Oceanographic observations in coastal waters of Shelburne County, Nova Scotia, 2008-2014

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ABSTRACT

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Oceanographic data were collected in coastal waters of Shelburne County, Nova Scotia, where two new salmon aquaculture leases were approved in December 2012. Acoustic Doppler Current Profilers (ADCPs) were deployed in 2012, 2013, and 2014. Data from an earlier ADCP deployment in 2008 are also included in this report. Hydrographic data (vertical temperature and salinity profiles) were collected at several locations in 2012, 2013, and 2014. Sea level recorders were deployed at 4 locations in 2013. The data will be used to calibrate and validate circulation models, which will be used to improve predictions of environmental impacts of fish farms in this area.

RÉSUMÉ

Page, F.H., Haigh, S.P., Chang, B.D., and Losier, R.J. 2017. Oceanographic observations in coastal waters of Shelburne County, Nova Scotia, 2008-2014. Can. Tech. Rep. Fish. Aquat. Sci. 3240: iv + 108 p.

Des données océanographiques ont été recueillies dans les eaux côtières du comté de Shelburne, en Nouvelle-Écosse, où deux nouvelles concessions à bail de salmoniculture ont été approuvées en décembre 2012. Des profileurs de courant à effet Doppler (ADCP) ont été mis en place en 2012, 2013 et 2014. Des données tirées d'un précédent déploiement d'un ADCP en 2008 sont également incluses dans le présent rapport. Des données hydrographiques (profils verticaux de la température et de la salinité) ont été recueillies à plusieurs endroits en 2012, 2013 et 2014. Des enregistreurs du niveau de la mer ont été installés à quatre endroits en 2013. Les données seront utilisées pour étalonner et valider les modèles de circulation qui seront utilisés pour améliorer les prévisions des impacts environnementaux des exploitations aquacoles dans cette zone.

INTRODUCTION

The coast of Shelburne County, Nova Scotia is a developing aquaculture area (Fig. 1). In 2010, three new fish farms were proposed in this area: one near McNutts Island (site 1357) and two in Jordan Bay (sites 1358 and 1359). In December 2012, two of the farms (sites 1358 and 1359) were approved, but they did not stock salmon smolts until the spring of 2013; the other proposed farm (site 1357) was not approved. There are also four previously approved salmon farm leases in the area: three in Shelburne Harbour (sites 0983, 1192, and 0602) and one near McNutts Island (site 1345). The addition of new salmon farms in this area has raised concerns for potential environmental effects of having several farms operating within the Shelburne area.

Previously, the DEPOMOD model was used to predict benthic impacts of the three proposed salmon farms in this area (DFO 2012). Research has been recently conducted on developing improved water circulation predictions in the Shelburne area using the Finite Volume Community Ocean Model (FVCOM) (Chen et al. 2006); FVCOM will be used to provide improved predictions of environmental impacts of fish farms in this area. The purpose of this study was to collect additional current velocity and hydrographic data, to assist in the validation and calibration of FVCOM in the Shelburne area.

Acoustic Doppler Current Profilers (ADCPs) were deployed to collect current velocity data in the Shelburne area in 2012, 2013, and 2014. Conductivity-temperature-depth (CTD) profiles were obtained at several locations in the same years. Existing sea level data for the Shelburne area were limited, somewhat dated, and largely consisted of tidal parameters rather than the raw data needed to address wind-driven circulation issues (e.g. sea level data for Shelburne Harbour reported in Lively 1984, 1985 & 1989); hence, additional sea level data were collected in 2013.

This report includes data collected as part of a project supported by the DFO Program for Aquaculture Regulatory Research (PARR, project 2012-M-06), including the original project during 2012-2013 and project extensions for 2013-2014 and 2014-2016.

METHODS

Study area

The study area was in the coastal waters of Shelburne County, in southwestern Nova Scotia. As noted above, there are 4 previously approved finfish farms in this area, as well as 2 new farms that were approved in 2012 and one proposed farm that was rejected in 2012 (Fig. 1). The tidal range in Shelburne Harbour is small: the mean predicted tidal range during 2012-2014 was 1.5 m (range: 0.7-2.5 m) (WWW Tide and Current Predictor: http://tbone.biol.sc.edu/tide/).

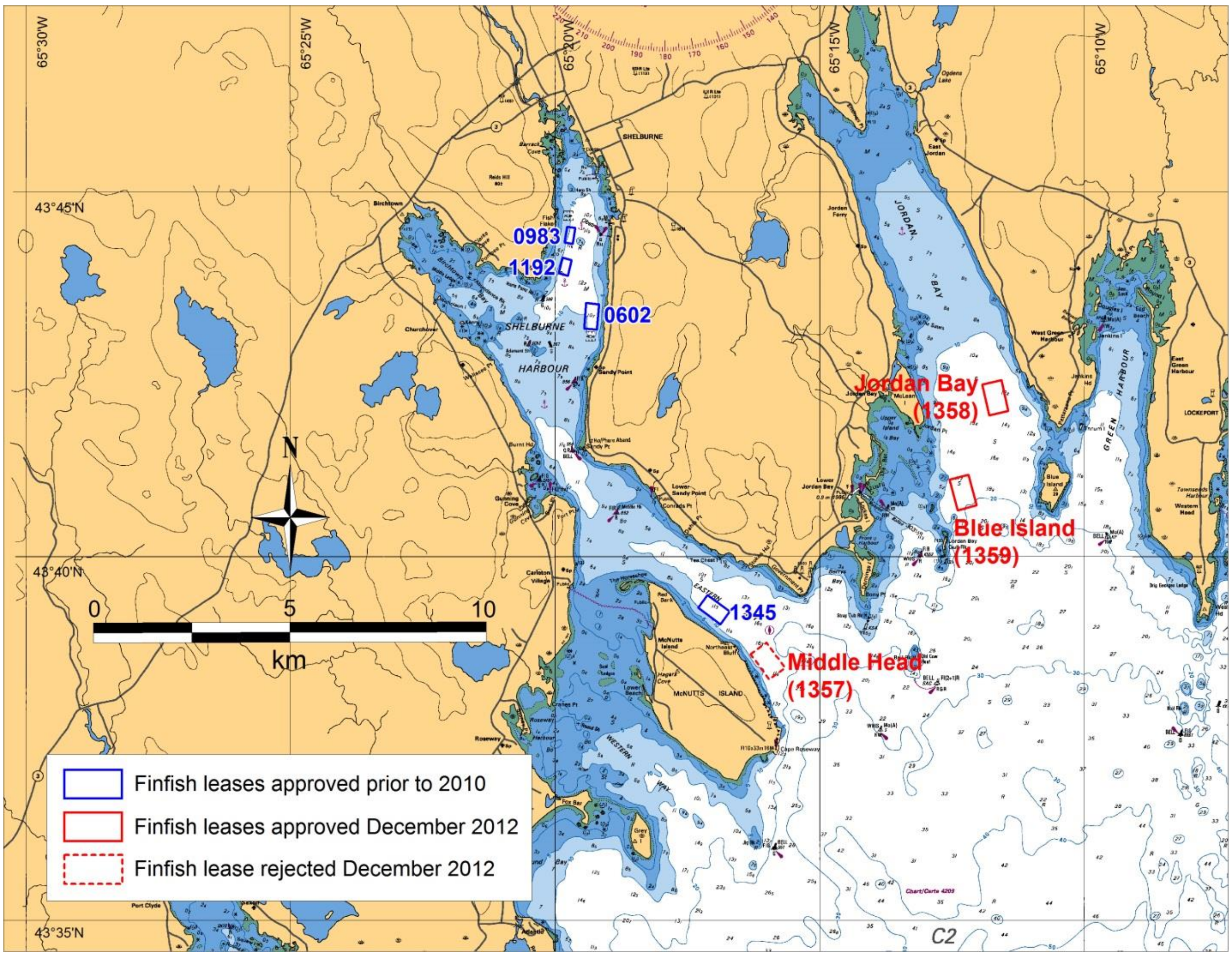


Fig. 1. Map of the Shelburne area, showing locations of finfish farm leases. Four farms had been approved prior to 2010: three in Shelburne Harbour (0602, 0983, and 1192) and one off McNutts Island (1345). Three new farms were proposed in 2010: sites in Jordan Bay (1358) and Blue Island (1359) were approved in December 2012, while a site at Middle Head (1357) was rejected. The background map is part of Canadian Hydrographic Service chart 4241 (Lockeport to Cape Sable, November 2002 edition); depths are in metres below Chart Datum (lowest normal tide).

Current meter deployment

Current velocity data were collected using Teledyne RD Instruments WorkHorse Sentinel Acoustic Doppler Current Profilers (ADCPs), either 300 or 600 kHz frequency (Fig. 2). ADCPs use the Doppler effect by transmitting sound at a fixed frequency and listening to echoes returning from sound scatterers (such as small particles or plankton) in the water (Teledyne RD Instruments 2011). ADCPs were deployed near the seafloor, facing upwards. In each deployment an ADCP was mounted in a SUBS™ ADCP model A2 buoy (Open Seas Instrumentation Inc.), which was attached via a Teledyne Benthos 866-A acoustic release to an anchor (~90 kg of steel chain), so that the pressure sensor at the top of the meter was ~1.5 m above the seafloor (Fig. 2). A groundline (~100 m) was attached to the anchor to facilitate instrument recovery.

In 2012, two ADCPs were deployed, one at each of the farms that were approved in December 2012 (Table 1 & Fig. 3): deployment 527 was at site 1358 from 16 October 2012 to 12 January 2013, prior to the start of farm operations; another ADCP was deployed at the same time at site 1359 (also prior to the start of farm operations), but the instrument could not be recovered, so no data were obtained. Two other ADCP deployments started on 2 October 2013, neither located near farm sites (Table 1 & Fig. 3): deployment 530 in Shelburne Harbour and deployment 531 in inner Jordan Bay; both were retrieved on 13 November 2013. Two more ADCP deployments started on 24 September 2014 (Table 1 & Fig. 3): deployment 559 at site 1359 (which was actively farming at the time) and deployment 560 at site 0602 (which was inactive). Deployment 560 was retrieved on 17 November 2014 and deployment 559 on 4 December 2014.

Current velocity data are also presented from a previous ADCP deployment conducted by our research team within the study area: deployment 358 (Table 1 & Fig. 3) was at salmon farm site 1345, near McNutts Island, from 7 March to 7 April 2008, prior to the start of that farm's operations later in 2008.

Of the 6 ADCP deployments included in this report, the shortest was deployment 358 at McNutts Island in 2008 (31 d) and the longest was deployment 527 at Jordan Bay in 2012 (88 d) (Table 1).

Prior to each deployment, battery packs were degaussed and ADCP compasses were calibrated and swung. An overall error <2° in compass swing (calculated by the ADCP calibration software) was considered to be acceptable.

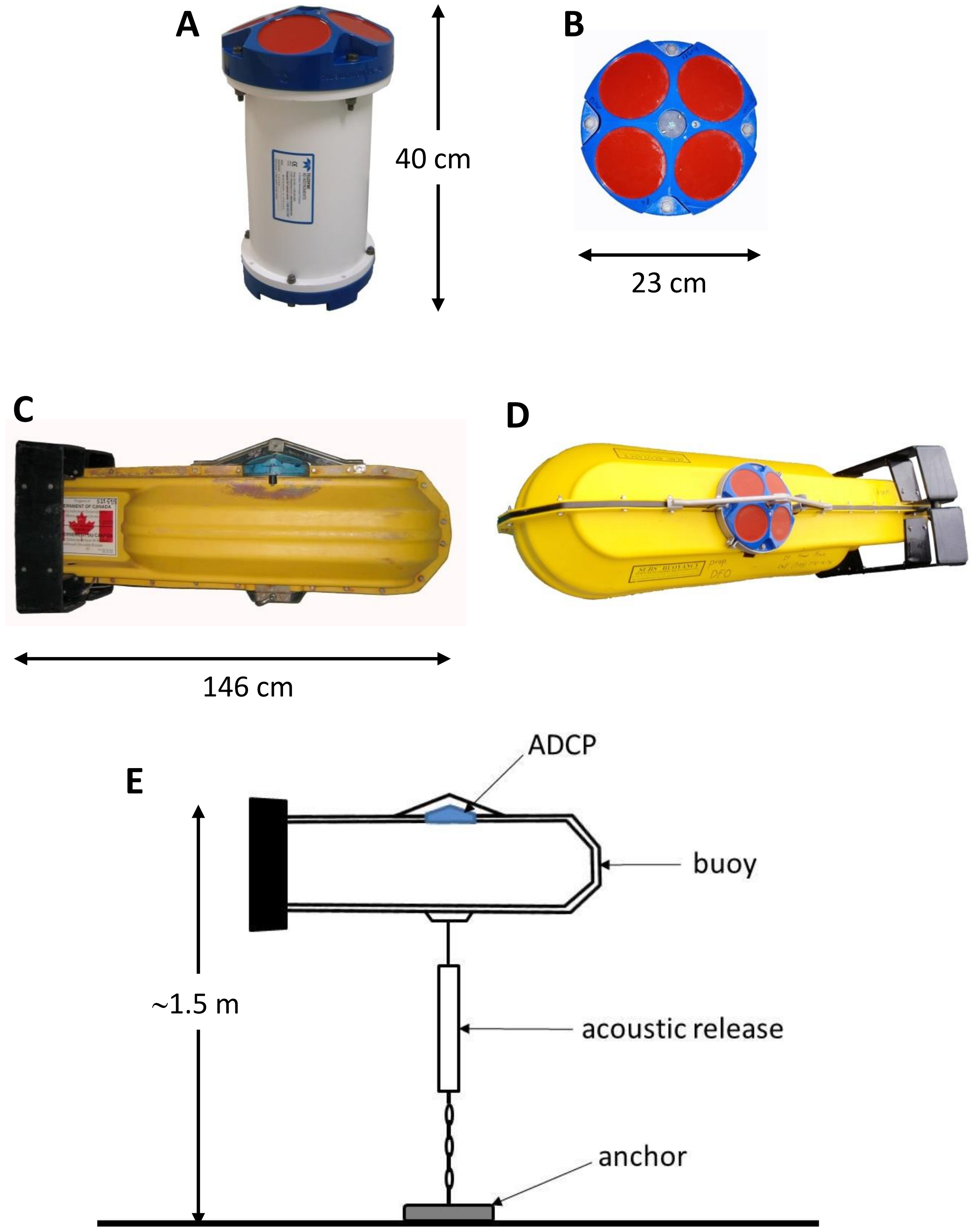


Fig. 2. RDI Workhorse Sentinel Acoustic Doppler Current Profiler (ADCP). A: side view. B: top view. C & D: ADCP mounted in SUBS™ ADCP buoy (model A2), side and top views. E: schematic diagram of an ADCP deployment; there was also a groundline (~100 m) attached to the anchor (not shown).

Table 1. Dates of deployment and retrieval of Acoustic Doppler Current Profilers (ADCPs) in the Shelburne area, 2008-2014. Deployment locations are shown in Fig. 3.

Location	Deploy-ment	Latitude (°N)	Longitude (°W)	Deployment date	Retrieval date	Duration (d)	Duration (h)
McNutts I. (site 1345)	358	43.65443	65.28359	7-Mar-2008	7-Apr-2008	31.0	743
Jordan Bay (site 1358)	527	43.70308	65.19624	16-Oct-2012	12-Jan-2013	88.2	2 116
Shelburne Harbour	530	43.71450	65.33640	2-Oct-2013	13-Nov-2013	42.1	1 011
Inner Jordan Bay	531	43.72680	65.20880	2-Oct-2013	13-Nov-2013	42.0	1 008
Blue Island (site 1359)	559	43.67807	65.19936	24-Sep-2014	4-Dec-2014	72.2	1 732
Shelburne Harbour (site 0602)	560	43.71808	65.32289	24-Sep-2014	17-Nov-2014	54.6	1 310

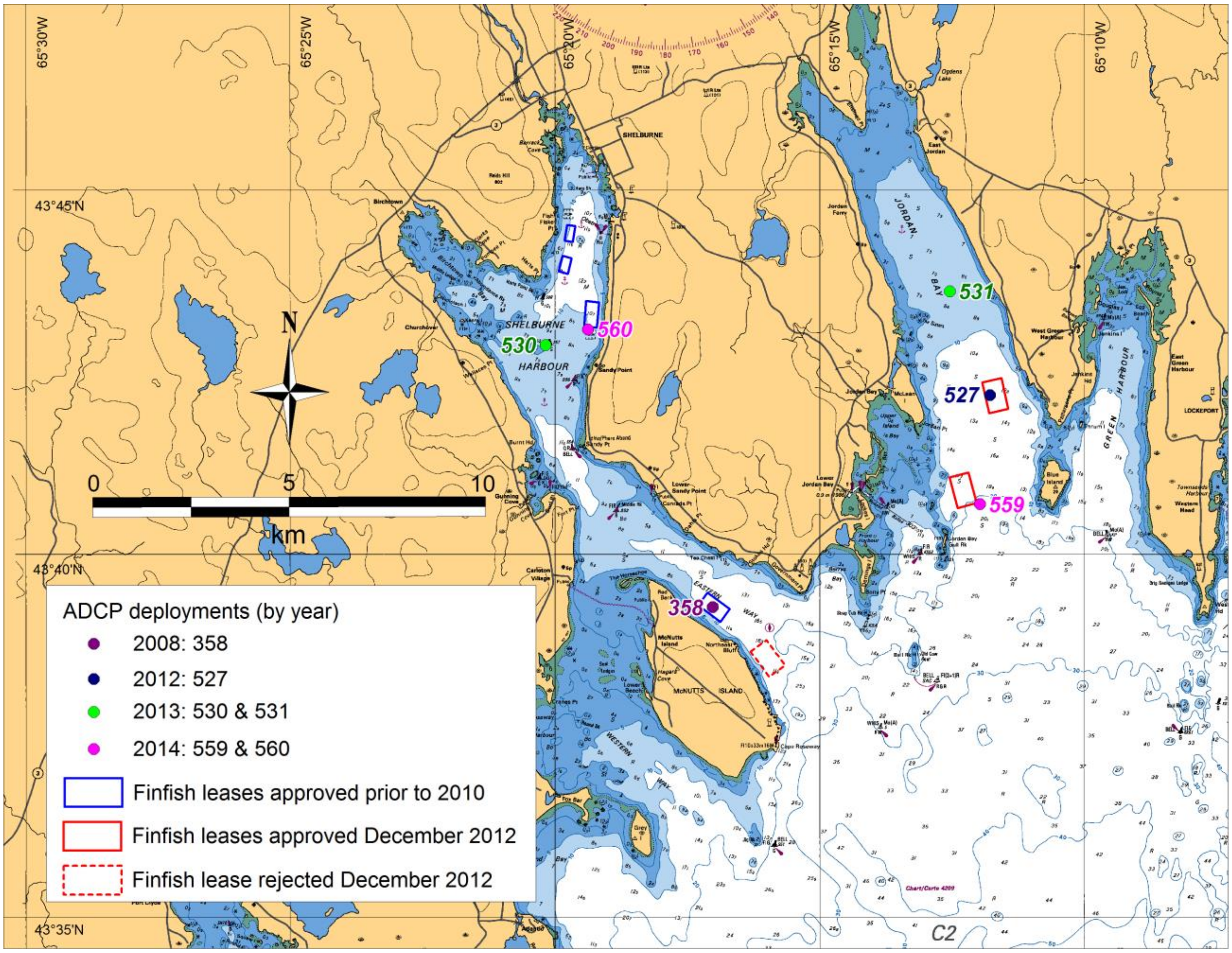


Fig. 3. Map of the Shelburne area, showing locations of Acoustic Doppler Current Profiler (ADCP) deployments during 2008-2014. Also shown are locations of finfish farms. The background map is part of Canadian Hydrographic Service chart 4241 (Lockeport to Cape Sable, November 2002 edition); depths are in metres below Chart Datum (lowest normal tide).

Current meter data collection and editing

ADCP data were collected in raw internally processed mode. The raw data records contained data read directly by the ADCP and were for the most part not scaled or corrected by offsets that could be entered by the user when initializing the ADCP for deployment. This allowed the user to do the necessary adjustments and scaling when post processing the raw ADCP data. Data that were adjusted at post processing were the depth of the transducer face and the current direction, which was adjusted to account for magnetic variation. Variables that were entered during the initialization of the ADCP were salinity and temperature estimates which were used for computation of the speed of sound in water; in all deployments, the temperature entered was 5°C and the salinity was 32 psu. Although the near surface temperature in Shelburne Harbour can reach 15°C in October-November, and the near surface salinity can fall to as low as 12 psu (see below), these variations would change the speed of sound in water by ≤2%.

Editing of the current meter data was done after the raw ADCP data was output into a readable ASCII text matrix file. Each segment (data collection period) generated from the output included averages of the current speed, echo intensity, correlation magnitude, and percent of good data for each depth bin collected in the segment. Echo intensity, correlation magnitude, and percent good are key quality control parameters. Echo intensity is a measure of the signal strength intensity returned to the transducer. Correlation magnitude is a measurement of how much the particle distribution changes between phase measurements; the less the distribution changes, the higher the correlation, and the more precise the velocity measurement. Percent good indicates the fraction of the pings that pass a variety of criteria in each of the 4 beams. Rejection criteria include low correlation, large error velocity, and false target thresholds. Ancillary data describing the instrument setup, date, time, pitch, and roll for each ensemble were also exported to the data matrix.

The ambiguity velocity (the maximum allowable radial motion for phase measurements to be unambiguous) was set at the default value (175 cm s^{-1}) in all deployments. Other set up parameters for the ADCPs are shown in Appendix A. The meters recorded current velocities in 1-m depth bins (except 0.5-m depth bins for deployment 358). The current velocity was recorded at 20-min intervals (except 15-min intervals for deployment 358). Segment lengths ranged from 4-20 min, ping intervals ranged from 1-6 s, and the number of pings per segment ranged from 200-250. The data output was an average of all pings collected during each segment in each depth bin. The time stamp associated with each average ping value was the time half-way through each segment and the depth was the mid-depth within each of the depth bins (1-m bins, except 0.5-m bins in deployment 358).

The standard deviation (SD) of the current velocity measurements was calculated by the instrument software:

$$SD_{velocity} = \frac{SD_{single\ ping}}{\sqrt{number\ of\ pings\ per\ segment}}$$

Values for the SD of a single ping vary with the instrument frequency and bin size, and are available in the ADCP Operation Manual (Teledyne RD Instruments 2014).

The ADCPs were deployed near the seafloor, facing upwards, and the first recorded raw depth intervals were 1.6-3.2 m above the transducer head. Depths were calculated by the instrument software from the pressure sensor output:

$$\text{Depth(m)} = \text{Pressure(kPa)} * (1.02 - 0.00069 * \text{ES})$$

where ES is the salinity setting (Teledyne RD Instruments 2016). Depths were compensated to include the mooring height (the distance between the seafloor and the pressure sensor located at the top of the ADCP), which was ≅1.5 m, so the deepest measurements were 3.1-4.7 m above the seafloor.

Data were edited to exclude records beyond the water depth recorded by the ADCP pressure sensor. The tidal amplitudes in this area require that measurements be taken at depths beyond the highest predicted tides in the area of the mooring. Accordingly, the ADCPs sampled well beyond the maximum water depth (i.e. including some measurements above the water surface). Therefore, the echoes and backscatter caused by the surface water layer must be identified and removed. This echo contaminated data was within 2.5 bin sizes of the water surface in most deployments; therefore, measurements from the top 2.5 m were removed. Data segments with recorded pitch or roll in excess of 15° were removed. Within each data segment, data from depth bins with <90% "percent good" were also removed.

To show differences in current velocity among depths, data were analyzed for three depth levels in each deployment: near bottom, mid-water, and near surface. The near bottom level was the closest depth bin to the seafloor which had good data in ≥85% of the segments (see Appendix B). The mid-water level was the bin which contained the mid-depth between the seafloor and the mean sea level. The near surface level was the depth range equal to the bin size closest to the sea surface, which had good data in ≥85% of the segments; this was 2.5-3.5 m below the surface, except 2.5-3.0 m in deployment 358 (see Appendix B). The depths for each of the three depth levels in each deployment, as well as the number and percentage of data records for each depth level, are shown in Table 2.

Current meter data processing

Principal current direction (PCD)

The average speed, $||\vec{u}||$, and magnetic direction, θ, of the ocean currents were recorded by the instrument for each depth bin and each time segment. As the direction does not take into account the local magnetic variation, δ, nor the instrument magnetic variation adjustment, δ_{ADCP}, these must be included when converting the current data into their east-west, u, and north-south, v, components:

$$u = ||\vec{u}|| \sin(\theta + \delta - \delta_{ADCP})$$

$$v = ||\vec{u}|| \cos(\theta + \delta - \delta_{ADCP})$$

where u and v are positive in the eastward and northward directions, respectively. Magnetic declination varies with location and time. For deployment 358, δ = -17.9° (i.e. 17.9° West); for deployment 527, δ = -17.4°; for deployment 530, δ = -17.2°; for deployment 531, δ = -17.3°, and for deployments 559 and 560, δ = -17.1°. In all deployments, the instrument magnetic variation was not adjusted pre-deployment, so $\delta_{ADCP} = 0$.

Before performing a tidal analysis on the current data, for each vertical level the horizontal currents were transformed from the recorded east-west and north-south components into the components along the major and minor principal axes, u_{maj} and u_{min}, respectively as described in section 4.3 of Emery and Thomson (2004):

$$u_{maj} = u \cos\theta_p + v \sin\theta_p$$

$$u_{min} = -u \sin\theta_p + v \cos\theta_p$$

where θ_p is the principal angle (measured counter-clockwise from the x-axis) and is given by

$$\theta_p = \frac{1}{2} \tan^{-1}\left[\frac{2\overline{u'v'}}{\overline{u'^2} - \overline{v'^2}}\right]$$

In the above equation, the overbar indicates that the quantities were averaged over the time series and u' and v' are the velocity fluctuations which were obtained by removing the means from the velocity components, i.e., $u' = u - \bar{u}$ and $v' = v - \bar{v}$.

Tidal Analysis

Tidal analysis of the ADCP data was performed on both the water depths and the horizontal velocities using the versatile tidal analysis program described by Foreman et al (2009). This program eliminates some of the restrictions of the earlier Institute of Ocean Sciences (IOS) tidal analysis package (Foreman 2004) that resulted from computer limitations. The newer versatile tidal analysis program allows for unevenly spaced data, gaps in the data, and multiple inferences from a single constituent. Unlike the original IOS tidal package (Foreman, 2004), which, based on record length, determined the constituents to include in the analysis, the newer versatile tidal analysis program requires the user to specify which constituents to include in the analysis. The methodology used to analyse the data is that suggested by Foreman et al. (2009).

Table 2. Depths and numbers of current velocity records for three depth levels (near surface, mid-water, and near bottom) in ADCP deployments in the Shelburne area, 2008-2014. See Table 1 and Fig. 3 for deployment dates and locations.

Location	Deploy-ment	Total water depth (m)	Total no. of segments	Depth level	Depth below surface (m)	Depth above seafloor (m)	No. of velocity records	% of total
McNutts I. (site 1345)	358	10.9 – 13.6	2 973	Near surface	2.5 – 3.0	8.1 – 10.6	2 759	93
				Mid-water	5.3 – 7.0	5.6 – 6.6	2 950	99
				Near bottom	7.8 – 10.5	3.1	2 963	>99
Jordan Bay (site 1358)	527	13.3 – 16.8	6 349	Near surface	2.5 – 3.5	10.7 – 13.7	6 047	95
				Mid-water	6.6 – 8.7	6.7 – 8.7	6 289	99
				Near bottom	9.6 – 13.1	3.7	6 284	99
Shelburne Harbour	530	8.7 – 11.2	3 032	Near surface	2.5 – 3.5	6.1 – 8.1	2 859	94
				Mid-water	4.1 – 6.1	4.1 – 6.1	2 950	97
				Near bottom	5.6 – 8.1	3.1	2 989	99
Inner Jordan Bay	531	9.2 – 11.7	3 026	Near surface	2.5 – 3.5	6.6 – 8.6	2 921	97
				Mid-water	4.6 – 6.1	4.6 – 5.6	2 954	98
				Near bottom	5.6 – 8.1	3.6	2 972	98
Blue Island (site 1359)	559	21.4 – 24.1	5 098	Near surface	2.5 – 3.5	18.7 – 20.7	4 482	88
				Mid-water	10.7 – 12.4	10.7 – 11.7	5 035	99
				Near bottom	16.7 – 19.4	4.7	5 036	99
Shelburne Harbour (site 0602)	560	11.0 – 13.9	3 860	Near surface	2.5 – 3.5	7.7 – 10.7	3 561	92
				Mid-water	5.3 – 7.2	5.7 – 6.7	3 812	99
				Near bottom	6.3 – 9.2	4.7	3 816	99

The tidal analysis was performed in a two pass process. For the first pass, a set of constituents that depends on the record length, and is based on the Rayleigh criterion decision tree described in Foreman (2004), was used. Table 3 lists the constituents included in the first pass of the tidal analysis program for three different time ranges.

For each constituent included, the tidal analysis program outputs the results of a Student's t-test. These results were used to determine if a given constituent should be included in the final analysis. If, for a given constituent, the t-test value was ≥2.58 (for an infinite degrees of freedom, 99% confident that the constituent is significant), then it was included in the final call to the tidal analysis program. Note that Z0 (mean depth, for water depth analyses; mean flow, for current velocity analyses) was always included in the analysis.

As all the records analysed were shorter than 180 d, inferring the amplitudes and phases of important constituents was crucial in order to correctly compute the amplitudes and phases of the constituents included in the tidal analysis. A constituent was inferred from one of the five reference constituents: M2 (principal lunar semidiurnal), N2 (lunar elliptical semidiurnal), S2 (principal solar semidiurnal), K1 (lunisolar diurnal), and O1 (principal lunar diurnal). If the record length was such that the constituent was not included in the analysis, the constituent was connected to the reference constituent through one of Foreman's (2004) Rayleigh criterion decision trees, providing there were constituent data available for inference.

The record lengths (durations) of the ADCP deployments (Table 1) fell into one of two ranges: 662-764 h (deployment 358) and 764-4383 h (all others). Inferred constituents included in the tidal analysis depend on the record length and were based on the Rayleigh comparison pairs for diurnal and semi-diurnal constituents (from Tables 2 & 3 in Foreman 2004). Table 4 lists the inferred constituents used for the analysis of water depths for the two ranges of record length. Inference relies on the availability of tidal constituent information based on long term time series at a nearby geographic location. Shelburne is located mid-way between Yarmouth and Halifax, the two closest permanent tide gauges. Tidal amplitudes and phases for sea level height for the five main constituents, M2, N2, S2, K1 and O1, are given in Table 5 for Halifax, Shelburne, and Yarmouth. The semi-diurnal constituents for Shelburne are tidally closest to Halifax and so inference from M2, N2 and S2 was based on tidal constituents for Halifax from 2001 tide gauge data. For the diurnal constituents, K1 is tidally closest to Yarmouth and so inference of constituents from K1 was based on tidal constituents for Yarmouth from 2001 tide gauge data. The amplitudes and phases for O1 at Shelburne lie between those at Halifax and Yarmouth but are closer to those at Yarmouth and so inference from O1 was also based on Yarmouth data. As no nearby long term time series of currents were available, equilibrium tides were used for inference. Ratios for the amplitudes were calculated using values from Tables 2 and 3 in Foreman (2004). Phase differences were set to zero as described in Pugh (1987).

Table 3. List of constituents included in the tidal analysis of both depth and current data, based on record length.

Record length														
355–662 h			662–764 h					764–4383 h						
Z0	M3	2SK5	Z0	K1	S2	MN4	2MN6	Z0	O1	N2	ETA2	M4	2MN6
MSF	SK3	M6	MSF	J1	ETA2	M4	M6	MM	NO1	EPS2	MO3	SN4	M6
O1	M4	2MS6	2Q1	OO1	MO3	MS4	2MS6	MSF	K1	MU2	M3	MS4	2MS6
K1	MS4	2SM6	Q1	UPS1	M3	S4	2SM6	ALP1	J1	M2	MK3	S4	2SM6
M2	S4	3MK7	O1	N2	MK3	2MK5	3MK7	2Q1	OO1	L2	SK3	2MK5	3MK7
S2	2MK5	M8	NO1	M2	SK3	2SK6	M8	Q1	UPS1	S2	MN4	2SK5	M8

Table 4a. Inferred constituents used in tidal analysis of depths with record lengths 662-764 h.

Reference constituent	Inferred constituent	amp. ratio[1]	phase diff.[2]
M2[3]	MKS2	0.0072	-83.08
	H1	-	-
	GAM2	-	-
	H2	-	-
N2[3]	NU2	0.2137	-3.64
	MU2	0.1515	-7.23
	2N2	0.1325	16.77
S2[3]	K2	0.2929	3.87
	L2	0.1876	8.42
	LDA2	0.0671	38.22
	T2	-	-
	R2	-	-
K1[4]	P1	0.3293	2.21
	PHI1	0.0197	-96.59
	PI1	-	-
	S1	-	-
	PSI1	-	-
O1[4]	TAU1	0.00436	29.64

[1] The ratio of the amplitude of the inferred constituent to the amplitude of the constituents from which it is inferred [e.g., amp(MKS2)/amp(M2)].

[2] The difference between the phase of a constituent and the phase of a constituent that is being inferred [e.g., phase(M2)–phase(MKS2)].

[3] Inference of semi-diurnal constituents used Halifax data.

[4] Inference of diurnal constituents used Yarmouth data.

Table 4b. Inferred constituents used in tidal analysis of depths with record lengths 764-4383 h.

Reference Constituent	Inferred Constituent	amp. ratio[1]	phase diff.[2]
M2[3]	MKS2	0.0072	83.08
	H1	-	-
	GAM2	-	-
	H2	-	-
N2[3]	NU2	0.2137	-3.64
S2[3]	K2	0.2929	3.87
	T2	-	-
	R2	-	-
K1[4]	P1	0.3293	2.21
	PHI1	0.0197	-96.59
	PI1	-	-
	S1	-	-
	PSI1	-	-
O1[4]	TAU1	0.0436	29.64

[1] The ratio of the amplitude of the inferred constituent to the amplitude of the constituents from which it is inferred [e.g., amp(MKS2)/amp(M2)].

[2] The difference between the phase of a constituent and the phase of a constituent that is being inferred [e.g., phase(M2)–phase(MKS2)].

[3] Inference of semi-diurnal constituents used Halifax data.

[4] Inference of diurnal constituents used Yarmouth data.

Table 5. Amplitudes and phases of the five main tidal constituents (M2, N2, S2, K1 and O1) at Yarmouth, Shelburne, and Halifax, from WebTide's Scotian Shelf grid (http://www.bio.gc.ca/science/research-recherche/ocean/webtide/index-en.php).

	Yarmouth		Shelburne		Halifax	
Tidal constituent	Amplitude (m)	Phase (°)	Amplitude (m)	Phase (°)	Amplitude (m)	Phase (°)
M2	1.696	64.5	0.746	4.3	0.629	-10.7
N2	0.359	36.7	0.169	-21.2	0.139	-34.3
S2	0.278	103.1	0.149	37.8	0.142	24.7
K1	0.137	177.6	0.132	150.6	0.113	118.3
O1	0.106	158.0	0.088	121.2	0.059	74.6

Conductivity-temperature-depth (CTD) profiles

Six conductivity-temperature-depth (CTD) profiles were obtained using a YSI CastAway-CTD (Fig. 4) on 25 July 2012 (Table 6 & Fig. 5). During 16-18 October 2012, CTD profiles were obtained using a Sea-Bird Electronics model SBE 25-03 Sealogger (Fig. 4) at 20 stations (Table 6 & Fig. 5). CTD profiles were also obtained at or near 18 of the same 20 stations on 2-3 October 2013 (Table 7 & Fig. 6) using the Sea-Bird instrument. CTD profiles were also obtained (using the Sea-Bird instrument) at 9 of these 18 stations on 13-14 November 2013 (Table 7 & Fig. 6). Sea-Bird CTD profiles were also obtained at 20 stations on 23-24 September 2014, including all 18 of the stations sampled in 2013 (Table 8 & Fig. 7).

Sea level data loggers

Temporally varying pressure and water temperature data were collected using RBR*duo* temperature and depth loggers (Fig. 4). These instruments were deployed on the seafloor at four locations on 2-3 October 2013 and were retrieved on 13-14 November 2013 (Table 9 & Fig. 6). These loggers recorded pressure and temperature data at 5 min intervals. Depths were calculated by the instrument software from the pressure sensor output and were compensated to include the mooring height, which was ≅25 cm (the distance between the seafloor and the pressure sensor).

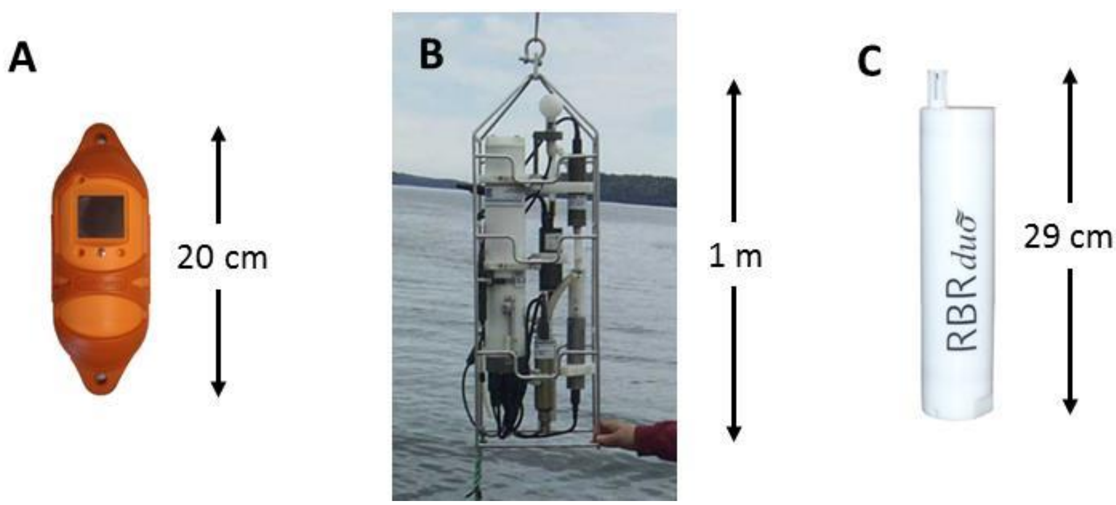


Fig. 4. Instruments used to collect hydrographic and sea level data. A: YSI CastAway-CTD. B: Sea-Bird Electronics model SBE 25-03 Sealogger. C: RBR*duo* temperature and depth logger.

Table 6. Locations and dates for CTD profiles in the Shelburne area in 2012. Profiles were conducted using a YSI CastAway-CTD in July and a Sea-Bird SBE 25-03 Sealogger in October. See Fig. 5 for deployment locations. UTC was 3 h ahead of local time (Atlantic Daylight Time).

Station	Deployment	Date	Time (UTC)	Latitude (°N)	Longitude (°W)
CA-1	-	25-Jul-2012	16:39	43.70312	65.19541
CA-2	-	25-Jul-2012	16:51	43.67977	65.20258
CA-3	-	25-Jul-2012	17:12	43.65453	65.28237
CA-4	-	25-Jul-2012	17:31	43.69013	65.32815
CA-5	-	25-Jul-2012	17:45	43.73393	65.32902
CA-6	-	25-Jul-2012	17:50	43.75291	65.32186
CTD12-1	3183	16-Oct-2012	16:33	43.66766	65.30497
CTD12-2	3184	16-Oct-2012	16:46	43.68045	65.31961
CTD12-3	3185	16-Oct-2012	17:28	43.69514	65.33315
CTD12-4	3186	16-Oct-2012	17:44	43.71387	65.32979
CTD12-5	3187	16-Oct-2012	17:58	43.72269	65.34928
CTD12-6	3188	16-Oct-2012	18:11	43.73011	65.32902
CTD12-7	3189	16-Oct-2012	18:26	43.74690	65.32233
CTD12-8	3190	17-Oct-2012	12:42	43.67831	65.20197
CTD12-9	3191	17-Oct-2012	13:11	43.67687	65.20365
CTD12-10	3192	17-Oct-2012	14:16	43.70228	65.19340
CTD12-11	3193	17-Oct-2012	14:57	43.75765	65.22739
CTD12-12	3194	17-Oct-2012	15:21	43.72880	65.21522
CTD12-13	3195	17-Oct-2012	15:37	43.69350	65.20441
CTD12-14	3196	17-Oct-2012	16:04	43.67386	65.15865
CTD12-15	3197	17-Oct-2012	16:21	43.64344	65.18354
CTD12-16	3198	17-Oct-2012	16:47	43.62962	65.20790
CTD12-17	3199	17-Oct-2012	17:04	43.59048	65.20578
CTD12-18	3200	17-Oct-2012	17:33	43.64757	65.25946
CTD12-19	3201	17-Oct-2012	17:55	43.65606	65.27975
CTD12-20	3202	18-Oct-2012	10:05	43.59128	65.25087

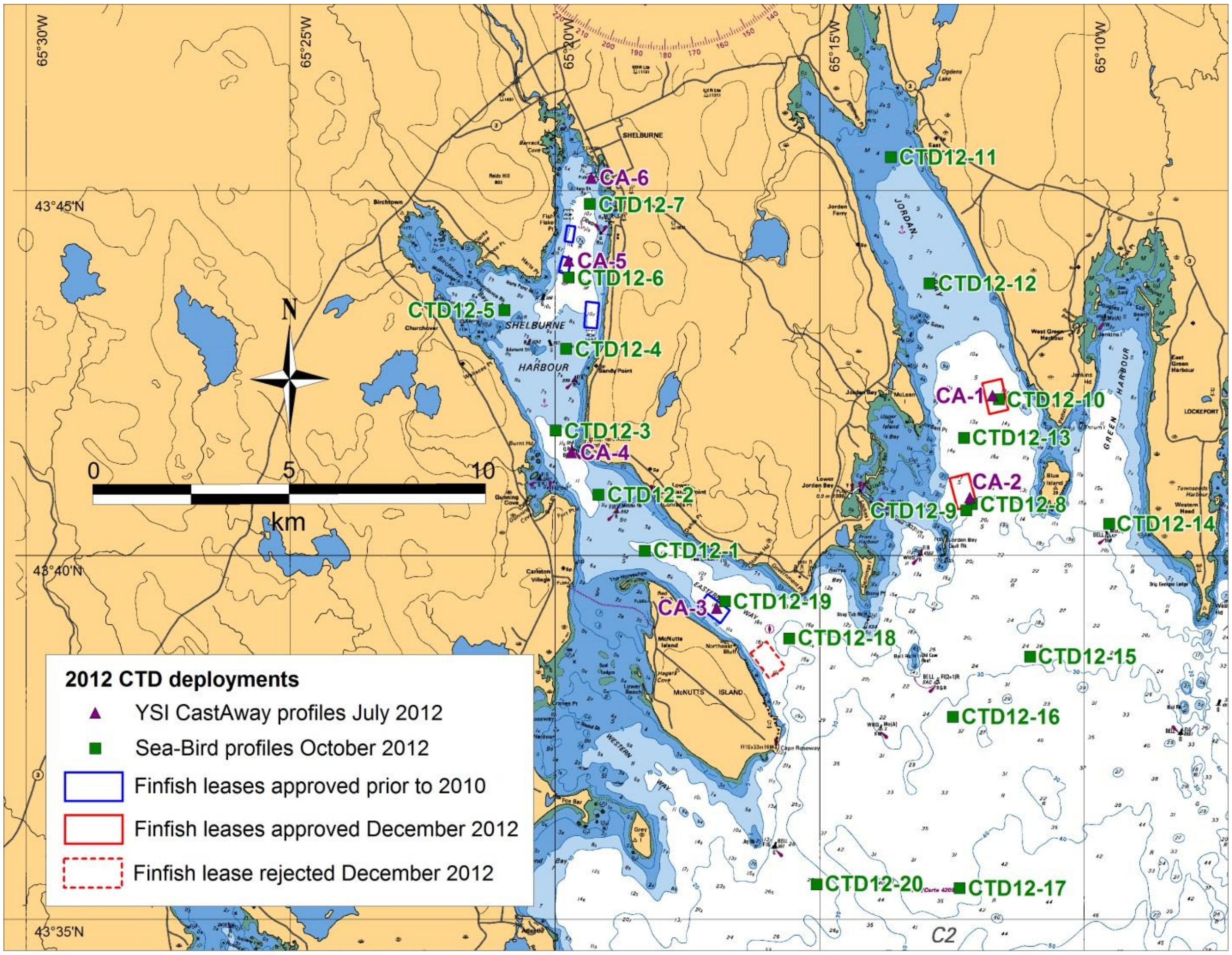


Fig. 5. Map of the Shelburne area, showing stations for conductivity-temperature-depth (CTD) profiles in 2012. Profiles were conducted using a YSI CastAway-CTD in July and a Sea-Bird SBE 25-03 Sealogger in October. The locations of finfish farm leases are also shown. The background map is part of Canadian Hydrographic Service chart 4241 (Lockeport to Cape Sable, November 2002 edition); depths are in metres below Chart Datum (lowest normal tide). See Table 6 for dates and times of deployments.

Table 7. Locations and dates for CTD profiles in the Shelburne area in 2013. All profiles were conducted using a Sea-Bird SBE 25-03 Sealogger. See Fig. 6 for deployment locations. UTC was 3 h ahead of local time (Atlantic Daylight Time) for the October deployments and 4 h ahead of local time (Atlantic Standard Time) for the November deployments.

Station	Deployment	Date	Time (UTC)	Latitude (°N)	Longitude (°W)
CTD13-1	3430	03-Oct-2013	12:52	43.66508	65.29610
CTD13-2	3431	03-Oct-2013	13:29	43.68030	65.31927
CTD13-3	3432	03-Oct-2013	13:38	43.69400	65.32875
CTD13-4	3434	03-Oct-2013	13:53	43.71690	65.32422
CTD13-5	3433	03-Oct-2013	13:47	43.72423	65.34855
CTD13-6	3435	03-Oct-2013	14:03	43.73175	65.32620
CTD13-7	3436	03-Oct-2013	14:10	43.74443	65.31838
CTD13-8	3424	03-Oct-2013	11:37	43.68338	65.20163
CTD13-10	3421	02-Oct-2013	18:39	43.70782	65.19552
CTD13-11	3419	02-Oct-2013	18:10	43.76658	65.22672
CTD13-12	3420	02-Oct-2013	18:29	43.72690	65.21223
CTD13-13	3423	02-Oct-2013	19:31	43.69882	65.20048
CTD13-14	3422	02-Oct-2013	18:57	43.67030	65.16075
CTD13-15	3428	03-Oct-2013	12:33	43.64343	65.18353
CTD13-16	3427	03-Oct-2013	12:13	43.62962	65.20790
CTD13-17	3426	03-Oct-2013	12:04	43.59047	65.20577
CTD13-18	3429	03-Oct-2013	12:42	43.64787	65.25773
CTD13-20	3425	03-Oct-2013	11:49	43.59112	65.25087
CTD13-1	3483	14-Nov-2013	13:09	43.66508	65.29610
CTD13-2	3482	14-Nov-2013	13:04	43.68030	65.31927
CTD13-3	3481	14-Nov-2013	13:00	43.69400	65.32875
CTD13-4	3480	14-Nov-2013	12:49	43.71690	65.32422
CTD13-7	3479	14-Nov-2013	12:41	43.74443	65.31838
CTD13-11	3486	13-Nov-2013	18:22	43.76658	65.22672
CTD13-12	3487	13-Nov-2013	20:17	43.72690	65.21223
CTD13-16	3485	14-Nov-2013	13:22	43.62962	65.20790
CTD13-18	3484	14-Nov-2013	13:15	43.64787	65.25773

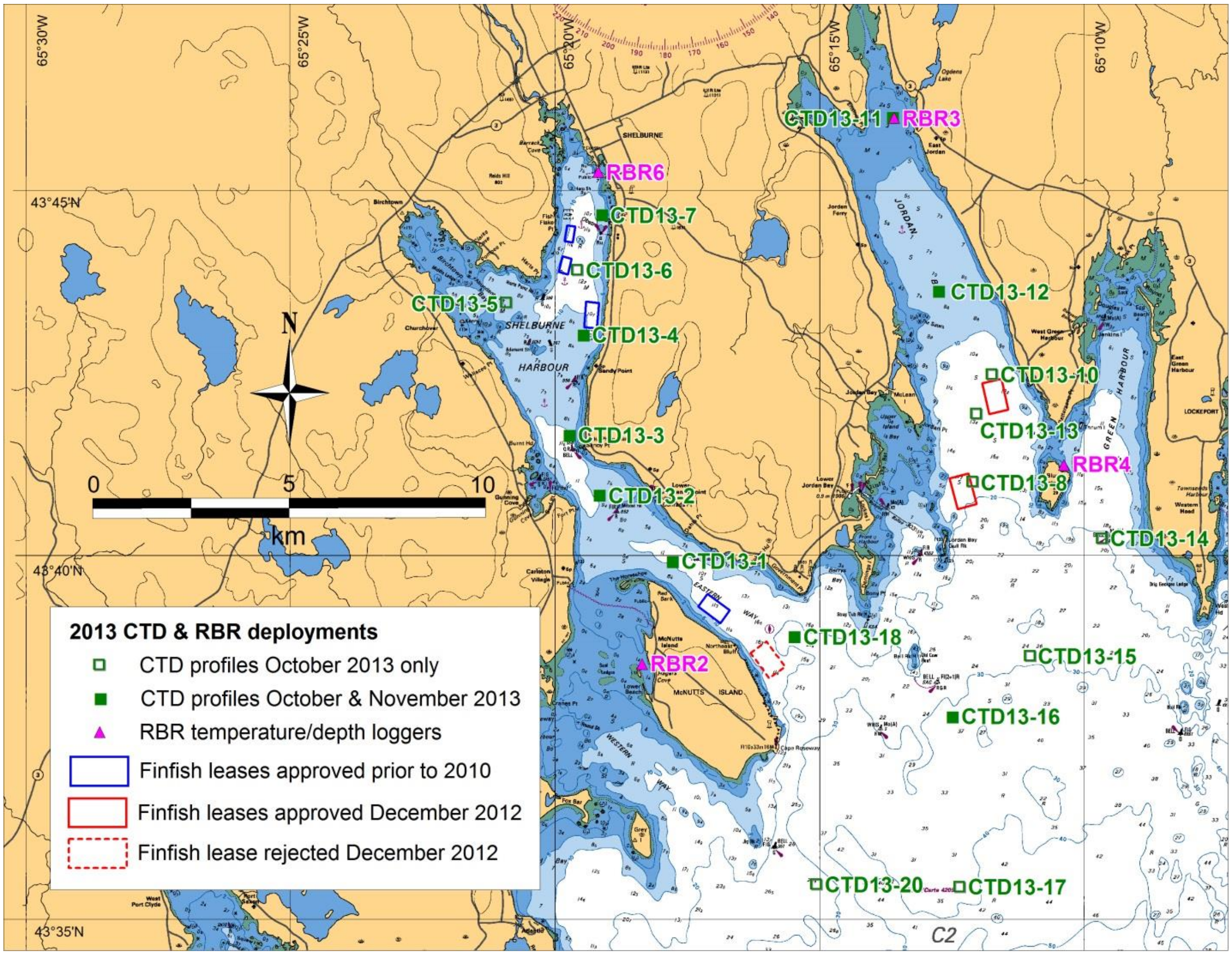


Fig. 6. Map of the Shelburne area, showing stations for conductivity-temperature-depth (CTD) profiles (using a Sea-Bird SBE 25-03 Sealogger) and temperature and depth logger (RBR*duo*) deployments in 2013. Also shown are locations of finfish farms. The background map is part of Canadian Hydrographic Service chart 4241 (Lockeport to Cape Sable, November 2002 edition); depths are in metres below Chart Datum (lowest normal tide). See Table 7 for dates and times of CTD profiles and Table 9 for dates of RBR*duo* deployments.

Table 8. Locations and dates for CTD profiles in the Shelburne area in 2014. All profiles were conducted using a Sea-Bird SBE 25-03 Sealogger. See Fig. 7 for deployment locations. UTC was 3 h ahead of local time (Atlantic Daylight Time).

Station	Deployment	Date	Time (UTC)	Latitude (°N)	Longitude (°W)
CTD14-1	3751	24-Sep-2014	17:02	43.66482	65.29628
CTD14-2	3760	24-Sep-2014	17:12	43.68080	65.31850
CTD14-3	3761	24-Sep-2014	17:19	43.69493	65.32958
CTD14-4	3748	23-Sep-2014	19:05	43.71692	65.32443
CTD14-5	3749	23-Sep-2014	18:54	43.73068	65.34718
CTD14-6	3765	23-Sep-2014	18:47	43.73107	65.32438
CTD14-7	3750	23-Sep-2014	19:16	43.74460	65.31867
CTD14-8	3762	24-Sep-2014	15:26	43.68317	65.20218
CTD14-10	3752	24-Sep-2014	14:50	43.70782	65.19543
CTD14-11	3753	24-Sep-2014	15:01	43.76635	65.22668
CTD14-12	3754	24-Sep-2014	15:18	43.72583	65.21220
CTD14-13	3755	24-Sep-2014	14:30	43.69832	65.19973
CTD14-14	3756	24-Sep-2014	14:17	43.67050	65.16000
CTD14-15	3757	24-Sep-2014	13:24	43.64208	65.18473
CTD14-16	3763	24-Sep-2014	13:34	43.62977	65.20733
CTD14-17	3758	24-Sep-2014	13:46	43.59070	65.20667
CTD14-18	3759	24-Sep-2014	16:53	43.64817	65.25705
CTD14-20	3764	24-Sep-2014	13:57	43.59128	65.25157
CTD14-21	3746	23-Sep-2014	18:29	43.75567	65.32482
CTD14-22	3747	23-Sep-2014	18:37	43.74410	65.32325

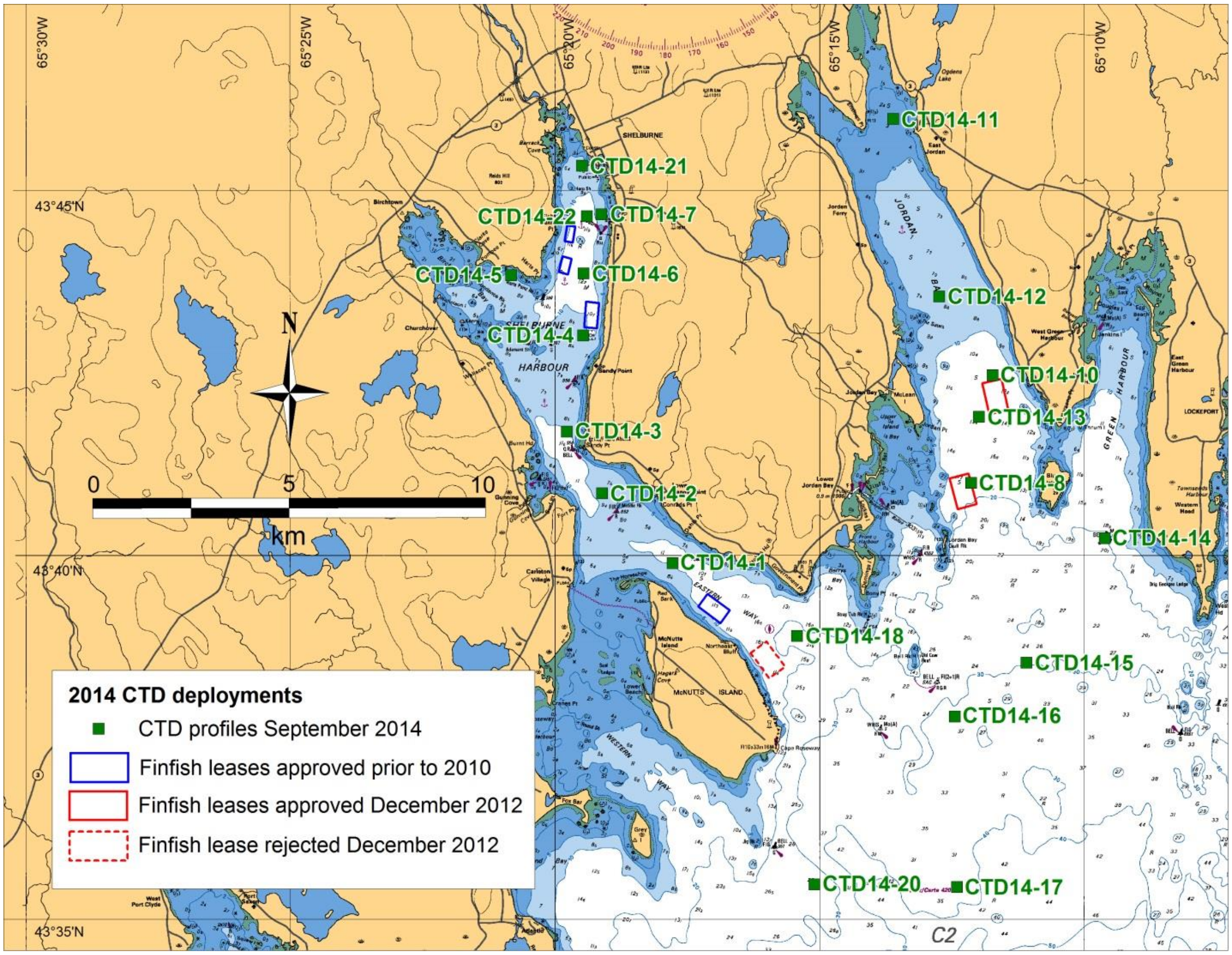


Fig. 7. Map of the Shelburne area, showing stations for conductivity-temperature-depth (CTD) profiles in 2014. All profiles were conducted using a Sea-Bird SBE 25-03 Sealogger. Also shown are locations of finfish farms. The background map is part of Canadian Hydrographic Service chart 4241 (Lockeport to Cape Sable, November 2002 edition); depths are in metres below Chart Datum (lowest normal tide). See Table 8 for dates and times of profiles.

Table 9. Dates of deployment and retrieval of RBR*duo* temperature and depth loggers in the Shelburne area in 2013. See Fig. 6 for deployment locations.

Location	Deploy-ment	Latitude (°N)	Longitude (°W)	Deployment date	Retrieval date	Duration (d)
McNutts Island	RBR2	43.64167	65.30580	3-Oct-2013	13-Nov-2013	41.3
Jordan Bay	RBR3	43.76658	65.22643	2-Oct-2013	13-Nov-2013	42.0
Blue Island	RBR4	43.68730	65.17297	2-Oct-2013	13-Nov-2013	41.9
Shelburne Harbour	RBR6	43.75427	65.31972	3-Oct-2013	14-Nov-2013	42.0

RESULTS AND DISCUSSION

Water depth

The RBR deployment stations were all in shallow waters, with mean depths ranging from 3.44-5.02 m, and mean measured tidal ranges of 1.64-1.74 m (Table 10). The mean measured tidal range in deployment RBR6 was 1.7 m, compared to a mean predicted tidal range of 1.5 m at the nearby Shelburne Harbour tide station during the deployment period (2 October to 14 November 2013) (WWW Tide and Current Predictor: http://tbone.biol.sc.edu/tide/). Plots of the water depth data from the RBR deployments are shown in Fig. 8. Results of the tidal analysis (Table 11) indicated that the phases were within 1-2° among the 4 stations, where 1° corresponds to approximately 2 min for semi-diurnal tides and 4 min for diurnal tides.

The ADCP deployment stations had mean depths ranging from 9.83 m (deployment 530, Shelburne Harbour) to 22.81 m (deployment 559, Blue Island) (Table 12 & Fig. 9) and mean measured tidal ranges of 1.51 (deployment 527, Jordan Bay) to 1.71 m (deployment 560, Shelburne Harbour) (Table 12 & Fig. 9).

The tides in the Shelburne area are dominated by M2. With a mean amplitude (equal to one-half of the mean range) of 0.733 m, the M2 amplitudes are approximately 4.5 times greater than those of N2, the next largest constituent (Table 13). For the RBR data, the five main tidal constituents (M2, N2, S2, K1 and O1) accounted for 96-98% of the variance of the water depth time series, with M2 accounting for 82-83% of the variance (Table 14). For the ADCP data, the same five main tidal constituents accounted for 88-98% of the variance of the water depth time series, with M2 accounting for 75-86% of the variance (Table 15).

Table 10. Summary of water depth and tidal range data for deployments of RBR*duo* temperature and depth loggers in the Shelburne area, October-November 2013. See Table 9 and Fig. 6 for deployment dates and locations. The mean predicted tidal range at the Shelburne Harbour tidal station during the deployment period was 1.5 m (range: 0.8-2.2 m) (WWW Tide and Current Predictor: http://tbone.biol.sc.edu/tide/).

		Water depth (m)			Tidal range (m)		
Deployment	Location	Mean	Min.	Max.	Mean	Min.	Max.
RBR2	McNutts Island	3.44	2.23	4.74	1.66	0.8	2.4
RBR3	Inner Jordan Bay	4.85	3.53	6.20	1.74	0.9	2.5
RBR4	Blue Island	5.02	3.81	6.32	1.64	0.8	2.3
RBR6	Shelburne Harbour	4.56	3.34	5.83	1.68	0.9	2.4

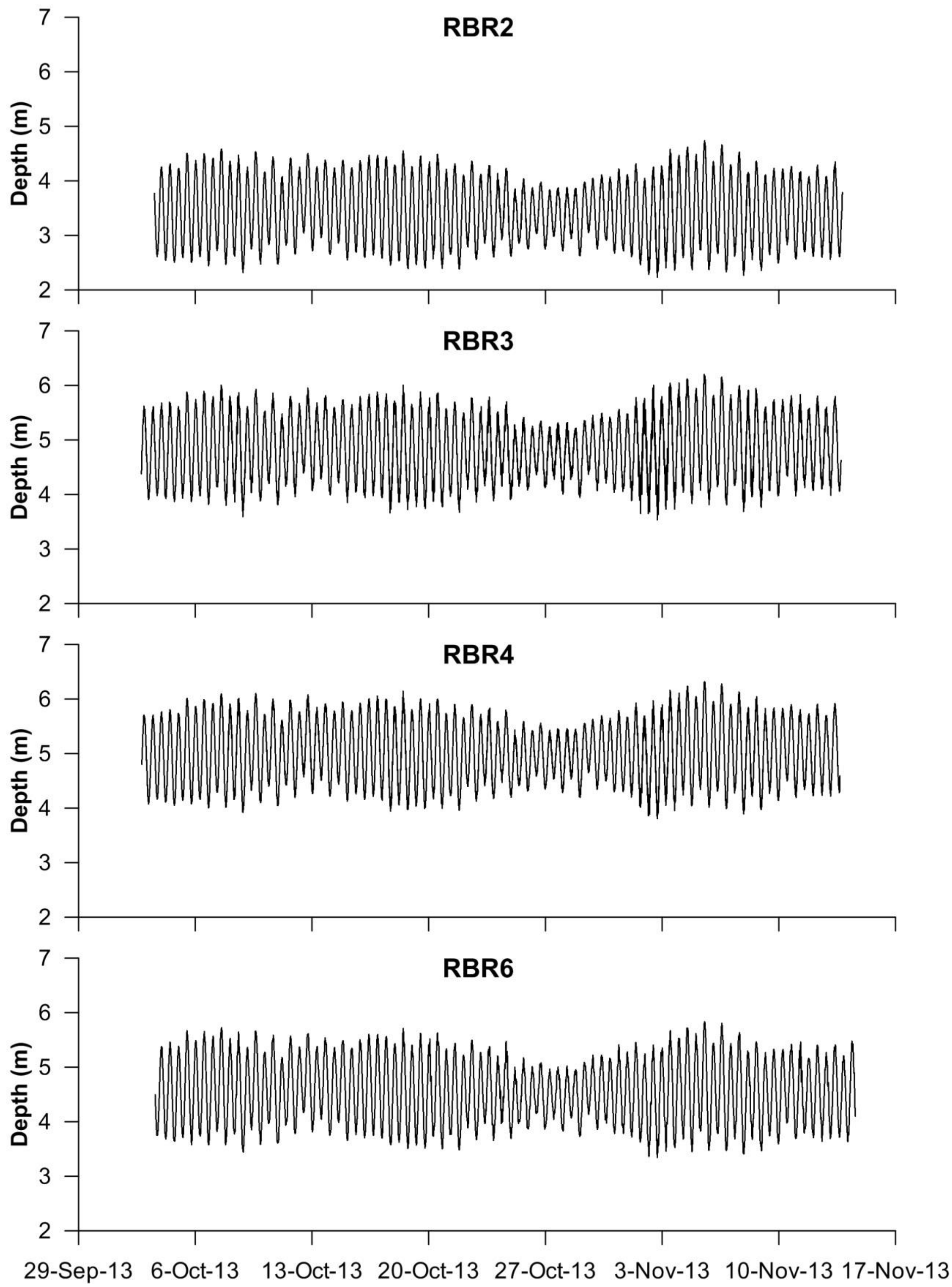
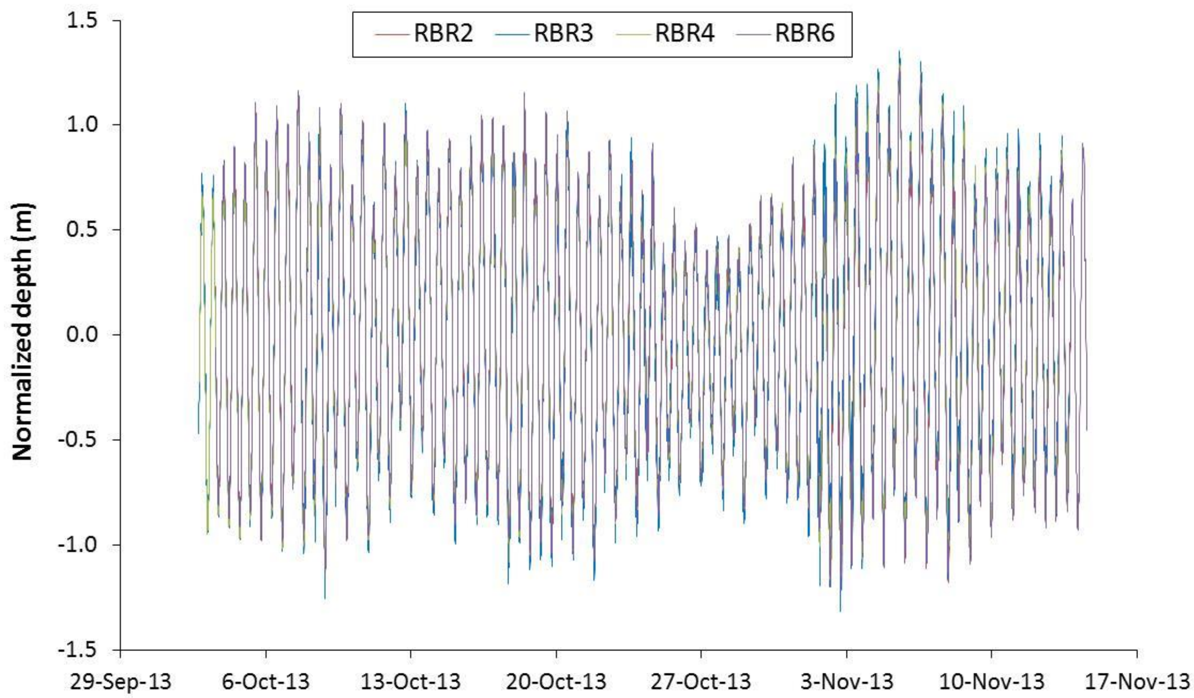


Fig. 8a. Water depth data from RBR*duo* temperature and depth loggers deployed on the seafloor at 4 locations in the Shelburne area in October-November 2013 (see Fig. 6 for locations). Individual depth vs. time plots.



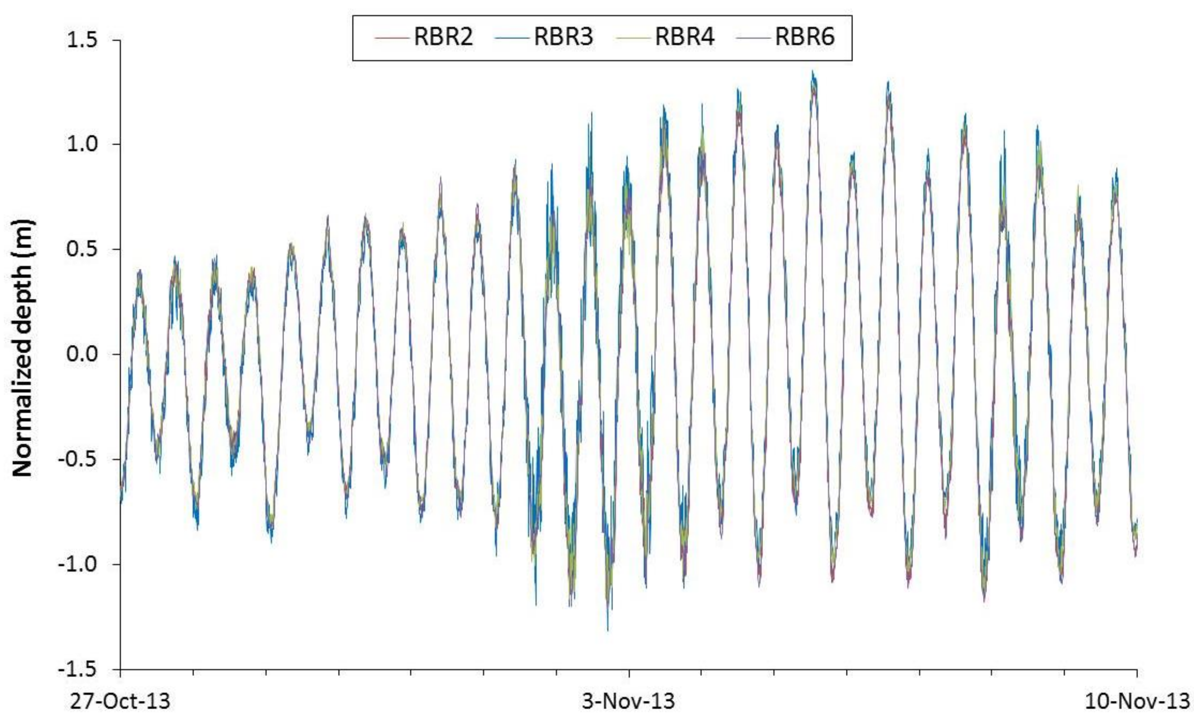


Fig. 8b. Water depth data from RBR*duo* temperature and depth loggers deployed on the seafloor at 4 locations in the Shelburne area in October-November 2013 (see Fig. 6 for locations). Depths are normalized to the mean depths in each deployment. Top: entire deployment period. Bottom: close-up of a 2-week period.

Table 11. Tidal analysis of water depth data for RBR*duo* deployments in the Shelburne area in October-November 2013. Z0 represents the mean depth during the time series. Amplitude = one-half of the range. Time zone used in calculation of phases = UTC.

Deployment	Constituent	Amplitude (m)	Phase (°)
RBR2	Z0	3.437	-
	M2	0.728	3.9
	N2	0.161	341.8
	S2	0.149	31.9
	K1	0.138	148.4
	O1	0.083	119.7
RBR3	Z0	4.830	-
	M2	0.722	3.0
	N2	0.158	340.5
	S2	0.148	31.0
	K1	0.135	148.3
	O1	0.081	117.7
RBR4	Z0	5.011	-
	M2	0.713	2.7
	N2	0.157	339.8
	S2	0.146	30.4
	K1	0.136	148.1
	O1	0.082	117.9
RBR6	Z0	4.549	-
	M2	0.739	3.9
	N2	0.163	341.8
	S2	0.151	31.8
	K1	0.139	149.0
	O1	0.081	119.2

Table 12. Summary of water depth and tidal range data for ADCP deployments in the Shelburne area, 2008-2014. See Table 1 and Fig. 3 for deployment dates and locations. The mean predicted tidal range at the Shelburne Harbour tidal station during 2012-2014 was 1.5 m (range: 0.7-2.5 m) (WWW Tide and Current Predictor: http://tbone.biol.sc.edu/tide/).

		Water depth (m)			Tidal range (m)		
Deployment	Location	Mean	Min.	Max.	Mean	Min.	Max.
358	McNutts Island	12.34	10.91	13.57	1.55	0.52	2.34
527	Jordan Bay	15.23	13.31	16.75	1.51	0.85	2.56
530	Shelburne Harbour	9.83	8.65	11.19	1.67	0.83	2.40
531	Inner Jordan Bay	10.37	9.23	11.72	1.62	0.80	2.31
559	Blue Island	22.81	21.41	24.10	1.54	0.87	2.21
560	Shelburne Harbour	12.57	11.02	13.90	1.71	0.96	2.52

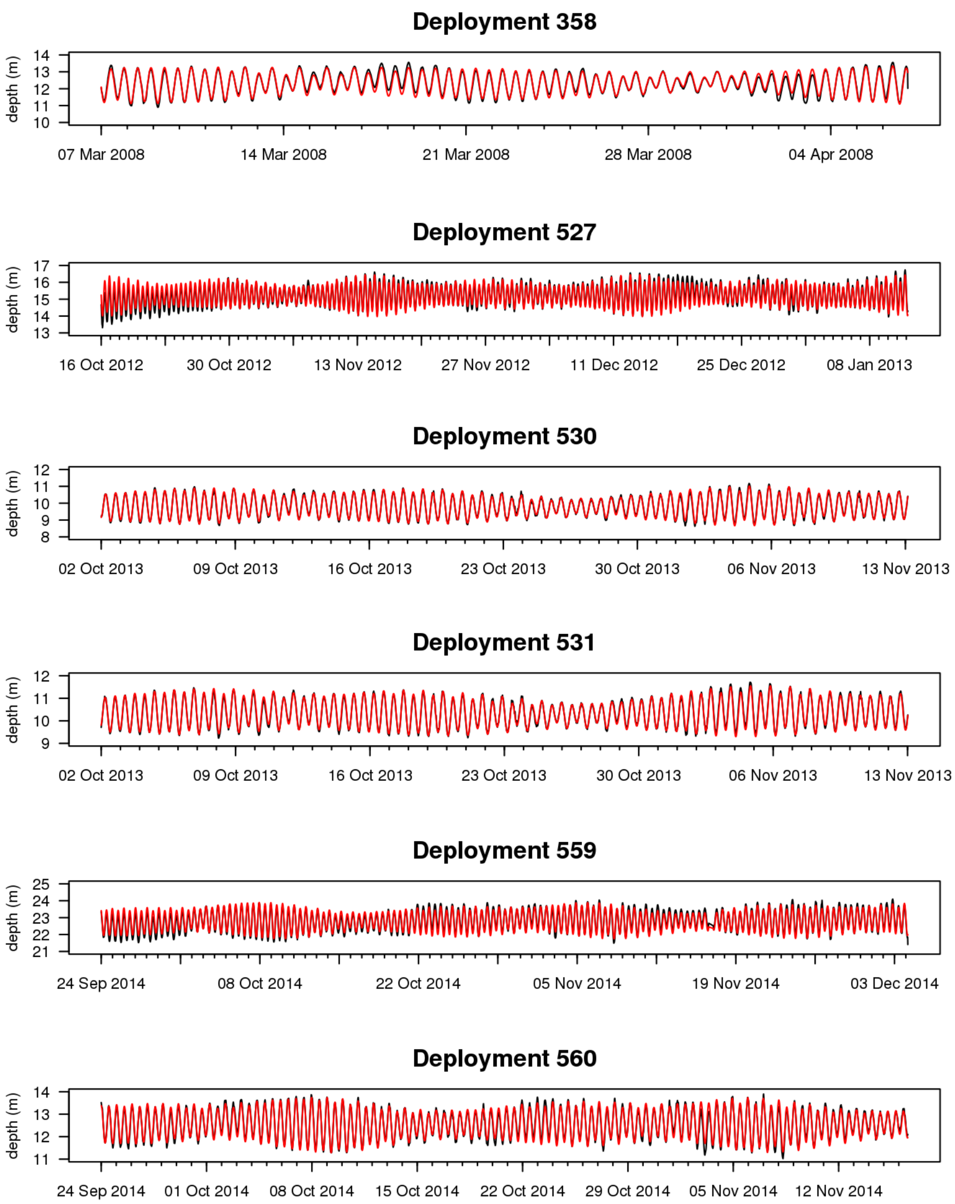


Fig. 9. Time series plots of water depth for ADCP deployments in the Shelburne area, 2008-2014. Black lines are the observed depths; red lines are the reconstructed time series from the tidal analyses. See Fig. 3 for deployment locations.

Table 13. Tidal analysis of water depth data for ADCP deployments in the Shelburne area in 2008-2014. Z0 represents the mean depth during the time series. Amplitude = one-half of the range. Time zone used in calculation of phases = UTC.

Deployment	Constituent	Amplitude	Phase (°)
358	Z0	12.336	-
	M2	0.743	359.4
	N2	0.167	333.4
	S2	0.155	34.1
	K1	0.150	148.7
	O1	0.088	118.4
527	Z0	15.239	-
	M2	0.717	357.4
	N2	0.161	335.7
	S2	0.152	25.1
	K1	0.134	148.6
	O1	0.083	129.9
530	Z0	9.810	-
	M2	0.750	2.9
	N2	0.165	343.3
	S2	0.156	30.0
	K1	0.139	148.5
	O1	0.083	118.7
531	Z0	10.350	-
	M2	0.728	2.1
	N2	0.162	339.8
	S2	0.147	29.3
	K1	0.139	148.0
	O1	0.081	117.2
559	Z0	22.810	-
	M2	0.707	1.2
	N2	0.149	337.8
	S2	0.140	29.4
	K1	0.120	147.6
	O1	0.071	119.4
560	Z0	12.566	-
	M2	0.781	2.8
	N2	0.170	337.1
	S2	0.156	28.9
	K1	0.128	149.1
	O1	0.082	123.0

Table 14. Variance of observed RBR*duo* water depth (m) time series, the percent contribution of the 5 main constituents (M2, N2, S2, K1, and O1) to the variance, and the percent contribution of M2 to the variance, for deployments in the Shelburne area in October-November 2013. The percent contribution is calculated by reconstructing the time series from the specified tidal constituents when they were included in the analysis, as well as any constituents that were inferred from these. The variance was then calculated for the reconstructed signal and used to calculate the percent contribution to the total signal.

Deployment	Variance	% of variance (M2+N2+S2+K1+O1)	% of variance (M2 only)
RBR2	0.336	97.8	82.5
RBR3	0.335	96.4	81.6
RBR4	0.323	97.6	82.6
RBR6	0.347	97.5	82.4

Table 15. Variance of observed ADCP water depth (m) time series, the percent contribution of the 5 main constituents (M2, N2, S2, K1, and O1) to the variance, and the percent contribution of M2 to the variance, for deployments in the Shelburne area in 2008-2014. The percent contribution is calculated by reconstructing the time series from the specified tidal constituents when they were included in the analysis, as well as any constituents that were inferred from these. The variance was then calculated for the reconstructed signal and used to calculate the percent contribution to the total signal.

Deployment	Variance	% of variance (M2+N2+S2+K1+O1)	% of variance (M2 only)
358	0.347	91.9	74.9
527	0.355	88.2	75.2
530	0.357	97.5	82.5
531	0.337	97.1	82.2
559	0.336	89.0	79.3
560	0.380	95.0	85.6

Current velocity

Summary current speed data for ADCP deployments in the Shelburne area in 2008-2014, at three depth levels, are presented in Table 16.

Table 16. Summary of current speed data from ADCP deployments in the Shelburne area, 2008-2014. Data are presented for three depth levels: near surface, mid-water, and near bottom. See Table 1 and Fig. 3 for deployment dates and locations.

Deployment and location	Mean depth (m)	Deployment depth	Current speed ($cm\ s^{-1}$)			
			Mean	Median	Min	Max
358	12.3	Near surface: 2.5–3.0 m below surface	16.1	15.2	0.2	54.5
McNutts I.		Mid-water: 5.6–6.6 m above bottom	13.2	12.2	0.2	41.1
(site 1345)		Near bottom: 3.1 m above bottom	10.9	10.2	0.4	32.1
527	15.2	Near surface: 2.5–3.5 m below surface	8.7	7.7	0.2	46.0
Jordan Bay		Mid-water: 6.7–8.7 m above bottom	8.7	8.0	0.1	29.6
(site 1358)		Near bottom: 3.7 m above bottom	10.5	9.7	0.4	34.4
530	9.8	Near surface: 2.5–3.5 m below surface	6.5	5.9	0.2	27.2
Shelburne		Mid-water: 4.1–6.1 m above bottom	6.3	5.8	0.2	24.2
Harbour		Near bottom: 3.1 m above bottom	5.4	5.0	0.2	19.9
531	10.4	Near surface: 2.5–3.5 m below surface	7.2	6.4	0.2	27.8
Inner Jordan		Mid-water: 4.6–5.6 m above bottom	7.6	6.7	0.1	28.0
Bay		Near bottom: 3.6 m above bottom	7.8	6.9	0.1	30.0
559	22.8	Near surface: 2.5–3.5 m below surface	8.5	7.7	0.1	38.3
Blue Island		Mid-water: 10.7–11.7 m above bottom	8.0	7.2	0.1	32.2
(site 1359)		Near bottom: 4.7 m above bottom	10.2	9.8	0.2	28.5
560	12.6	Near surface: 2.5–3.5 m below surface	6.0	5.2	0.1	26.8
Shelburne Hbr		Mid-water: 5.7–6.7 m above bottom	6.6	5.8	0.1	32.2
(site 0602)		Near bottom: 4.7 m above bottom	6.7	6.0	0.1	27.6

Current velocity data for each ADCP deployment are presented in a series of Tables and Figures:

- Stick plots of current velocities in each data segment at three depth levels (near surface, mid-water, near bottom).
- Current speed histograms and current velocity rose diagrams for three depth levels.
- Scatter plots of current velocities for observed and residual currents at three depth levels.
- Table of tidal analysis of current velocities. Amplitudes and phases are shown for the 5 main tidal constituents (M2, N2, S2, K1, O1). Current data have been decomposed into major and minor axes, for three depth levels.
- Table of variances of observed water current velocity time series, the percent contribution of the current in the major and minor directions to the total variance of the currents, the percent contribution by the 5 main tidal constituents, and the percent contribution of the M2 constituent. Current variances are presented for three depth levels.
- Time series plots of current velocities at three depth levels, including observed currents and reconstructed time series from the tidal analysis (tidal constituent); current speeds are plotted in the major and minor directions.
- Progressive vector plots for three depth levels.

Tidal analysis results (amplitudes and phases for the 5 main tidal constituents, decomposed into major and minor axes, plotted versus depth using three depth scales) are also presented in Appendix C.

Deployment 358: McNutts Island (site 1345)

Deployment 358 was at a moderate depth, averaging 12.3 m (Table 12). Mean speeds at the three depth levels (near surface, mid-water, and near bottom) ranged from 10.9-16.1 cm s^{-1} and maximum speeds were 32.1-54.5 cm s^{-1} (Table 16).

Current directions were parallel to the nearby coast of McNutts Island (Fig. 3): they were mostly to the west-northwest at all three depth levels (Figs. 10-12). The major axis (from principal components analysis) was in the west-northwest to east-southeast direction at all three depth levels (Fig. 12). Tidal analyses of current velocities (Table 17 & Appendix C) indicated that, along the major axis, the largest tidal amplitude was for the M2 constituent at all three depth levels. Along the minor axis, M2 was dominant only near the bottom. The major axis accounted for 95-97% of the total variance (Table 18). The 5 main tidal constituents contributed to 61-82% of the currents' variance along the major axis, but only 0.1% of the variance along the minor axis (Table 18 & Fig. 13); 53-68% of the variance along the major axis was due to M2 alone.

The progressive vector plot (Fig. 14) indicated that the net displacement at the end of the data record (31.0 d) was ~50 km to the west near the surface and ~100 km to the west-northwest at mid-water and near the bottom.

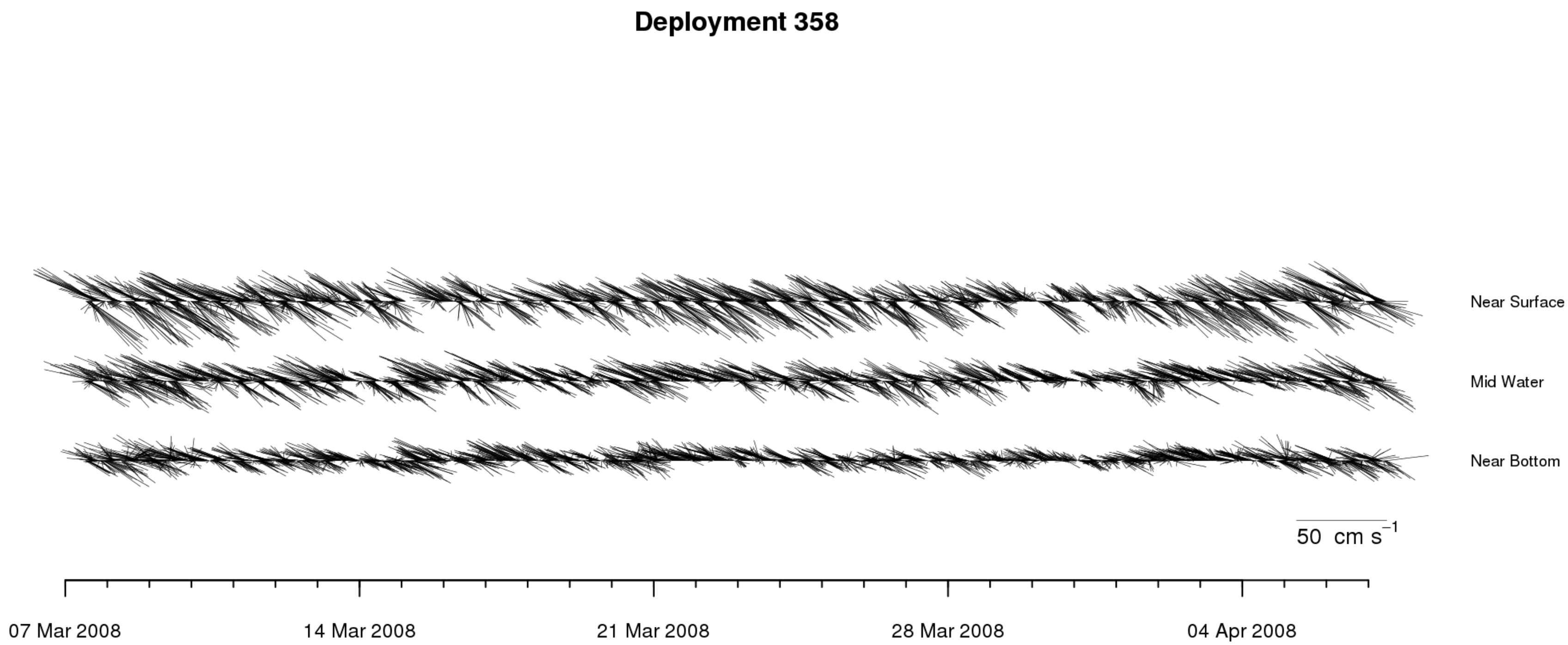


Fig. 10. Stick plots of current velocities in ADCP deployment 358 (McNutts Island, 7 March to 7 April 2008) at three depth levels (near surface, mid-water, and near bottom). The lines show the current direction (true north is straight up) and speed (see scale on graph) in each data segment (15-min intervals).

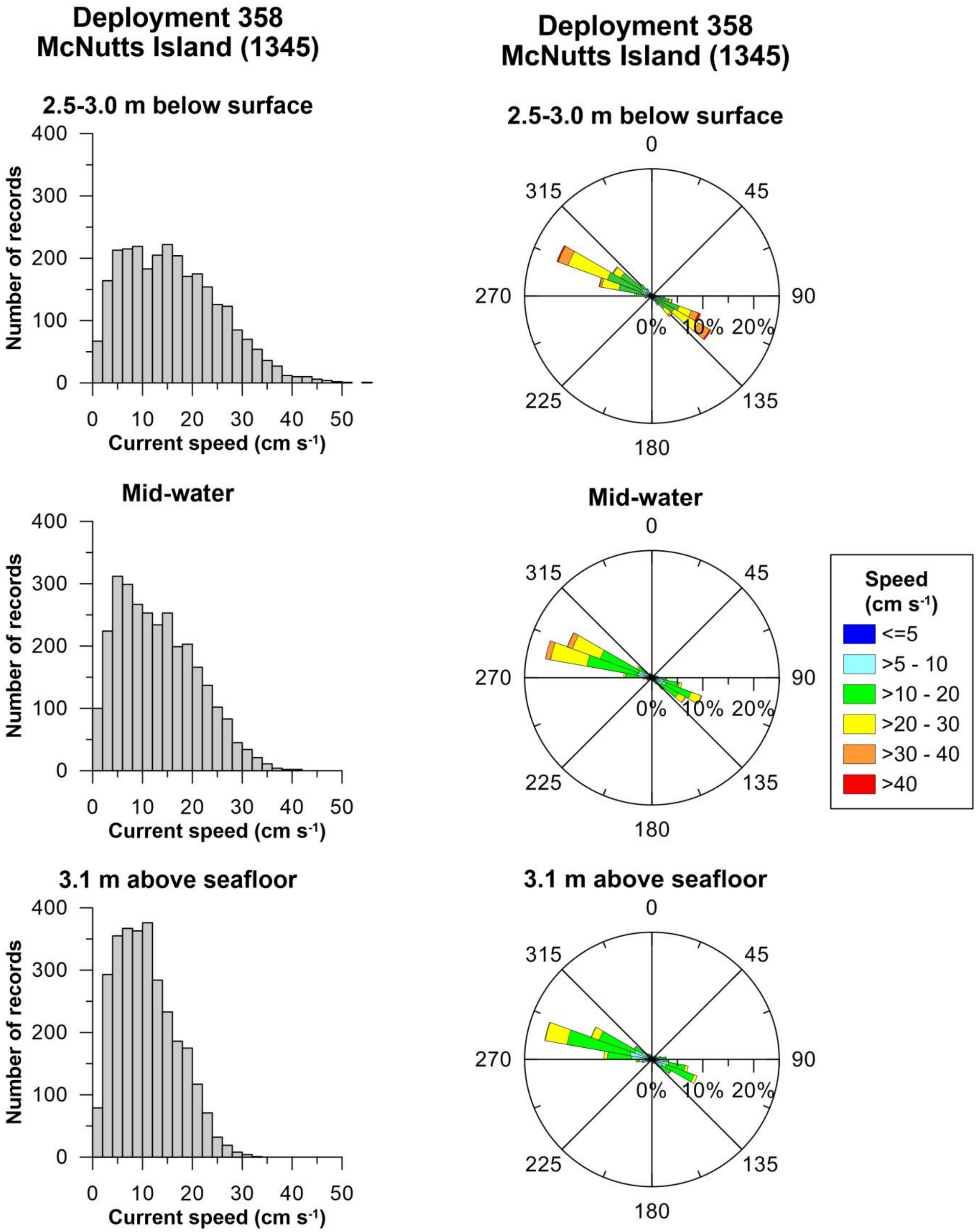


Fig. 11. Current speed histograms (left) and current velocity rose diagrams (right) for ADCP deployment 358 (McNutts Island, 7 March to 7 April 2008). Data are presented for three depth levels: near surface (top), mid-water (middle), and near bottom (bottom).

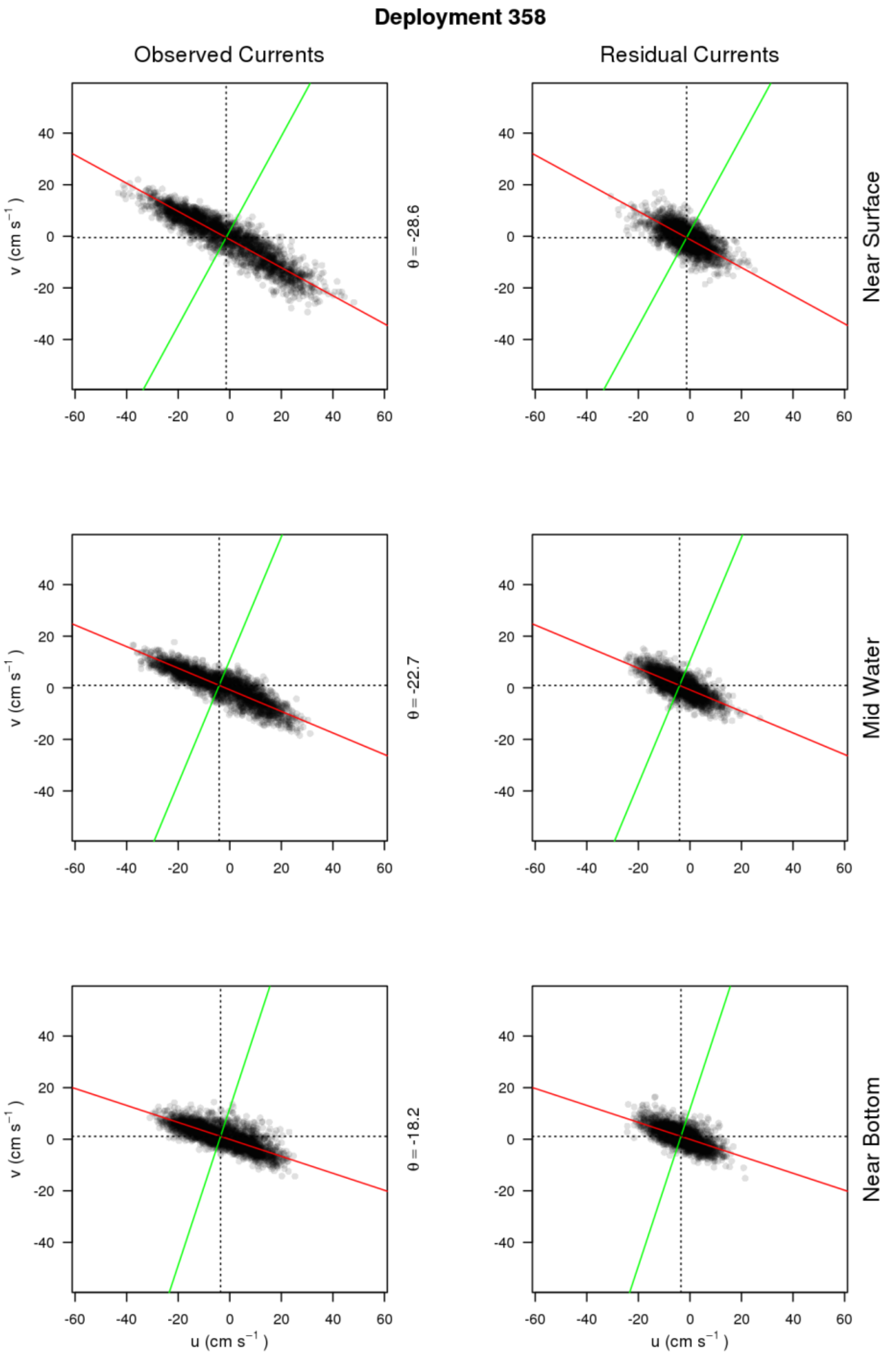


Fig. 12. Scatter plots for current velocities in ADCP deployment 358 (McNutts Island, 7 March to 7 April 2008). Left: observed currents. Right: residual currents (obtained by removing the tidal signal from the original observation). Current velocity data in the east-west (u) and north-south (v) directions are presented for three depth levels: near surface (top), mid-water (middle), and near bottom (bottom). The red line is the major principal axis and the green line is the minor principal axis. θ = angle of the major axis (degrees from the east-west axis, in a counter-clockwise direction). The dotted lines indicate the mean currents in the east-west and north-south directions.

Table 17. Tidal analysis of water current velocities for ADCP deployment 358. Data are shown for the 5 main tidal constituents (M2, N2, S2, K1, O1). Z0 represents the mean flow in the direction of each principal axis at each depth level (near surface, mid-water, and near bottom). Amplitude = one-half of the range. Maj = in the direction of the major principal axis. Min = in the direction of the minor principal axis. * indicates that the constituent was not included in the 2nd pass of the tidal analysis program based on the value of the t-test. θ = angle of the major axis (degrees from the east-west axis, in a counter-clockwise direction). Time zone used in calculation of phases = UTC.

Deployment 358	Constituent		Amplitude	Phase (°)
Near surface currents (cm s^{-1}) θ = -28.6	Z0	Maj	-0.858	0.0
	Z0	Min	-1.079	0.0
	M2	Maj	21.894	106.4
	M2	Min	0.639	33.4
	N2	Maj	3.573	72.1
	N2	Min	0.374	1.6
	S2	Maj	5.052	134.2
	S2	Min	0.243	24.4
	K1	Maj	3.659	276.1
	K1	Min	0.765	177.8
	O1	Maj	1.216	215.3
	O1	Min	0.283	329.2
Mid-water currents (cm s^{-1}) θ = -22.7	Z0	Maj	-4.051	0.0
	Z0	Min	-0.724	0.0
	M2	Maj	16.623	89.1
	M2	Min	0.570	48.8
	N2	Maj	3.132	58.8
	N2	Min	*	*
	S2	Maj	3.018	119.8
	S2	Min	0.582	108.8
	K1	Maj	1.531	222.5
	K1	Min	*	*
	O1	Maj	*	*
	O1	Min	*	*
Near bottom currents (cm s^{-1}) θ = -18.2	Z0	Maj	-3.645	0.0
	Z0	Min	-0.047	0.0
	M2	Maj	12.252	78.9
	M2	Min	1.228	132.3
	N2	Maj	2.684	59.3
	N2	Min	0.325	178.0
	S2	Maj	1.898	108.3
	S2	Min	0.282	159.6
	K1	Maj	1.216	196.6
	K1	Min	*	*
	O1	Maj	0.385	136.8
	O1	Min	*	*

Table 18. Variance of observed water current velocity (cm s^{-1}) time series for ADCP deployment 358, with the percent contribution of the current in the major (Maj) and minor (Min) directions to the total variance of the currents, the percent contribution of the 5 main tidal constituents (M2, N2, S2, K1, and O1) to the variances in the Maj and Min directions, and the percent contribution of the M2 constituent to the variances in the Maj and Min directions. The percent contribution was calculated by reconstructing the time series from the specified tidal constituents when they were included in the analysis, as well as any constituents that were inferred from these. The variance was then calculated for the reconstructed signal and used to calculate the percent contribution to the total signal. All variances were calculated using N degrees of freedom where N is the total number of observations in a given record. Maj = in the direction of the major principal axis. Min = in the direction of the minor principal axis.

Deployment 358		Variance	% of variance in Maj and Min directions	% of variance contributed by M2+N2+S2+K1+O1	% of variance contributed by M2 only
Near surface	Maj	333.839	97.1	81.5	67.7
	Min	10.033	2.9	0.1	<0.05
Mid-water	Maj	211.080	96.8	70.6	61.7
	Min	7.004	3.2	0.1	<0.05
Near bottom	Maj	133.332	94.8	61.0	53.0
	Min	7.274	5.2	0.1	0.1

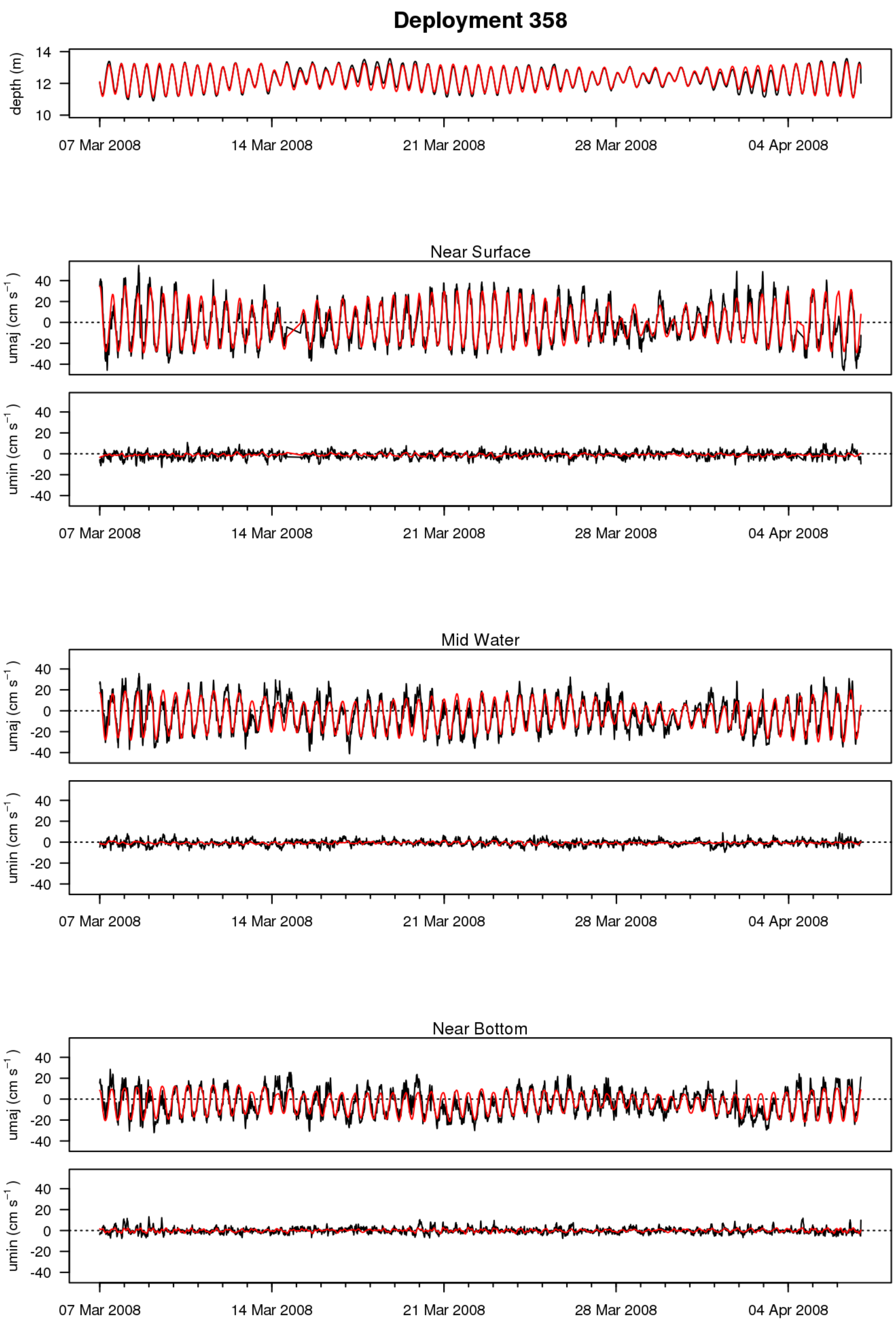


Fig. 13. Time series plots of water depth (depth) and current velocity for ADCP deployment 358 (McNutts Island, 7 March to 7 April 2008). Current speeds are plotted in the major (umaj) and minor (umin) directions (as determined by the principal component analysis), for three depth levels (near surface, mid-water, and near bottom). Black lines are the observed currents; red lines are the reconstructed time series from the tidal analyses.

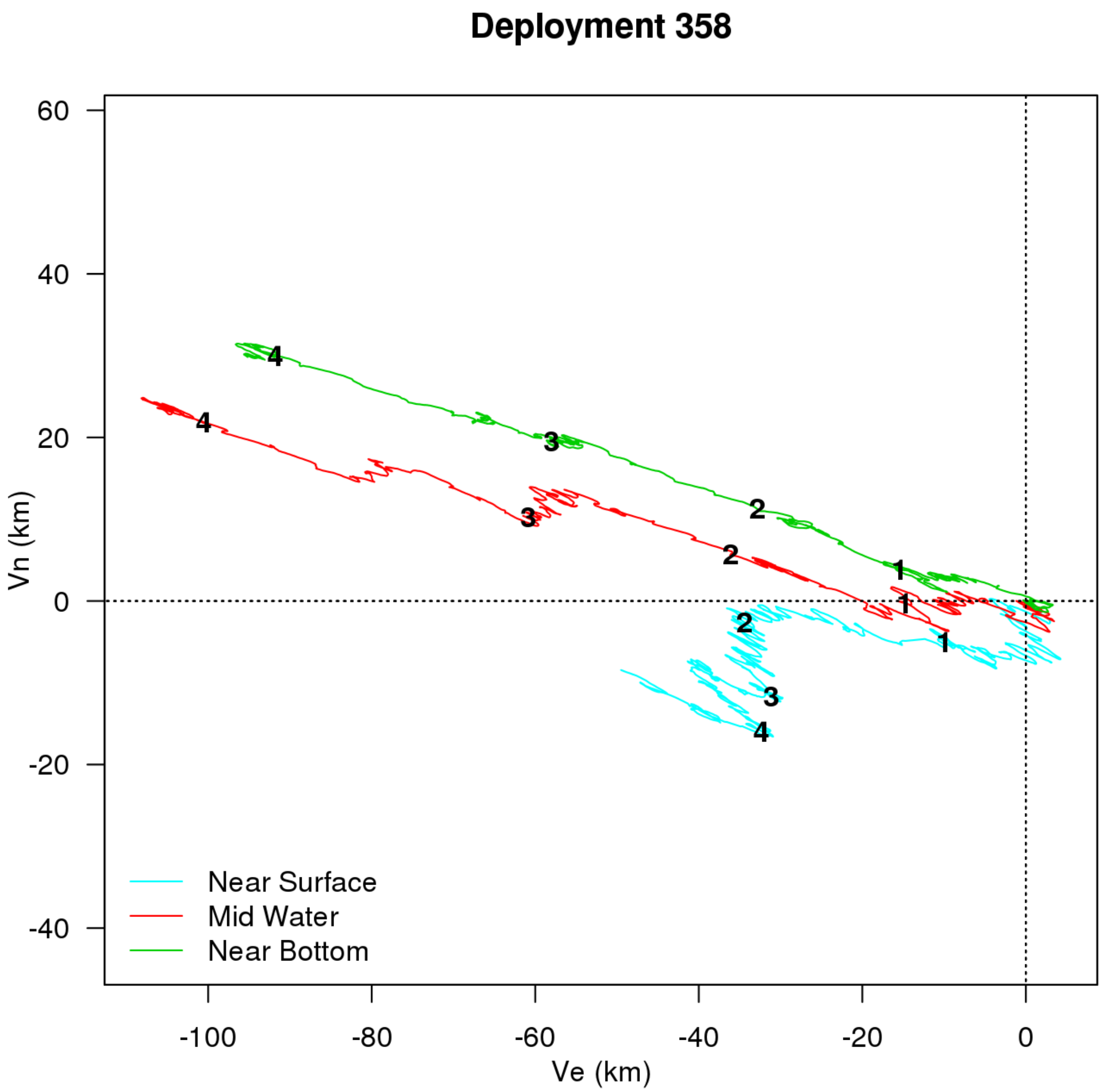


Fig. 14. Progressive vector plots for ADCP deployment 358 (McNutts Island, 7 March to 7 April 2008). Successive movements of a particle are estimated using current velocities measured at 15-min intervals by the current meter. Ve = east-west direction; Vn = north-south direction. Data are presented for three depth levels: near surface (blue), mid-water (red), and near bottom (green). Numbers on the vectors indicate the number of weeks from the time of the first data record. Duration = 31.0 d (4.4 weeks).

Deployment 527: Jordan Bay (site 1358)

Deployment 527 at site 1358 was at a moderate depth, averaging 15.2 m (Table 12). Mean speeds at the three depth levels ranged from 8.7-10.5 cm s^{-1} and maximum speeds were 29.6-46.0 cm s^{-1} (Table 16).

Current directions were predominantly north-south (Figs. 15-17), but with some differences among depths: currents were mostly to the south near the surface and mostly to the north at mid-water and near the bottom (Fig. 16). The major axis (from principal components analysis) was in the north-south direction at all three depth levels (Fig. 17). Tidal analyses of current velocities (Table 19 & Appendix C) indicated that M2 was the dominant constituent along the major axis with similar amplitudes at all three depth levels. Along the minor axis, M2 was the most important constituent at mid-water and near the bottom, but not near the surface. The major axis accounted for 82-87% of the total variance (Table 20). The 5 main tidal constituents explained from 42-57% of the currents' variance along the major axis (from principal components analysis), but ≤0.1% of the variance along the minor axis (Table 20 & Fig. 18); 38-50% of the variance along the major axis was due to M2 alone.

The progressive vector plot (Fig. 19) indicated that the net displacement at the end of the data record (88.2 d) was ~180-200 km at all three depth levels, to the south near the surface and to the north at mid-water and near the bottom.

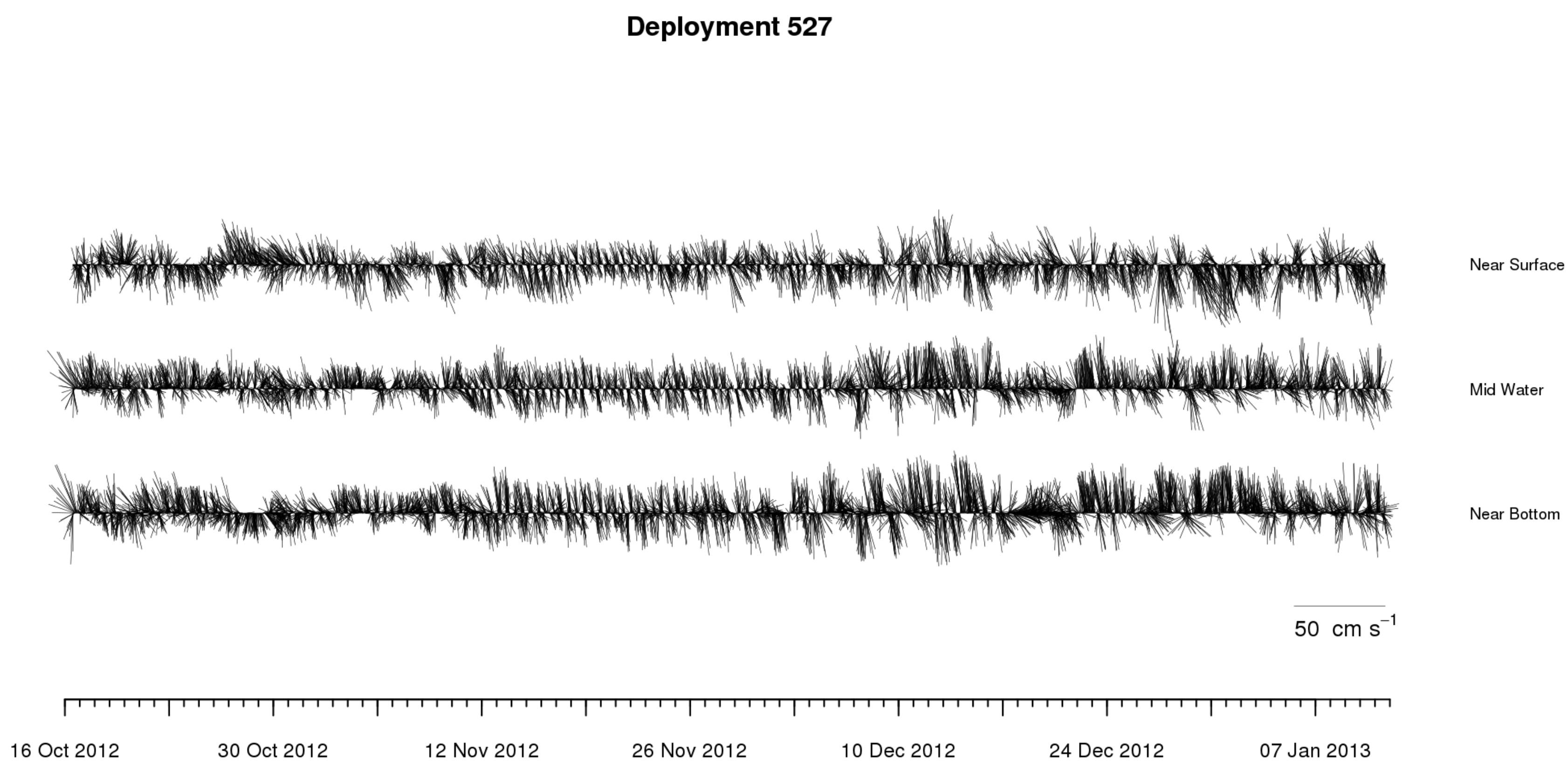


Fig. 15. Stick plots of current velocities in ADCP deployment 527 (Jordan Bay, 16 October 2012 to 12 January 2013) at three depth levels (near surface, mid-water, and near bottom). The lines show the current direction (true north is straight up) and speed (see scale on graph) in each data segment (20-min intervals).

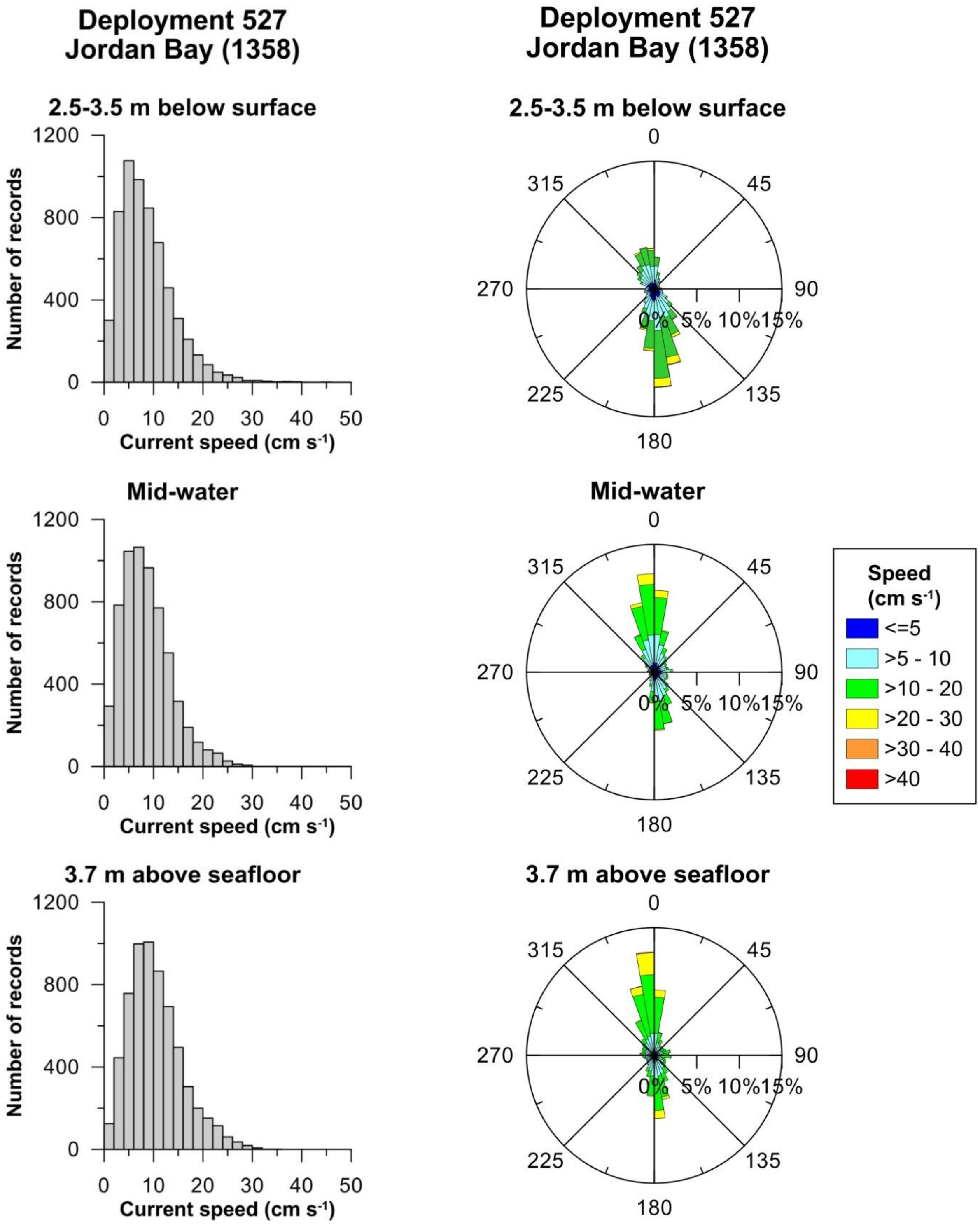


Fig. 16. Current speed histograms (left) and current velocity rose diagrams (right) for ADCP deployment 527 (Jordan Bay, 16 October 2012 to 12 January 2013). Data are presented for three depth levels: near surface (top), mid-water (middle), and near bottom (bottom).

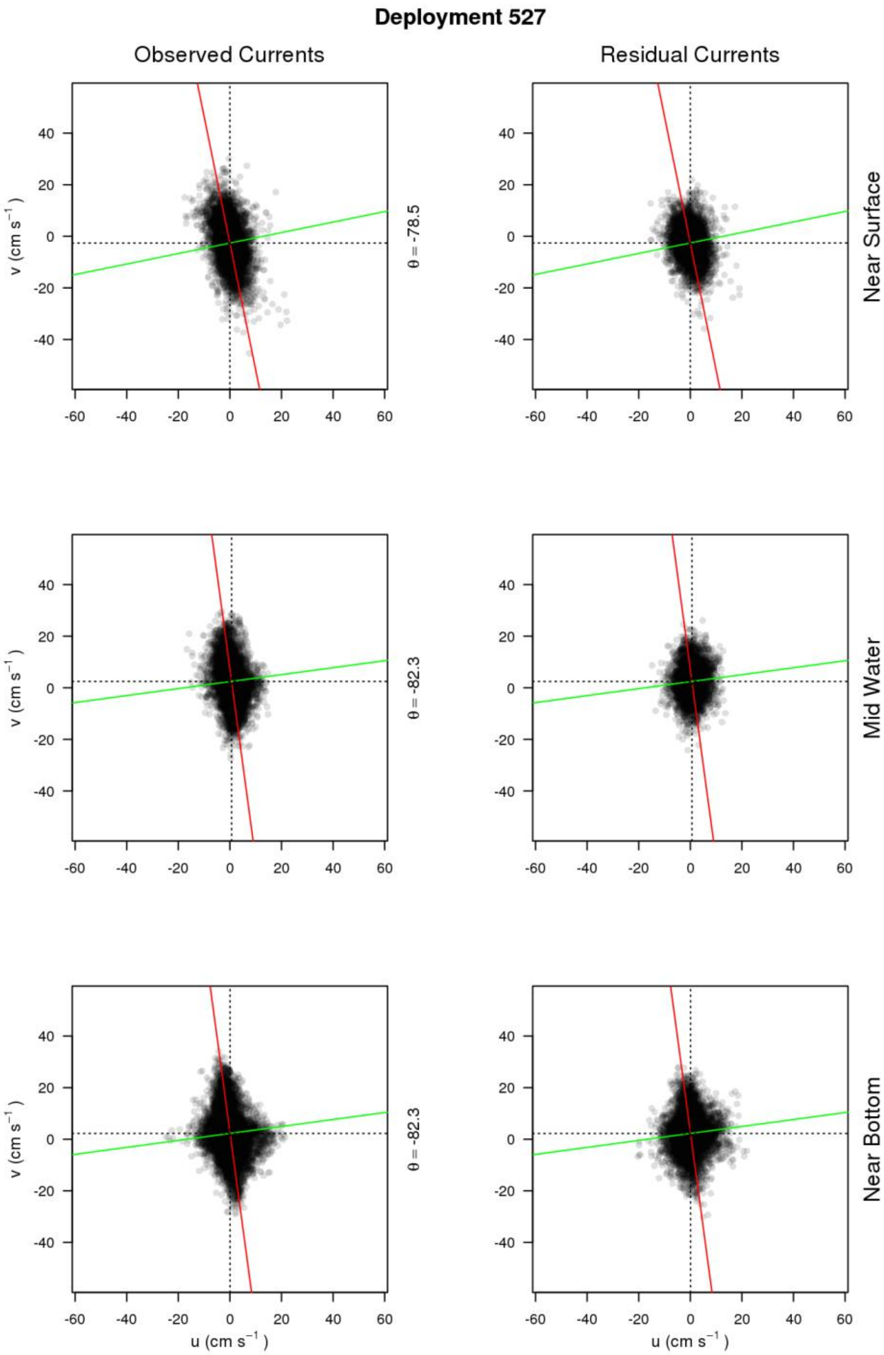


Fig. 17. Scatter plots for current velocities in ADCP deployment 527 (Jordan Bay, 16 October 2012 to 12 January 2013). Left: observed currents. Right: residual currents (obtained by removing the tidal signal from the original observation). Current velocity data in the east-west (u) and north-south (v) directions are presented for three depth levels: near surface (top), mid-water (middle), and near bottom (bottom). The red line is the major principal axis and the green line is the minor principal axis. θ = angle of the major axis (degrees from the east-west axis, in a counter-clockwise direction). The dotted lines indicate the mean currents in the east-west and north-south directions.

Table 19. Tidal analysis of water current velocities for ADCP deployment 527. Data are shown for the 5 main tidal constituents (M2, N2, S2, K1, O1). Z0 represents the mean flow in the direction of each principal axis at each depth level (near surface, mid-water, and near bottom). Amplitude = one-half of the range. Maj = in the direction of the major principal axis. Min = in the direction of the minor principal axis. * indicates that the constituent was not included in the 2nd pass of the tidal analysis program based on the value of the t-test. θ = angle of the major axis (degrees from the east-west axis, in a counter-clockwise direction). Time zone used in calculation of phases = UTC.

Deployment 527	Constituent		Amplitude	Phase (°)
Near surface currents ($cm\ s^{-1}$) θ = -78.5	Z0	Maj	2.543	0.0
	Z0	Min	-0.536	0.0
	M2	Maj	8.250	92.7
	M2	Min	0.304	1.2
	N2	Maj	1.457	74.0
	N2	Min	*	*
	S2	Maj	1.938	135.1
	S2	Min	0.239	79.2
	K1	Maj	0.854	250.9
	K1	Min	0.202	274.6
	O1	Maj	*	*
	O1	Min	0.413	13.0
Mid-water currents ($cm\ s^{-1}$) θ = -82.3	Z0	Maj	-2.338	0.0
	Z0	Min	0.967	0.0
	M2	Maj	8.812	89.5
	M2	Min	0.954	60.3
	N2	Maj	2.172	66.4
	N2	Min	0.537	4.3
	S2	Maj	1.554	115.6
	S2	Min	0.205	88.7
	K1	Maj	0.784	235.7
	K1	Min	0.198	130.0
	O1	Maj	0.378	211.6
	O1	Min	0.347	164.7
Near bottom currents ($cm\ s^{-1}$) θ = -82.3	Z0	Maj	-2.210	0.0
	Z0	Min	0.383	0.0
	M2	Maj	8.976	80.5
	M2	Min	1.338	117.2
	N2	Maj	2.255	49.1
	N2	Min	0.257	35.4
	S2	Maj	1.145	88.1
	S2	Min	*	*
	K1	Maj	0.650	230.0
	K1	Min	*	*
	O1	Maj	*	*
	O1	Min	0.317	175.4

Table 20. Variance of observed water current velocity (cm s^{-1}) time series for ADCP deployment 527, with the percent contribution of the current in the major (Maj) and minor (Min) directions to the total variance of the currents, the percent contribution of the 5 main tidal constituents (M2, N2, S2, K1, and O1) to the variances in the Maj and Min directions, and the percent contribution of the M2 constituent to the variances in the Maj and Min directions. The percent contribution was calculated by reconstructing the time series from the specified tidal constituents when they were included in the analysis, as well as any constituents that were inferred from these. The variance was then calculated for the reconstructed signal and used to calculate the percent contribution to the total signal. All variances were calculated using N degrees of freedom where N is the total number of observations in a given record. Maj = in the direction of the major principal axis. Min = in the direction of the minor principal axis.

Deployment 527		Variance	% of variance in Maj and Min directions	% of variance contributed by M2+N2+S2+K1+O1	% of variance contributed by M2 only
Near surface	Maj	84.284	87.2	46.6	42.1
	Min	12.372	12.8	<0.05	<0.05
Mid-water	Maj	80.428	86.9	56.7	50.0
	Min	12.176	13.1	0.1	<0.05
Near bottom	Maj	109.951	82.3	42.4	37.9
	Min	23.611	17.7	<0.05	<0.05

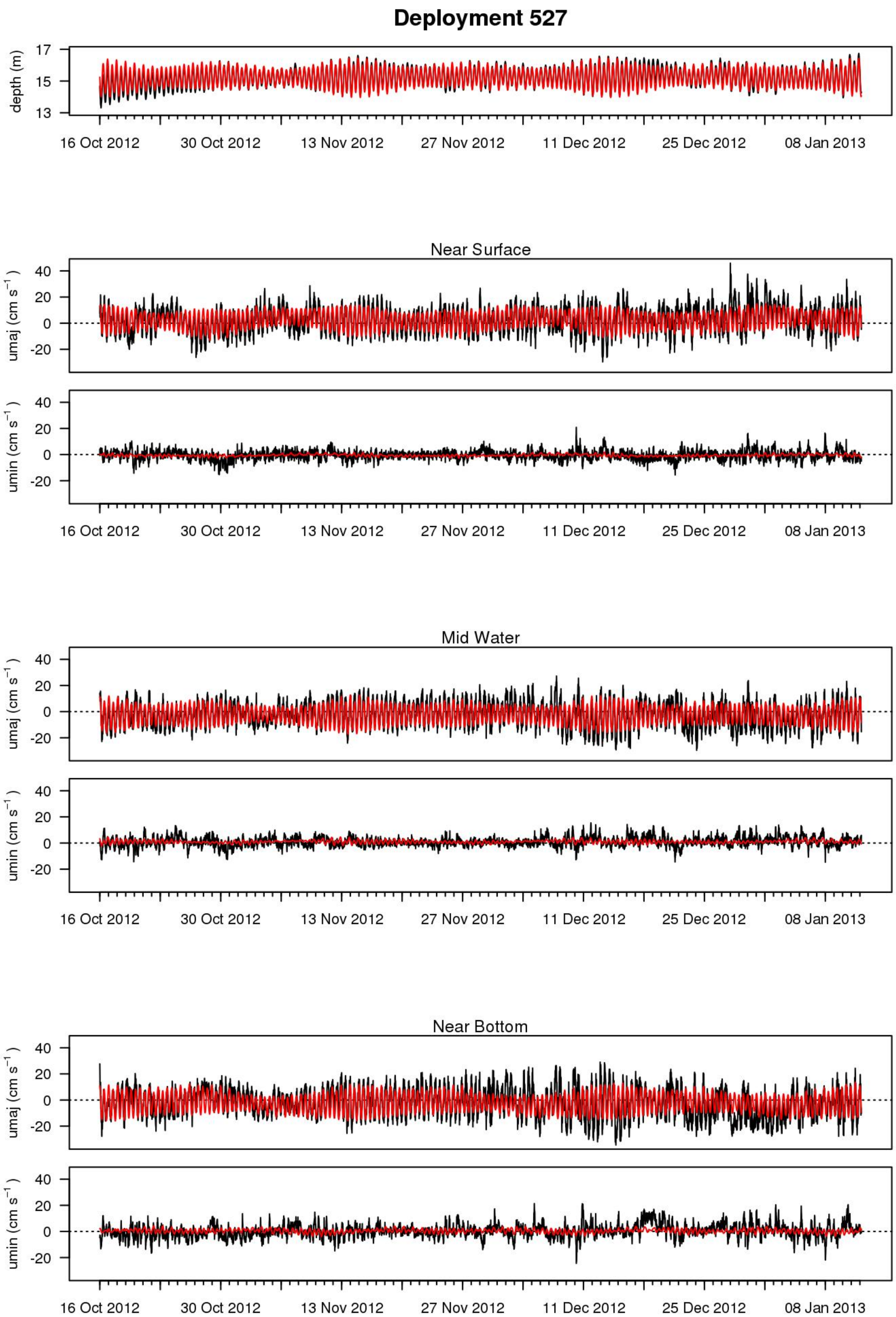


Fig. 18. Time series plots of water depth (depth) and current velocity for ADCP deployment 527 (Jordan Bay, 16 October 2012 to 12 January 2013). Current speeds are plotted in the major (umaj) and minor (umin) directions (as determined by the principal component analysis), for three depth levels (near surface, mid-water, and near bottom). Black lines are the observed currents; red lines are the reconstructed time series from the tidal analyses.

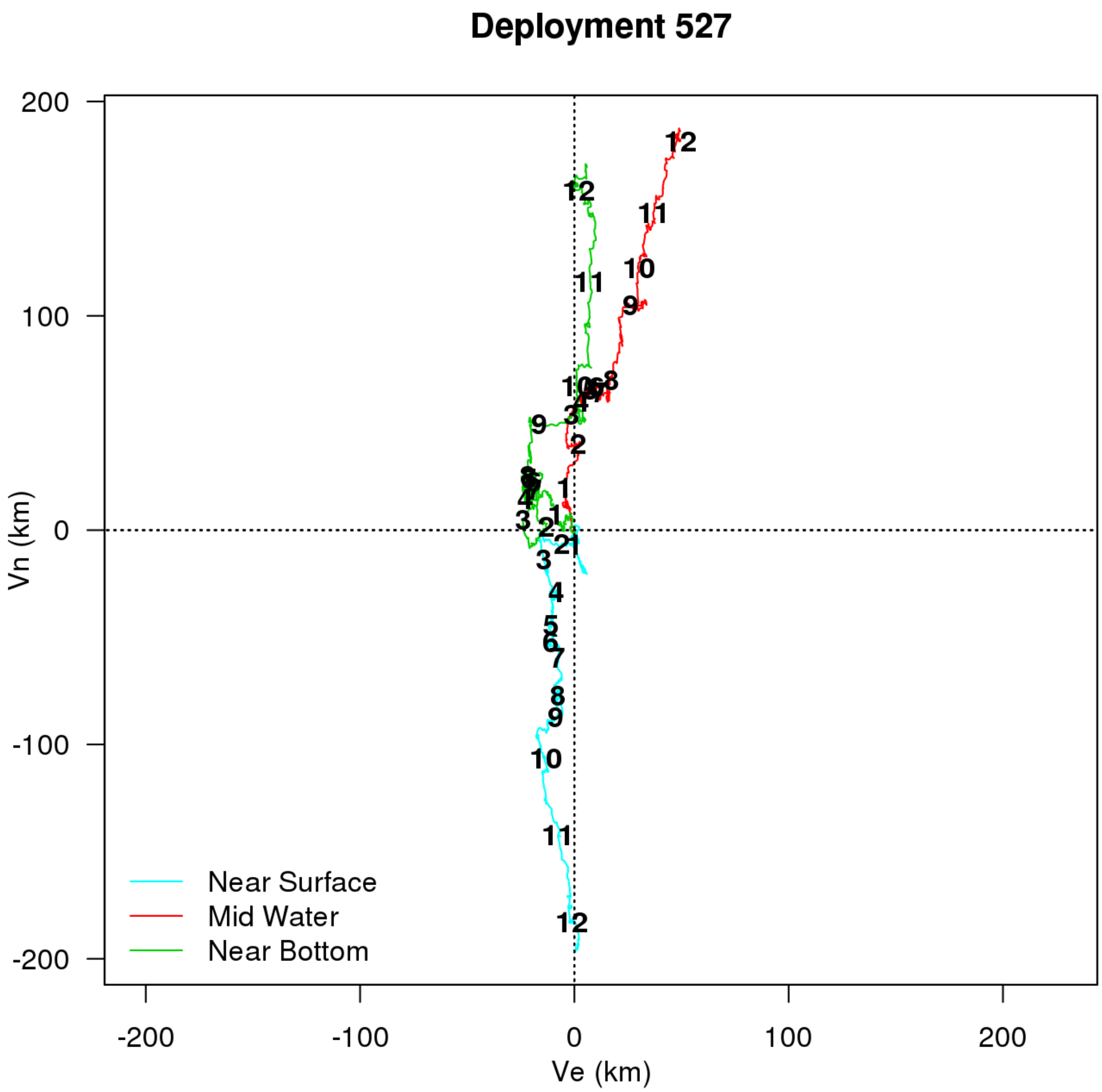


Fig. 19. Progressive vector plots for ADCP deployment 527 (Jordan Bay, 16 October 2012 to 12 January 2013). Successive movements of a particle are estimated using current velocities measured at 20-min intervals by the current meter. Ve = east-west direction; Vn = north-south direction. Data are presented for three depth levels: near surface (blue), mid-water (red), and near bottom (green). Numbers on the vectors indicate the number of weeks from the time of the first data record. Duration = 88.2 d (12.6 weeks).

Deployment 530: Shelburne Harbour

This deployment was in relatively shallow waters, with a mean depth of 9.8 m (Table 12). Current speeds were low: mean speeds at the three depth levels ranged from 5.4-6.5 cm s^{-1} and maxima were 19.9-27.2 cm s^{-1} (Table 16).

Current directions were predominantly north-south at all three depth levels (Figs. 20-22). The major axis (from principal components analysis) was also in the north-south direction at all three depth levels (Fig. 22). Tidal analyses of current velocities (Table 21 & Appendix C) indicated that M2 was the dominant tidal constituent along the major axis at all three depth levels. Along the minor axis, M2 was the most important constituent at mid-water and near the bottom, but not near the surface. The major axis accounted for 76-82% of the total variance (Table 22). The 5 main tidal constituents explained 43-56% of the currents' variance along the major axis (from principal components analysis), but ≤0.1% of the variance along the minor axis (Table 22 & Fig. 23); 35-48% of the variance along the major axis was due to M2 alone.

The progressive vector plot (Fig. 24) indicated relatively little net movement. Net displacement at the end of the data record (42.1 d) was ~45 km to the southeast near the surface, ~15 km to the east at mid-water, and ~10 km to the west near the bottom.

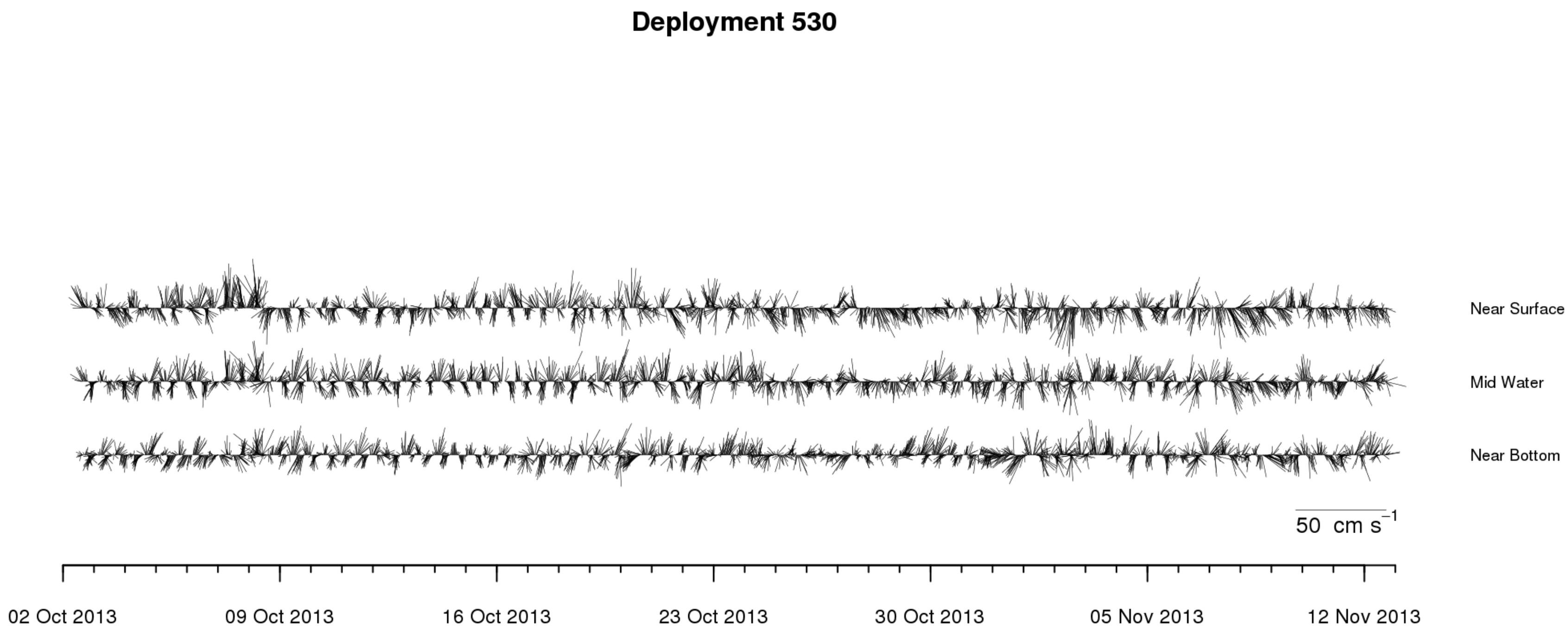


Fig. 20. Stick plots of current velocities in ADCP deployment 530 (Shelburne Harbour, 2 October to 13 November 2013) at three depth levels (near surface, mid-water, and near bottom). The lines show the current direction (true north is straight up) and speed (see scale on graph) in each data segment (20-min intervals).

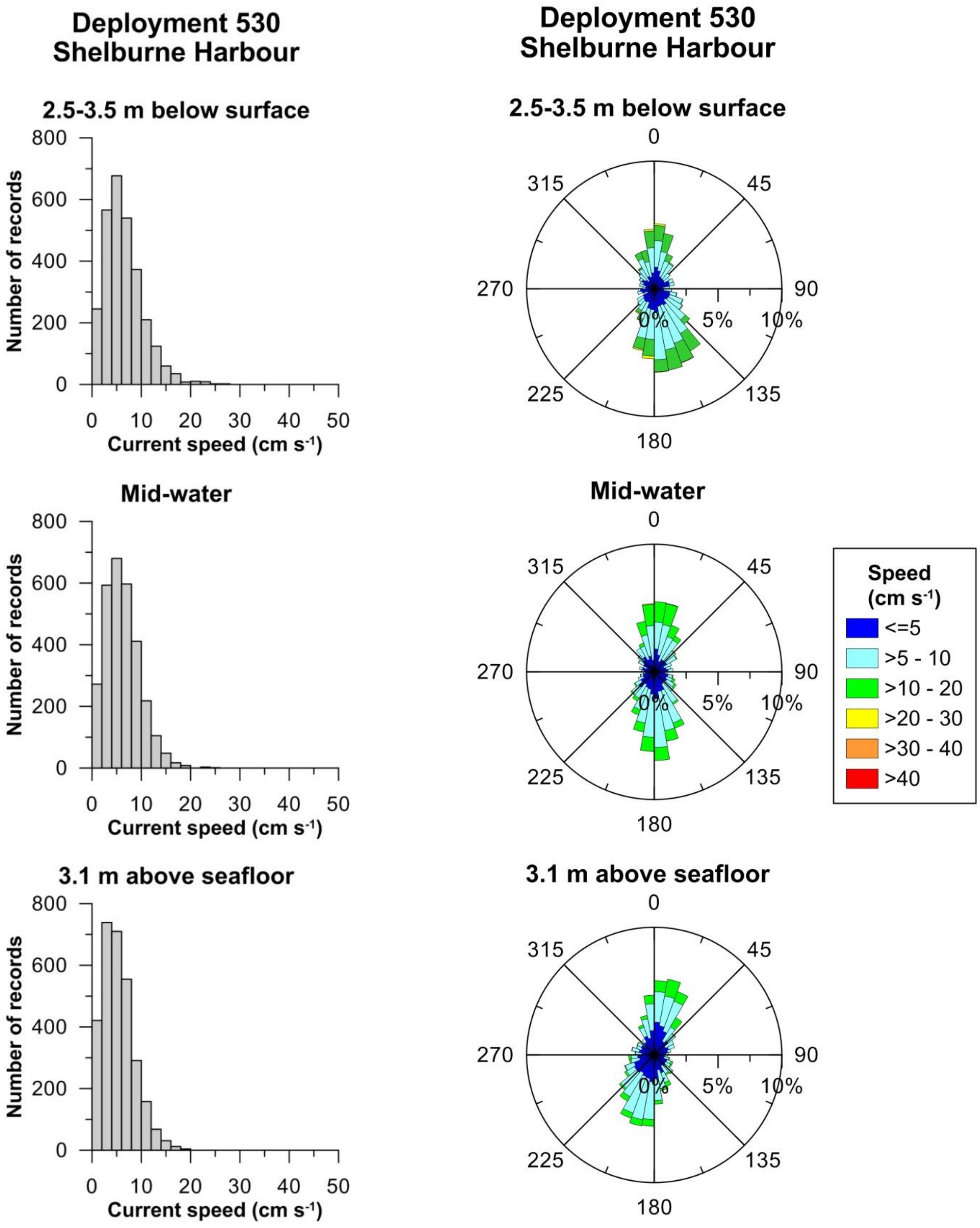


Fig. 21. Current speed histograms (left) and current velocity rose diagrams (right) for ADCP deployment 530 (Shelburne Harbour, 2 October to 13 November 2013). Data are presented for three depth levels: near surface (top), mid-water (middle), and near bottom (bottom).

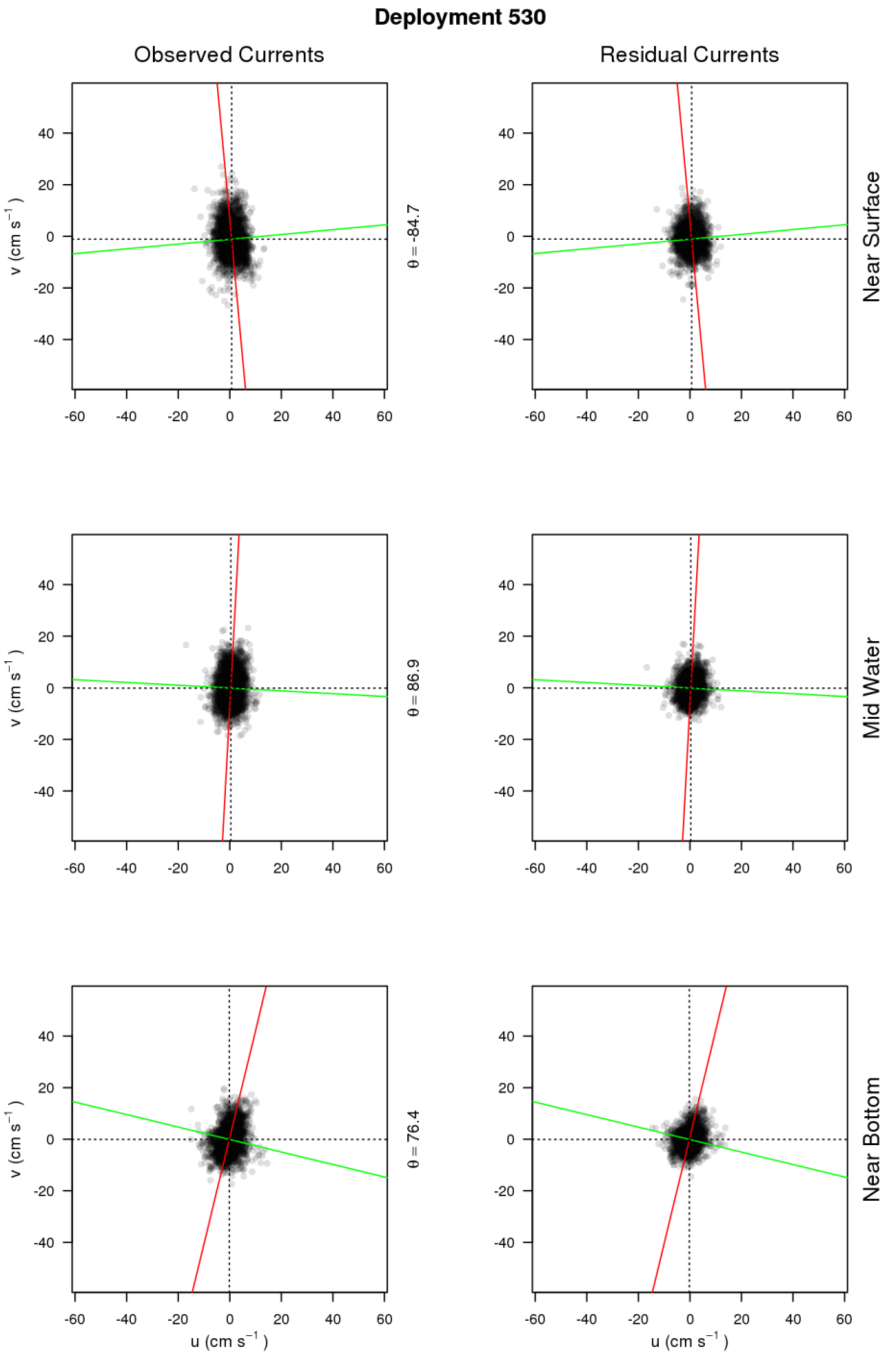


Fig. 22. Scatter plots for current velocities in ADCP deployment 530 (Shelburne Harbour, 2 October to 13 November 2013). Left: observed currents. Right: residual currents (obtained by removing the tidal signal from the original observation). Current velocity data in the east-west (u) and north-south (v) directions are presented for three depth levels: near surface (top), mid-water (middle), and near bottom (bottom). The red line is the major principal axis and the green line is the minor principal axis. θ = angle of the major axis (degrees from the east-west axis, in a counter-clockwise direction). The dotted lines indicate the mean currents in the east-west and north-south directions.

Table 21. Tidal analysis of water current velocities for ADCP deployment 530. Data are shown for the 5 main tidal constituents (M2, N2, S2, K1, O1). Z0 represents the mean flow in the direction of each principal axis at each depth level (near surface, mid-water, and near bottom). Amplitude = one-half of the range. Maj = in the direction of the major principal axis. Min = in the direction of the minor principal axis. * indicates that the constituent was not included in the 2nd pass of the tidal analysis program based on the value of the t-test. θ = angle of the major axis (degrees from the east-west axis, in a counter-clockwise direction). Time zone used in calculation of phases = UTC.

Deployment 530	Constituent		Amplitude	Phase (°)
Near surface currents (cm s^{-1}) θ = -84.7	Z0	Maj	1.115	0.0
	Z0	Min	0.574	0.0
	M2	Maj	5.467	98.4
	M2	Min	0.367	127.8
	N2	Maj	0.982	81.8
	N2	Min	0.273	216.2
	S2	Maj	1.574	150.4
	S2	Min	0.573	87.8
	K1	Maj	1.518	229.3
	K1	Min	*	*
	O1	Max	*	*
	O1	Min	0.314	197.1
Mid-water currents (cm s^{-1}) θ = 86.9	Z0	Maj	-0.137	0.0
	Z0	Min	-0.357	0.0
	M2	Maj	6.104	287.0
	M2	Min	0.922	222.9
	N2	Maj	1.211	264.2
	N2	Min	0.592	190.4
	S2	Maj	1.266	323.2
	S2	Min	0.508	217.3
	K1	Maj	1.199	99.4
	K1	Min	0.298	211.2
	O1	Maj	*	*
	O1	Min	0.515	321.0
Near bottom currents (cm s^{-1}) θ = 76.4	Z0	Maj	-0.137	0.0
	Z0	Min	0.201	0.0
	M2	Maj	4.756	288.6
	M2	Min	1.014	215.0
	N2	Maj	1.207	243.6
	N2	Min	0.768	234.7
	S2	Maj	0.985	294.7
	S2	Min	0.272	123.3
	K1	Maj	0.845	106.2
	K1	Min	0.265	175.0
	O1	Maj	0.549	55.3
	O1	Min	0.252	299.3

Table 22. Variance of observed water current velocity (cm s^{-1}) time series for ADCP deployment 530, with the percent contribution of the current in the major (Maj) and minor (Min) directions to the total variance of the currents, the percent contribution of the 5 main tidal constituents (M2, N2, S2, K1, and O1) to the variances in the Maj and Min directions, and the percent contribution of the M2 constituent to the variances in the Maj and Min directions. The percent contribution was calculated by reconstructing the time series from the specified tidal constituents when they were included in the analysis, as well as any constituents that were inferred from these. The variance was then calculated for the reconstructed signal and used to calculate the percent contribution to the total signal. All variances were calculated using N degrees of freedom where N is the total number of observations in a given record. Maj = in the direction of the major principal axis. Min = in the direction of the minor principal axis.

Deployment 530		Variance	% of variance in Maj and Min directions	% of variance contributed by M2+N2+S2+K1+O1	% of variance contributed by M2 only
Near surface	Maj	45.200	81.1	43.3	35.1
	Min	10.510	18.9	<0.05	<0.05
Mid-water	Maj	41.480	81.6	55.5	47.7
	Min	9.367	18.4	0.1	<0.05
Near bottom	Maj	30.218	76.3	46.5	39.8
	Min	9.410	23.7	0.1	0.1

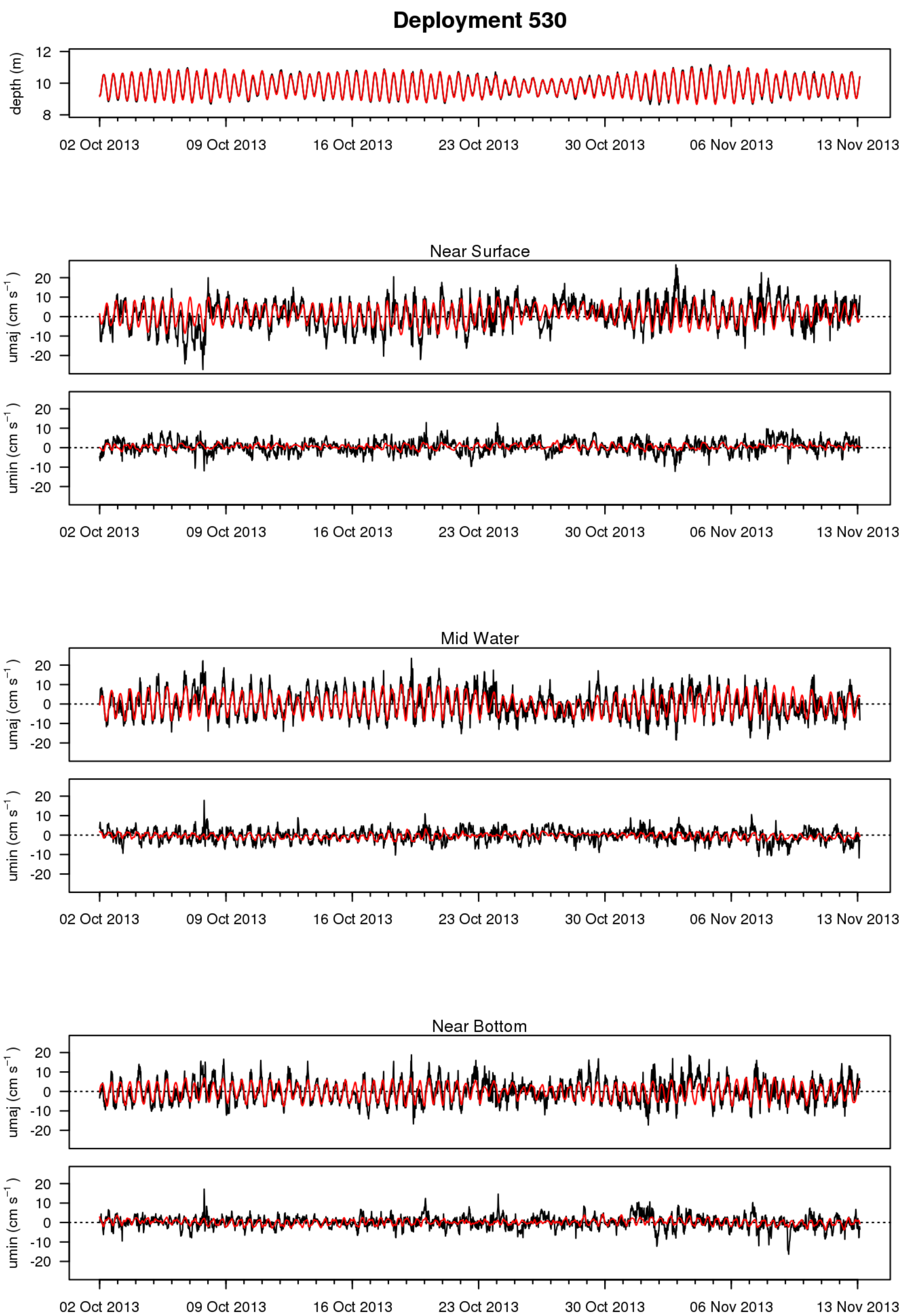


Fig. 23. Time series plots of water depth (depth) and current velocity for ADCP deployment 530 (Shelburne Harbour, 2 October to 13 November 2013). Current speeds are plotted in the major (umaj) and minor (umin) directions (as determined by the principal component analysis), for three depth levels (near surface, mid-water, and near bottom). Black lines are the observed currents; red lines are the reconstructed time series from the tidal analyses.

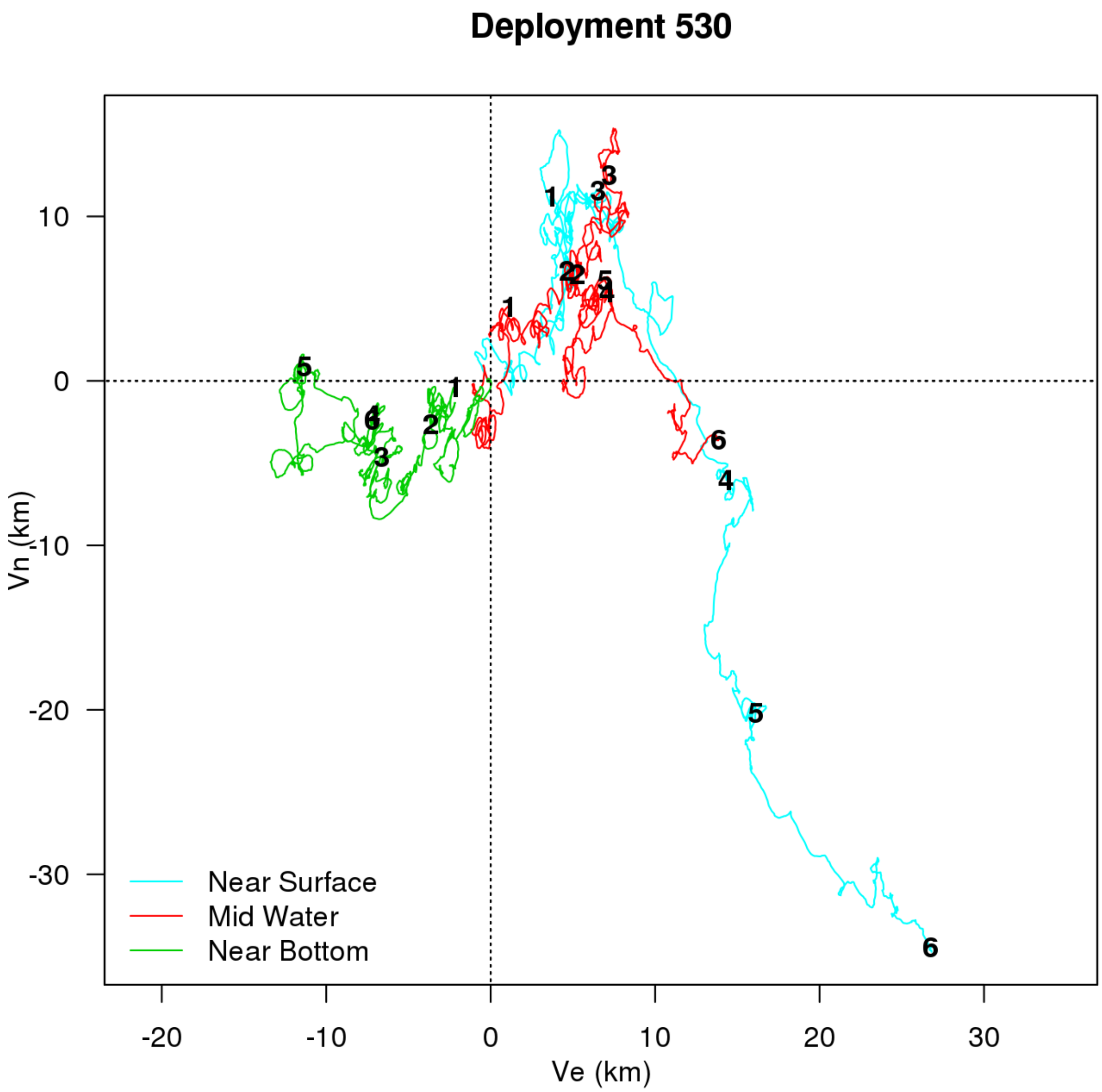


Fig. 24. Progressive vector plots for ADCP deployment 530 (Shelburne Harbour, 2 October to 13 November 2013). Successive movements of a particle are estimated using current velocities measured at 20-min intervals by the current meter. Ve = east-west direction; Vn = north-south direction. Data are presented for three depth levels: near surface (blue), mid-water (red), and near bottom (green). Numbers on the vectors indicate the number of weeks from the time of the first data record. Duration = 42.1 d (6.0 weeks).

Deployment 531: Inner Jordan Bay

This deployment was in relatively shallow water, with a mean depth of 10.4 m (Table 12). Current speeds were low, with mean speeds at the three depth levels ranging from 7.2-7.8 cm s^{-1} and maxima 27.8-30.0 cm s^{-1} (Table 16).

Current directions were predominantly north-south at all three depth levels (Figs. 25-27). The major axis (from principal components analysis) was also in the north-south direction at all three depth levels (Fig. 27). At all three depth levels, tidal analyses of current velocities (Table 23 & Appendix C) indicated that the M2 constituent had the largest amplitude along the major axis. Along the minor axis, M2 was the most important constituent near the bottom, but not near the surface or mid-water. The major axis accounted for 90-91% of the total variance (Table 24). The 5 main tidal constituents explained 55-62% of the currents' variance along the major axis (from principal components analysis), but ≤0.1% of the variance along the minor axis (Table 24 & Fig. 28); 47-54% of the variance along the major axis was due to M2 alone.

The progressive vector plot (Fig. 29) indicated that net movement was mainly to the north. The net displacement at the end of the data record (42.0 d) was ~20 km to the northwest near the surface, and 80-100 km to the north at mid-water and near the bottom.

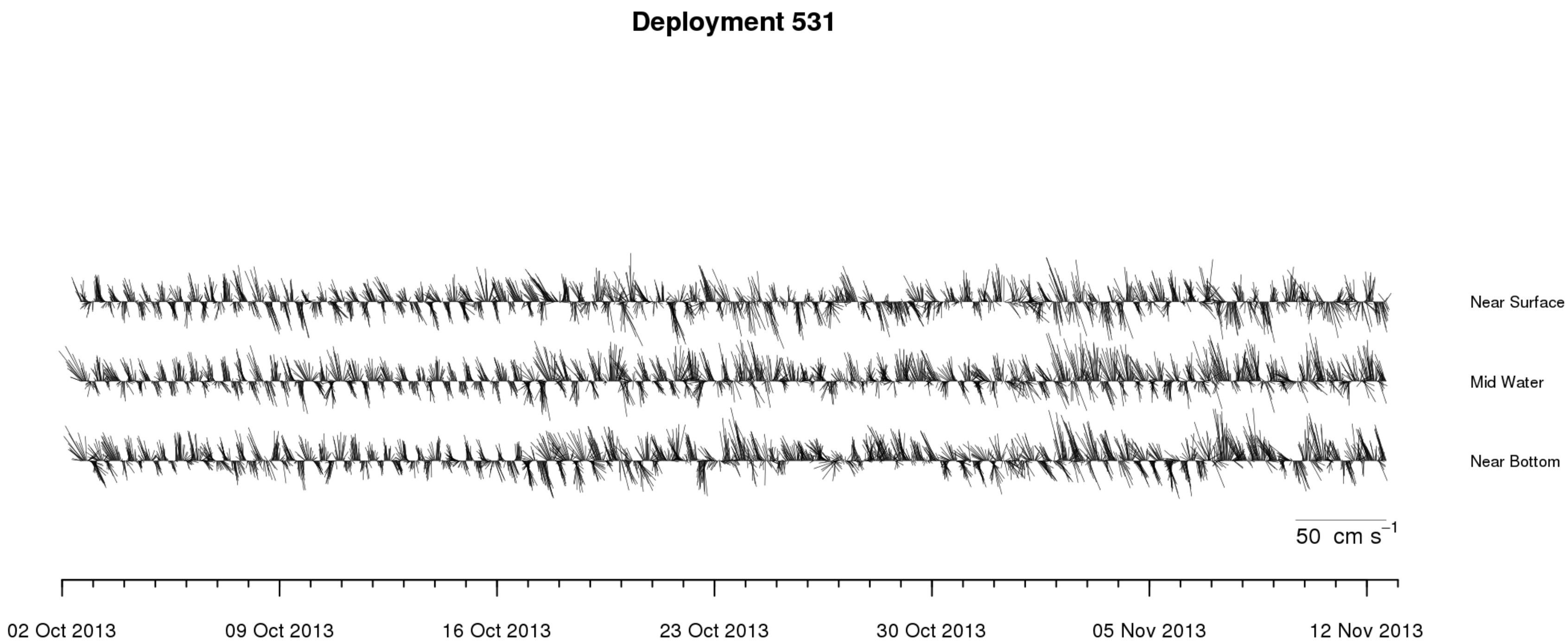


Fig. 25. Stick plots of current velocities in ADCP deployment 531 (inner Jordan Bay, 2 October to 13 November 2013) at three depth levels (near surface, mid-water, and near bottom). The lines show the current direction (true north is straight up) and speed (see scale on graph) in each data segment (20-min intervals).

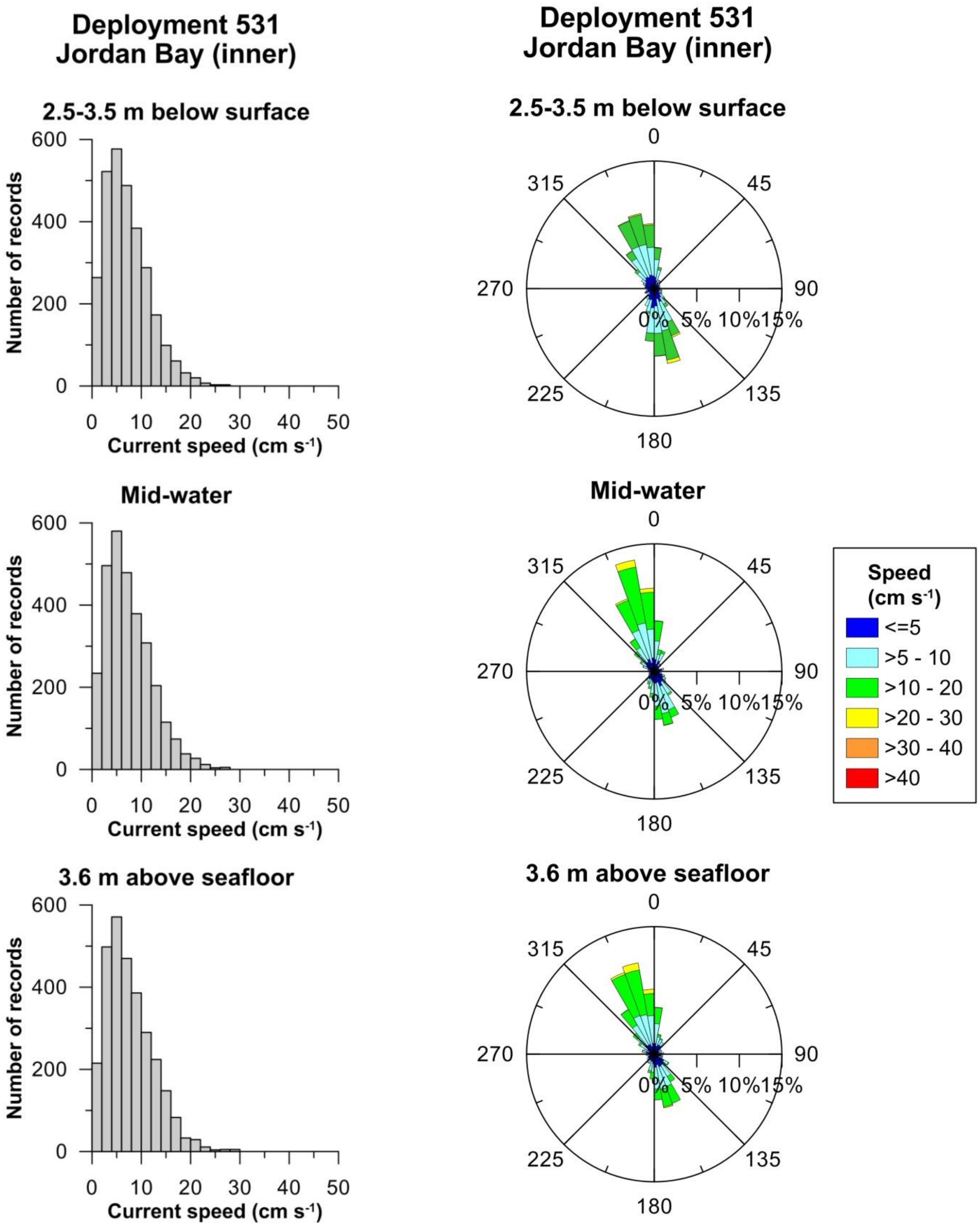


Fig. 26. Current speed histograms (left) and current velocity rose diagrams (right) for ADCP deployment 531 (inner Jordan Bay, 2 October to 13 November 2013). Data are presented for three depth levels: near surface (top), mid-water (middle), and near bottom (bottom).

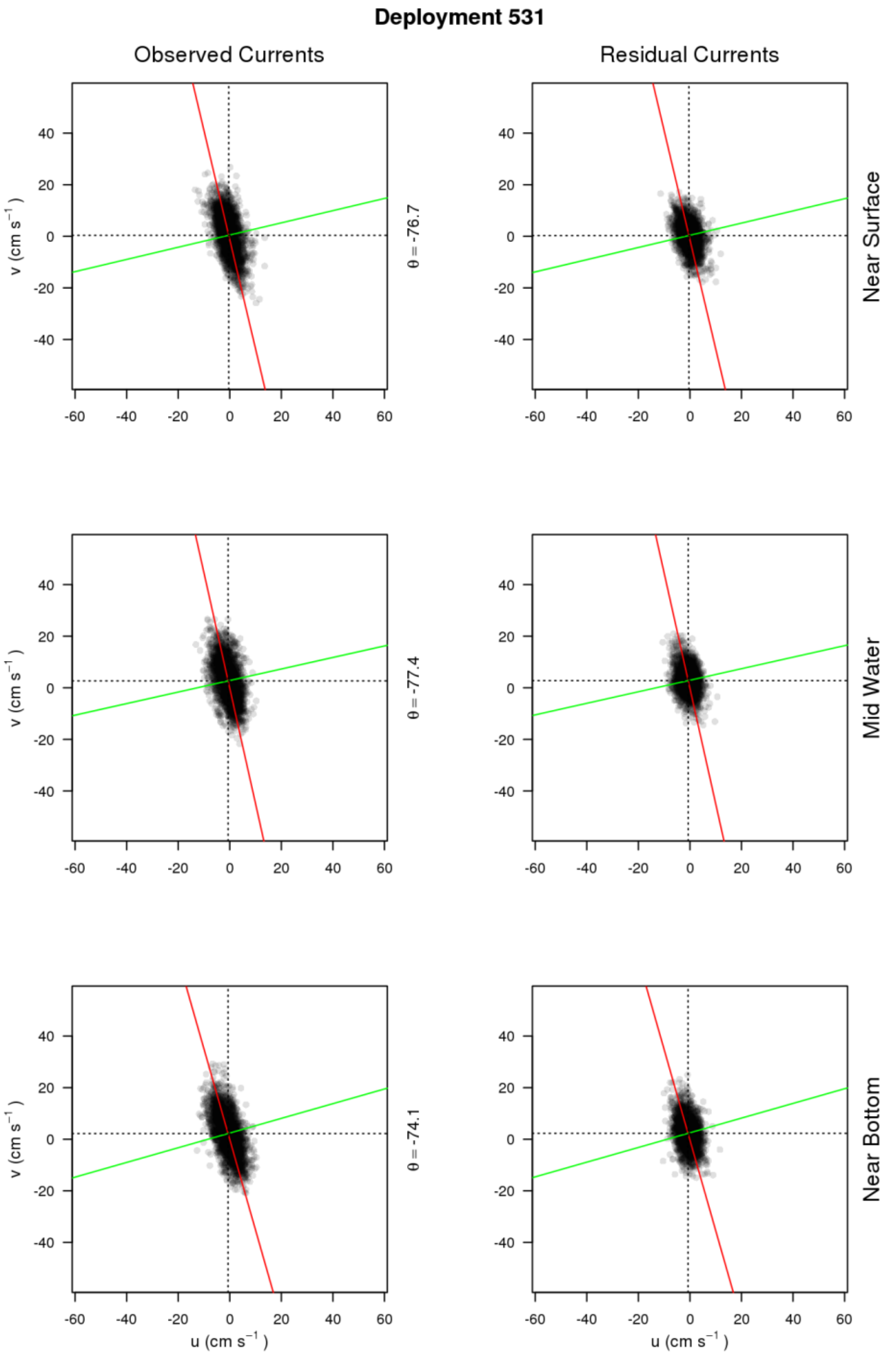


Fig. 27. Scatter plots for current velocities in ADCP deployment 531 (inner Jordan Bay, 2 October to 13 November 2013). Left: observed currents. Right: residual currents (obtained by removing the tidal signal from the original observation). Current velocity data in the east-west (u) and north-south (v) directions are presented for three depth levels: near surface (top), mid-water (middle), and near bottom (bottom). The red line is the major principal axis and the green line is the minor principal axis. θ = angle of the major axis (degrees from the east-west axis, in a counter-clockwise direction). The dotted lines indicate the mean currents in the east-west and north-south directions.

Table 23. Tidal analysis of water current velocities for ADCP deployment 531. Data are shown for the 5 main tidal constituents (M2, N2, S2, K1, O1). Z0 represents the mean flow in the direction of each principal axis at each depth level (near surface, mid-water, and near bottom). Amplitude = one-half of the range. Maj = in the direction of the major principal axis. Min = in the direction of the minor principal axis. * indicates that the constituent was not included in the 2nd pass of the tidal analysis program based on the value of the t-test. θ = angle of the major axis (degrees from the east-west axis, in a counter-clockwise direction). Time zone used in calculation of phases = UTC.

Deployment 531	Constituent		Amplitude	Phase (°)
Near surface currents (cm s^{-1}) θ = -76.7	Z0	Maj	-0.370	0.0
	Z0	Min	-0.307	0.0
	M2	Maj	7.739	94.8
	M2	Min	0.317	320.9
	N2	Maj	1.494	78.3
	N2	Min	0.259	116.3
	S2	Maj	1.436	141.8
	S2	Min	*	*
	K1	Maj	1.382	251.2
	K1	Min	0.402	92.5
	O1	Maj	0.931	226.9
	O1	Min	0.408	181.6
Mid-water currents (cm s^{-1}) θ = -77.4	Z0	Maj	-2.837	0.0
	Z0	Min	-0.053	0.0
	M2	Maj	8.068	99.2
	M2	Min	0.674	27.5
	N2	Maj	1.669	71.8
	N2	Min	0.267	337.0
	S2	Maj	1.777	131.6
	S2	Min	0.560	41.0
	K1	Maj	0.458	282.4
	K1	Min	0.831	39.3
	O1	Maj	0.829	240.2
	O1	Min	0.352	344.4
Near bottom currents (cm s^{-1}) θ = -74.1	Z0	Maj	-2.400	0.0
	Z0	Min	-0.085	0.0
	M2	Maj	7.899	99.3
	M2	Min	0.824	64.5
	N2	Maj	1.832	59.6
	N2	Min	0.233	300.0
	S2	Maj	1.819	121.5
	S2	Min	0.632	27.8
	K1	Maj	*	*
	K1	Min	*	*
	O1	Maj	0.821	250.4
	O1	Min	*	*

Table 24. Variance of observed water current velocity (cm s^{-1}) time series for ADCP deployment 531, with the percent contribution of the current in the major (Maj) and minor (Min) directions to the total variance of the currents, the percent contribution of the 5 main tidal constituents (M2, N2, S2, K1, and O1) to the variances in the Maj and Min directions, and the percent contribution of the M2 constituent to the variances in the Maj and Min directions. The percent contribution was calculated by reconstructing the time series from the specified tidal constituents when they were included in the analysis, as well as any constituents that were inferred from these. The variance was then calculated for the reconstructed signal and used to calculate the percent contribution to the total signal. All variances were calculated using N degrees of freedom where N is the total number of observations in a given record. Maj = in the direction of the major principal axis. Min = in the direction of the minor principal axis.

Deployment 531		Variance	% of variance in Maj and Min directions	% of variance contributed by M2+N2+S2+K1+O1	% of variance contributed by M2 only
Near surface	Maj	64.546	91.2	57.1	49.1
	Min	6.196	8.8	<0.05	<0.05
Mid-water	Maj	63.953	90.3	62.3	54.2
	Min	6.898	9.7	0.1	<0.05
Near bottom	Maj	69.819	90.3	54.7	47.4
	Min	7.459	9.7	0.1	<0.05

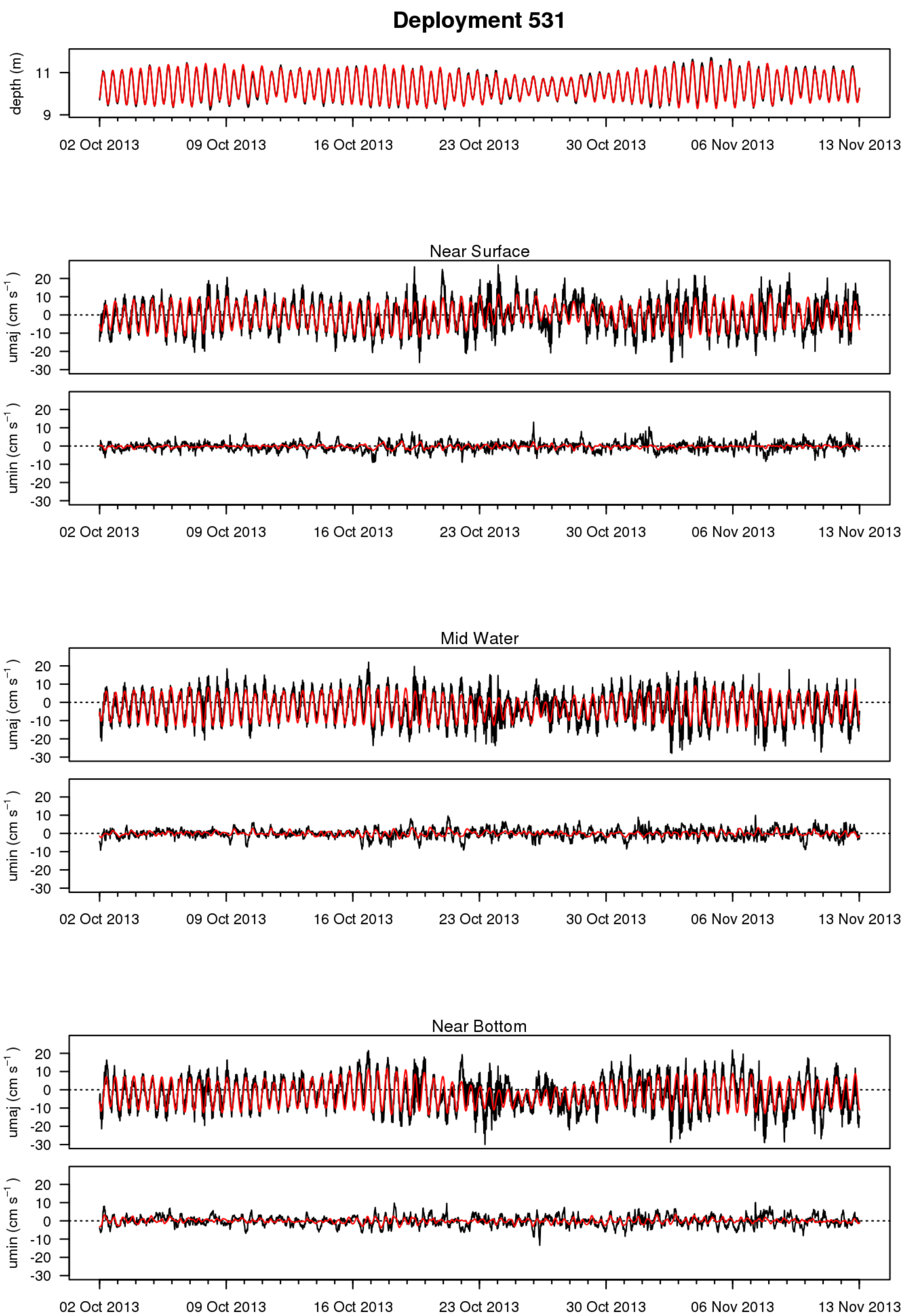


Fig. 28. Time series plots of water depth (depth) and current velocity for ADCP deployment 531 (inner Jordan Bay, 2 October to 13 November 2013). Current speeds are plotted in the major (umaj) and minor (umin) directions (as determined by the principal component analysis), for three depth levels (near surface, mid-water, and near bottom). Black lines are the observed currents; red lines are the reconstructed time series from the tidal analyses.

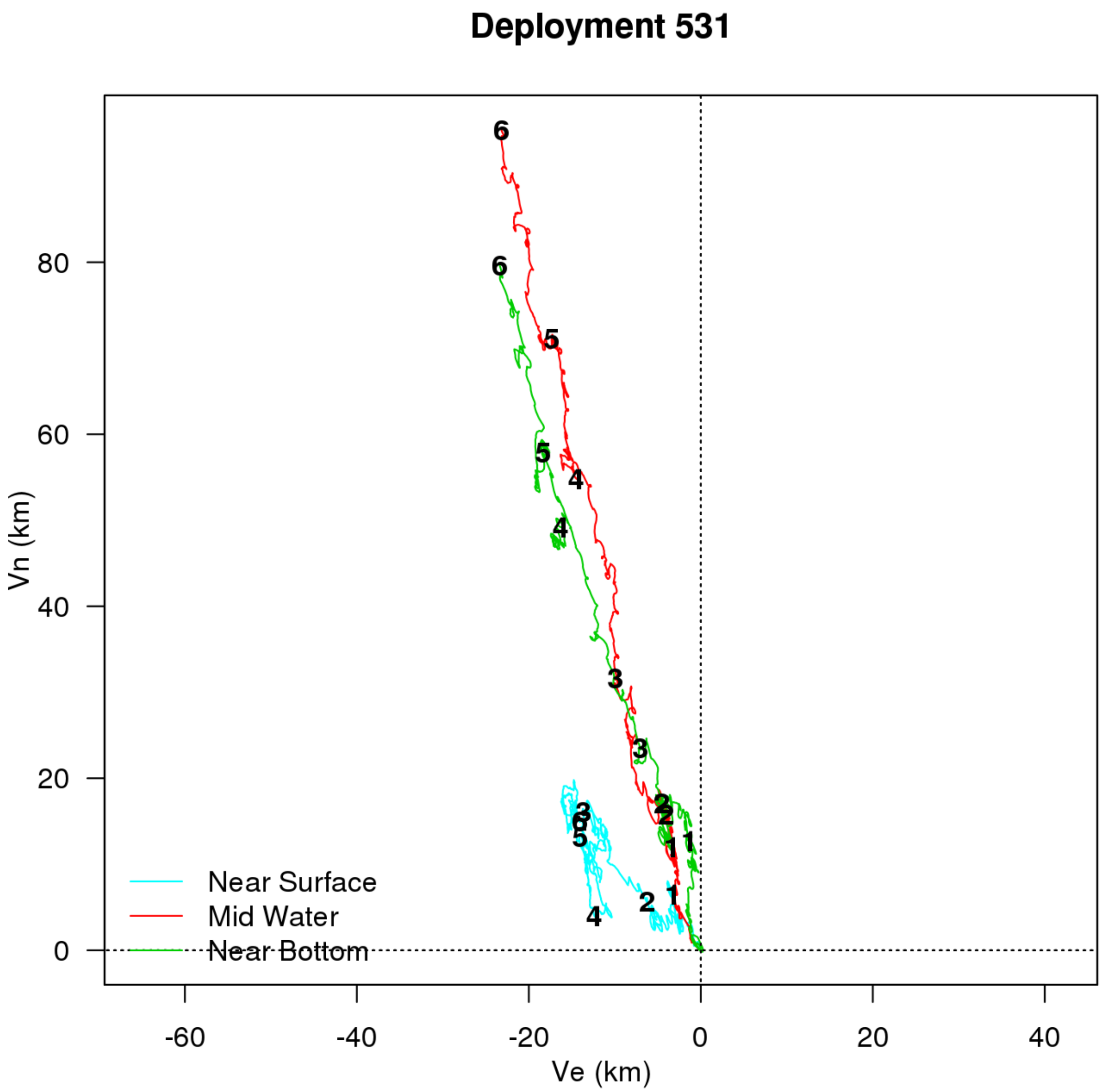


Fig. 29. Progressive vector plots for ADCP deployment 531 (inner Jordan Bay, 2 October to 13 November 2013). Successive movements of a particle are estimated using current velocities measured at 20-min intervals by the current meter. Ve = east-west direction; Vn = north-south direction. Data are presented for three depth levels: near surface (blue), mid-water (red), and near bottom (green). Numbers on the vectors indicate the number of weeks from the time of the first data record. Duration = 42.0 d (6.0 weeks).

Deployment 559: Blue Island (site 1359)

This was the deepest deployment, at a mean depth of 22.8 m (Table 12). Current speeds were moderate: mean speeds at the three depth levels ranged from 8.0-10.2 cm s^{-1} and maxima were 28.5-38.3 cm s^{-1} (Table 16).

The current direction was predominantly north-south at all three depth levels (Figs. 30-32). The major axis (from principal components analysis) was also in the north-south direction at all three depth levels (Fig. 32). Tidal analyses of current velocities (Table 25 & Appendix C) indicated that M2 was the dominant constituent along the major axis at all three depth levels. Along the minor axis, M2 was also the most important constituent (but not as dominant) at all three depths. The major axis accounted for 70-83% of the total variance (Table 26). The 5 main tidal constituents explained 27-48% of the variance along the major axis (from principal components analysis), but ≤0.1% of the variance along the minor axis (Table 26 & Fig. 33); 25-44% of the variance along the major axis was due to M2 alone.

The progressive vector plot (Fig. 34) indicated that the net displacement at the end of the data record (72.2 d) was ~50 km to the south near the surface, ~150 km to the north-northwest at mid-water, and ~50 km to the south near the bottom.

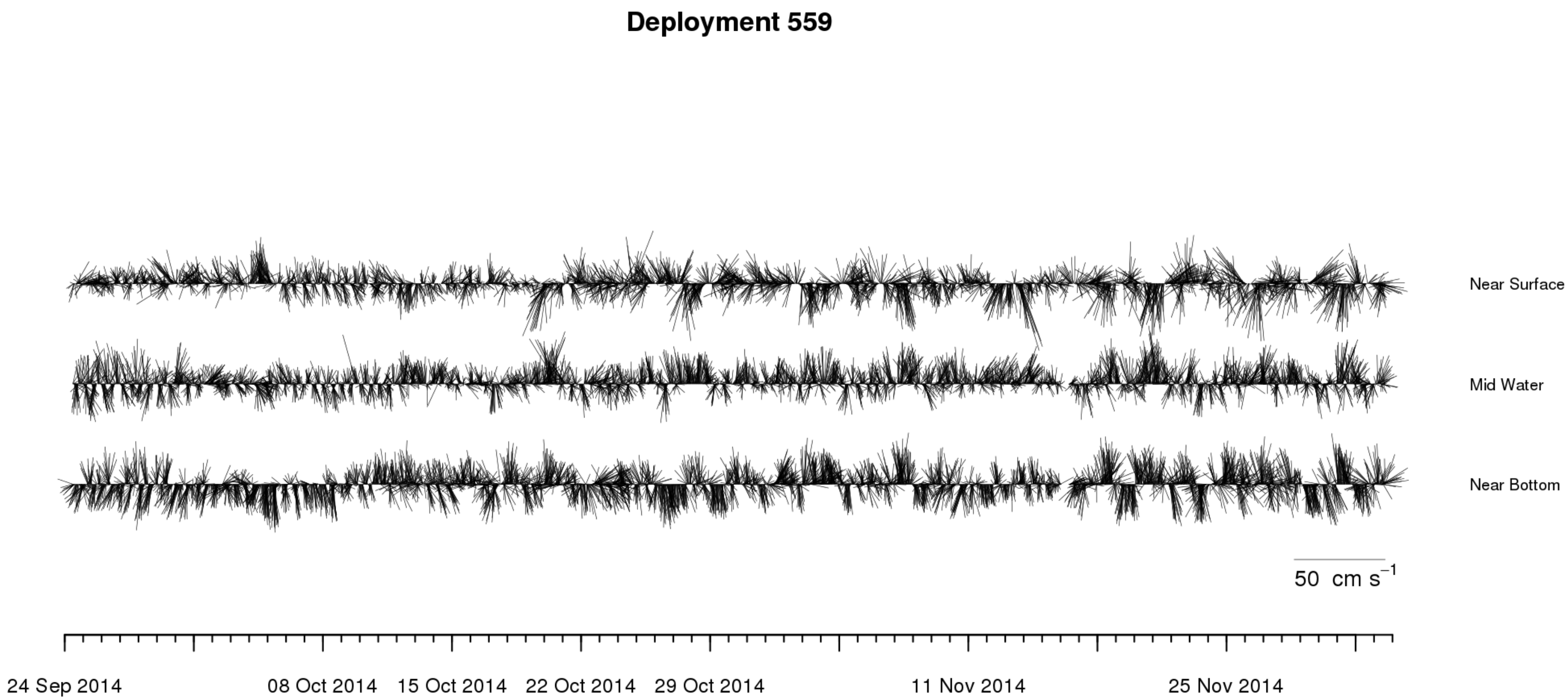


Fig. 30. Stick plots of current velocities in ADCP deployment 559 (Blue Island, 24 September to 4 December 2014) at three depth levels (near surface, mid-water, and near bottom). The lines show the current direction (true north is straight up) and speed (see scale on graph) in each data segment (20-min intervals).

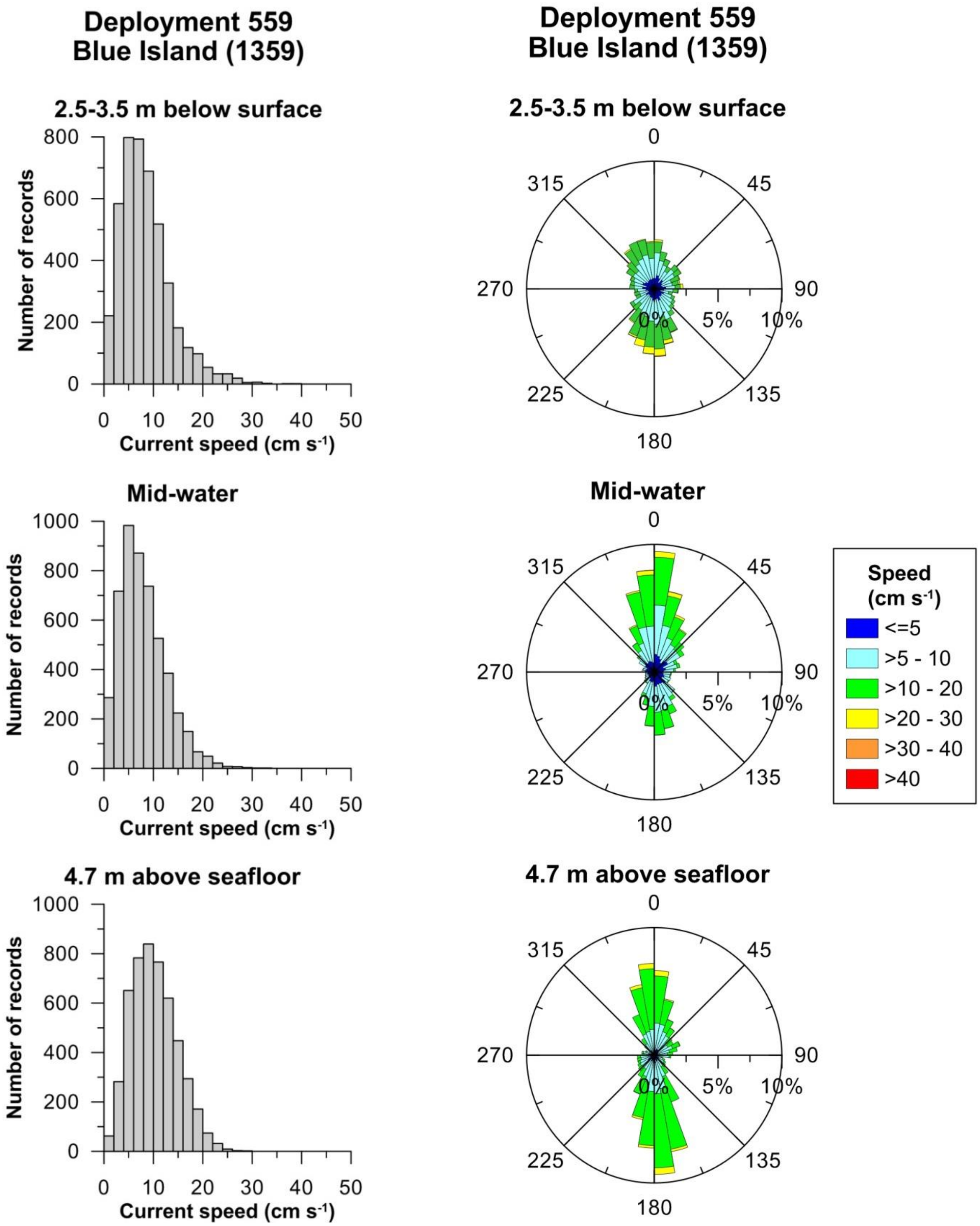


Fig. 31. Current speed histograms (left) and current velocity rose diagrams (right) for ADCP deployment 559 (Blue Island, 24 September to 4 December 2014). Data are presented for three depth levels: near surface (top), mid-water (middle), and near bottom (bottom).

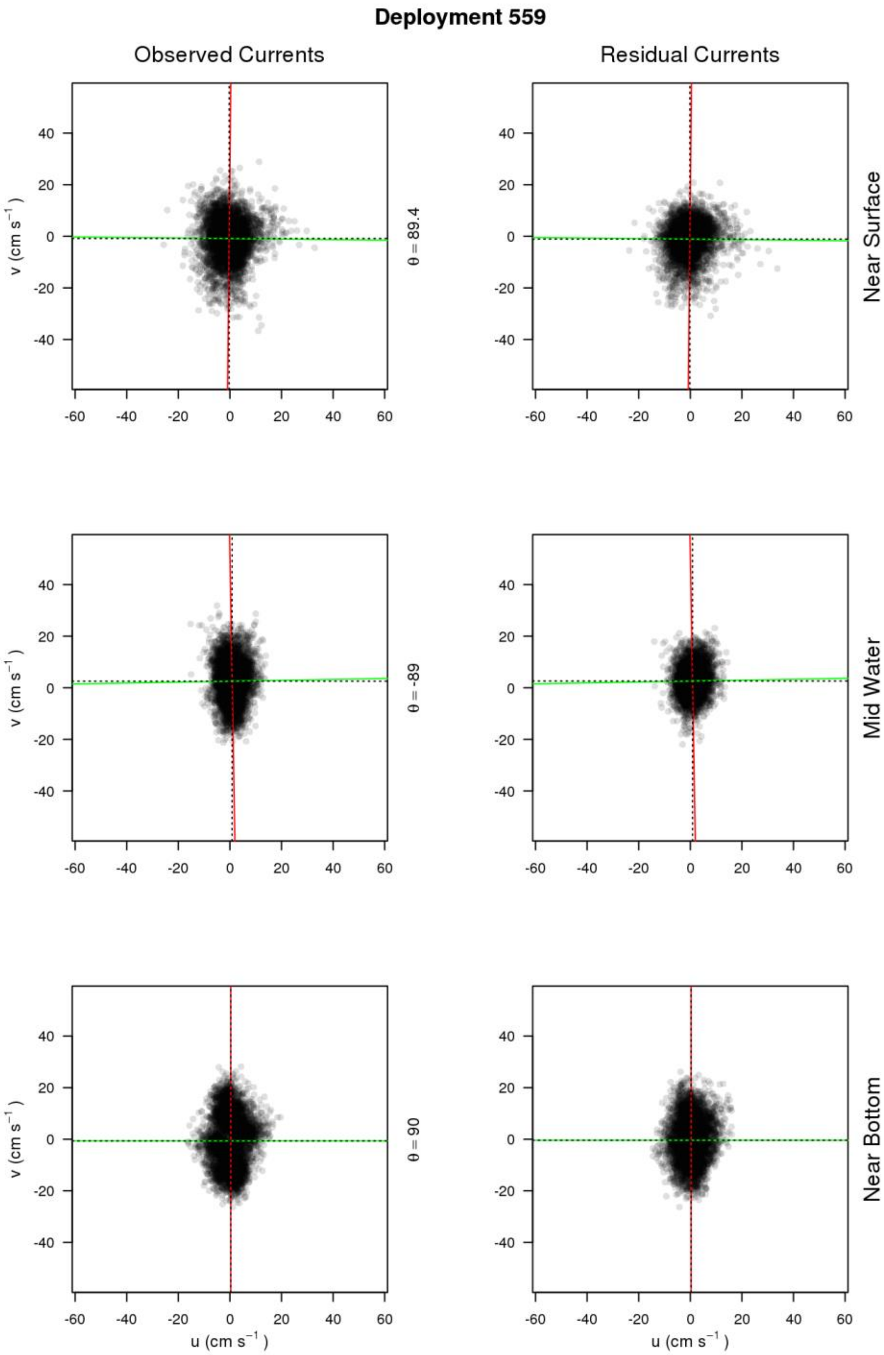


Fig. 32. Scatter plots for current velocities in ADCP deployment 559 (Blue Island, 24 September to 4 December 2014). Left: observed currents. Right: residual currents (obtained by removing the tidal signal from the original observation). Current velocity data in the east-west (u) and north-south (v) directions are presented for three depth levels: near surface (top), mid-water (middle), and near bottom (bottom). The red line is the major principal axis and the green line is the minor principal axis. θ = angle of the major axis (degrees from the east-west axis, in a counter-clockwise direction). The dotted lines indicate the mean currents in the east-west and north-south directions.

Table 25. Tidal analysis of water current velocities for ADCP deployment 559. Data are shown for the 5 main tidal constituents (M2, N2, S2, K1, O1). Z0 represents the mean flow in the direction of each principal axis at each depth level (near surface, mid-water, and near bottom). Amplitude = one-half of the range. Maj = in the direction of the major principal axis. Min = in the direction of the minor principal axis. * indicates that the constituent was not included in the 2nd pass of the tidal analysis program based on the value of the t-test. θ = angle of the major axis (degrees from the east-west axis, in a counter-clockwise direction). Time zone used in calculation of phases = UTC.

Deployment 559	Constituent		Amplitude	Phase (°)
Near surface currents ($cm\ s^{-1}$) θ = 89.4	Z0	Maj	-1.090	0.0
	Z0	Min	0.163	0.0
	M2	Maj	5.890	284.4
	M2	Min	1.386	242.9
	N2	Maj	1.486	256.7
	N2	Min	0.349	104.4
	S2	Maj	1.386	313.8
	S2	Min	0.379	66.6
	K1	Maj	0.786	26.7
	K1	Min	0.653	43.3
	O1	Maj	1.601	35.1
	O1	Min	0.432	239.2
Mid-water currents ($cm\ s^{-1}$) θ = -89.0	Z0	Maj	-2.590	0.0
	Z0	Min	0.898	0.0
	M2	Maj	7.297	108.2
	M2	Min	1.139	48.5
	N2	Maj	0.958	89.2
	N2	Min	0.391	102.2
	S2	Maj	1.668	142.7
	S2	Min	0.236	18.9
	K1	Maj	0.910	254.0
	K1	Min	0.453	190.4
	O1	Maj	*	*
	O1	Min	0.383	182.8
Near bottom currents ($cm\ s^{-1}$) θ = 90.0	Z0	Maj	-0.403	0.0
	Z0	Min	-0.300	0.0
	M2	Maj	6.985	284.5
	M2	Min	0.982	222.6
	N2	Maj	1.759	242.3
	N2	Min	0.897	237.9
	S2	Maj	0.759	0.9
	S2	Min	*	*
	K1	Maj	*	*
	K1	Min	0.292	345.7
	O1	Maj	*	*
	O1	Min	*	*

Table 26. Variance of observed water current velocity (cm s^{-1}) time series for ADCP deployment 559, with the percent contribution of the current in the major (Maj) and minor (Min) directions to the total variance of the currents, the percent contribution of the 5 main tidal constituents (M2, N2, S2, K1, and O1) to the variances in the Maj and Min directions, and the percent contribution of the M2 constituent to the variances in the Maj and Min directions. The percent contribution was calculated by reconstructing the time series from the specified tidal constituents when they were included in the analysis, as well as any constituents that were inferred from these. The variance was then calculated for the reconstructed signal and used to calculate the percent contribution to the total signal. All variances were calculated using N degrees of freedom where N is the total number of observations in a given record. Maj = in the direction of the major principal axis. Min = in the direction of the minor principal axis.

Deployment 559		Variance	% of variance in Maj and Min directions	% of variance contributed by M2+N2+S2+K1+O1	% of variance contributed by M2 only
Near surface	Maj	67.957	69.5	32.7	27.5
	Min	29.841	30.5	<0.05	<0.05
Mid-water	Maj	64.668	83.1	48.3	44.2
	Min	13.154	16.9	0.1	0.1
Near bottom	Maj	104.473	83.4	27.1	25.1
	Min	20.801	16.6	<0.05	<0.05

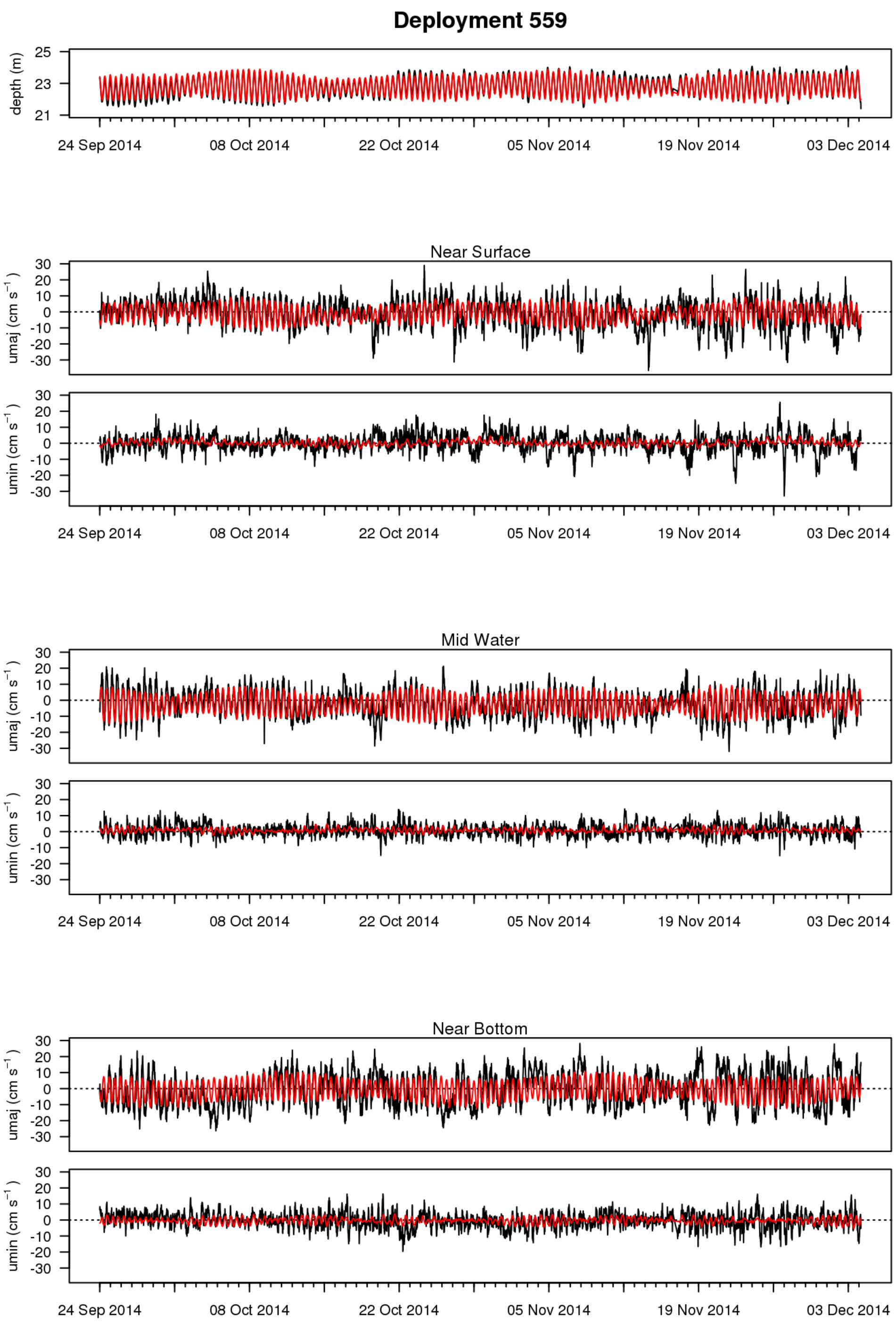


Fig. 33. Time series plots of water depth (depth) and current velocity for ADCP deployment 559 (Blue Island, 24 September to 4 December 2014). Current speeds are plotted in the major (umaj) and minor (umin) directions (as determined by the principal component analysis), for three depth levels (near surface, mid-water, and near bottom). Black lines are the observed currents; red lines are the reconstructed time series from the tidal analyses.

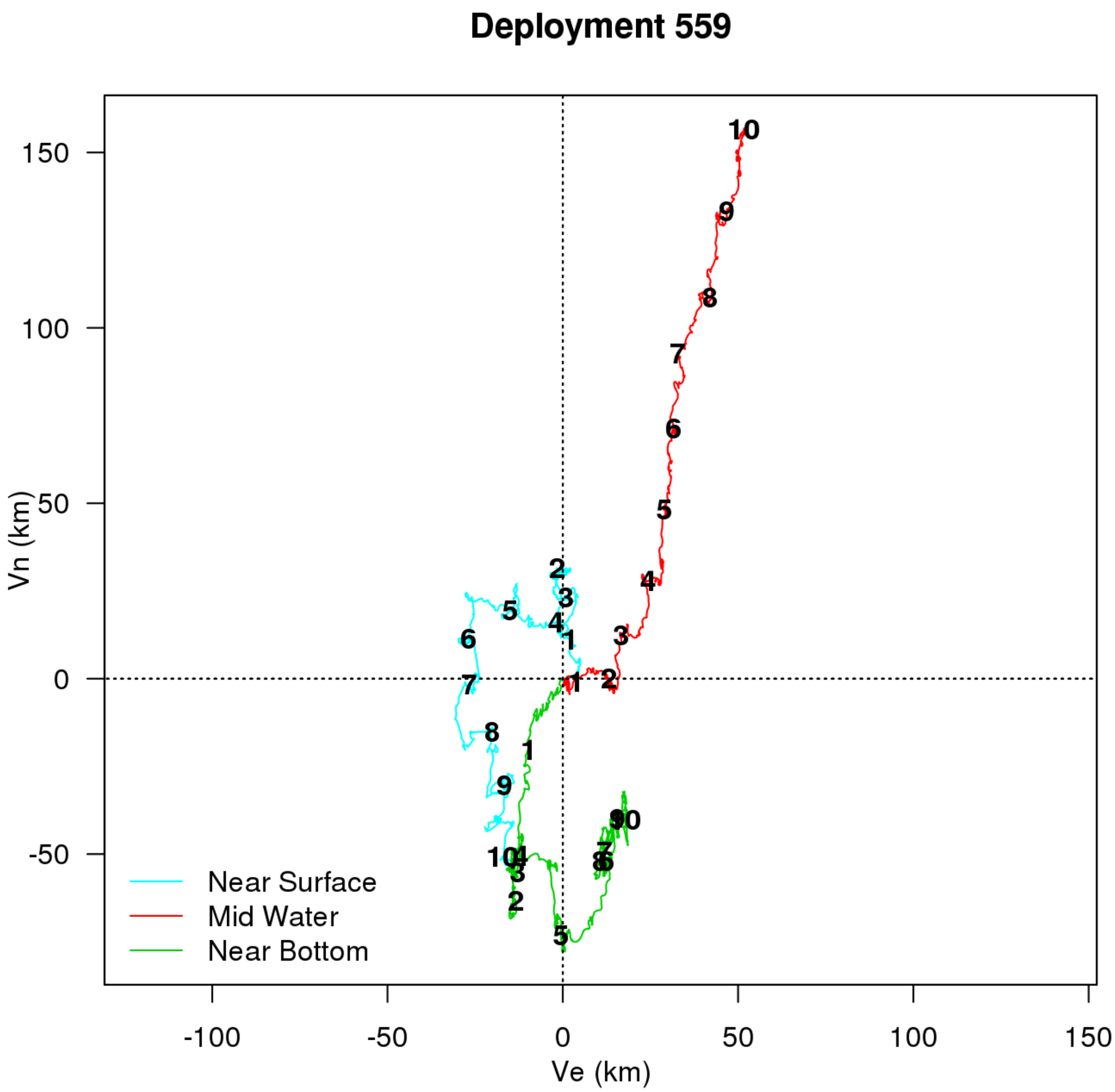


Fig. 34. Progressive vector plots for ADCP deployment 559 (Blue Island, 24 September to 4 December 2014). Successive movements of a particle are estimated using current velocities measured at 20-min intervals by the current meter. Ve = east-west direction; Vn = north-south direction. Data are presented for three depth levels: near surface (blue), mid-water (red), and near bottom (green). Numbers on the vectors indicate the number of weeks from the time of the first data record. Duration = 72.2 d (10.3 weeks).

Deployment 560: Shelburne Harbour (site 0602)

This deployment was in relatively shallow waters, with a mean depth of 12.6 m (Table 12). Current speeds were low: mean speeds at the three depth levels ranged from ranged from 6.0-6.7 cm s^{-1} and maxima were 26.8-32.2 cm s^{-1} (Table 16).

Current directions were predominantly north-south at all three depth levels (Figs. 35-37). The major axis (from principal components analysis) was also in the north-south direction at all three depth levels (Fig. 37). Tidal analyses of current velocities (Table 27 & Appendix C) indicated that M2 was the dominant constituent along the major axis at all three depth levels. Along the minor axis, M2 was also the most important constituent (but not as dominant) at all three depths. The major axis accounted for 77-84% of the total variance (Table 28). The 5 main tidal constituents explained 35-38% of the currents' variance along the major axis (from principal components analysis), but ≤0.1% of the variance along the minor axis (Table 28 & Fig. 38); 33-36% of the variance along the major axis was due to M2 alone.

The progressive vector plot (Fig. 39) indicated relatively little net movement. Net displacement at the end of the data record (54.6 d) was ~25 km to the northeast near the surface, ~40 km to the north at mid-water, and ~50 km to the north near the bottom.

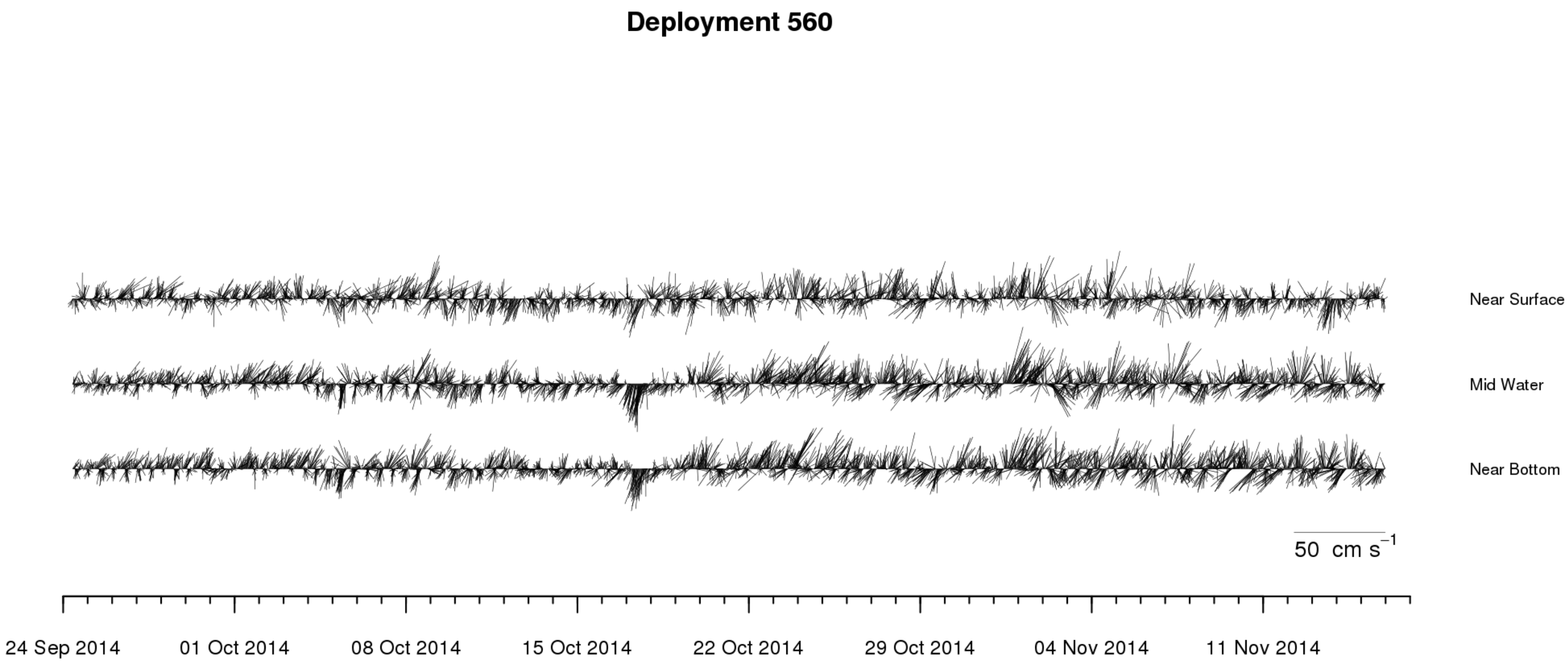


Fig. 35. Stick plots of current velocities in ADCP deployment 560 (Shelburne Harbour, 24 September to 17 November 2014) at three depth levels (near surface, mid-water, and near bottom). The lines show the current direction (true north is straight up) and speed (see scale on graph) in each data segment (20-min intervals).

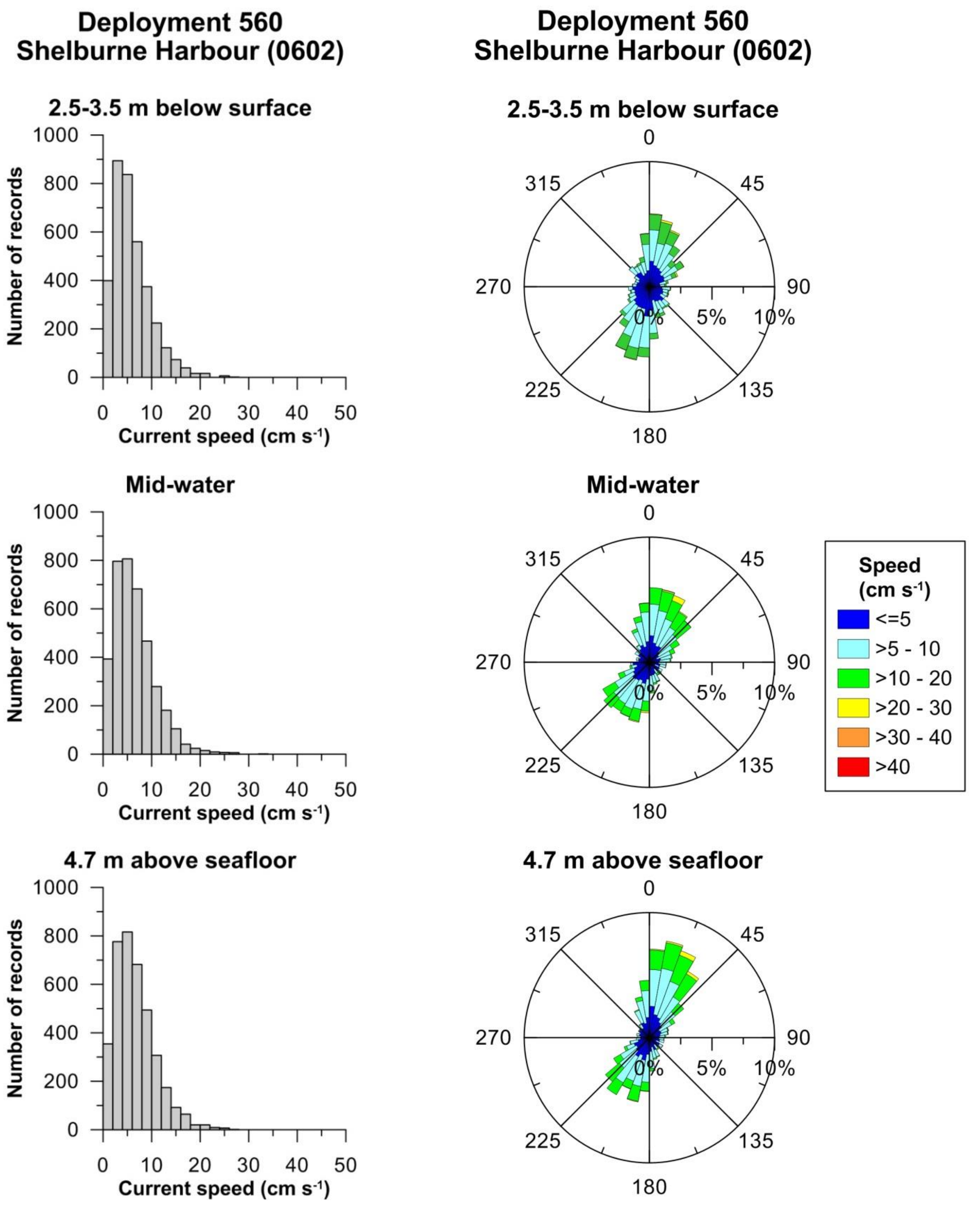


Fig. 36. Current speed histograms (left) and current velocity rose diagrams (right) for ADCP deployment 560 (Shelburne Harbour, 24 September to 17 November 2014). Data are presented for three depth levels: near surface (top), mid-water (middle), and near bottom (bottom).

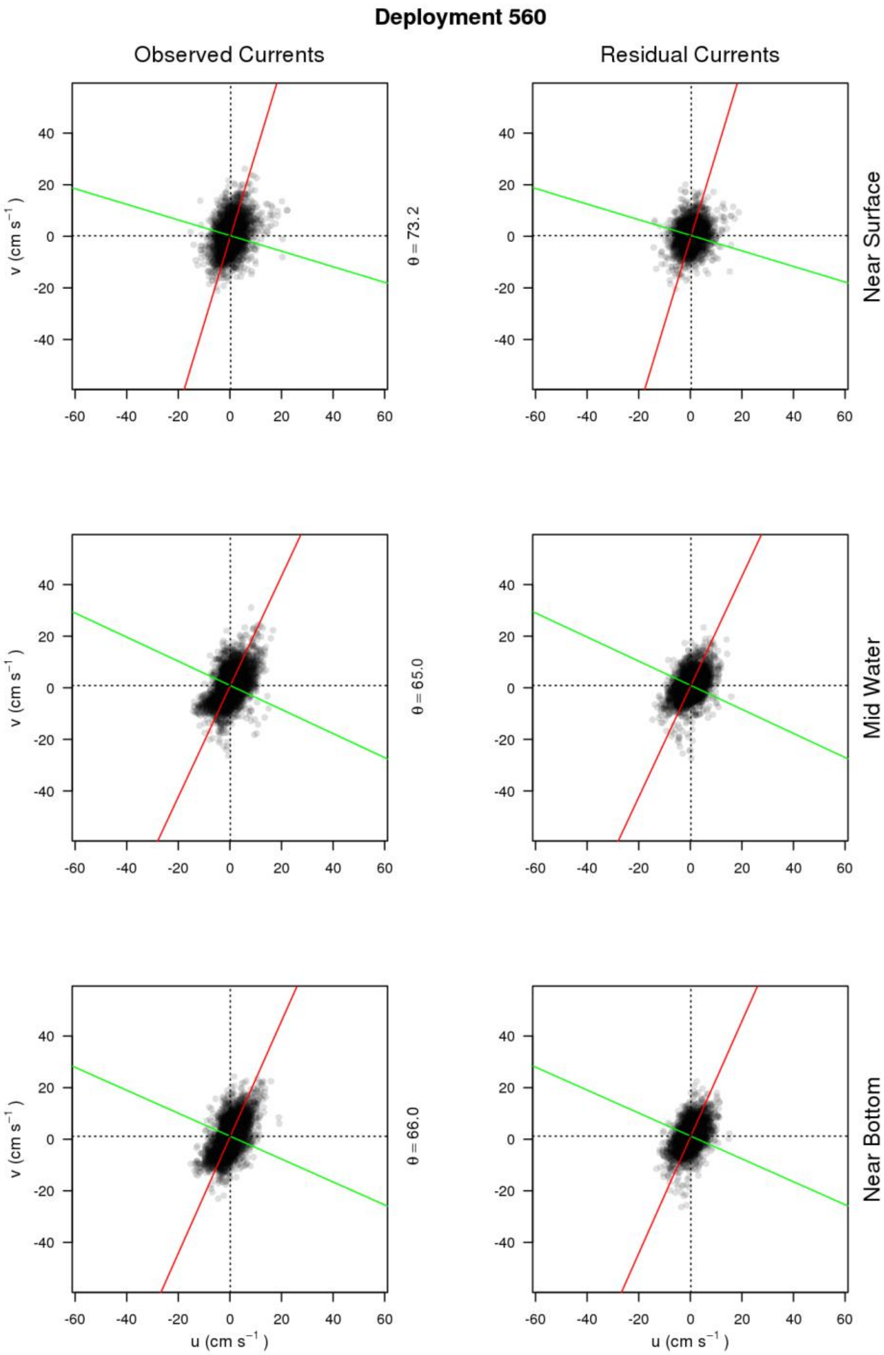


Fig. 37. Scatter plots for current velocities in ADCP deployment 560 (Shelburne Harbour, 24 September to 17 November 2014). Left: observed currents. Right: residual currents (obtained by removing the tidal signal from the original observation). Current velocity data in the east-west (u) and north-south (v) directions are presented for three depth levels: near surface (top), mid-water (middle), and near bottom (bottom). The red line is the major principal axis and the green line is the minor principal axis. θ = angle of the major axis (degrees from the east-west axis, in a counter-clockwise direction). The dotted lines indicate the mean currents in the east-west and north-south directions.

Table 27. Tidal analysis of water current velocities for ADCP deployment 560. Data are shown for the 5 main tidal constituents (M2, N2, S2, K1, O1). Z0 represents the mean flow in the direction of each principal axis at each depth level (near surface, mid-water, and near bottom). Amplitude = one-half of the range. Maj = in the direction of the major principal axis. Min = in the direction of the minor principal axis. * indicates that the constituent was not included in the 2nd pass of the tidal analysis program based on the value of the t-test. θ = angle of the major axis (degrees from the east-west axis, in a counter-clockwise direction). Time zone used in calculation of phases = UTC.

Deployment 560	Constituent		Amplitude	Phase (°)
Near surface currents (cm s^{-1}) θ = 73.2	Z0	Maj	0.381	0.0
	Z0	Min	-0.272	0.0
	M2	Maj	4.941	264.5
	M2	Min	0.873	340.5
	N2	Maj	0.333	257.7
	N2	Min	*	*
	S2	Maj	0.846	281.6
	S2	Min	0.429	306.3
	K1	Maj	0.374	211.2
	K1	Min	*	*
	O1	Maj	0.462	333.0
	O1	Min	*	*
Mid-water currents (cm s^{-1}) θ = 65.0	Z0	Maj	0.892	0.0
	Z0	Min	0.156	0.0
	M2	Maj	5.405	286.0
	M2	Min	1.478	218.9
	N2	Maj	0.653	276.0
	N2	Min	0.544	231.8
	S2	Maj	0.790	326.7
	S2	Min	0.396	228.7
	K1	Maj	0.753	162.9
	K1	Min	0.295	11.3
	O1	Maj	0.703	152.9
	O1	Min	0.562	77.7
Near bottom currents (cm s^{-1}) θ = 66.0	Z0	Maj	1.174	0.0
	Z0	Min	0.288	0.0
	M2	Maj	5.771	288.4
	M2	Min	1.358	208.1
	N2	Maj	0.915	251.4
	N2	Min	0.195	207.1
	S2	Maj	0.833	313.5
	S2	Min	0.406	181.6
	K1	Maj	0.659	100.2
	K1	Min	0.286	195.3
	O1	Maj	0.559	123.3
	O1	Min	0.346	112.2

Table 28. Variance of observed water current velocity (cm s^{-1}) time series for ADCP deployment 560, with the percent contribution of the current in the major (Maj) and minor (Min) directions to the total variance of the currents, the percent contribution of the 5 main tidal constituents (M2, N2, S2, K1, and O1) to the variances in the Maj and Min directions, and the percent contribution of the M2 constituent to the variances in the Maj and Min directions. The percent contribution was calculated by reconstructing the time series from the specified tidal constituents when they were included in the analysis, as well as any constituents that were inferred from these. The variance was then calculated for the reconstructed signal and used to calculate the percent contribution to the total signal. All variances were calculated using N degrees of freedom where N is the total number of observations in a given record. Maj = in the direction of the major principal axis. Min = in the direction of the minor principal axis.

Deployment 560		Variance	% of variance in Maj and Min directions	% of variance contributed by M2+N2+S2+K1+O1	% of variance contributed by M2 only
Near surface	Maj	39.018	77.3	35.0	33.7
	Min	11.481	22.7	<0.05	<0.05
Mid-water	Maj	47.741	80.0	35.1	32.9
	Min	11.948	20.0	0.1	0.1
Near bottom	Maj	50.505	84.0	37.6	35.5
	Min	9.614	16.0	0.1	0.1

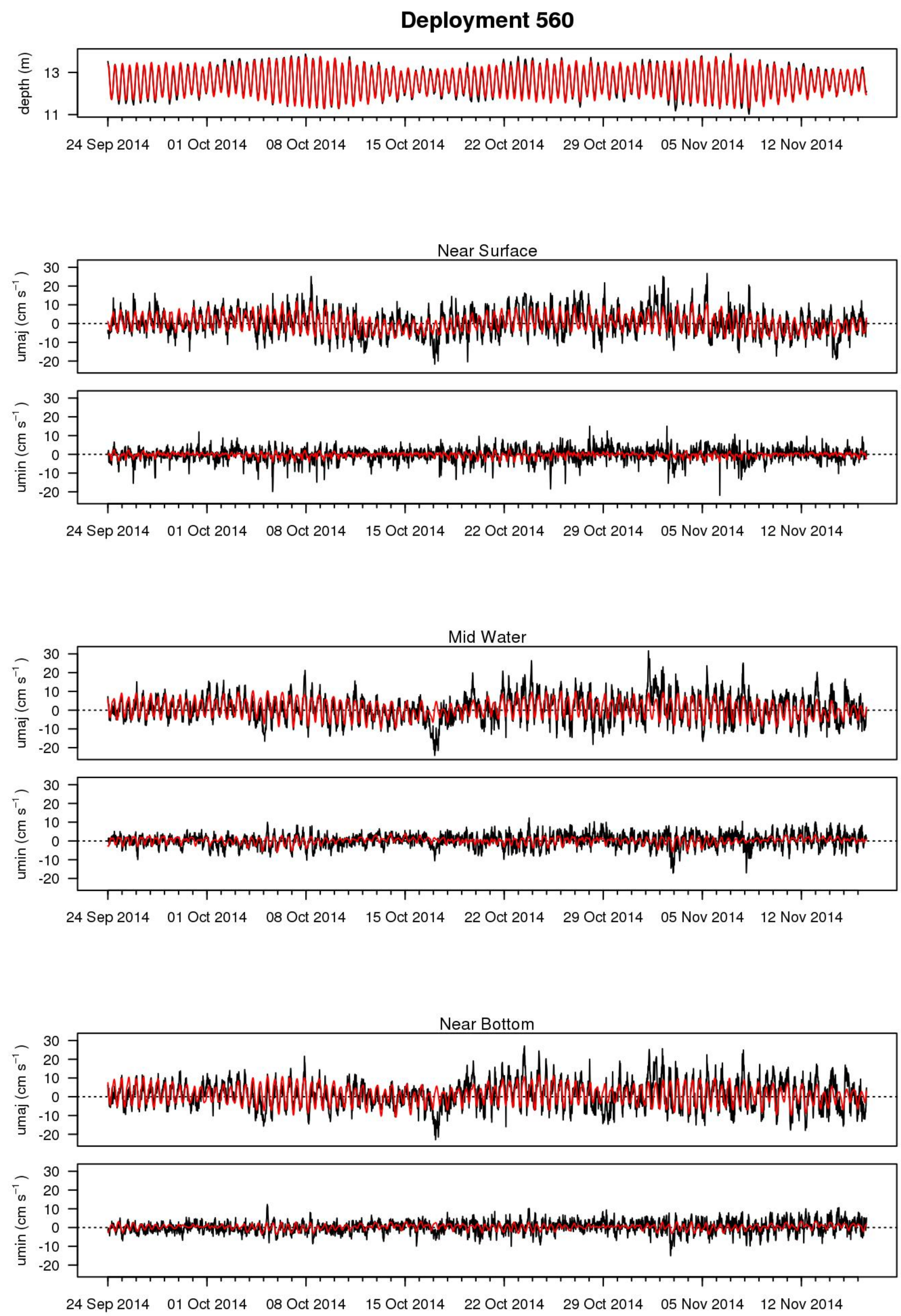


Fig. 38. Time series plots of water depth (depth) and current velocity for ADCP deployment 560 (Shelburne Harbour, 24 September to 17 November 2014). Current speeds are plotted in the major (umaj) and minor (umin) directions (as determined by the principal component analysis), for three depth levels (near surface, mid-water, and near bottom). Black lines are the observed currents; red lines are the reconstructed time series from the tidal analyses.

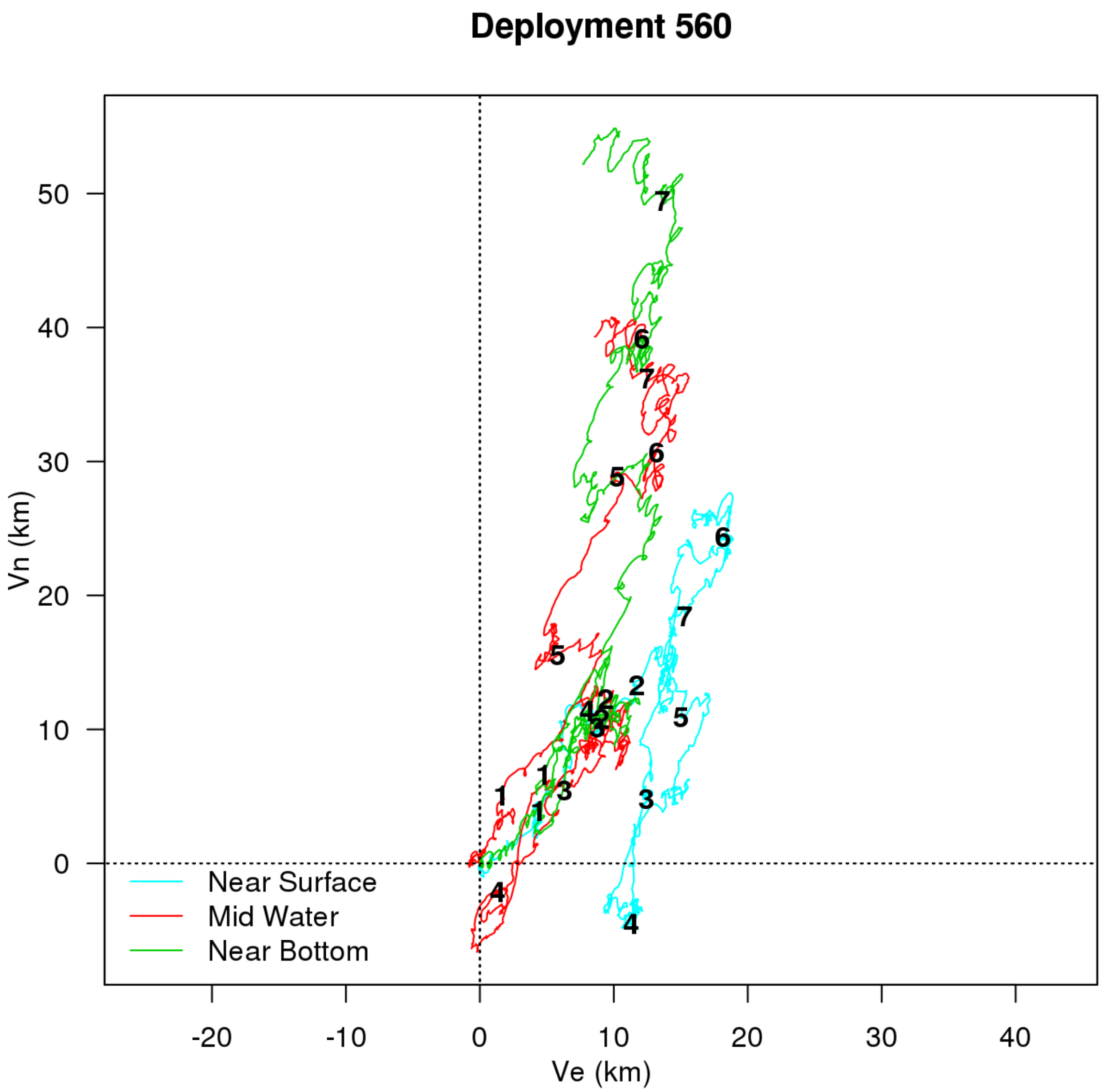


Fig. 39. Progressive vector plots for ADCP deployment 560 (Shelburne Harbour, 24 September to 17 November 2014). Successive movements of a particle are estimated using current velocities measured at 20-min intervals by the current meter. Ve = east-west direction; Vn = north-south direction. Data are presented for three depth levels: near surface (blue), mid-water (red), and near bottom (green). Numbers on the vectors indicate the number of weeks from the time of the first data record. Duration = 54.6 d (7.8 weeks).

Hydrographic data

Temperature vs. time from RBR deployments

Near bottom water temperature data were obtained from the RBR*duo* deployments during October-November 2013. Temperatures were similar among the 4 deployments (Fig. 40). The overall temperature range among all deployments was 6.4-15.3°C. Temperatures were initially high and relatively constant, and then decreased in late October and early November. These deployments were in shallow waters, with mean depths ranging from 3.4-5.0 m (Table 10).

Temperature-depth profiles (from CTDs)

In 2012, temperatures declined with depth at both sampling times (Fig. 41). In July 2012, surface temperatures were 14-17°C, while temperatures at depth were 9-11°C; higher temperatures were in the top ~5 m. In October, surface temperatures were 10-15°C, while temperatures at depth were 6-8°C; higher temperatures were in the top ~5 m; the largest decreases with depth were observed in the shallower stations.

In October 2013, temperatures declined with depth at all stations, with the highest rate of change at the shallowest stations. High temperatures were observed in the surface layer that extended up to depths of ~20-25 m at some deeper stations (Fig. 42). Surface temperatures were 13-15°C, while minimum temperatures (at depth) were 8-10°C. In November 2013 temperatures were much lower (6-8°C) and relatively constant with depth, although temperatures were slightly lower in the top ~5 m, except at one shallow station in Jordan Bay (CTD13-12).

In September 2014, temperatures declined with depth at all stations, with the highest rate of change at the shallowest stations. The highest temperatures occurred near the surface and could extend down to depths of up to 15-25 m at deeper stations (Fig. 43). Surface temperatures were 15-16°C, while minimum temperatures (at depth) were 6-8°C.

Salinity-depth profiles (from CTDs)

In July 2012 the salinity showed little change with depth, ranging from 30-31 psu (Fig. 44). In October 2012 lower salinities were observed near the surface at most stations, with the least change with depth at deeper stations (further offshore), and a large decrease in surface salinity (down to 12 psu) at station CTD12-7, the innermost station in Shelburne Harbour (Fig. 44).

In 2013 salinities were relatively constant with depth at both sampling times (October and November), with salinities of 30-31 psu, except slightly lower (28-30 psu) near the surface, especially at shallower stations in Shelburne Harbour (Fig. 45).

In September 2014 there was little or no change in salinity with depth at the deeper stations, while shallower stations showed lower salinities near the surface, with the lowest surface salinities (down to 24 psu) at the two innermost stations in Shelburne Harbour (CTD14-7 & CTD14-21) (Fig. 46).

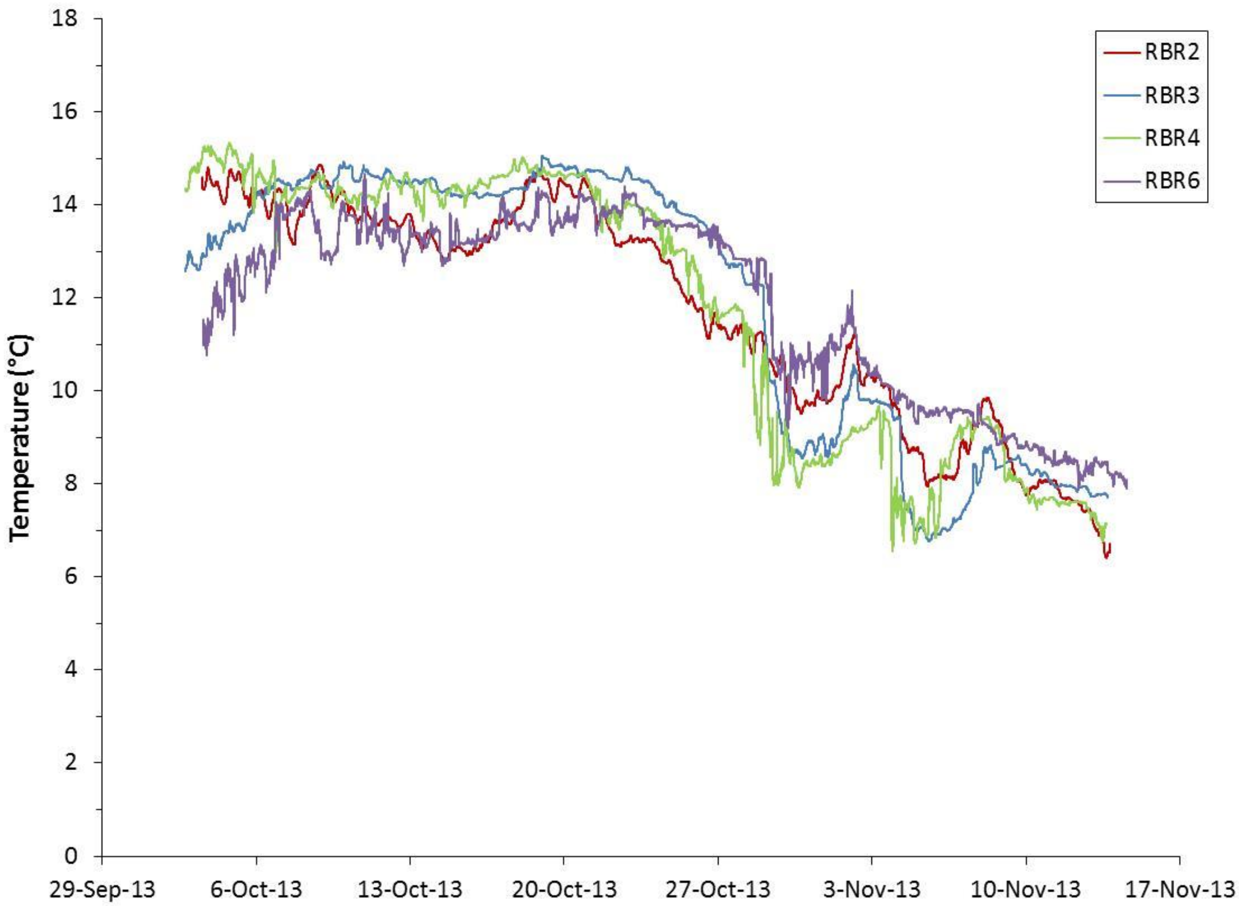
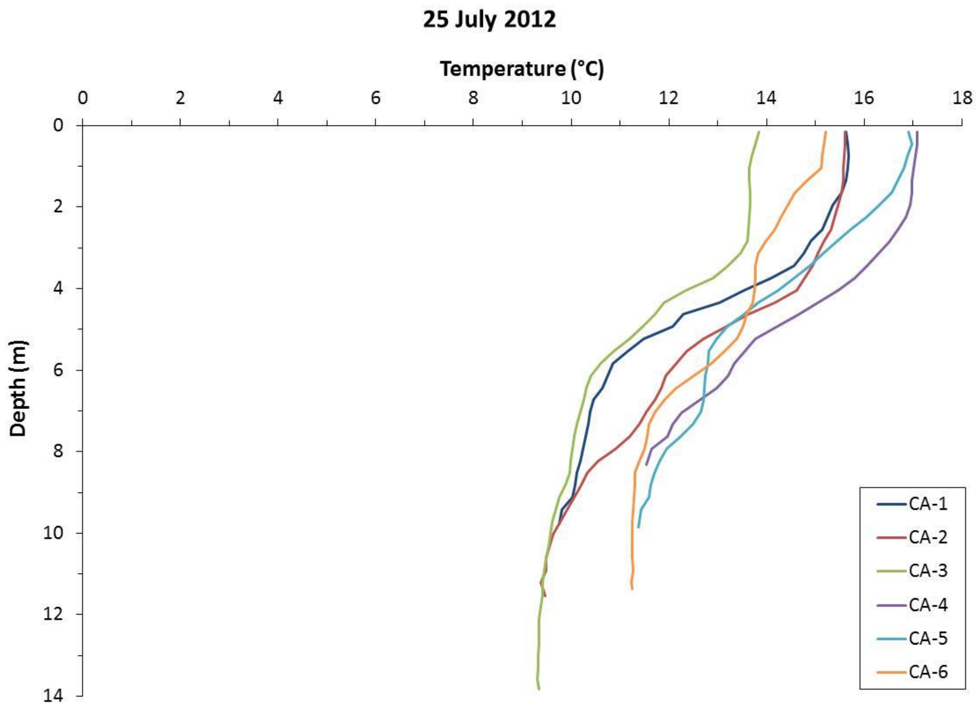


Fig. 40. Temperature data from RBR*duo* temperature and depth loggers deployed on the seafloor at four locations in the Shelburne area in October-November 2013 See Fig. 6 for deployment locations.



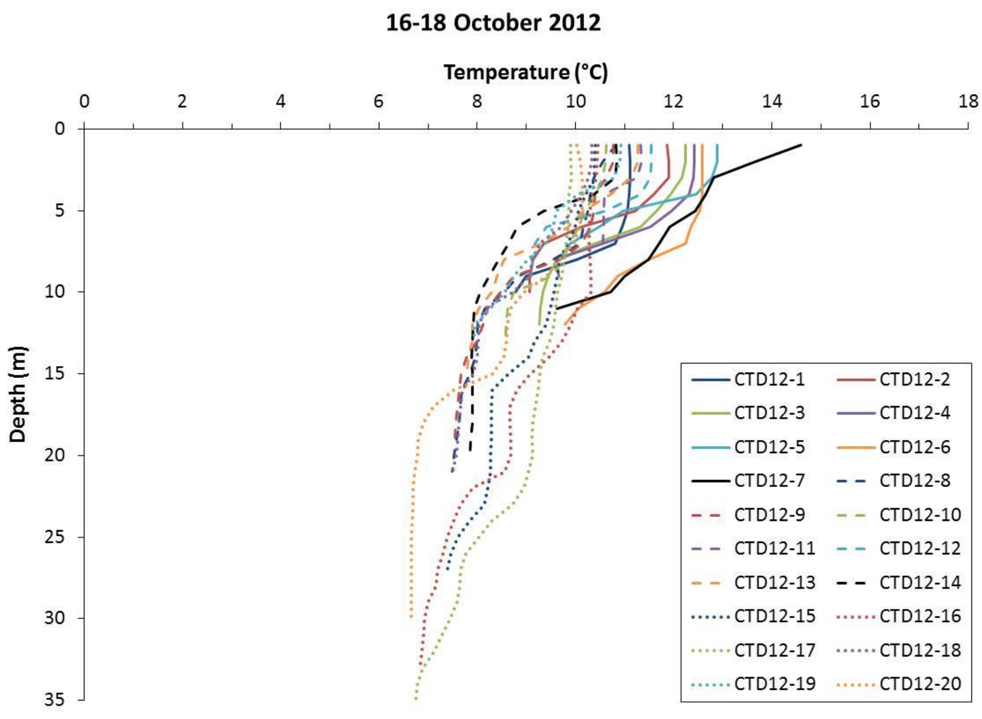
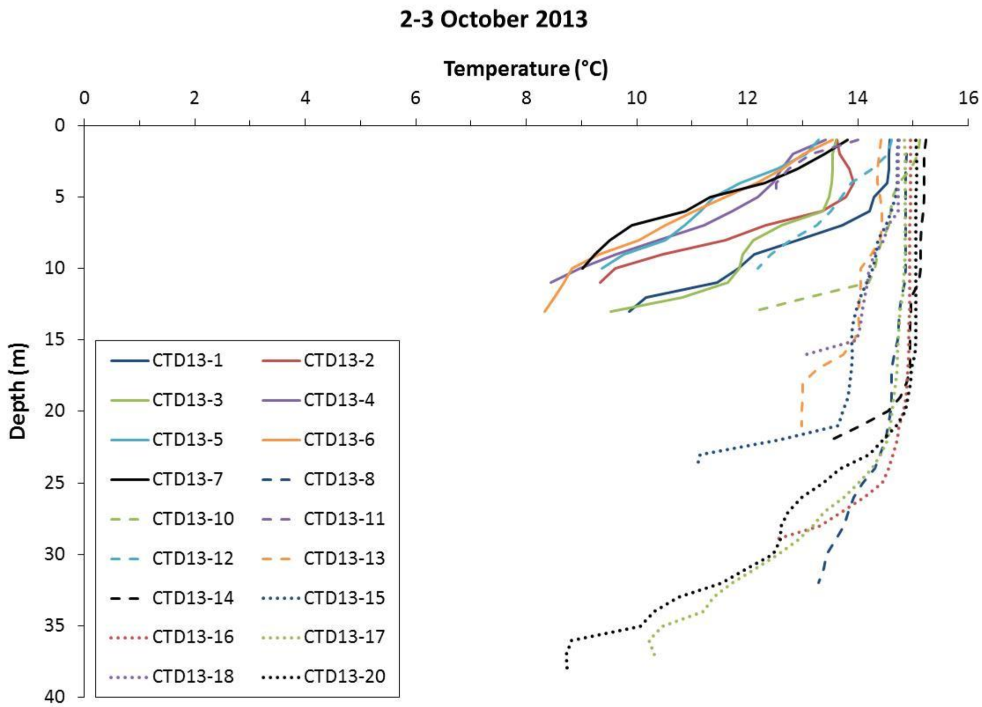


Fig. 41. Temperature-depth profiles in the Shelburne area in July and October 2012. Top: July (YSI CastAway-CTD). Bottom: October (Sea-Bird Electronics SBE 25-03 Sealogger). See Table 6 and Fig. 5 for locations and times of the conductivity-temperature-depth (CTD) profiles.



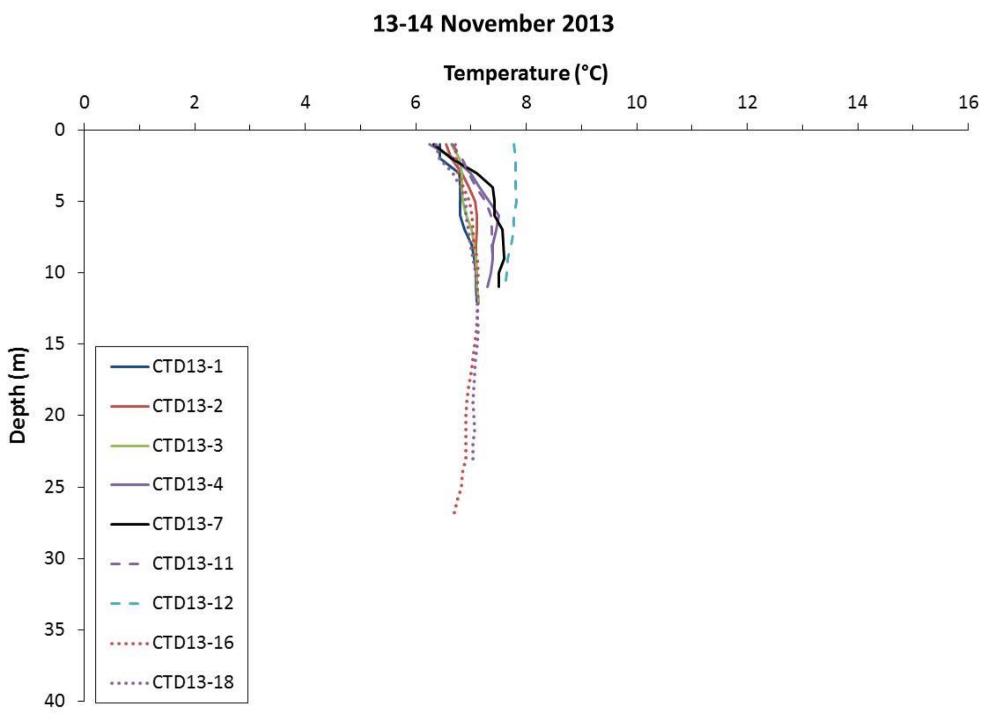


Fig. 42. Temperature-depth profiles in the Shelburne area in October (top) and November (bottom) 2013. Data were collected using a Sea-Bird Electronics SBE 25-03 Sealogger. See Table 7 and Fig. 6 for locations and times of the conductivity-temperature-depth (CTD) profiles.

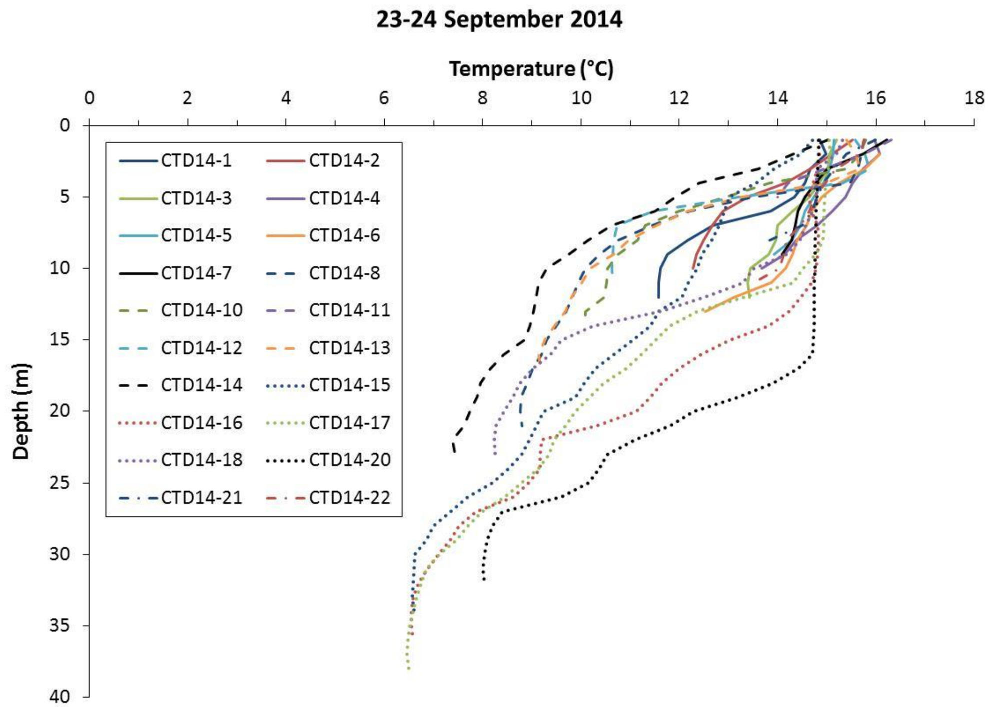
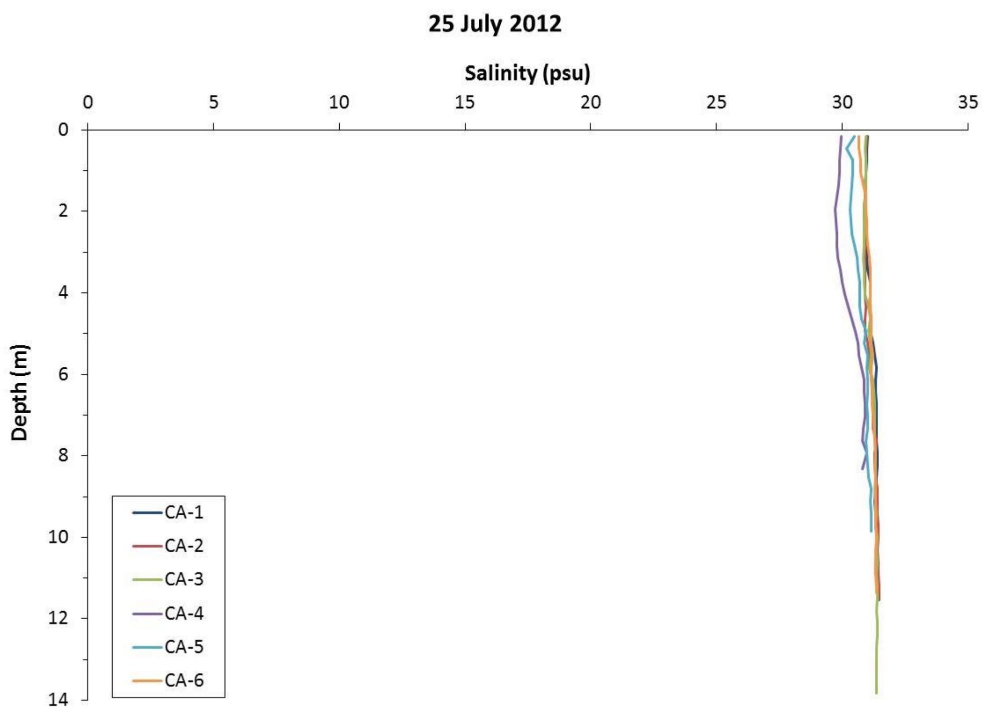


Fig. 43. Temperature-depth profiles in the Shelburne area in September 2014. Data were collected using a Sea-Bird Electronics SBE 25-03 Sealogger. See Table 8 and Fig. 7 for locations and times of the conductivity-temperature-depth (CTD) profiles.



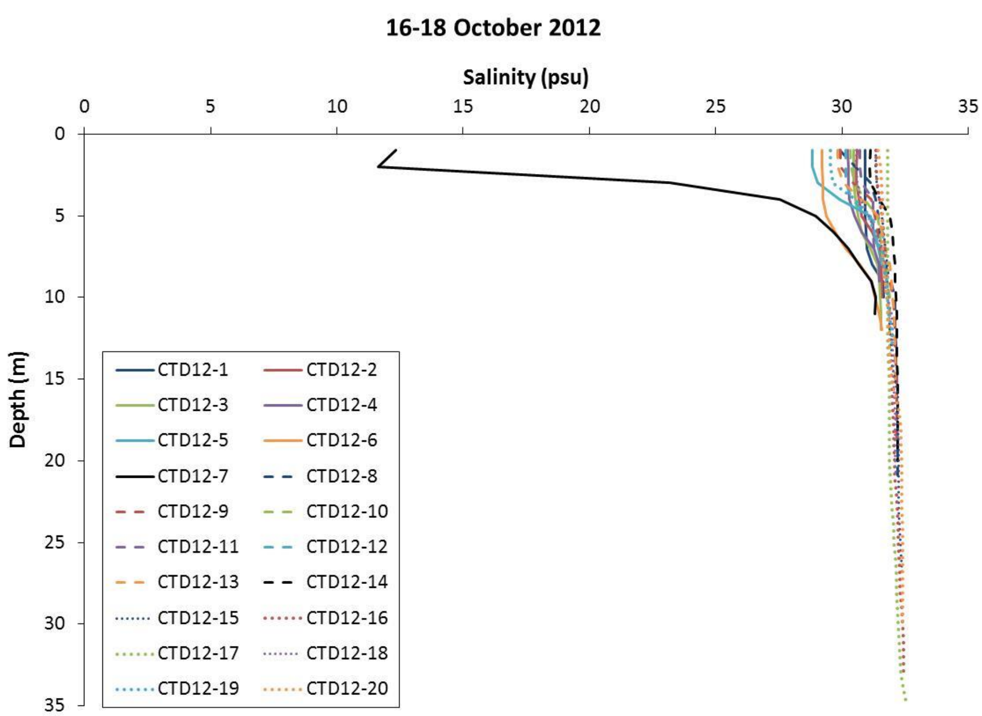
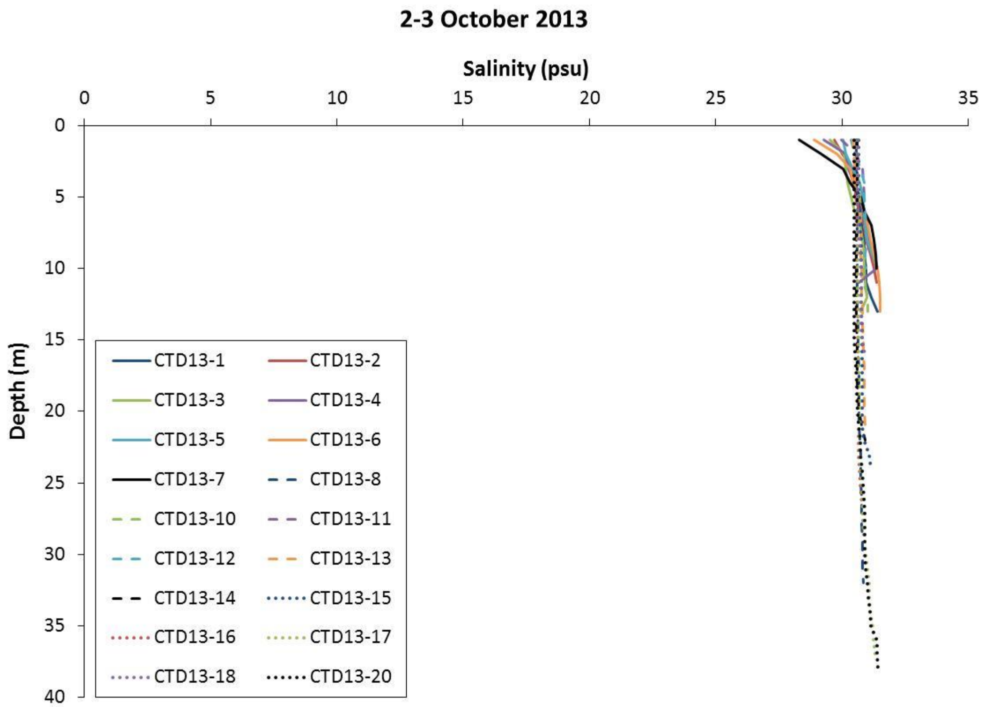


Fig. 44. Salinity-depth profiles in the Shelburne area in July and October 2012. Top: July (YSI CastAway-CTD). Bottom: October (Sea-Bird Electronics SBE 25-03 Sealogger). See Table 6 and Fig. 5 for locations and times of the conductivity-temperature-depth (CTD) profiles.



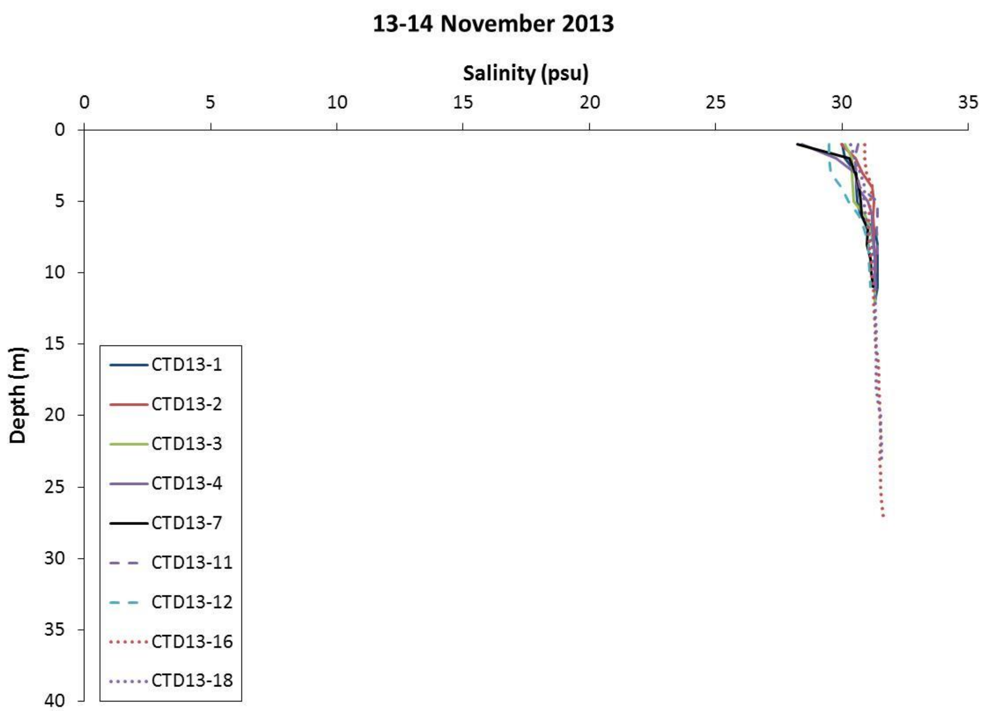


Fig. 45. Salinity-depth profiles in the Shelburne area in October (top) and November (bottom) 2013. Data were collected using a Sea-Bird Electronics SBE 25-03 Sealogger. See Table 7 and Fig. 6 for locations and times of the conductivity-temperature-depth (CTD) profiles.

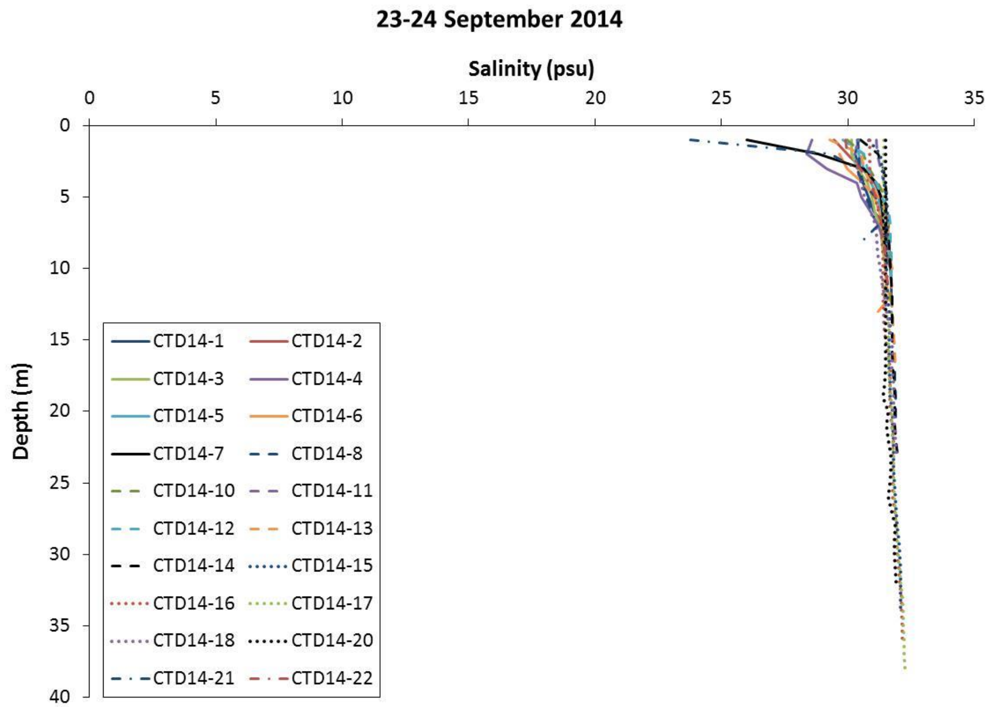


Fig. 46. Salinity-depth profiles in the Shelburne area in September 2014. Data were collected using a Sea-Bird Electronics SBE 25-03 Sealogger. See Table 8 and Fig. 7 for locations and times of the conductivity-temperature-depth (CTD) profiles.

SUMMARY AND CONCLUSIONS

Sea level, current velocity, and hydrographic (temperature-salinity-depth) data were obtained in coastal waters of Shelburne County in 2012-2014; data from a current meter deployment in 2008 are also reported. The Shelburne area has a small predicted tidal range (averaging ~1.5 m). Nevertheless, tidal constituents accounted for most of the variance in water depth (≥88% for the 5 main tidal constituents (M2, N2, S2, K1 and O1) and ≥75% for M2 alone). By contrast, the tides accounted for much less of the currents' variations, with contributions to the variance along the major axes ranging from 27-82% for the 5 main tidal constituents and 25-68% for M2. For all deployments, tidal contributions to the variance of currents along the minor axes were neglibible (≤0.1%). Tidal contributions to the variation in currents varied not only from location to location but also with depth.

Mean current speeds were usually <10 cm s^{-1}, except at McNutts Island (site 1345, deployment 358, in March-April 2008) where mean current speeds were 11-16 cm s^{-1}. Current speeds were lowest in the innermost locations (deployments 530, 531, and 560). Current directions were influenced by the local topography: directions were along a predominantly north-south axis in all deployments, except deployment 358 where currents were along a west-northwest to east-southeast axis, parallel to the coastline of McNutts Island.

Thermal stratification was observed in July 2012, October 2012, October 2013, and September 2014, when surface temperatures were mostly >10°C. In November 2013, when surface temperatures were <8°C, there was little change in temperature with depth. The salinity showed little change with depth at all stations in July 2012. On other sampling dates, salinities showed little change with depth at deeper stations, while at most shallower stations, slightly lower salinities were observed near the surface. In October 2012 and September 2014, much lower surface salinities were observed at the innermost stations in Shelburne Harbour.

ACKNOWLEDGEMENTS

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SET UP PARAMETERS FOR ADCP DEPLOYMENTS

Set up parameters for ADCPs deployed in the Shelburne area, 2008-2014. Bin size = vertical distance over which measurements are averaged. Segment interval = time between the start of consecutive segments. Segment length = time duration of each segment. Ping interval = time between consecutive acoustic pings within a segment. Standard deviation = estimated standard deviation of current velocity measurements (see the Methods section in the main report for further details).

Deployment	ADCP frequency (kHz)	Depth bin size (m)	Segment interval (min)	Segment length (min)	Ping interval (s)	Number of pings per segment	Standard deviation (cm s^{-1})
358	600	0.5	15	15	3.6	250	0.86
527	300	1.0	20	20	6.0	200	0.96
530	600	1.0	20	4	1.0	240	0.45
531	600	1.0	20	4	1.0	240	0.45
559	300	1.0	20	4	1.0	240	0.87
560	300	1.0	20	4	1.0	240	0.87

SIGNAL INTENSITY PER DEPTH INTERVAL FOR ADCP DEPLOYMENTS

Box and whisker plots of signal intensity at 1-m depth intervals for ADCP deployments in the Shelburne area, 2008-2014. Thick vertical lines represent medians. Boxes extend from the 1st to 3rd quartiles (= the interquartile range). Thin vertical lines (at the ends of the dashed horizontal lines) represent the ranges, excluding outliers. Small circles represent outliers; outliers are values that are at least 1.5 interquartile ranges below the 1st quartile or at least 1.5 interquartile ranges above the 3rd quartile. Also shown are the percentages of current velocity data records at 1-m depth intervals (red diamonds); 100% indicates that data were obtained in every 20-min segment throughout the deployment.

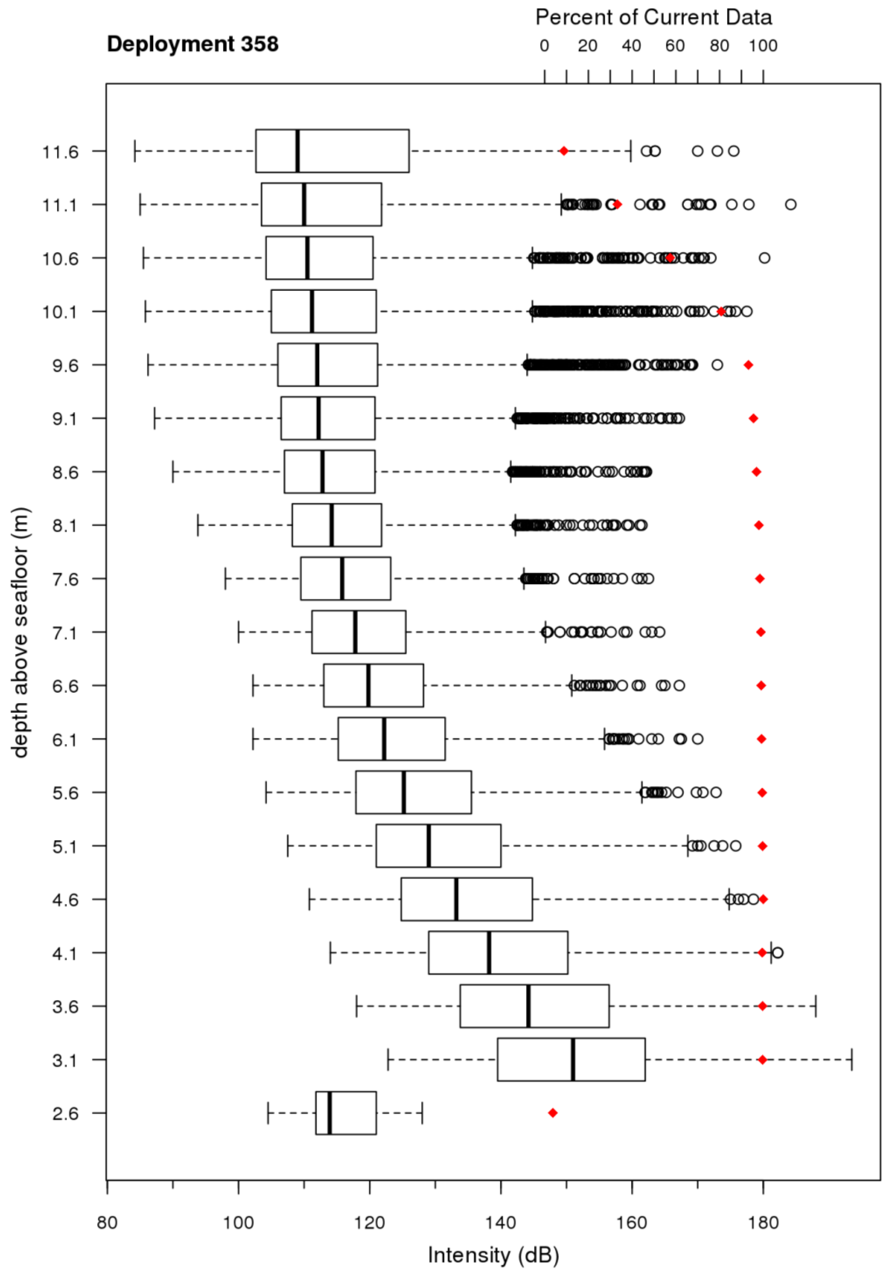

Fig. B1. Box and whisker plots of signal intensity at 0.5-m depth intervals for ADCP deployment 358 (McNutts Island, 7 March to 7 April 2008). Mean water depth = 12.3 m.

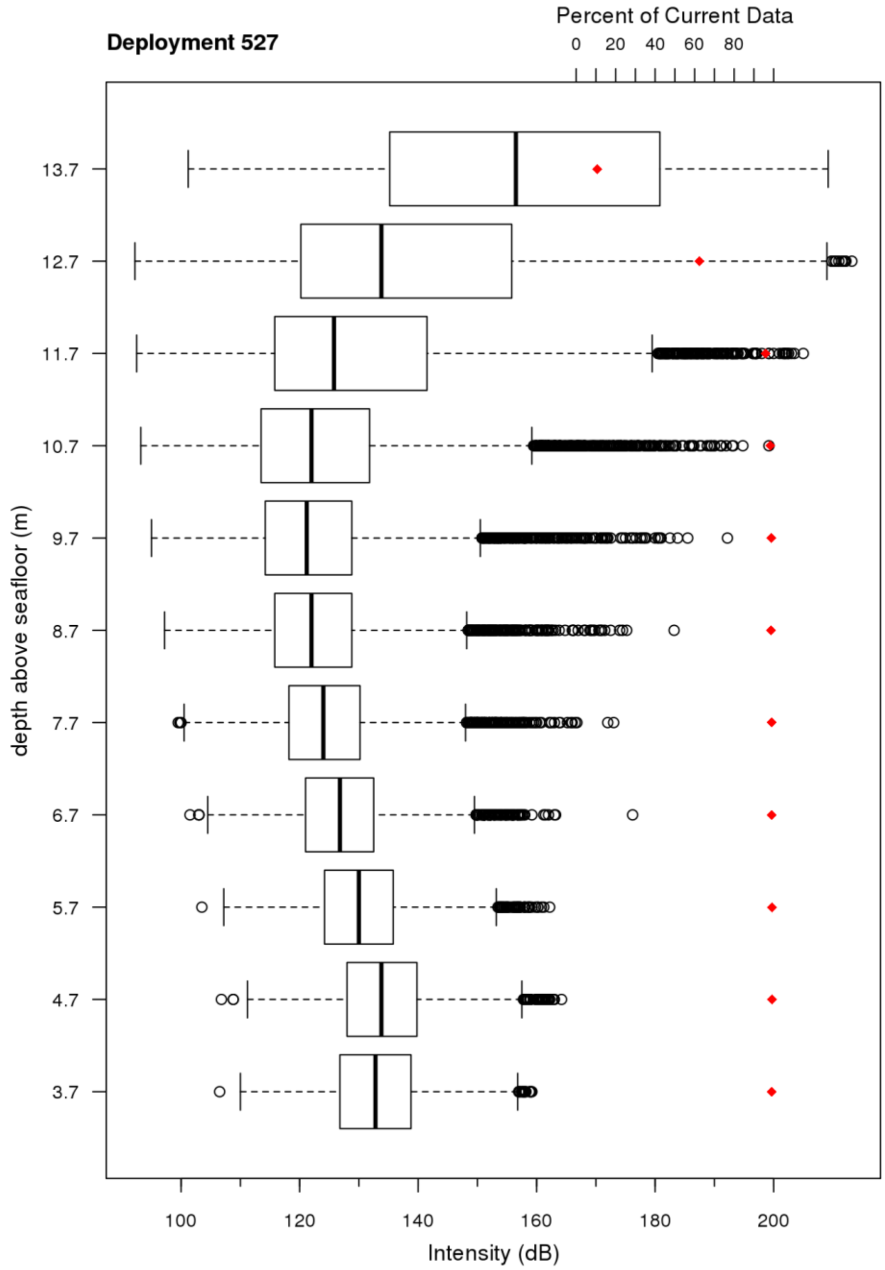

Fig. B2. Box and whisker plots of signal intensity at 1-m depth intervals for ADCP deployment 527 (Jordan Bay, 16 October 2012 to 12 January 2013). Mean water depth = 15.2 m.

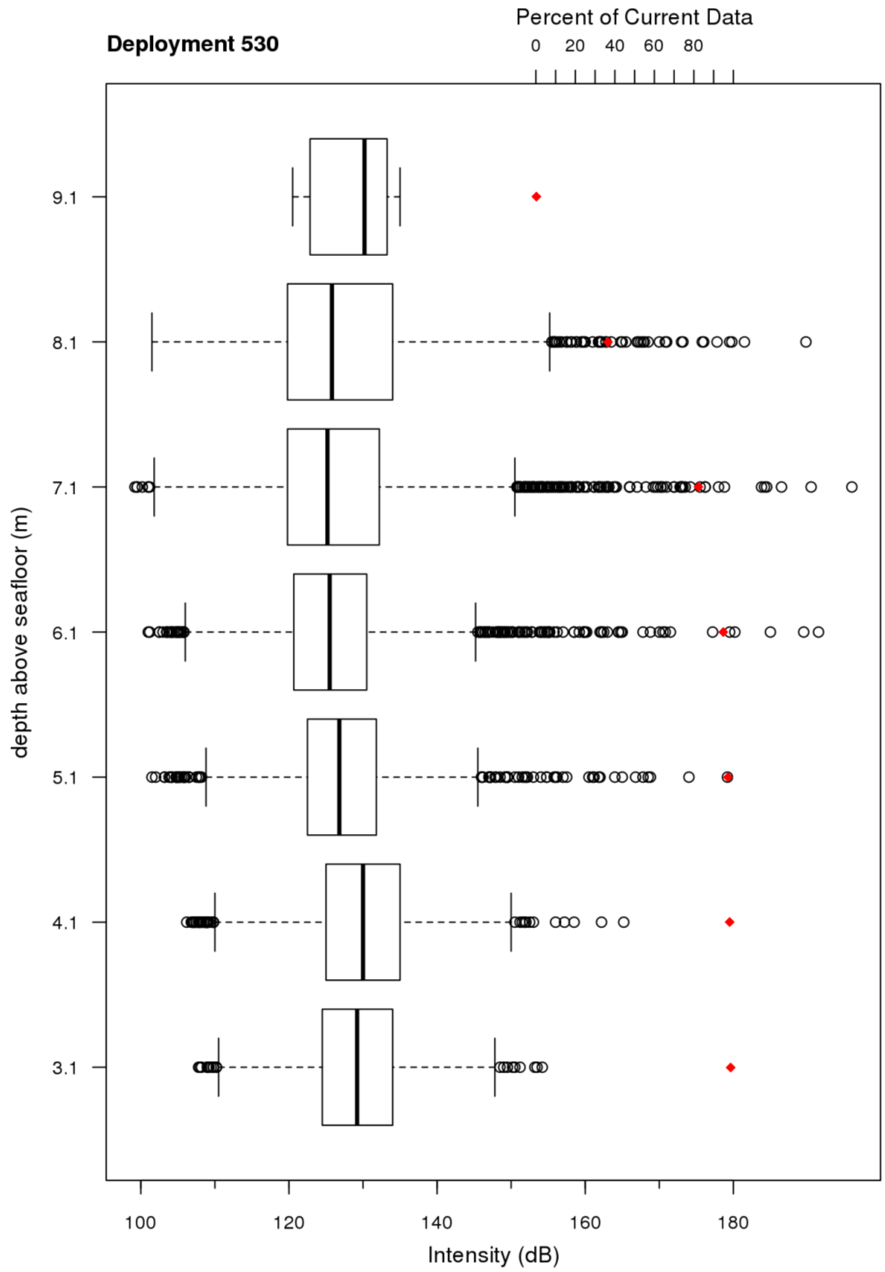

Fig. B3. Box and whisker plots of signal intensity at 1-m depth intervals for ADCP deployment 530 (Shelburne Harbour, 2 October to 13 November 2013). Mean water depth = 9.8 m.

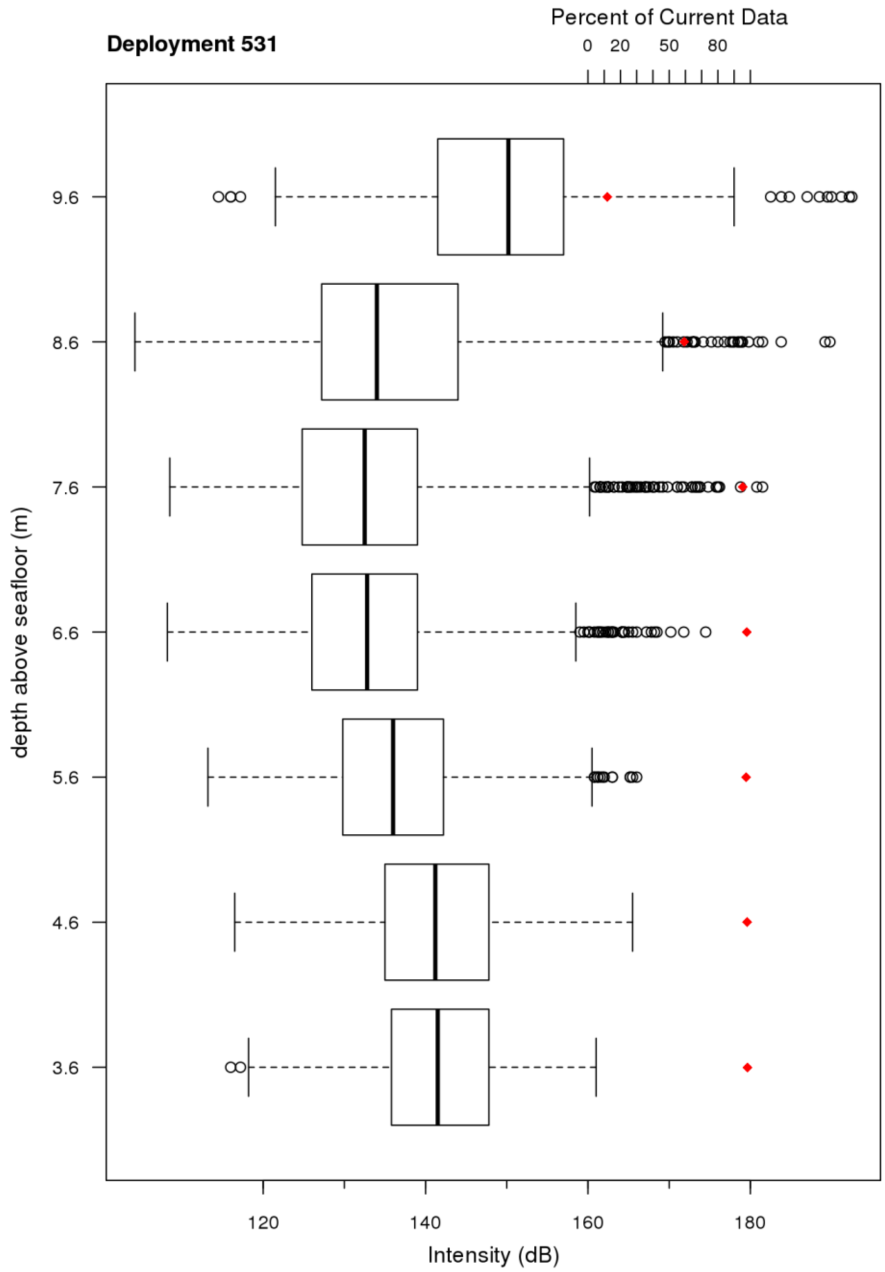

Fig. B4. Box and whisker plots of signal intensity at 1-m depth intervals for ADCP deployment 531 (inner Jordan Bay, 2 October to 13 November 2013). Mean water depth = 10.4 m.

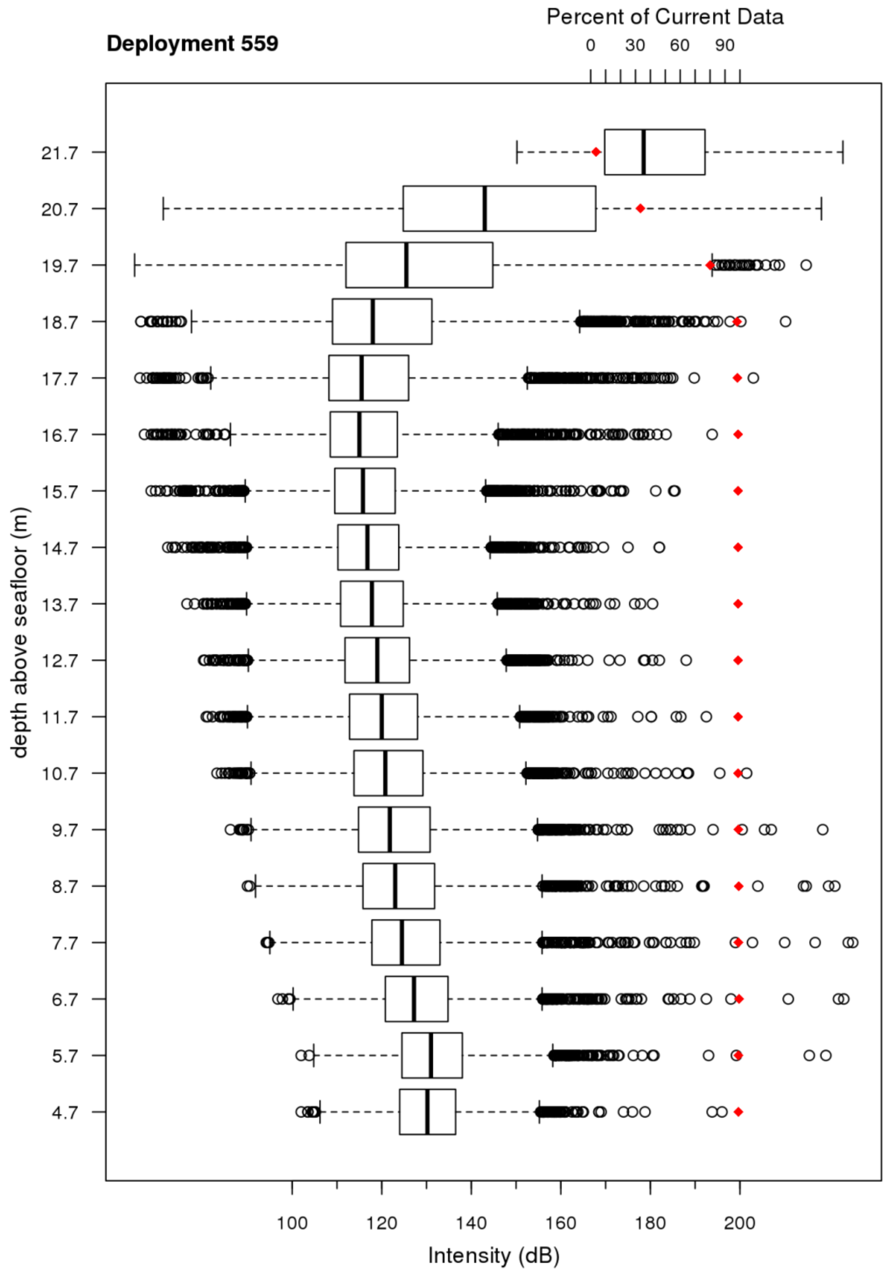

Fig. B5. Box and whisker plots of signal intensity at 1-m depth intervals for ADCP deployment 559 (Blue Island, 24 September to 4 December 2014). Mean water depth = 22.8 m.

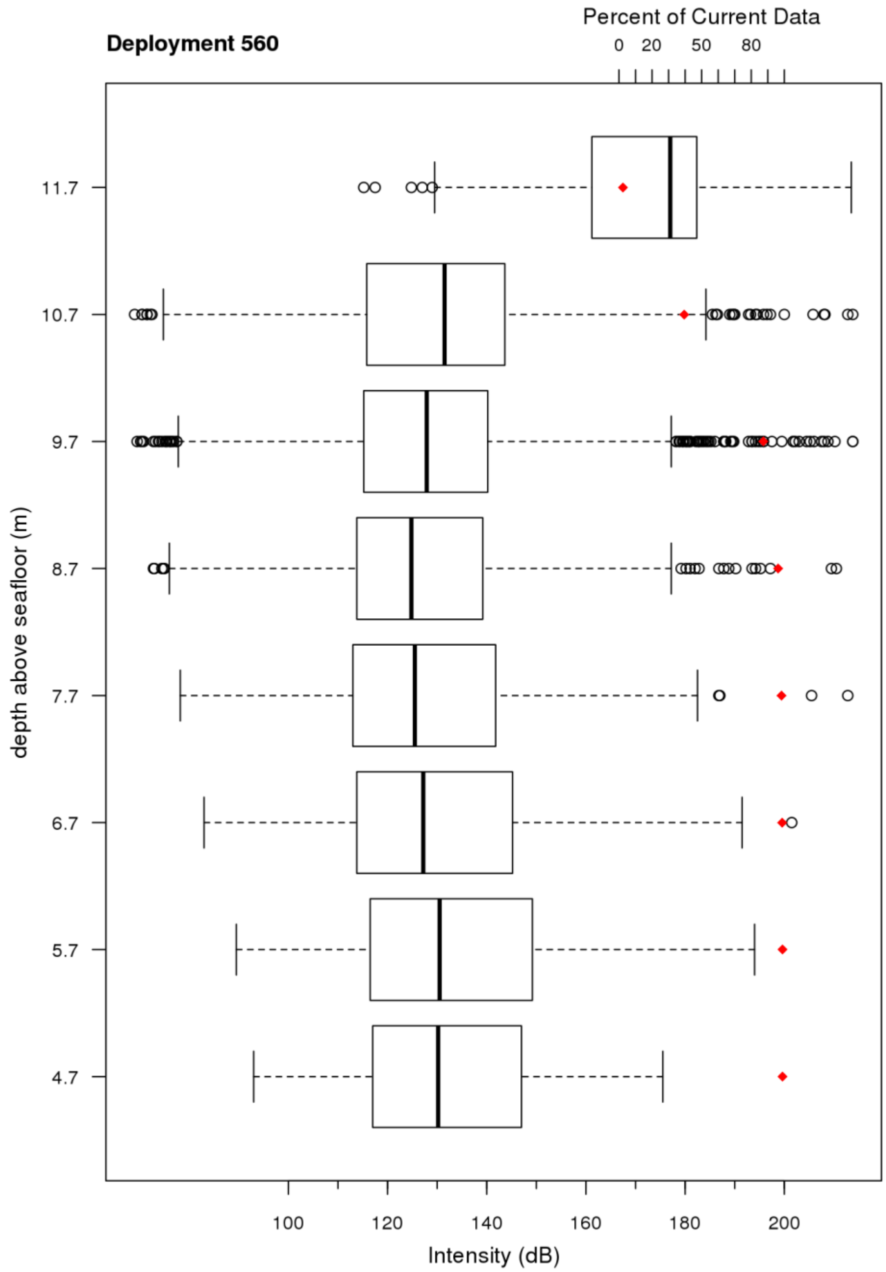

Fig. B6. Box and whisker plots of signal intensity at 1-m depth intervals for ADCP deployment 560 (Shelburne Harbour, 24 September to 17 November 2014). Mean water depth = 12.6 m.

TIDAL ANALYSIS OF ADCP CURRENT DATA

Results of tidal analysis of ADCP current velocity data from the Shelburne area, 2008-2014. The data have been decomposed into major and minor axes using principal component analysis. Data shown include θ (angle of the major principal components axis, in degrees from the east-west axis in a counter-clockwise direction; blue dots), and amplitude (A) and phase (P) for the 5 main tidal constituents (M2, N2, S2, K1, and O1). For amplitude and phase, red/green dots are for the results of the tidal analysis of currents along the major/minor axes. Data are presented using three depth axes: σ (10 equal depth bins, from the sea surface [0.0] to the seafloor [-1.0]), depth above the seafloor, and depth below the surface. Data are shown for depth levels where current measurements were obtained in ≥80% of all segments during the deployment. See the Methods section in the main report for further details.

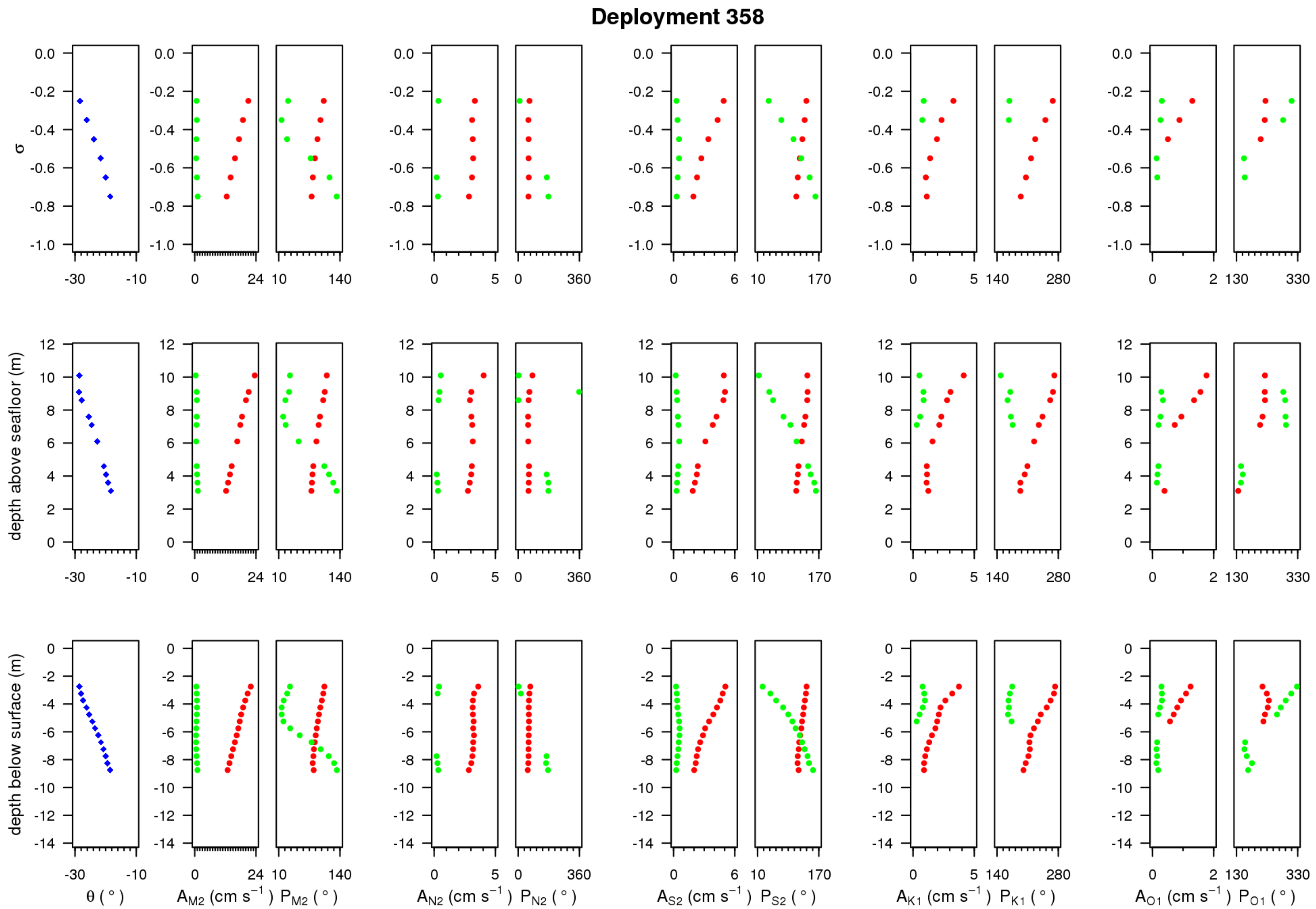

Fig. C1. Results of tidal analyses for ADCP deployment 358 (McNutts Island, 7 March to 7 April 2008). Amplitudes (A) and phases (P) of the 5 main tidal constituents (M2, N2, S2, K1, O1) along the major (red dots) and minor (green dots) axes (determined using principal component analysis) are plotted against depth (using three depth scales). θ = angle of major axis (blue dots).

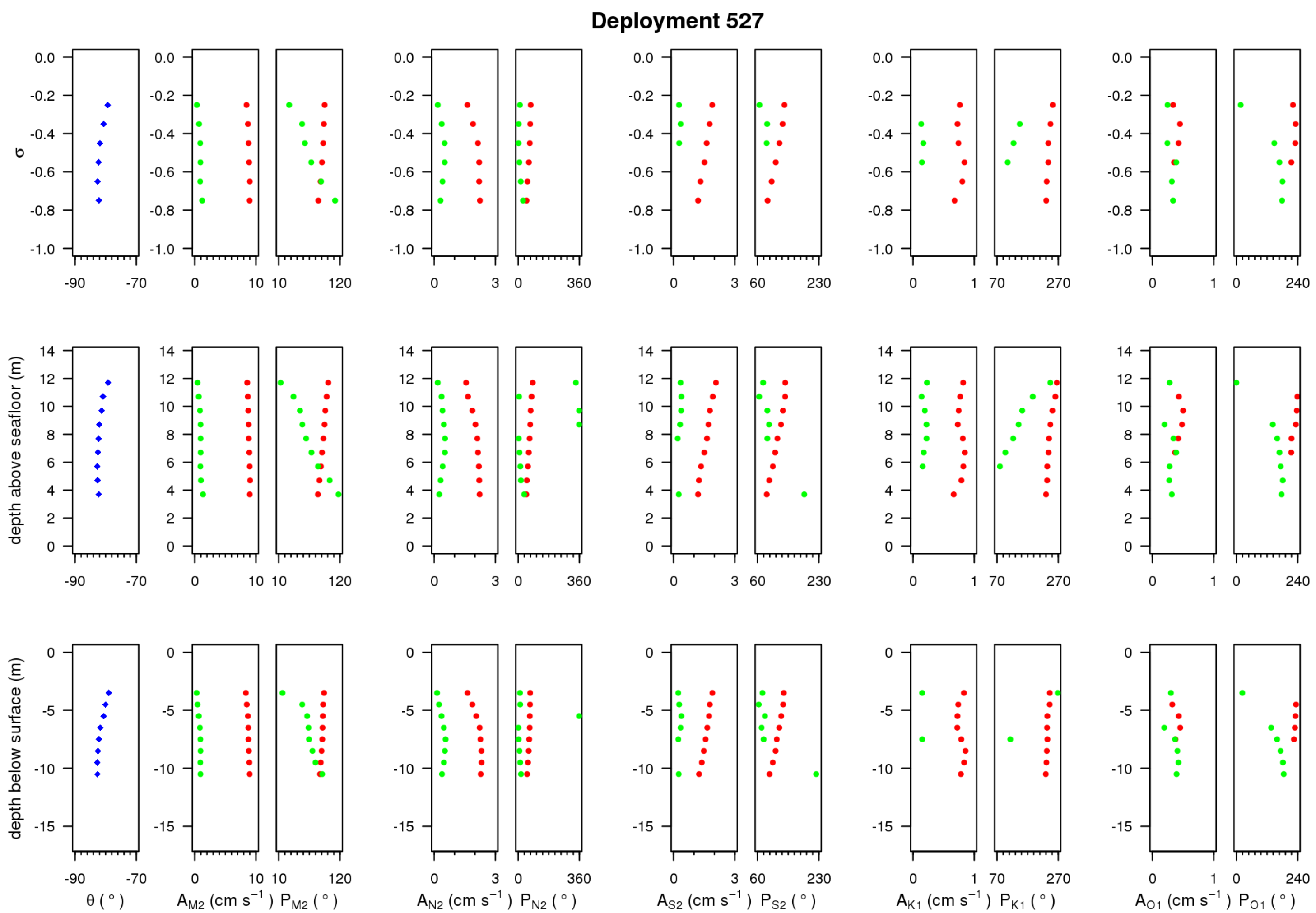

Fig. C2. Results of tidal analyses for ADCP deployment 527 (Jordan Bay, 16 October 2012 to 12 January 2013). Amplitudes (A) and phases (P) of the 5 main tidal constituents (M2, N2, S2, K1, O1) along the major (red dots) and minor (green dots) axes (determined using principal component analysis) are plotted against depth (using three depth scales). θ = angle of major axis (blue dots).

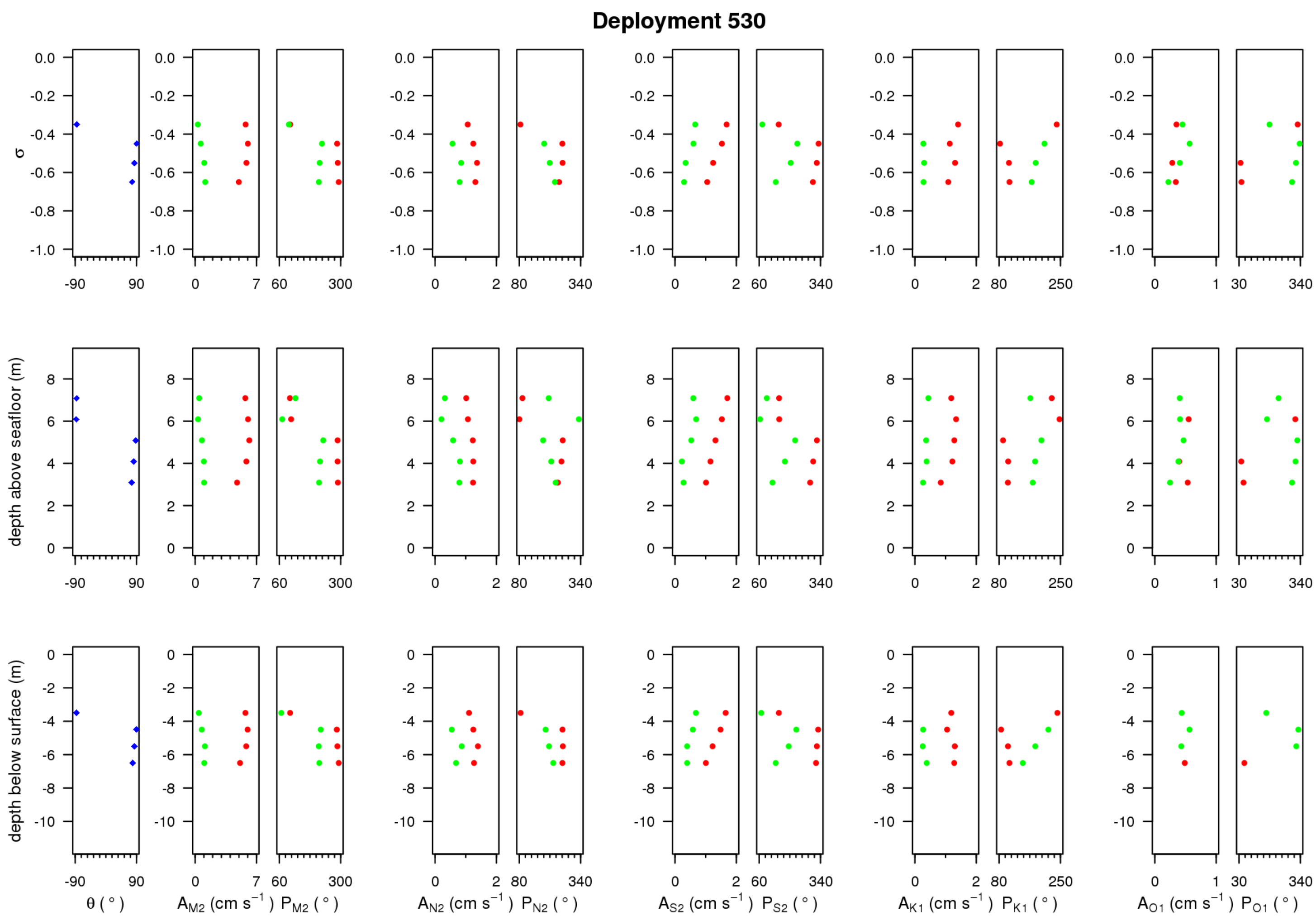

Fig. C3. Results of tidal analyses for ADCP deployment 530 (Shelburne Harbour, 2 October to 13 November 2013). Amplitudes (A) and phases (P) of the 5 main tidal constituents (M2, N2, S2, K1, O1) along the major (red dots) and minor (green dots) axes (determined using principal component analysis) are plotted against depth (using three depth scales). θ = angle of major axis (blue dots).

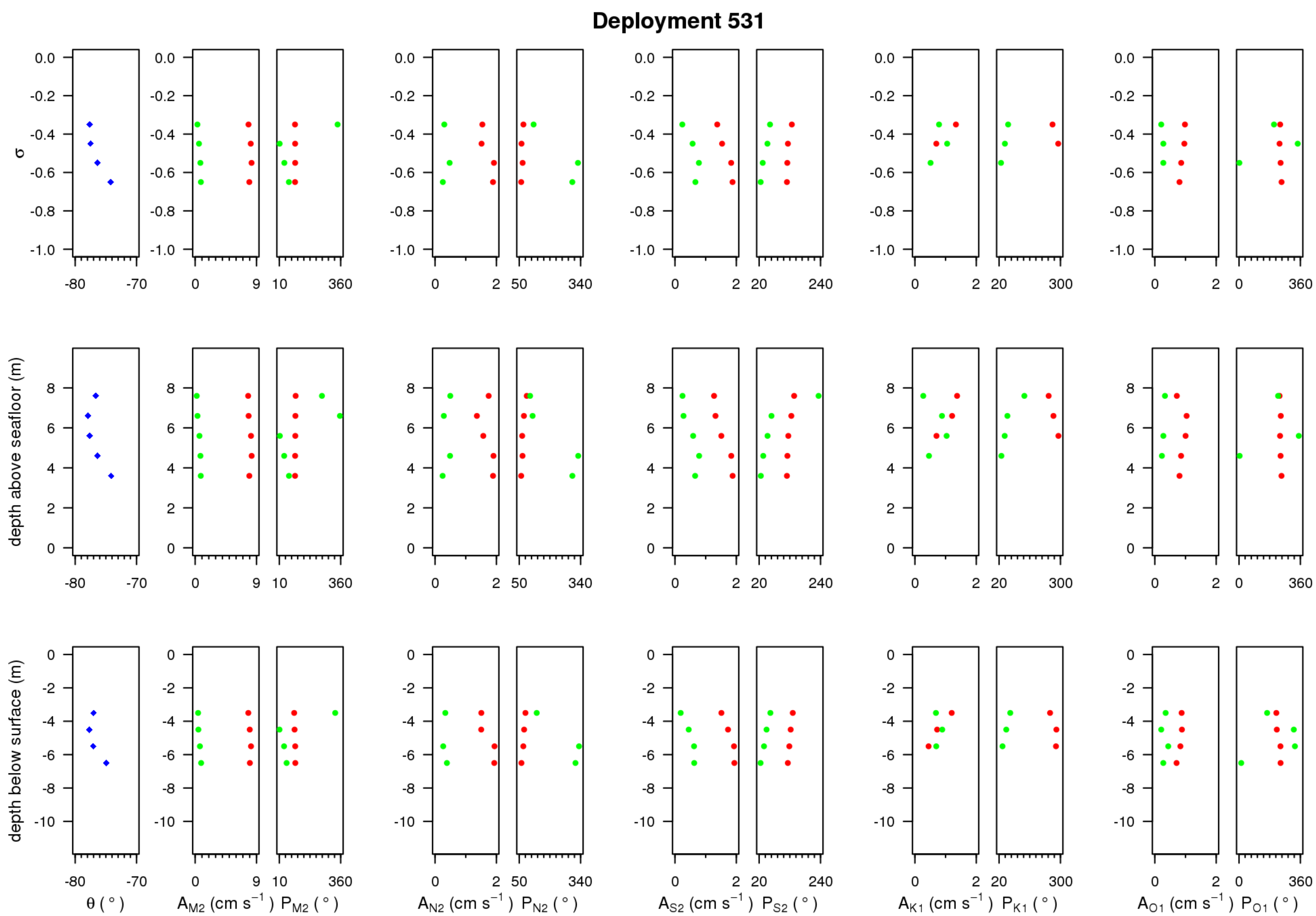

Fig. C4. Results of tidal analyses for ADCP deployment 531 (inner Jordan Bay, 2 October to 13 November 2013). Amplitudes (A) and phases (P) of the 5 main tidal constituents (M2, N2, S2, K1, O1) along the major (red dots) and minor (green dots) axes (determined using principal component analysis) are plotted against depth (using three depth scales). θ = angle of major axis (blue dots).

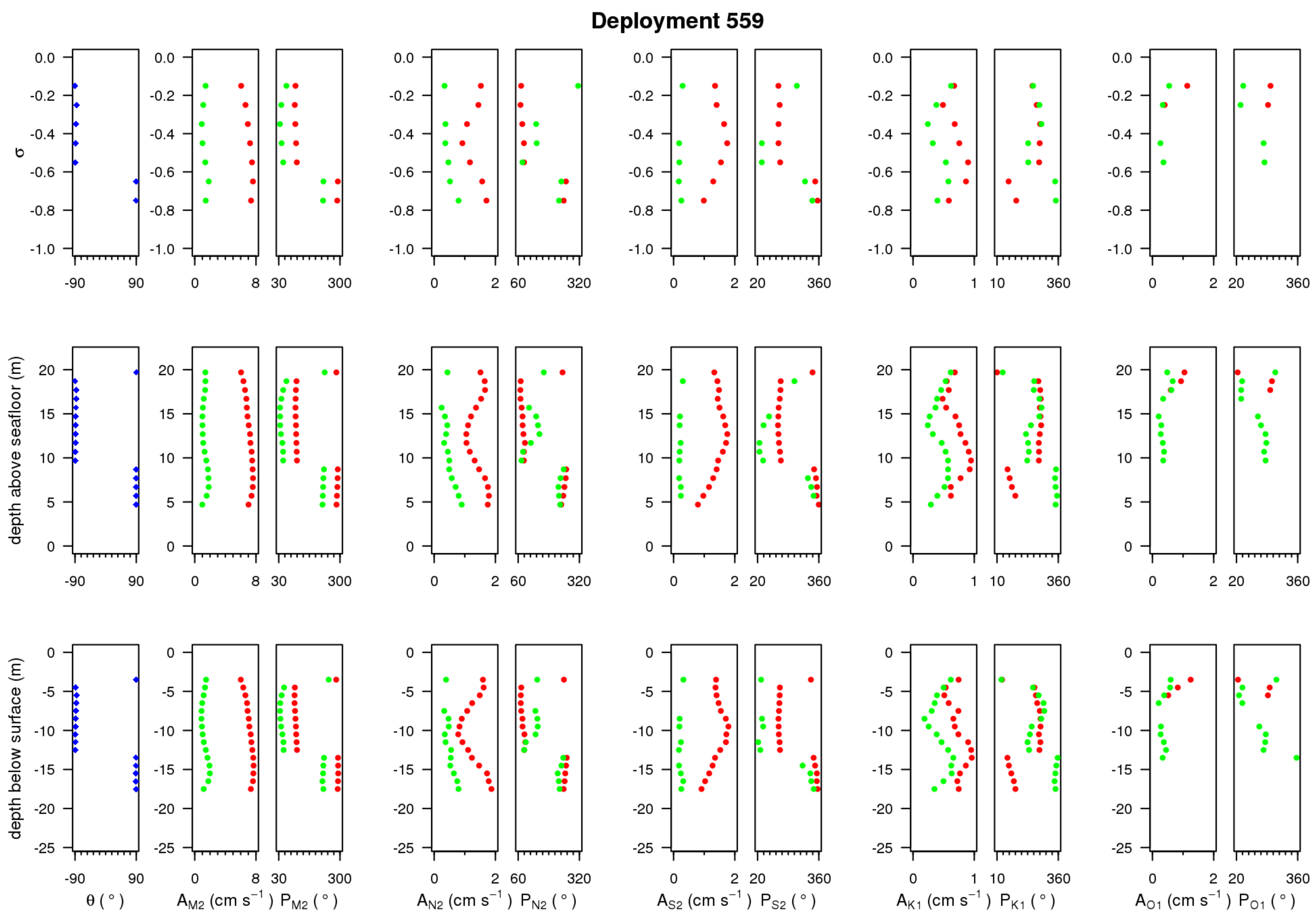

Fig. C5. Results of tidal analyses for ADCP deployment 559 (Blue Island, 24 September to 4 December 2014). Amplitudes (A) and phases (P) of the 5 main tidal constituents (M2, N2, S2, K1, O1) along the major (red dots) and minor (green dots) axes (determined using principal component analysis) are plotted against depth (using three depth scales). θ = angle of major axis (blue dots).

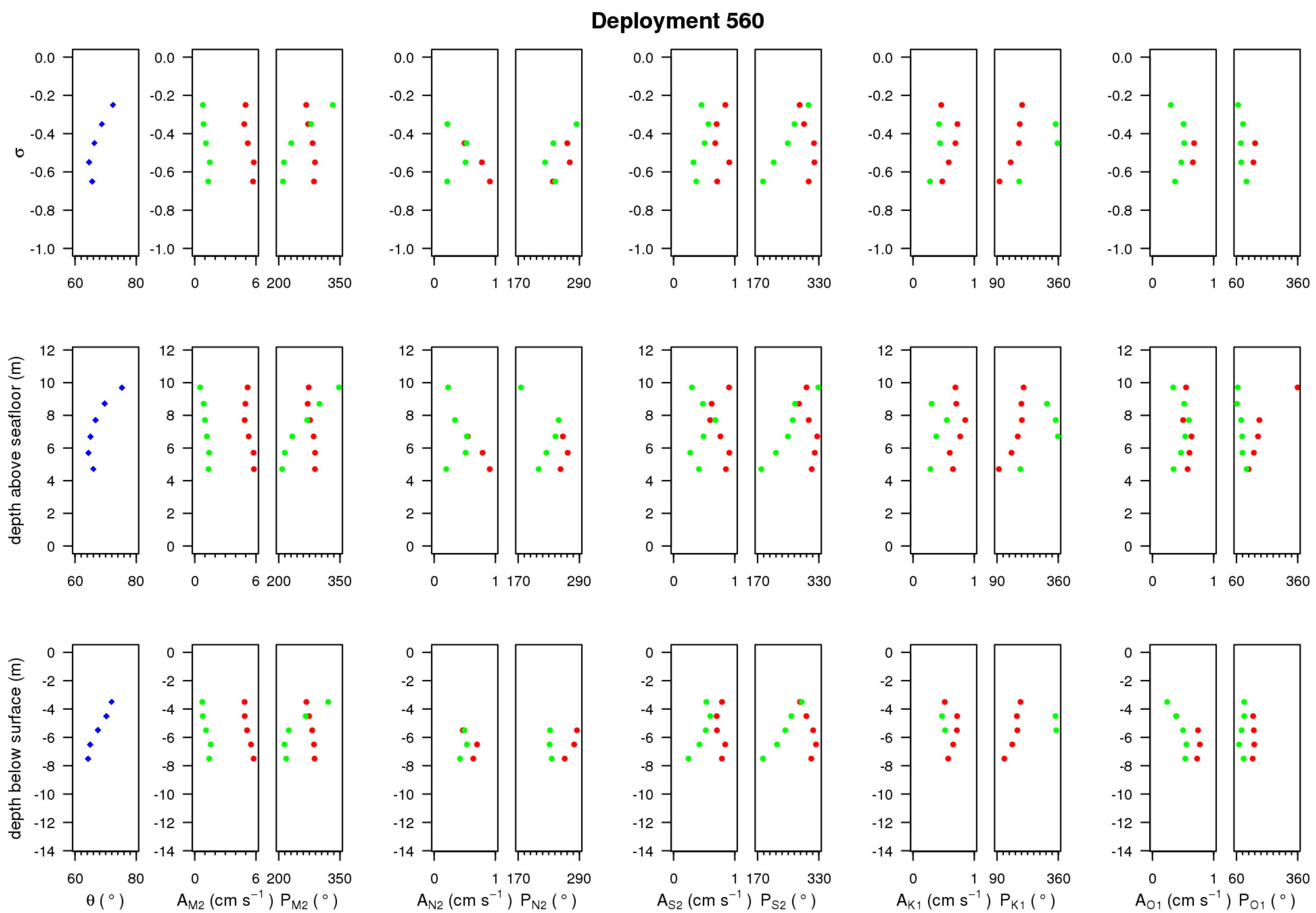

Fig. C6. Results of tidal analyses for ADCP deployment 560 (Shelburne Harbour, 24 September to 17 November 2014). Amplitudes (A) and phases (P) of the 5 main tidal constituents (M2, N2, S2, K1, O1) along the major (red dots) and minor (green dots) axes (determined using principal component analysis) are plotted against depth (using three depth scales). θ = angle of major axis (blue dots).