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Acoustic Measurements of Flocculating Sediments in the Tamar estuary: A record of the POL data collection during the FLOCSAM fieldwork

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ACOUSTIC MEASUREMENTS OF FLOCCULATING SEDIMENTS IN THE TAMAR ESTUARY:

A RECORD OF THE POL DATA COLLECTION DURING THE FLOCSAM FIELDWORK

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Overview

This document provides details of the POL contribution to the FLOCSAM fieldwork carried out in the Tamar estuary, June 2009. The aim is to provide a record of instrument settings, calibration coefficients and deployment details to aid in the future analysis of the data obtained. A preliminary analysis of the POL data is also presented to aid the focus of further analysis.

Contents

1 Introduction

The fieldwork component of the FLOCSAM project aimed to obtain optical and acoustic backscatter measurements from natural flocculating sediments, over a number of tidal cycles to allow for a range of suspended concentrations, floc sizes and clay content. Thus, a range of instruments were deployed 9th – 11th June 2009, near to Weir Quay in the upper Tamar estuary, where flocculation of suspended sediments has been previously observed (Manning and Bass, 2006). Measurements were obtained in the bottom 1 m or so above the bed using a seabed lander type frame built by the University of Plymouth (UoP), deployed from the back of the UoP small boat *Catfish*. Instruments deployed included Acoustic Backscatter Systems (ABS), Optical Backscatter sensors (OBS), Acoustic Doppler Velocimeters (ADVs), a LISST particle sizer, an In-Situ Settling Velocity camera (INSSEV), pump sample hoses, and an Acoustic Ripple Profiler (ARP). CTD and ADCP profiles covering the whole water column were also obtained frequently throughout the tidal cycles. The pumped water samples were collected using a peristaltic pump, and analysed for suspended load by the University of Plymouth (UoP), and primary particle size and mineralogical composition by the University of East Anglia (UEA). Filtration of the majority of the UoP water samples was carried out onboard.

To obtain simultaneous backscatter data at as many acoustic frequencies as possible, two AQUAscat ABS units were utilised, one from UEA, and the second from POL. Similarly, to obtain independent measurements of particle size from more than one height above the bed, the aim was to use two LISST instruments, with a UEA LISST-100X deployed at a fixed height on the frame, and a POL LISST-ST used as a bench-top particle sizer on deck. The LISST-ST samples were collected using a Van Dorn water sampler, with suspended particles being transferred into the LISST-ST sample volume via a pipette, following the same methodology as used for the LabSFLOC camera operated by UoP (Manning et al, 2007). Additional in-situ FLOC-CAM measurements were collected by HR-Wallingford. A full list of fieldwork participants and their respective affiliations is provided in Appendix I.

2 Calibration of POL and UEA ABS

Calibrations were performed prior to the FLOCSAM fieldwork in the POL Sediment Tower, 4th – 5th June 2009, following the procedure detailed in Betteridge *et al* (2008). During these pre-deployment calibrations, only the 0.5 and 3 MHz transducers from the POL AQUAscat, and the 2 and 5 MHz transducers from the UEA AQUAscat were calibrated, due to time limitations. As the intention was to run both AQUAscat's independently in the field, tests were carried out to check that the two unsynchronised instruments did not cause measurable interference in each others data. None was observed in the laboratory. A complete post-deployment calibration of the POL AQUAscat was carried out on 31st July 2009, to check system stability. The resulting mean system constants, K_t, are presented in Table I, along with additional transducer characteristics required for analysis of the field data.

3 Frame configuration and instrument settings

Figure 1 presents a schematic of the instrument locations on the frame, with photos of the frame before and after modification shown in Figure 2. All instruments were cabled to power supplies onboard *Catfish*, to keep the weight and size of the frame to a minimum. The original frame assembly, deployed on 09/06, included a downward looking ADCP (Figure 2a). This was deemed to be causing frame instabilities and was removed on the evening of 09/06, at which time rear stabilising legs were also added (Figure 2b). Both POL and UEA ABS transducers were deployed in a 6 port mounting disc aligned to the vertical (see Figure 1). The operating frequencies of the POL ABS were 0.5, 3 and 4 MHz (see Table I), whilst those of the UEA ABS were 1, 2 and 5 MHz. Both ABS units were set to record 125, 1 cm bins, using hourly bursts of duration 59 minutes and 55 seconds, and configured to transmit with a Pulse Repetition Frequency (PRF) of 64 Hz, averaging over 16 transmissions, recording at 4 Hz. During both the calibrations and fieldwork, the 0.5 MHz transducer was operated with +12 dB's of receiver gain.

The LISST-ST was operated manually for each sample. Background measurements were collected before each water sample was analysed. Measurements on water samples were collected at 1 Hz for a period of 60 seconds with the pipette held at the surface of the water in the sampling chamber.

Pump samples hoses were attached to the frame at four locations, shown in Figure 1, with photos provided in Figure 3. Three pump sample inlets were located on the ADV support leg, one inlet immediately behind each ADV (see Figure 3a), whilst the fourth inlet was located 7 cm above and 20 cm behind the ABS transducers (see Figure 3b).

4 Deployment summary

Owing to the cable connections between the power supplies onboard *Catfish* and the instruments on the frame, the frame was deployed each morning at high water, recovered at low-water slack, re-deployed on the early flood, and recovered again at high water slack in the early evening. Table II presents the tidal predictions for Weir Quay on each deployment date. A field log was kept to record deployment times and is provided in Appendix II. *It should be noted that all times in the field log, instrument timestamps, and this document, were recorded in GMT*. The frame was subject to falling over in strong flows, particularly on 09/06, before the addition of rear stabilising legs. The INSSEV, ARP and ADV instruments provided real-time information that enabled changes in the frame orientation to be discerned in the field (times noted in Appendix II). Figure 4 presents a Gant chart showing deployment periods when the instrument frame was on the bed and orientated correctly. At all other times the instrument frame was either tipped over at the bed, raised to the surface for re-orientation purposes, or on the back deck of *Catfish*. For illustration purposes, Figure 5 shows how each of these four scenarios manifest in the raw ABS data, for one burst collected at 13:45 on 09/06. The deployment on 10/06 provided the greatest data return, with ~ 7½ hours of data recorded with the frame at the bed (see Figure 4), with 11/06 the next most successful day (~ 6¼ hours of data). The POL ABS failed to record during the final burst on 11/06 at 18:00. This did not cause a significant loss of data however, since it occurred at the end of the operational day, with the frame being recovered at 18:05. This problem was likely due to a loose connection on the power supply cable.

The POL LISST-ST was not used on 09/06, as the focus was on addressing the difficulties with the frame noted above. In addition, a problem with the LISST-ST software resulted in only one LISST-ST sample being collected on 10/06 at 17:12. On 11/06, LISST-ST samples were collected every 30 – 50 minutes up until low water, after which, again due to problems with the frame, only one further sample was collected at 16:40. The LISST-ST data should be considered to provide a qualitative measurement of the suspended size distribution only, due to uncertainties in the sampling methodology used, and at this stage, interpretation of the optical backscatter. Prior to the fieldwork, the settling tube for the LISST-ST was found to leak, and consequently a rubber floor seal was used to enable the LISST-ST to collect measurements onboard *Catfish*. The sample chamber was filled with seawater that had been passed through a standard GF/F 0.7 µm pore size filter. Filtered seawater was used to minimise the density difference between the water held in the chamber and that of the water samples collected using the Van Dorn sampler. The sampling chamber was emptied, rinsed and refilled between each water sample. What appeared to be chaff from the (unwashed) filters could be seen in the filter water visually, and may have caused elevated background signals in the LISST-ST data. Tests showed background measurements collected with the filtered seawater were higher then those obtained using deionised water. Vibrations from the engine, frame winch, and peristaltic pump visually caused changes in the LISST-ST real-time background measurements. These vibrations may also have contaminated water sample measurements; however this could not be verified visually due to the variability caused by sediment particles settling past the LISST-ST sensor.

5 Results of preliminary analysis

5.1 ABS

The root mean square voltage recorded by an ABS, V_{RMS}, received from multiple spherical scatters with an arbitrary size distribution at range r is (Thorne and Hanes, 2002):

$$V_{RMS}(r) = \frac{K_t f_0 M^{1/2}}{r\psi(r)\sqrt{a_0 \rho}} e^{-2r\alpha} \tag{1}$$

where K_t is the system constant determined during calibration (see Table I), f_0 is the ensemble backscatter form function, M is the suspended mass concentration, ψ accounts for the transducer near field correction (Downing et al, 1995), a_0 is the mean particle size, ρ is the density of the grains, and α is the attenuation, consisting of contributions from absorption by water, scattering by the particles, and if ka_0 is sufficiently small, viscous absorption by the particles (Richards et al, 1996), where $k = 2\pi/\lambda$, with λ being the wavelength of sound in water.

A description of the acoustic scattering properties of flocculating particles was not available at the time of writing, therefore only a relative assessment of changes in the mass concentration was possible. Re-arranging Equation 1, an estimate of the relative mass concentration, ζ_M, is obtained, normalised for changes in particle size and size distribution, thus:

$$\zeta_M = \frac{[V_{RMS}(r)]^2[\psi(r)]^2 r^2}{K_t^2} e^{4r\alpha_W} = \frac{f_0^2 M}{a_0 \rho} e^{-4r\alpha_S} \qquad (2)$$

where α_W is absorption by water (Kaye and Laby, 1986), and α_S is the attenuation by the suspended sediments. Figure 6 presents time series of burst mean ζ_M, normalised by the observed maximum of ζ_M for each deployment date, at 10 cm above the bed and at each operating frequency. At this basic level, the ABS data suggests suspended mass concentrations were least at periods approaching slack water (see Table II), and increased measurably during the ebb and flood tides, as would reasonably be expected. However, it should be noted that changes in particle size and/or density around low water could also produce the temporal pattern observed in ζ_M shown in Figure 6. Figure 6 shows a lack of coherency between the observed normalised ζ_M at 0.5 MHz and that observed at the other operating frequencies for some bursts. Eyeballing of the raw ABS data revealed this was caused by the backscattered signal at 0.5 MHz being close to the noise floor for these bursts. Figure 7 presents the intra-burst variation of ζ_M, for one burst obtained on 11/06 at 11:45. Figure 7 illustrates that in addition to variations in ζ_M over the tidal cycles, variations over shorter timescales also occurred, with an increase in ζ_M visible in Figure 7 at around 12:40 GMT, approximately 1 hour before low water (see Table II).

5.2 LISST-ST

As LISST-ST measurements were obtained at 1 Hz, whilst allowing suspended particles to settle under gravity past the LISST-ST sensor, the suspended size distribution was taken as the sum over all scans during a specified observation period for each water sample (usually about 1 minute). Following this approach, d_{50} was taken as the size for which 50 % of the particles were finer by volume. Figure 8 presents a time series of d_{50} obtained in this way on 11/06, and shows a small decrease in mean particle size was observed around the time of the expected peak ebb tide, ~ 11:00 (see Table II). The maximum d_{50} was observed at 16:40 on 11/06, ~ 3 hours after low water, mid-flood.

References

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Acknowledgements

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TABLES

TABLE I – Operating frequencies, radiating aperture, a_t, and mean system calibration constants, K_t, for the AQUAscat ABS. S.D. denotes one standard deviation about the mean.

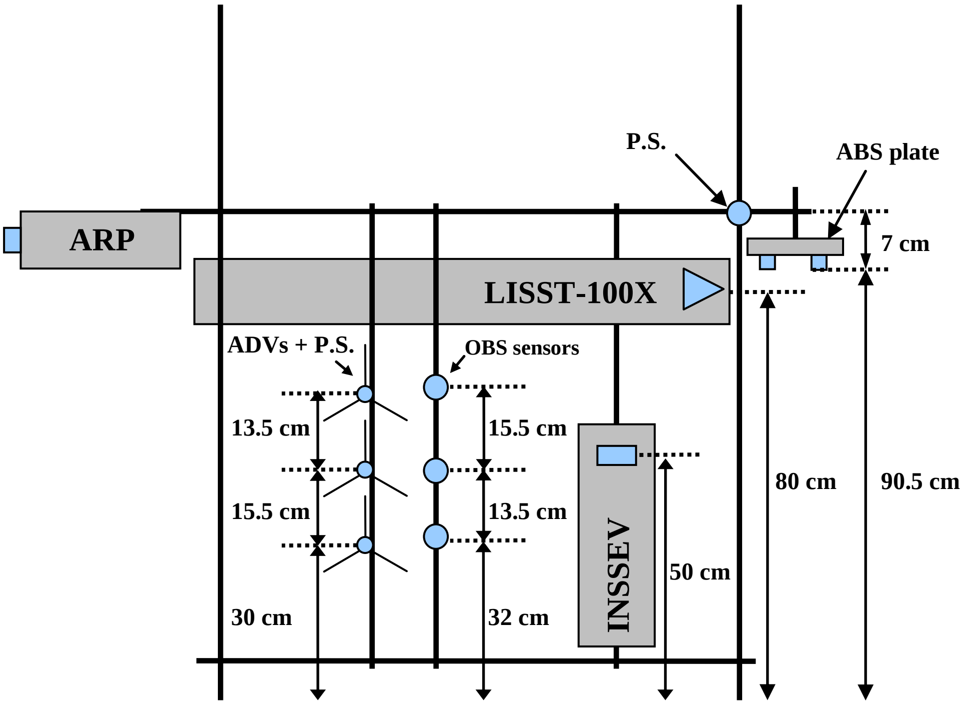
Operating Frequency (MHz)	ABS unit	a_t (mm)	K_t ($Vm^{2/3}$) ± S.D.
0.50	POL	10.0	0.0527 ± 0.0034
2.00	UEA	4.8	0.0094 ± 0.0004
2.93	POL	4.9	0.0220 ± 0.0004
4.02	POL	4.9	0.0165 ± 0.0016
5.00	UEA	5.2	0.0049 ± 0.0001

TABLE II – Tidal predictions for High Water (HW) and Low Water (LW) at Devonport (GMT). Tide times at Weir Quay are + 15 – 20 minutes.

Date	HW	Height (m)	LW	Height (m)	HW	Height (m)
09/06	06:26	4.9	12:44	1.3	18:37	5.2
10/06	07:01	4.8	13:17	1.4	19:11	5.1
11/06	07:37	4.7	13:48	1.5	19:46	5.0

FIGURES

(a)



(b)

Figure 1 – Schematic of the instrument frame showing view from front, facing into flow (a), and a close-up of the ABS transducer mounting plate (b). P.S. denotes Pump Sample inlet.

(a)

(b)

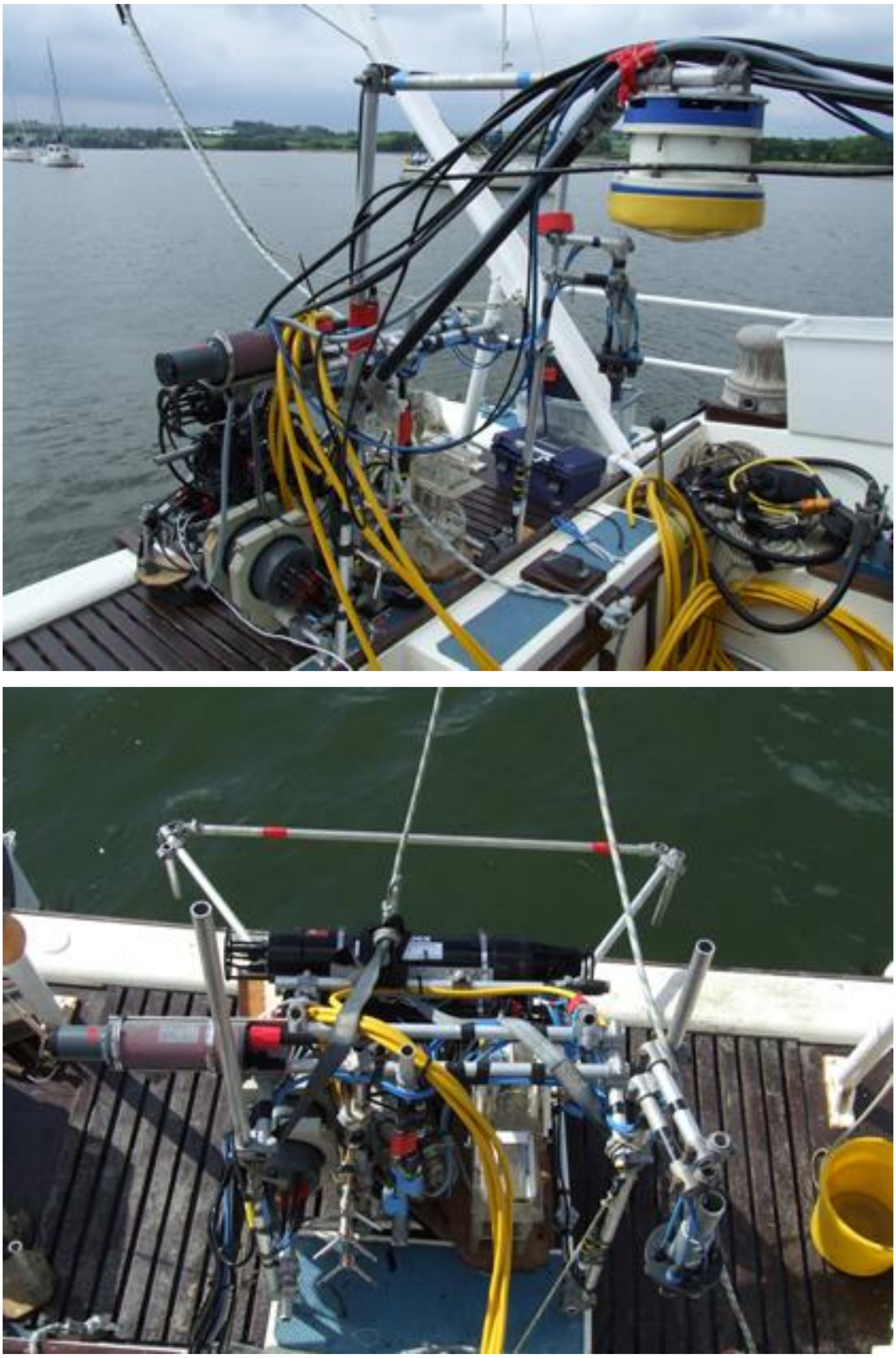


Figure 2 – Photos of the instrument frame (a) before modification, with the ADCP attached, and (b) after removal of the ADCP and addition of rear stabilising legs.

(a)

(b)

Figure 3 – Photos showing locations of the pump sample inlets on the instrument frame, with (a) three inlets, one positioned behind each ADV, and (b) one inlet located 7 cm above and 20 cm behind the ABS transducers.

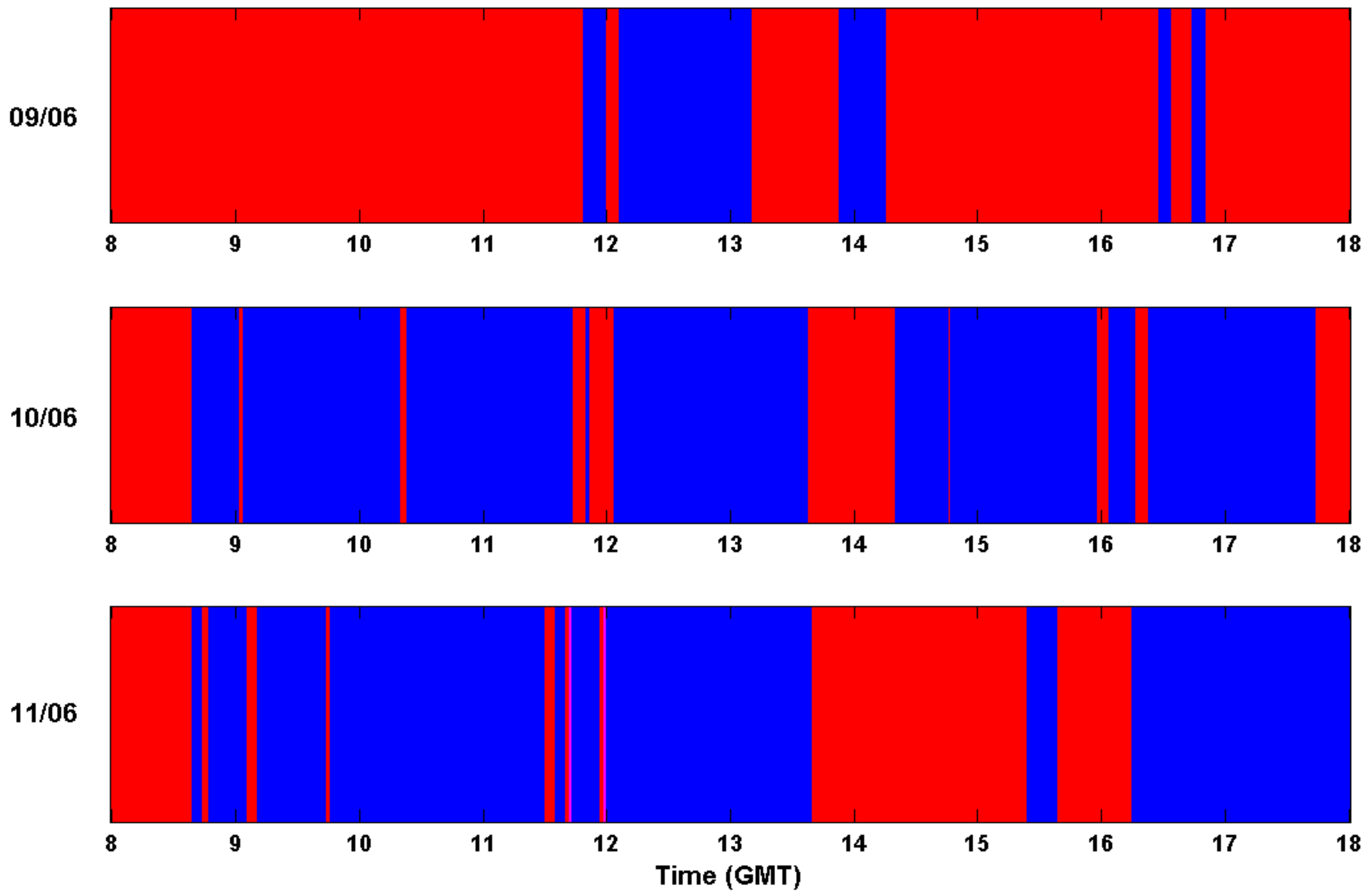


Figure 4 – Gant chart showing the frame deployment timeline for each sampling date. Periods when the frame was on the bed and orientated correctly are shown in blue. At all other times the frame was either tipped over, raised to the surface, or on deck (red).

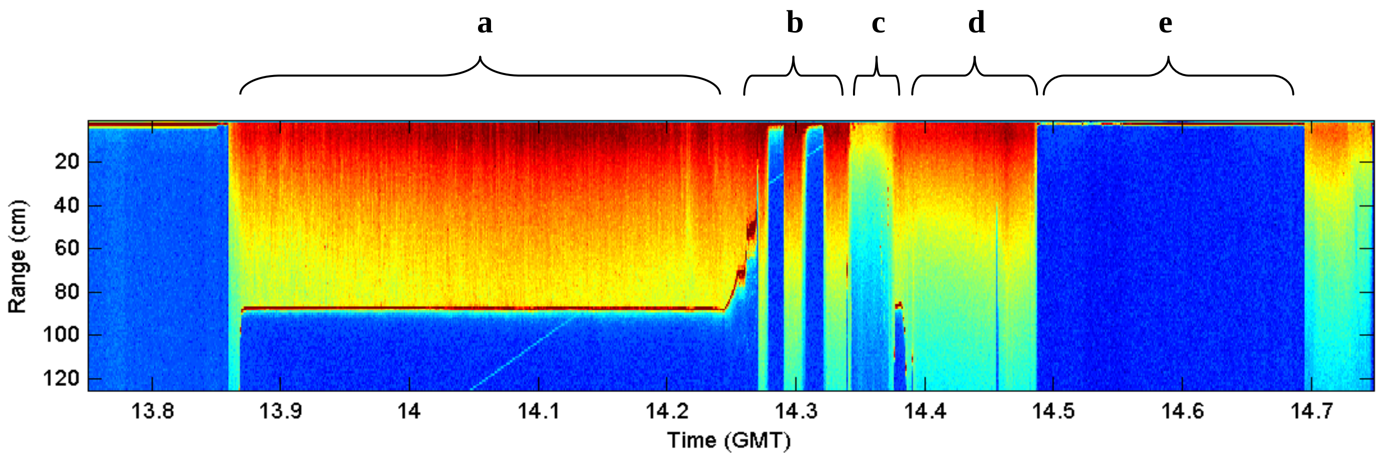


Figure 5 – Raw 4 MHz ABS obtained 13:45 09/06. Plot illustrates instrument frame: (a) on bed, (b) fallen over, (c) raised to the surface for re-orientation and lowered back to the bed, (d) fallen over, and (e) returned to the deck.

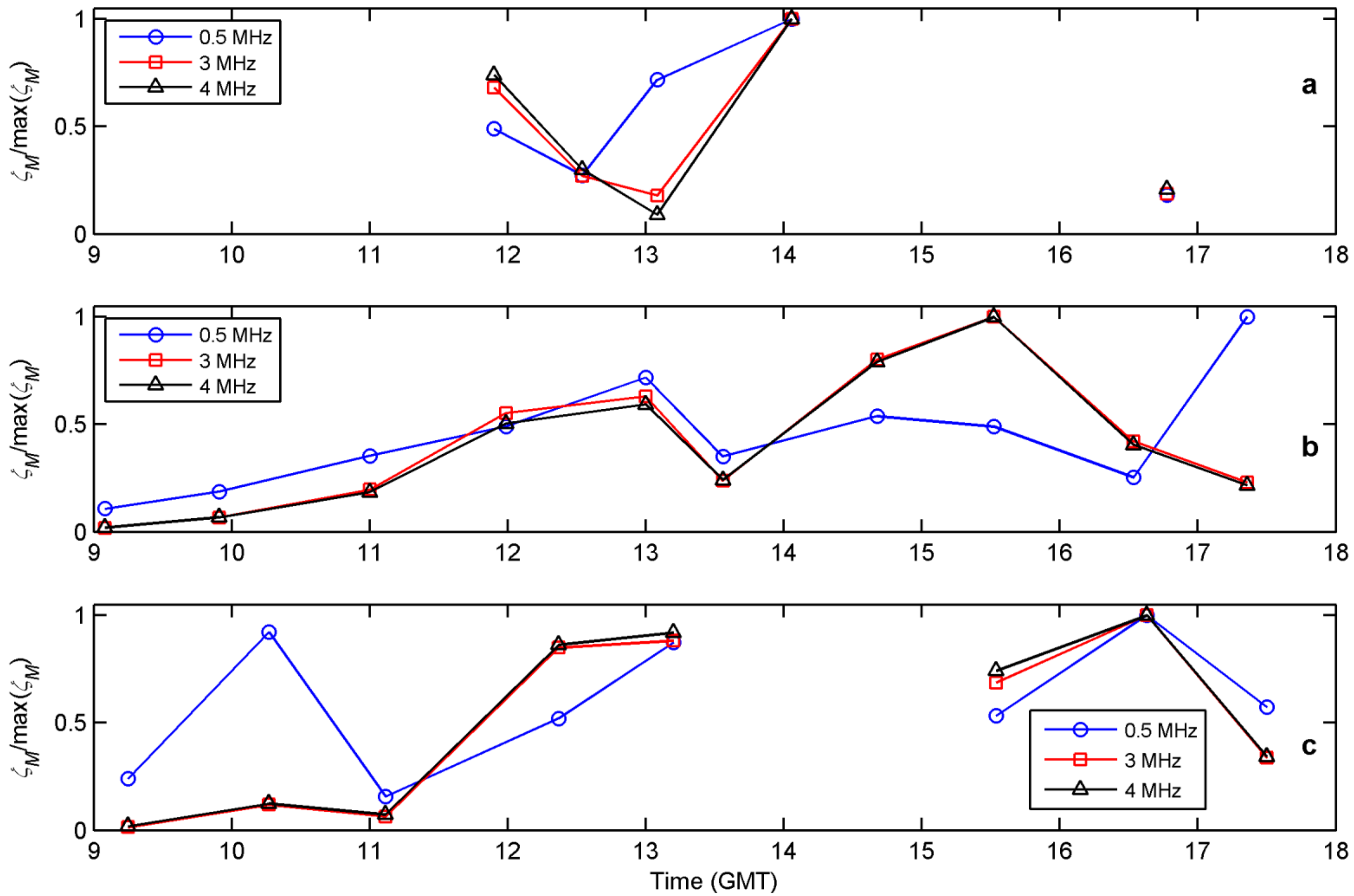


Figure 6 – Time series of burst mean, normalised relative mass concentration, $\zeta_M/\max(\zeta_M)$, at 10 cm above the bed on (a) 09/06, (b) 10/06, and (c) 11/06.

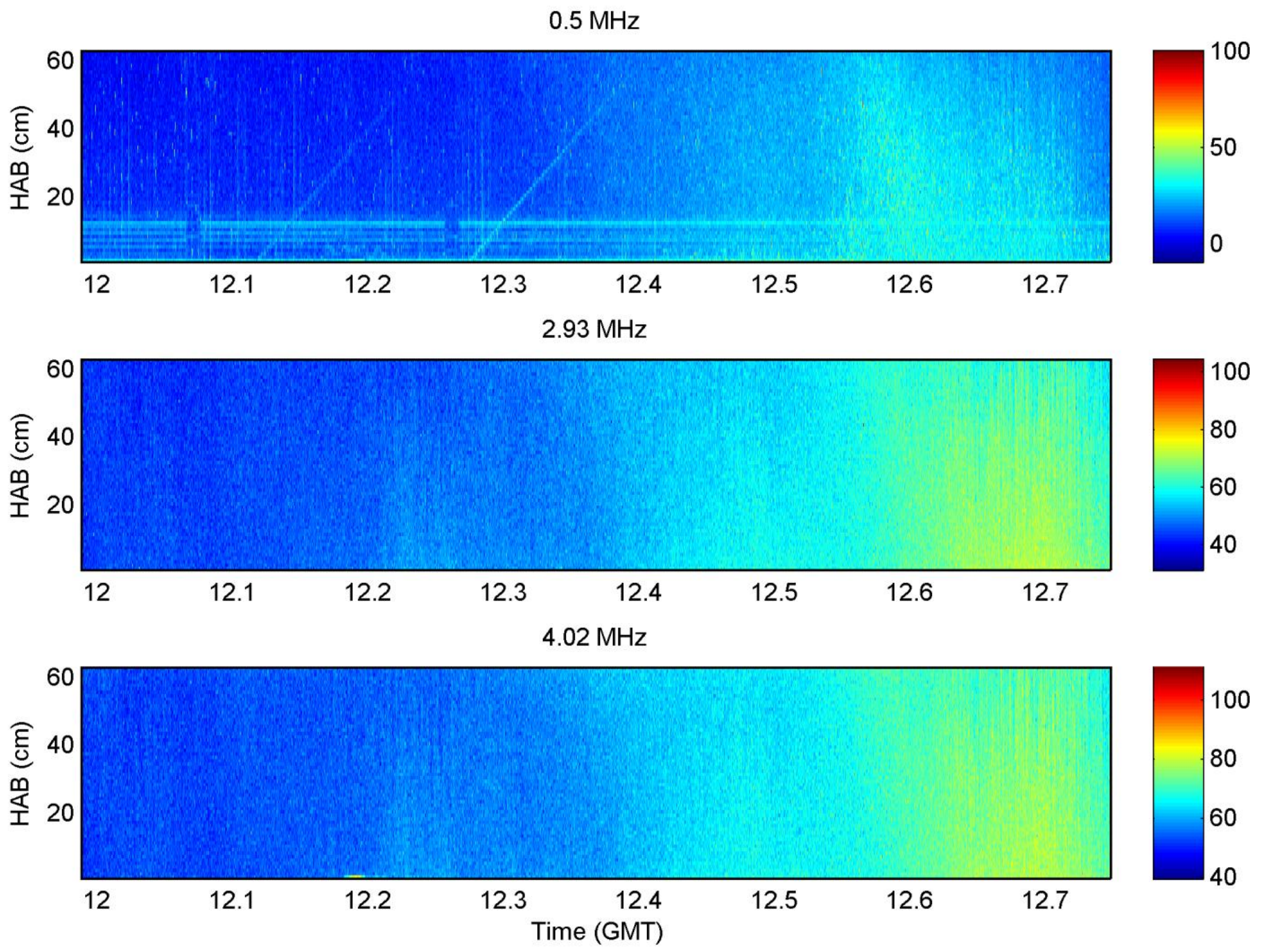


Figure 7 – Intra-burst time series of relative mass concentration obtained on 11/06, in dBs, as a function of Height Above Bed (HAB).

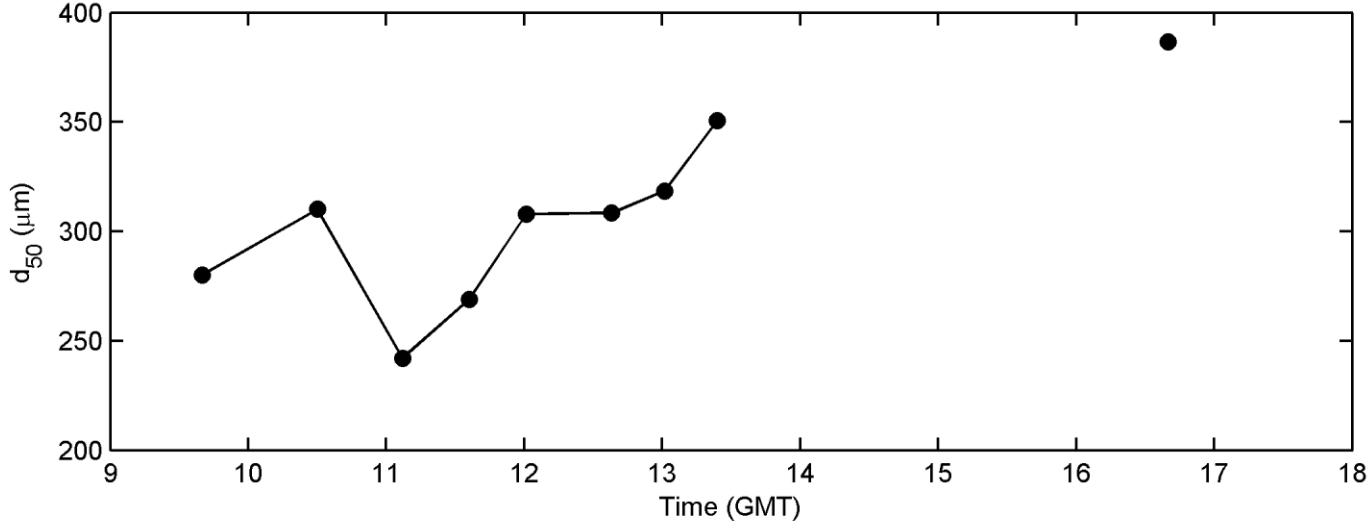


Figure 8 – Time series of d_{50} obtained from the LISST-ST on 11/06.

APPENDIX I – FIELDWORK PARTICIPANTS

NAME	AFFILIATION
Sarah Bass	University of Plymouth (UoP)
Robert Schindler	UoP
Peter Ganderton	UoP
Andrew Manning	UoP/HR Wallingford
Tom Benson	HR Wallingford
Chris Vincent	University of East Anglia (UEA)
Iain McDonald	UEA
Benjamin Moate (BDM)	POL
Richard Cooke (RDC)	POL

APPENDIX II – FIELD LOG

<u>09/06/2009</u>

07:30 – BDM and RDC boarded *Catfish*. RDC attached AQUAscat to UoP frame. BDM synched VIAO laptop time to boat GPS (GMT). Note: all times in this log are in GMT, approximately 1 second behind *Catfish* GPS time. Secured 3 MHz transducer in mounting plate using a short length of thin rubber, as the transducer was slightly loose in housing. Transducers mounted to 90.5 cm above Feet Of Frame (FOF). RDC took photos and measurements of frame and transducer mounting.

09:15 - AQUAscat set to record 125, 1 cm bins, using hourly bursts, set to start at 10 am GMT, 09/06/2009. 0.5, 3 and 4 MHz transducers connected. POL 2 MHz connection capped off. 3 MHz connected to 1 MHz port. PRF = 64 Hz, averaging 16, recording at 4 Hz. +12 dB gain on the 0.5 MHz.

10:16 – Note: ADVs and ADCP all have a considerable amount of free play, and may be subject to vibrations.

10:40 – Pump samples mounted at same heights and side of frame as ADVs. One pump sample mounted on ABS side of frame (white tape), ~ 7 cm above ABS and 20 cm horizontally behind.

11:48 – Frame in water.

11:49 – Frame on bottom.

12:02 – Raised frame due to observed jolt on INSSEV display.

12:04 – Frame back on bottom.

12:20 – Tested pump sampler, water quite turbid at bottom.

12:30 – Collected first proper set of pump samples.

13:15 – Frame recovered to deck for low water.

13:30 – Downloaded POL AQUAscat data to SONY VIAO. Set to start recording again at 13:45 GMT.

13:50 – Frame back in water and down to bed.

14:20 – INSSEV suggest frame has fallen over. Frame lifted.

14:24 – frame back on bed.

14:27 – INSSEV suggests frame has fallen over.

14:29 – Frame lifted. Lift confirms frame had tipped. No obvious damage to the legs.

14:33 – Frame returned to deck.

15:14 – Frame back in water and down to bed.

15:21 – Acoustic Ripple Profiler suggests frame has tipped over.

15:29 – Frame back out of water and returned to deck.

15:48 – Frame back in water and at bed.

15:53 – INSSEV suggests frame has fallen over again.

15:56 – Frame lifted. – ABS arm measured at 163° w.r.t. North (RDC)

16:25 – Frame back down to bed.

16:44 – Not much sediment in suspension according to INSSEV.

17:05 – Frame returned to deck. Compass heading from ADV suggested frame not facing into direction of flow (180 degrees out?). Positions of OBS sensors adjusted.

17:25 – Downloaded POL AQUAscat data onto SONY VIAO.

17:27 – Disconnected POL AQUAscat from battery.

18:00 – Modifications to the instrument frame were made, including the addition of rear stabilising legs and the removal of the ADCP.

10/06/2009

RDC onboard *Catfish*. BDM onshore.
06:15 – AQUAscat powered up, configured and put into deployment mode.

07:30 – AQUAscat set to start recording at this time.

08:39 – Frame deployed off *Catfish*.

09:01 – Frame brought to surface for INSSEV check.

09:02 – Frame lowered to bed again.

10:05 – RDC returned to shore to pickup POL LISST-ST.

10:30 – RDC back onboard *Catfish* with LISST-ST and additional 500 ml sample bottles.

11:48 – Frame raised to surface and lowered back down to bed. Boat had shifted position and increased cable tension.

12:02 – Frame brought to surface and lowered back down to bed.

13:37 – Frame returned to deck for low water. POL AQUAscat data downloaded to SONY VIAO.

14:17 – Frame back in water and down to bed.

16:19 – Frame returned to surface for reorientation and lowered back down to bed.

16:21 – Frame returned to surface for reorientation and lowered back down to bed.

16:30 – Frame cables payed out further as frame was tilting and being dragged.

17:12 – 1st successful POL LISST sample recorded.

17:36 – ADVs switched off.

17:43 – Frame returned to deck. POL AQUAscat data downloaded to SONY VIAO.

11/06/2009

07:12 – Both BDM and RDC onboard *Catfish*. Synched laptop time with *Catfish* GPS.

07:20 – AQUAscat clock synched to laptop and instrument set to record at 07:45 am on same settings as previous.

08:08-08:11 – Tested LISST-ST. Collected background scatter file on filtered seawater intended for INSSEV. Then collected scatter file on the same water, using the background file as a reference. Scatter file still showed significant signal at larger sizes. Engine was running so possible that LISST-ST was subject to vibrations which would affect the data. Will repeat when engines off.

08:37 – Frame in water and down to bed.

09:06 – Frame raised due to tilt.

09:10 – Frame back down to bed. OBS and INSSEV suggest not much sediment in suspension.

09:43 – Frame raised to surface. Frame not aligned to flow correctly.

09:46 – Frame back on bed.

Filter sample note: all SPM samples before 5pm 10/06/2009 were not rinsed to remove salts, so they may include a salt bias. Samples including and after 5pm were rinsed with 100 ml deionised water. UoP may rinse previous filters on return to lab.

11:20 – umbilical cable slackened due to boat swing at anchor.

11:39 – Frame lifted.

11:42 – Frame returned to bed.

11:57 – Frame raised to surface to reorient frame.

11:59 – Frame returned to bed.

13:40 – Frame returned to deck for low water.

13:56 – POL AQUAscat data downloaded and reset to start recording again at 14:00

15:21 – Frame in water and back down to bed.

15:42 – Frame lifted to surface to reorient frame. Several attempts made.

15:51 – Frame returned to deck.

16:13 – Frame back in water and down to bed by 16:15.

17:43 – Turned LISST-ST off.

18:06 – Frame on deck. Removed AQUAscat, AQUAscat battery pack, transducers, and the LISST-ST from *Catfish*.

12/06/2009

10:00 – BDM and RDC boarded *Catfish* at Plymouth dock and removed transducer mounting plate from frame and collected AQUAscat 20 m battery cable.