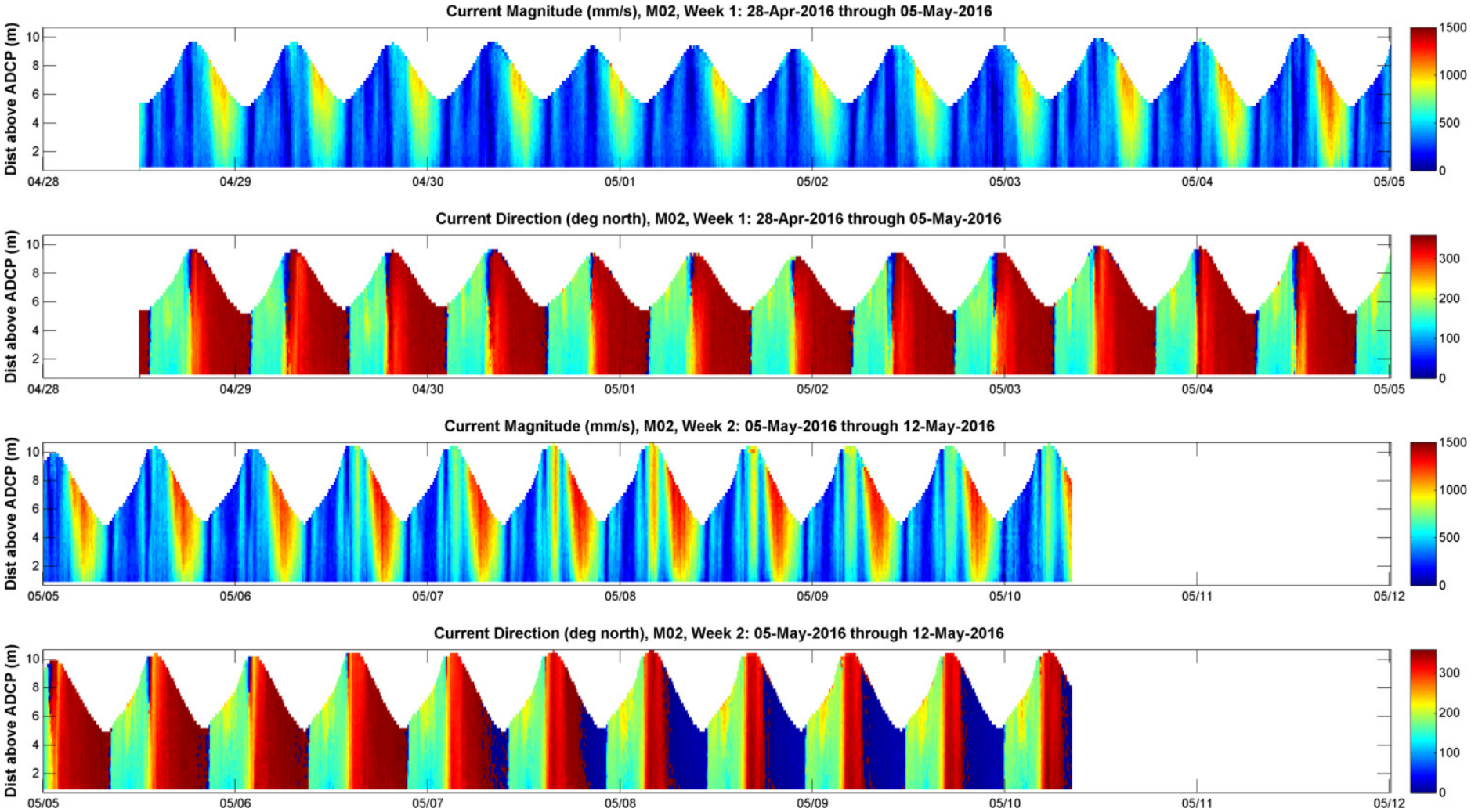


Figure 44 – Current magnitude and direction for frame M03.

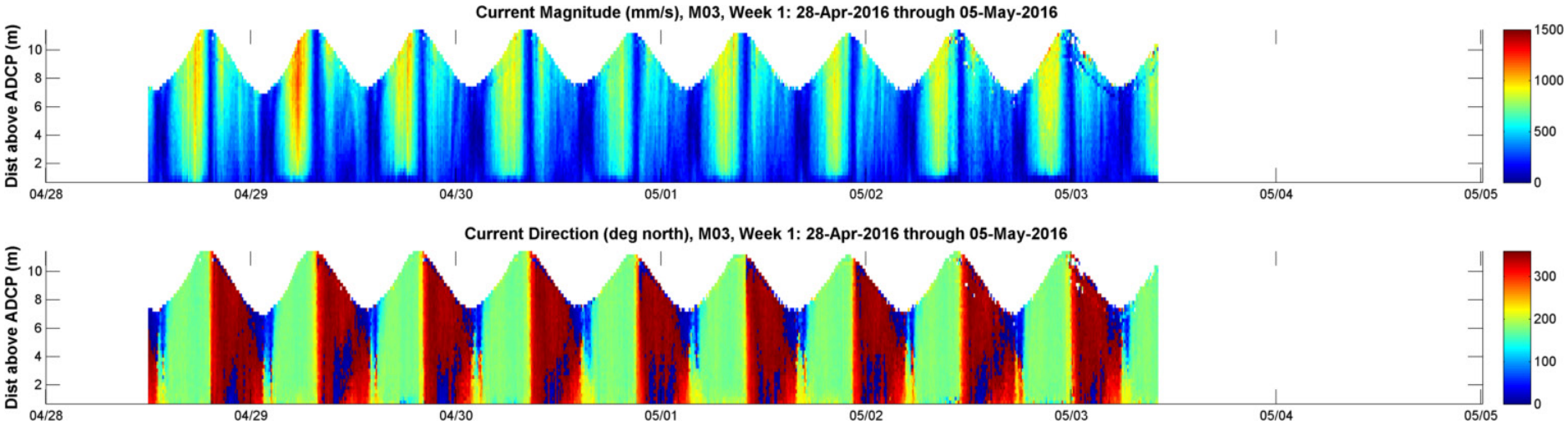
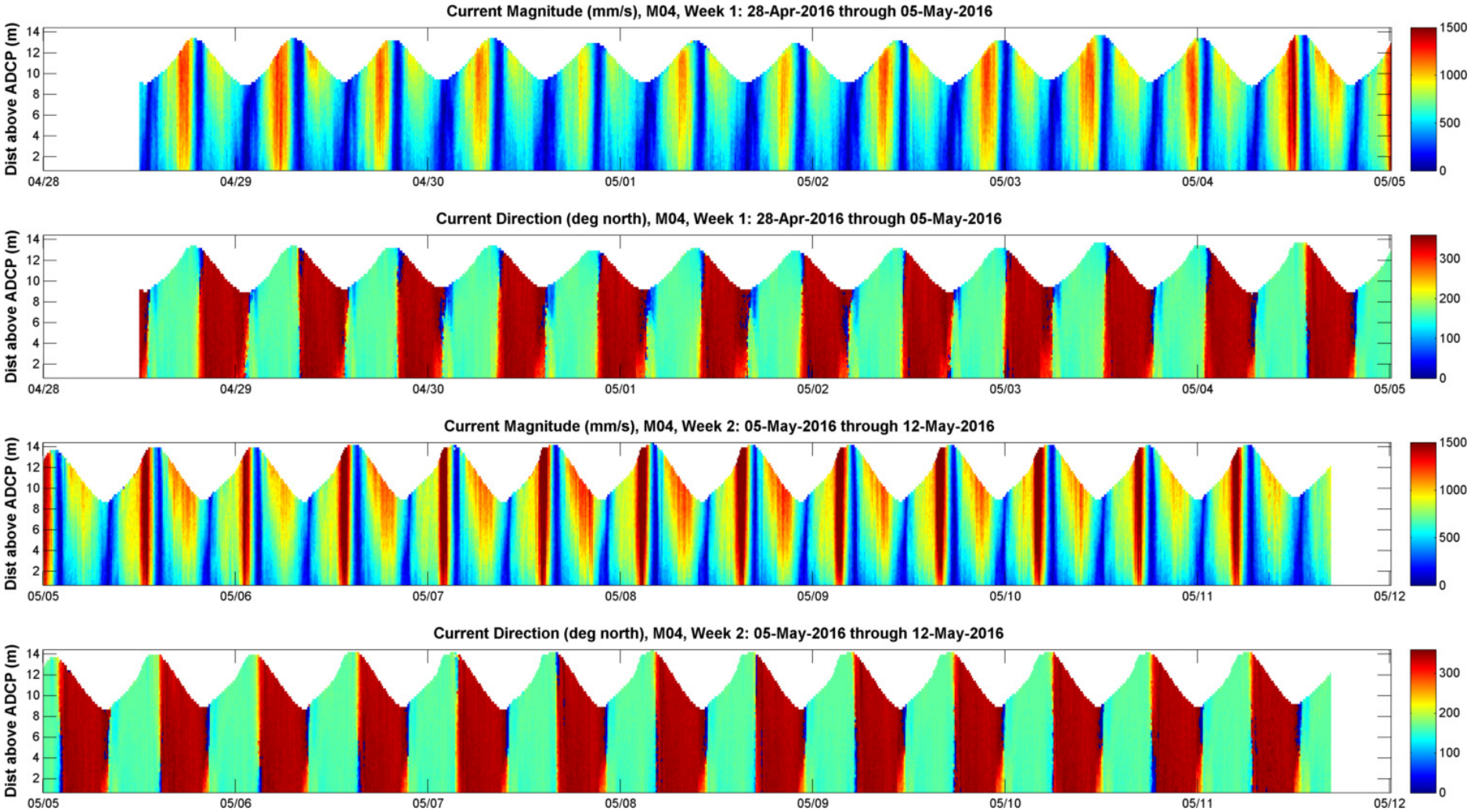


Figure 45 – Current magnitude and direction for frame M04.



5.3 Sediment Transport

Figure 46 through Figure 49 present the sediment transport rates for the long-term measurement frames (M1 part 1, M1 part 2, M2, and M4). These rates were calculated according to the methods outlined in section 3.3. Rates for frame M3 are not presented since the calibration campaign did not overlap with the M3 measurements (the frame was already covered with sand).

Figure 46 – Suspended sediment concentration and sediment transport rate profiles and total sediment transport rate for frame M01, part 1.

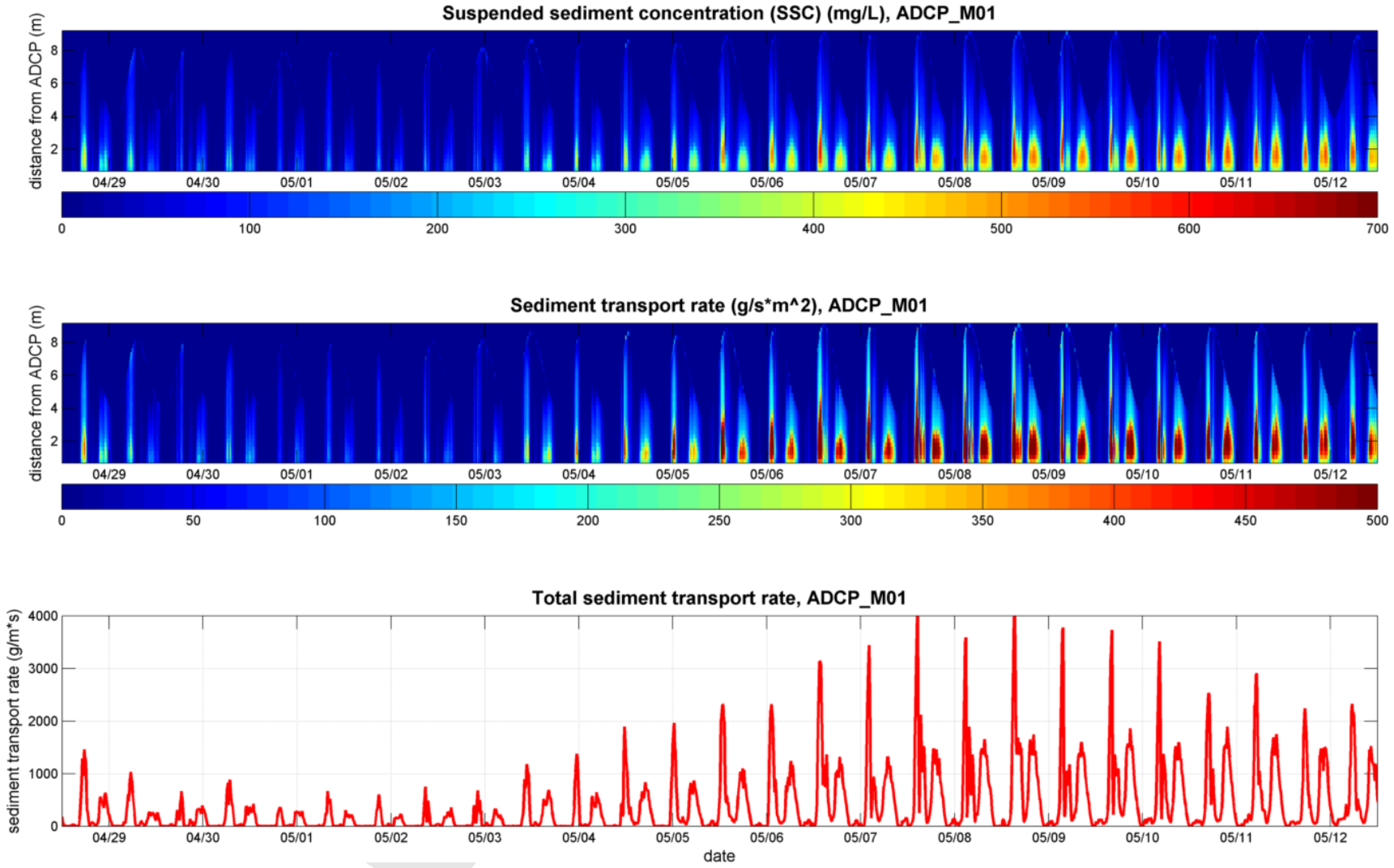


Figure 47 – Suspended sediment concentration and sediment transport rate profiles and total sediment transport rate for frame M01, part 2.

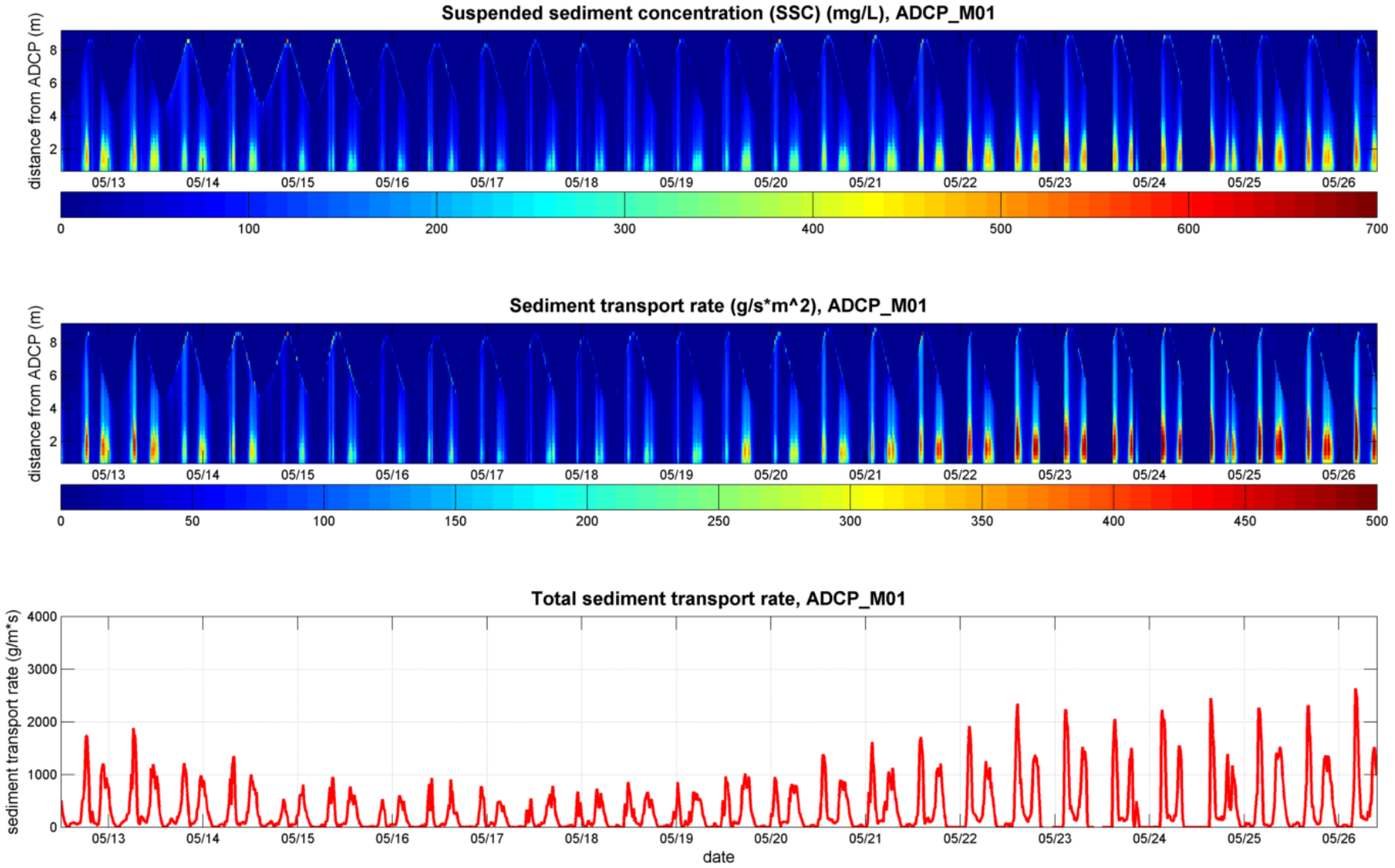


Figure 48 – Suspended sediment concentration and sediment transport rate profiles and total sediment transport rate for frame M02.

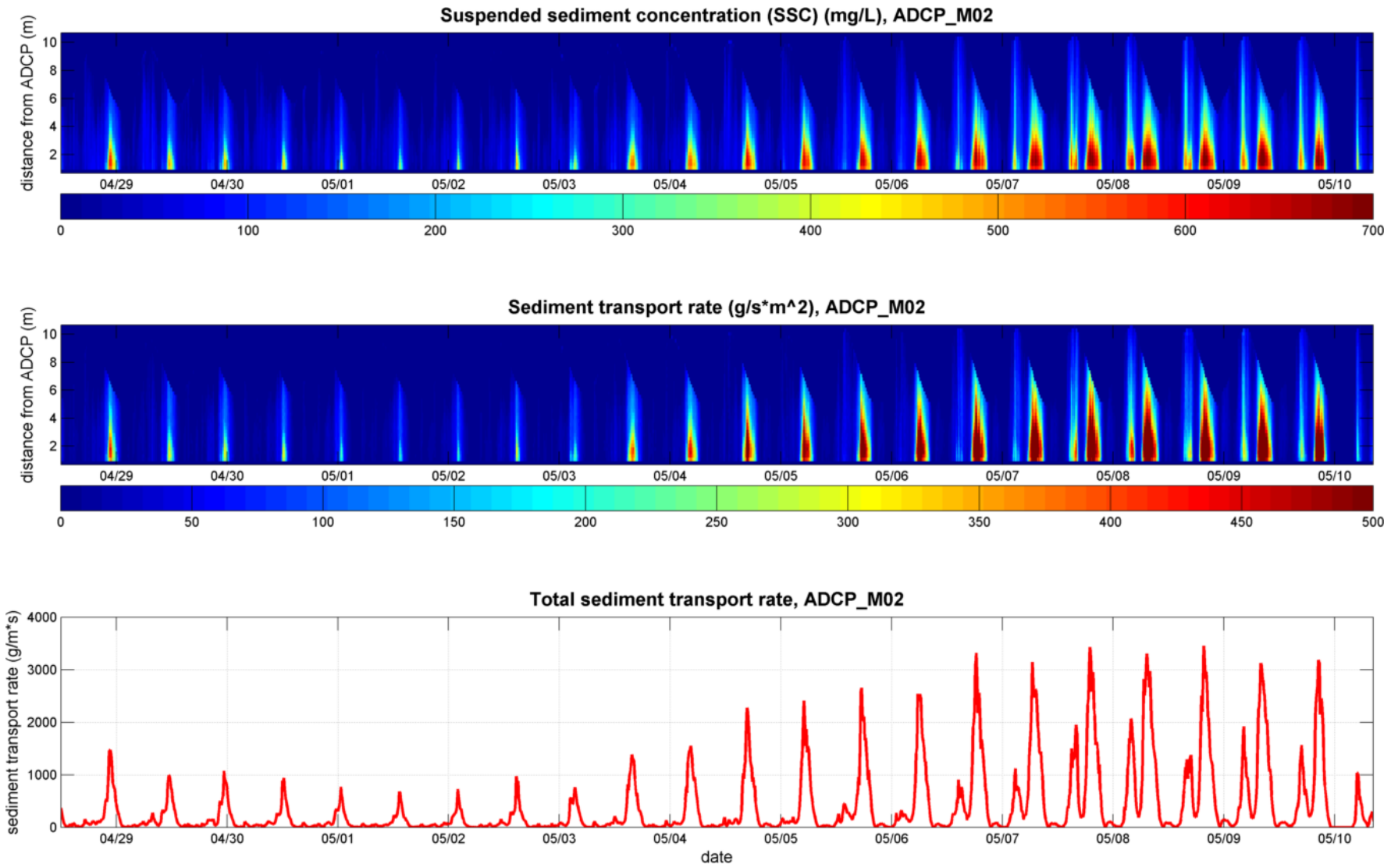
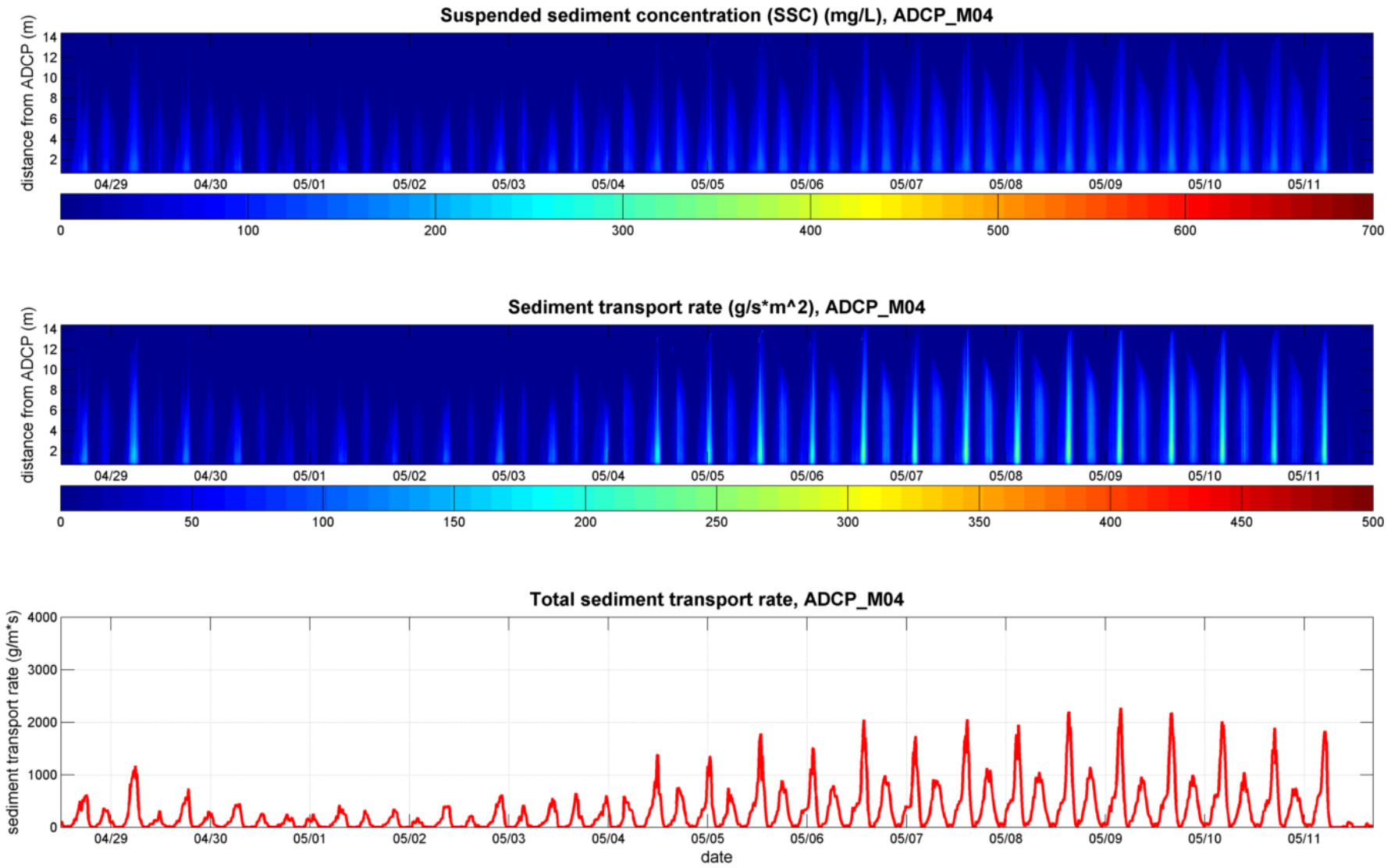


Figure 49 – Suspended sediment concentration and sediment transport rate profiles and total sediment transport rate for frame M04.



6 References

Aardoom, J.H. (2006). Quantification of sediment concentrations and fluxes from ADCP measurements, in: Evolutions in hydrography, 6th - 9th November 2006, Provincial House Antwerp, Belgium: Proceedings of the 15th International Congress of the International Federation of Hydrographic Societies. Special Publication (Hydrographic Society), 55: pp. 166-171.

Gartner, J.W.; Cheng, R.T.; Wang, P.-F.; Richter, K. (2001). Laboratory and field evaluations of the LISST-100 instrument for suspended particle size determinations. Mar. Geol. 175(1): 199–219. doi:10.1016/S0025-3227(01)00137-2

Gartner, J.W. (2005). Estimating suspended solids concentrations from backscatter intensity measured by acoustic Doppler current profiler in San Francisco Bay, California. Marine Geology 2011, 169-187.

International Marine and Dredging Consultants (IMDC); Waterbouwkundig Laboratorium (WL) (2007). Deelrapport 3: valsnelheid slib - INSSEV. Versie 2.0. Waterbouwkundig Laboratorium: Borgerhout. VI, 86 + 97 p. Appendices pp.

Lohrmann, A. (2001). Monitoring sediment concentration with acoustic backscattering instruments. Nortek AS Technical Note No. 003.

Nortek (2001). Monitoring Sediment Concentration with acoustic backscattering instruments.

Plancke, Y. and K. Paridaens (2012). Comparison of measurement techniques for monitoring sediment transport, under field conditions, in the Scheldt estuary. *Hydraulic Measurements and Experimental Methods 2012 Conference* (HMEM 2012), Snowbird, Utah, August 12-15, 2012. pp. [1-8].

Vandebroek, E.; Plancke, Y.; Verwaest, T.; Mostaert, F. (2017). Hydrodynamics and Sediment Dynamics in the Schelde Estuary: Factual data report for frame- measurements at Drempel van Frederik in December 2015 and January 2016. Version 4.0. WL Rapporten, 14_024. Flanders Hydraulics Research & Antea Group: Antwerp, Belgium.

7 Appendices

Appendix A – RDI Workhorse Monitor Technical Specifications

Workhorse Monitor

Direct Reading 1200, 600, 300 kHz ADCP

TECHNICAL SPECIFICATIONS

Water Profiling	Depth Cell Size[1]	Typical Range[3] 12m **1200kHz**		Typical Range[3] 50m **600kHz**		Typical Range[3] 110m **300kHz**	
	Vertical Resolution	Range[3]	Std. Dev.[4]	Range[3]	Std. Dev.[4]	Range[3]	Std. Dev.[4]
	0.25m	11m	14.0cm/s				
	0.5m	12m	7.0cm/s	38m	14.0cm/s	see note [1]	
	1m	13m	3.6cm/s	42m	7.0cm/s	83m	14.0cm/s
	2m	15m[2]	1.8cm/s	46m	3.6cm/s	93m	7.0cm/s
	4m	see note [1]		51m[2]	1.8cm/s	103m	3.6cm/s
	8m					116m[2]	1.8cm/s
Long Range Mode	2m	19m	3.4m/s				
	4m			66m	3.6cm/s		
	8m					154m	3.7cm/s
Profile Parameters	Velocity Accuracy	0.3% of water velocity relative to ADCP ±0.3cm/s		0.3% of water velocity relative to ADCP ±0.3cm/s		0.5% of water velocity relative to ADCP ±0.5cm/s	
	Velocity resolution	0.1cm/s		0.1cm/s		0.1cm/s	
	Velocity range	±5m/s default, ±20m/s max		±5m/s default, ±20m/s max		±5m/s default, ±20m/s max	
	Number of depth cells	1–128		1–128		1-128	
	Ping rate	2Hz (typical)		2Hz (typical)		2Hz (typical)	
Echo Intensity Profile	Vertical resolution	Depth cell size, user configurable					
	Dynamic range	80dB					
	Precision	±1.5dB					
Transducer and Hardware	Beam angle	20°					
	Configuration	4-beam, convex					
	Internal memory	Two PCMCIA card slots; no memory card included					
	Communications	Serial port selectable by switch for RS-232 or RS-422. ASCII or binary output at 1200-115,200 baud					
Environmental	Standard depth rating	200m; optional to 500m, 1000m, 6000m					
	Operating temperature	-5° to 45°C					
	Storage temperature (without batteries)	-30° to 60°C					
	Weight in air	7.0kg					
	Weight in water	3.0kg					
Software	TRDI's Windows™-based software included: **WinSC**–Data Acquisition System; **WinADCP**–Data Display and Export;						
Power	Input Power	20–50VDC					
Standard Sensors	Temperatures (mounted on transducer)	Range -5° to 45°C, Precision ±0.4°C, Resolution 0.01°					
	Tilt	Range ±15°, Accuracy ±0.5°, Precision ±0.5°, Resolution 0.01°					
	Compass (fluxgate type, includes built-in field calibration feature)	Accuracy ±2°[5], Precision ±0.5°[5], Resolution 0.01°, Maximum tilt ±15°					
Available Options	• Memory: 2 PCMCIA slots; total 4GB • Pressure sensor • External battery case • High-resolution water-profiling modes • Bottom tracking • AC/DC power converter, 48VDC output • Conversion kit for internal power supply and memory • Directional Waves Array • **Velocity**–Data Display, Processing, and Export software						
Dimensions	228.0mm wide x 201.5mm long *(line drawings available upon request)*						

1 User's choice of depth cell size is not limited to the typical values specified.
2 Longer ranges available.
3 Profiling range based on temperature values at 5°C and 20°C, salinity = 35ppt.
4 BroadBand mode single-ping standard deviation (Std. Dev.).
5 <±1.0° is commonly achieved after calibration.

Appendix B – LISST-100X Technical Specifications

Parameters Measured

- Particle size distribution
- Particle volume concentration
- Volume scattering function
- Optical transmission
- Depth
- Temperature

Sediment size distribution and scattering angles

- 32 log-spaced size classes
- 1.25 – 250 or 2.5 – 500 µm size range (equivalent to scattering at 0.08-15° or 0.04-7.5° in water, respectively)

Sediment concentration

  - Range: 1 – 800 mg l^{-1} for standard 50 mm optical path (actual range depends on grain size)
  - Resolution: < 1 mg l^{-1}

Material	SSC [mg/l] @ 98% optical transmission	SSC [mg/l] @ 30% optical transmission	D10[µm]	D50[µm]	D90[µm]	SMD[µm]
ISO Fine (ISO 12103-1,A2)	1	70	1.5	7	41	3
ISO Coarse (ISO 12103-1,A4)	5	150	4	38	99	10
Whitehouse 20-30 µm glass beads	8	445	19	24	34	24
Sieved sand 75-125 µm	13	810	85	122	175	112

- With a 50% PRM in place, all SSC values in the table above should be multiplied by 2.
- With an 80% PRM in place, all SSC values in the table above should be multiplied by 5.
- With a 90% PRM in place, all SSC values in the table above should be multiplied by 10.

Technology

- Solid state diode laser @ 670 nm, 1mW
- 32-ring custom photodiode detector
- Sample rate programmable, up to 25 Hz internally, 1Hz saving to data logger
- Optical path length @ 50 mm standard; bolt-on path reduction modules are available for higher concentration environments.

Mechanical and electrical

- Dimensions: 13.3 cm diameter x 87 cm long (5.25" x 34.25")
- Weight: 11 kg (25 lbs) in air; 3.6 kg (8 lbs) in water
- 300 m depth rating
- Serial interface: RS232C @ 9600 baud; high-speed offload at 115K baud
- Alkaline battery pack: Custom 9V nominal, 42 Ah
- External power input (optional): 12VDC nominal, 10-24VDC
- CF memory card: 128Mb standard (1,600,000 size distributions)
- Battery current drain: 146mA/8mA/128µA (measuring/quiescent/sleeping)

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