PORT OTAGO WAVE AND SEDIMENT DYNAMICS STUDY

Measurements of waves and currents

Prepared for Port Otago Ltd

PO Box 441, New Plymouth, New Zealand
T: 64-6-7585035 E: enquiries@metocean.co.nz

MetOcean Solutions Ltd: P0140-02

November 2014

Report status

Version	Date	Status	Approved by
RevA	29/07/2013	Draft for internal review	Guedes
RevB	19/11/2013	Updated draft including new field data	Guedes
RevC	29/11/2013	Updated draft for internal review	Weppe
RevD	29/11/2013	Draft for client review	McComb
RevE	18/02/2014	Updated draft with new field data	Guedes
RevF	18/03/2014	Updated draft with meteorological data	Guedes
RevG	02/11/2014	Updated draft with new field data	Weppe
Rev0	29/11/2014	Approved for release	McComb

It is the responsibility of the reader to verify the currency of the version number of this report.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

A field campaign to measure waves and currents offshore of Otago harbour was carried out over a 3-month period, between 22 July and 29 October 2013. Field deployments were undertaken by MetOcean Solutions Ltd, with assistance from staff of the Department of Marine Science at the University of Otago. The deployments were designed to further understand wave transformations and nearshore circulation off the coast and to support on-going numerical modelling work in the area.

Nine instruments were deployed between 7 and 29 m water depth, including an ADCP, a wave buoy, MAVS and FSI current meters, an RBR pressure sensor and four S4 wave and current meters (Figure 1.1; Table 2.1). The University research vessels *Beryl Brewin* and *Polaris II*, as well as the Port Otago vessel Kapu were used for deployment and recovery operations (Figure 1.2).

The field work was undertaken in three phases. All the instruments were initially deployed on 22–23 July. On 30 August, a second campaign was carried out to service some of the instruments, and redeploy three S4s at different locations. All instruments were recovered and brought ashore on 29 October, with exception of the offshore ADCP, which was redeployed on 30 October and finally recovered on 24 January 2014. Divers supported the deployment and recovery of four nearshore sensors, which were secured using sand anchors.

The scope of this report is to describe the field deployments, and present a synthesis of the field measurements undertaken by all instruments during the field campaign. Section 2 provides an overview of the field campaign and shows the methods used to configure and deploy each instrument. Time series plots of waves and current statistics are presented in Section 3. Additional meteorological and turbidity data measured by the Port of Otago are presented in Section 4, and currents measured inside the harbour are presented in Section 5.

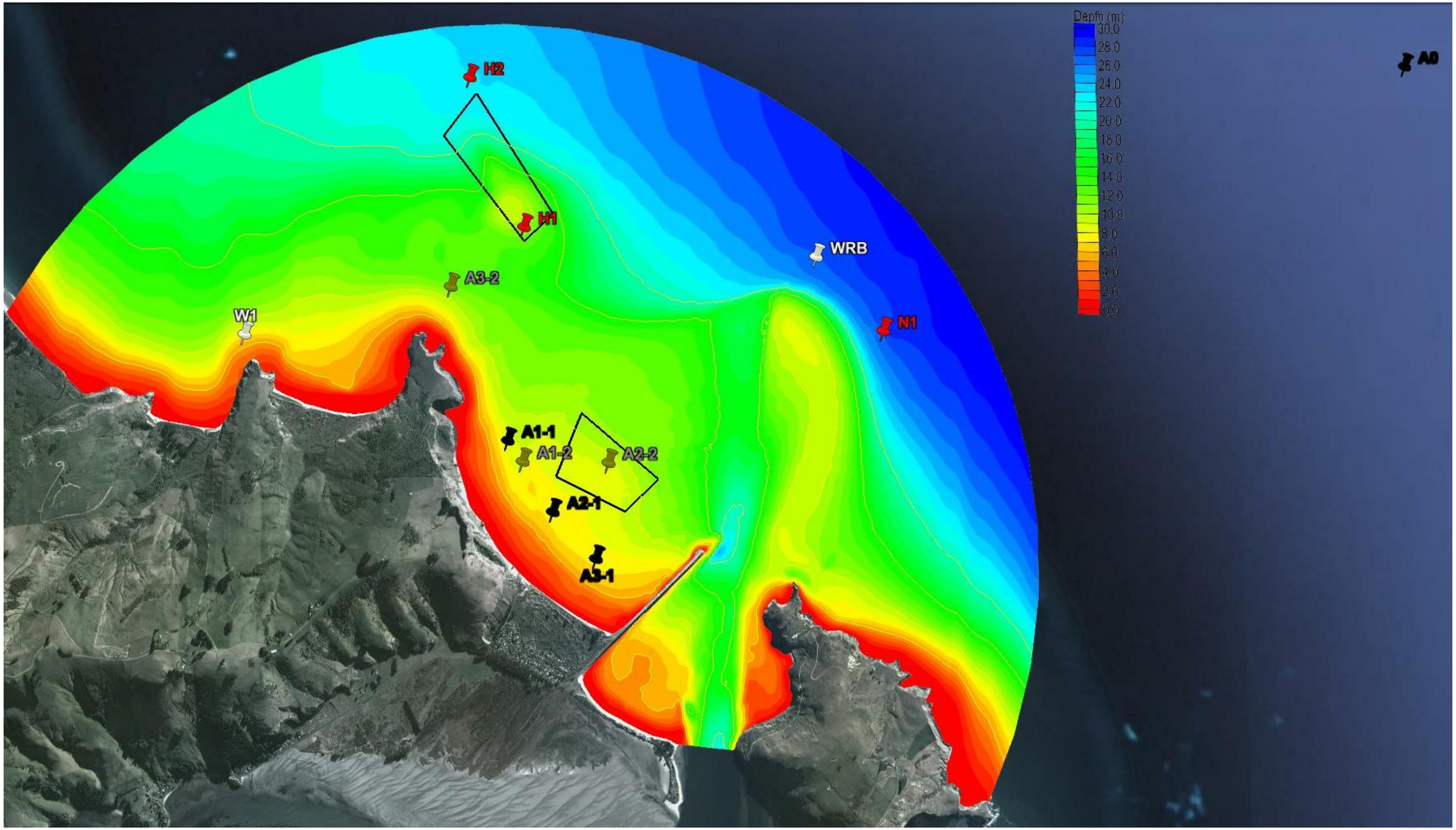

Figure 1.1. Nearshore bathymetry around Otago Harbour showing the positions of the wave and current meters. Marker colours indicate measurements of (red) currents, (white) waves, and (black/grey) both currents and waves (see Table 2.1). Google Earth imagery provided NASA.

Figure 1.2. University of Otago Research Vessels used for deployment and recovery operations: (a) *Beryl Brewin*, and (b) *Polaris II*.

2. METHODS

Field measurements of waves and currents were undertaken using a range of instruments. The wave and current meters were deployed between 7 and 29 m water depth, extending along the coast from Aramoana beach to Purehurehu Point and including the regions around and offshore of the disposal mounds (Figure 1.1). The coordinates of each deployment site are provided in Table 2.1.

Directional waves and currents were measured in 29 m water depth at site A0, using an ADCP. An wave rider buoy and a MAVS current meter measured directional waves and currents respectively offshore of the existing dredge disposal sites, near the tip of the submerged ebb delta bar, in about 25 m water depth.

Currents were also measured close to the southeast (site H1, 12 m depth) and northwest corners (site H2, 22 m depth) of the dredge disposal ground off Heyward Point. An S4 and a FSI current meter were used at site H1 and H2, respectively.

Closer to the shore, S4s were used to simultaneously measure directional waves and currents at sites A1-1, A2-1, A3-1 and A1-2, A2-2, A3-2. The water depths of these nearshore sites ranged between 7 and 10 m. Non-directional waves were also measured offshore of Purehurehu Point at site W1, in 7.5 m depth, using an RBR data logger.

The periods over which each instrument collected data are shown by Figure 2.1. The offshore ADCP, wave rider buoy and the RBR recorded data during almost the entire deployment period. The 3 nearshore S4s also recorded over the majority of the periods they remained at each site. On the other hand, the two current meters from sites H1, H2 only recorded currents data over a shorter period that ranged between 20–30 days. There was a short overlapping period close to 09 August when data were simultaneously recorded by all nine instruments (Figure 2.1).

Four different mooring schemes were used to deploy the different instruments. Schematics of the different moorings are shown in Figure 2.2. More detailed descriptions of each mooring and the configurations used for setting up the instruments are presented in the following subsections.

Table 2.1. Dates and positions of the instruments deployed during the field campaigns. Colours on second column are associated with the marker colours in Figure 1.1.

Site		Instrument	Measurement		Dates		Deployment position (WGS 84)		Depth (m)
			Waves	Currents	Deployment	Recovery	Latitude	Longitude	
A0		ADCP	X	X	22/07/2013	29/10/2013	45° 44.196'S	170° 47.327'E	29
A0		ADCP	X	X	30/10/2013	25/01/2014	45° 44.196'S	170° 47.327'E	29
WRB		Wave buoy	X		22/07/2013	29/10/2013	45° 45.060'S	170° 43.800'E	25
N1		MAVS		X	22/07/2013	29/10/2013	45° 45.367'S	170° 44.198'E	27
H1		S4		X	22/07/2013	29/10/2013	45° 44.955'S	170° 42.069'E	12
H2		FSI		X	23/07/2013	29/10/2013	45° 44.313'S	170° 41.712'E	22
W1		RBR	X		23/07/2013	30/08/2013	45° 45.425'S	170° 40.453'E	7.5
W1		RBR	X		30/08/2013	29/10/2013	45° 45.425'S	170° 40.453'E	7.5
A1-1		S4	X	X	23/07/2013	30/08/2013	45° 45.846'S	170° 42.018'E	8.0
A2-1		S4	X	X	23/07/2013	30/08/2013	45° 46.132'S	170° 42.294'E	7.7
A3-1		S4	X	X	23/07/2013	30/08/2013	45° 46.317'S	170° 42.550'E	7.0
A1-2		S4	X	X	31/08/2013	29/10/2013	45° 45.930'S	170° 42.110'E	7.8
A2-2		S4	X	X	31/08/2013	29/10/2013	45° 45.929'S	170° 42.607'E	8.7
A3-2		S4	X	X	31/08/2013	29/10/2013	45° 45.212'S	170° 41.651'E	10.2

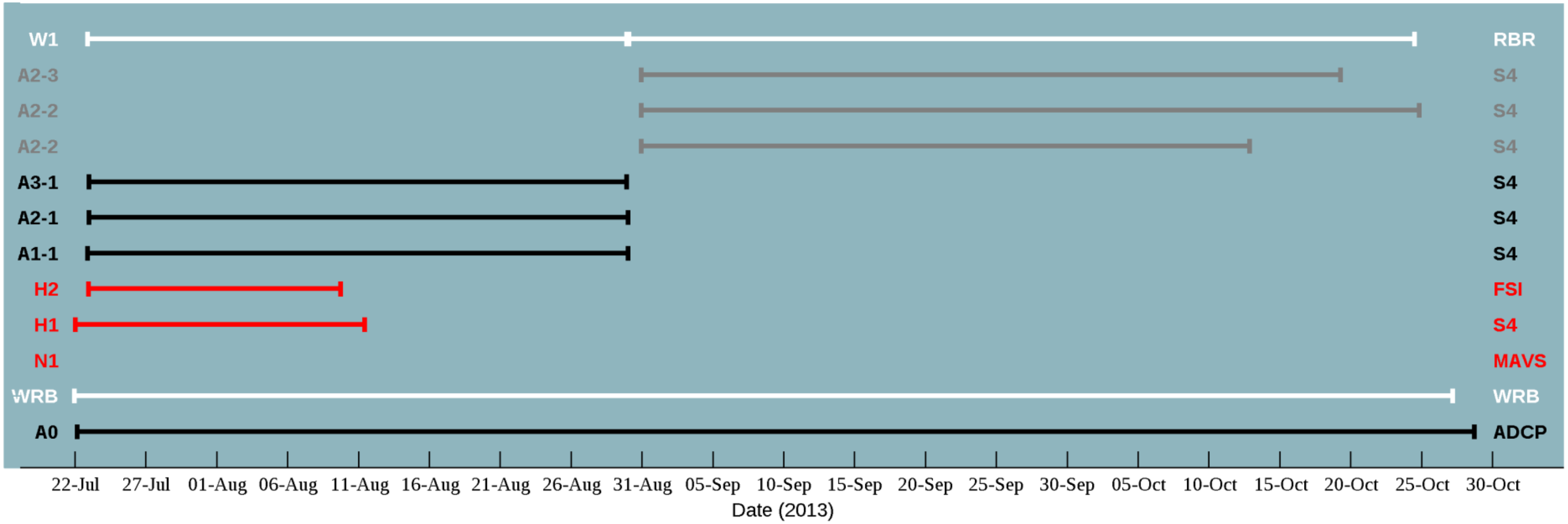

Figure 2.1. Periods over which (good) data were recorded by the instruments. Colours indicate measurements of (red) currents, (white) waves, and (black/grey) both currents and waves (see Figure 1.1 and Table 2.1). The three S4s from sites A1-1, A2-1 and A3-1 were recovered on 30 August and redeployed on 31 August at sites A1-2, A2-2 and A3-2, respectively; all the other instruments collected data at the same location during the entire period. The ADCP was redeployed on 30 October, and collected good data until 07 December 2013.

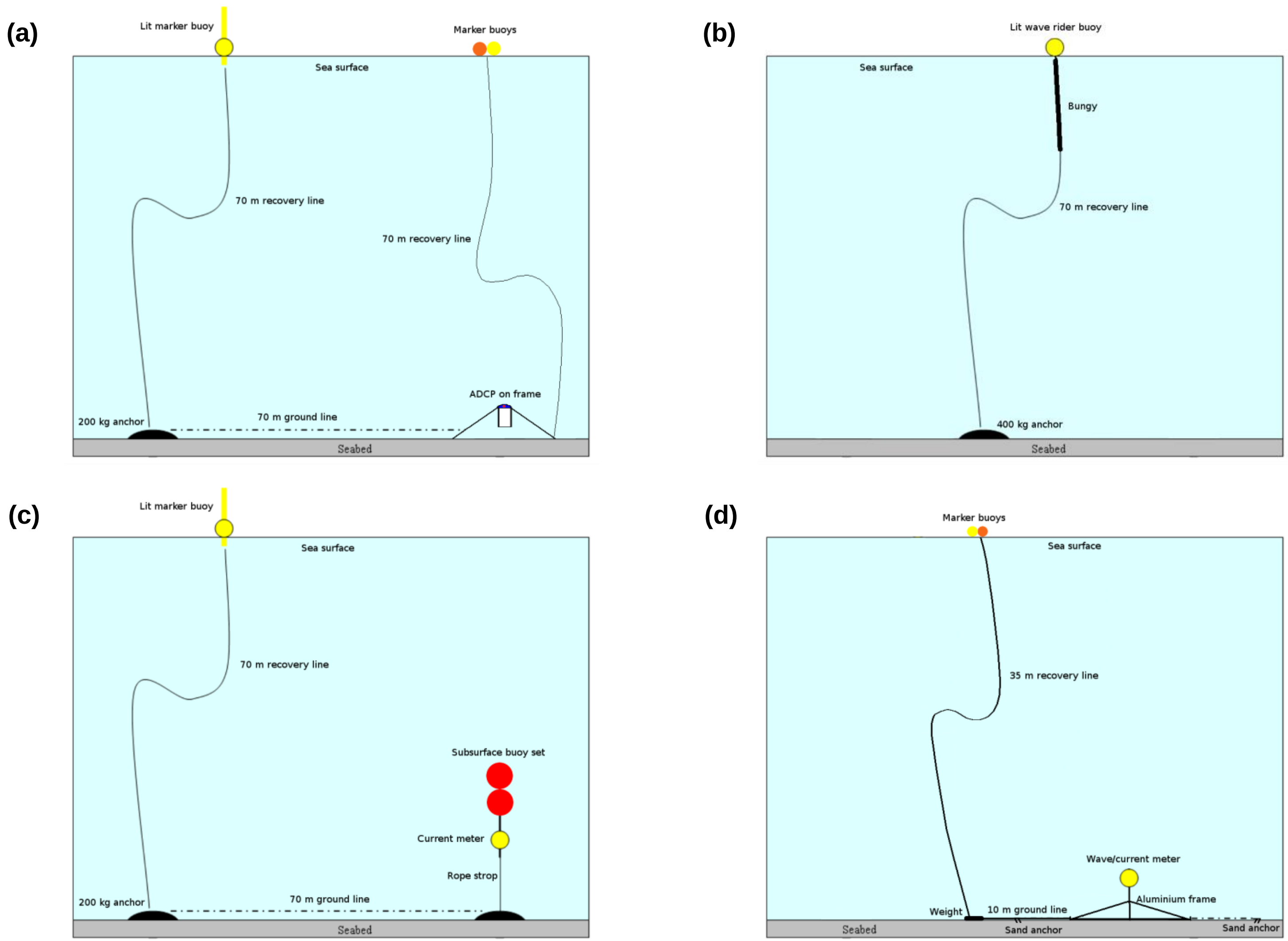

Figure 2.2. Schematic of the moorings: (a) ADCP, (b) wave rider buoy, (c) current meters, and (d) nearshore wave and current meters.

2.1. Site A0

A 600 kHz RDI ADCP was deployed at site A0, the deepest location where instruments were deployed. The ADCP and a case carrying two extra battery packages were placed within a triangular frame (Figure 2.3a-b), which was connected to a 200 kg chain using a 70 m ground line (see Figure 2.2a). A lit marker buoy was attached to the chain by a 70 m mooring line (Figure 2.3c).

The ADCP was deployed on 22 July, and recovered on 29 October for downloading the data and replacing the batteries (Table 2.2). The instrument was redeployed on 30 October with a new battery set installed, at the same location of the first deployment, and finally recovered on 24 January 2014 (Table 2.3).

The data collected by the ADCP during the second deployment presented became corrupted after 07 December 2013. Figure 2.4 shows time series of waves and currents during the second ADCP deployment. Wave statistics calculated from the ADCP data were consistent with wave statistics from MetOcean Solution's forecast system until 07 December (about 16:40pm NZDT). After this, there was an abrupt increase in pressure-derived water depth of about 1 m, and the velocity time series showed unrealistic patterns with negative mean current speeds over a number of depth cells. It is unclear what may have caused these patterns but they might have resulted from the instrument having been turned upside-down on the sea floor.

Table 2.2. Configurations defined for the ADCP deployed at site A0 during the first deployment.

Site		A0
Instrument		RDI Workhorse ADCP 600 kHz
Deployment date		22/07/2013
Recovery date		29/10/2013
Period of recorded data	**Start**	22/07/2013, 04:00 utc
	End	28/10/2013, 18:00 utc
Waves	**Sampling frequency**	2 Hz
	Sampling length	20 min
	Interval between samples	120 min
	Percentage of recorded data	97%
Currents	**Ping rate**	1 Hz
	Number of pings	300
	Interval between samples	30 min
	Bin size	1 m
	Number of bins	38

Table 2.3. Configurations defined for the ADCP deployed at site A0 during the second deployment.

Site		A0
Instrument		RDI Workhorse ADCP 600 kHz
Deployment date		30/10/2013
Recovery date		24/01/2014
Period of recorded data	**Start**	30/10/2013, 01:00 utc
	End	07/12/2013, 02:00 utc
Waves	**Sampling frequency**	2 Hz
	Sampling length	20 min
	Interval between samples	120 min
	Percentage of recorded data	44%
Currents	**Ping rate**	1 Hz
	Number of pings	300
	Interval between samples	30 min
	Bin size	1 m
	Number of bins	38

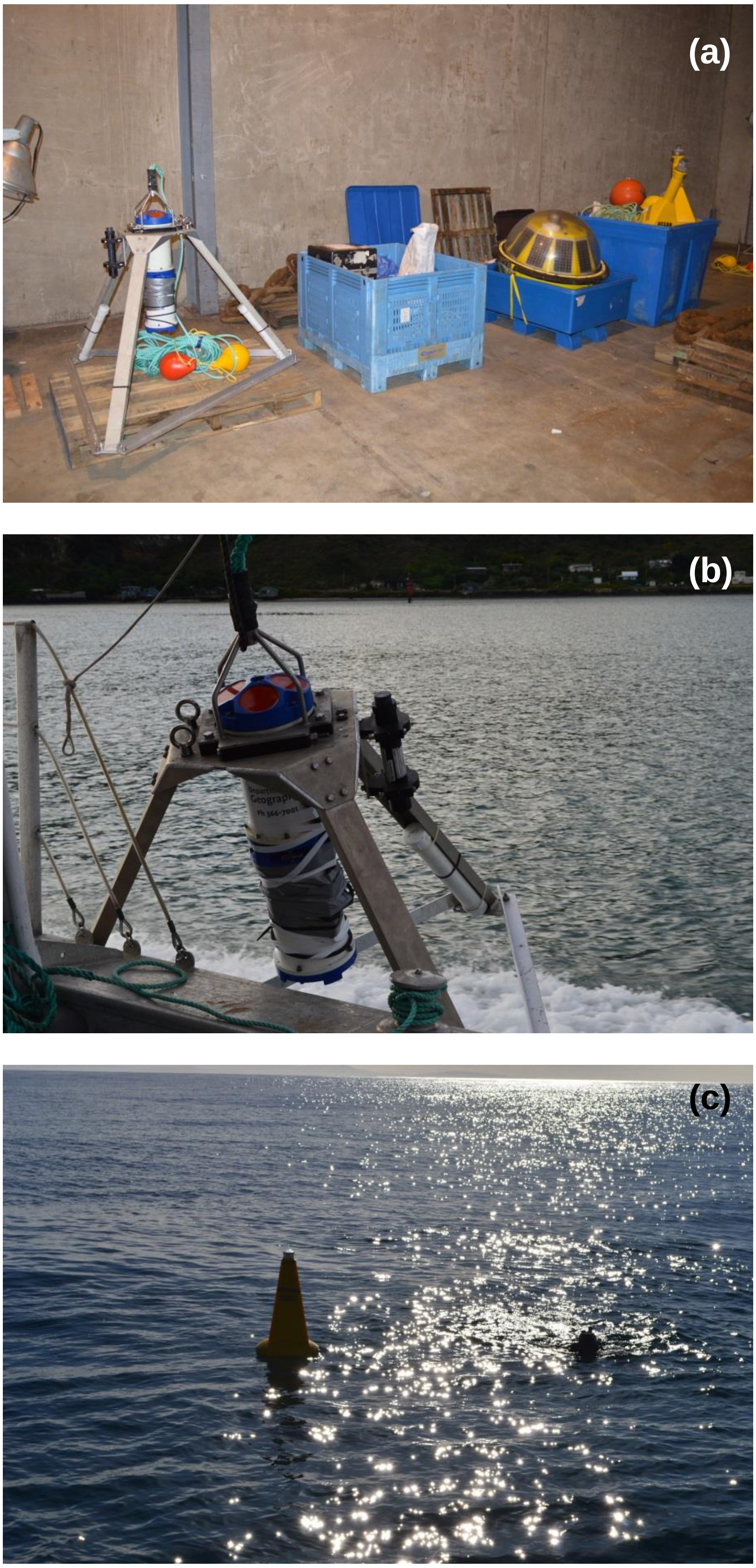

Figure 2.3. Deployment of the RDI ADCP: (a) Overview of the ADCP fixed within the triangular frame, with the battery case attached; (b) ADCP and frame on the side of the boat, ready to be deployed; (c) lit marker buoy deployed about 70 m from the ADCP at site A0.

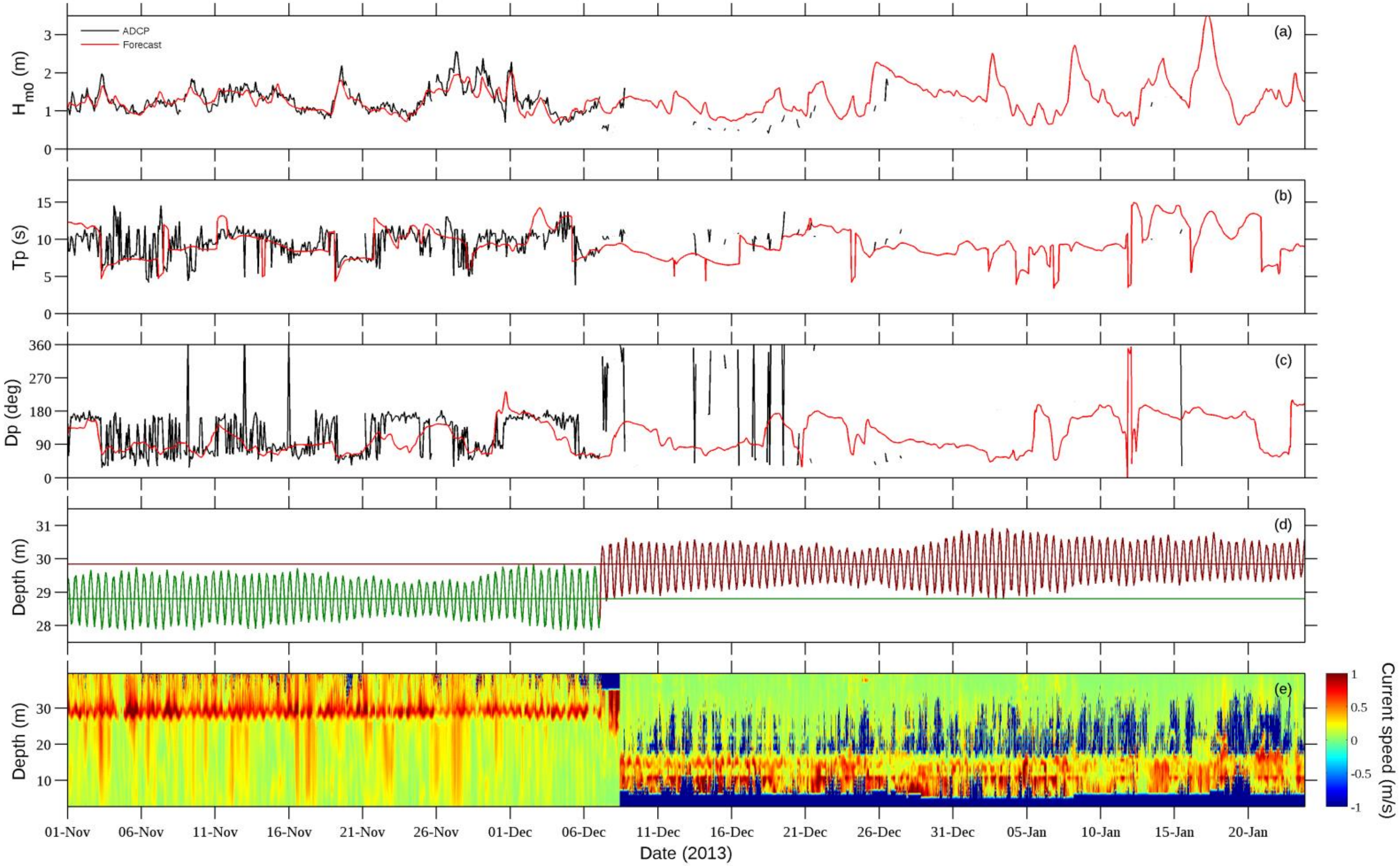

Figure 2.4. Time series of waves and currents during the third phase of the field work at site A0: (a) spectral significant wave height H_{m0}, (b) peak wave period Tp, (c) peak wave direction Dp, (d) mean water depth, and (e) 5-min averaged current speed. Black and red lines in panels (a–c) are associated with data derived from the ADCP's velocity sensors and MetOcean Solution's forecast system respectively. Mean water depth in panel (d) was obtained from the ADCP's pressure sensor (the two colours highlight the period before and after the shift in water depth).

2.2. WRB

A TRIAXYS directional wave buoy was deployed in 25 m water depth. The buoy was attached to a 400 kg chain (see Figure 2.2b) which was set about 230 m east from the Fairway Beacon. The wave buoy was deployed on 22 July, and recovered on 29 October 2013 (Table 2.4). Figure 2.5 shows the deployment of the buoy at site WRB.

Table 2.4. Configurations defined for the Wave Rider buoy deployed at site WRB.

<table>
<tr><td colspan="3">Site</td><td>WBR</td></tr>
<tr><td colspan="3">Instrument</td><td>TRIAXYS Wave Buoy</td></tr>
<tr><td colspan="3">Deployment date</td><td>22/07/2013</td></tr>
<tr><td colspan="3">Recovery date</td><td>29/10/2013</td></tr>
<tr><td colspan="2" rowspan="2">Period of recorded data</td><td>Start</td><td>31/07/2013, 01:00 utc</td></tr>
<tr><td>End</td><td>27/10/2013, 07:00 utc</td></tr>
<tr><td rowspan="4">Waves</td><td colspan="2">Sampling frequency</td><td>2 Hz</td></tr>
<tr><td colspan="2">Sampling length</td><td>18 min</td></tr>
<tr><td colspan="2">Interval between samples</td><td>60 min</td></tr>
<tr><td colspan="2"></td><td></td></tr>
</table>

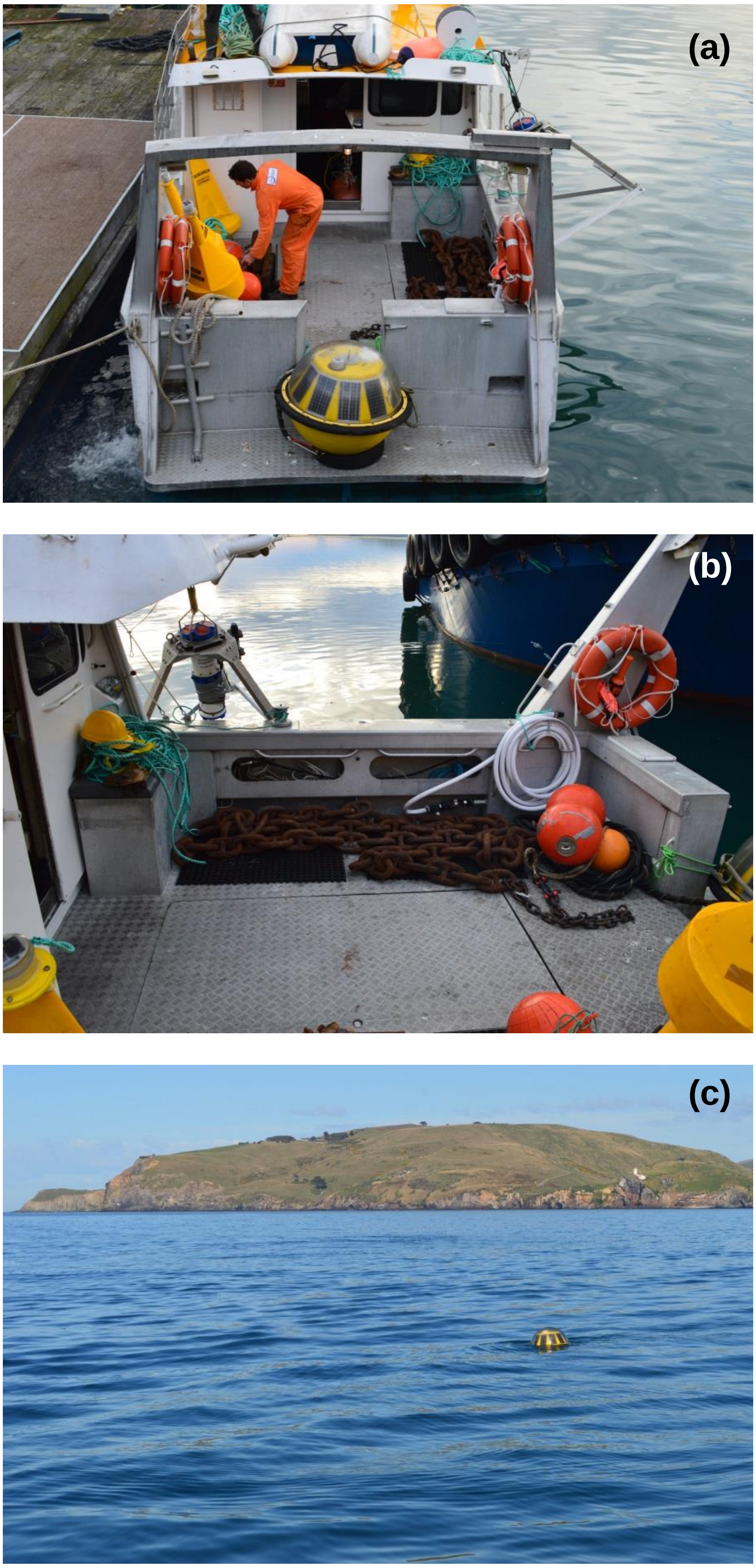

Figure 2.5. Deployment of the wave rider buoy: (a) wave buoy on the boat prior leaving the Port; (b) chain used to secure the wave buoy; (c) wave buoy deployed at site WRB, about 230 m from the Fairway Beacon (see Table 2.1).

2.3. Site N1

A Nobska MAVS current meter was deployed at site N1, to the east of the submerged ebb delta bar in about 27 m water depth (see Figure 1.1). The current meter was placed inside a box-shaped frame with two subsurface buoys attached at the top of the structure (Figure 2.6). The frame was set on a 200 kg chain, connected by a 70 m ground line to another chain where a lit marker buoy was deployed (Figure 2.7) using a 70 m mooring line (see Figure 2.2c). The settings defined for the MAVS are shown in Table 2.5.

The MAVS was deployed on 22 July, and recovered on 29 October 2013. However, the data appears to be corrupted (Table 2.5).

Table 2.5. Configurations defined for the MAVS current meter deployed at site N1.

Site		N1
Instrument		MAVS current meter
Deployment date		22/07/2013
Recovery date		29/10/2013
Period of recorded data	**Start**	08/08/2013, 23:00 utc
	End	11/09/2013, 18:30 utc
Currents	**Sampling frequency**	1 Hz
	Sampling length	5 min
	Interval between samples	30 min

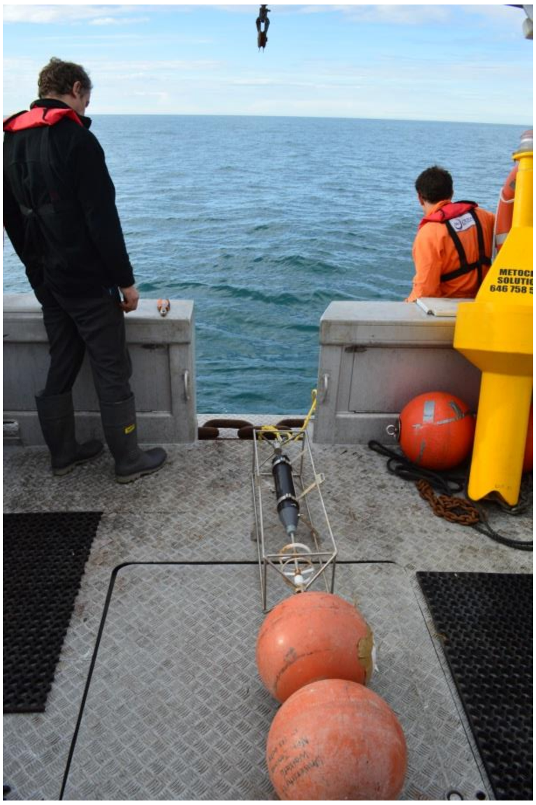

Figure 2.6. Deployment of the MAVS current meter showing the instrument inside the frame, with the two subsurface buoys attached.

Figure 2.7. Lit marker buoy deployed at site N1.

2.4. Site H1

An InterOcean S4 current meter was deployed at site H1, close to the SE corner of the dredge disposal ground off Heyward Point, in about 12 m water depth (see Figure 1.1). The deployment configuration was similar to site N1, with the S4 connected to two subsurface buoys and set on a 200 kg chain (Figure 2.2c). A 35 m long ground line connected the instrument chain to another 200 kg chain, where a 20 m mooring line attached to a lit marker buoy was set (Figure 2.8).

The S4 was deployed on 22 July, and recovered on 29 October 2013. Table 2.6 shows the configurations defined for the S4 at site H1. The instrument collected data over a 20-day period, between 22 July and 11 August.

Table 2.6. Configurations defined for the S4 current meter deployed at site H1.

<table>
<tr><td colspan="3">Site</td><td>H1</td></tr>
<tr><td colspan="3">Instrument</td><td>S4 current meter</td></tr>
<tr><td colspan="3">Deployment date</td><td>22/07/2013</td></tr>
<tr><td colspan="3">Recovery date</td><td>29/10/2013</td></tr>
<tr><td colspan="2" rowspan="2">Period of recorded data</td><td>Start</td><td>22/07/2013, 01:00 utc</td></tr>
<tr><td>End</td><td>11/08/2013, 11:00 utc</td></tr>
<tr><td rowspan="4">Currents</td><td colspan="2">Sampling frequency</td><td>2 Hz</td></tr>
<tr><td colspan="2">Sampling length</td><td>5 min</td></tr>
<tr><td colspan="2">Interval between samples</td><td>60 min</td></tr>
<tr><td colspan="2"></td><td></td></tr>
</table>

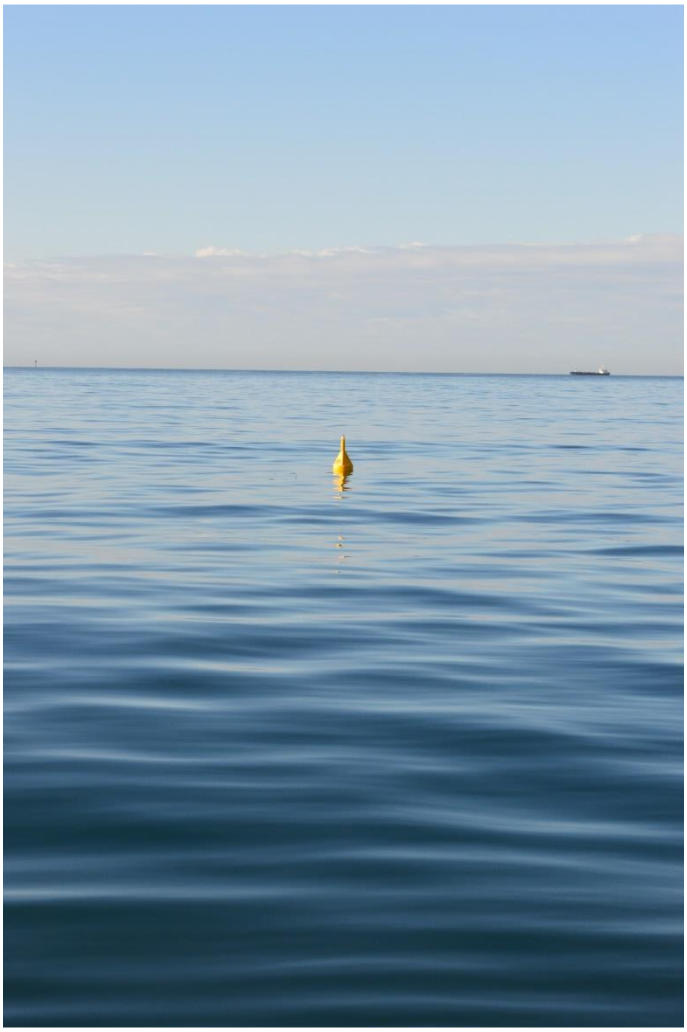

Figure 2.8. Lit marker buoy deployed at site H1.

2.5. Site H2

A Falmouth Scientific FSI current meter was deployed at site H2, close to the NW corner of the dredge disposal ground off Heyward Point, in about 22 m water depth. The deployment configuration was similar to those for sites N1 and H1, schematised in Figure 2.2c. The FSI was placed within a box-shaped frame, with two subsurface buoys at the top of the frame (Figure 2.9), and set on a 200 kg chain. The chain was connected by a 70 m ground line to a second 200 kg chain, where a lit marker buoy was set using a 35 m mooring line.

The deployment of the FSI at site H2 was undertaken over two days. The chain with the lit marker buoy was deployed on 22 July. However, there was a problem with the battery of the FSI, and new battery packages needed to be ordered before deploying the instrument on the following day. The FSI was put in the water on 23 July, and recovered on 29 October 2013.

Table 2.7 presents the settings defined for the FSI. The instrument recorded data between 22 July and 09 August, similar to the S4 at site H1 H1.

Table 2.7. Configurations defined for the FSI current meter deployed at site H2.

Site		H2
Instrument		FSI current meter
Deployment date		22/07/2013
Recovery date		29/10/2013
Period of recorded data	**Start**	22/07/2013, 23:00 utc
	End	09/08/2013, 17:00 utc
Currents	**Sampling frequency**	2 Hz
	Sampling length	5 min
	Interval between samples	60 min

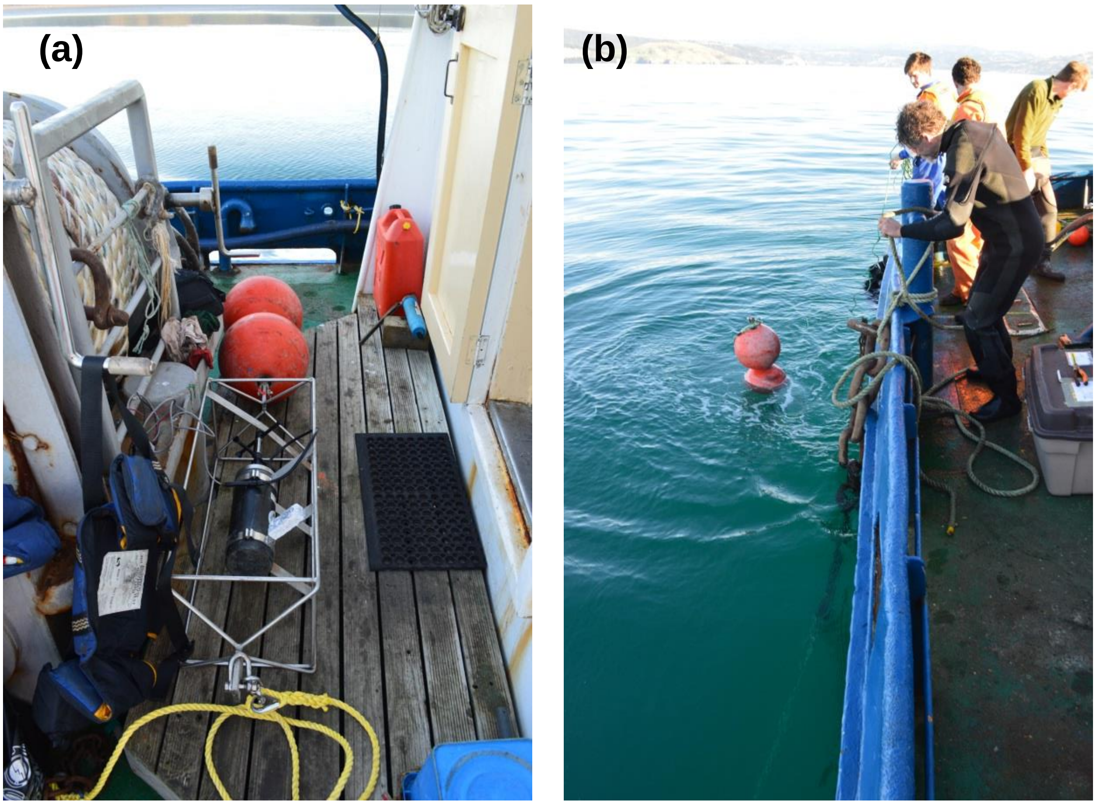

Figure 2.9. FSI deployment at site H2: (a) instrument fixed inside frame with subsurface buoys attached prior to deployment; (b) deployment of the chain where instrument was set.

2.6. Site W1

An RBR data logger with pressure sensor was deployed at site W1, the nearshore site adjacent to Purehurehu Point, in about 7.5 m water depth (Figure 1.1). The instrument was fixed on a triangular frame (Figure 2.10a-b) which was secured on the bottom using three sand anchors. Two small marker buoys (Figure 2.10c) were set on a 15 kg iron using a 10 m line, and attached to the frame at the bottom. A schematic of the nearshore deployments is provided in see Figure 2.2d.

The RBR was firstly deployed on 23 July, and recovered on 30 August 2013. After downloading the data and replacing the batteries, the instrument was redeployed on 30 August at the same site, and finally recovered on 29 October 2013. The settings defined for the RBR sensor are shown in Table 2.8.

Table 2.8. Configurations defined for the RBR deployed at site W1.

Site		W1
Instrument		RBR pressure sensor
Deployment 1	**Deployment**	23/07/2013
	Recovery	30/08/2013
Deployment 2	**Deployment**	30/08/2013
	Recovery	29/10/2013
Period of recorded data	**Start**	22/07/2013, 22:00 utc
	End	24/10/2013, 12:00 utc
Waves	**Sampling frequency**	2 Hz
	Sampling length	17 min
	Interval between samples	60 min

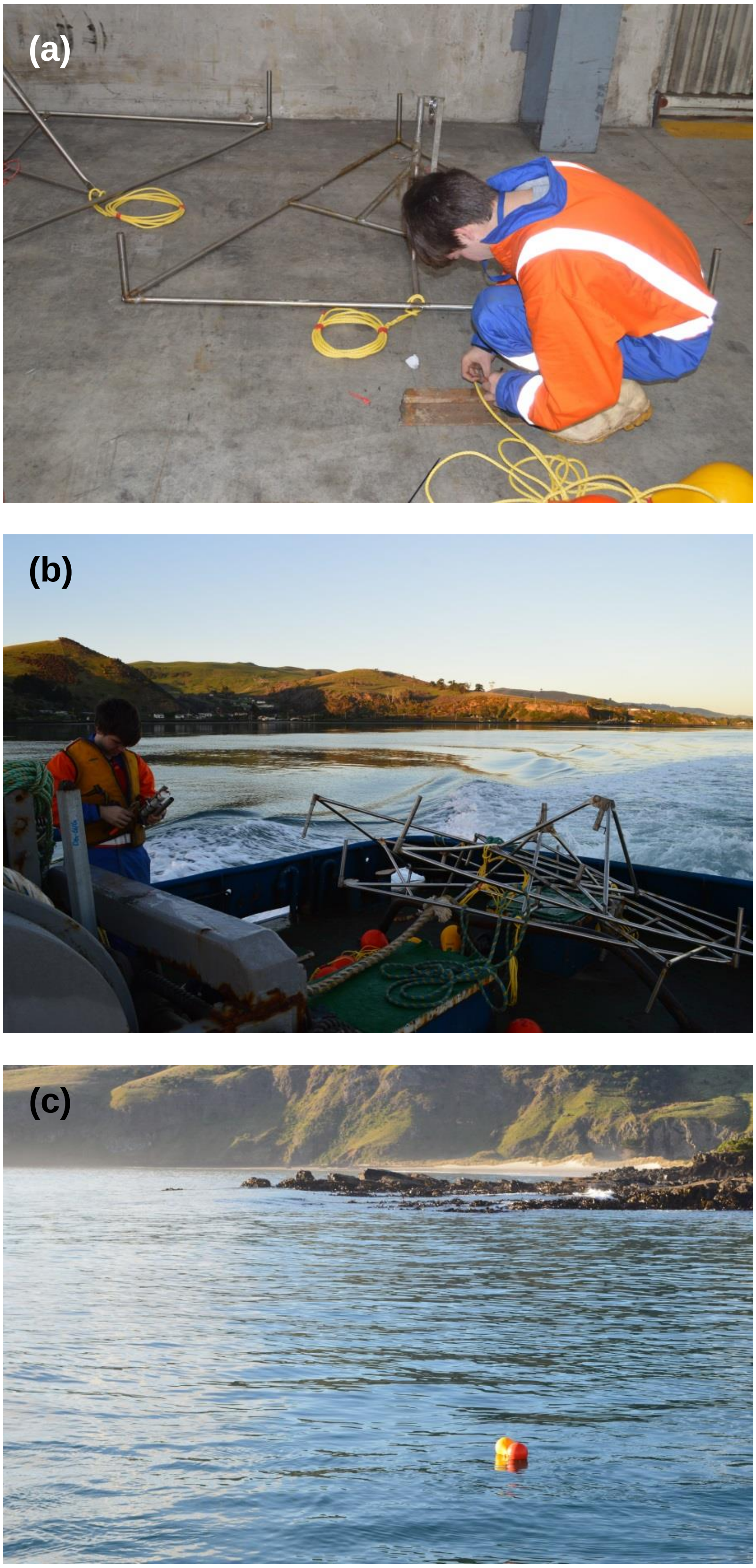

Figure 2.10. RBR deployment at site W1: (a) triangular frame where the RBR was installed; (b) overview of the deck of boat used in the second day showing the RBR; (c) marker buoys deployed with the RBR frame.

2.7. Sites A1-1 to A3-1

Three InterOcean S4 wave and current meters were deployed off Aramoana beach, at the nearshore sites A1-1, A2-1 and A3-1, between 7–8 m water depths. The structures used for the three deployments were very similar to the one used for the RBR, with instruments placed on triangular frames (Figure 2.11a-b) and fixed on the bottom using three sand anchors each (see Figure 2.2d). Marker buoys set on a 15 kg iron were also attached to the frames (Figure 2.11c).

The S4s were deployed on 23 July, and recovered on 30 August 2013. The settings used to configure the three S4s are presented in Table 2.9.

Table 2.9. Configurations defined for the RBR deployed at sites A1-1, A2-1 and A3-1.

<table>
<tr><td colspan="5">Site</td><td>A1-1, A2-1, A3-1</td></tr>
<tr><td colspan="5">Instrument</td><td>S4 wave and current meters</td></tr>
<tr><td colspan="5">Deployment date</td><td>22/07/2013</td></tr>
<tr><td colspan="5">Recovery date</td><td>30/08/2013</td></tr>
<tr><td colspan="2" rowspan="6">Period of recorded data</td><td colspan="2" rowspan="2">A1-1</td><td>Start</td><td>22/07/2013, 22:00 utc</td></tr>
<tr><td>End</td><td>30/08/2013, 01:00 utc</td></tr>
<tr><td colspan="2" rowspan="2">A2-1</td><td>Start</td><td>23/07/2013, 00:00 utc</td></tr>
<tr><td>End</td><td>30/08/2013, 01:00 utc</td></tr>
<tr><td colspan="2" rowspan="2">A3-1</td><td>Start</td><td>23/07/2013, 00:00 utc</td></tr>
<tr><td>End</td><td>29/08/2013, 22:00 utc</td></tr>
<tr><td rowspan="6">Waves</td><td colspan="4">Sampling frequency</td><td>2 Hz</td></tr>
<tr><td colspan="4">Sampling length</td><td>17 min</td></tr>
<tr><td colspan="4">Interval between samples</td><td>60 min</td></tr>
<tr><td colspan="2" rowspan="3">Percentage of recorded data</td><td colspan="2">A1-1</td><td>100%</td></tr>
<tr><td colspan="2">A2-1</td><td>100%</td></tr>
<tr><td colspan="2">A3-1</td><td>100%</td></tr>
</table>

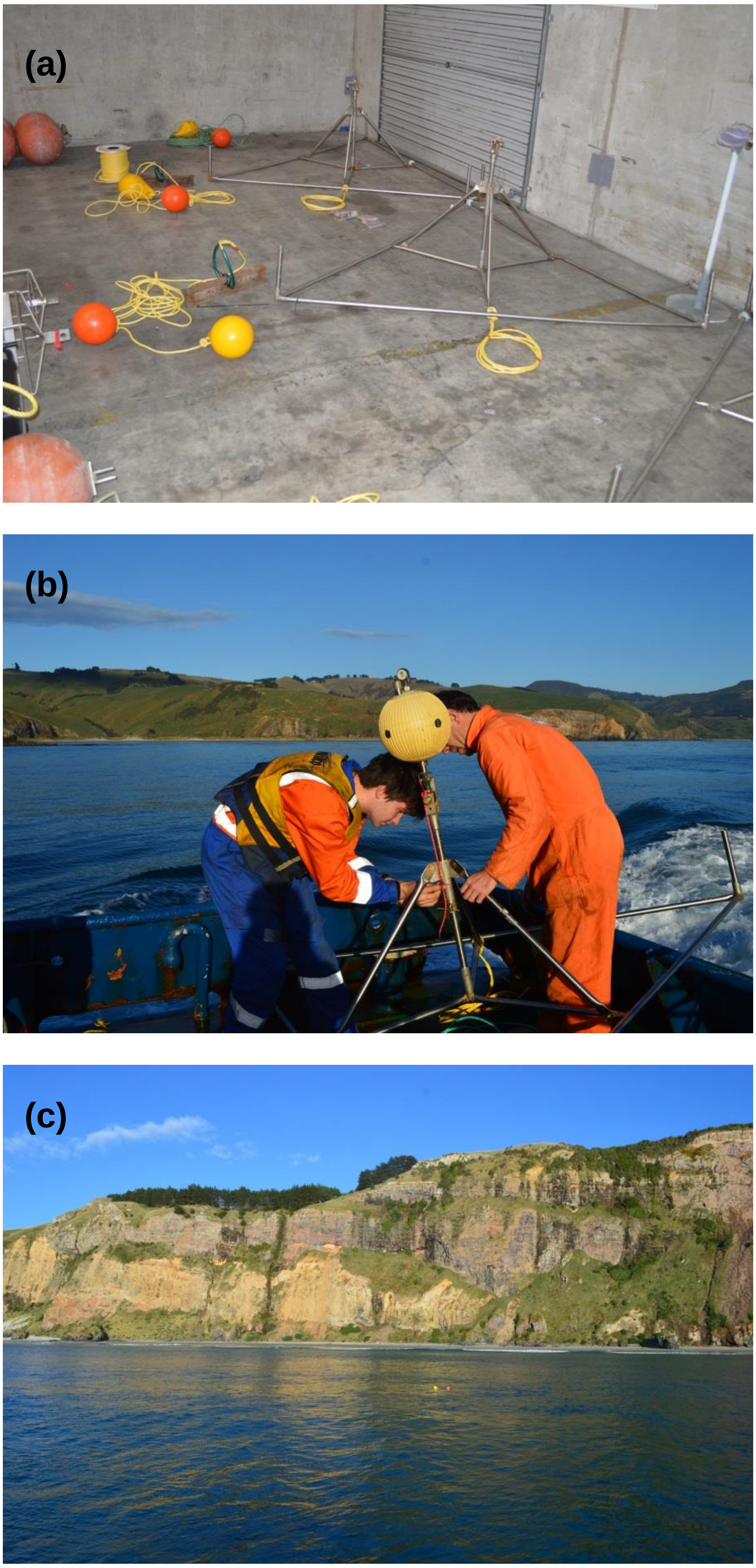

Figure 2.11. Deployment of S4s at the nearshore sites: (a) triangular frame and iron used to deploy the nearshore S4s; (b) S4 from site A1-1 being fixed on the frame; (c) overview of Aramoana beach showing the marker buoys at site A1-1.

2.8. Sites A1-2 to A3-2

The three InterOcean S4s deployed at sites A1-1, A2-1 and A3-1 were redeployed on 31 August at three different sites A1-2, A2-2 and A3-2, using the same deployment configurations. The site locations are shown in Figure 1.1. A1-2 was just SE of site A1-1, in about 7.8 m. A2-2 was close to the centre of the spit disposal mound offshore Aramoana beach, in about 8.7 m. A3-2 was located offshore Heyward Point in 10.2 m water depth.

The S4s were deployed on 30 August, and recovered on 29 October 2013. The settings used to configure the three S4s are presented in Table 2.10.

Table 2.10. Configurations defined for the RBR deployed at sites A1-2, A2-2 and A3-2.

Site			A1-2, A2-2, A3-2
Instrument			S4 wave and current meters
Deployment date			30/08/2013
Recovery date			29/10/2013
Period of recorded data	**A1-2**	**Start**	30/08/2013, 23:00 utc
		End	12/10/2013, 21:00 utc
	A2-2	**Start**	30/08/2013, 23:00 utc
		End	24/10/2013, 20:00 utc
	A3-2	**Start**	30/08/2013, 23:00 utc
		End	19/10/2013, 07:00 utc
Waves	**Sampling frequency**		2 Hz
	Sampling length		17 min
	Interval between samples		60 min
	Percentage of recorded data	**A1-2**	73%
		A2-2	93%
		A3-2	84%

3. RESULTS

The field data are presented separately for the three phases of the field experiment: the first phase, from the 22th of July to the 30th of August 2013, the second, from the 30th August to the 29th October 2013 - when the nearshore S4s were transferred to the new sites – and the third phase, from the 30th October 2013 to the 24th January 2014, during which the ADCP was redeployed at site A0.

Wave directions are shown in the “coming from” convention, whereas currents are shown in the “going to” frame. The directions are relative to the True North (i.e., the local magnetic declination of 25.1°E was corrected from the measured data). All times in the time series plots are in UTC.

3.1. Phase 1: 22 July – 30 August

The first phase of the field campaign was characterised by four high energy events with waves exceeding 2 m at the offshore site A0 (Figure 3.1a). The highest-energy event occurred around August 13th, with the significant wave height H_{m0} peaking at 3.7 m at site A1-1.

Peak wave period Tp was remarkably consistent across all different sites (Figure 3.1b). The values ranged from 4 to 16 seconds, with the first three events characterised swell-dominated conditions (Tp>12 sec.) and the last and most persistent event by shorter periods, typically smaller than 10 seconds.

The peak wave direction at the offshore site A0 was variable, generally comprised within the south-eastern quarter (Figure 3.1c). At the sites WRB, A1-1, A2-1 and A3-1, wave directions are reduced and generally more homogeneous due to refraction effects near the coast.

There was a notable alongshore variability in wave energy at the nearshore sites A1-1, A2-1 and A3-1. Though waves were clearly smaller at A3-1 over the entire period, distinct patterns were observed at sites A1-1 and A2-1. Site A2-1, located shoreward from the dredge disposal site (and mound), received the highest wave energy during easterly-dominated events, whereas south-easterly offshore waves generally resulted in the highest waves at site A1-1 (Figure 3.1). This trend is visible during the high energy event from the 11th to 13th October 2013, where the A1-1 wave heights become larger than A2-1 heights as the offshore wave direction shifts to the southeast.

With respect to wave incidence, directions are consistently smaller (i.e. more north-east) at the A3-1 site compared to A1-1 and A2-1. This is due sheltering from the Mole along with refraction effects over the underlying concave morphology of that part of the beach (see Figure 1.1). Directions at A2-1 are consistently larger than at A3-1 by ~ 5-10 degrees over the deployment period. Differences of up to 20 degrees are visible around the 13th of August. This overall offset can most likely be attributed to refraction effects over the offshore beach morphology, including the mound feature off Aramoana (Figure 1.1). Incident waves will effectively be refracted over the mound with crests aligning with underlying convex depth contours. Here, A2-1 is approximately in line with the mound tip, while A3-1 is positioned further north along the beach. As a result, A3-1 is generally exposed to waves that undergone relatively more refraction than at A2-1, thereby causing the consistent difference in direction.

At the W1 site located off Purehurehu Point, wave heights were generally slightly smaller than at the exposed A1-1 and A2-1 sites. During the largest wave event (~12th Aug.), there is a distinct wave height reduction as the offshore incidence goes from easterly to southerly direction, which is related to sheltering effects.

Time series of the mean current at the nearshore sites (A1-1, A2-1, A3-1) and at the deeper sites (A0, H1, H2) are shown in Figure 3.2 and Figure 3.4 respectively. The nearshore flow regime is dominated by wave-driven effects, with a clear increase of current magnitudes under more energetic wave conditions at the sites A1-1, A2-1, A3-1. The highest mean current speeds near the shore were observed during the storm event around the 12th of August, peaking at about 0.5 m/s at A1-1 (Figure 3.2).

In terms of directions, a positive easterly component was consistently present at A3-1 (i.e. easterly-directed) while a negative easterly component was observed at A1-1 (i.e. westerly directed). More variability develops for increased level of wave energy. At A2-1 and A3-1 strongest current magnitudes are generally east to northeast-directed (i.e. towards the Mole). Strong northerly component magnitudes are measured in A1-1 during the largest wave events. Notably, a strong northeast current (0.5 m/s) coincides with the peak wave conditions around the12th of October and is likely associated with a rip current. (offshore-directed current feature).

Archived nowcast winds from MetOcean Solutions forecast system are provided in Figure 3.3 over the deployment period, for reference. Relatively strong winds (~ 20kts) from the northerly sector were sustained over several days during both the second and fourth events and likely generated local seas.

Currents measured at the offshore sites A0, H1, H2 are presented in Figure 3.4. Tidal modulation of currents is present at all sites although, superimposed on residual flows which may dominate depending on the wave forcing. At H1 and H2, largest current magnitudes of ~0,2-0.25 m/s were measured during the wave event around the 3rd of August, with a northwest direction. At A0, strongest currents were southerly-directed of order 0.4 m/s and occurred during the fourth wave event.

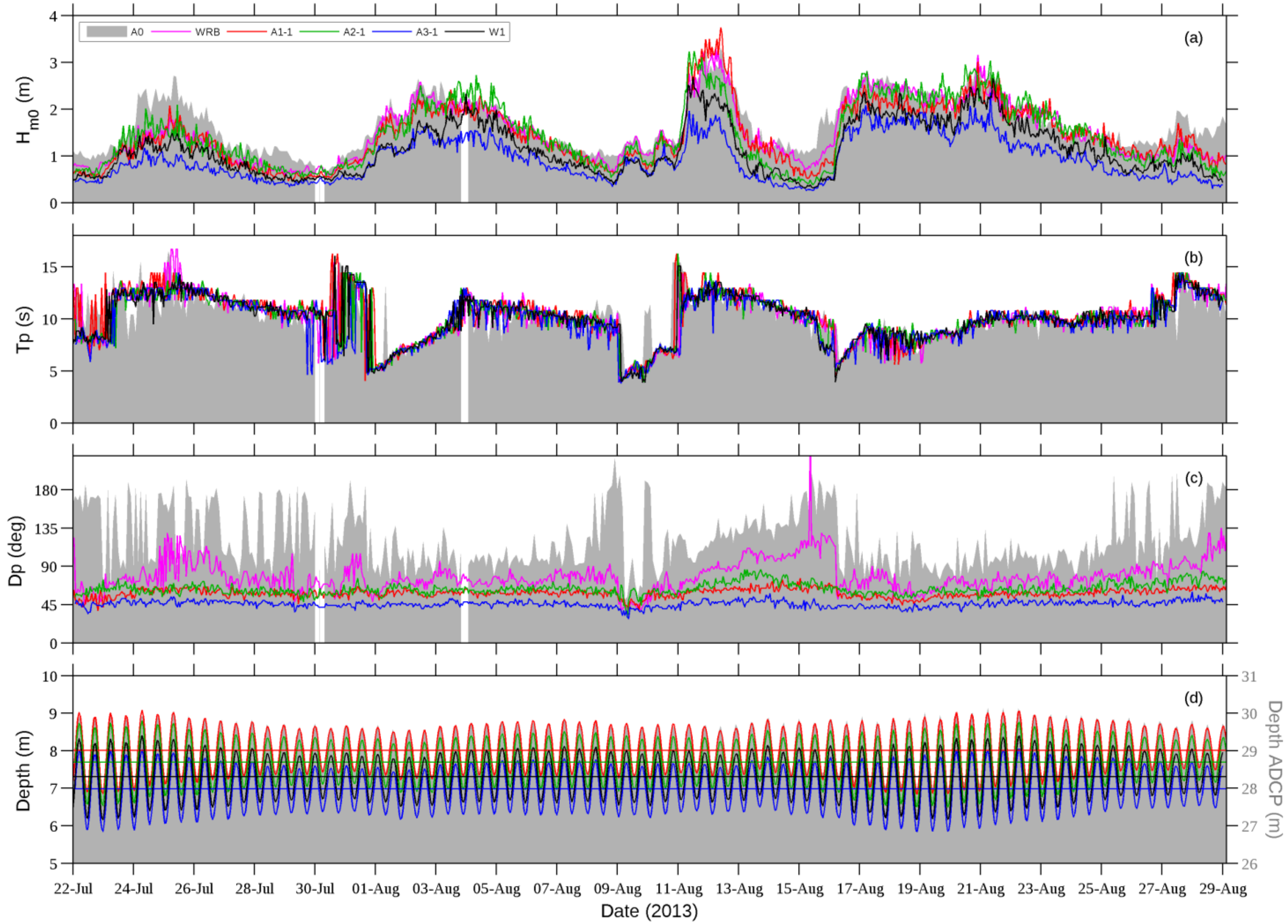

Figure 3.1. Time series of waves for the first deployment phase: (a) spectral significant wave height H_{m0}, (b) peak wave period Tp, (c) peak wave direction Dp, and (d) water depth. Grey patches show the data measured at site A0 (depths for site A0 in (d) are shown by the right axis).

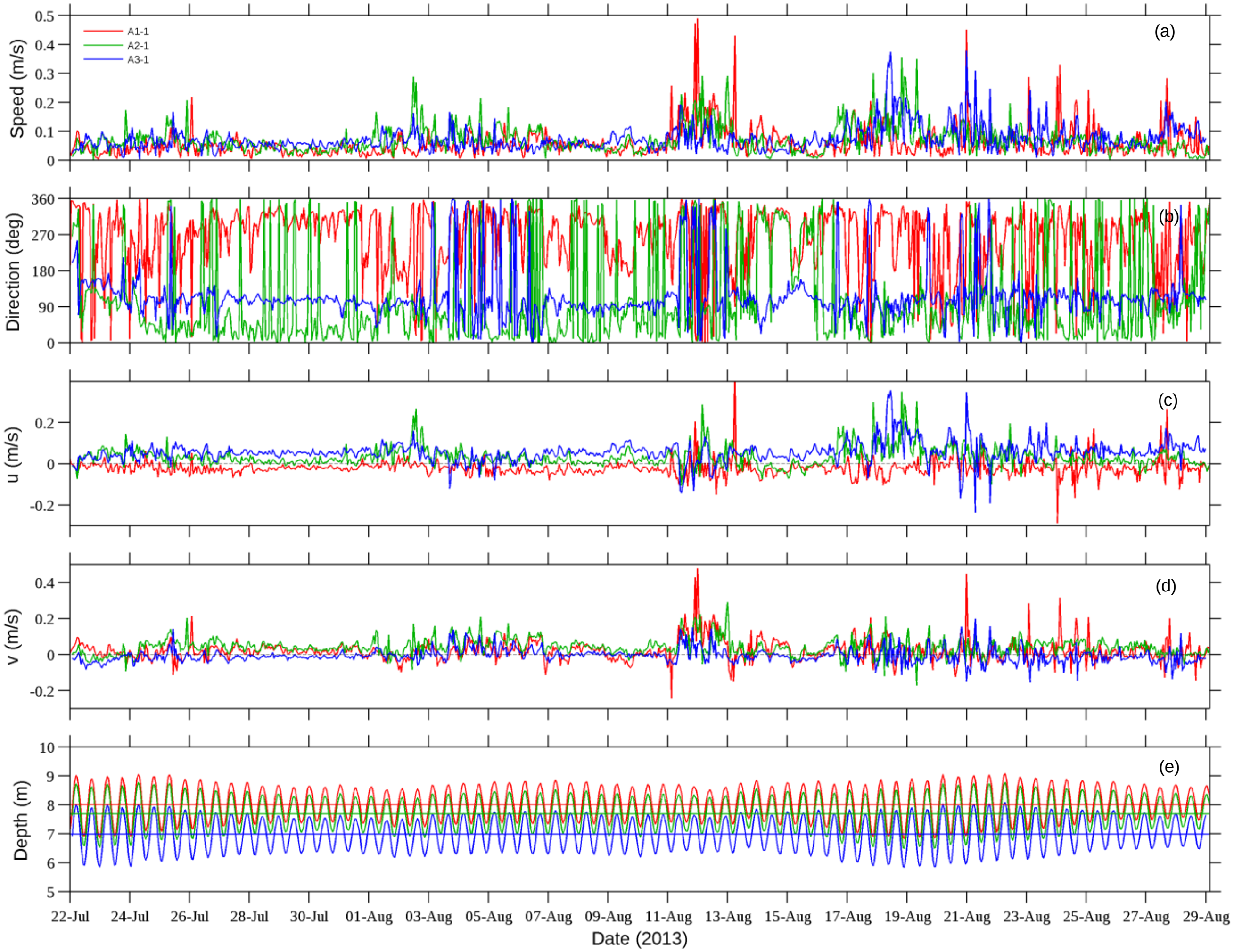

Figure 3.2. Time series of mean currents for the nearshore sites A1-1, A2-1 and A3-1, during the first deployment phase: (a) mean current speed and (b) mean current direction; (c) u (W–E), and (d) v (S–N) components of the mean current; (e) mean water depth.

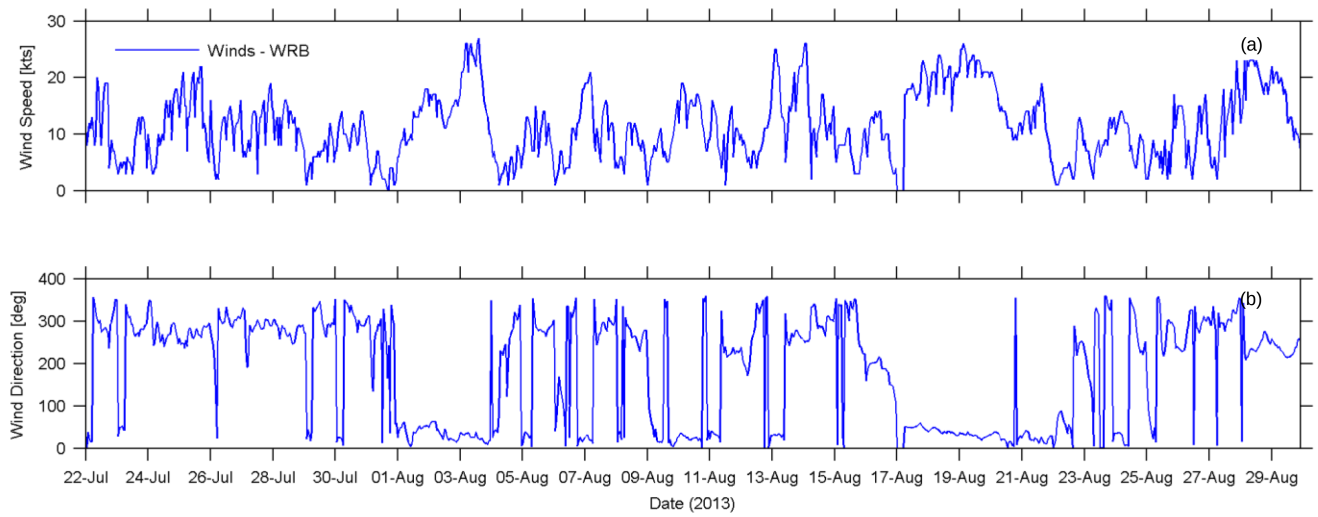

Figure 3.3 Time series of archived nowcast of (a) wind speed and (b) direction from the MetOcean forecast system (MetOceanView) over the first deployment phase, at the WRB location.

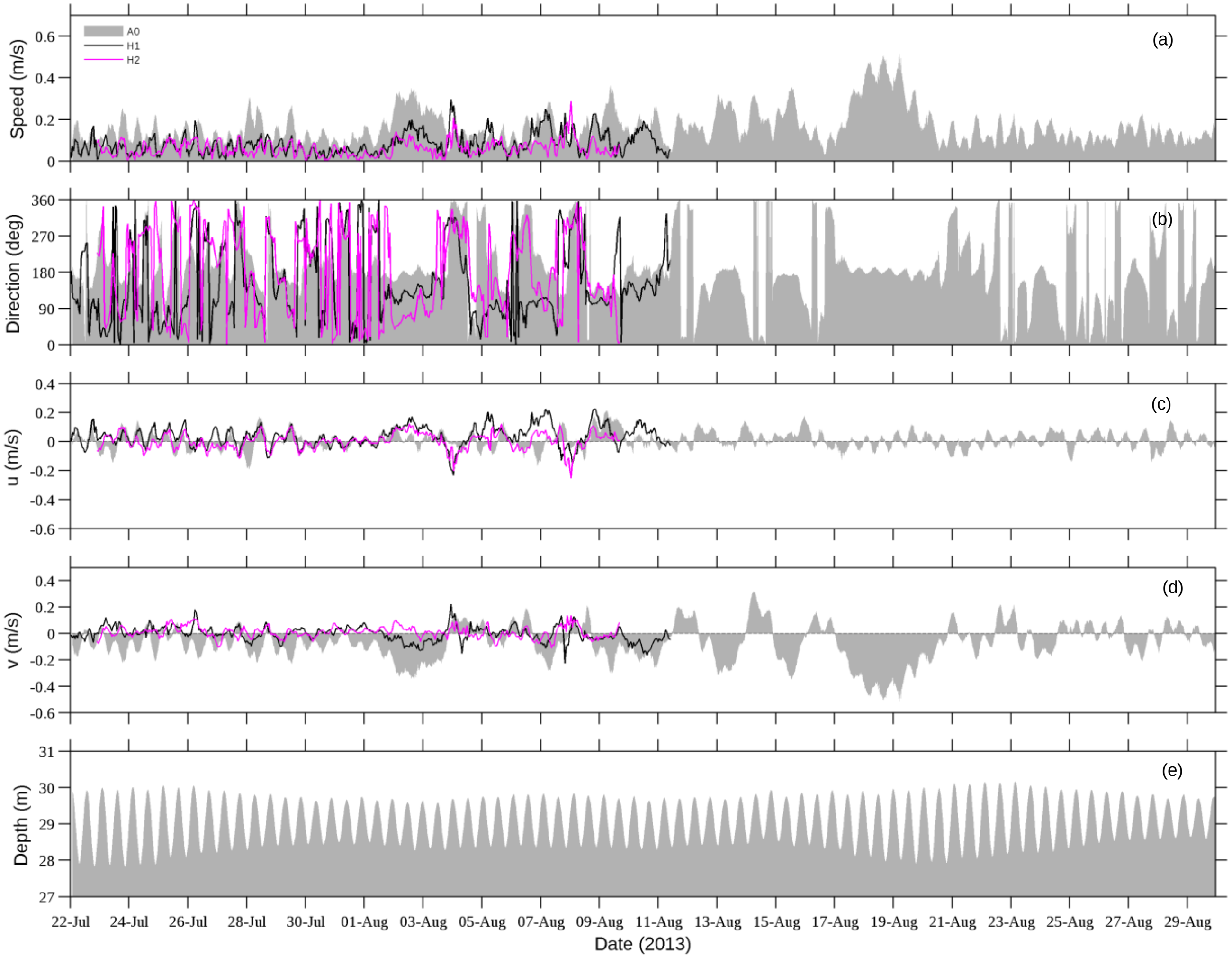

Figure 3.4. Time series of mean currents for sites A0, H1, H2, during the first deployment phase: (a) mean current speed and (b) mean current direction; (c) u (W–E), and (d) v (S–N) components of the mean current; (e) mean water depth.

3.2. Phase 2: 30 August – 29 October

Wave time series for the second phase of the deployment are shown in Figure 3.5. The highest energy event took place around the 26th of September, with significant wave height H_{m0} reaching 2.9 m at sites A1-2 and A2-2. The peak wave period Tp ranged from 4 and 20 seconds over the entire period, and peak wave direction Dp at site A0 were comprised within the eastern and southern quadrants.

The first third of the deployment period was characterized by southerly offshore wave incidence resulting in wave height at A0 much larger than at the nearshore sites. In contrast, A0 and nearshore wave heights were similar for the more easterly offshore wave incidence experienced over the second third of the deployment.

At the nearshore sites, A3-2 wave heights, off Heyward Point, are generally close to these at A1-2 and A2-2, off the beach, when offshore directions are in the offshore southerly range. During larger easterly wave events (e.g. 26th September, 6th October), A3-2 heights become smaller than at A1-2, A2-2 sites by up to ~ 1m. This gradient can be attributed to wave refraction effects over the ebb delta bar that will focus wave energy towards Aramoana beach, more efficiently than for southerly waves. The focusing process will also potentially result in a relative wave shadowing of the A3-2 location.

As observed over the first deployment, offshore waves direction (A0) are progressively realigned with the coast due to (large scale) refraction effects as they propagate inshore, which result in measured directions at the WRB and A sites consistently within the east to northeast quarters. In the vicinity of the mound, A1-2 directions are generally slightly smaller (i.e. more northerly) than at A2-2. As for the A2-1 and A3-1 sites during the first deployment, this can be related to local refraction processes over the particular beach morphology (i.e. convex mound contours). A3-2 directions are generally comprised between the A1-2 and A2-2 directions.

Mean current speeds are shown for the nearshore sites (A1-2, A2-1, A3-2) in Figure 3.6 and for the deeper locations (A0) in Figure 3.8 (currents data from H1 and H2 were not available for the second deployment period).

Measured magnitudes at A1-2 and A2-2 sites are smaller than these measured over the first deployment, generally less than 0.1 m/s and up to about 0.2 m/s. More significant events were measured at the A3-2 position, with several episodes around 0.3 m/s and up to 0.5 m/s. However, these events were typically easterly-directed, which is opposed to the ambient wave direction, and coincided with strong north-westerly winds (Figure 3.7) and smaller wave periods. This indicates that these episodes were dominated by the wind forcing rather than wave forcing.

At the offshore site A0, mean currents were more significantly modulated by the tidal oscillations (Figure 3.8). Maximum mean velocities of up to 0.3 m/s were measured.

An overview of the typical current velocities at each site is provided in Figure 3.9, as u-v scatter plots. The predominantly southwards component at site A0 is also highlighted in the progressive vector plot in Figure 3.10.

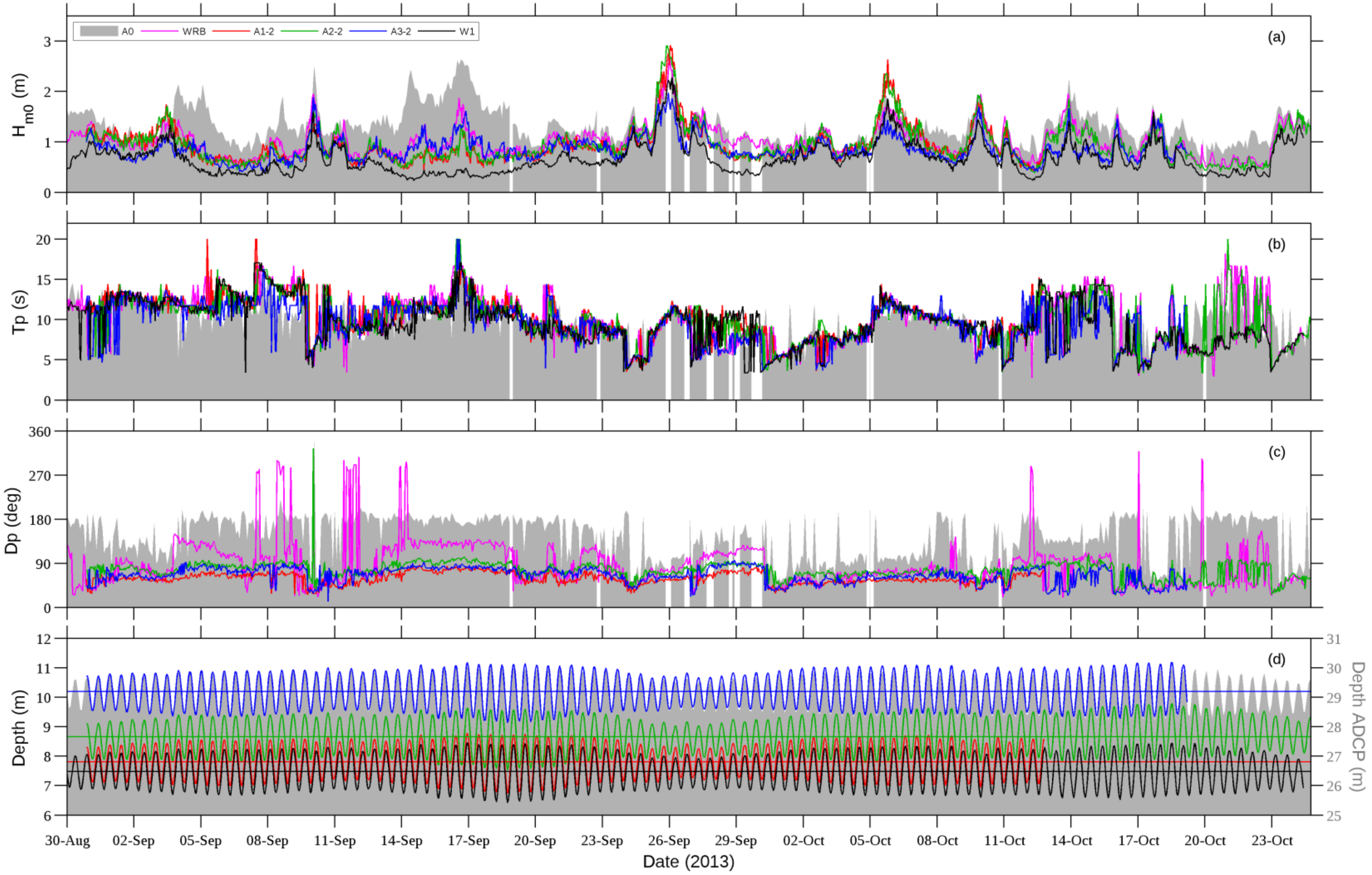

Figure 3.5. Time series of waves for the second deployment phase: (a) spectral significant wave height H_{m0}, (b) peak wave period Tp, (c) peak wave direction Dp, and (d) water depth. Grey patches show the data measured at site A0 (depths for site A0 in (d) are shown by the right axis).

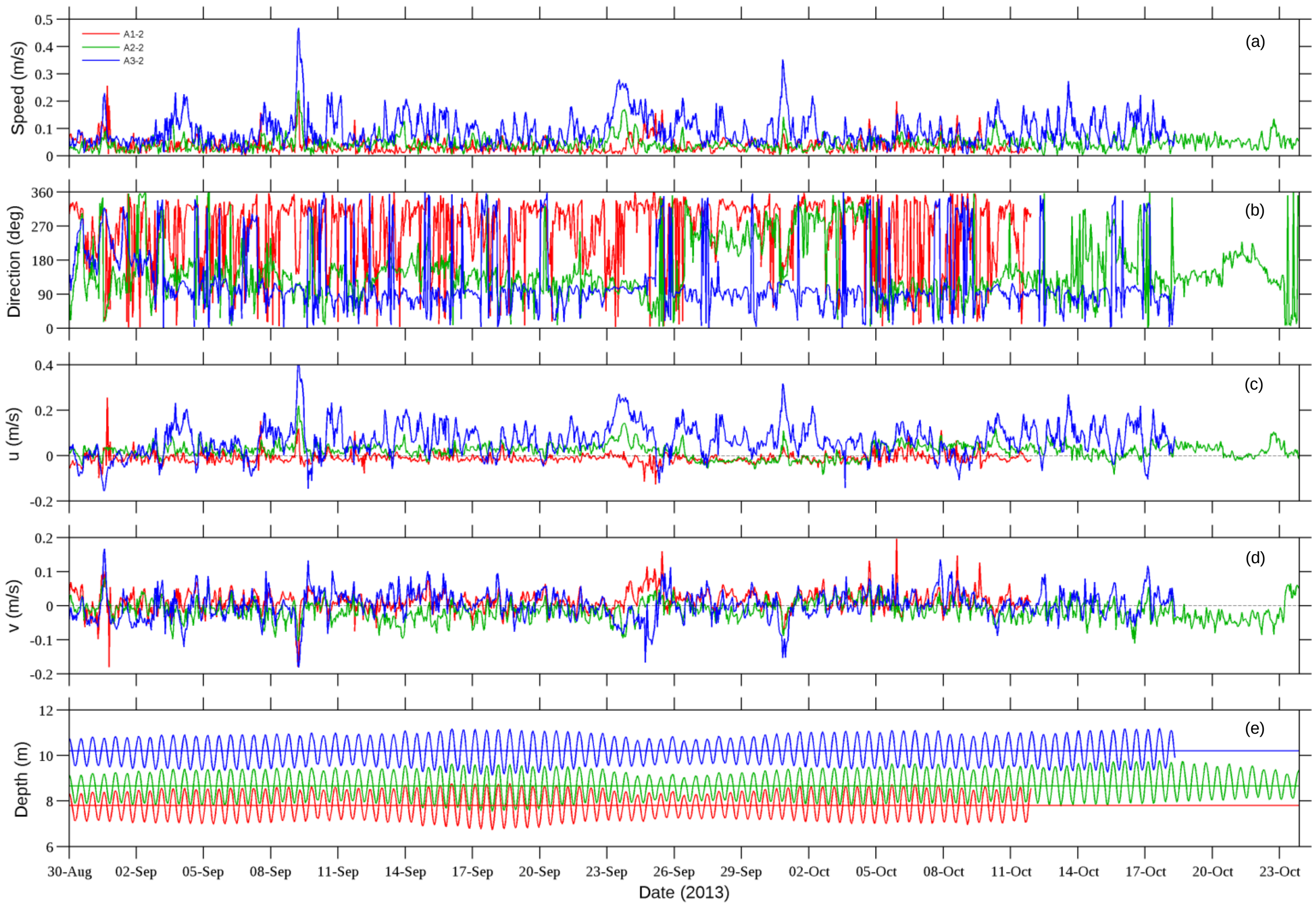

Figure 3.6. Time series of mean currents for the nearshore sites A1-1, A2-1 and A3-1, during the first deployment phase: (a) mean current speed and (b) mean current direction; (c) u (W–E), and (d) v (S–N) components of the mean current; (e) mean water depth.

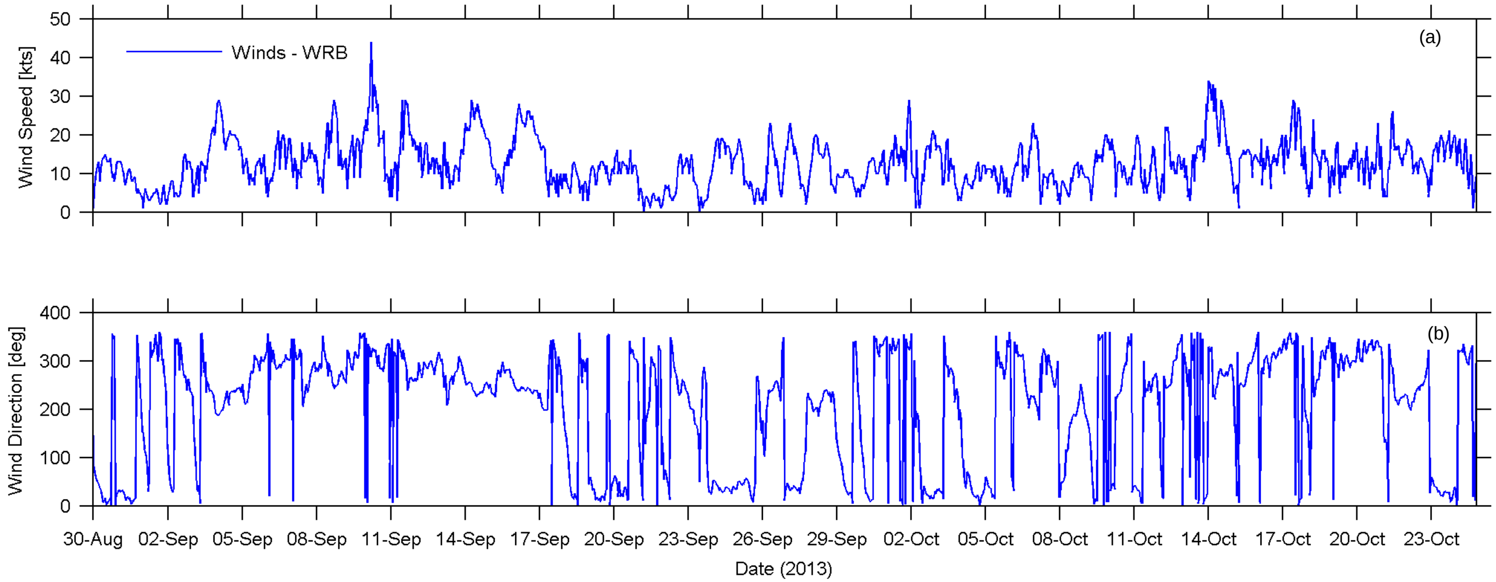

Figure 3.7 Time series of archived nowcast of (a) wind speed and (b) direction from the MetOcean forecast system (MetOceanView) over the second deployment phase, at the WRB location.

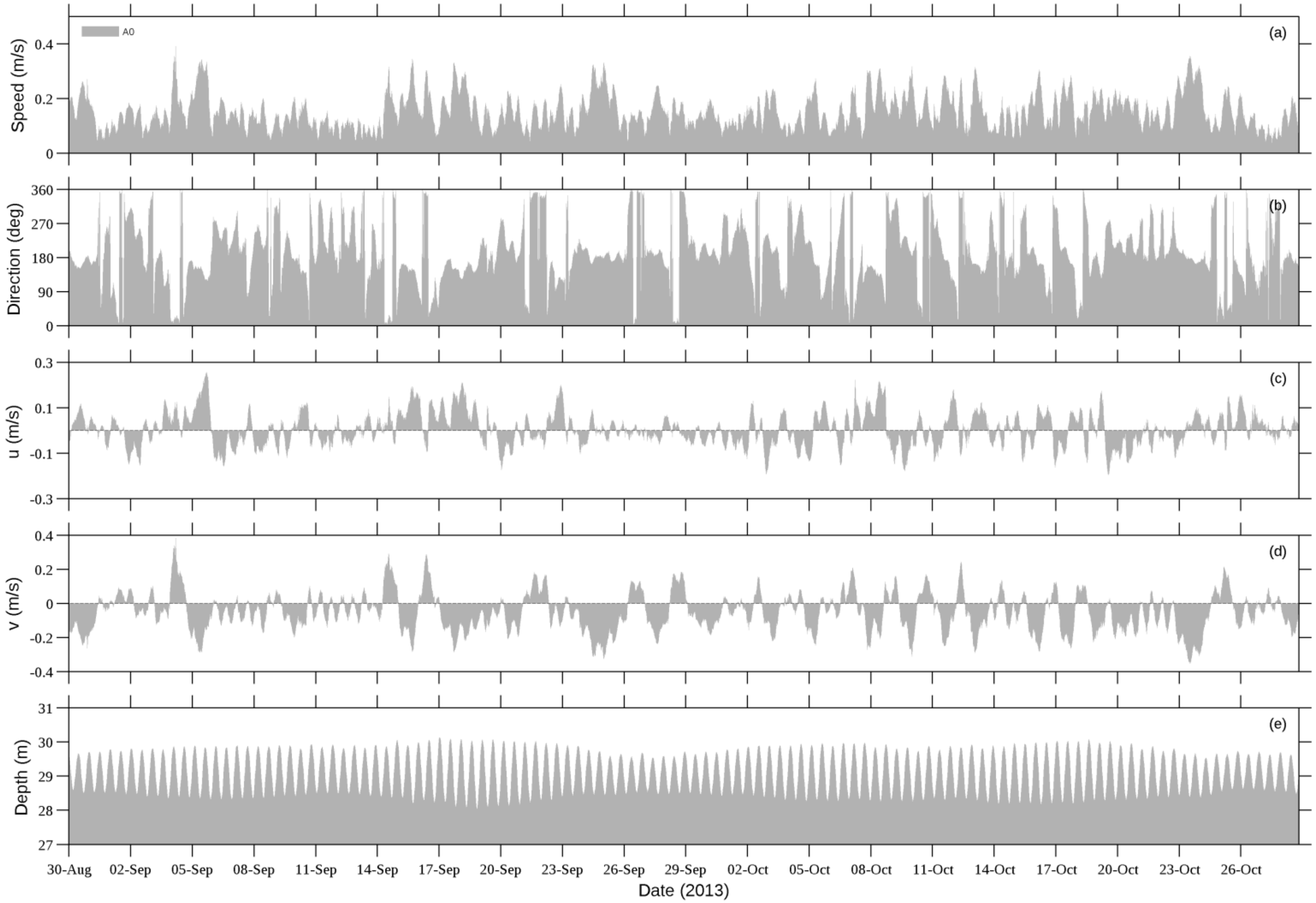

Figure 3.8. Time series of mean currents for site A0, during the second deployment phase: (a) mean current speed and (b) mean current direction; (c) u (W–E), and (d) v (S–N) components of the mean current; (e) mean water depth.

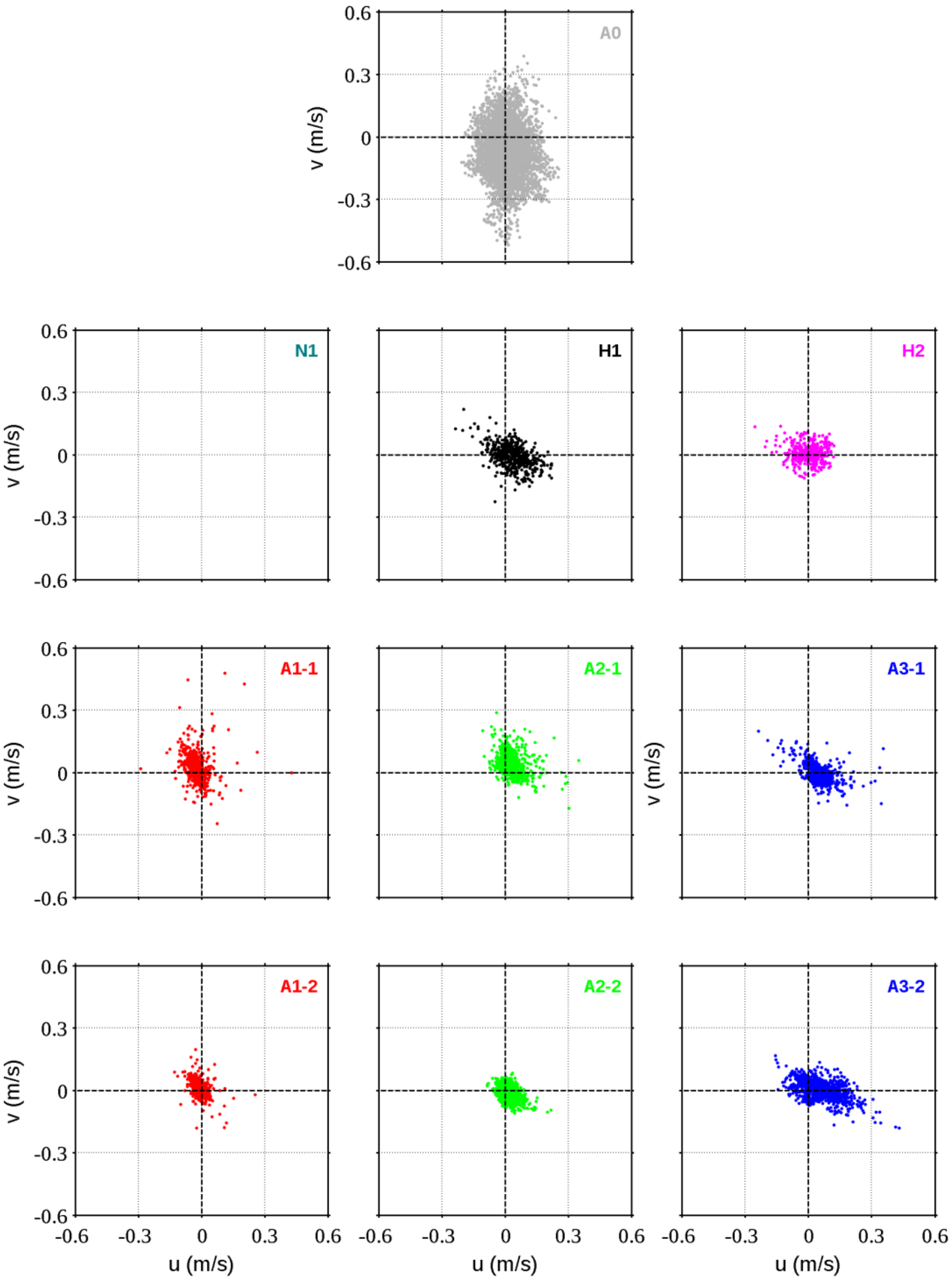

Figure 3.9. Scatter plots of the horizontal (u) versus vertical (v) components of the mean current velocity, for all the sites where currents were measured during phase 1 and 2 of the field campaign.

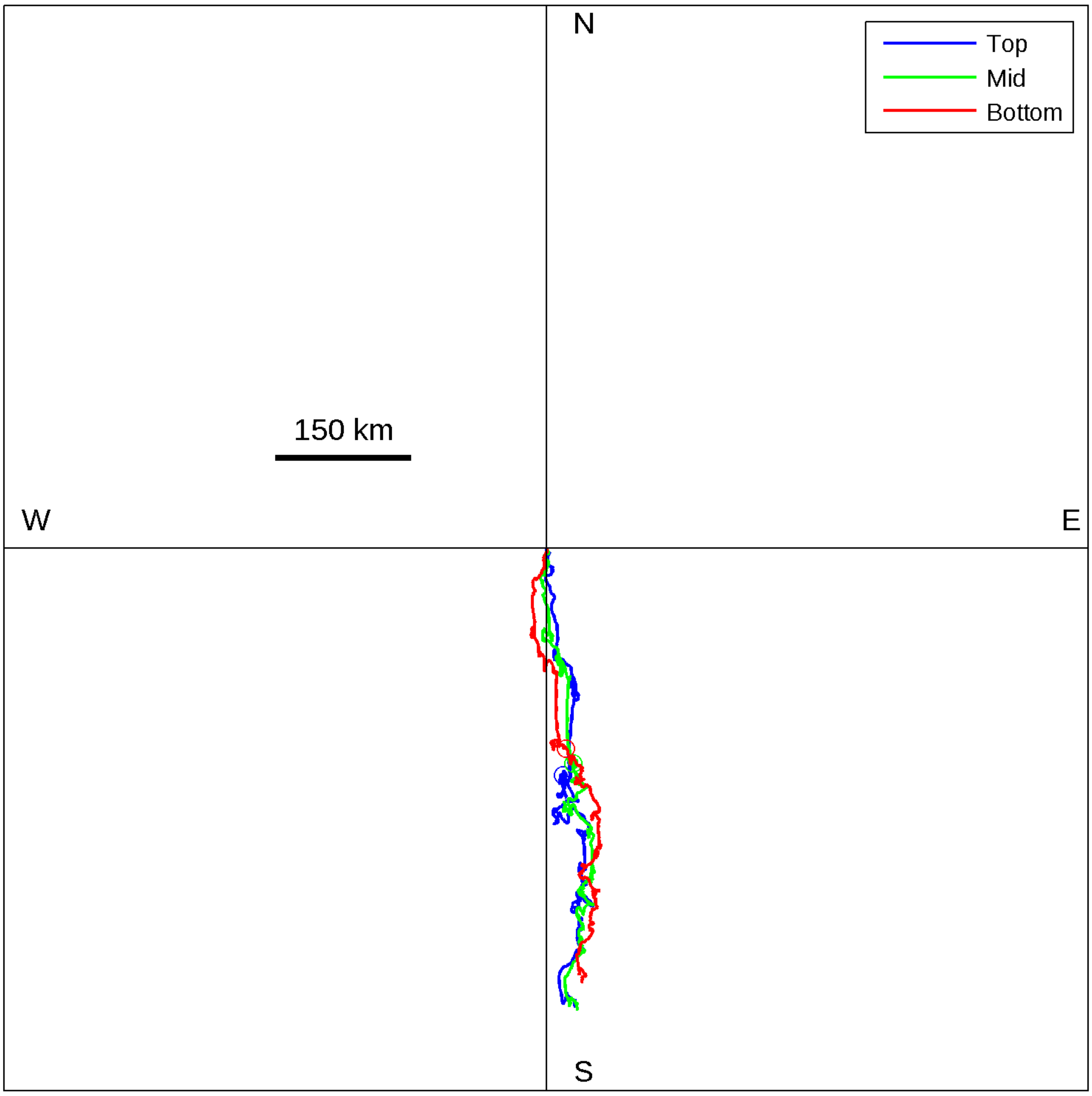

Figure 3.10. Progressive vector plot for current velocity bins near the surface, mid-water column and bottom at site A0, during phases 1 and 2 of the field deployment. Circles show “position” where phase 2 starts.

3.3. Phase 3: 30 October – 07 December

Wave time series from the ADCP for the third phase of the deployment are shown in Figure 3.11. The period was characterised by predominant easterly-northeasterly wave incidence, intercalated by some southerly events. The significant wave height H_{m0} was mostly within 1–2 m, and the peak wave period Tp tended to be smaller compared with the first two deployment phases. The largest-energy event was recorded at the end of November, with Hm0 peaking at 2.56 m.

Depth-averaged current speeds and directions at site A0 are shown in Figure 3.12. Currents had mean speeds ranging between 0.1 and 0.4 m/s, and were predominantly oriented towards the southeasterly–southwesterly directions, consistent with predominant winds from the north quadrant (Figure 3.13). Tidal modulation can also be observed in the mean current components, particularly the easting (*u*) component of the mean current (Figure 3.12).

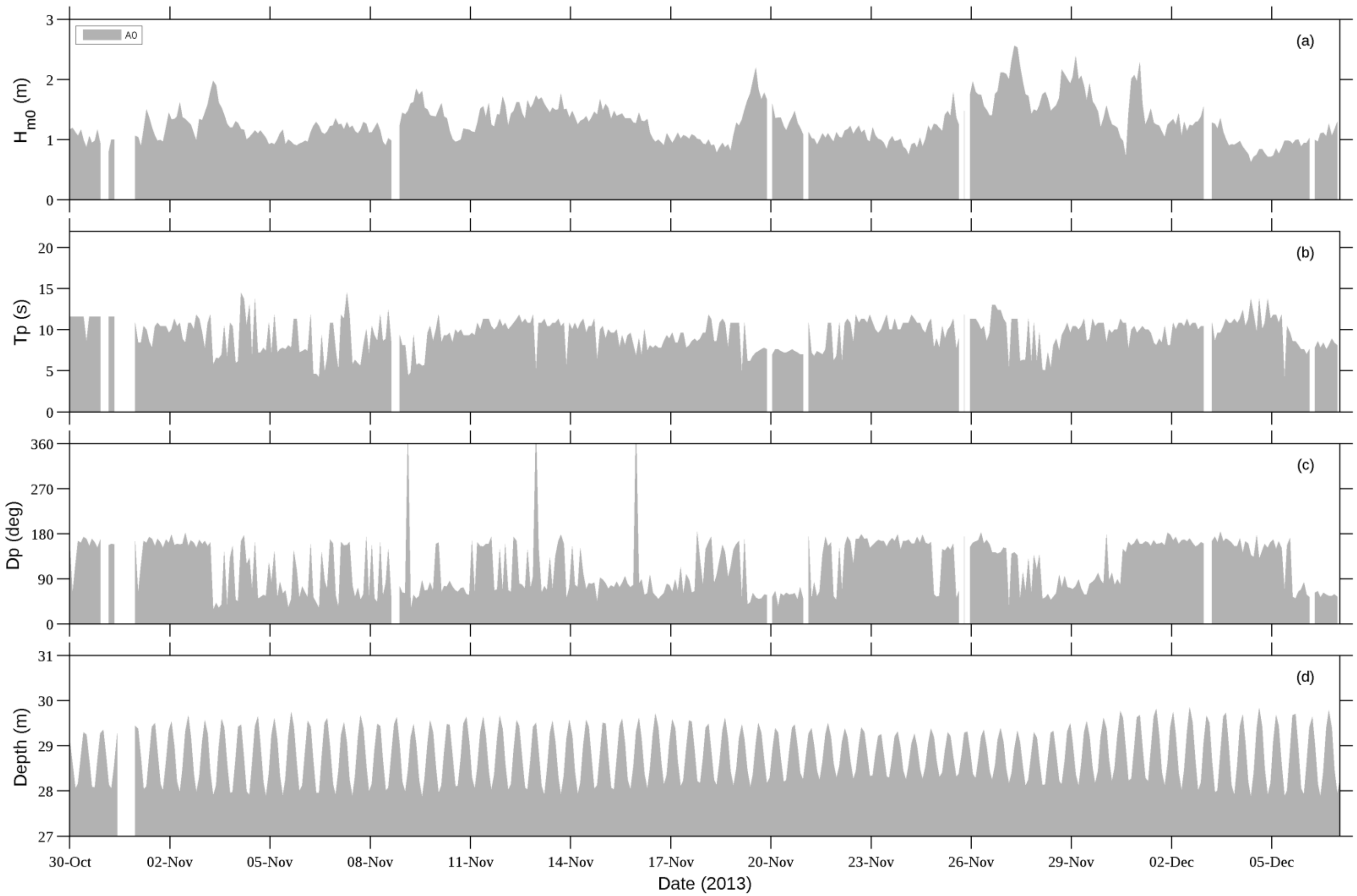

Figure 3.11. Time series of waves at site A0 for the third deployment phase: (a) spectral significant wave height Hm0, (b) peak wave period Tp, (c) peak wave direction Dp, and (d) mean water depth.

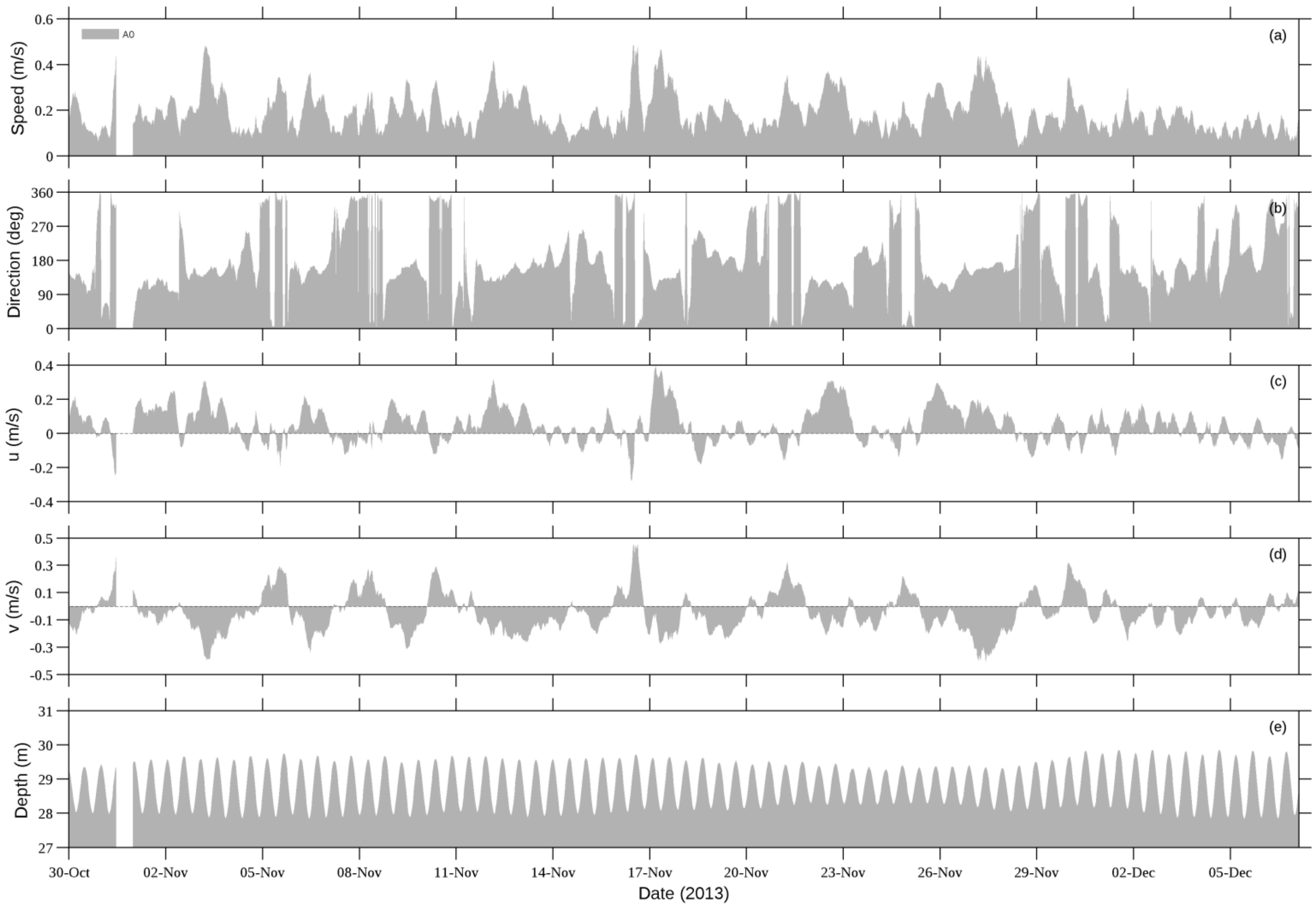

Figure 3.12. Time series of mean currents for site A0, during the third deployment phase: (a) mean current speed and (b) mean current direction; (c) u (W–E), and (d) v (S–N) components of the mean current; (e) mean water depth.

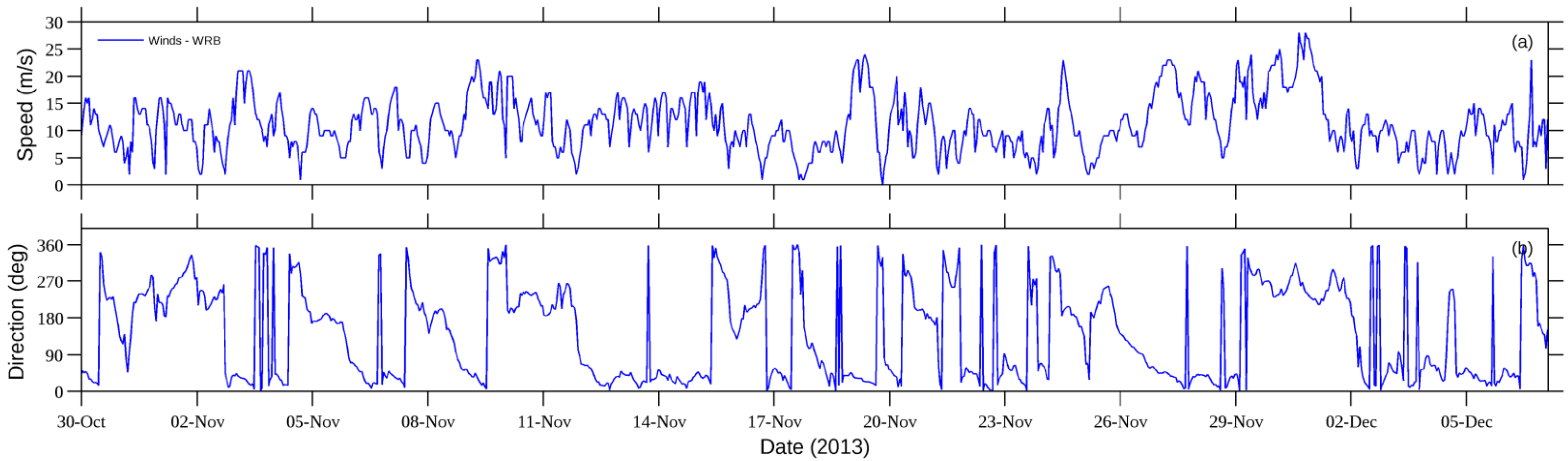

Figure 3.13. Time series of archived nowcast of (a) wind speed and (b) direction from the MetOcean forecast system (MetOceanView) over the third deployment phase, at the WRB location.

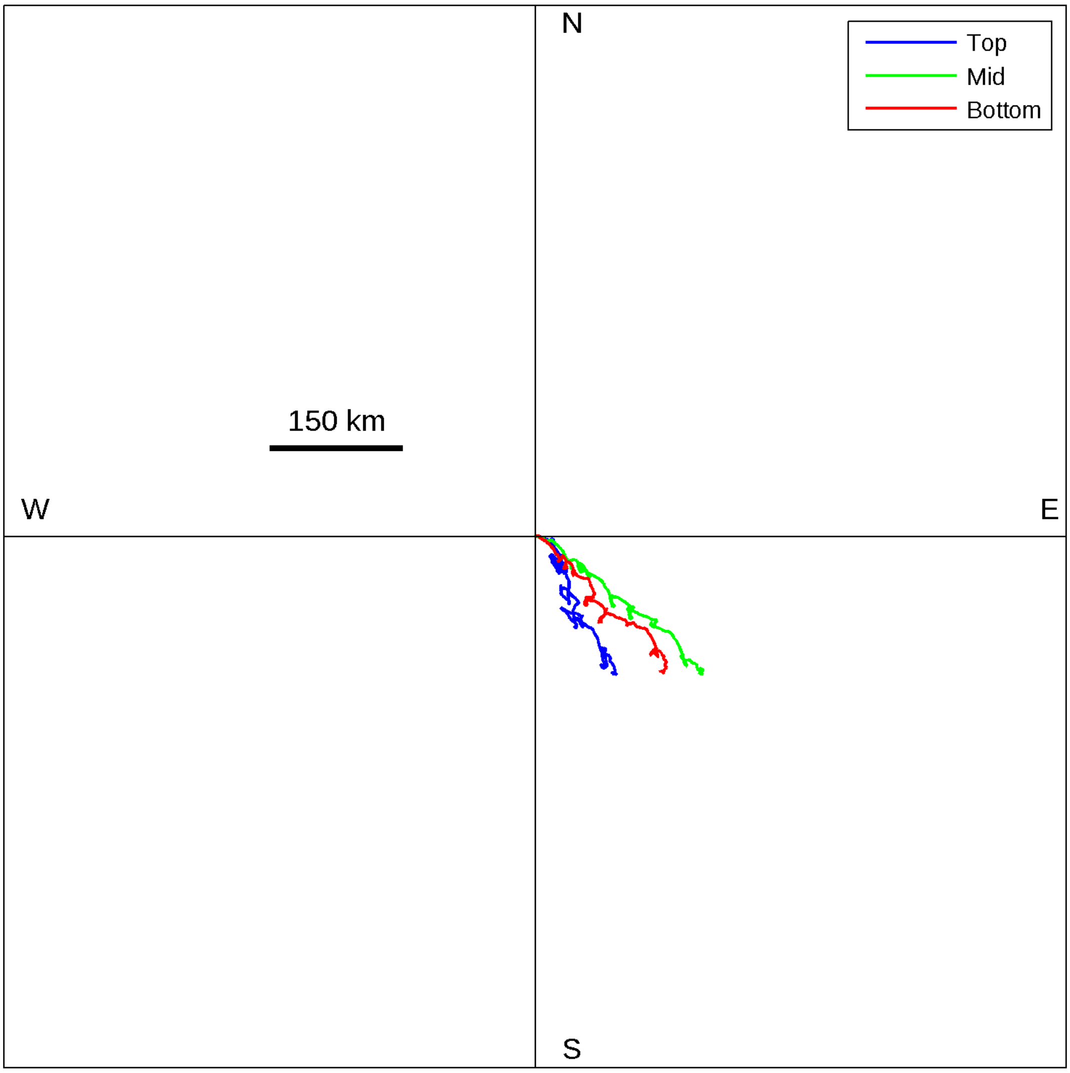

Figure 3.14. Progressive vector plot for current velocity bins near the surface, mid-water column and bottom at site A0, during phase 3 of the field deployment.

4. METEOROLOGICAL DATA

The data measured by the meteorological stations during the field deployment period are provided below. The meteorological buoys were deployed at site A0 and off Cornish Head by the Port of Otago. Environmental parameters measured by the buoys included barometric pressure, air temperature, wind speed and direction, and water turbidity.

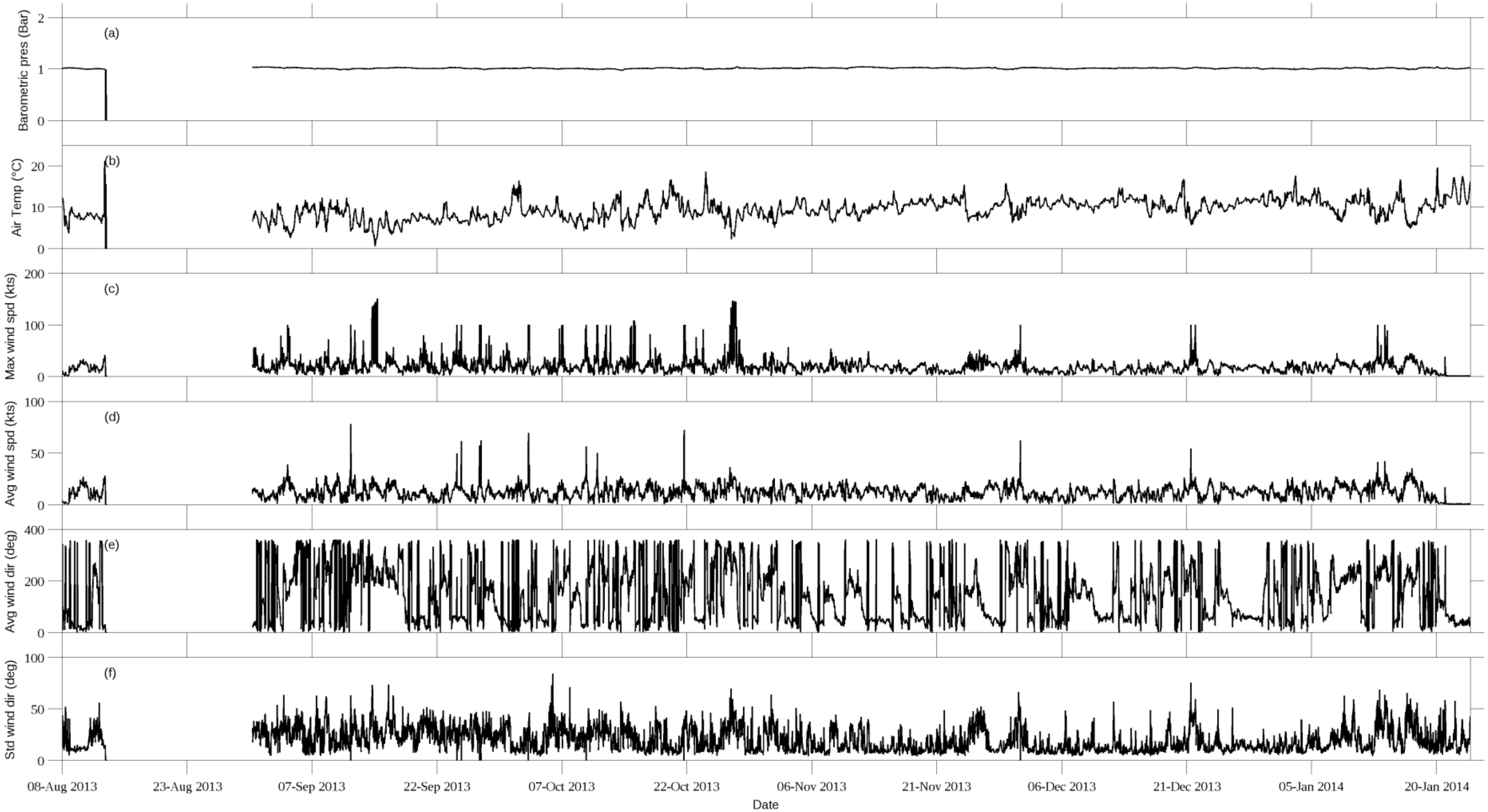

Figure 4.1. Time series of meteorological parameters measured by the *µWQ Buoy - Site B*: (a) barometric pressure, (b) air temperature, (c) maximum and (d) average wind speeds, (e) average and (f) standard deviation wind direction.

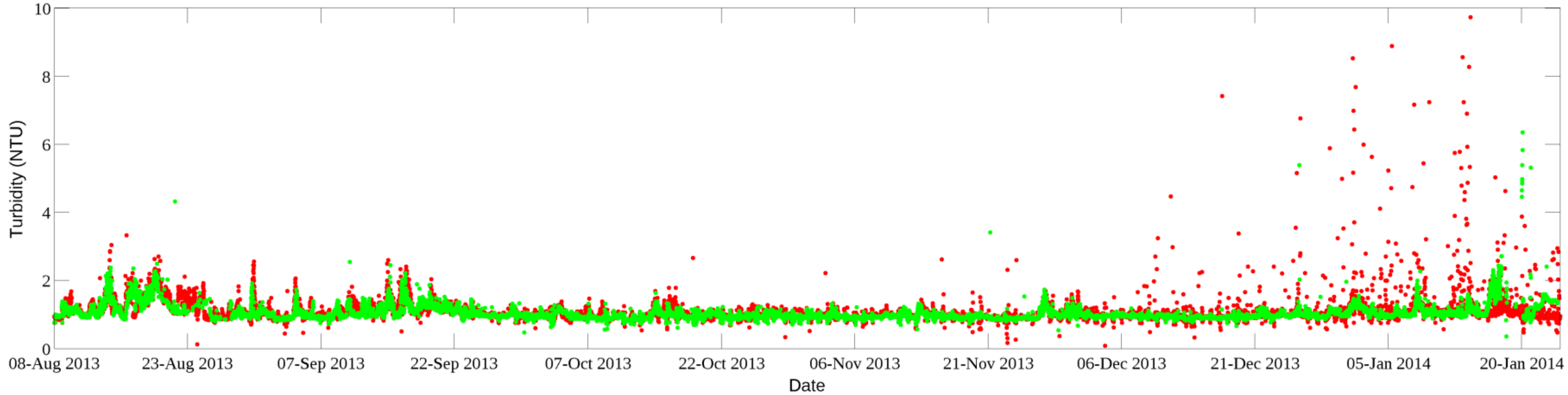

Figure 4.2. Turbidity at 2 m below the surface measured by buoys A (red) and B (green) at site A0.

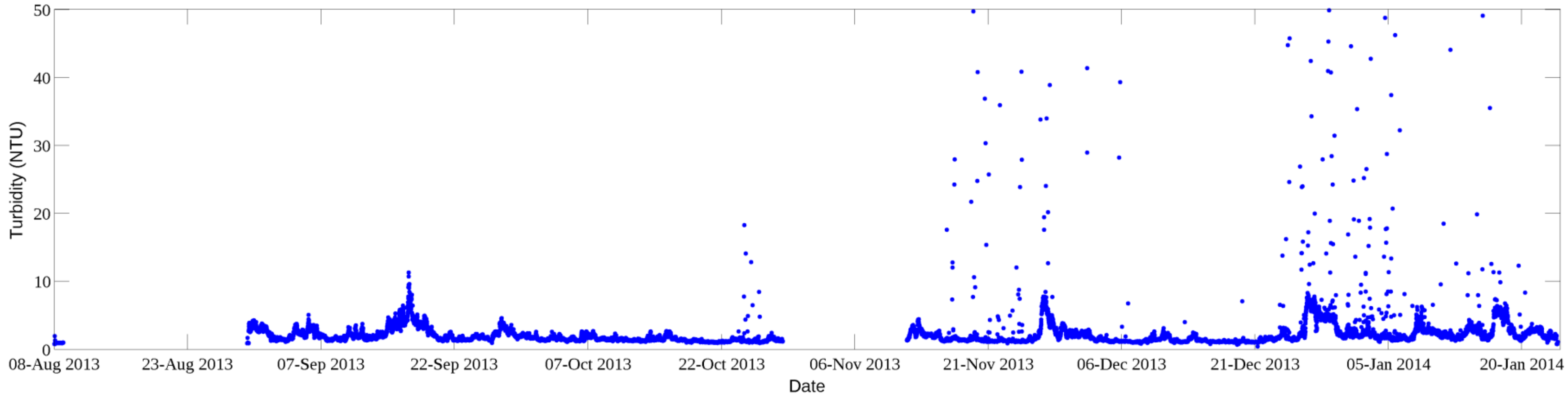

Figure 4.3. Turbidity at 2 m below the surface measured by buoy C off Cornish Head. Notice the different scale compared to that in Figure 4.2.

5. CURRENTS INSIDE OTAGO HARBOUR

Current measured at two positions inside the Otago Harbour (Table 5.1) are provided below. Total and tidal depth averaged signals are shown in Figures 5.2 and 5.3. Tidal constituents are provided in Tables 5.2 and 5.3.

Figure 5.1 Positions of the ADCP instruments in Otago Harbour.

Table 5.1 Dates and positions of the instruments deployed in the Harbour in January 2014.

Site	Instrument	Measurement		Dates		Deployment position (WGS 84)		Depth (m)
		Waves	Currents	Deployment	Recovery	Latitude	Longitude	
Entrance	ADCP		X	28/10/2013	10/03/2014	45 46.991	170 43.271	20.9
Swinging basin	ADCP		X	29/01/2014	10/03/2014	45 48.928	170 37.923	16.6

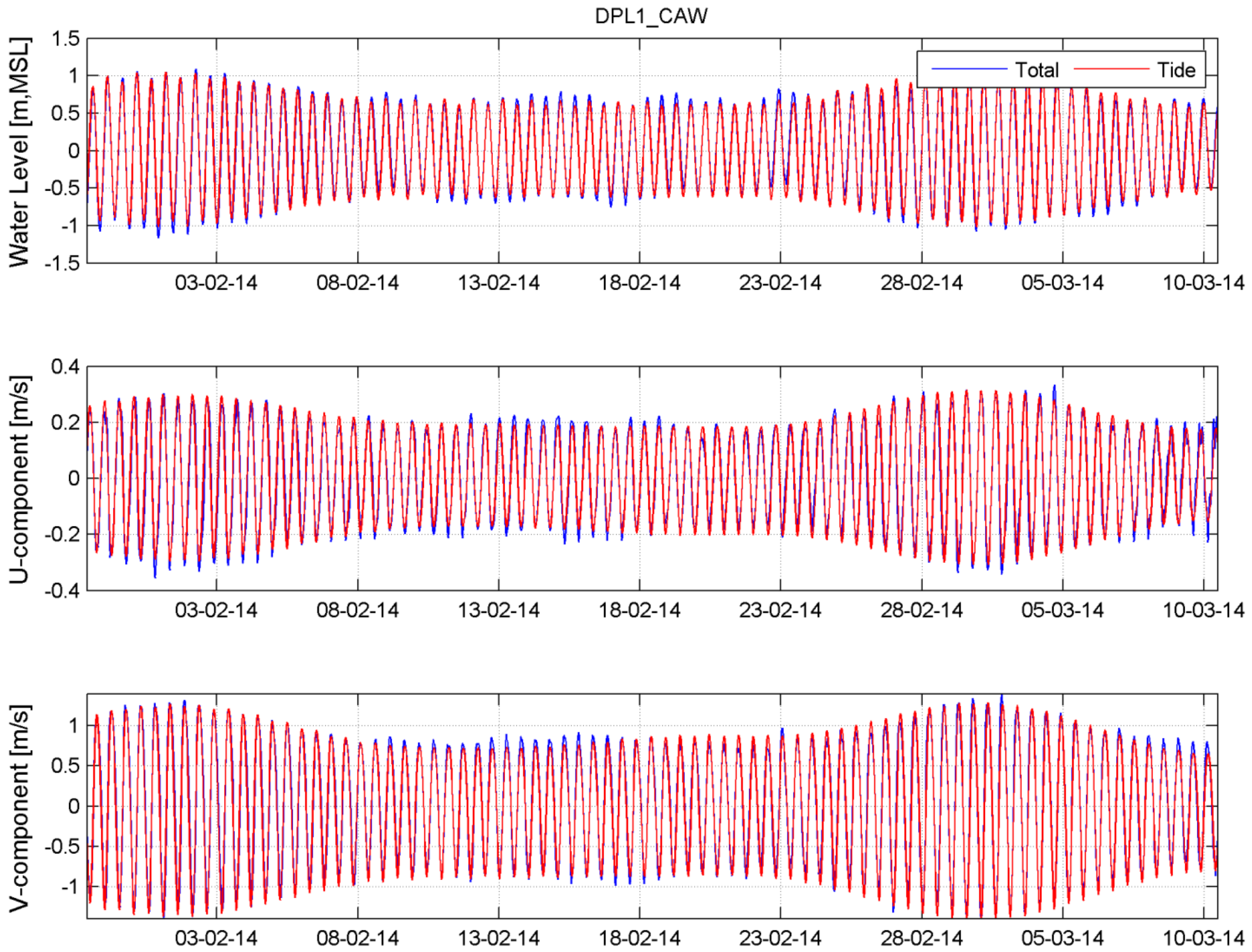

Figure 5.2 Time series of water level and depth-averaged currents at Entrance. Tidal signals are shown in red.

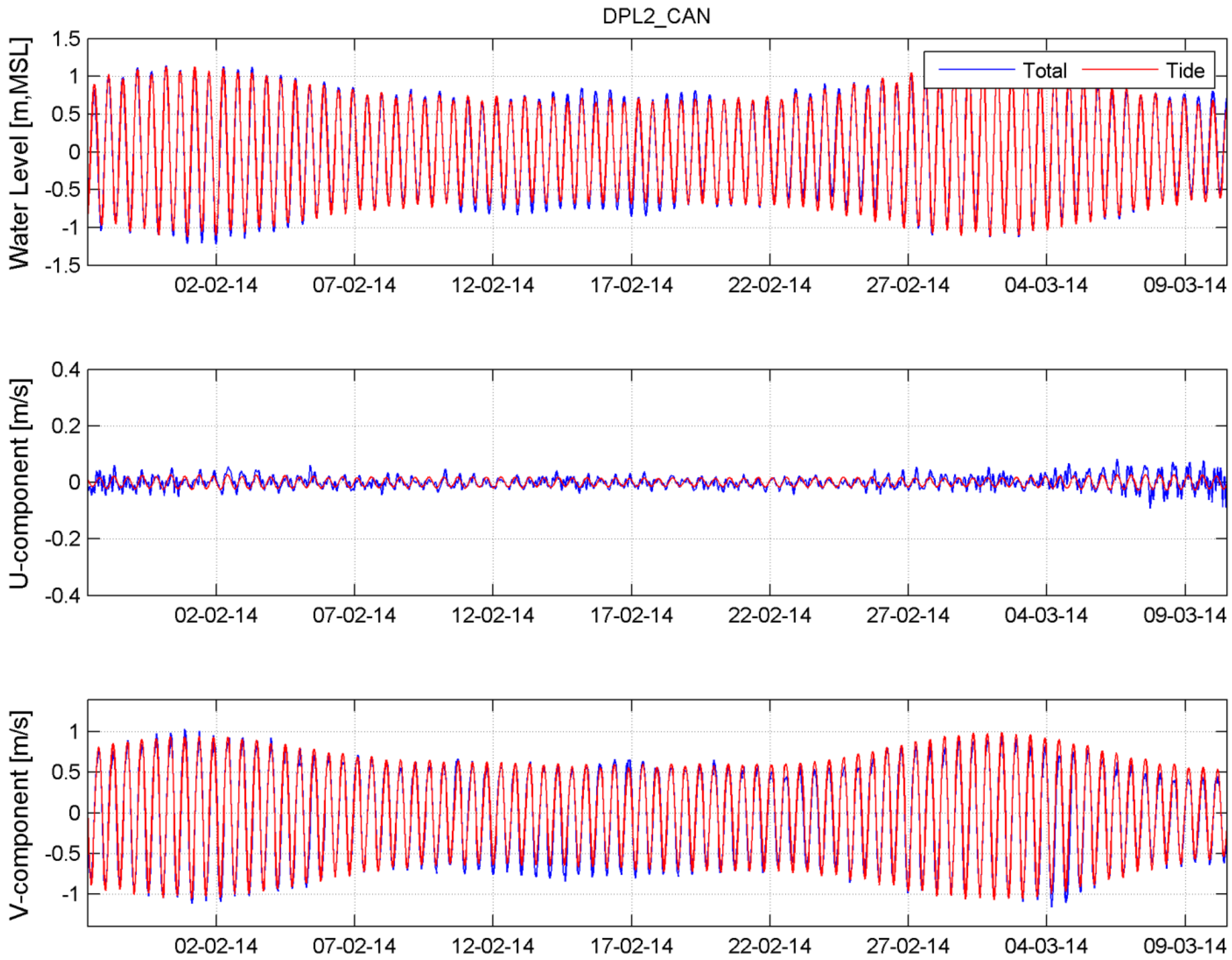

Figure 5.3 Time series of water level and depth-averaged currents at Swinging Basin. Tidal signals are shown in red.

Table 5.2 Tidal elevation and current constituents at Entrance.

	Elevation		U-component		V-component	
	amp [m]	**pha [deg.]**	**amp [m/s]**	**pha [deg.]**	**amp [m/s]**	**pha [deg.]**
Q1	0.01	36.71	0.00	20.17	0.01	156.29
O1	0.03	58.61	0.00	54.24	0.01	158.23
P1	0.01	78.89	0.01	27.28	0.01	199.58
K1	0.03	106.07	0.01	340.11	0.02	168.29
N2	0.19	66.14	0.06	355.39	0.25	176.80
M2	0.69	106.71	0.21	33.14	0.91	213.99
S2	0.08	119.21	0.03	16.61	0.11	220.24
K2	0.03	95.40	0.03	57.11	0.06	241.22
M4	0.02	251.39	0.01	144.84	0.08	294.65

Table 5.3 Tidal elevation and current constituents at Swinging Basin.

	Elevation		U-component		V-component	
	amp [m]	**pha [deg.]**	**amp [m/s]**	**pha [deg.]**	**amp [m/s]**	**pha [deg.]**
Q1	0.01	58.89	0.00	330.62	0.01	155.98
O1	0.03	67.70	0.00	115.16	0.01	164.75
P1	0.00	61.93	0.00	165.90	0.01	301.09
K1	0.02	121.49	0.00	121.85	0.02	230.67
N2	0.20	88.91	0.00	156.67	0.19	198.06
M2	0.76	127.44	0.02	245.69	0.70	233.23
S2	0.10	140.91	0.01	338.04	0.11	237.86
K2	0.01	157.76	0.01	99.53	0.05	291.35
M4	0.01	276.05	0.00	255.15	0.06	243.22