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Ocean currents and benthic habitat in the Sackville Spur Region

Courants océaniques et habitat benthique dans la région de l'éperon de Sackville

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OCEAN CURRENTS AND BENTHIC HABITAT IN THE SACKVILLE SPUR REGION

COURANTS OCÉANIQUES ET HABITAT BENTHIQUE DANS LA RÉGION DE L'ÉPERON DE SACKVILLE

Final Report for Project 2013-01S

Prepared for
Environmental Studies Research Funds

by

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ABSTRACT

The Grand Banks of Newfoundland and Flemish Cap are separated by the Flemish Pass which reaches depth of 1200 m. The northern approach to the pass is the site of the prominent Sackville Spur sediment drift that is currently an area of significant offshore hydrocarbon exploration. This report presents a summary of oceanographic data collected during a field program carried out in 2013-14 with funding from the Environmental Studies Research Fund. The primary objective of this research project is to provide an improved understanding of ocean currents, variability and dispersion in the vicinity of Sackville Spur as well as to characterize some of the benthic habitat for assessment of vulnerable marine ecosystems. The data collected include shipboard CTD, lowered ADCP, vessel-mounted ADCP and water samples during two cruises in July 2013 and 2014. Moorings were deployed at three locations for that duration between the cruises and successfully collected CTD and current meter data. The oceanographic data have been made available for industry, research and public access through the DFO Ocean Data and Information Section at the Bedford Institute of Oceanography (Email: BIO.Datashop@dfo-mpo.gc.ca). These data were used to develop particle trajectory simulations using high-resolution computer model results for the region which demonstrate strong seasonality in the flow field in the area of Sackville Spur even at depths near the ocean bottom. In addition, benthic imagery and grabs were collected on the 2013 cruise to characterize coral and sponge species present in the region of Sackville Spur and provide samples for experimental lab cultures of these organisms.

RÉSUMÉ

Les Grands Bancs de Terre-Neuve et le bonnet Flamand sont séparés par la passe Flamande, qui atteint une profondeur de 1 200 mètres. L'approche du nord de la passe est le site de l'amas considérable de sédiments de l'éperon de Sackville qui est actuellement une zone importante d'exploration extracôtière d'hydrocarbures. Ce rapport présente un résumé des données océanographiques obtenues lors d'un programme réalisé sur le terrain en 2013-2014 avec le financement du Fonds pour l'étude de l'environnement. Le principal objectif du projet de recherche consiste à mieux faire comprendre les courants océaniques ainsi que la variabilité et la dispersion aux environs de l'éperon de Sackville, et à caractériser une partie de l'habitat benthique aux fins de l'évaluation d'écosystèmes marins vulnérables. Les données ont été obtenues d'une sonde CTP (conductivité, température, profondeur) de bord, d'un courantomètre à effet Dopper (ADCP) abaissé et monté à bord du vaisseau ainsi que d'échantillons d'eau lors de deux expéditions en juillet 2013 et juillet 2014. Des mouillages ont été déployés dans trois lieux pour la durée entre les deux expéditions et ont permis de faire la collecte de données CTP et du courantomètre. Les données océanographiques ont été mises à la disposition de l'industrie, pour la recherche et l'accès par le public au moyen de la Section sur les données et informations océanographiques du MPO de l'Institut océanographique de Bedford (courriel : BIO.Datashop@dfo-mpo.gc.ca). Ces données ont été utilisées pour élaborer des simulations de trajectoires de particules au moyen d'un modèle informatique à haute résolution pour la région, qui démontre une forte saisonnalité dans le champ de courant aux environs de l'éperon Sackville, même à des profondeurs s'approchant du plancher océanique. De plus, des images et des échantillons-prises benthiques ont été obtenus lors de l'expédition en 2013 afin de caractériser les espèces de coraux et d'éponges présentes dans la région de l'éperon de Sackville et de fournir des échantillons pour les cultures expérimentales en laboratoire de ces organismes.

1. INTRODUCTION

The Grand Banks of Newfoundland and Flemish Cap are separated by the Flemish Pass which reaches depth of 1200 m. The Cap is an isolated, circular bedrock feature that rises to within a few hundred metres of the sea surface. The northern approach to the pass is the site of the prominent Sackville Spur sediment drift that extends northeastward across the pass for at least 140 km. At present, the Labrador Current (LC) and the Deep Western Boundary Current (DWBC) appear to be the two major hydrodynamic forces controlling sedimentation patterns on the flanks of the spur (Kennard et al., 1990). Near the upper part of the spur's north flank, a deep offshore component of the LC appears to be selectively winnowing silt and clay-size particles, leaving a lag deposit composed of about 43% sand-size material.

There is a lack of data and knowledge about ocean currents in the vicinity of Sackville Spur in the Flemish Cap region. This limits our ability to provide accurate estimates of both flow speed and direction which are fundamental to the risk assessment of the drilling mud/hydrocarbon spills and their environmental impact. This is a very dynamic area of the ocean with the strong southward-flowing Labrador current bifurcating in the region (i.e., a major portion of the Labrador current continues eastward from this site around the north and east flanks of Flemish Cap while a smaller portion turns south at the Spur and flows through Flemish Pass). The seasonal and shorter timescale variability of physical oceanographic processes taking place in this area is poorly understood and likely quite complex. This variability is also modulated on decadal timescales by external forcing factors such as the North Atlantic Oscillation (NAO).

From July 2013 to July 2014 a field program was mounted to study the oceanography in the area of Significant Discovery Licences 1047 and 1048 in the region of the Sackville Spur just north of the Flemish Cap (Figure 1, Licence maps: http://www.cnlopb.ca/). The project was funded by the Environmental Studies Research Funds (ESRF; http://www.esrfunds.org/). This is a region strongly influenced by the southward-flowing Labrador Current (LC) which bifurcates in this area with most of the water continuing around the north and east slopes of the Flemish Cap (FC; Mertens et al., 2014) and a smaller portion exiting west of Flemish Cap though the Flemish Pass (Schneider et al., 2015). This is a region of both intense fishing pressure and high biodiversity. Substantial concentrations of deep water corals and sponges have been observed over the past four years. Hydrocarbon spills and dispersion of drilling mud in the area of Sackville Spur (SS) could have a detrimental impact on these slow-growing deep water species (Murillo et al, 2010).

This report describes the field program, the data collected and provides some preliminary analysis. The methods and data are summarized in Section 2 and processing methods are summarized in Section 3. Results are presented in Section 4 and a summary is provide is Section 5. A series of 8 appendices present plots of the data as well as some derived data products.

2. METHODS AND DATA

2.1 Field Program Overview

The field program consisted of two cruises on CCGS Hudson – HUD2013012 (28 June – 9 July 2013) and HUD2014017 (30 June – 15 July 2014) with the following primary activities: three moorings (deployment July 1-4, 2013, recovery July 7-11, 2014); shipboard conductivity, temperature, depth (CTD) and bottle sample surveys; Lowered- acoustic Doppler current profiler (LADCP) profiles; and Vessel-Mounted-ADCP (VADCP) measurements. A total of 39 CTD/LADCP stations were completed in the Flemish Pass, on Sackville Spur and the northern flank of Flemish Cap (July 1-5, 2013; July 6-11, 2014) and included salinity and oxygen sampling. The CTD/LADCP and mooring locations are given in Tables 1 and 2 and Figure 1. See Appendix 1 for mooring design details.

Table 1 Mooring locations.

Mooring	Mooring #	Latitude N (DD)	Longitude W (DD)	Depth (m)
Flemish Pass	1842	47.0959	47.2813	400
Sackville Spur West	1841	48.3627	46.5313	1400
Sackville Spur East	1840	48.7877	45.5998	1400

Table 2 CTD/LADCP locations.

Station	Lat N (DD)	Long W (DD)	Depth (m)	Year	O_2 samples 2014
SS_29	48.9734	45.8751	2500	2013,2014	
SS_28	48.9353	45.8308	2400	2013,2014	Yes
SS_27	48.8949	45.7901	2200	2013,2014	
SS_26	48.8455	45.7459	2000	2013,2014	
SS_25	48.8074	45.6948	1600	2013,2014	Yes
SS_24	48.7557	45.6404	1400	2013,2014	
SS_23	48.7016	45.5894	1200	2013,2014	
SS_22	48.6476	45.5281	1100	2013	
SS_21	48.6002	45.4669	1000	2013	
SS_20	48.5393	45.3989	800	2013	
SS_19	48.4827	45.3410	600	2013	
SS_18.5	47.8087	45.9647	710	2014	
SS_18	47.8997	46.0632	900	2013,2014	Yes
SS_17	47.9750	46.1541	1100	2013,2014	
SS_16	48.0375	46.2330	1100	2013,2014	
SS_15	48.1013	46.3140	1100	2013,2014	Yes
SS_14	48.1651	46.4059	1000	2013,2014	
SS_13	48.2288	46.4637	1000	2013,2014	
SS_12	48.2719	46.5045	1000	2013,2014	Yes
SS_11	48.3083	46.5453	1000	2013,2014	
SS_10	48.3446	46.5862	1400	2013,2014	
SS_09	48.3922	46.6338	1800	2013,2014	Yes
SS_08	48.4420	46.6780	2200	2013,2014	
SS_07	48.4941	46.7290	2400	2013,2014	
SS_06	48.5438	46.7733	2500	2013,2014	Yes
FC_20	47.00	46.4830	400	2013	
FC_19.5	47.00	46.5594	900	2013	
FC_19	47.00	46.6670	900	2013	

FC_18.5	47.00	46.7417	1100	2013	
FC_18	47.00	46.8330	1100	2013	
FC_17.5	47.00	46.9083	1100	2013	
FC_17	47.00	47.0170	1100	2013	
FC_16.5	47.00	47.0833	900	2013	
FC_16	47.00	47.1680	800	2013	
FC_15	47.00	47.2500	500	2013	
FC_14.5	47.00	47.3583	300	2013	
FC_14	47.00	47.5000	300	2013	
FC_13	47.00	47.8170	200	2013	
1842	47.0959	47.2813	400	2014	

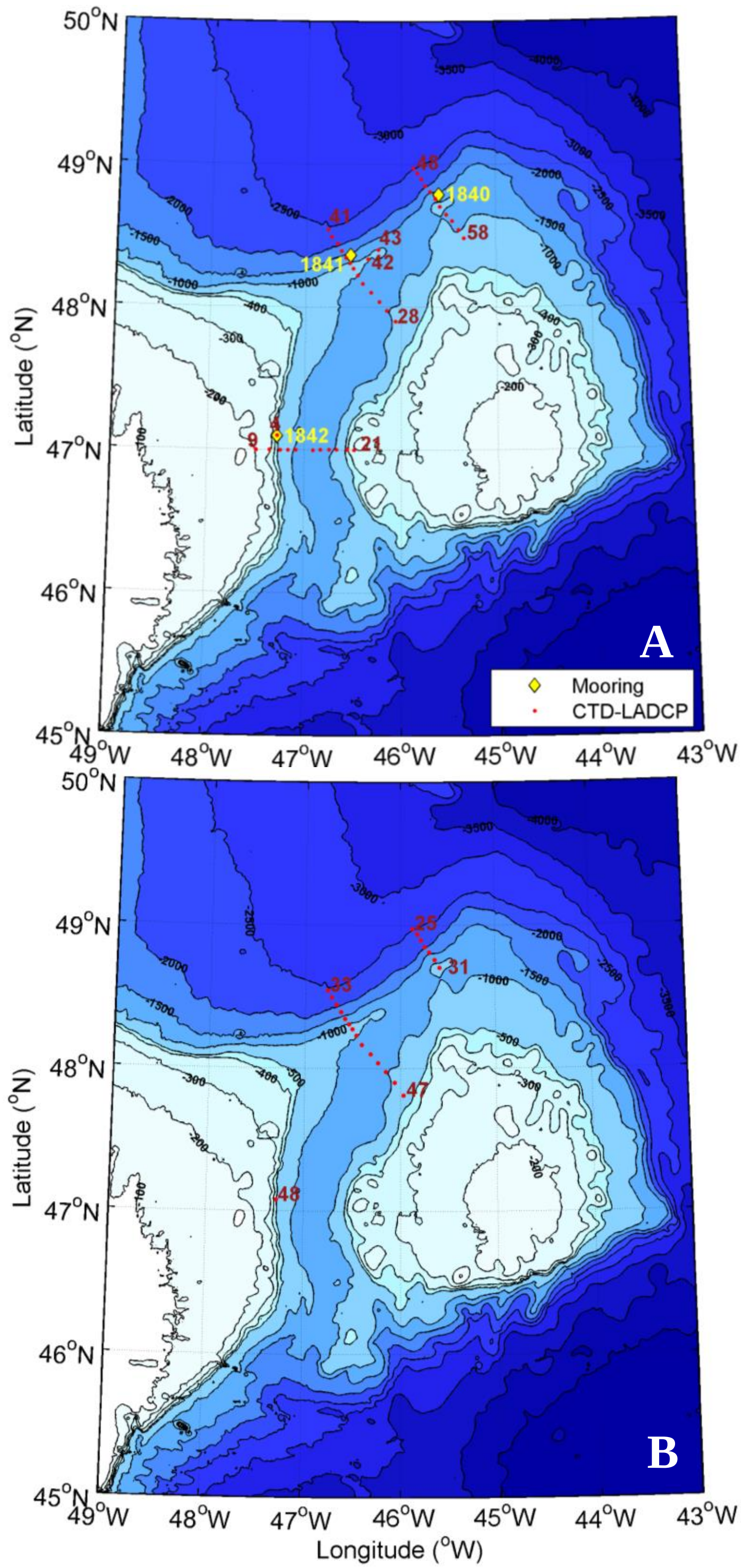

Figure 1. Mooring and profile locations, July 2013 (A) and July 2014 (B). CTD cast event numbers are shown at the end of each survey line. The three sections are referred to as FP

(Flemish Pass, event 9-21), SS (Sackville Spur, event 28-41) and NFC (Northern Flemish Cap, event 48-58).

2.2 CTD/LADCP Surveys

Profiles of water properties were obtained using a Sea-Bird 911 CTD-rosette equipped with dual temperature, conductivity and oxygen sensors and a single fluorescence sensor. The CTD surveys were completed for all the sites SS6-SS29 and FC13-FC20 in 2013, however, in 2014 neither SS19-22 nor any FC sites were surveyed. In 2014 one extra site, SS18.5, was added and a survey was done at the mooring site in the Flemish Pass 1842 (Figure 1, Table 1 and 2).

The temperature and conductivity sensors are calibrated annually by the manufacturer (Sea-Bird Electronics). Water samples were collected for salinity at the surface, mid-depth and bottom during the surveys using the CTD rosette; these were subsequently analyzed with an Autosal analysis system and the results were incorporated into the calibration of the CTD data. Full-depth oxygen samples were also collected for seven casts in the Sackville Spur area in 2014 and analyzed using the Winkler titration method (Table 2). The bottle oxygen concentrations were used to calibrate the oxygen sensors on the CTD. The fluorescence sensor output is based on the manufacturer's calibration for each instrument. The calibrations of the oxygen and conductivity sensors of the CTD are described in more detail in Section 3.

The LADCP system consisted of an upward and downward-looking pair of Teledyne RDI 300 kHz Workhorse Sentinel ADCPs were mounted on the CTD rosette system. LADCP data were collected at all stations. The details of the setup and sampling of the LADCP system is provided in Table 3.

2.3 VADCP

In 2013, the vessel mounted RDI acoustic Doppler current profiler Ocean Surveyor (75 kHz) (VADCP) was operated continuously in broadband mode from the departure at BIO until the start of LADCP survey at which point it was switched to narrowband. In 2014 it was run continuously in narrowband mode for the entire cruise. Time between pings was 3 seconds and long-term averaging was set to 5 minutes while short-term averaging was set to 30 seconds (Table 3). This data is used to assist in the processing of the LADCP data through corrections in the upper part of the water column where the VMADCP and LADCP overlap in coverage. The advantage of this is that the VMADCP velocities are corrected for ship drift through integration of GPS position data in the processing system; the LADCP system also corrects for ship drift in the processing but it is less accurate because the exact position of the CTD rosette is unknown as it descends through the water column.

2.4 Moorings

One mooring was deployed at each of the sites; a short near-bottom mooring on the 400 m isobath on the western flank of the Flemish Pass (1842); and two moorings on the 1400 m isobath on the north side of Sackville Spur extending through the water column to within 50 m of the surface (1840-41) (Figure 1, Table 1, 3). A description of each of the moorings is given in the diagrams in Appendix 1 and the configuration is in Table 3. The mooring on the Flemish Pass consisted of one upward-looking Teledyne RDI 75 kHz long ranger ADCP and MicroCAT near the bottom. Moorings on the Sackville Spur consisted of one upward-looking Teledyne RDI Long Ranger 300 kHz Workhorse acoustic Doppler current profiler (ADCP), 6 Aanderaa RCM11 single point current meters, and 8 Sea-Bird SBE37 MicroCAT temperature/conductivity sensors. The Sackville Spur moorings were designed to provide near-complete depth coverage. A sub-surface float, equipped with an upward-looking long ranger ADCP provided the main buoyancy and current measurements in the top 200 m. Below the float, the RCM single point current meters were mounted approximately every 200 m to the bottom. Above the float is a streamlined buoyancy package equipped with a MicroCAT placed 50 m below the ocean surface. Both Sackville Spur moorings were deployed with a five train-wheel anchor and dual Benthos 965A acoustic releases. The mooring on the Flemish Pass consists of a near bottom float equipped with an upward-looking long ranger ADCP and a MicroCAT. The mooring was deployed with one train-wheel anchor and a Benthos 865A acoustic release.

The moored ADCPs (MADCP) on the Sackville Spur moorings recorded vertical profiles of currents in 40 8-m bins; samples were recorded hourly with a setting of 120 pings per ensemble in burst mode. The Flemish Pass MADCP recorded vertical profiles of currents in 60 8-m bins hourly with a setting of 120 pings per ensemble in burst mode. The RCMs recorded currents, pressure and temperatures hourly at a single depth; the RCMs at 500 m also recorded salinity and the RCMs on mooring 1841 at 750 and 1150 m did not record pressure. The MicroCATs recorded pressure, salinity and temperature in 5 minute intervals and were paired with the RCMs except for near the surface above the float.

2.5 Mooring Data Return

The moorings provided high quality data for the full deployment with a few exceptions. The near bottom Microcat on mooring 1840 at 1358 m pressure sensor drifted. The RCM on mooring 1840 at 500 m failed about two and a half months before mooring recovery around April 15th 2014. The RCMs on mooring 1841 at 750 m and 1150 m had no pressure data.

Table 3 ADCP configuration that differ from the factory defaults.

	Moored	**Vessel Mounted**	**Lowered**
Instrument	Long Ranger	Ocean Surveyor	WorkHorse Sentinel
Frequency	75	75	300
Mode	Broadband	Narrowband	Broadband
Beam pattern	convex	concave	convex
Beam angle (deg)	20	30	20
Beam configuration	Janus 4 Beam	Janus 4 Beam	Janus 4 Beam
Vertical alignment (deg)	up	down	up/down
Bin mapping used	Yes	Yes	No
3-beam solution used	Yes	Yes	No

Tilt alignment correction used	Yes	No	No
Coordinates used	Earth	Beam	Beam
Ambiguity Velocity (cm/s)	175	450	250
Bin length (m)	8	8	10
Distance to middle of first bin (m)	19.88	17	5
Blanking length (m)	15	13	0
Number of bins	40 (60, 1842)	100	20
Number of pings per ensemble	120	100/10	1
Time between pings (s)	3	3	1
Averaging interval (s) long/short	N/A	300/30	N/A
Averaging distance first/second	N/A	10/1000	N/A
Reference layer start bin/end bin	N/A	3/10	N/A
Reporting interval (s)	3600	3/30/300	1
Temperature sensor	No	Yes	Yes
Pressure sensor	Yes	No	Yes
Salinity sensor	No	No	No
transducer misalignment (deg)	N/A	66.94	N/A
transducer depth (m)	200 (400, 1842)	6	profile

2.6 Benthic Data Collection

Benthic sampling was conducted on the HUD2013-021 mission to collect information on the distribution of sensitive benthic fauna in the vicinity of the Sackville Spur, with a focus on sponges. Sponges were collected as part of a pilot study to test the ability to collect and culture live deep-water sponges at BIO. A mapbook summary of all benthic sampling operations and processed biological collections from van Veen and Video grab sediment samples are shown in Appendix 8.

3. DATA PROCESSING

All shipboard profile data and moored time series, excluding LADCP and VADCP data, were processed using standard methodologies employed by the Ocean Data and Information Services (ODIS) group at the Bedford Institute of Oceanography. These procedures include spike removal and checks for other quality control issues such as low signal-to-noise ratio. The data are archived in a self-described ASCII file in the Ocean Data Format and are publicly available. For assistance in obtaining data, it is recommended to contact the BIO Datashop in the Ocean Data and Information Section at the following email addersss: BIO.Datashop@dfo-mpo.gc.ca.

The MADCP data quality control included; removing bad data from the beginning and end of the record, small gaps (maximum 4 consecutive ensembles) with less than 25% good pings are interpolated, entire bins are removed based on the percent good pings, bin depths are corrected based on data from other instruments and interpolation is used to remove spikes.

The RCM and Moored CTD data quality control included; applying calibrations to each data type, removing bad data from the beginning and end of the record, interpolating to remove spikes and pressure data is compared to data from other instruments on the mooring.

Profile LADCP data were processed using the LDEO LADCP Matlab processing software (Thurnherr et al., 2010, Thurnherr, 2014, http://www.ldeo.columbia.edu/~ant/LADCP.html) archived in NetCDF format. The processing used the CTD and VADCP data and included spike removal and checks for other quality control issues such as values below bottom.

VADCP data were processed using CODAS (Common Ocean Data Access System) processing software and procedures in Python and archived in NetCDF format (Firing and Hummond, 2010, Firing et al., 2012, http://currents.soest.hawaii.edu/docs/doc/index.html). VmDAS single-ping data (not the long term average data) together with the Ashtech ADU5 GPS heading receiver data were processed. Water track and bottom track data analysis were used to calibrate the data scale and alignment. Other quality control checks were performed to remove bad data caused by a variety of issues such as; values below bottom, wire interference, ringing, side lobe interference and low percent good values.

3.1 CTD Calibration

3.1.1 Oxygen

During the HUD2014017 cruise, bottle oxygen samples were analyzed using the Winkler titration method. No in situ dissolved oxygen samples were collected on the HUD2013021 cruise therefore the CTD oxygen sensor only uses the factory calibration. The bottle oxygen concentrations were used to calibrate the oxygen sensors on the CTD (two Seabird sensors and one Aanderaa optode). Oxygen samples were collected at stations indicated in Table 2.

The difference between the two oxygen values (ΔO_2) plotted versus sample identification number (*Figure 2*) shows that the two Seabird (SBE O_2) oxygen sensors need to be calibrated with bottle oxygen values (Winkler O_2).

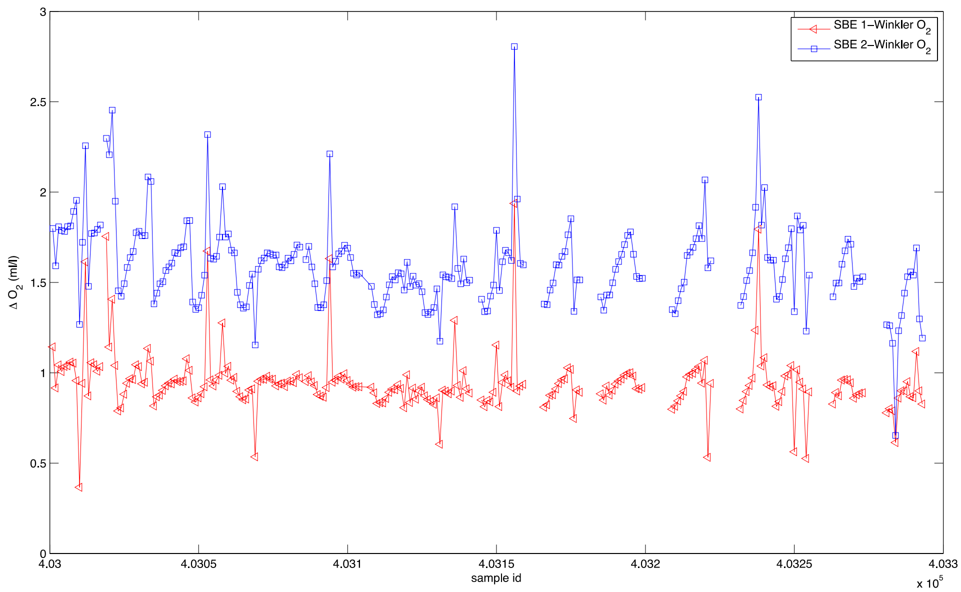

Figure 2: [SBE O2] – [Winkler O2] as a function of sample identification number before any corrections.

The Seabird oxygen equation is given by

oxygen (ml/l) = Soc(V+Voffset)*phi*

Where *Soc* is the linear slope scaling coefficient; *V* is the voltage; *Voffset* is the voltage at zero oxygen; and *phi* includes terms that correct for the effects of temperature and pressure, and also includes oxygen solubility dependence on temperature and salinity; because these terms remain essentially constant with fouling and sensor age, we will ignore *phi* for these corrections..

The slope term *Soc* needs to be corrected by multiplying by a correction factor ([Winkler O_2]/[SBE O_2]). However, some of the data points were removed due to bad titrations or bottle samples. To remove these outliers the mean ΔO_2 was subtracted from ΔO_2 and only the values within a threshold were kept (*Figure 3*). For the primary sensor the threshold was set to ±0.2 and to ±0.3 for the secondary sensor.

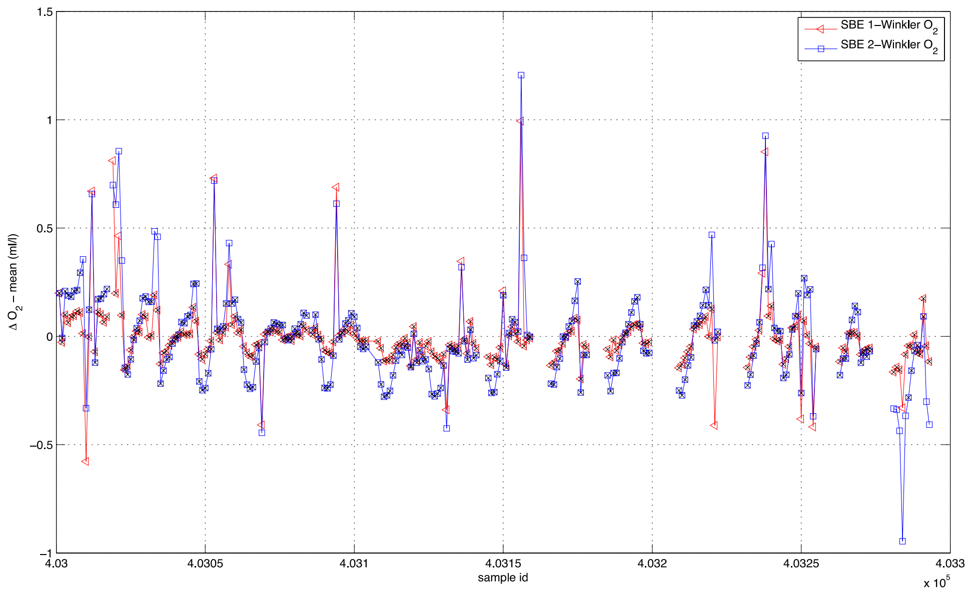

Figure 3: [SBE O_2] – [Winkler O_2] with the mean subtracted as a function of sample identification number. The black x's mark points that fall within the threshold and will be used in the correction factor calculations.

The new *Soc* coefficient becomes

*NewSoc = previousSoc*mean([Winkler O_2]/[SBE O_2])*

and the data will be reprocessed using this new value in the Seabird CTD processing program. *Table 4* gives the original and new *Soc* values.

Table 4: Previous and New Soc values for both SBE oxygen sensors

	Previous *Soc*	New *Soc*
Primary Sensor	4.1826e-1	3.6951e-1
Secondary Sensor	5.3465e-1	4.3679e-1

The SBE O_2 values were multiplied by the correction factor and *Figure 4* shows that this calibration of the two Seabird sensors with the Winkler bottle data greatly minimizes the difference between the two Seabird measurements.

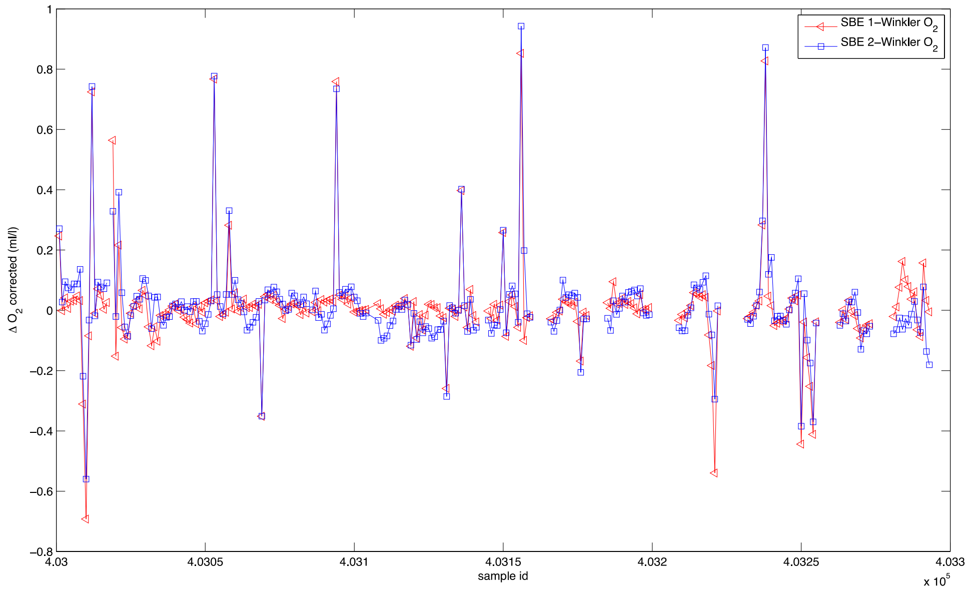

Figure 4: [SBE O_2] – [Winkler O_2] as a function of sample id after multiplying by the correction factor.

3.1.2 Salinity

Bottle samples were a collected at the surface, mid and bottom depths using the CTD rosette to calibrate the electronic CTD sensor. Bottle samples were analyzed using a Model 8400B Guideline salinometer. Conductivity calibrations were started onboard for the first few bottle samples. Final calibration of conductivity was done post-cruise once more samples are analyzed.

The salinometer outputs the conductivity as a ratio with standard seawater, therefore some conversions were done to get the conductivity of the bottle. The standard seawater has a given K_{15} value of:

K_{15} is the ratio of conductivity of standard seawater (at 15°C and 1atm) and the conductivity of the KCl solution (32.4356g/kg) at 15°C and 1atm

Where K_{15} = 0.99984 for this particular standard and the conductivity of KCl solution at the prescribed temperature and pressure is 4.29140 S/m and can be found in the Gibbs-SeaWater (GSW) Oceanographic Toolbox for MATLAB (McDougall & Baker, 2011, gsw_C3515 function). Knowing K_{15} and the conductivity of the KCl solution, the conductivity of the standard seawater can be determined. Then, by multiplying by the conductivity ratio from the salinometer, the conductivity of the sample can be determined.

It should be noted that these samples were analyzed with a bath temperature of 24°C rather than the 15°C used for the standard conductivity. The salinometer program accounted for this temperature difference so that the output sample conductivity ratios with the standard are at 15°C.

The conductivity value of the sample at 15°C and at the pressure of the bath needs to be converted to a conductivity at the temperature and pressure of the CTD. This can be done using some functions from the same MATLAB package.

First calculate the salinity of the bottle using the conductivity and pressure from the salinometer and a temperature of 15°C.

Salinity_bottle = gsw_SP_from_C(Conductivity_salinometer[mS/cm],T[C],P_bath)

Then re-calculate the conductivity from this salinity value using temperature and pressure from the CTD.

Conductivity_bottle = gsw_C_from_SP(Salinity_bottle,T_CTD,P_CTD)

This gives conductivity values that can be compared to the CTD values. To correct the CTD conductivity a linear regression is done on this equation:

*Bottle_conductivity = b1 + b2*CTD_conductivity*

to determine the best fit between the CTD conductivity and the bottle conductivity find the value of intercept b1, and slope b2.

4. RESULTS

4.1 CTD Data

CTD profiles are plotted for all stations (mooring deployment and recovery cruises) in one plot for each temperature, salinity, density, and dissolved oxygen data. Section plots were created for CTD-measured temperature, salinity, density and dissolved oxygen using the primary CTD sensors; the data were compared with those from the secondary sensors and no significant differences were found. A scatter plot was also created of temperature versus salinity with depth color contour for all the data combined on both the deployment and recovery cruises. All CTD data is presented in Appendix 2.

4.2 ADCPs

Section plots were also generated for LADCP north-south and east-west components of the currents for each cruise. LADCP current vector plots by depth were generated for each cruise. All LADCP data is presented in Appendix 3.

VADCP data is presented in Appendix 4 and includes depth averaged current vector plots and corresponding contour plots of current vs latitude and current vs longitude for several transects in the Flemish Cap region for each cruise.

It is evident from the LADCP and VMADCP data collected in 2013 (Figure 24, Figure 34) and 2014 (Figure 25, Figure 38) that as theorized before the start of this project, the area of Sackville Spur is an area of very complex ocean circulation. This will require further research to fully understand the processes controlling the ocean dynamics of this area. High resolution ocean models being developed for this region may enable us to further this research through utilization of the *in situ* data collected as part of this project.

Contoured time series are plotted for MADCP component current speed, current speed, current direction, percent good and average echo intensity. Current time series for certain bins, approximately every 24 m, are plotted for component current speed, current speed, and current direction. Progressive vector diagram were created for each MADCP for certain bins, approximately every 50 m. All MADCP data is presented in Appendix 5.

4.3 Moored RCM and MicroCAT

Time series plots of MicroCAT and RCM pressure, temperature and salinity and RCM component current speed, current speed, and current direction are presented in Appendix 6 and 7. In addition, progressive vector diagrams were created for each mooring showing all RCMs. It is notable that periods of sustained currents approaching 0.8 m/s were observed in the upper part of the water column on the two moorings on the north side of Sackville Spur (#1840 and #1841). In Flemish Pass, velocities in excess of 1 m/s were observed.

4.4 Simulating an Oil Spill in Flemish Pass using Particle Tracking

Particle trajectory plots were produced to trace the path of potential surface and deep oil spills in Flemish Pass. It is important to note that the results in this appendix reflect the trajectories and dispersion of particles, but do not incorporate oil fate and behaviour in this environment.

In this simulation, there was an instantaneous particle release at 46.5^{o}W, 47.9^{o}N, which is near the P78 Well site. The release was arbitrarily chosen to occur in 2014. The particle trajectories were produced using A. Drozdowski's particle tracking program, BBLT3D (Drozdowski, 2009). Trajectories of 100 particles were tracked for up to 90 days during four seasons. Trajectories were traced using simulated ocean current horizontal velocity (*U* and *V*) output from the NEMO ocean model (Nucleus for European Modelling of the Ocean; http://www.nemo-ocean.eu/, last accessed on 24 November 2015). BBLT3D does not include oil weathering processes; it is strictly a particle tracking algorithm.

The NEMO numerical simulations for 2004 were supplied by L. Zhai (Bedford Institute of Oceanography, DFO) whose output used the CREG36 domain for the Northwest Atlantic (Canadian REGional configuration with 1/36^{o} nominal resolution; Dupont et al., 2015). Numerical model velocity data were in 2-day time steps with each file representing a season of

90 days: time steps 1-45 represented J, F, M for Winter; A, M, J for Spring; J, A, S for Summer; and O, N, D for Winter.

Each run of BBLT3D started at the first time step for each seasonal file. BBLT3D uses bilinear interpolation of the gridded input data to pinpoint the appropriate release position, release time, and release depth. Although the surface level of the NEMO model for U and V is at 0.5 m, the sea surface was defined to be at 0 m for the oil spill and used the 0.5 m NEMO data. The bottom was defined to be at 1100 m. BBLT3D returned particle positions at hourly time steps.

An optimal value for the coefficient of diffusivity, Ah, was needed to run BBLT3D. To choose Ah, BBLT3D was run for varying Ah (0, 10, 20, 30, 40 , and 50 m^2s^{-1}). It was found that Ah = 10 m^2s^{-1} or 20 m^2s^{-1} gave the most realistic result. Ah = 10 m^2s^{-1} at the surface, and Ah = 20 m^2s^{-1} at the bottom where the system is presumed to be the least energetic. A higher Ah at the bottom caused too much spreading. The particles were tracked for 90 days, but it should be noted that most surface oil spills lose a large part of their volume after even a week because of weathering.

The trajectories of the 100 particles are shown in the following four figures: two for the surface, with Ah=10 m^2s^{-1} and Ah=20 m^2s^{-1}; and two at 1100 m with Ah=10 m^2s^{-1} and Ah=20 m^2s^{-1}. The particle positions are plotted every 2-hours for each 90-day season (winter, spring, summer, and autumn). The releases occurred on January 1, April 1, July 1, and October 1. The release site is marked with an “×”. The colour bar at the bottom of each plot represents the days since release.

There is definitely seasonality revealed in the particle trajectories. Not surprisingly, winter is the most energetic; the size of the region covered is the greatest for winter. The strength of the seasonality at depth is somewhat surprising and should be further investiaged.

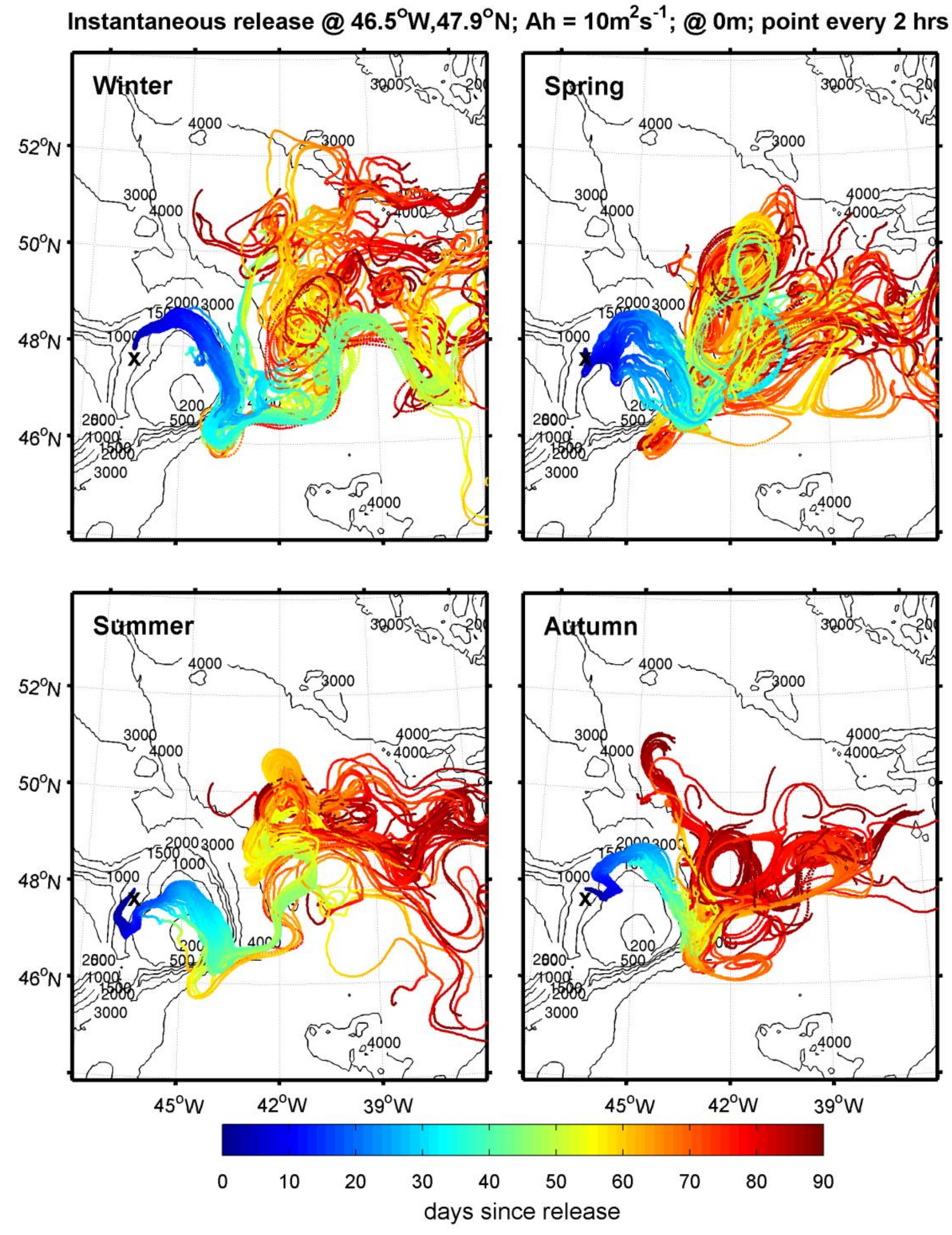

Figure 5 Surface particle trajectories that simulate an instantaneous release over 90 days for each season. Ah = 10 m^2s^{-1}. Particle positions are plotted every two hours.

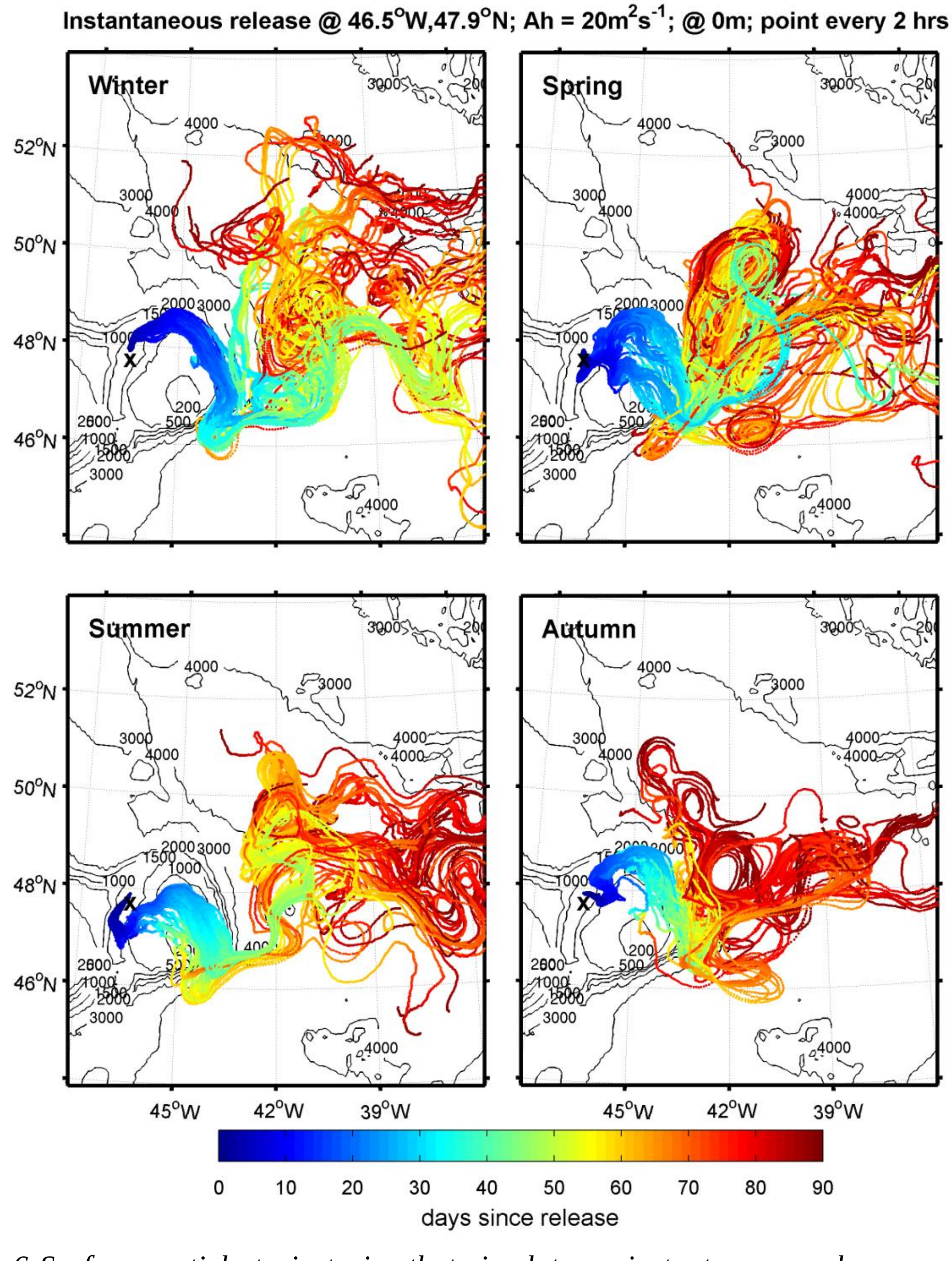

Figure 6 Surface particle trajectories that simulate an instantaneous release over 90 days for each season. Ah = 20 m^2s^{-1}. Particle positions are plotted every two hours.

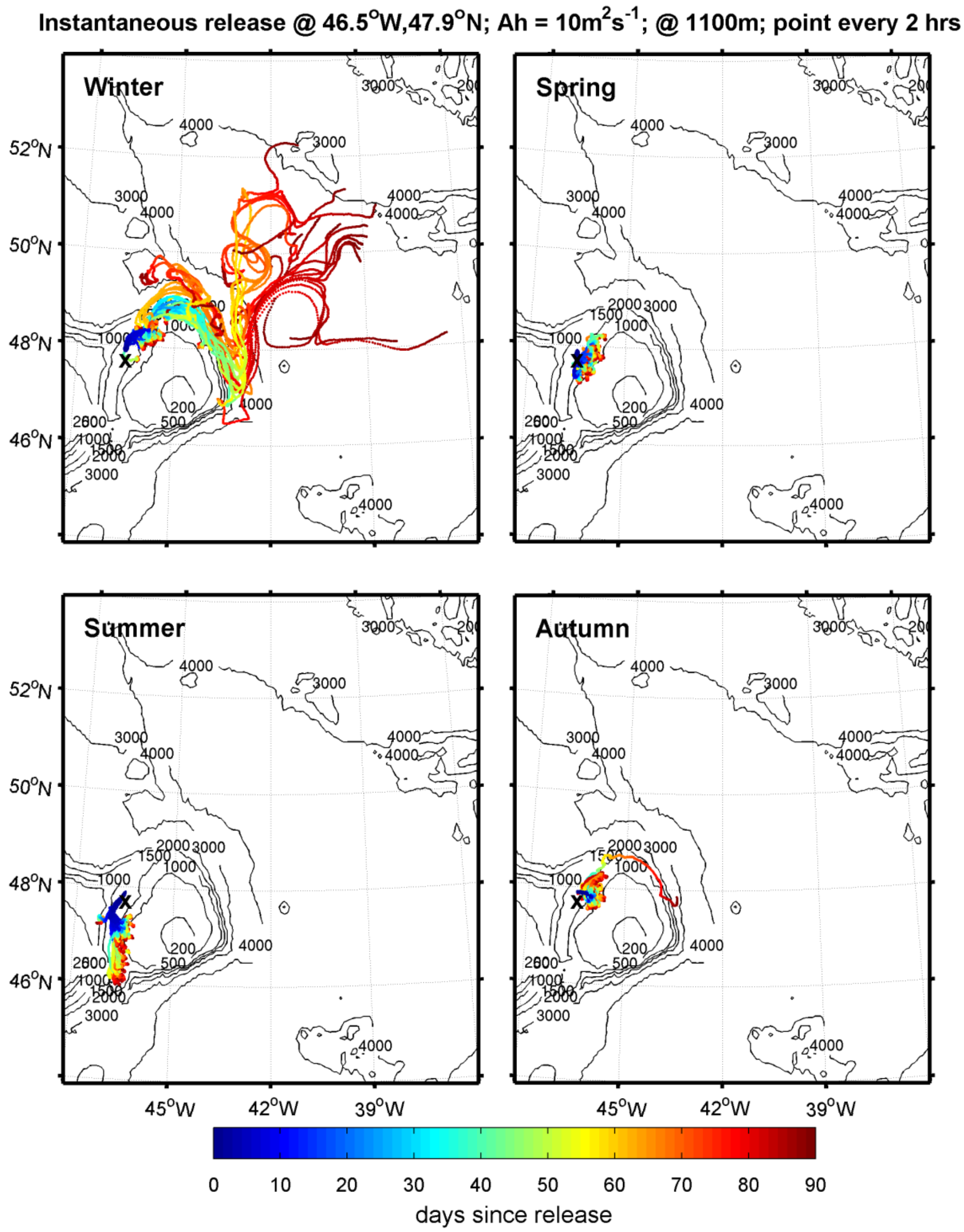

Figure 7 Bottom particle trajectories that simulate an instantaneous release over 90 days for each season. Ah = 10 m^2s^{-1}. Particle positions are plotted every two hours.

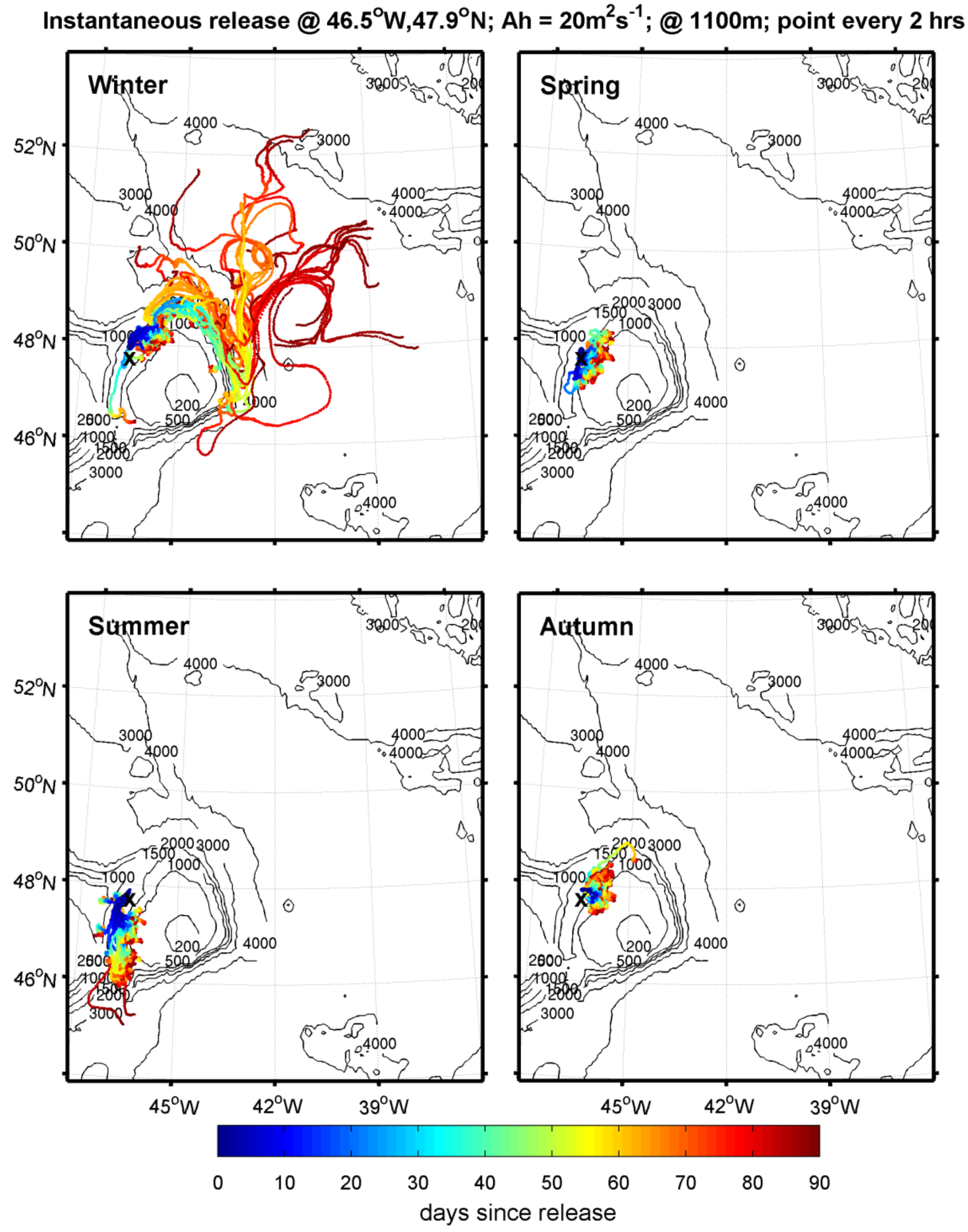

Figure 8 Bottom particle trajectories that simulate an instantaneous release over 90 days for each season. Ah = 20 m^2s^{-1}. Particle positions are plotted every two hours.

4.5 Benthic Sampling Results

4.5.1 Campod

Three Campod camera transects were conducted during the HUD2013-021 mission: one on the western side of the Flemish Pass (CON 6) and two on the eastern side (CONs 22 & 23). Initially only a single transect was planned on each side of Flemish Pass, but a second transect was conducted on the eastern side after the ship had difficulty drifting up/downslope there.

Preliminary assessment of the images collected on the east and west sides of the Flemish Pass revealed two very different biological assemblages (see *Figure 9*). The west side of the pass had an abundance of soft corals (likely *Duva florida*), *Polymastia* sponge, and a creeping *Iophon*-type sponge, with longfin hake, grenadier, and redfish. The east side had an abundance of what appeared to be surface-dwelling onuphid polychaetes and cod, and had the only occurrences of fan-shaped sponge and black coral *Stauropathes arctica*. Also observed was a large, unidentified sponge on both sides of the pass. The western side of Flemish Pass had a greater abundance of hard substrate (cobbles & boulders), likely supporting the high diversity there.

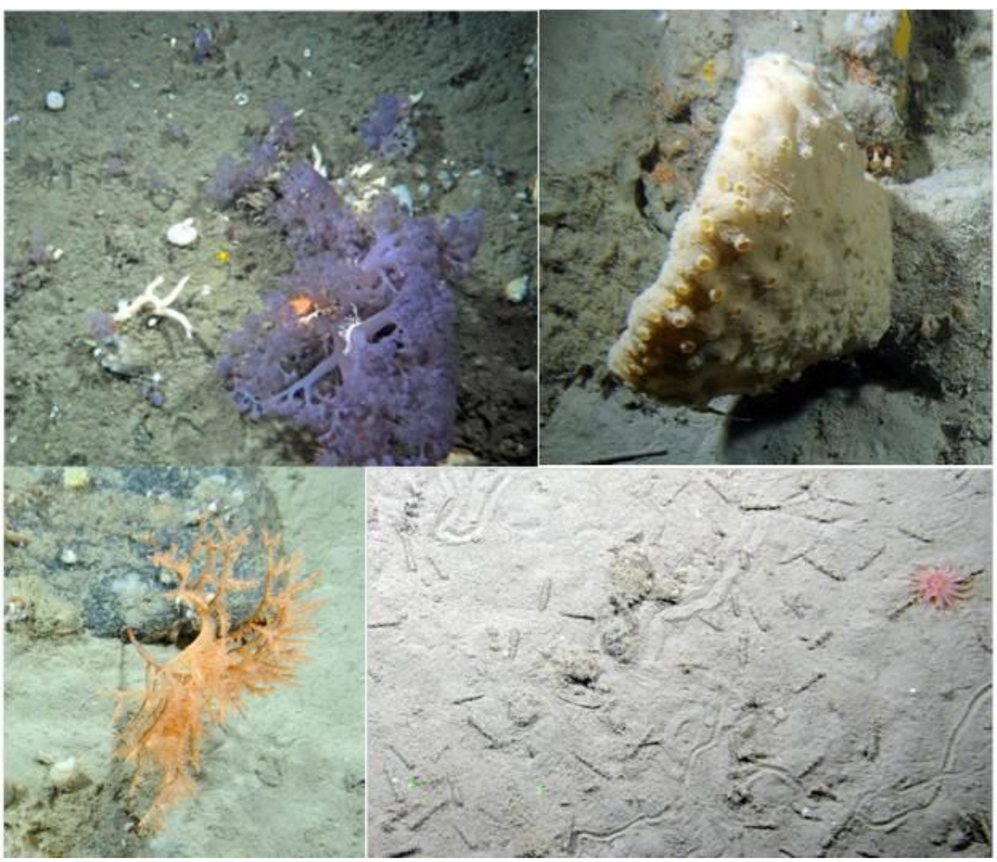

Figure 9 Top left- Soft corals (likely Duva florida) and Iophon-type sponge on the western slope of Flemish Pass. Top Right- Unidentified sponge found on both eastern and western sides of Flemish Pass. Bottom left- Black coral Stauropathes arctica on the eastern slope of Flemish Pass. Bottom right- Onuphid worm tubes on the eastern slope of Flemish Pass.

4.5.2 Video Grab Samples

Four video grab samples were collected on the eastern side of Flemish Pass (see Appendix 8). The density of sponges observed in the two Campod video transects here was less than hoped, so the first Video Grab station was designed to target an area of high sponge density previously sampled during the NEREIDA program. Sponge concentrations were very low, and after approximately an hour drifting, video grab efforts were relocated to the most promising Campod transect. Sponge concentrations at this transect were low until the end of the transect.

No sediments were collected with video grab, but cobbles with encrusting fauna as well as several larger animals were retained, preserved and catalogued (see Appendix 8). A selection of genetic samples were collected, including sponges. Only one sponge was collected, an Asconema species, but Video Grab successfully grabbed three different species of sponge, with two collections lost before the system reached the surface. One specimen washed out of a grab that could not close completely due to cobbles jamming the jaws. A second specimen was apparently pinched clear of the bucket during closure on the bottom even though fully visible in the downward looking video. For future sponge collections with Video Grab, the bucket should be closed sufficiently as to not allow wash out of the specimen during retrieval, and the collection target should not be at the periphery of the bucket when viewed in the downward looking video prior to closing the bucket.

Five additional video grabs were collected at the base of Sackville spur in transit to port, with multiple sponge species collected for culture, genetics, and taxonomy.

4.5.3 van Veen Grab Samples

Three van Veen grabs were collected from the Sackville Spur NAFO Closed Area 6 (see Appendix 8). The ship was allowed to drift during operation, and the samples are from three different depths, each differing by approximately 100 m. The grab performed well, returning full of sediment at each deployment. One grab collected a Geodia sponge. Two grabs were in an area of sponge mats, and a subsample was collected. All sediments were sieved into 0.5 mm & 1.0 mm fractions and were retained for post processing.

4.5.4 Sponge Cultures

A chilled seawater system was set up aboard CCGS Hudson inside a refrigerated 20ft container (see Figure 10). The system consisted of three 250L insulated tanks. Ship's saltwater was pumped through a 20µm filter into a holding tank, passed through an ultraviolet (UV) system (figure, top right) into a cooling tank, which was then chilled to 5°C. The water was then passed through a peristaltic pump into the sponge fragment culture tank at a rate of ~180mL/min, and subsequently drained through a drain hose which was vented through the container. The fragment culture tank contained 2 small air lifts to provide circulation and aeration in the tank. An additional air stone was added to increase circulation. New water was prepared daily, to provide some feeding for the fragments. Every 3 days additional supplements of algae and soluble silica were added.

According to the literature available, exposure to air is an extremely important factor in sponge culture survival. The nature of the sampling equipment used excluded the option of keeping the sponges completely submerged after collection, so efforts were made to minimize air exposure by quickly transferring sponges to containers of 5°C seawater, and placing them inside the refrigerated container prior to sectioning. All subsequent transfers of sponge material were carefully done to keep the specimens completely submerged at all times. Sponges were placed in a series of containers in an attempt to clear the sponges of debris, particularly those collected with the Van Veen.

Figure 10.Clockwise from the top left: Tank setup in the refrigerated container; filter housing and UV setup; sponge fragments in culture array; fragment culture arrays in tank..

In total, 7 species of sponge were sampled for culturing purposes (see Table 5):

Videograb Samples (02/07/2013):
Asconema sp., samples 1 & 2 (glass sponge)
Hexadella sp. (yellow encrusting sponge)
Demospongiae (broken piece from CON 26)
Tentorium on rock????

Van Veen Samples: (04/07/2013):
Geodia phlegraei/parva
Thenea sp.
Craniella sp.

Only 2 of these had sufficient tissue to culture fragments (Asconema sp. and Geodia phlegraei/parva), which are also the same two used for primmorph cultures.

Two unknown very small sponges attached to rocks (one is likely a Tentorium) as well as a Polymastia, were also retained.

Table 5. Summary of sponges collected for culturing purposes during the HUD2013-021 mission.

Taxa	Sampling Gear	Fragments/Whole	Primmorphs
Asconema sp. (1)	Videograb	Fragments	No
Asconema sp. (2)	Videograb	Fragments	Yes
Hexadella sp.	Videograb	Fragments (Half of sample)	No
Demospongiae	Videograb	Fragments	No
Geodia phlegraei/parva	Van Veen	Fragments	Yes
Thenea sp.	Van Veen	Whole	No
Craniella sp.	Van Veen	Whole	No
Tentorium sp.		Whole	No
Polymastia sp.		Whole	No

Samples were ideally cut in 1 – 2cm3 sections while submerged in a small (10L) glass aquarium, using a scalpel or scissors (*Figure 10*, bottom right). Fragments were placed in culture trays, and affixed to the mesh. A number of attachment methods were attempted (sewing thread, wooden pins), but plastic pins were found to be the most ideal. The sponges are generally suspended in 10cm dia. culture trays with a mesh bottom, stacked in a series ~10cm apart (*Figure 11*, bottom left). Two mesh bags were used and found to be less ideal.

Aside from Asconema sp., Geodia phlegraei/parva, and a tiny piece of Hexadella sp., the amount of tissue was so small that none remained for genetics or taxonomic sampling. Asconema sp. sponges are very thin, ~2mm, therefore the samples taken were flat, not cubes. The Thenea sp.

and Craniella sp. were too small for fragmenting and were placed whole in a modified culture tray, and the Hexadella was cut in half.

Cell cultures were attempted when enough material was available after fragment cultures. Cells were disassociated via manual manipulation through cheesecloth, then centrifuged at 500xG for 5 min. The supernatant was poured off and resuspended in sterile (0.22µm filtered) seawater (FSW) and re-centrifuged at 500xG for 5 min. The resulting cells were then resuspended in FSW and placed into petri dishes, and incubated at 3°C. The rocking of the ship seemed to keep the cells sufficiently in motion, so a shaker table wasn't necessary. A nutrient broth of RPMI medium, soluble silica and ferric citrate was prepared. Typically these nutrients are added after primmorphs are formed, however where no primmorphs were formed, a half concentration was added after 3 days to provide nutrients to the cells.

At sea collection and holding proved successful. There were a few issues with temperature creep, when we had to share the refrigerated container with another group who required a higher than expected temperature. This resulted in more work to keep the sponge culture tank at an acceptable temperature. Although the temperature did reach temperatures a bit higher than we would have preferred, it did not appear to affect the cultures.

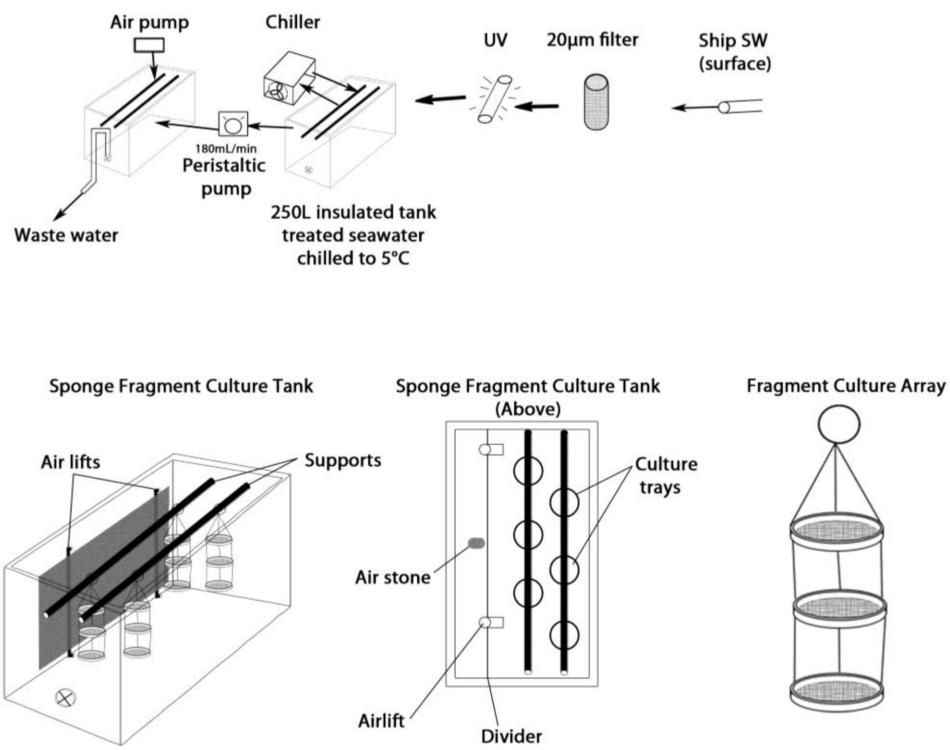

Figure 11. Schematic of holding system for sponge culturing.

4.5.5 Lab Cultures/Grow Out

Cultures were transferred to BIO on July 19, 2013. Cultures were placed into a flow through refrigerated tank maintained at 4-6 degrees Celsius, and a water flow at 5 – 10 L / min. The deep seawater system used has a yearly temperature range between 1 and 10 degrees Celsius and is filtered to 20u (nominal). Unfortunately the system was set to operate between 4-6 degrees so when the water temperature dropped below this the tank temperature followed. Salinity generally ran between 31.5 – 32 ppt. The sponges were fed a mixture of common cultured phytoplankton and supplemented with a Brightwell silicate solution.

An initial group of sponges collected during a scallop survey in area 29 (SFA29 SW Nova Scotia) were brought into BIO to test the facility's water system and holding tanks prior to the collection and transfer of Flemish Cap / Pass sponges.

Cultures were fed for about six months and examined. Pictures of the Primmorphs taken and that part of the experiment concluded. A few sponges from SFA 29 were removed early on as they were dying. This was likely due to the trauma and air exposure from the collection method. All of the fragment cultures, except the Demosponge, were dead at this time. The tanks were also fouled by a small local sponge as well as tunicates. All complete sponges appeared fine at this time. Feed was discontinued.

On Sept 5, 2014, the tanks were cleaned and cultures re-examined. Sponge fragments (Demosponge) were closely examined and it was determined that the cultures had grown through the nitex screen that they were attached to. Pictures reveal that the sponges have grown slightly over the one year period (*Figure 12* & *Figure 13*). The 2 small whole sponges as well as the Polymastia (whole) that were collected from the Flemish Cap / Pass area also appeared healthy. The SFA 29 sponges also appeared healthy and growth was apparent on at least the smaller of the two Polymastia specimens.

These sponges will remain in the current system and will receive a weekly feeding of cultured phytoplankton (various species including Terraselmis, Rhodomonas, Chaetoceros, Isochrysis and Pavlova).

Unfortunately, water flow was interrupted to the 2 sponge culture tank around March 12, 2015 and the sponges died. It is unknown how long or why the water flow was interrupted but the temperature in the tanks was about 7 degrees Celsius above ambient (3.5°C). Initially the sponges appeared fine but over the next few weeks they died.

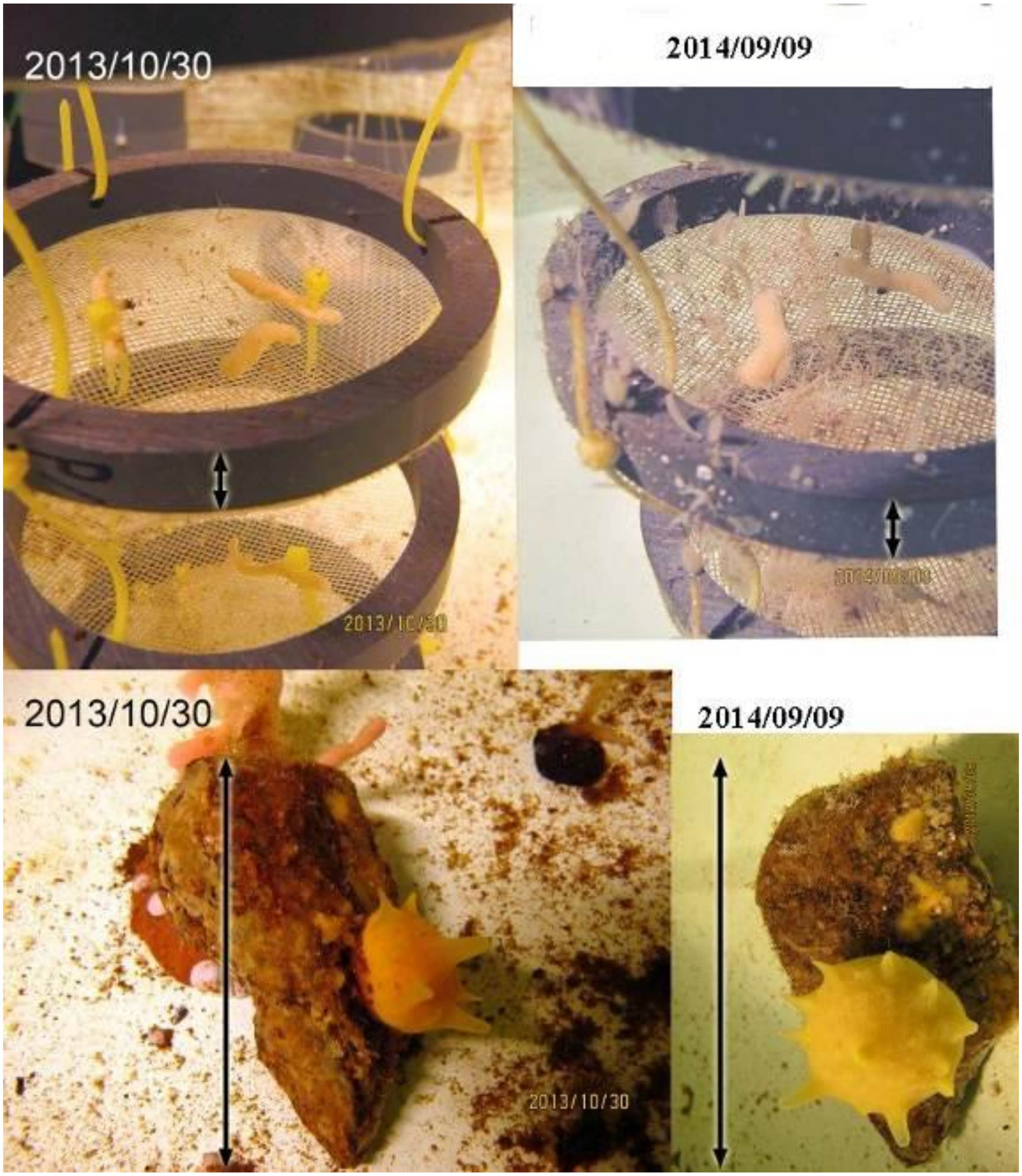

Figure 12. Top left and right- Sponges growing on nitex mesh in 2013 (top left) and 1 year later (top right). Bottom left and right- polymastid sponge growing on rocks in aquaria at BIO in 2013 (bottom left) and 1 year later (bottom right).

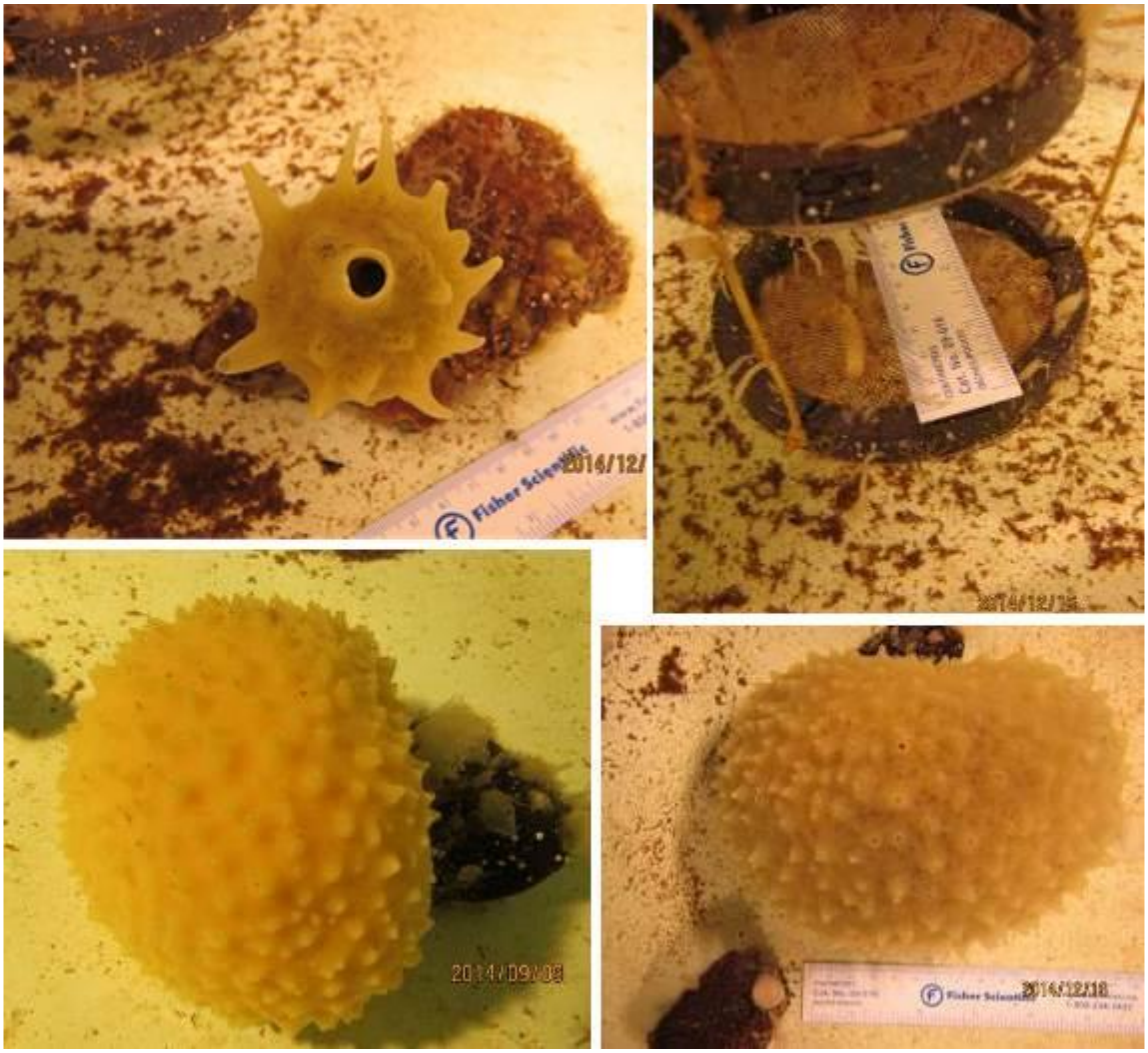

Figure 13. Polymastid sponges in culture at BIO.

4.5.6 Suggestions for Future Sponge Culturing

<u>*TANKS*</u>

- Larger tanks (less water in tank)
- Holding tray: Enclosed? Sewing/staples/price tag gun? Scallop hanging pins?
- Pump for surface water – even with continual running, Hudson system has too much rust. Estimate 10 – 15’ down to water, ~more with roll.
- Chill sponge tank to eliminate need for refrigerated container (uncomfortable working environment) *NOTE: Temperature in container was eventually raised to 11-13˚C. Possible set up in GP Lab with tank in tank system / additional chiller system.
- Prop up aquarium lid
- Set up peristaltic pump to face forward
- Better way to view / assess sponges in tank. Better lighting / set up in GP lab.

FILTER SETUP

- Double outdoor plug (extension cord with double plug) to eliminate need for power bar outside (~12’, current cord is too long)
- Handles for filter setup

GENERAL

- Better sponge photographs with scale bar / ruler in image. Perhaps have a specific underwater set up to facilitate pictures / angle that can easily be reproduced. This would allow for better future comparisons.
- Alarms for any tank / system holding live specimens.
- NOTE: be careful with sawdust etc. in the container – clogging the drains

PRIMMORPHS

- Proper size hose for vacuum pump
- Flat tray(s) for Petri dishes in fridge
- Primmorphs will not get us what we want so this could be dropped and time better spent on whole animals / fragment culture.

5. SUMMARY

Data collected during a field program carried out in 2013-14 with funding from the Environmental Studies Research Fund has resulted in a unique data set that will provide a very useful set of *in situ* data for future research. The data collected include shipboard CTD, lowered ADCP, vessel-mounted ADCP and water samples during two cruises in July 2013 and 2014. Moorings were deployed at three locations for that duration between the cruises and successfully collected CTD and current meter data. Benthic imagery and grabs were collected on the 2013 cruise to characterize species present in the region of Sackville Spur.

It is evident from the LADCP and VMADCP data collected that the area of Sackville Spur is an area of very complex ocean circulation. This will require further research to fully understand the processes controlling the ocean dynamics of this area. High resolution ocean models being developed for this region may enable us to further this research through utilization of the *in situ* data collected as part of this project. A product of the ocean model is particle trajectory simulations using high-resolution computer model results for the region which demonstrate strong seasonality in the flow field in the area of Sackville Spur even at depths near the ocean bottom. Further investigation will be required to determine the primary driver of the seasonal variability in circulation in this region.

Physical oceanography data has also been recently collected in this area by both Statoil and Bremen University (Germany). DFO has been granted access to data sets from both of these organizations in order to facilitate future research.

The Campod transect collected on the western side of Flemish Pass (CON 6) was fully analyzed upon return from sea. As this transect represents the only in situ data collected on the western Flemish Pass to date, results from this analysis will be used in an upcoming biodiversity study. In 2015, further in situ imagery was collected from the Flemish Pass in the vicinity of the Mizzen well. Those data, as well as data collected in 2013 will be used for reporting to NAFO on baseline data for this area. It is anticipated that results will be presented to the NAFO Working Group on Ecosystem Science (WGESA) in 2017.

Results of the sponge culturing project revealed that the culturing certain deep-water sponge species at BIO is possible. Whole sponges rather than fragments/primorphs survived longer in culture, and so culturing on whole sponges is recommended for the future. Future sponge culturing requires further investigation into methods of determining growth rates of the sponges.

Several stations had notable sponge densities and would be good waypoints for future sponge collection: Sponge waypoint 1 (a-c). Fan-shaped sponges and Polymastiidae spp. abundant (Con 27). Coordinates are: 47°07.8723 N, 46°32.5127 W.

GLOSSARY

ADCP - Acoustic Doppler current profiler
Aanderaa – Instrument manufacturer Analytics division of Xylem (http://www.aanderaa.com/)
AutoSal - Guildline's Autosal 8400B Laboratory Salinometer
BIO - Bedford Institute of Oceanography
CCGS - Canadian Coast Guard Ship
CTD - instrument that measures conductivity, temperature, and depth
ESRF - Environmental Studies Research Funds
FC – Flemish Cap
FP – Flemish Pass
HUD - CCGS Hudson vessel
LADCP – Lowered acoustic Doppler current profiler
LC – Labrador Current
MADCP – Moored ADCP
MicroCAT - Moored instrument that measures conductivity, temperature, and pressure
NFC – Northern Flemish Cap
RCM - Recording current meter
PAR – Photosynthetically Active Radiation sensor
RDI - Instrument manufacturer Teledyne RD Instruments (http://www.rdinstruments.com/)
SS - Sackville Spur
VADCP – vessel mounted acoustic Doppler current profiler

ACKNOWLEDGMENTS

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SOFTWARE ONLINE

The CODAS vessel mounted ADCP processing software and documentation.
http://currents.soest.hawaii.edu/docs/doc/index.html

The LDEO LADCP processing software and documentation
http://www.ldeo.columbia.edu/~ant/LADCP.html

Appendix 1 Mooring Diagrams

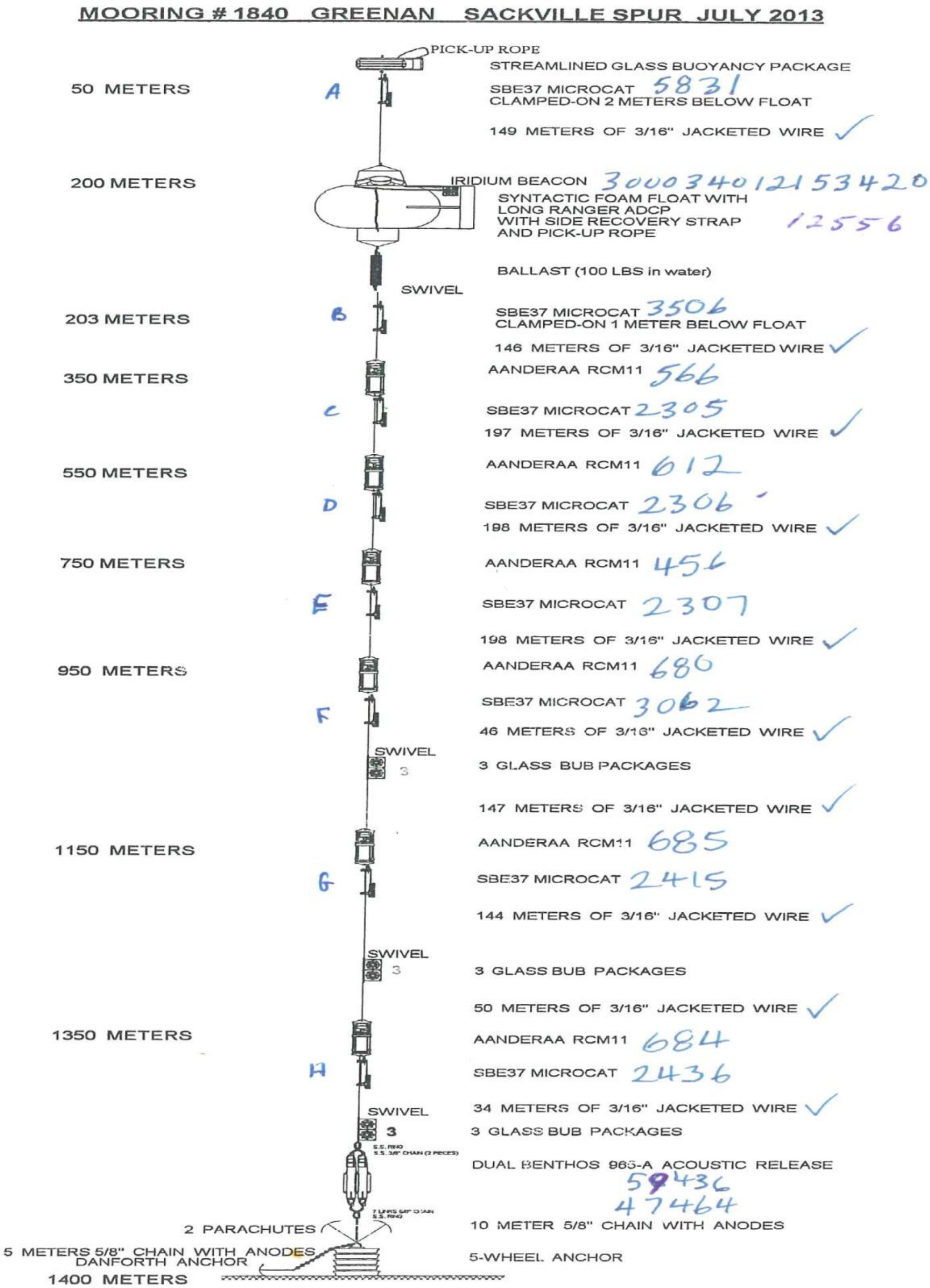


Figure 14 Mooring Design for mooring number 1840, northern Flemish Cap.

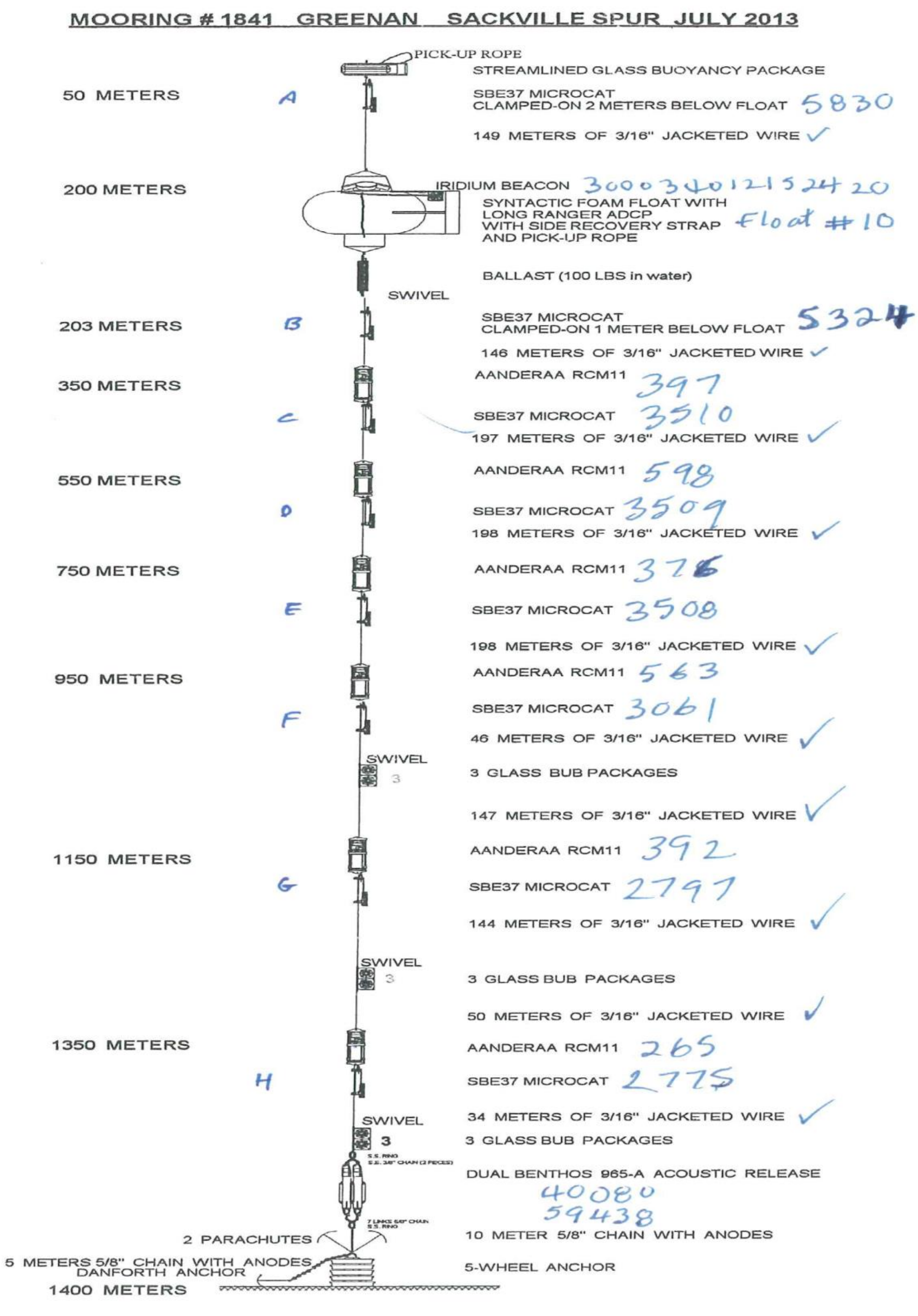


Figure 15 Mooring Design for mooring number 1841, Sackville Spur.

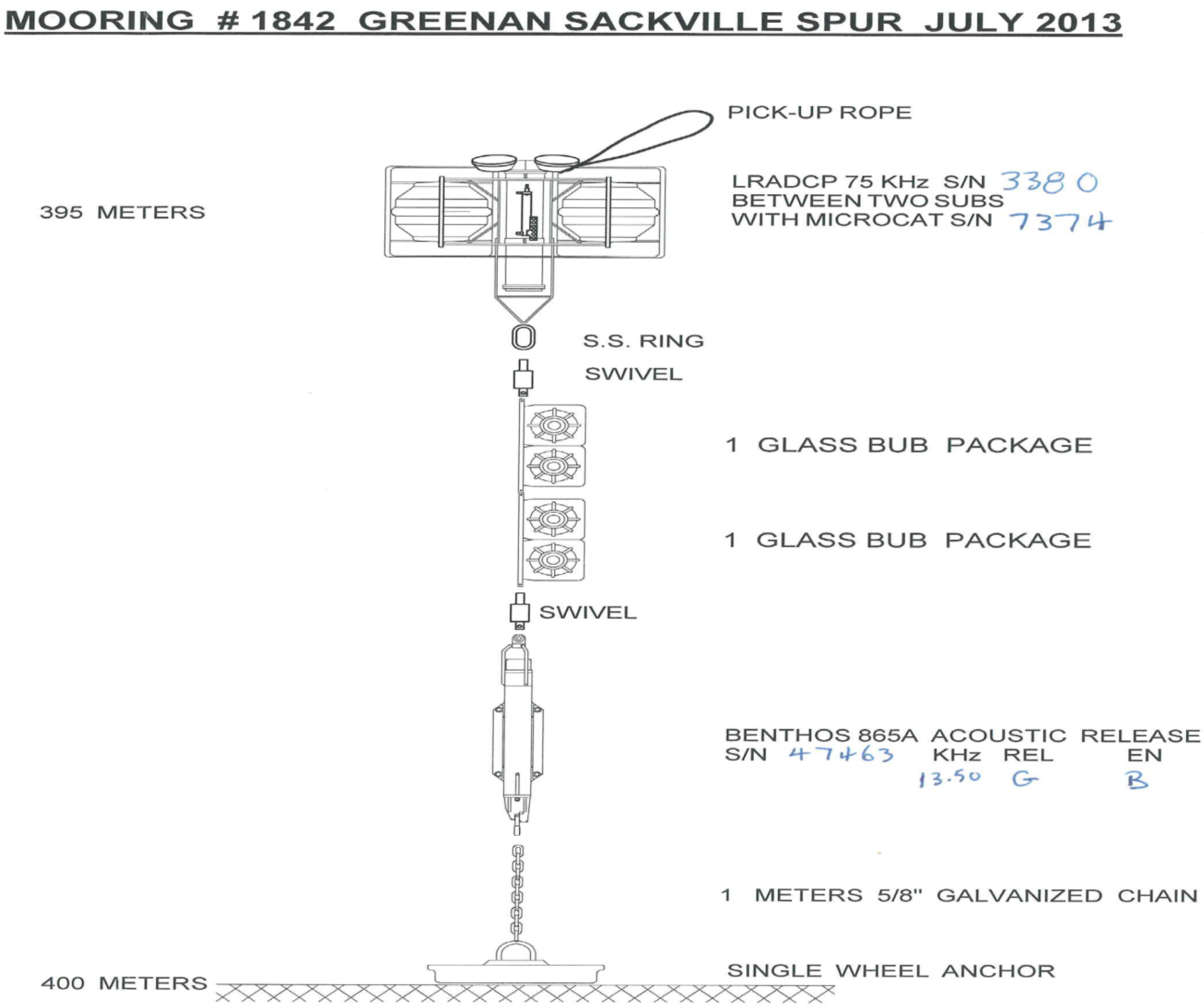


Figure 16 Mooring Design for mooring number 1842, Flemish Pass.

Appendix 2 CTD contour and profile data plots

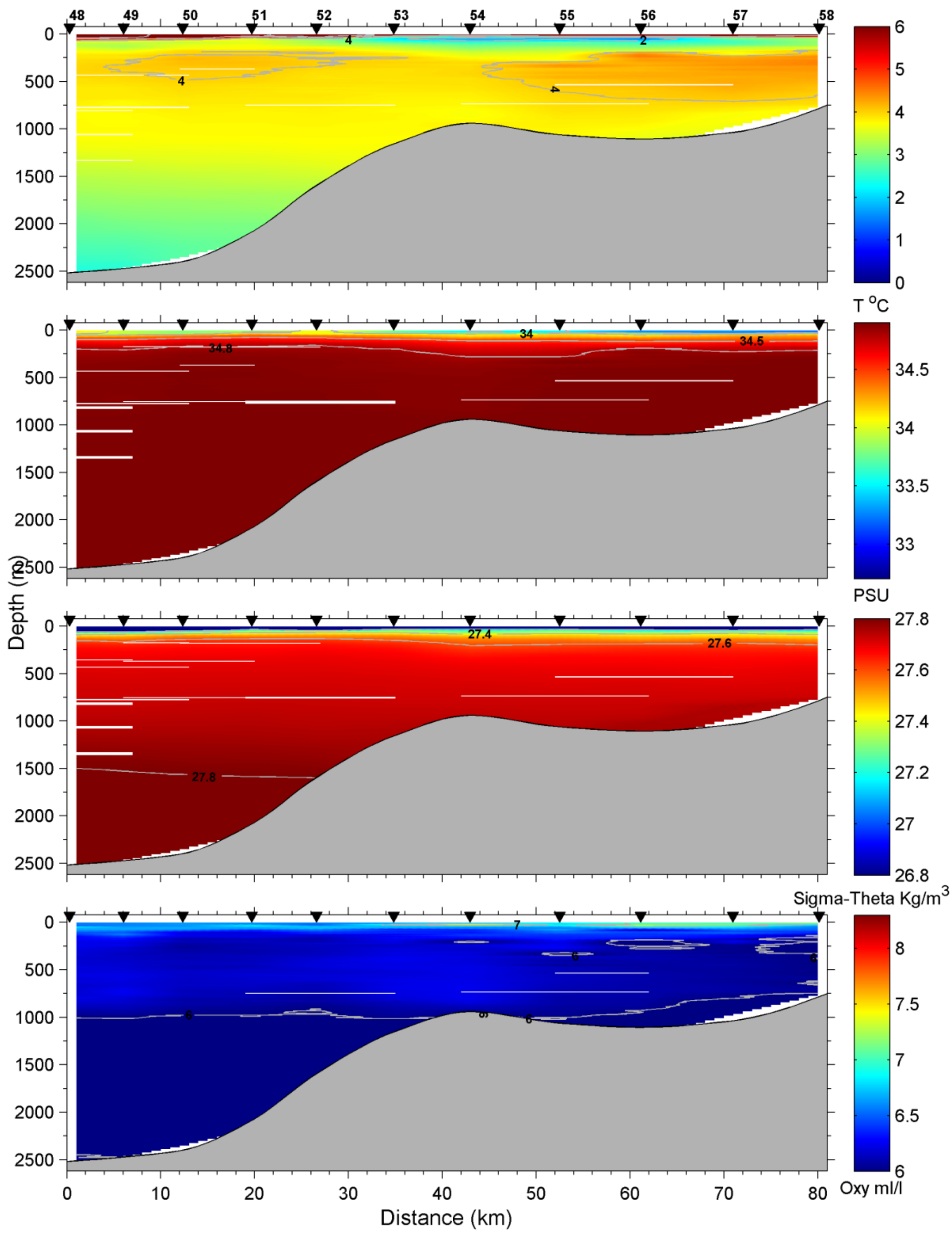


Figure 17 Contour of Temperature, Salinity, Density and Oxygen for cruise HUD2013021 northern Flemish Cap (NFC), casts 48 to 58.

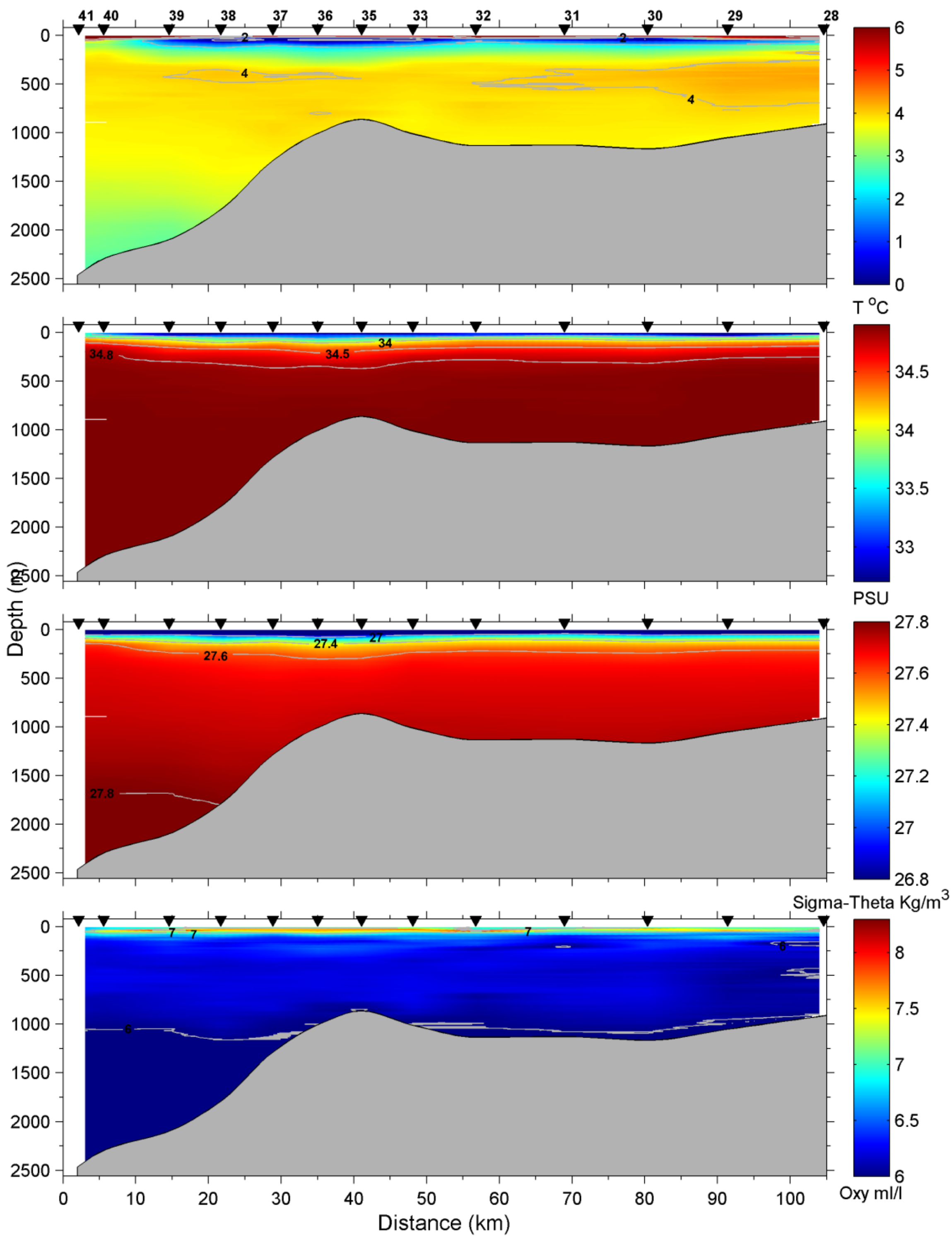


Figure 18 Contour of Temperature, Salinity, Density and Oxygen for cruise HUD2013021 Sackville Spur (SS), casts 41 to 28.

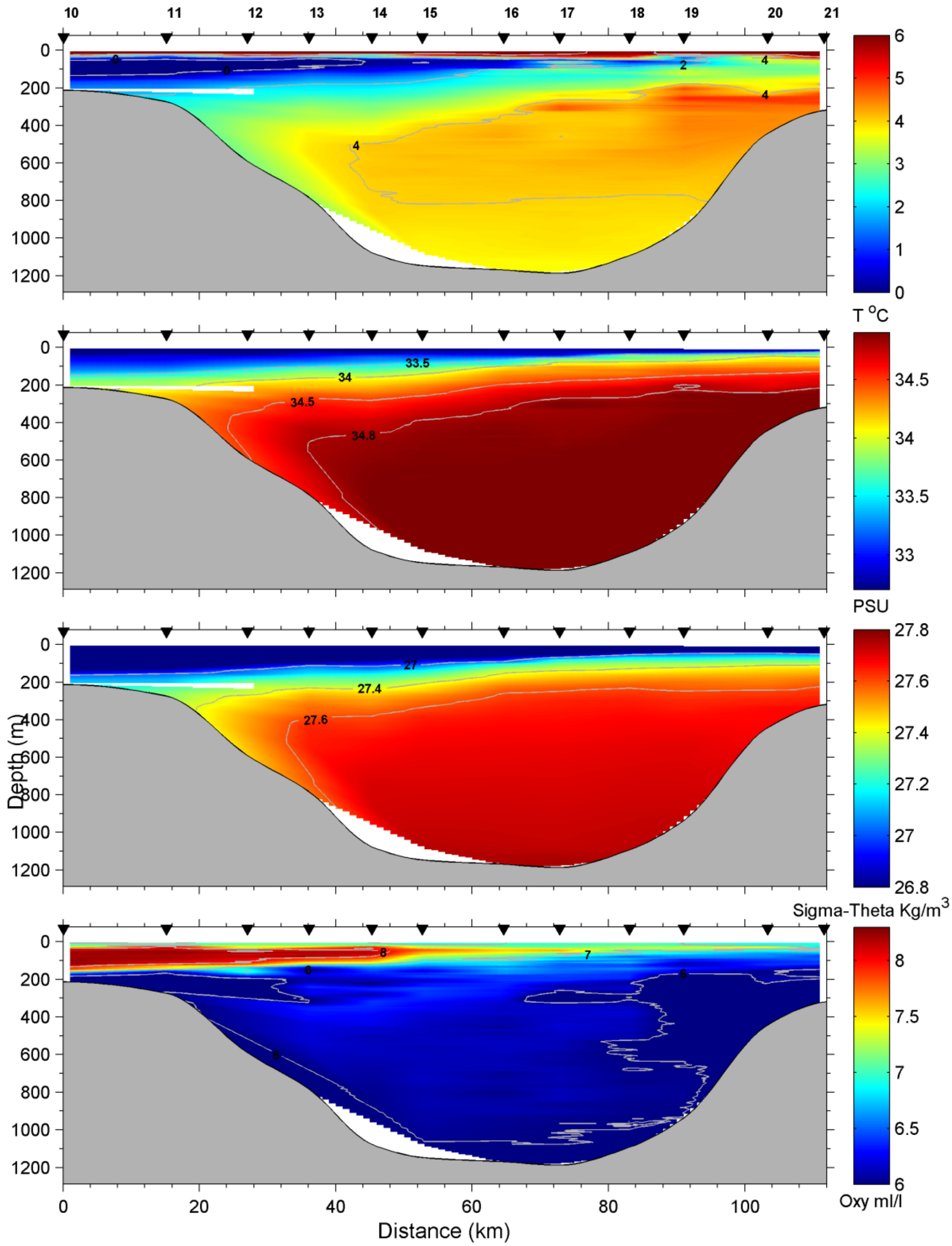
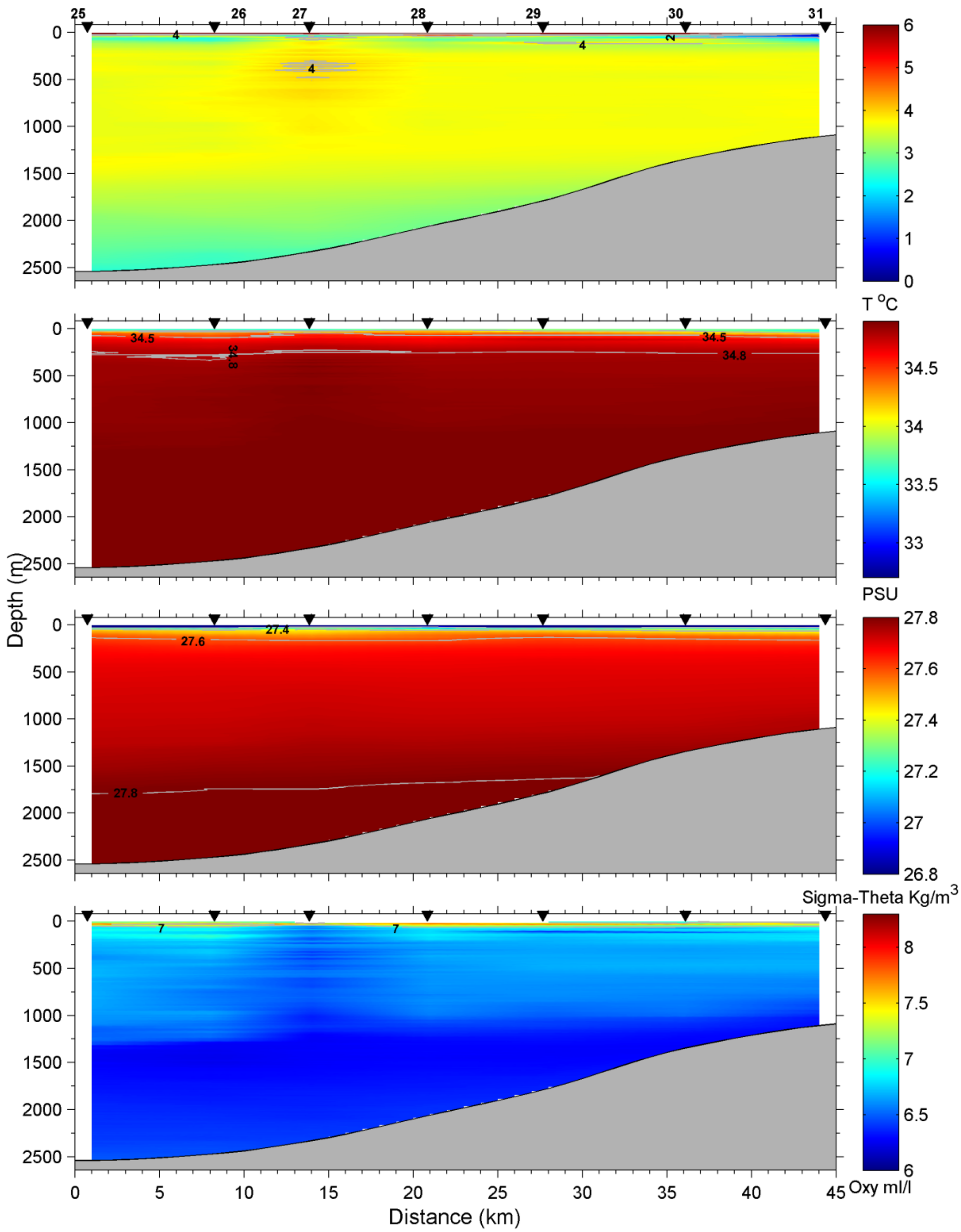


Figure 19 Contour of Temperature, Salinity, Density and Oxygen for cruise HUD2013021 Flemish Pass (FP), casts 9 to 21.



25
26
27
28
29
30
31
Depth (m)
T °C
PSU
Sigma-Theta Kg/m³
Oxy ml/l
Distance (km)

Figure 20 Contour of Temperature, Salinity, Density and Oxygen for cruise HUD2014017 Northern Flemish Cap (NFC), casts 25 to 31.

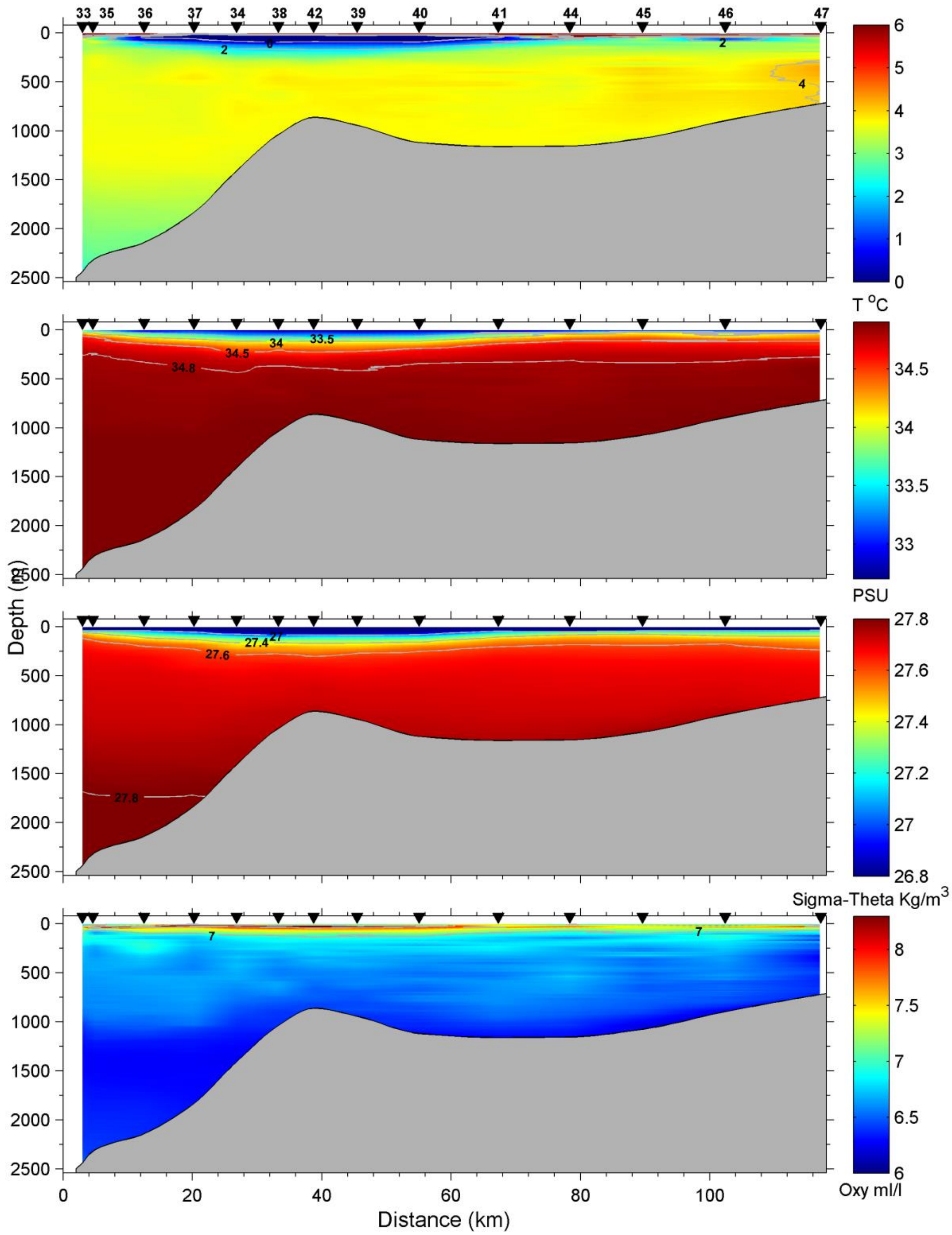


Figure 21 Contour of Temperature, Salinity, Density and Oxygen for cruise HUD2014017 Sackville Spur (SS), casts 33 to 47.

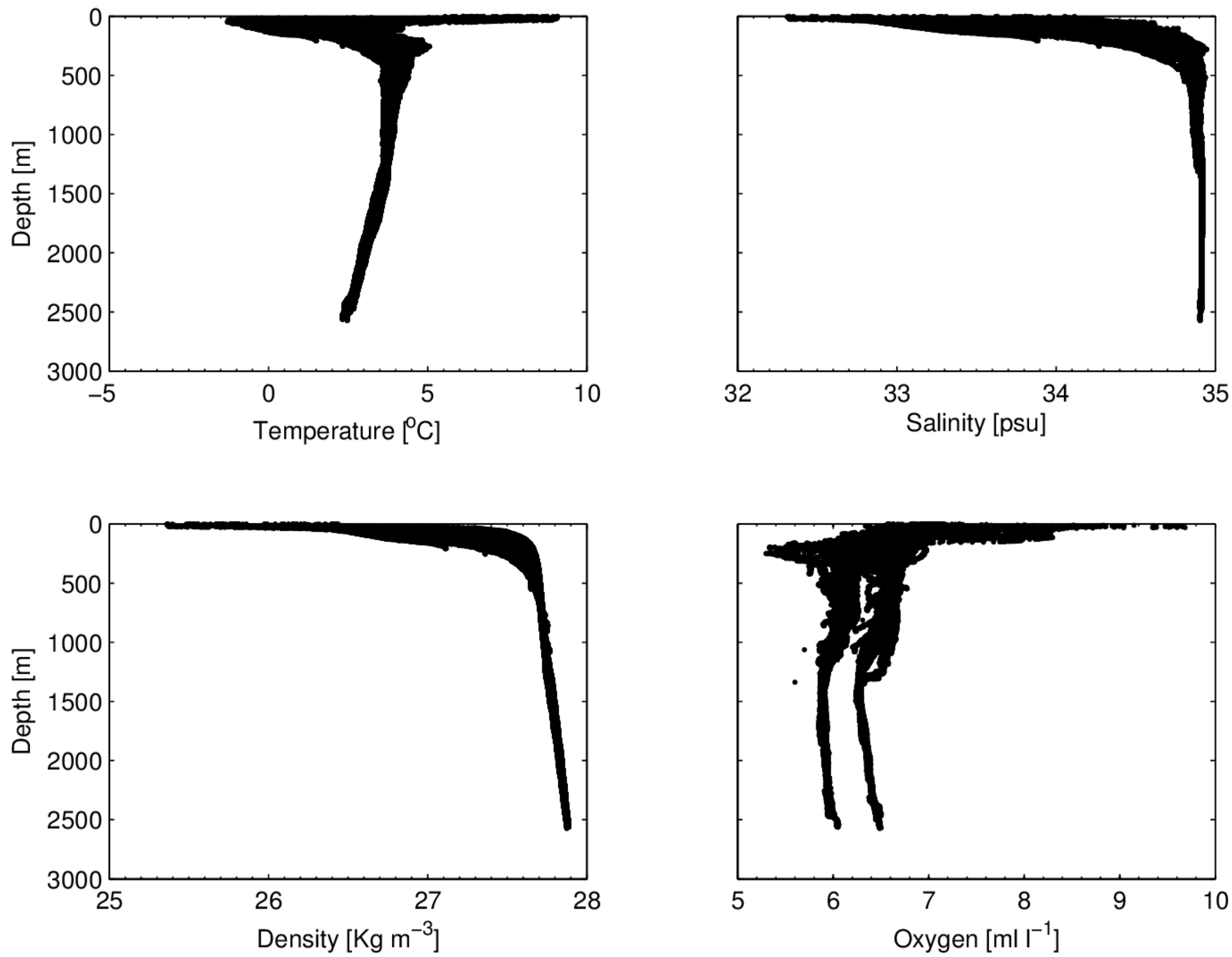


Figure 22 Profile of Temperature, Salinity, Density and Oxygen for both cruise HUD2013021 and HUD2014017 all casts. Note: No *in situ* dissolved oxygen samples were collected on the HUD2013021 cruise therefore the CTD oxygen sensor only uses the factory calibration.

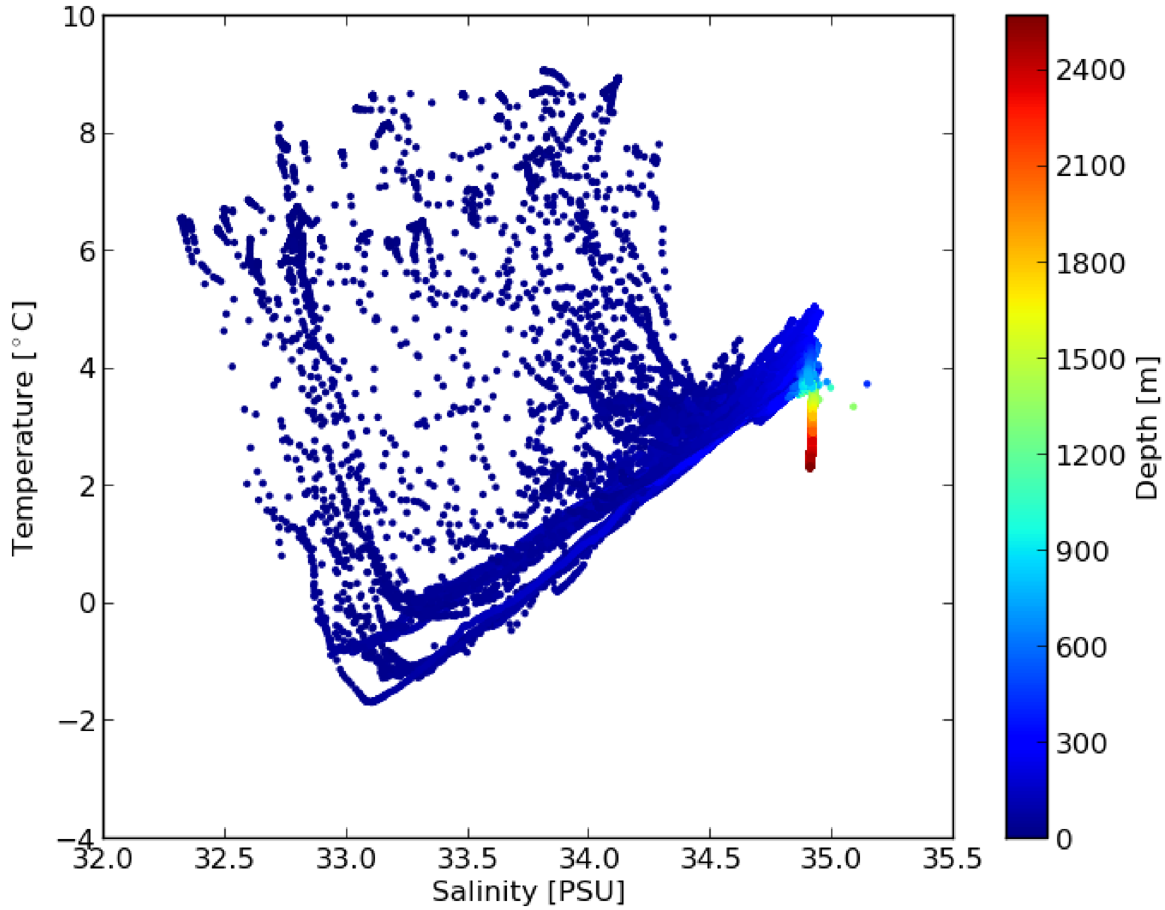


Figure 23 Scatter plot of Temperature versus Salinity with depth color contour for both cruise HUD2013021 and HUD2014017 all casts.

Appendix 3 Lowered ADCP vector and contour plots

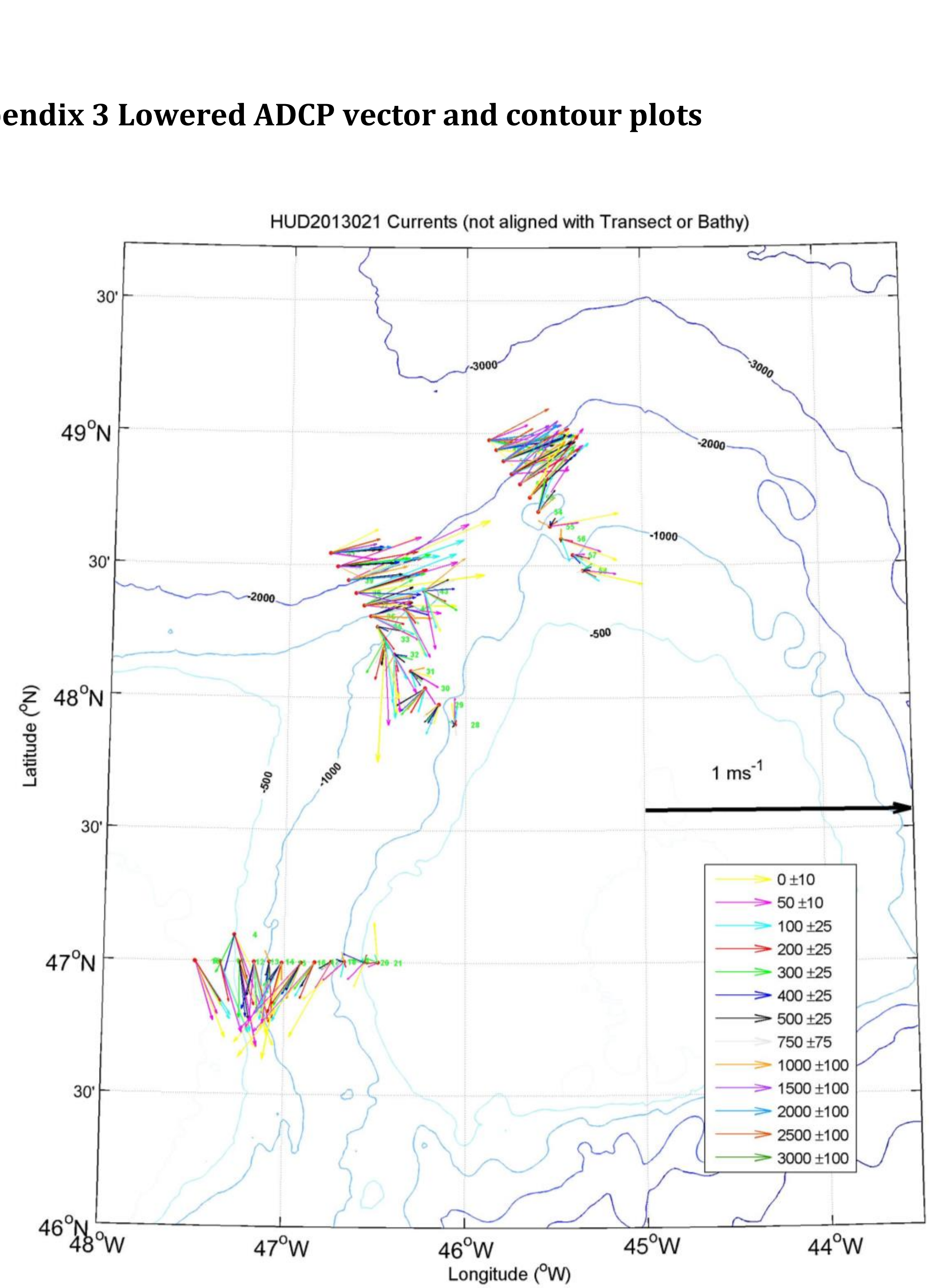


Figure 24 Lowered-ADCP currents at various depth ranges for cruise HUD2013021.

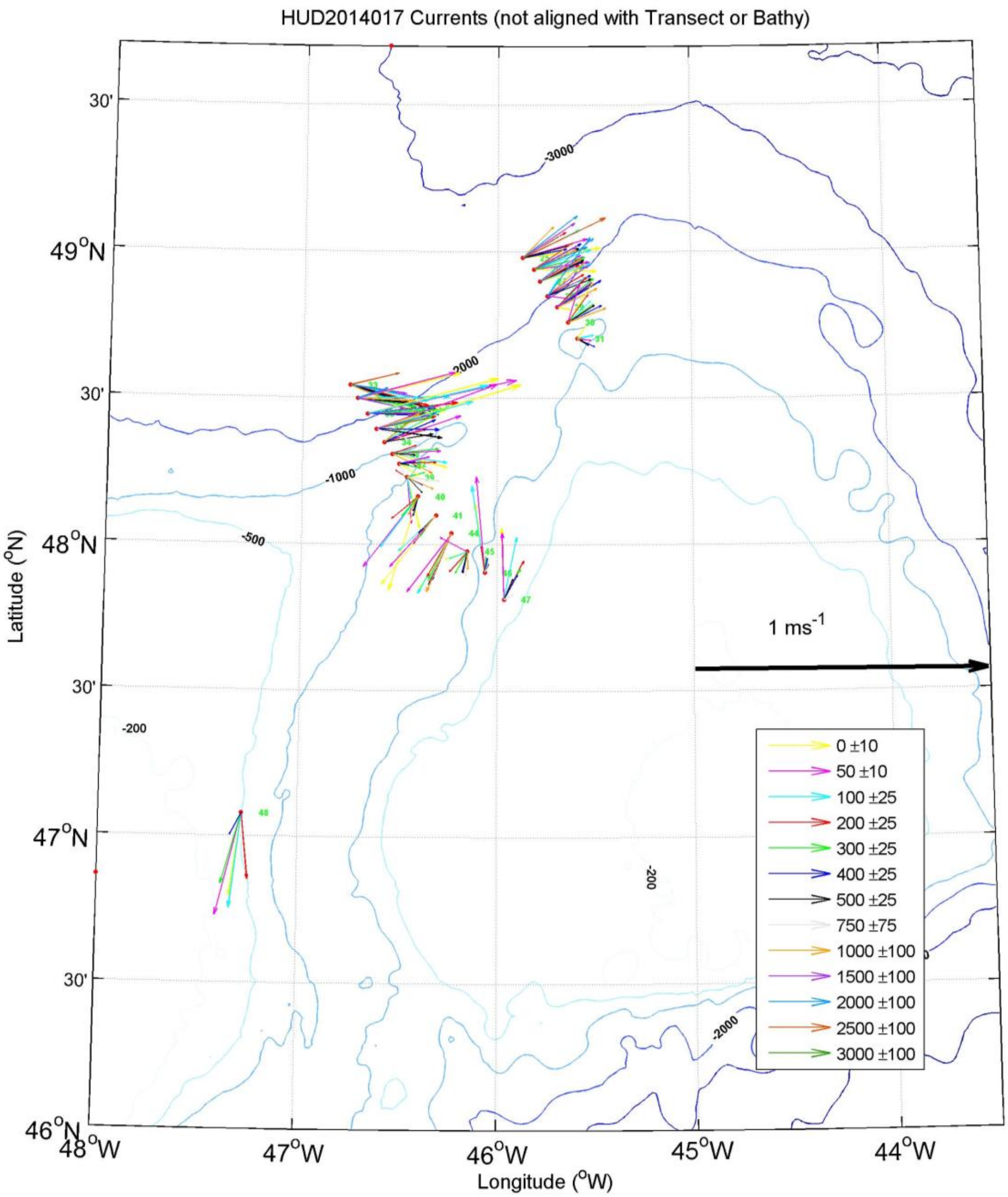
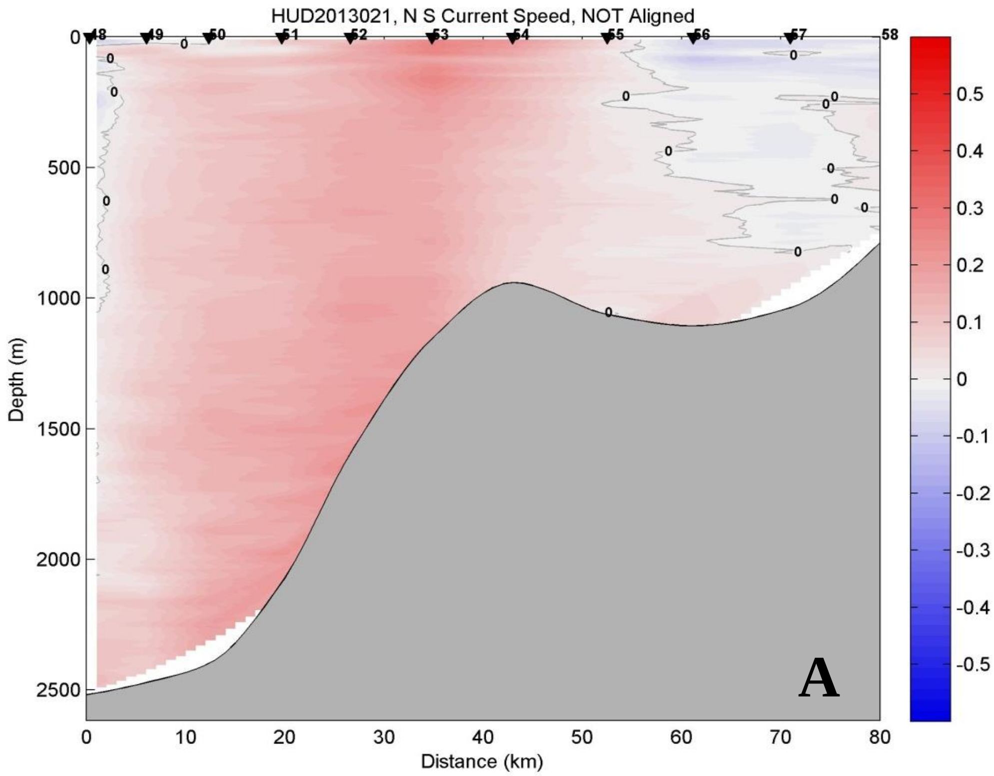


Figure 25 Lowered-ADCP currents at various depth ranges for cruise HUD2014017.



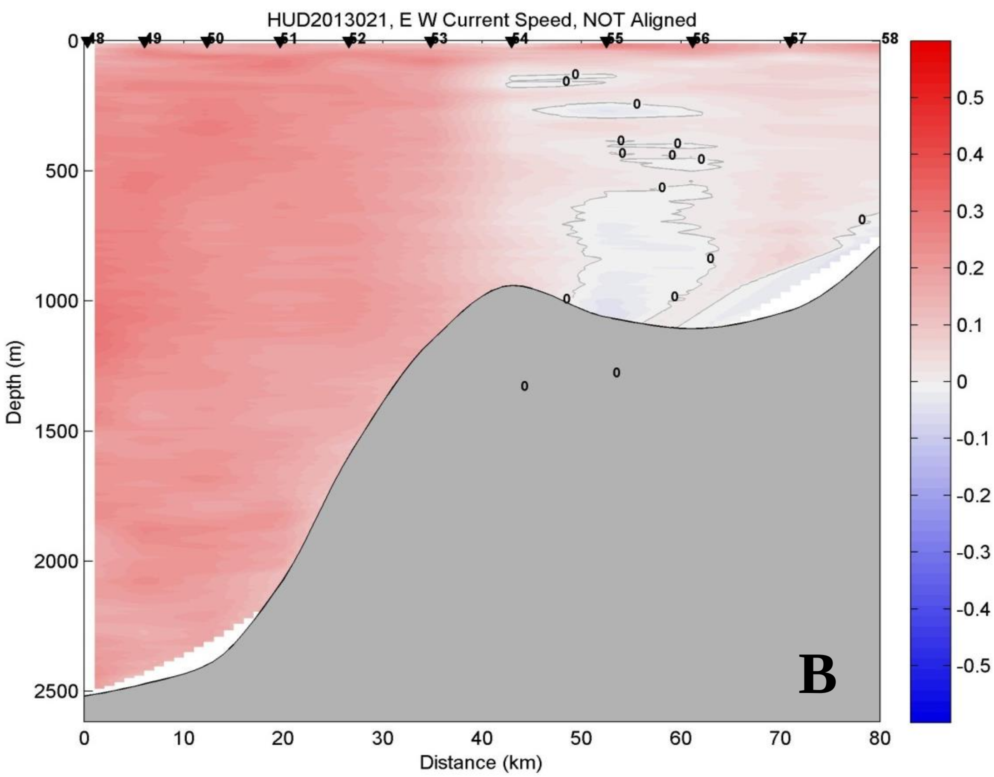


Figure 26 Lowered -ADCP north-south (A) and east-west current (B), current speed (m s^{-1}), northern Flemish Cap (NFC), cruise HUD2013021.

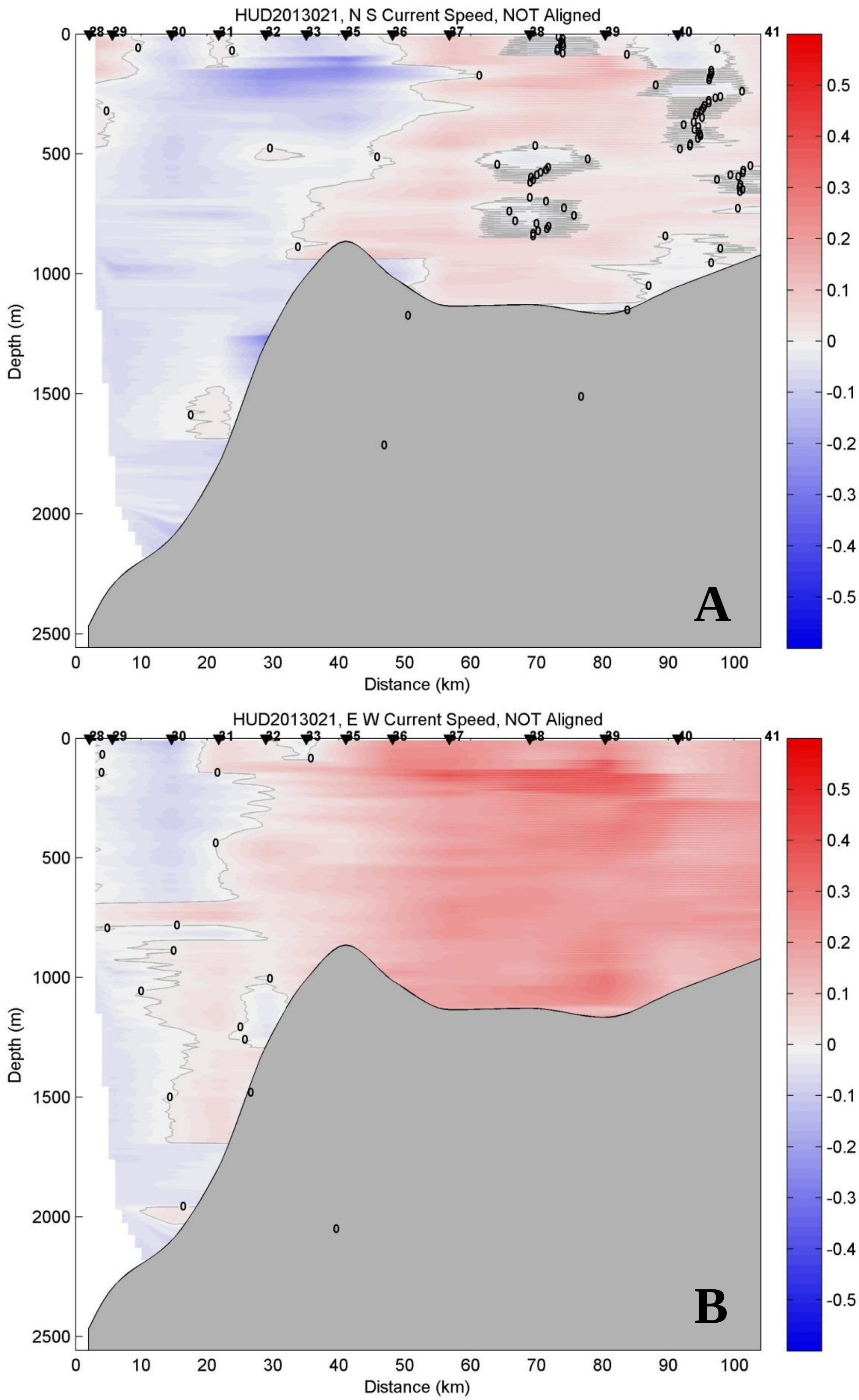


Figure 27 Lowered-ADCP north-south (A) and east-west current (B), current speed (m s^{-1}), Sackville Spur (SS), cruise HUD2013021.

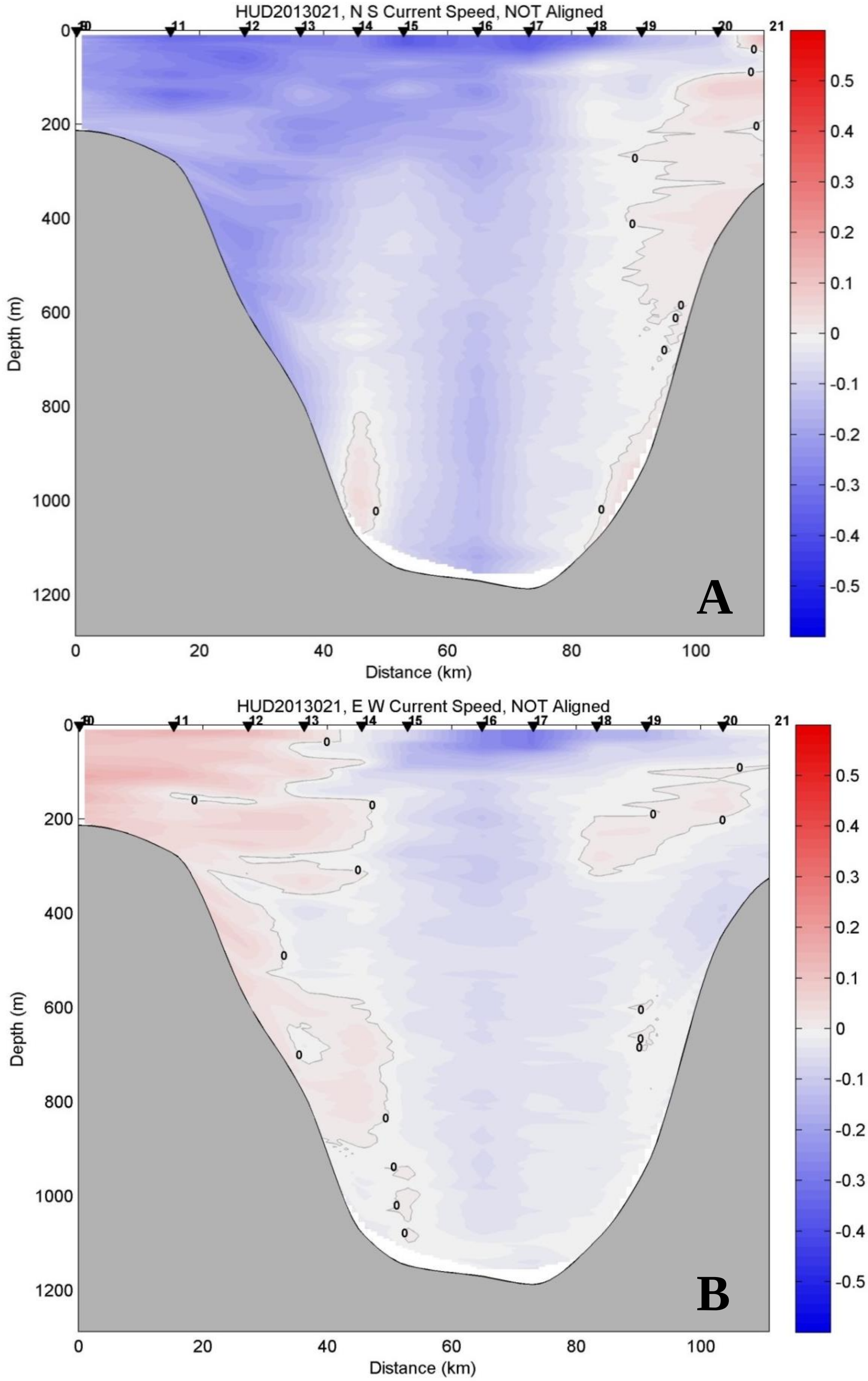
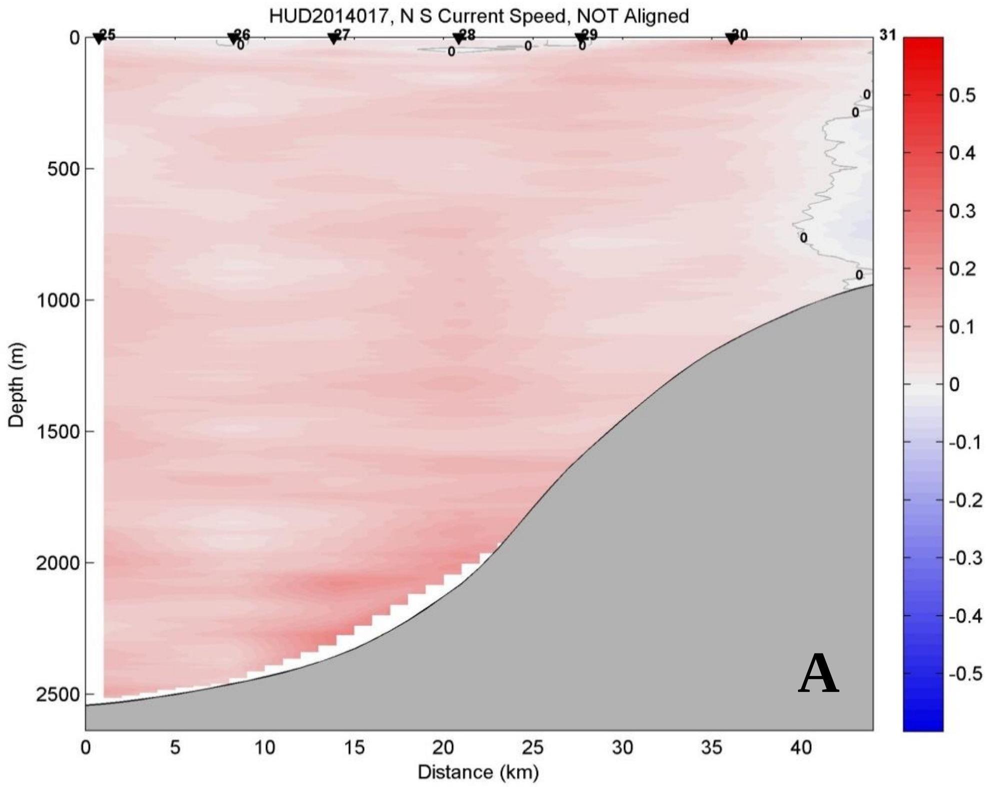


Figure 28 Lowered-ADCP north-south (A) and east-west current (B), current speed (m s^{-1}), Flemish Pass (FP), cruise HUD2013021.



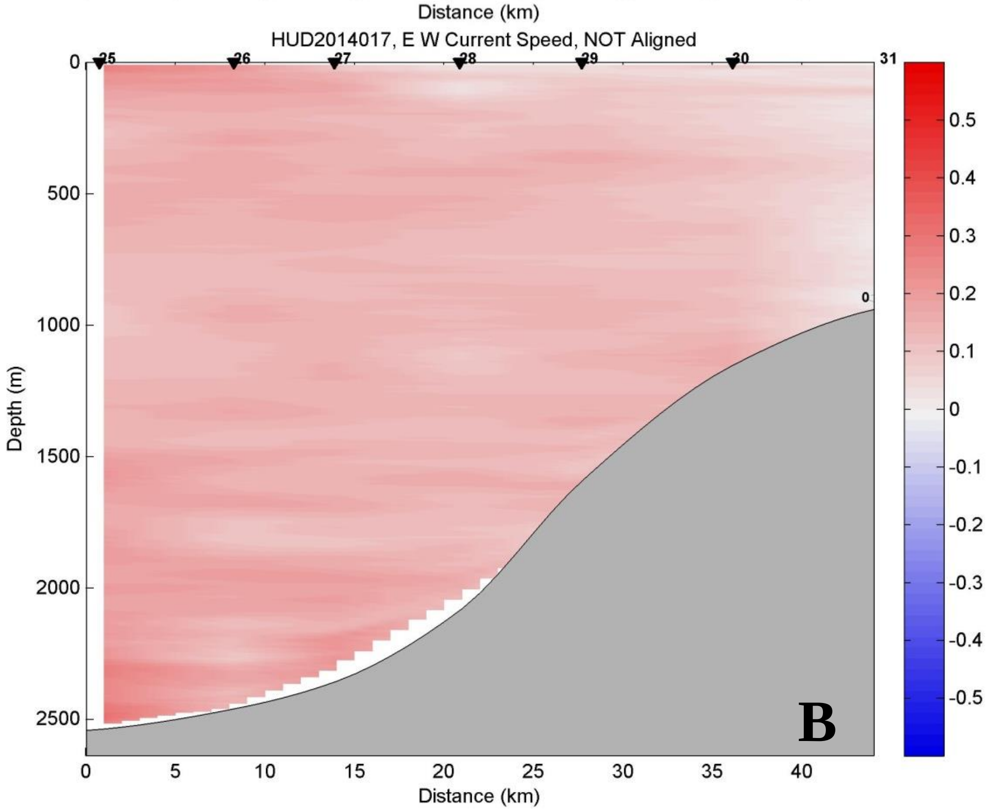


Figure 29 Lowered -ADCP north-south (A) and east-west current (B), current speed (m s^{-1}), northern Flemish Cap (NFC), cruise HUD2014017.

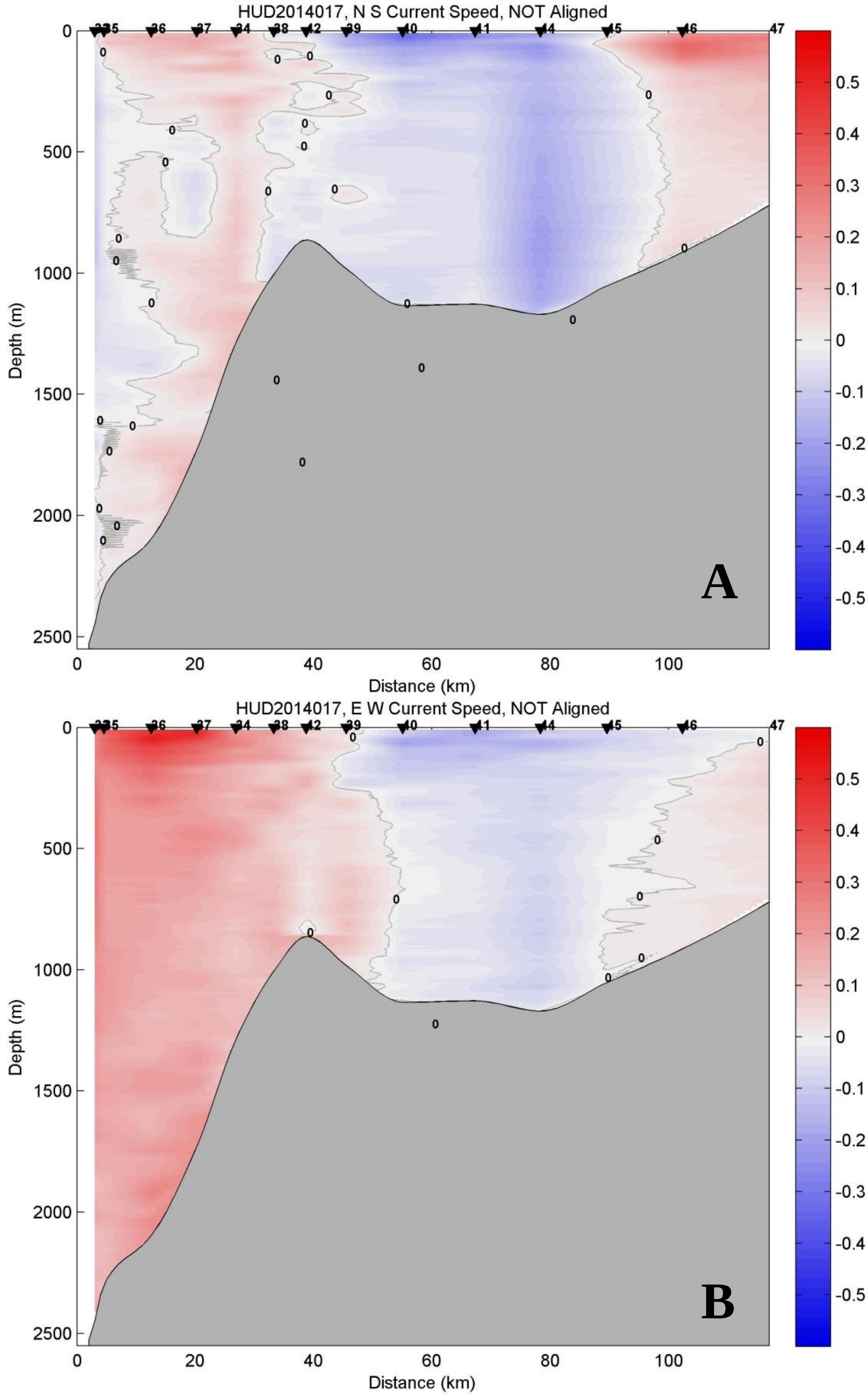


Figure 30 Lowered-ADCP north-south (A) and east-west current (B), current speed (m s^{-1}), Sackville Spur (SS), cruise HUD2014017.

Appendix 4 Vessel mounted ADCP vector and contour plots

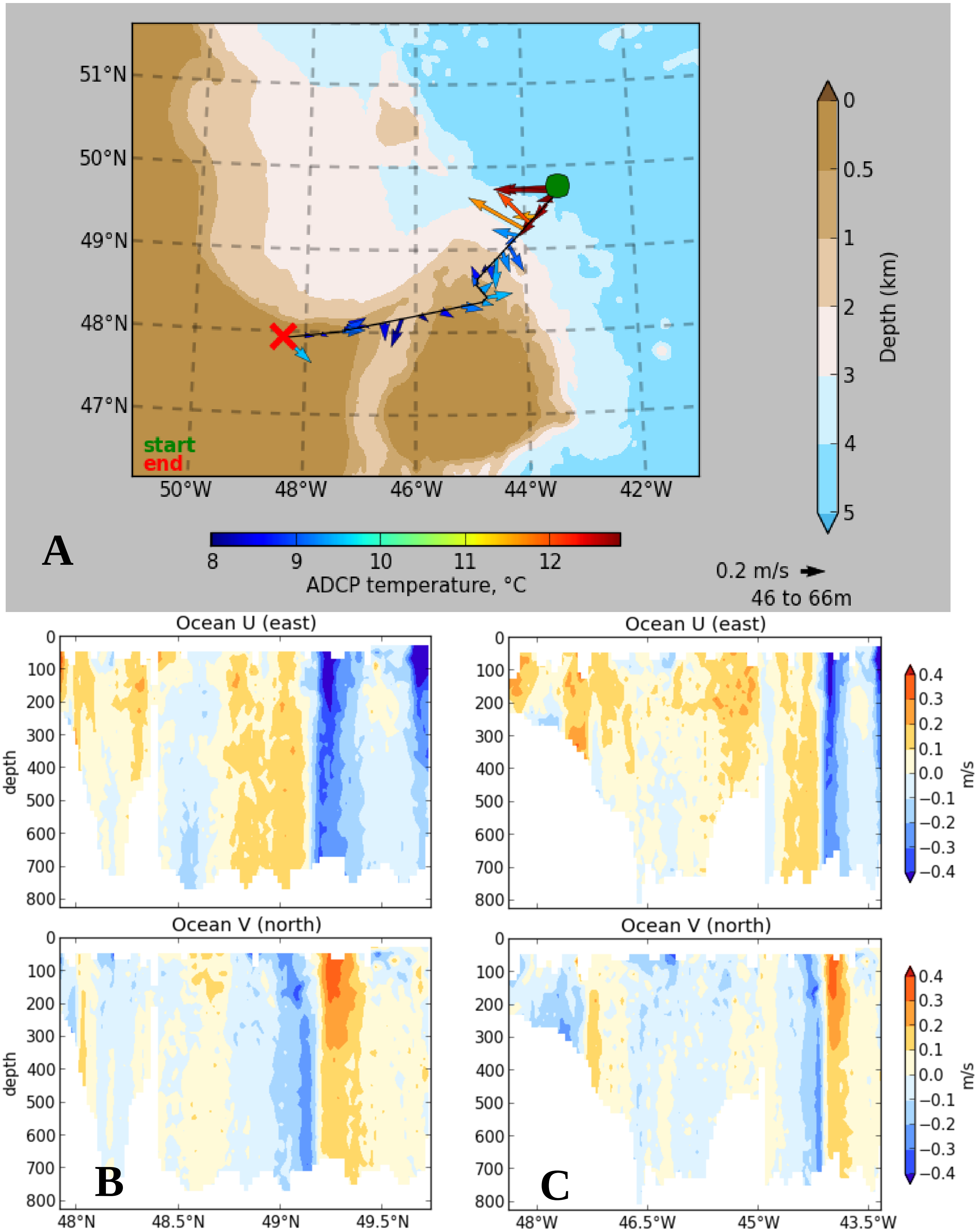


Figure 31 Vessel Mounted-ADCP depth averaged current (A), current speed (m s-1) vs latitude (B) and current speed (m s-1) vs longitude (C), cruise HUD2013021.

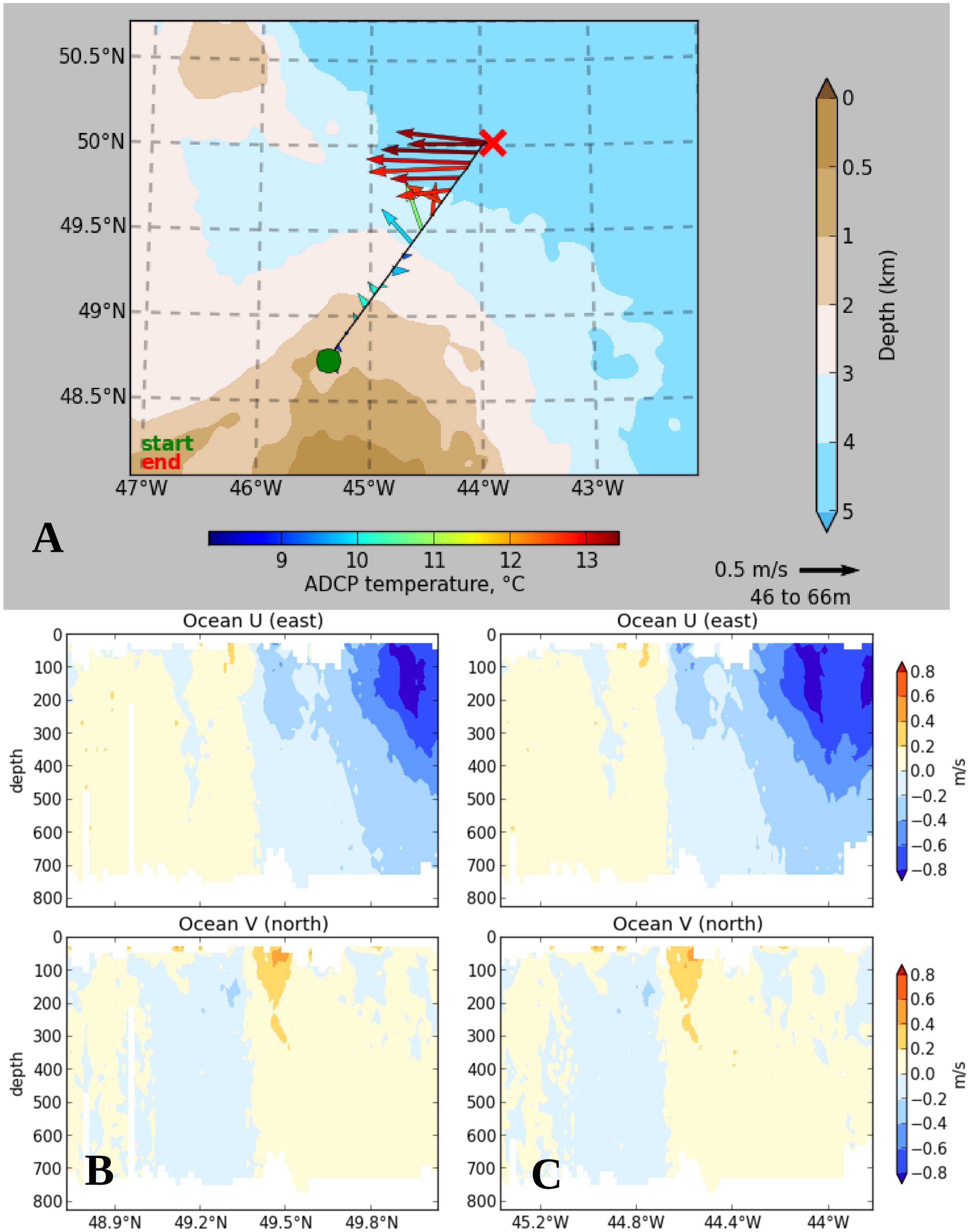


Figure 32 Vessel Mounted-ADCP depth averaged current (A), current speed (m s^{-1}) vs latitude (B) and current speed (m s^{-1}) vs longitude (C), cruise HUD2013021.

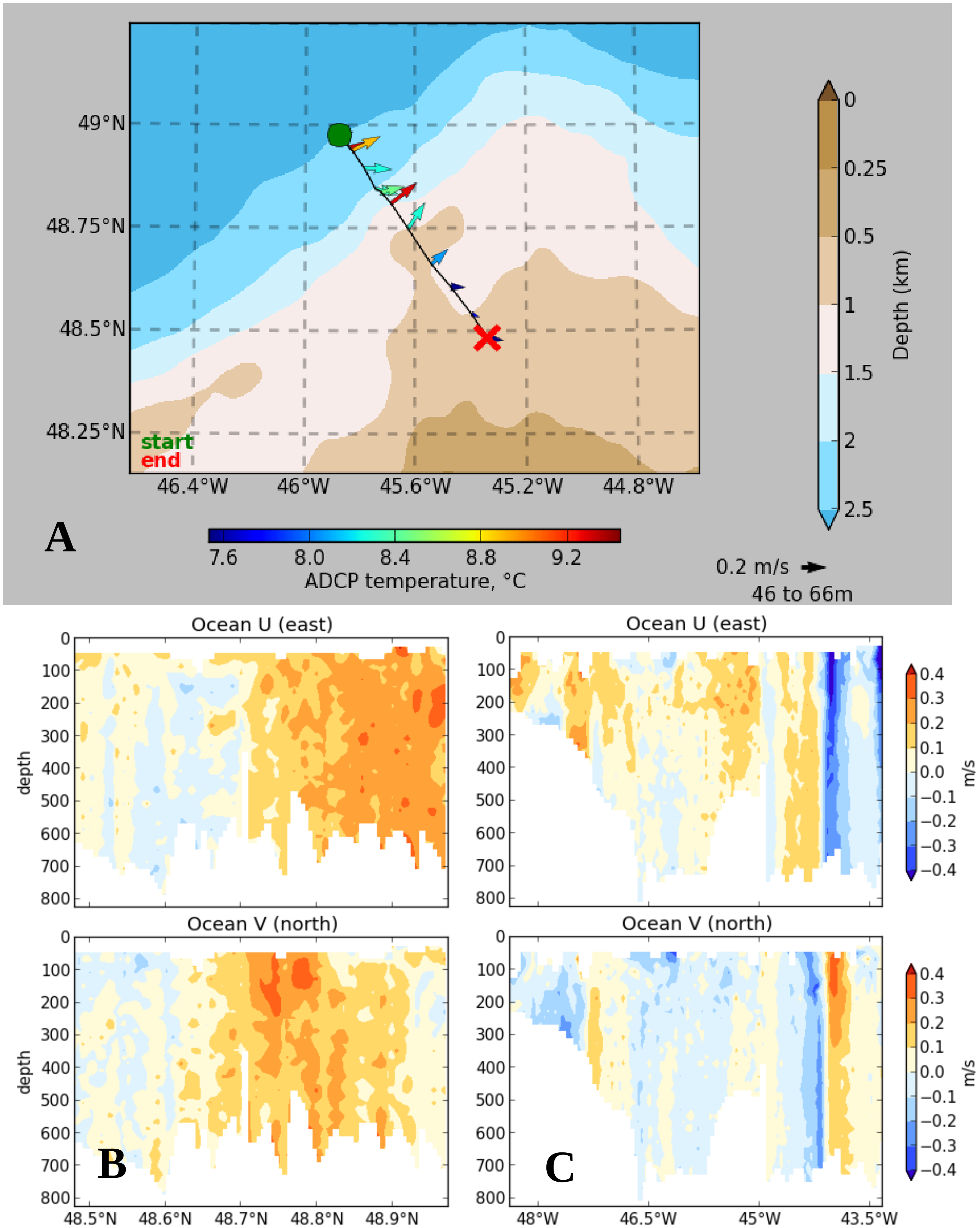


Figure 33 Vessel Mounted-ADCP depth averaged current (A), current speed (m s^{-1}) vs latitude (B) and current speed (m s^{-1}) vs longitude (C), cruise HUD2013021.

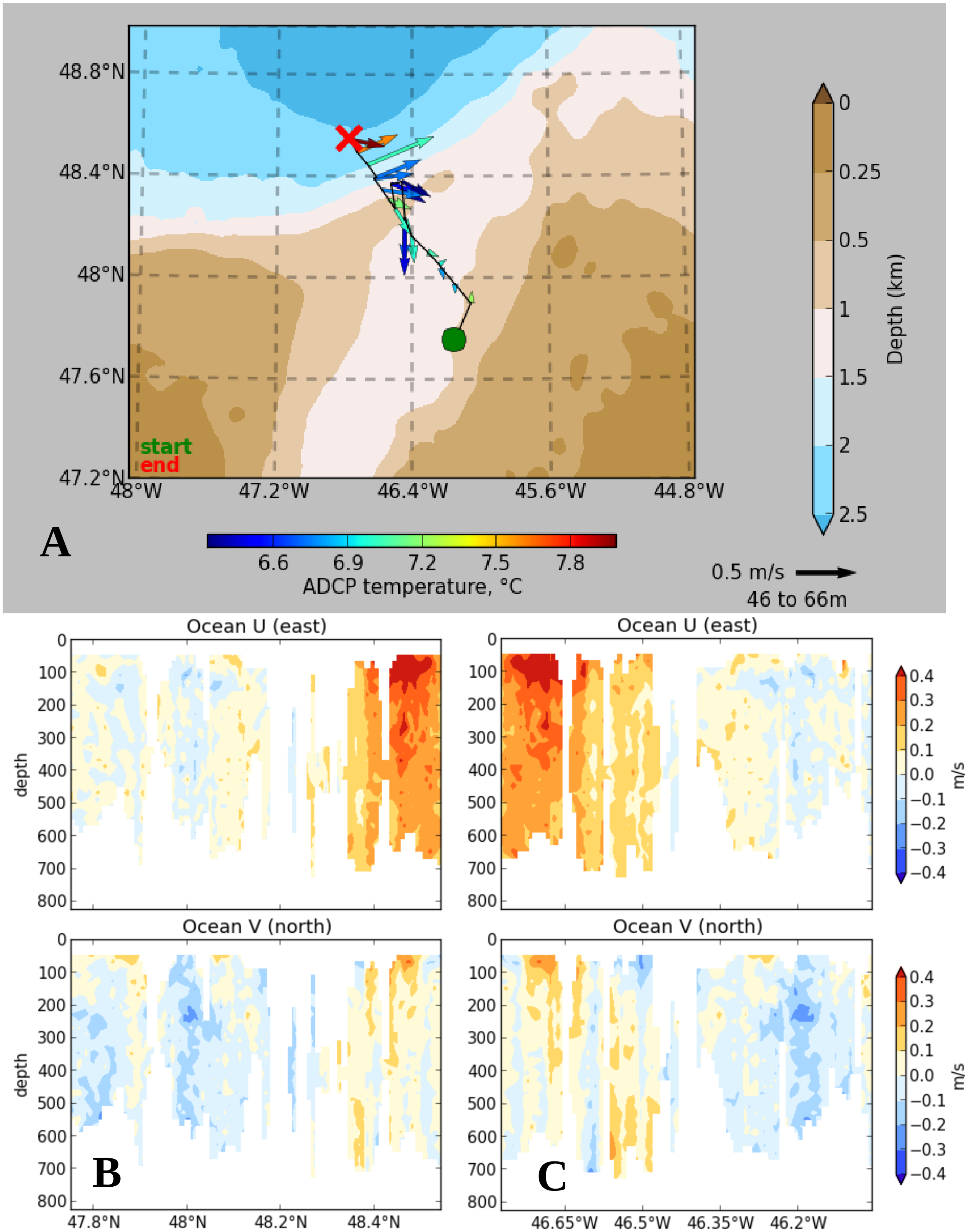


Figure 34 Vessel Mounted-ADCP depth averaged current (A), current speed (m s^{-1}) vs latitude (B) and current speed (m s^{-1}) vs longitude (C), cruise HUD2013021.

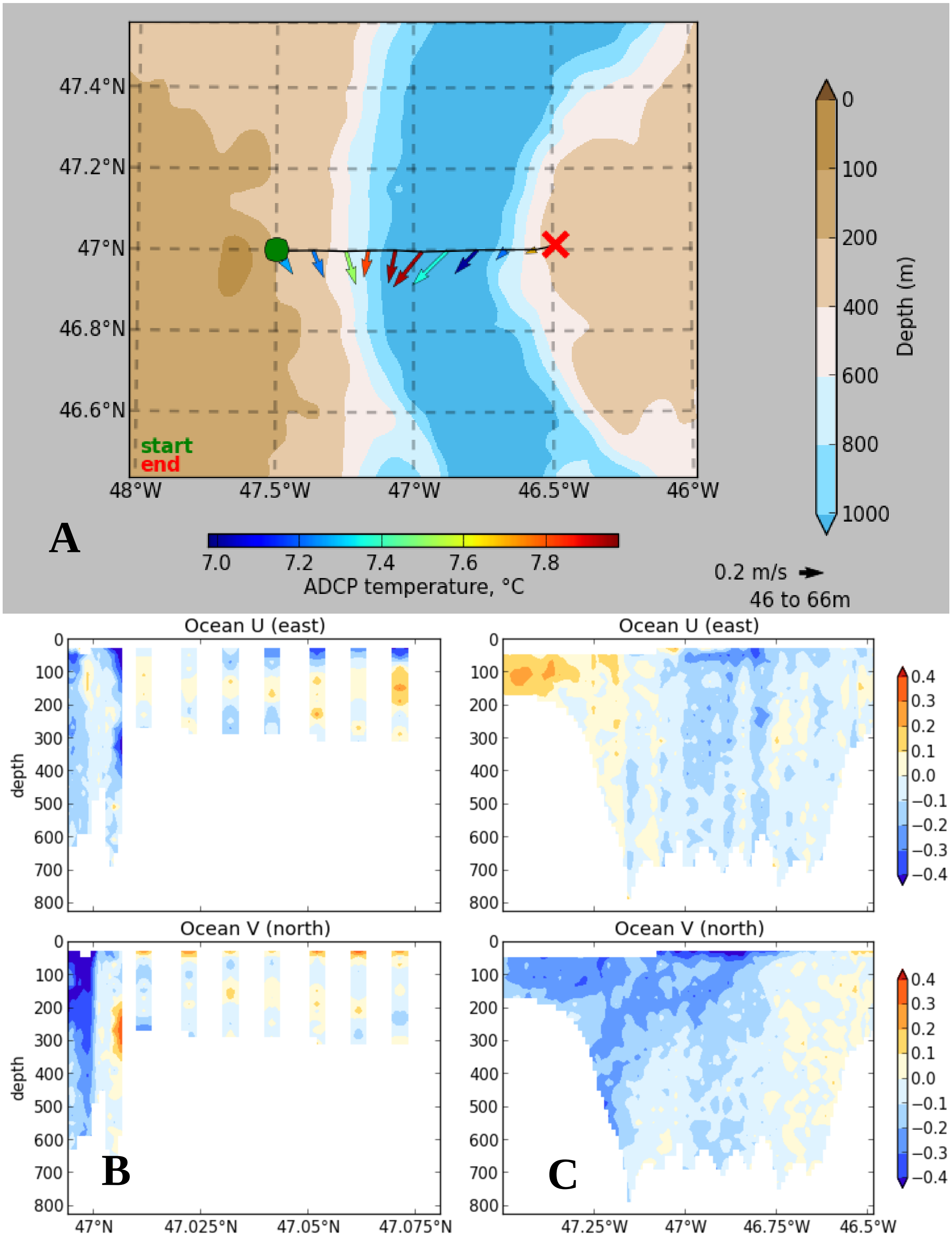


Figure 35 Vessel Mounted-ADCP depth averaged current (A), current speed (m s^{-1}) vs latitude (B) and current speed (m s^{-1}) vs longitude (C), cruise HUD2013021.

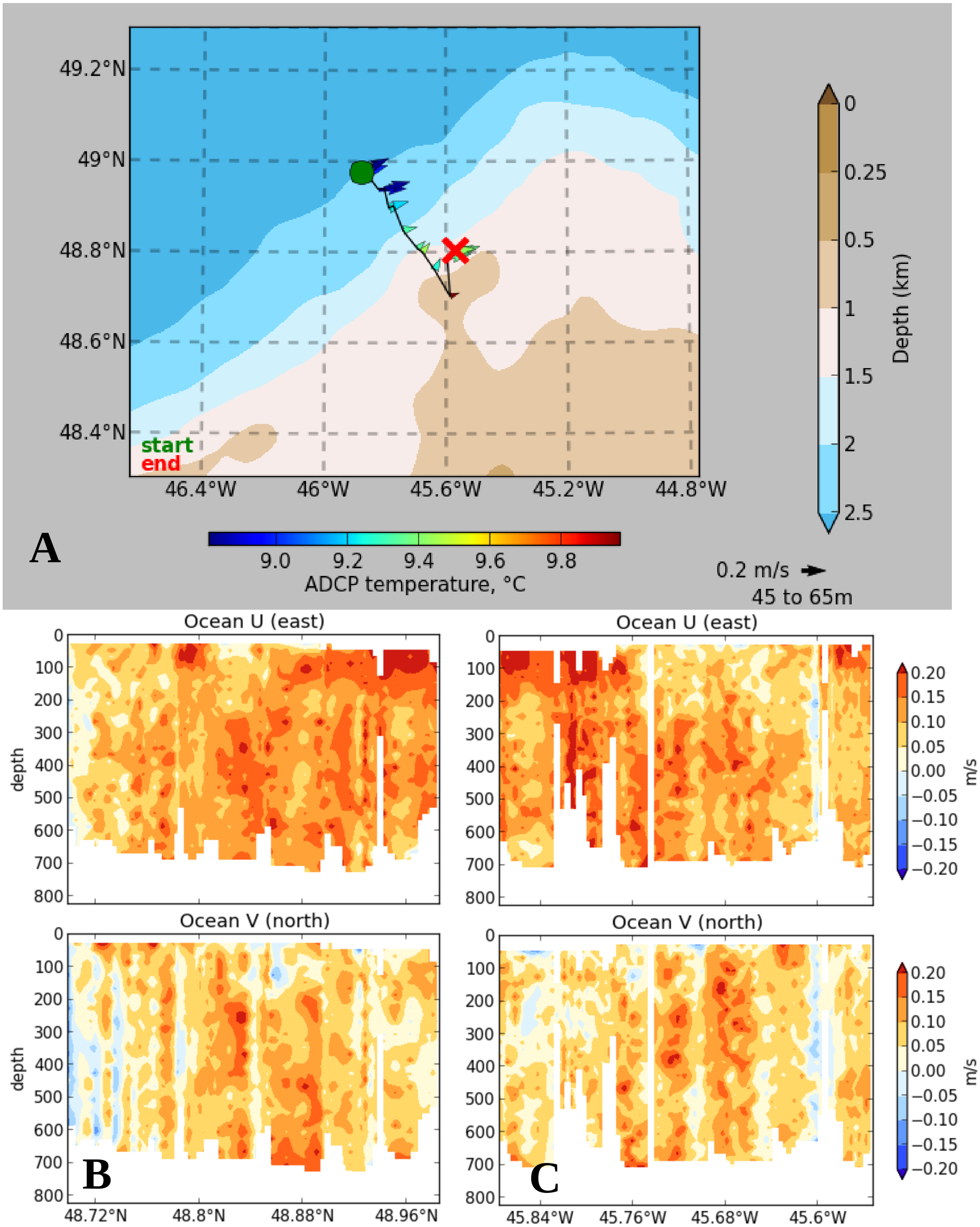


Figure 36 Vessel Mounted-ADCP depth averaged current (A), current speed (m s^{-1}) vs latitude (B) and current speed (m s^{-1}) vs longitude (C), cruise HUD2014017.

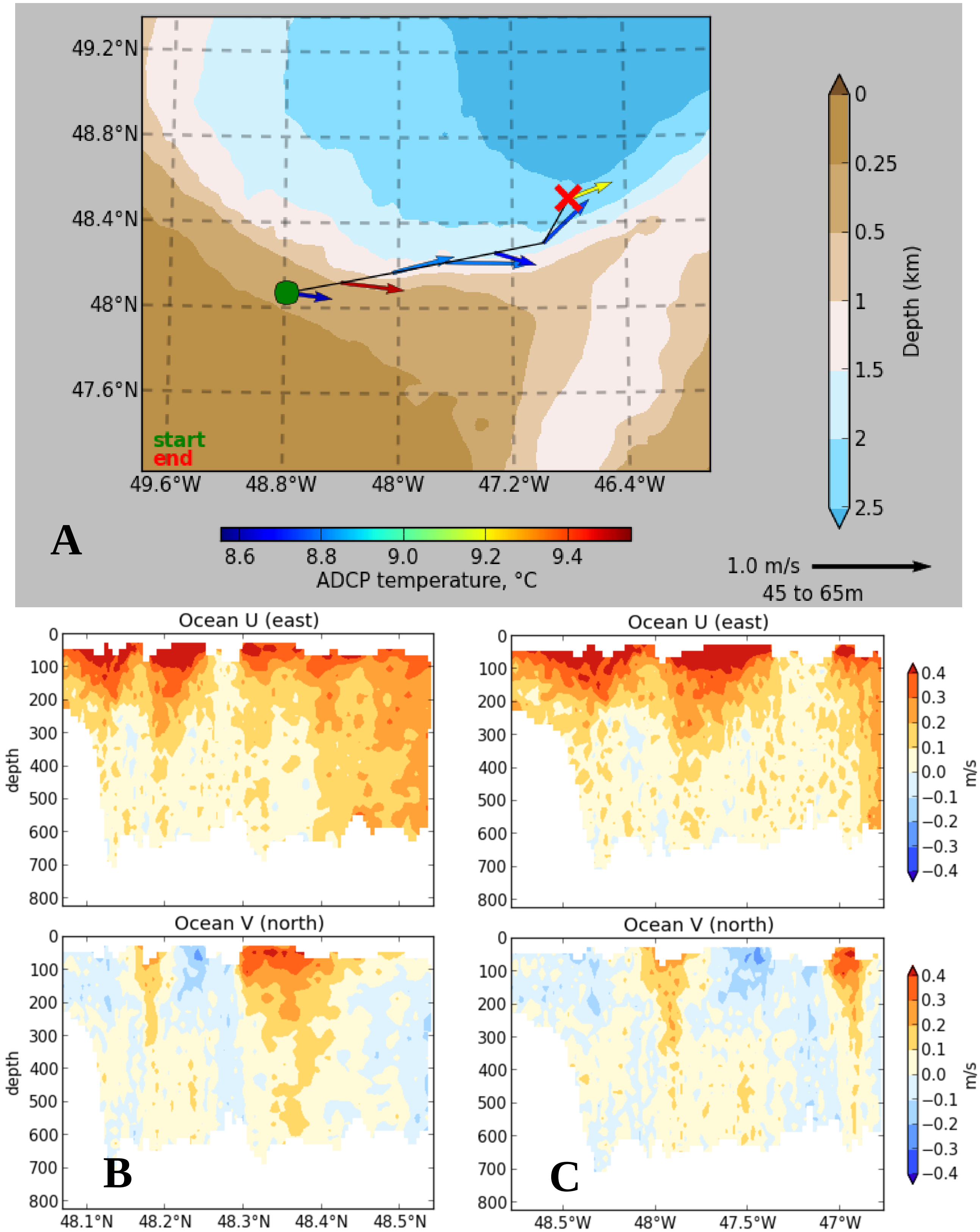


Figure 37 Vessel Mounted-ADCP depth averaged current (A), current speed (m s^{-1}) vs latitude (B) and current speed (m s^{-1}) vs longitude (C), cruise HUD2014017.

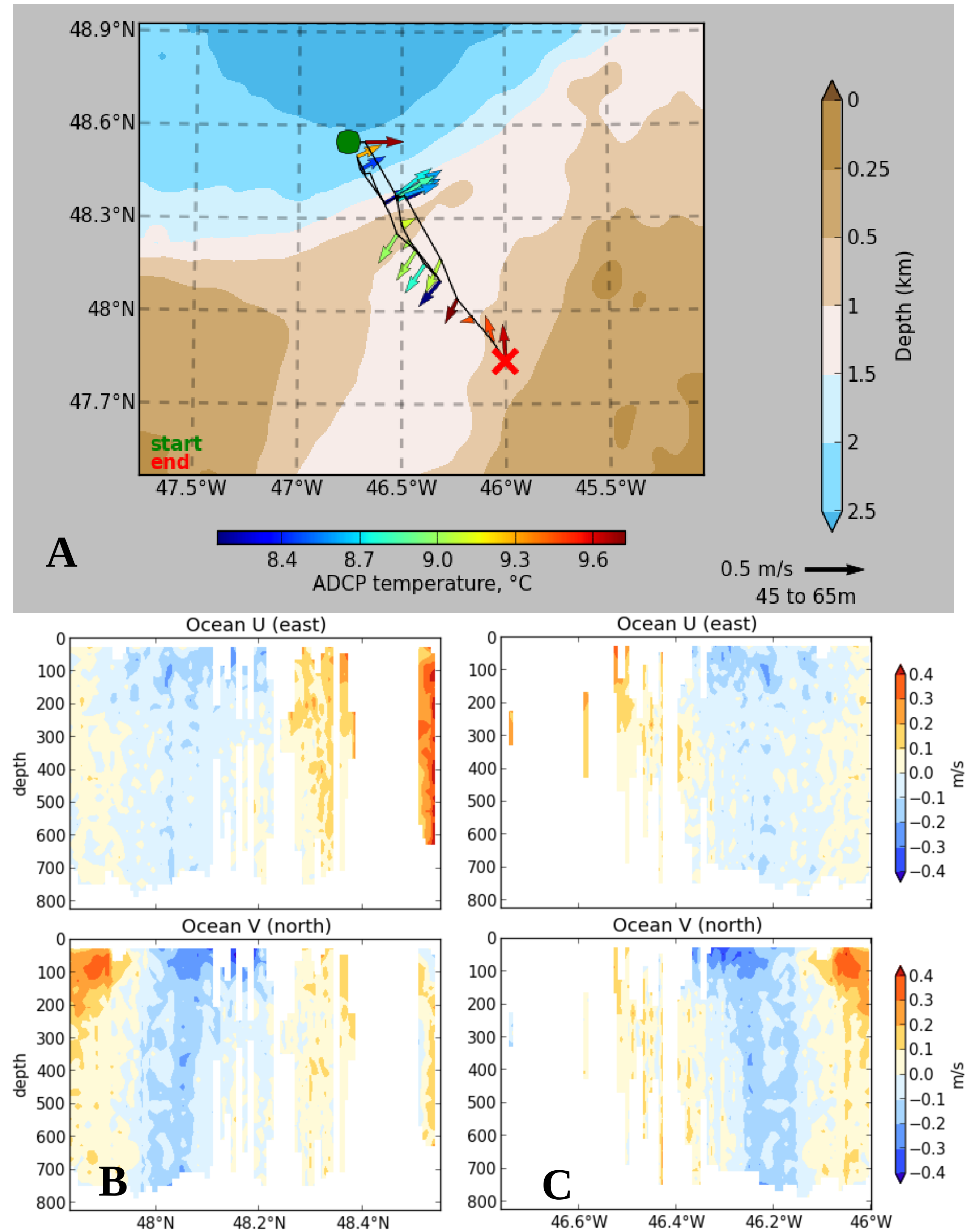


Figure 38 Vessel Mounted-ADCP depth averaged current (A), current speed (m s^{-1}) vs latitude (B) and current speed (m s^{-1}) vs longitude (C), cruise HUD2014017.

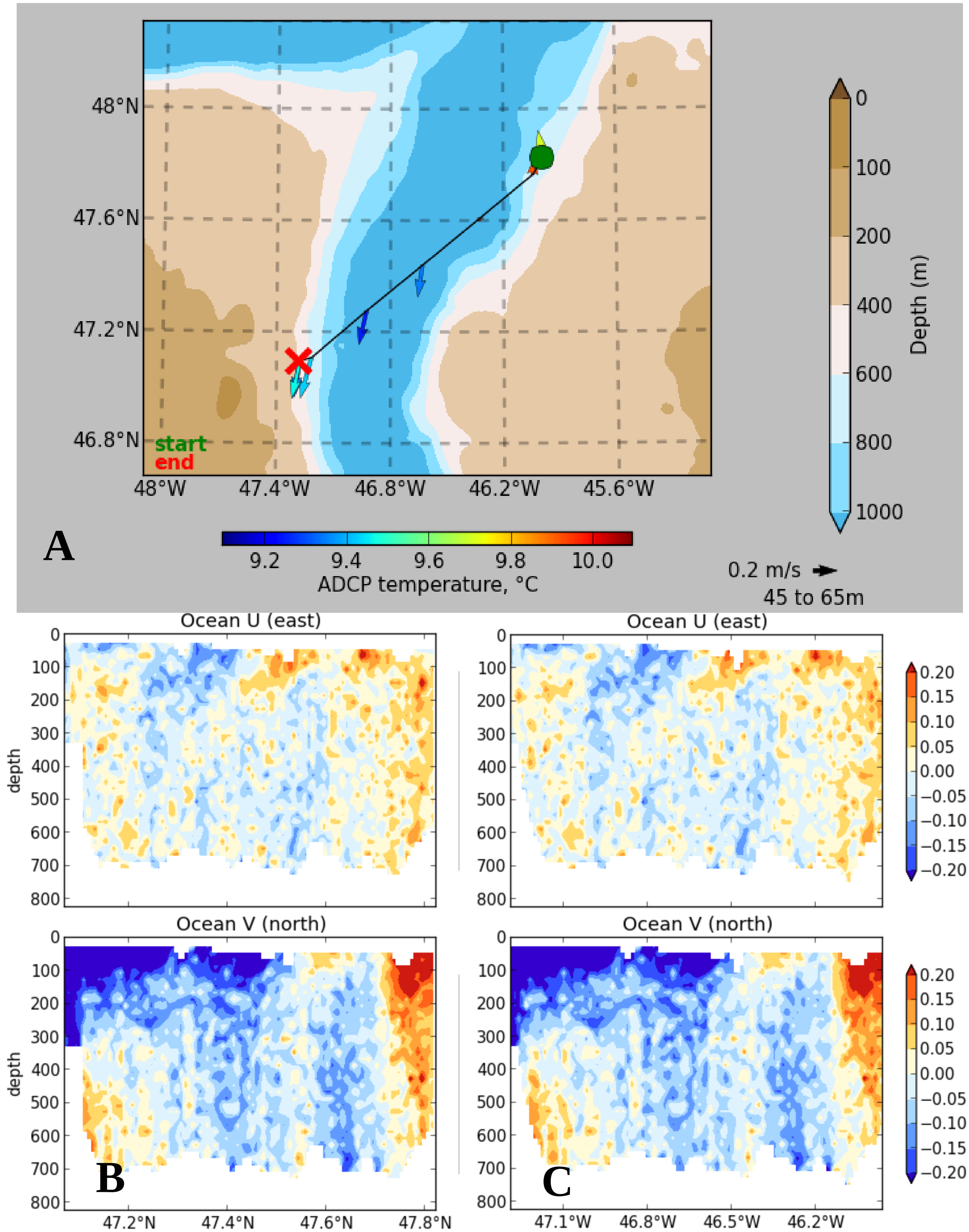


Figure 39 Vessel Mounted-ADCP depth averaged current (A), current speed (m s^{-1}) vs latitude (B) and current speed (m s^{-1}) vs longitude (C), cruise HUD2014017.

Appendix 5 Moored ADCP line, contour and progressive vector plots

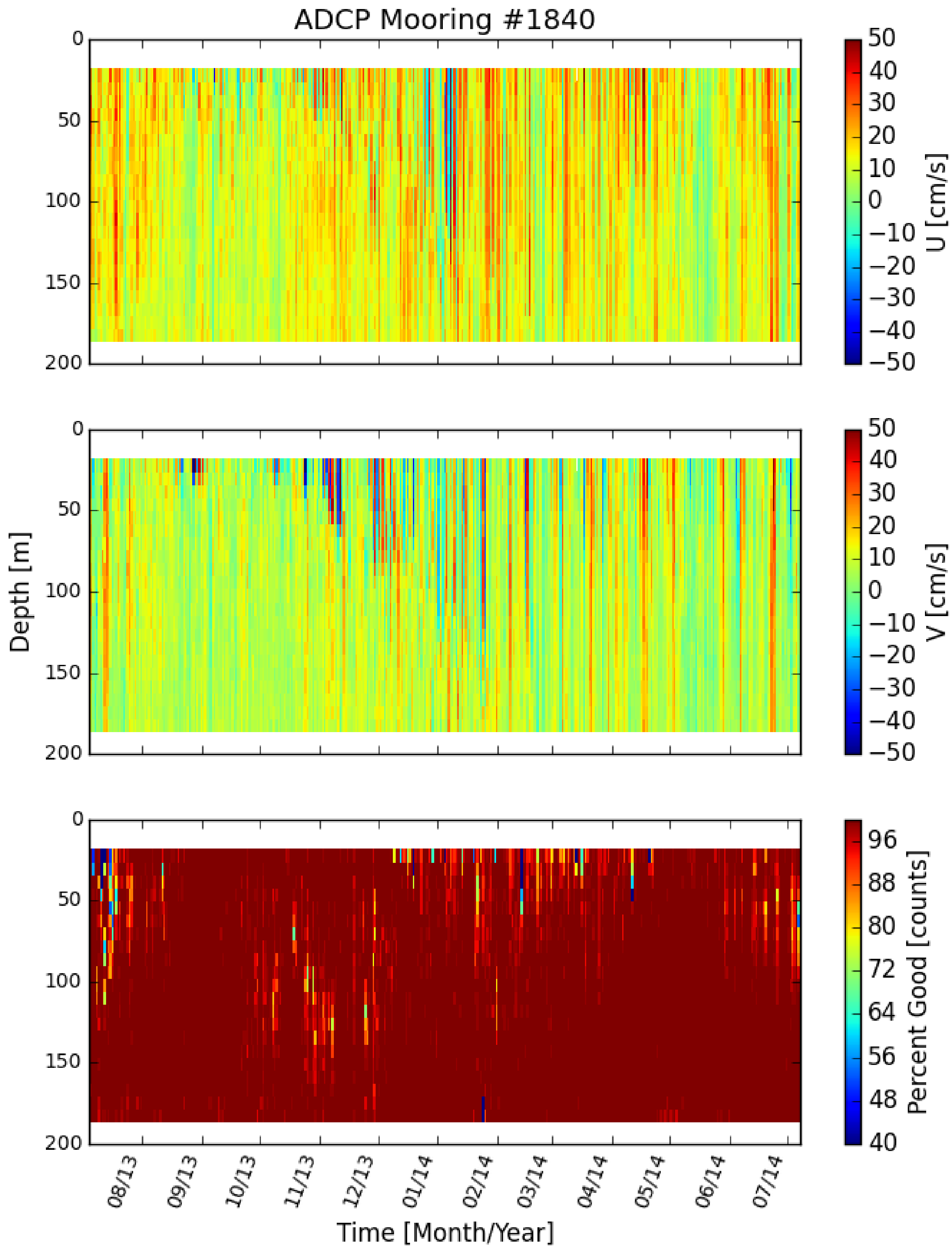


Figure 40 Moored-ADCP north-south current, east-west current and percent good, speed (cm s^{-1}), northern Flemish Cap (NFC).

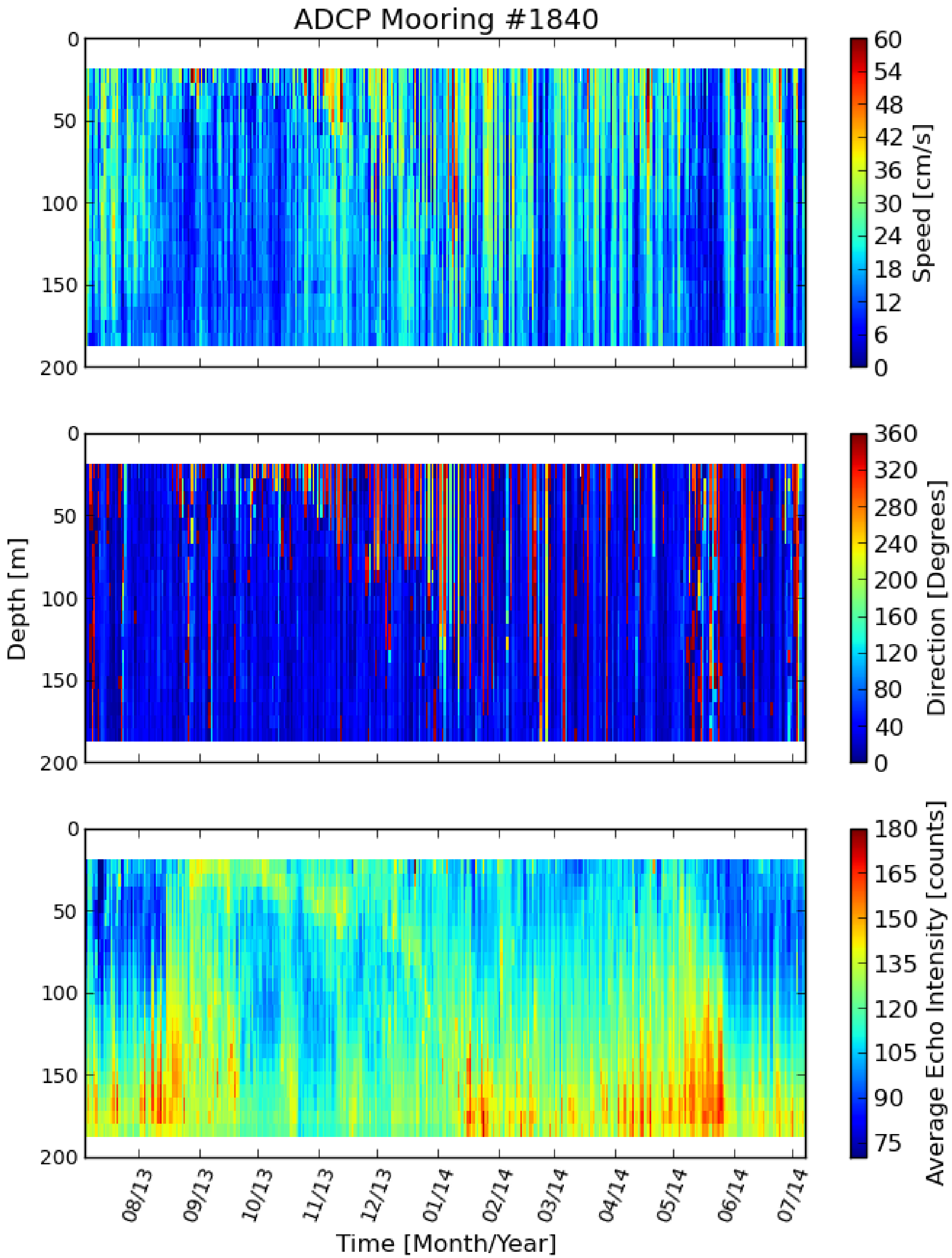


Figure 41 Moored-ADCP current speed, current direction and average echo intensity, northern Flemish Cap (NFC).

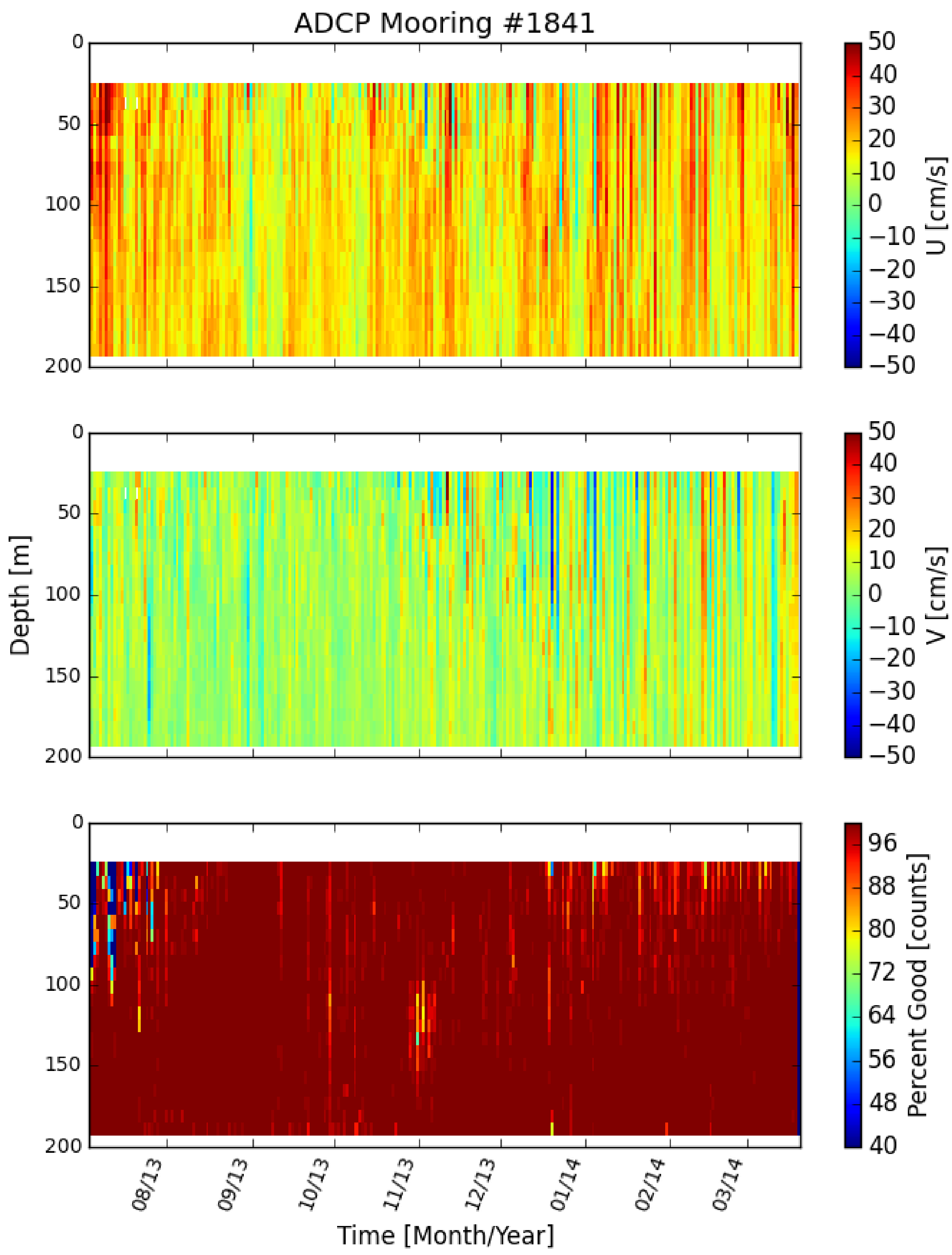


Figure 42 Moored-ADCP north-south current, east-west current and percent good, speed (cm s^{-1}), Sackville Spur (SS).

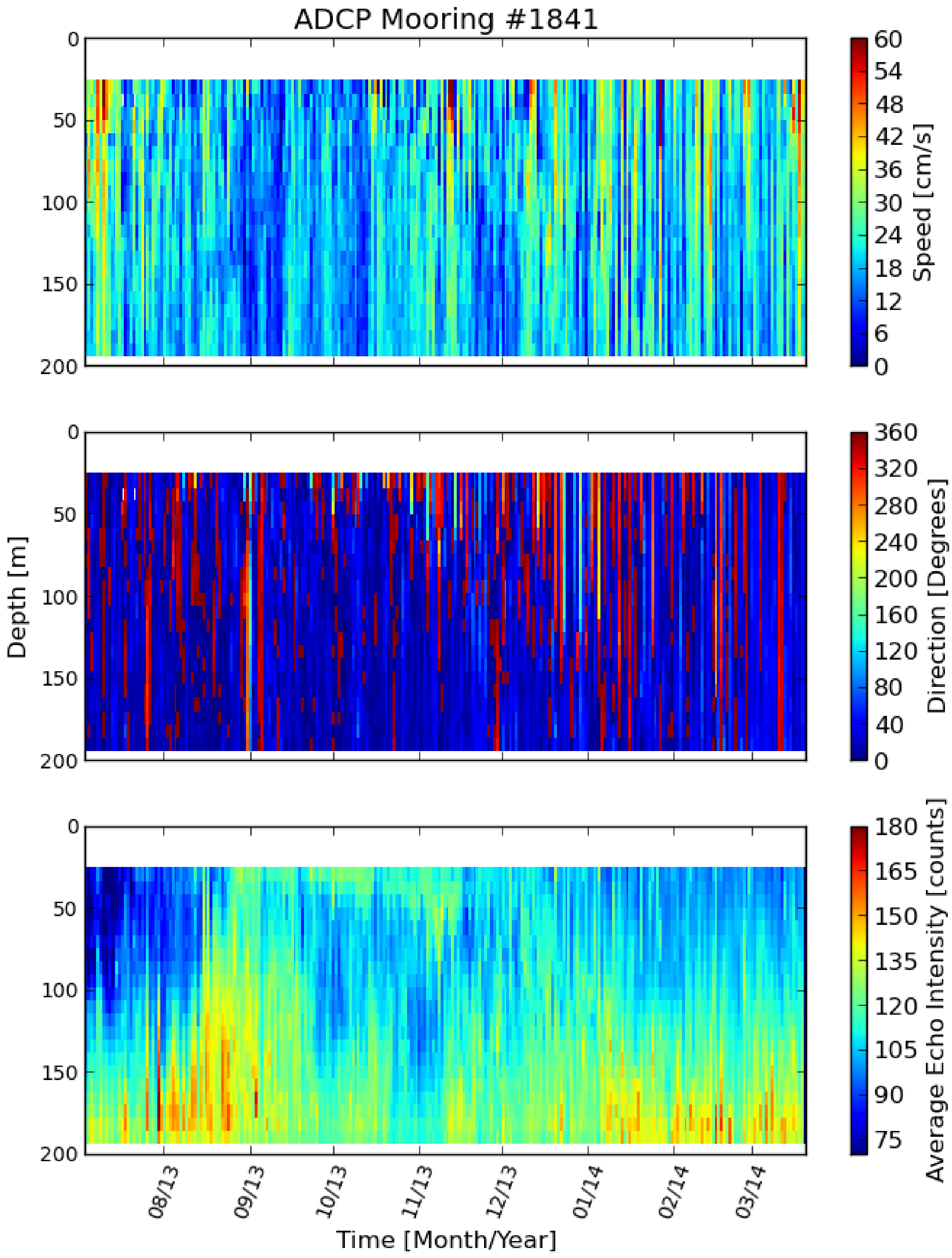


Figure 43 Moored-ADCP current speed, current direction and average echo intensity, Sackville Spur (SS).

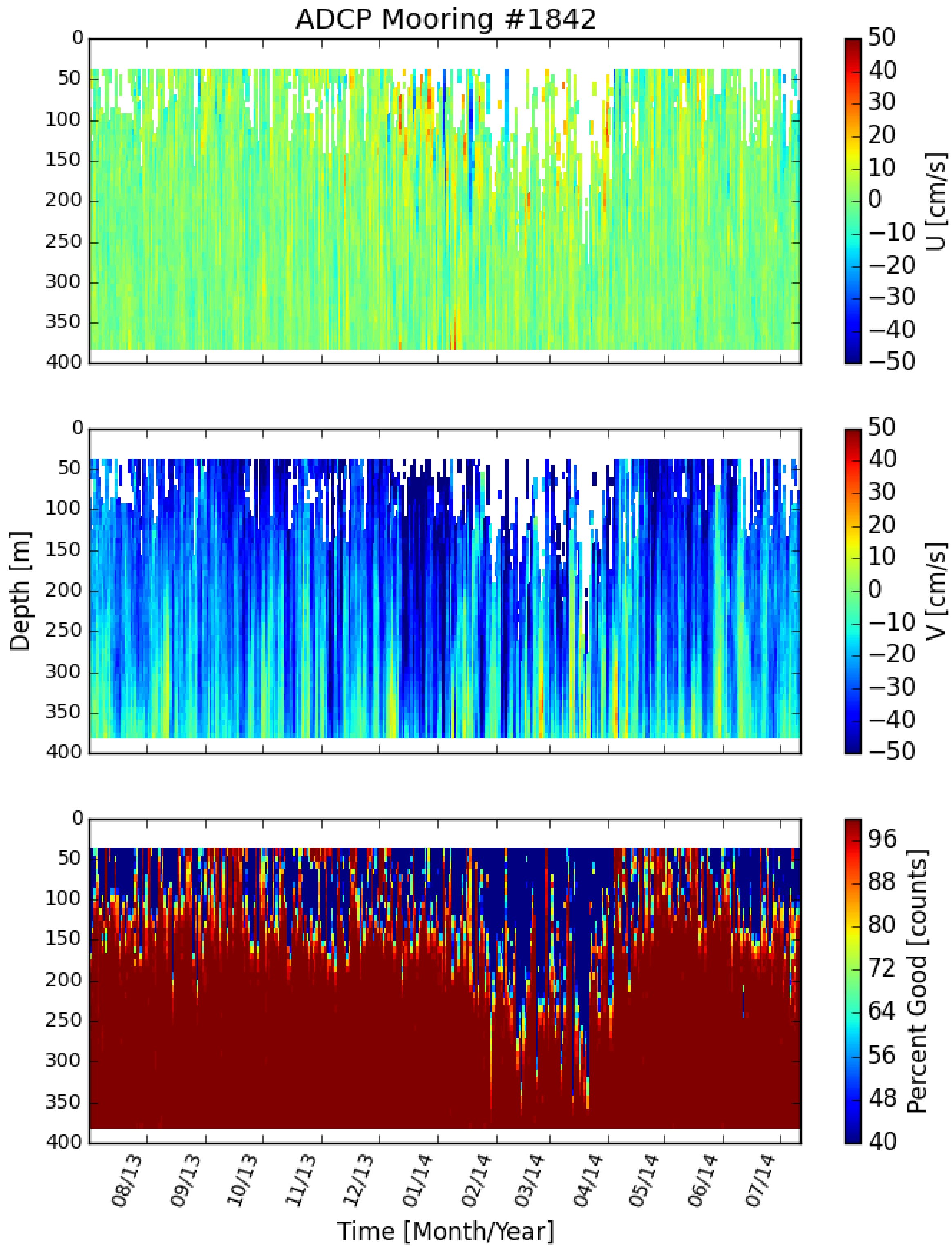


Figure 44 Moored-ADCP north-south current, east-west current and percent good, speed (cm s^{-1}), Flemish Pass (FP).

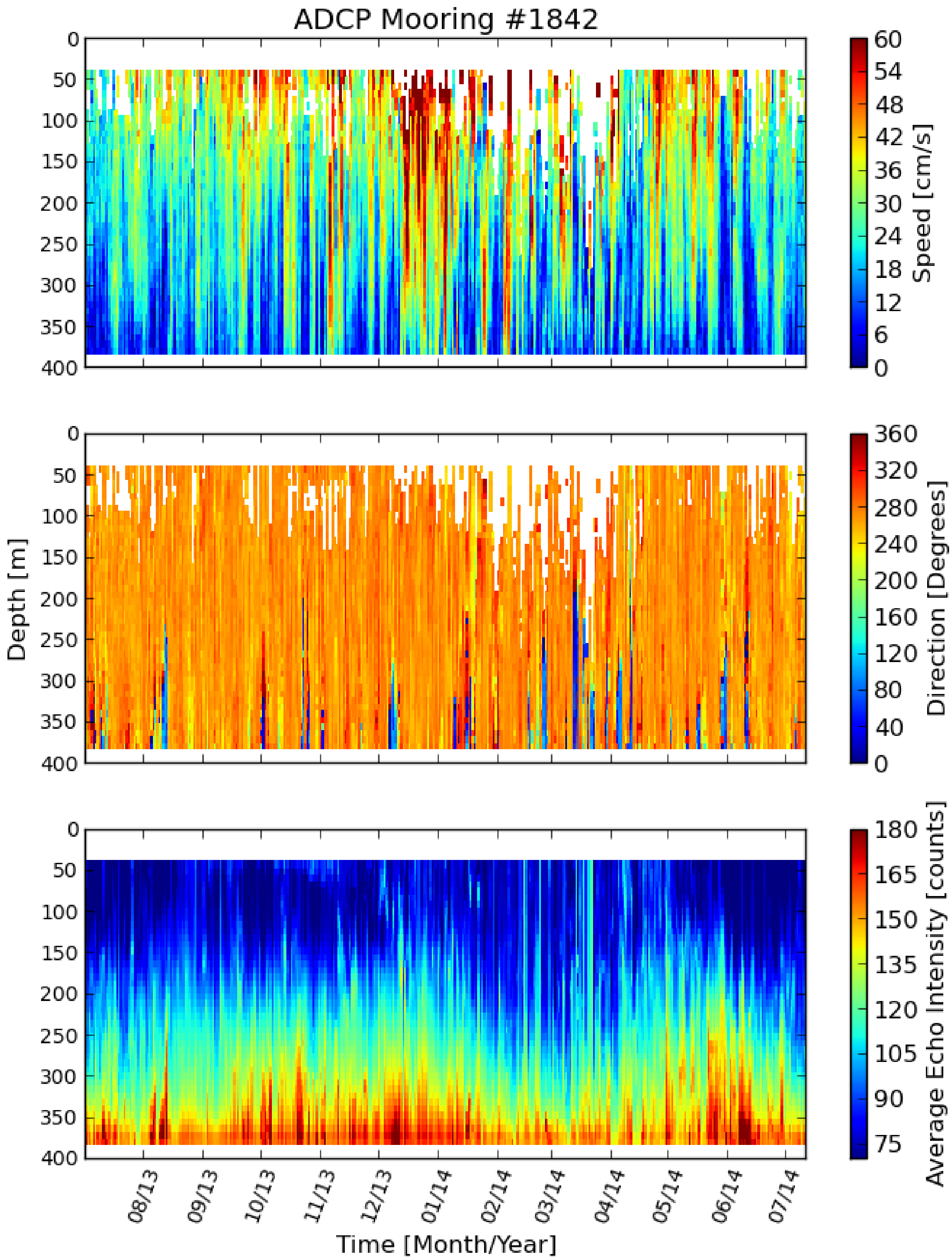


Figure 45 Moored-ADCP current speed, current direction and average echo intensity, Flemish Pass (FP).

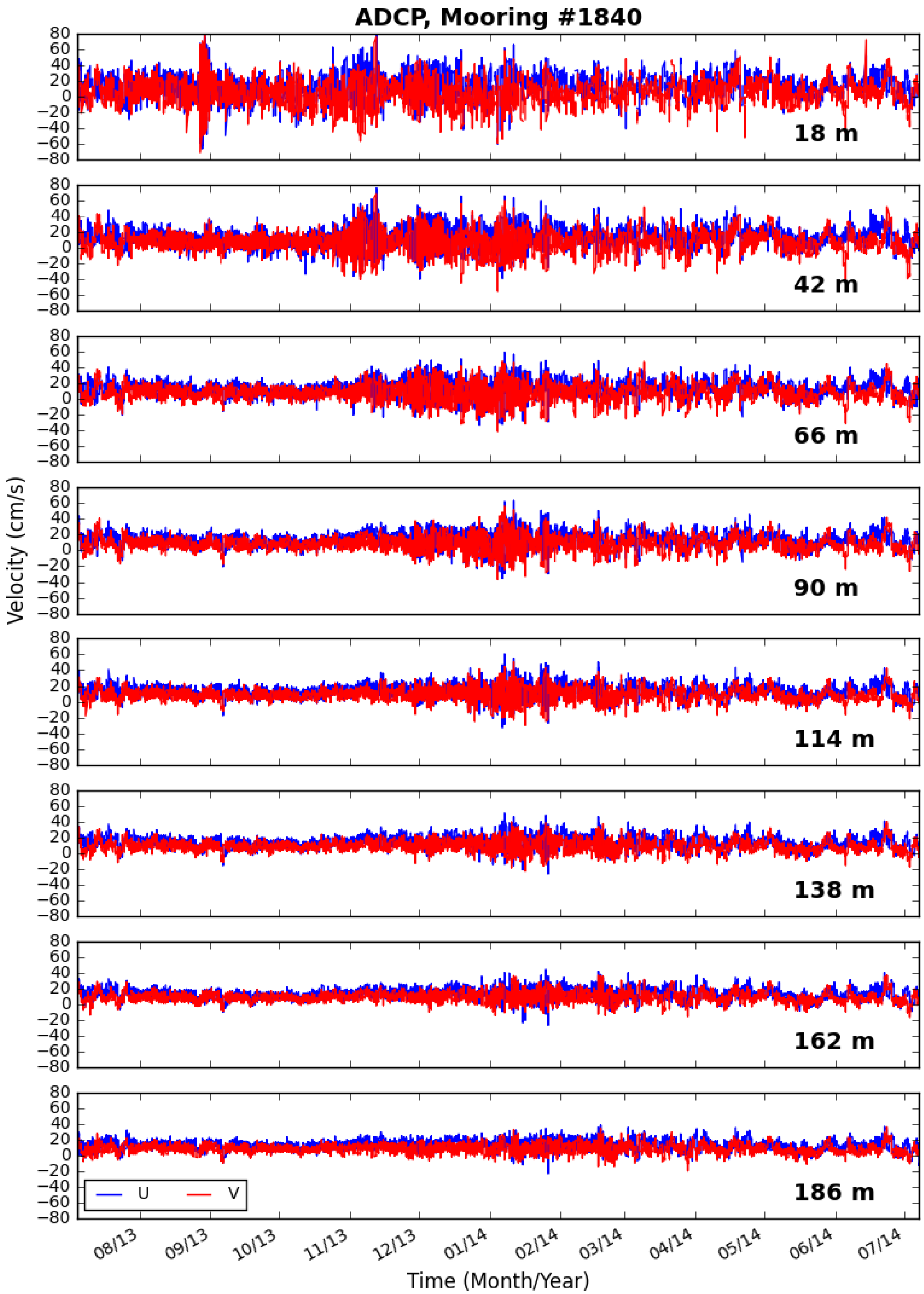


Figure 46 Moored-ADCP north-south (blue) and east-west (red) current by depth, speed (cm s^{-1}), northern Flemish Cap (NFC).

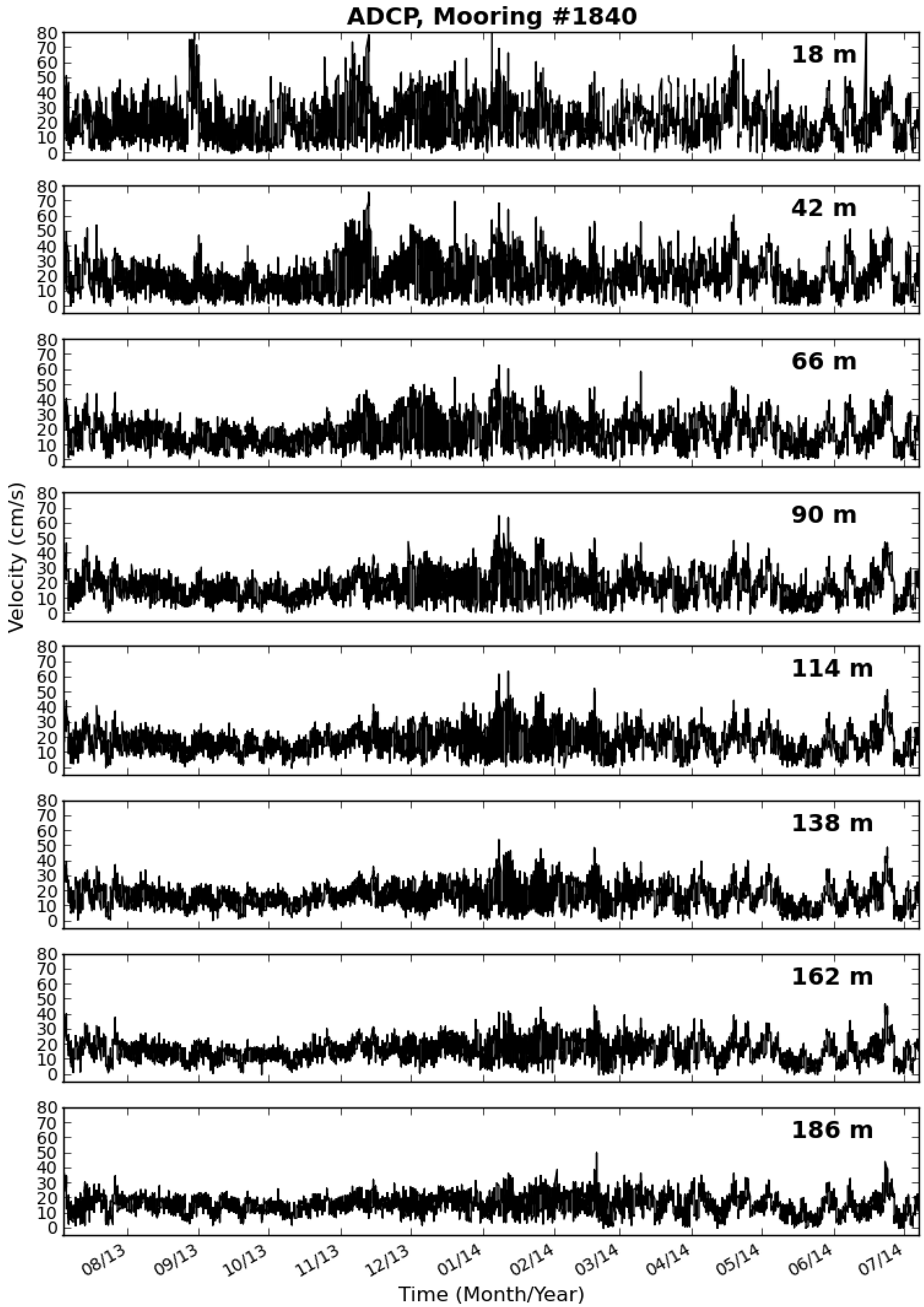


Figure 47 Moored-ADCP current speed (cm s^{-1}) by depth, northern Flemish Cap (NFC).

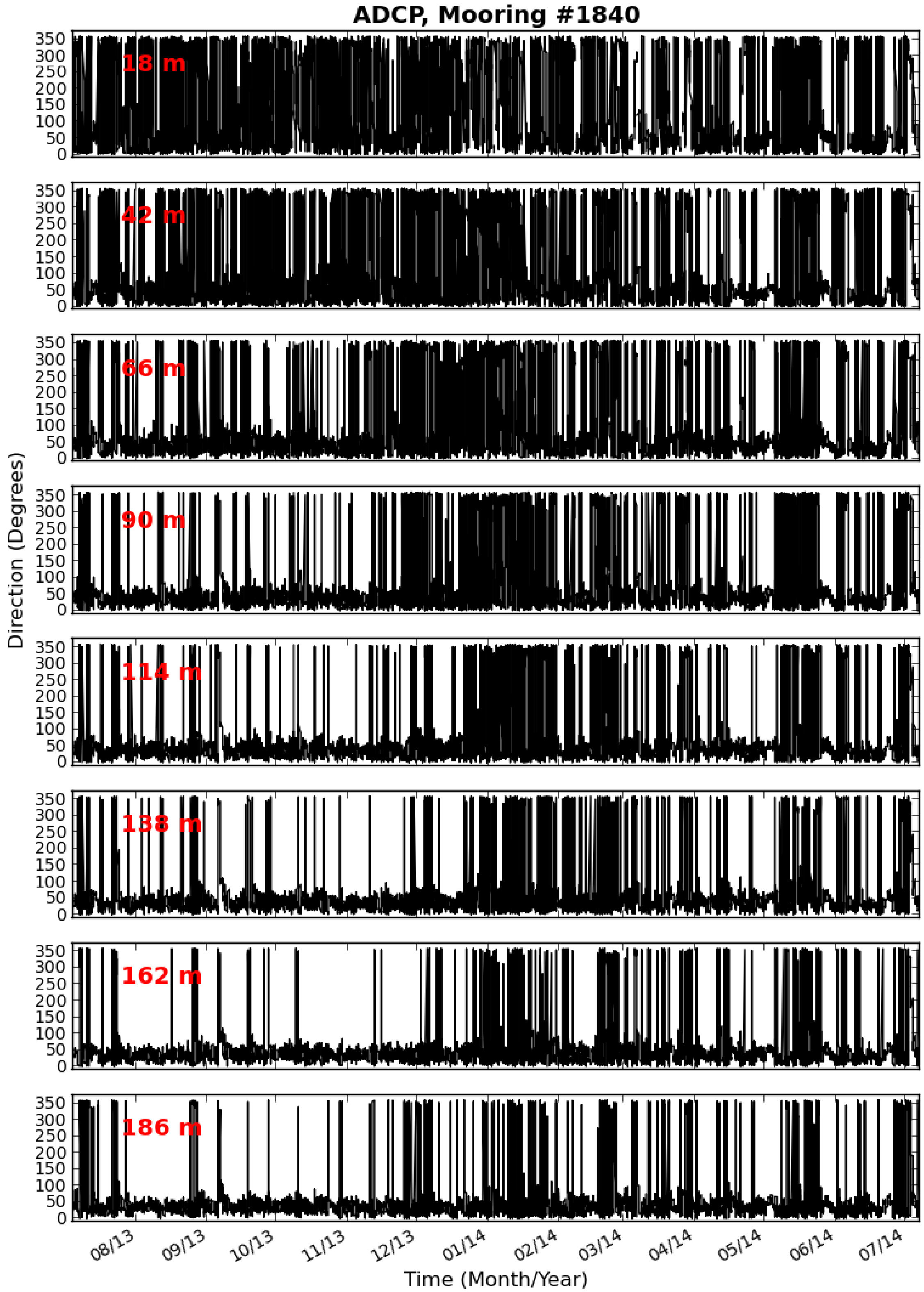


Figure 48 Moored-ADCP current direction by depth, northern Flemish Cap (NFC).

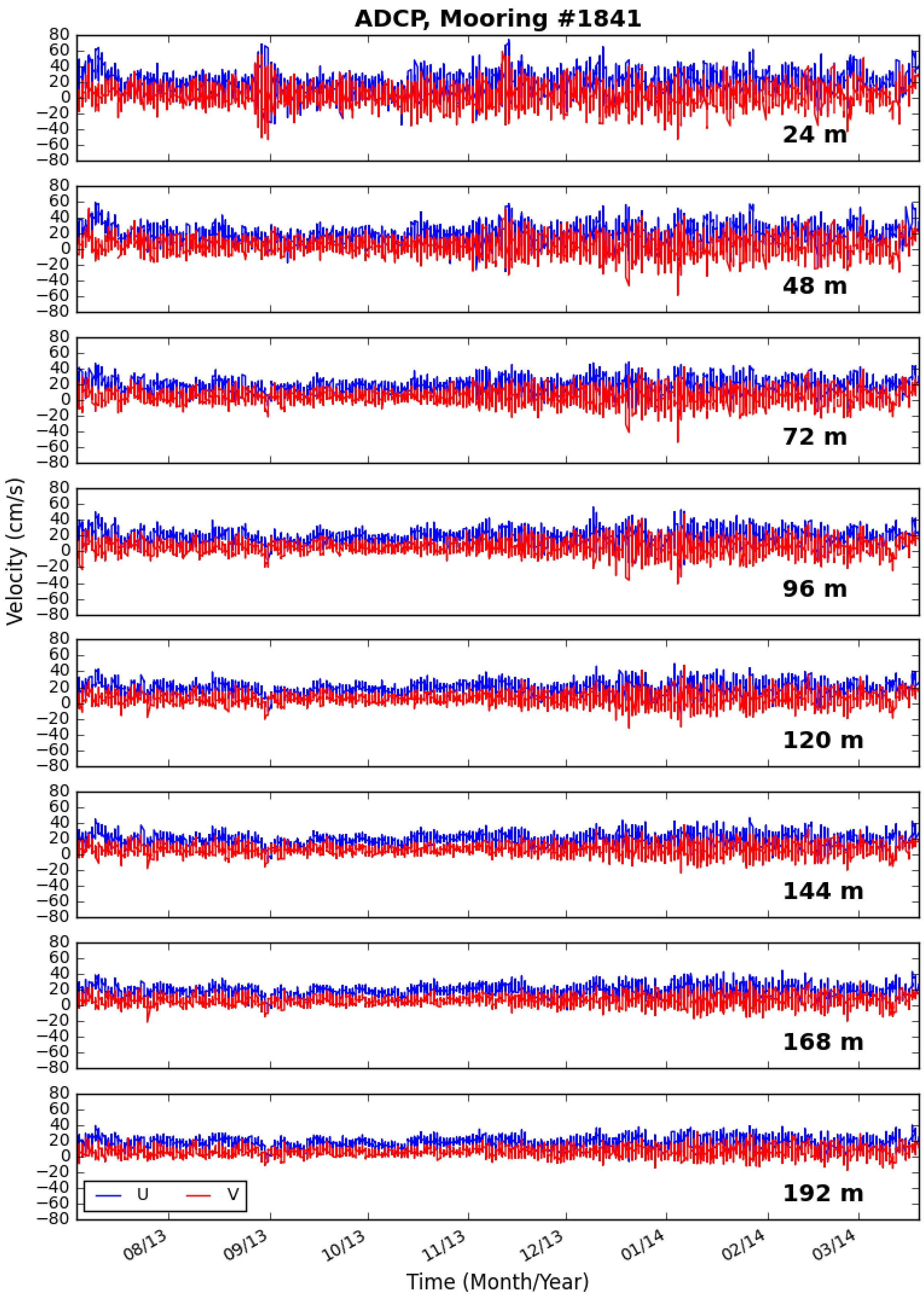


Figure 49 Moored-ADCP north-south (blue) and east-west (red) current by depth, speed (cm s^{-1}), Sackville Spur (SS).

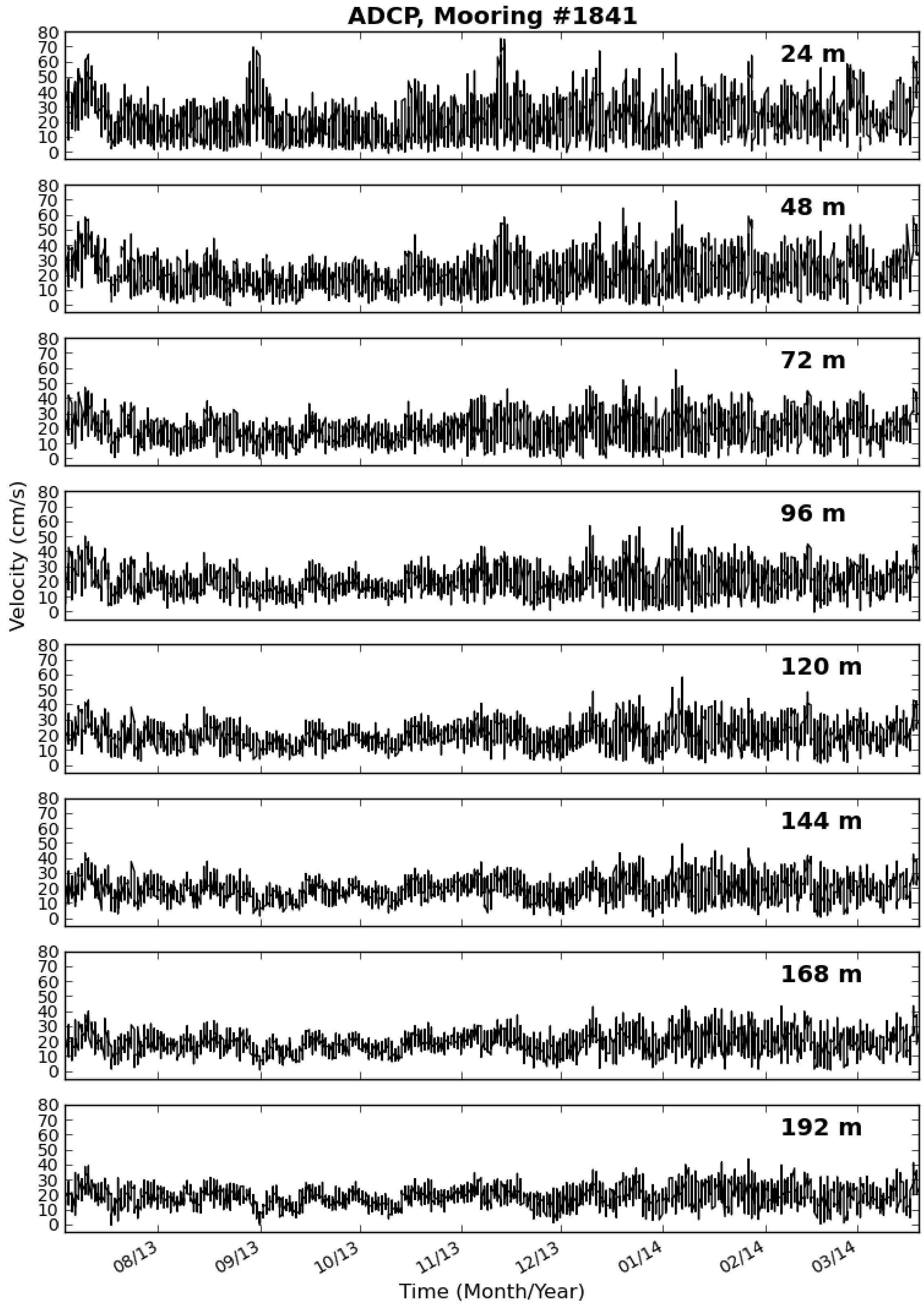


Figure 50 Moored-ADCP current speed (cm s^{-1}) by depth, Sackville Spur (SS).

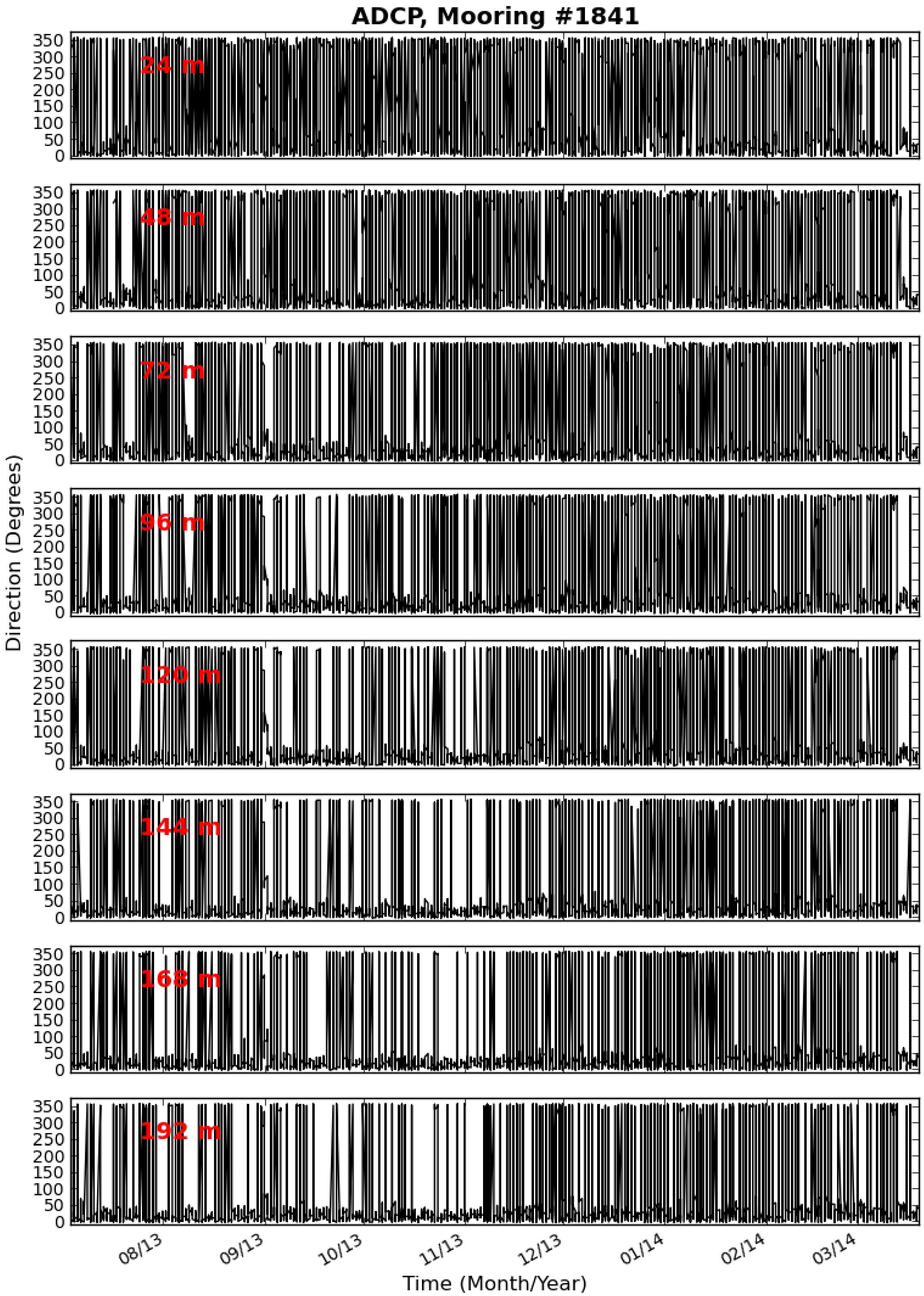


Figure 51 Moored-ADCP current direction by depth, Sackville Spur (SS).

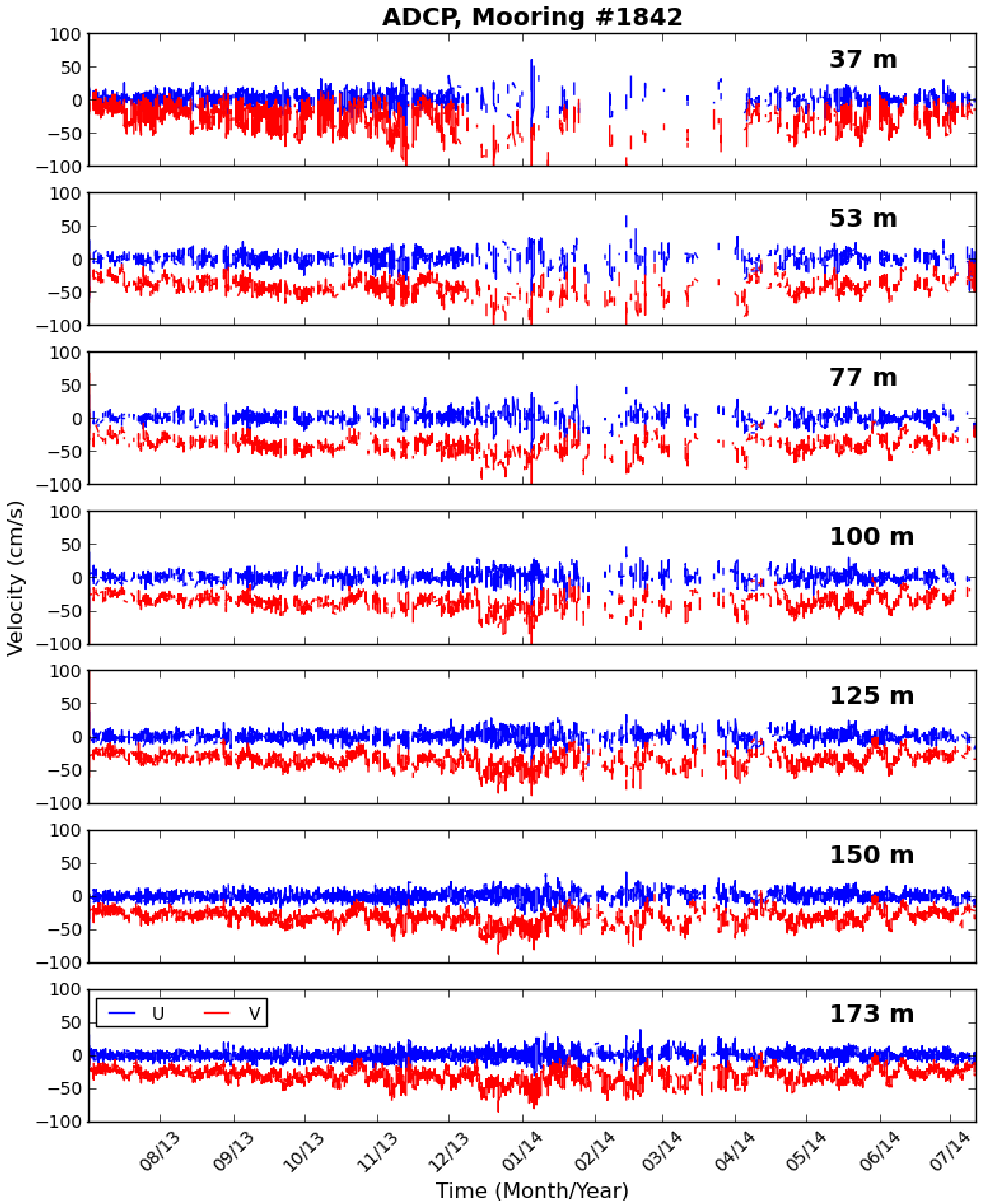


Figure 52 Moored-ADCP north-south (blue) and east-west (red) current by depth, speed (cm s^{-1}), Flemish Pass (FP).

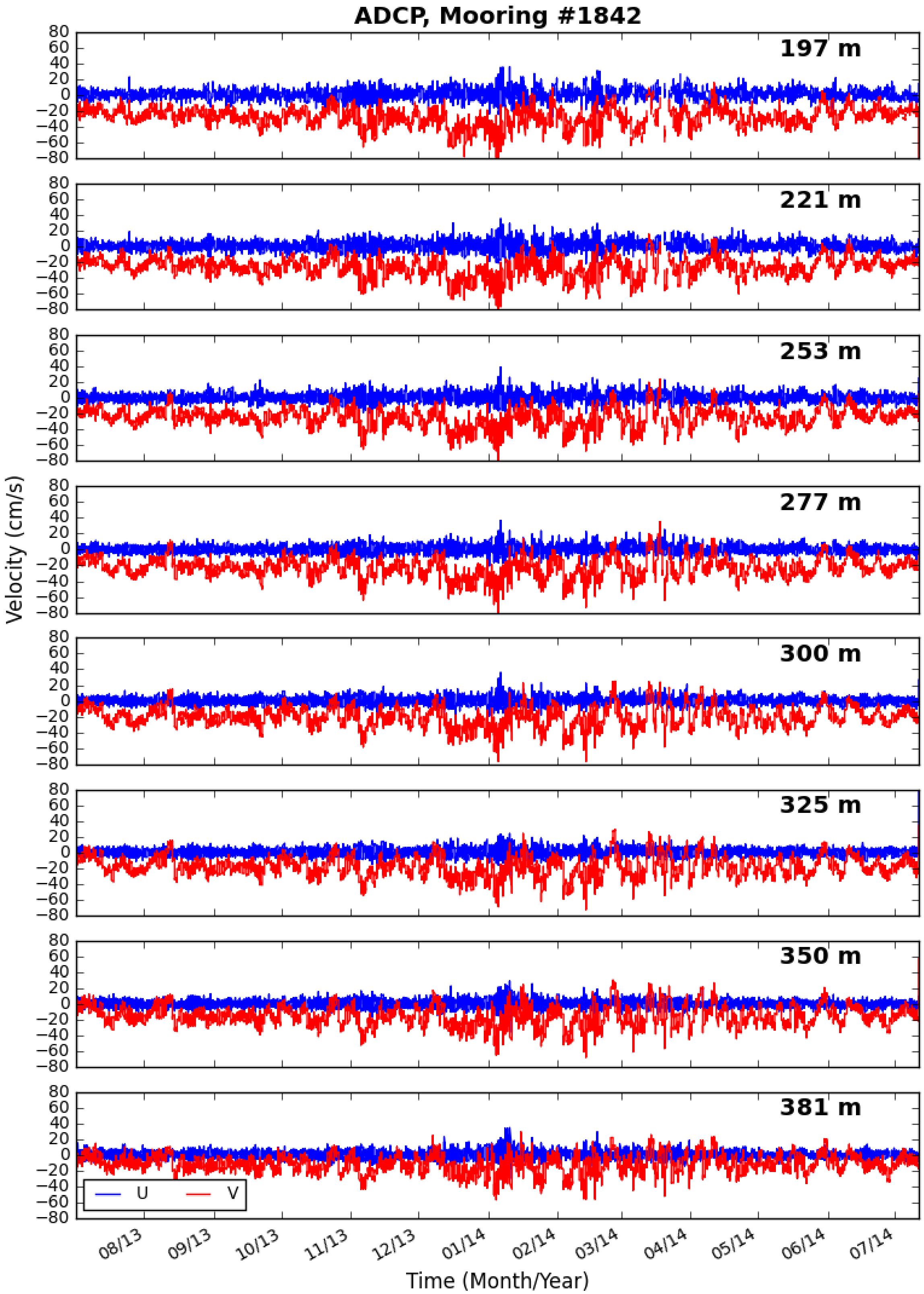


Figure 53 Moored-ADCP north-south (blue) and east-west (red) current by depth, speed (cm s^{-1}), Flemish Pass (FP).

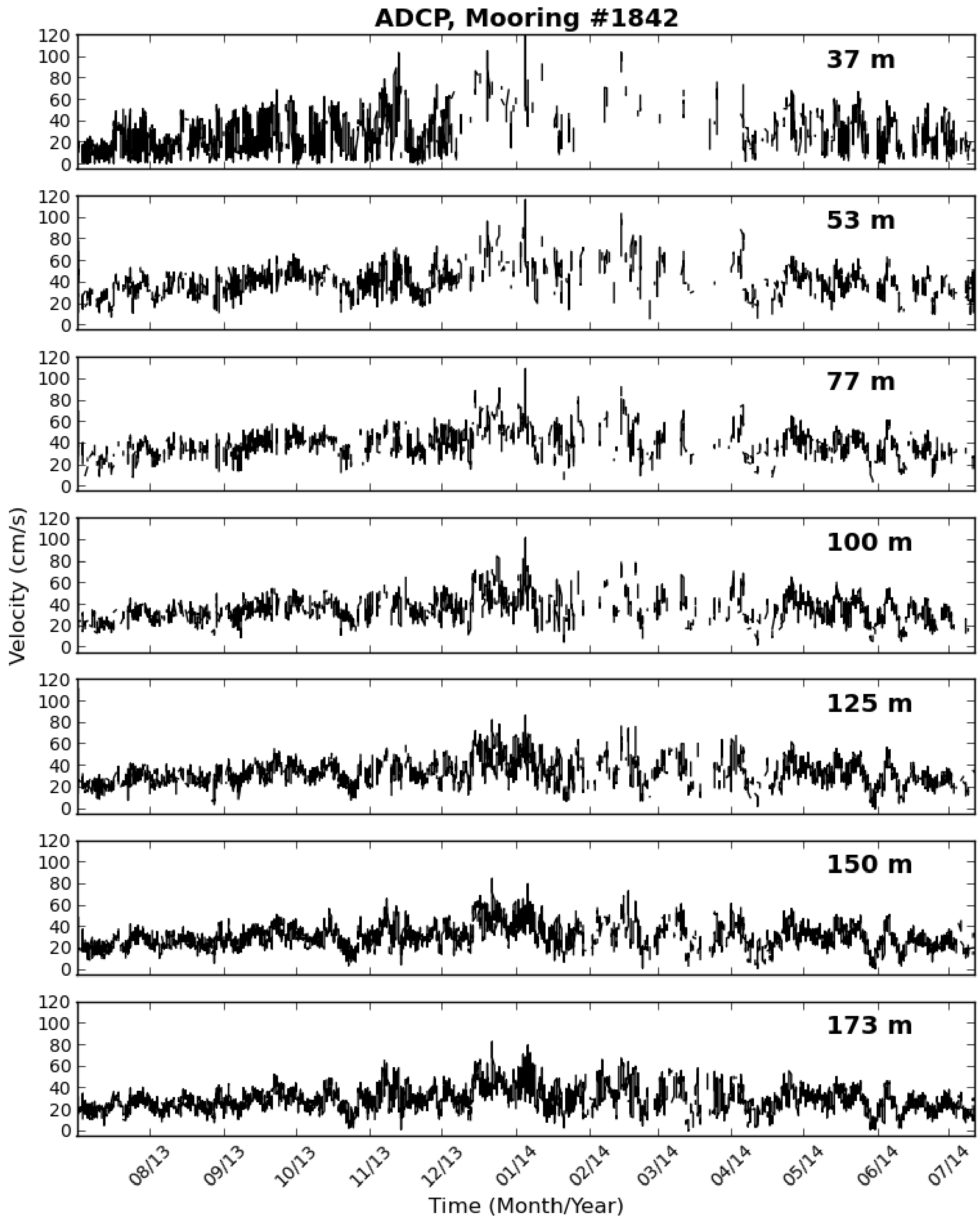


Figure 54 Moored-ADCP current speed (cm s^{-1}) by depth, Flemish Pass (FP).

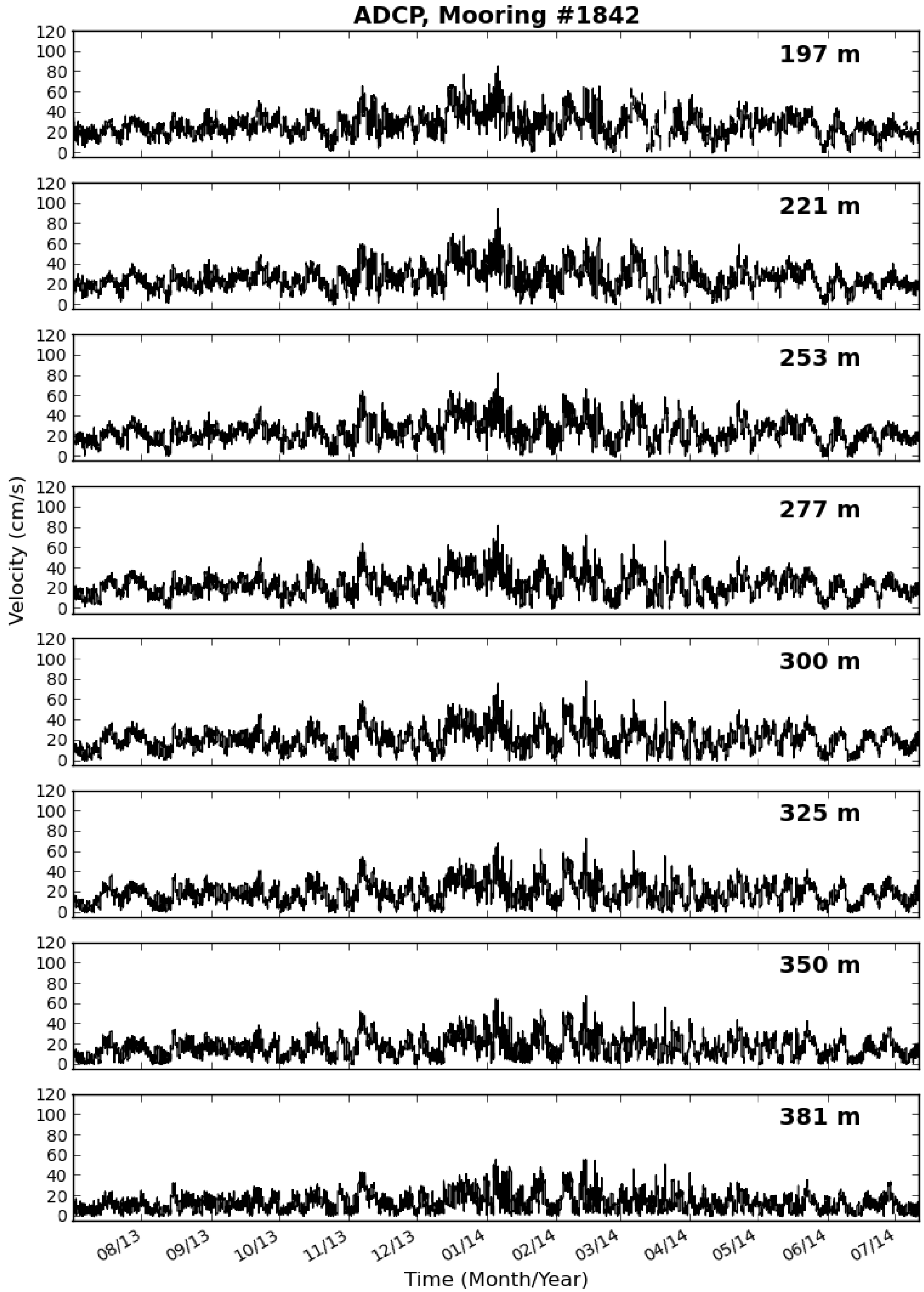


Figure 55 Moored-ADCP current speed (cm s^{-1}) by depth, Flemish Pass (FP).

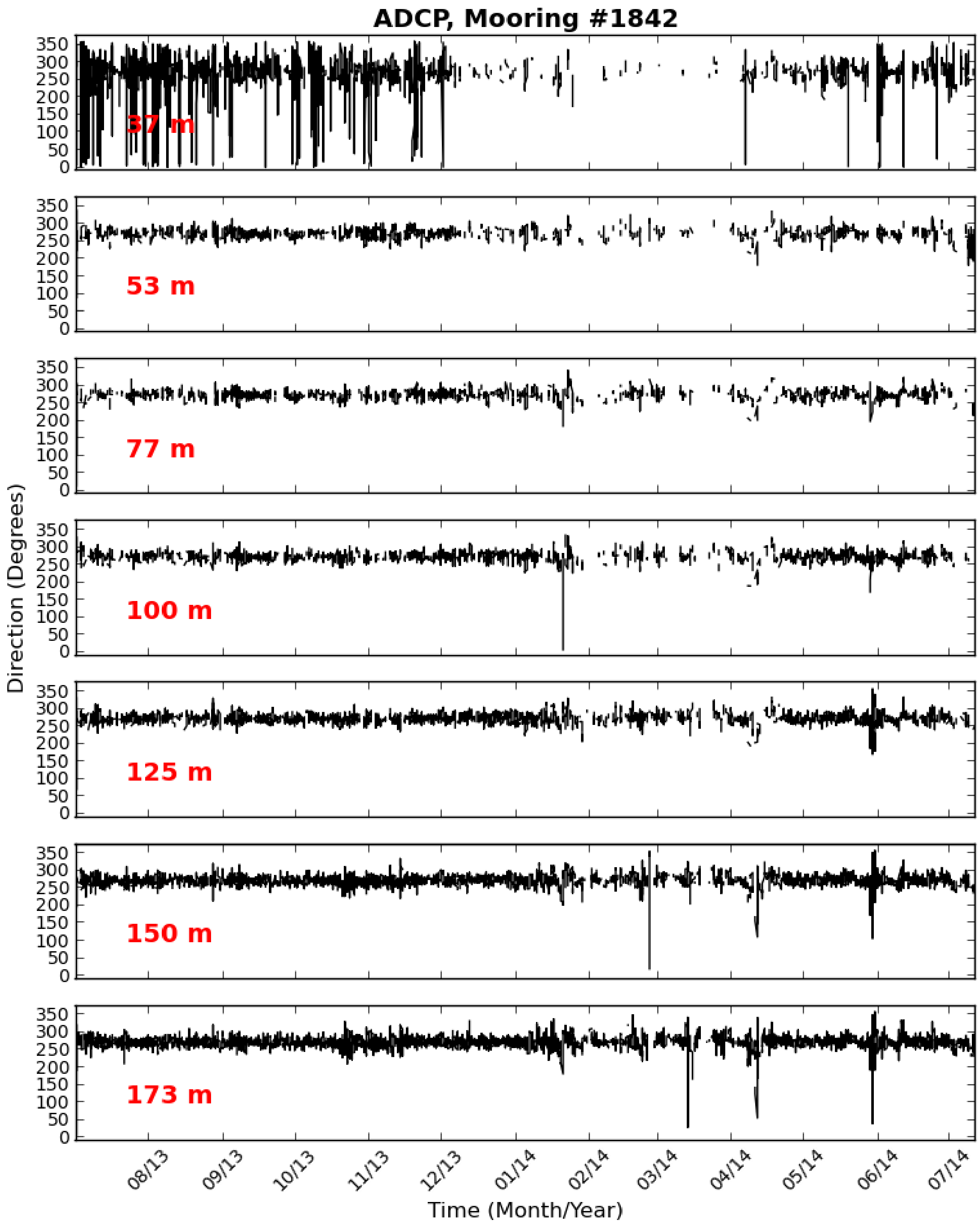


Figure 56 Moored-ADCP current direction by depth, Flemish Pass (FP).

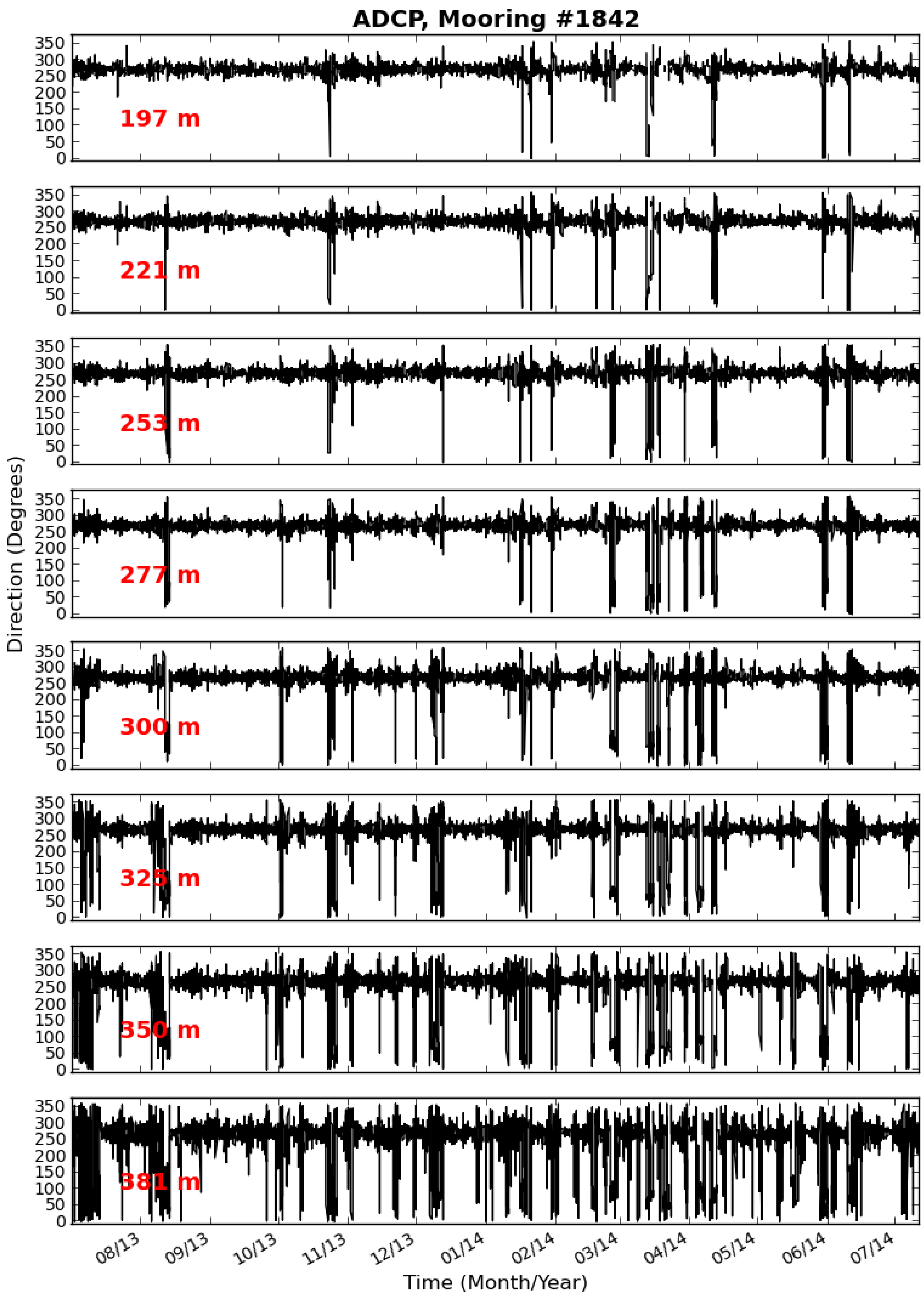
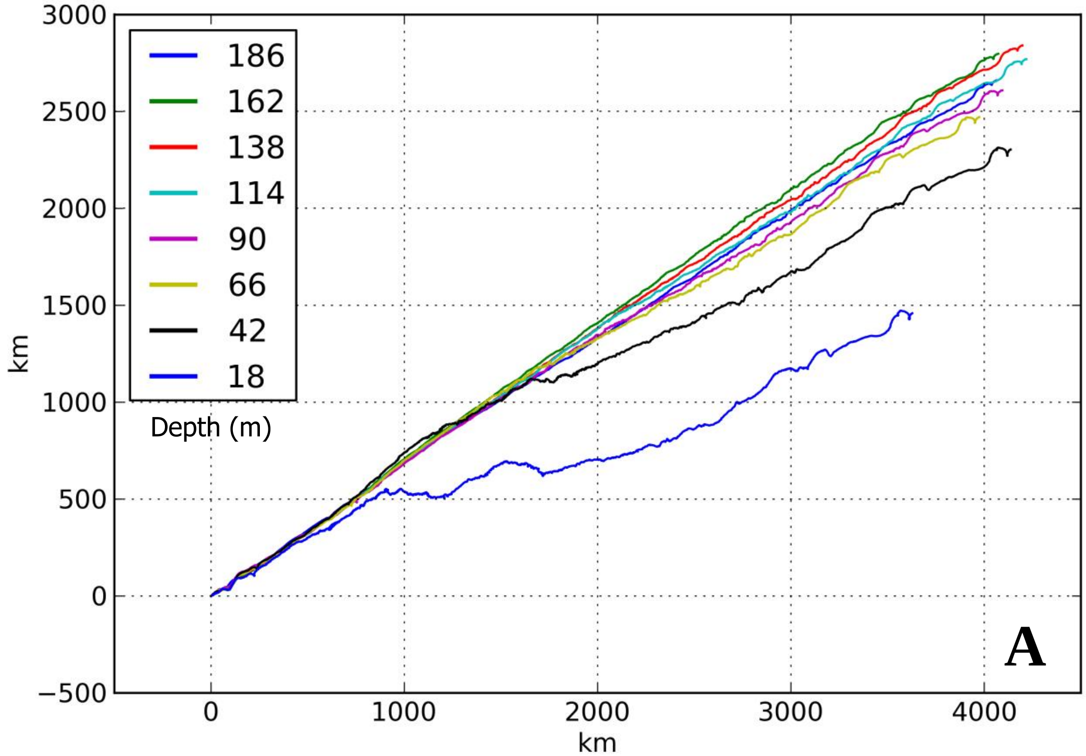


Figure 57 Moored-ADCP current direction by depth, Flemish Pass (FP).



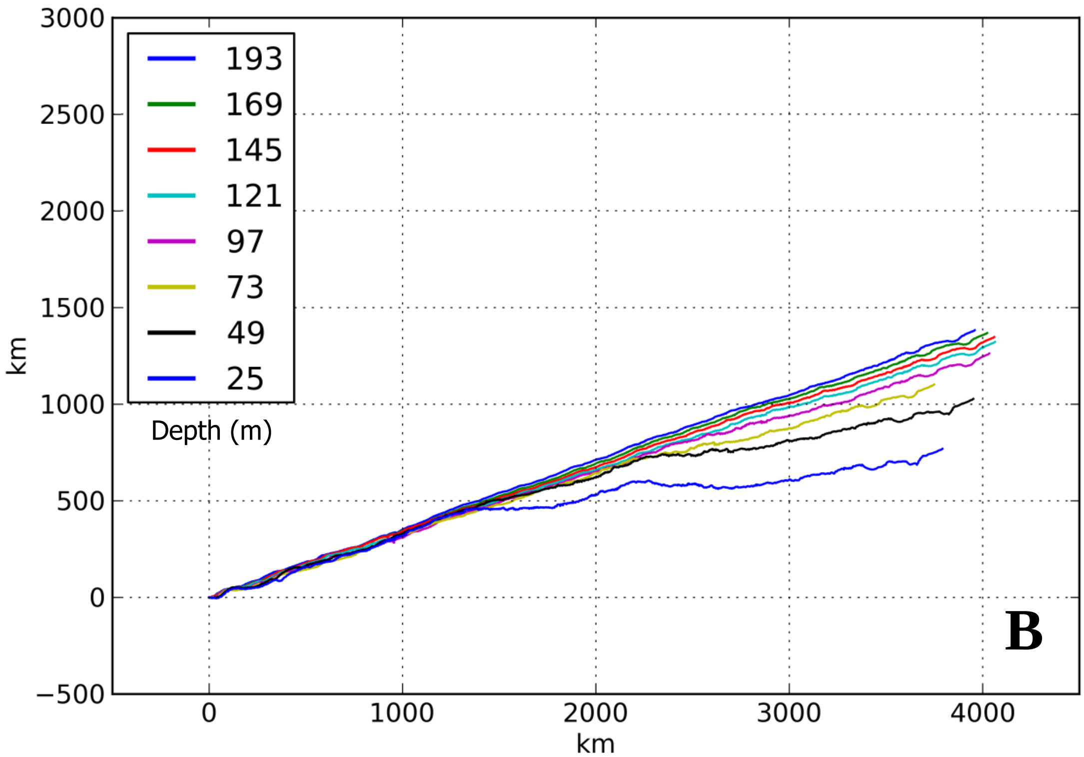


Figure 58 Moored-ADCP progressive vector diagram, mooring 1840 northern Flemish Cap (A), mooring 1841 Sackville Spur (B).

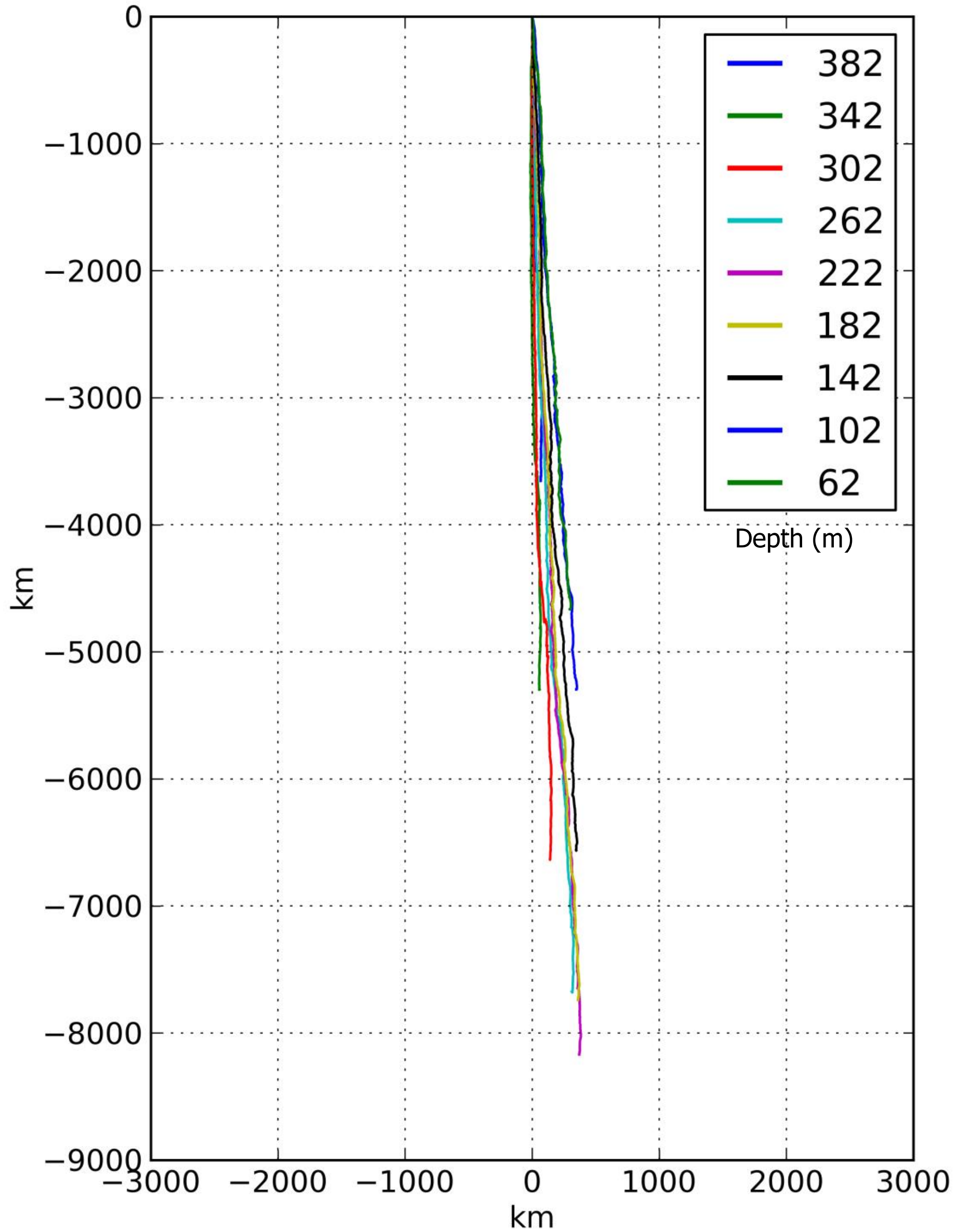


Figure 59 Moored-ADCP progressive vector diagram, mooring 1842 Flemish Pass.

Appendix 6 Moored single point current meters line and progressive vector plots

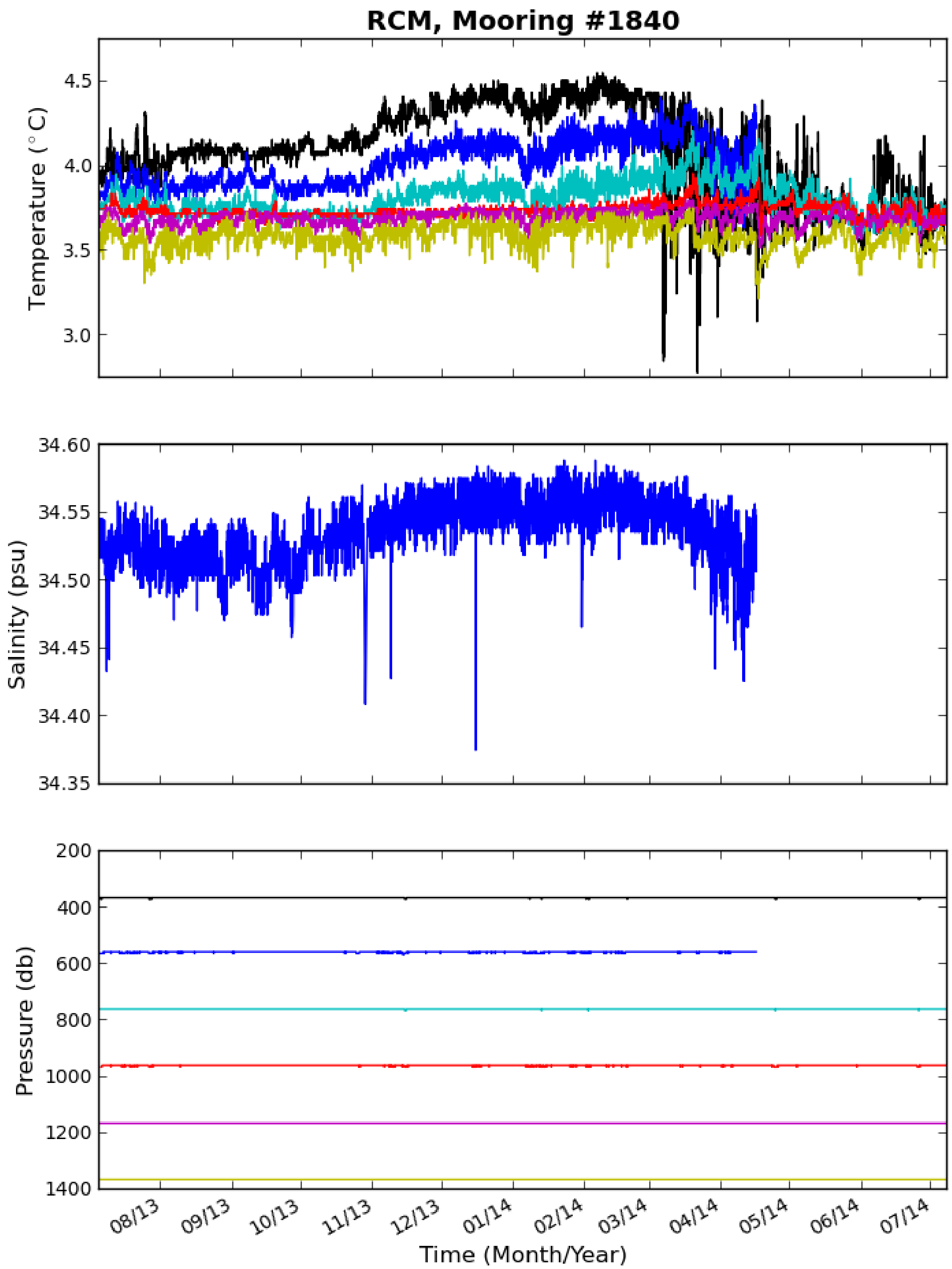


Figure 60 Moored-RCM temperature, salinity, pressure, northern Flemish Cap (NFC). Color-coding is common to each panel of the plot. Only one RCM with a conductivity sensor was deployed on this mooring.

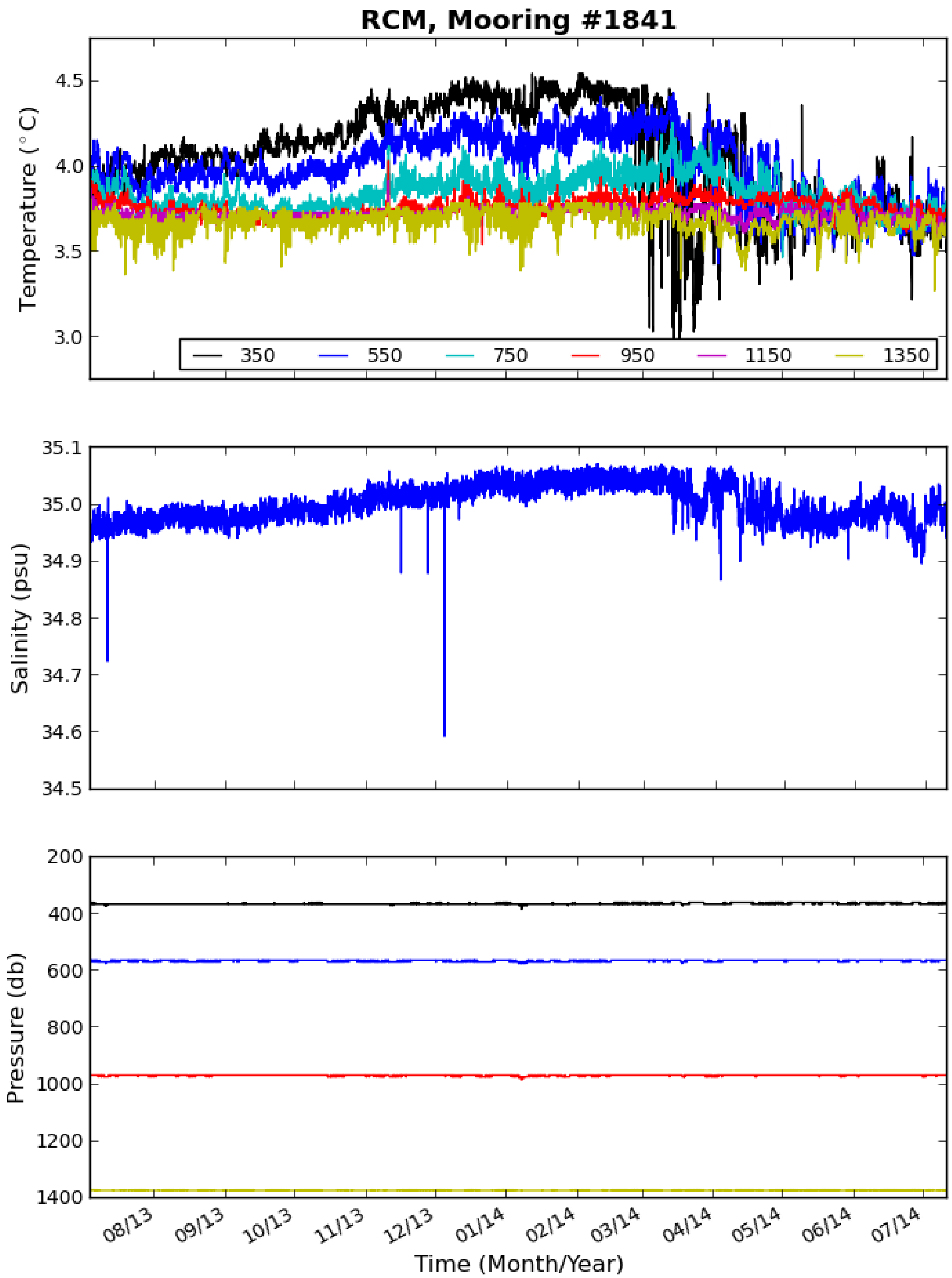


Figure 61 Moored-RCM temperature, salinity, pressure, Sackville Spur (SS). Color-coding is common to each panel of the plot. Only one RCM with a conductivity sensor was deployed on this mooring. The RCM at 750 m and 1150 m had no pressure data.

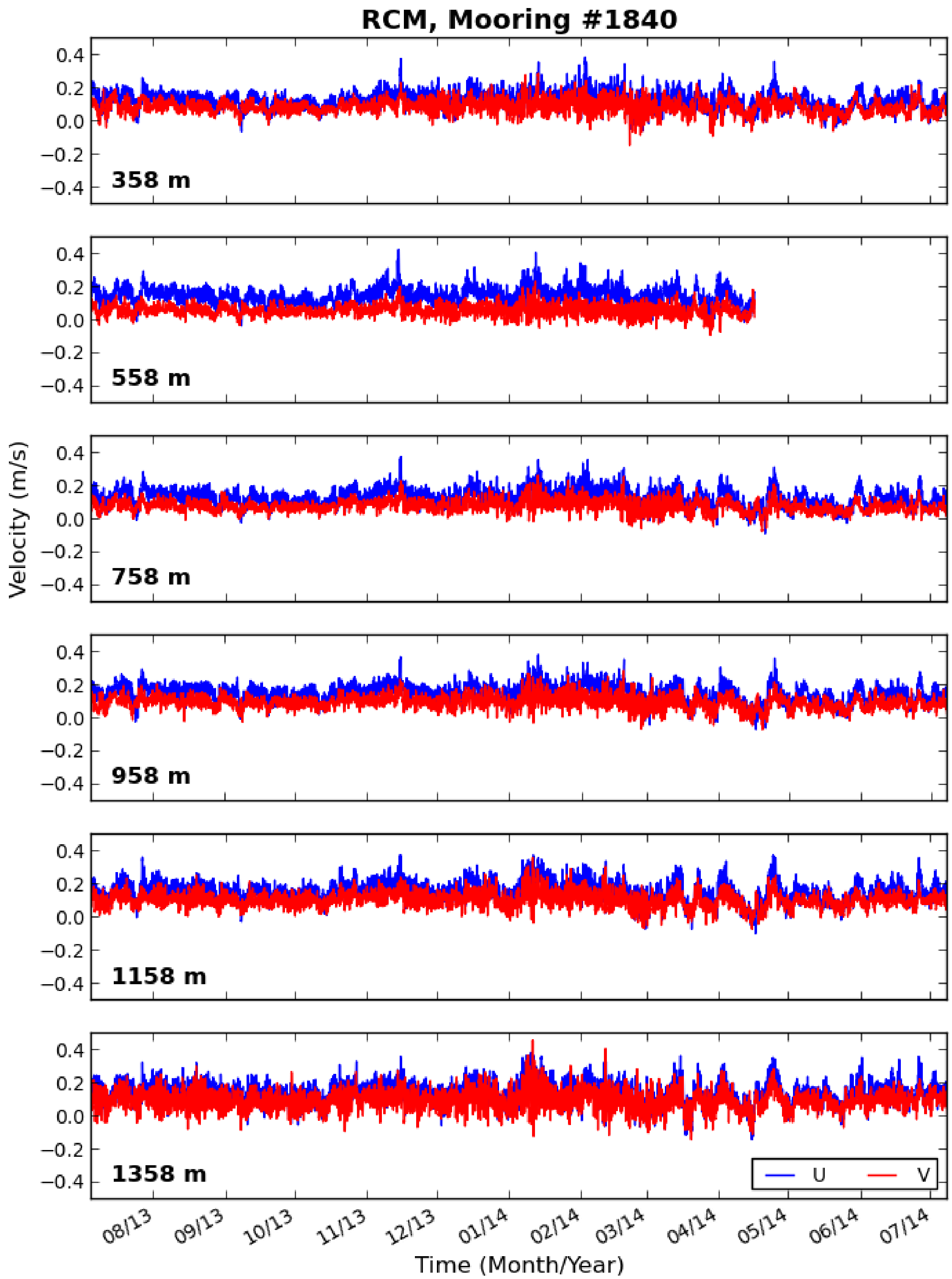


Figure 62 Moored-RCM north-south (blue) and east-west (red) current by depth, speed (m s^{-1}), northern Flemish Cap (NFC).

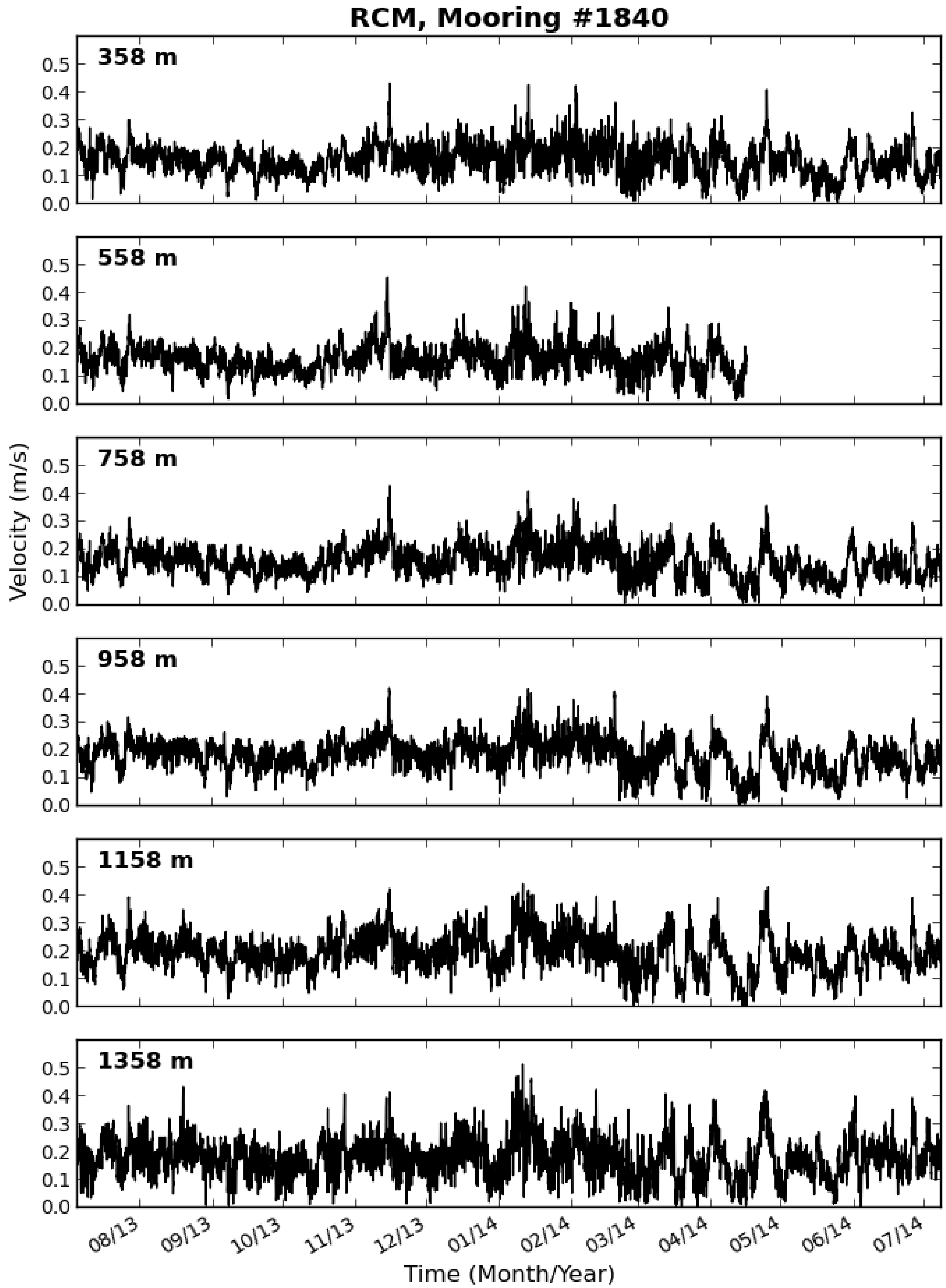


Figure 63 Moored-RCM current speed (m s^{-1}) by depth, northern Flemish Cap (NFC).

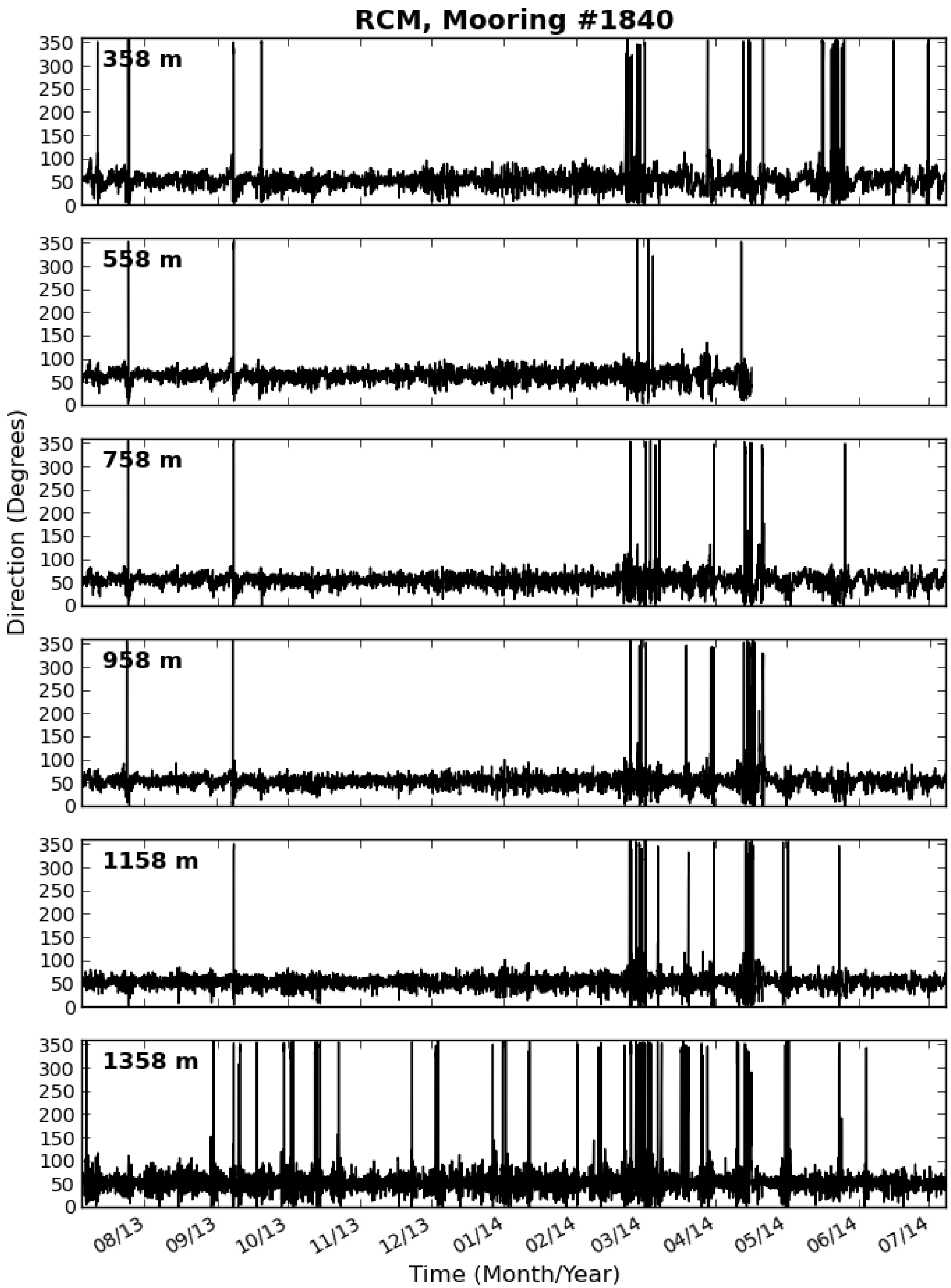


Figure 64 Moored-ADCP current direction by depth, northern Flemish Cap (NFC).

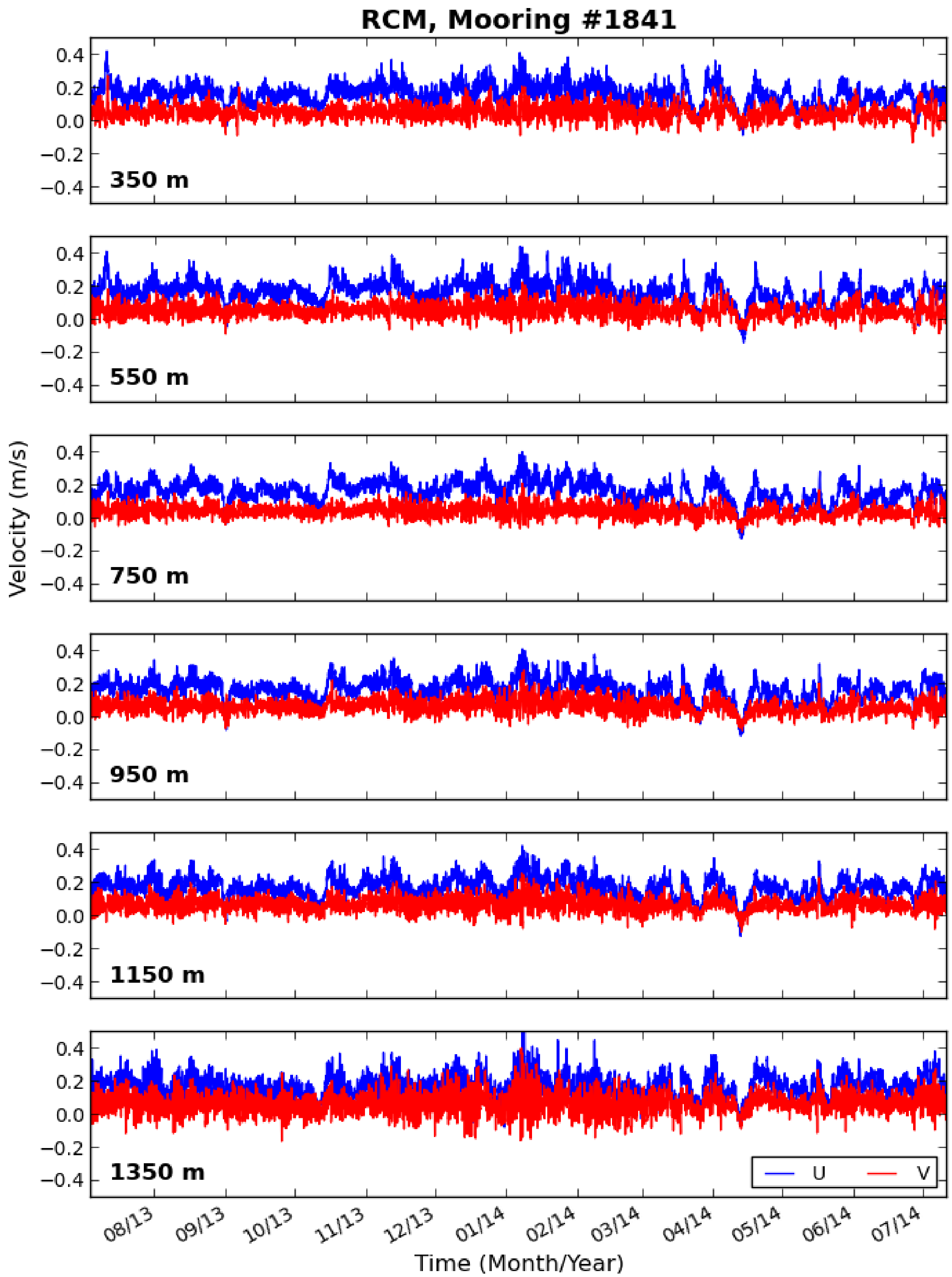


Figure 65 Moored-RCM north-south (blue) and east-west (red) current by depth, speed (m s^{-1}), Sackville Spur (SS).

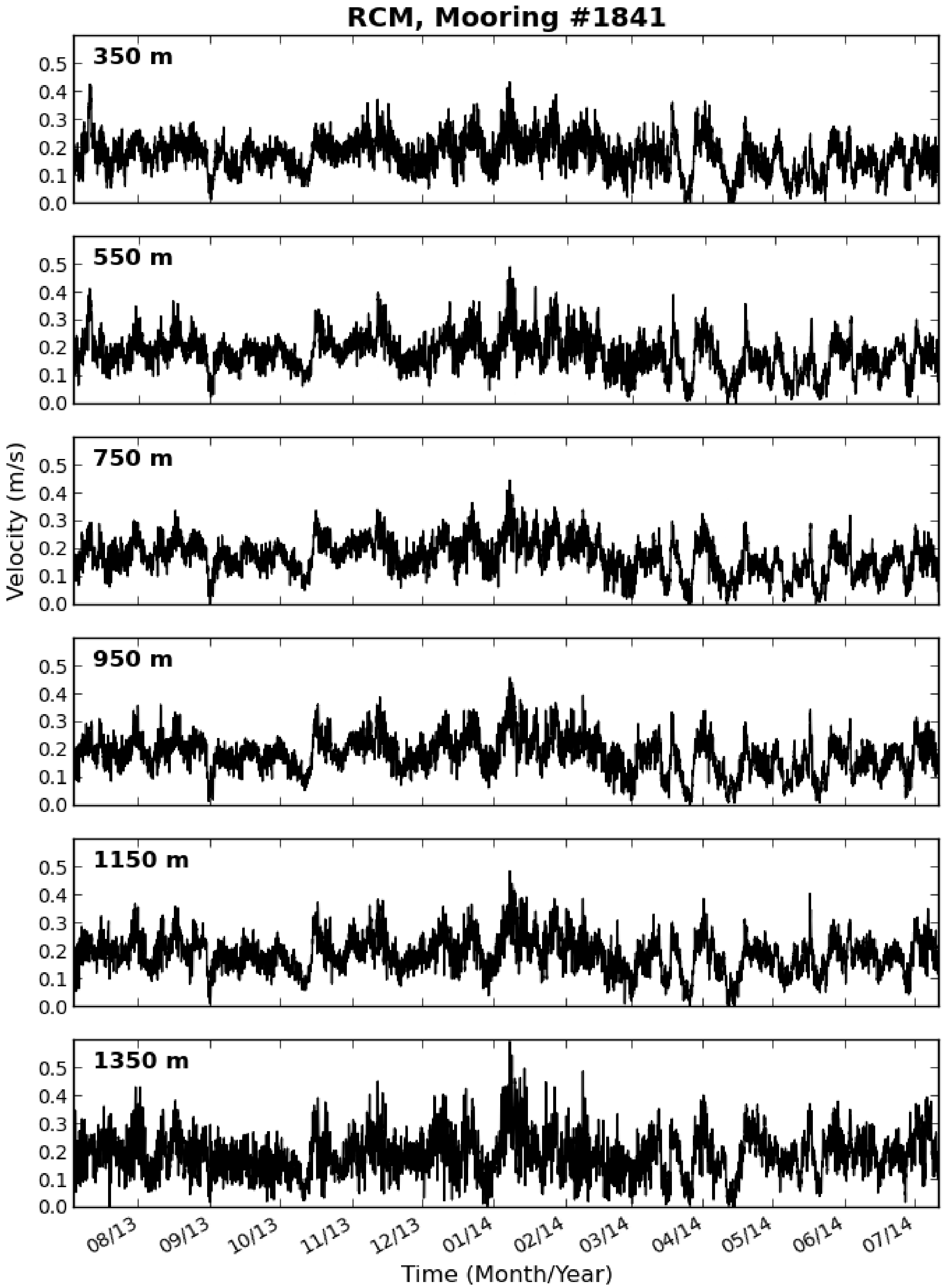


Figure 66 Moored-RCM current speed (m s^{-1}) by depth, Sackville Spur (SS).

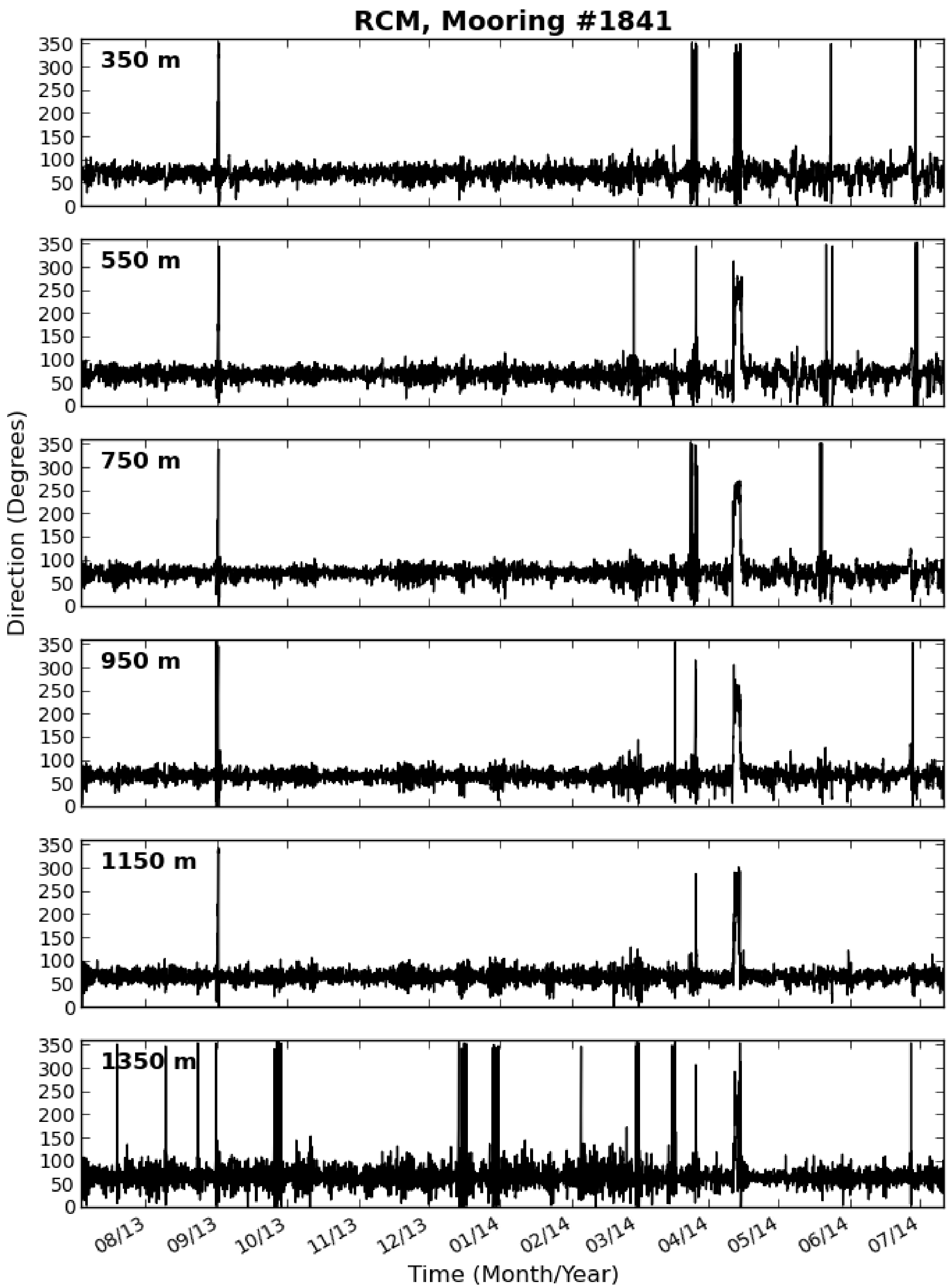


Figure 67 Moored-ADCP current direction by depth, Sackville Spur.

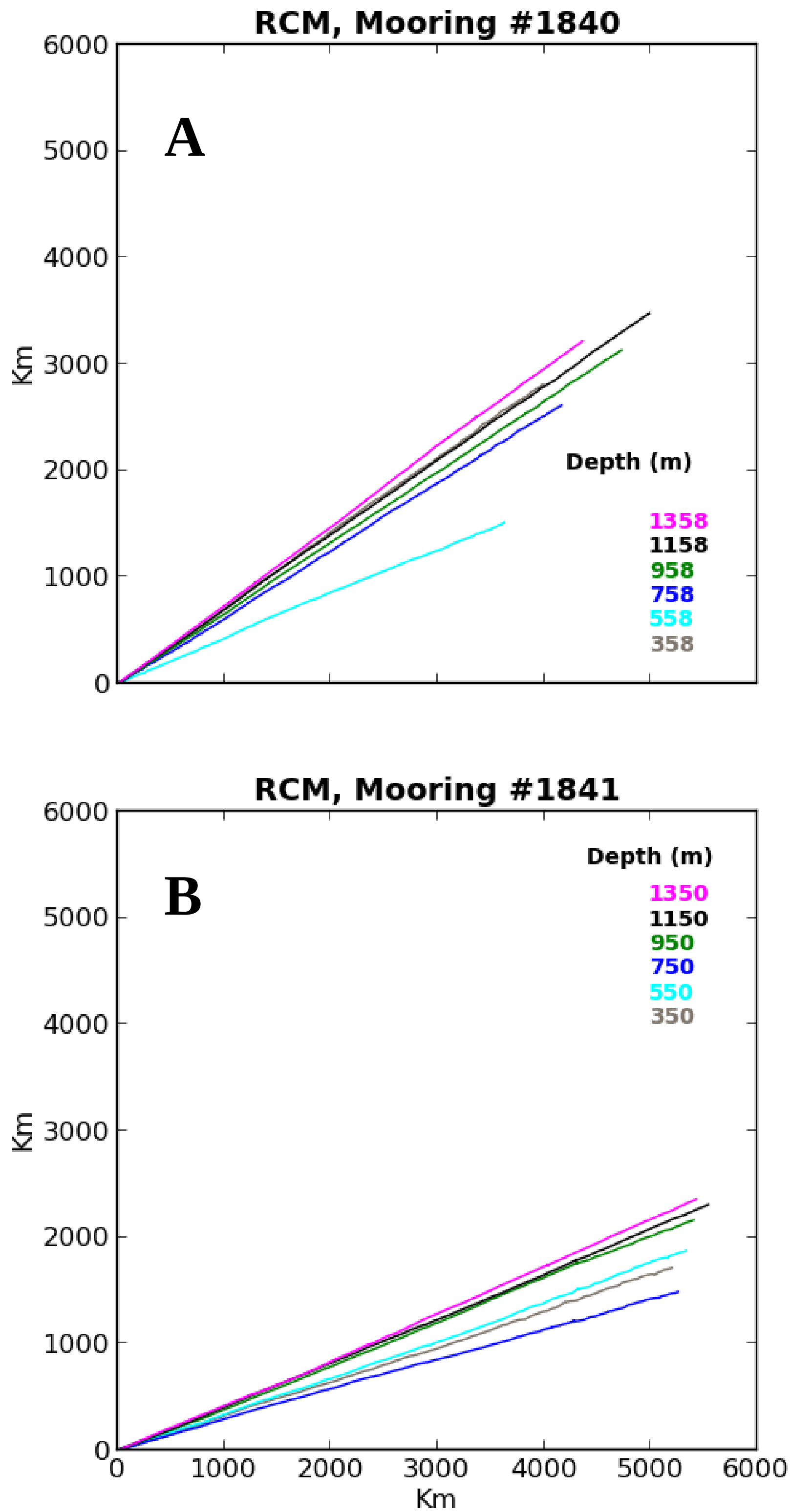


Figure 68 Moored-RCM progressive vector diagram, mooring 1840 northern Flemish Cap (A), mooring 1841 Sackville Spur (B). The grey line (358 m) is behind the black line (1150 m) for mooring 1840.

Appendix 7 Moored CTD line plots

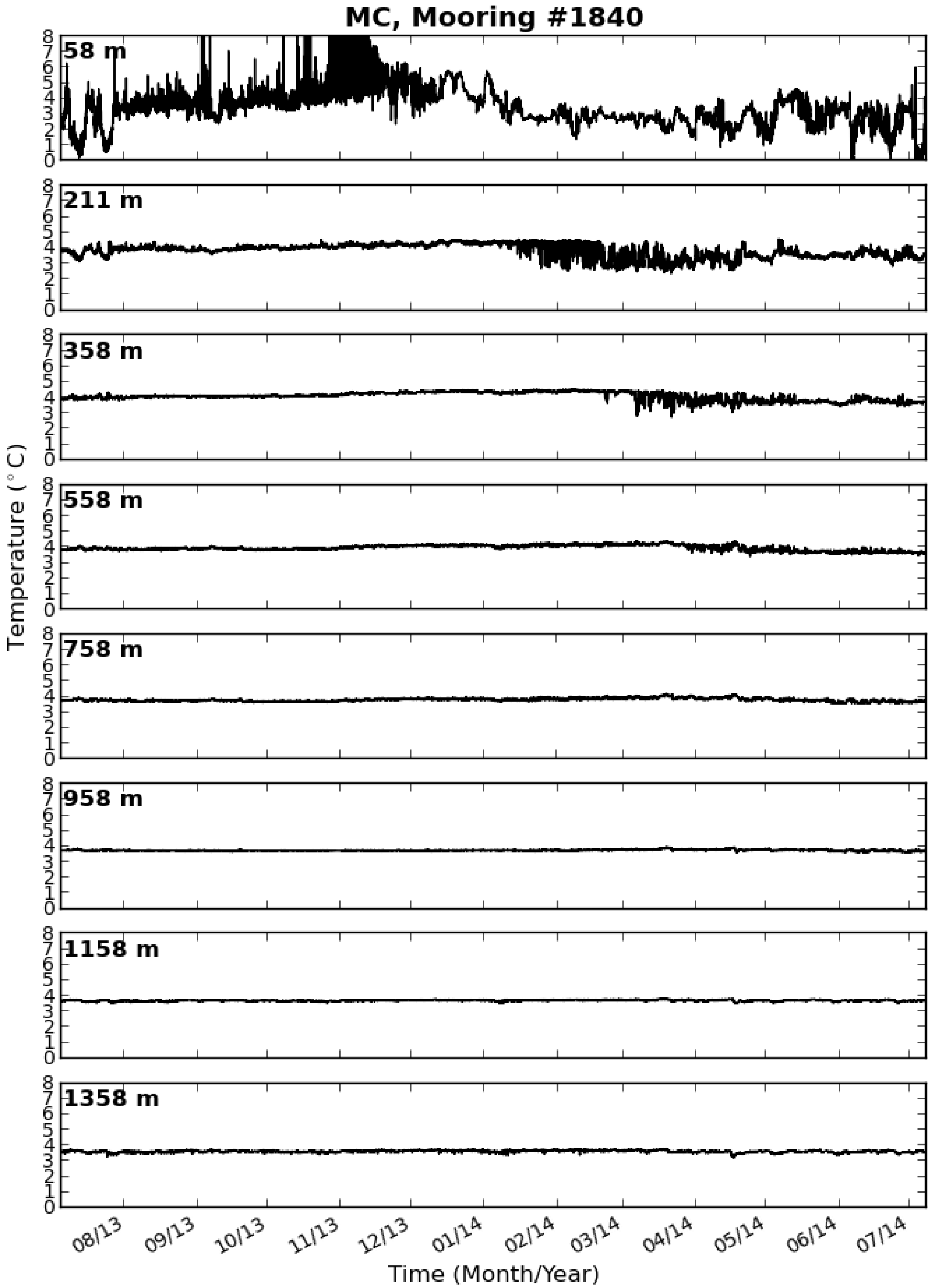


Figure 69 Moored-MC temperature, northern Flemish Cap (NFC).

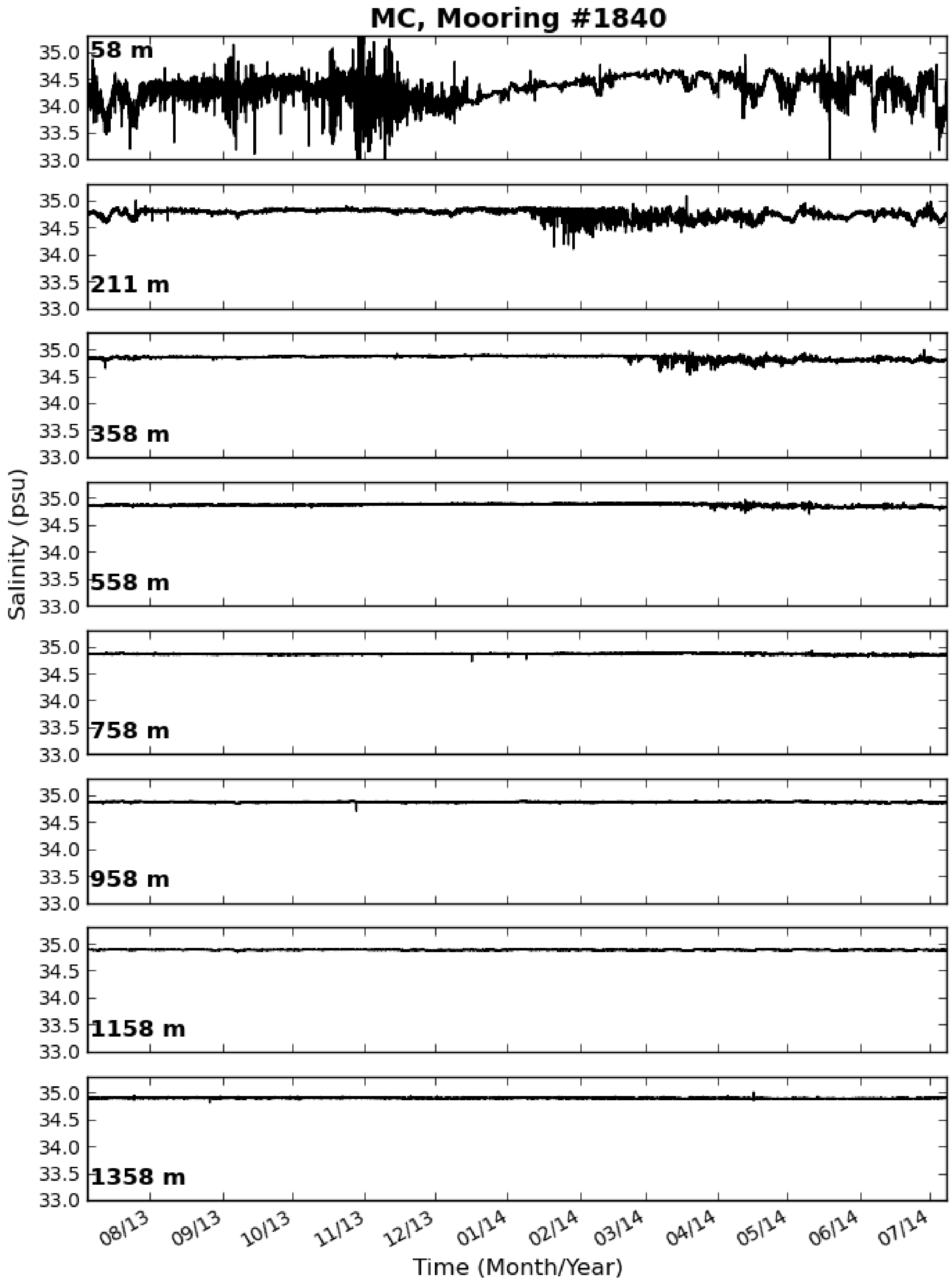


Figure 70 Moored-MC salinity, northern Flemish Cap (NFC).

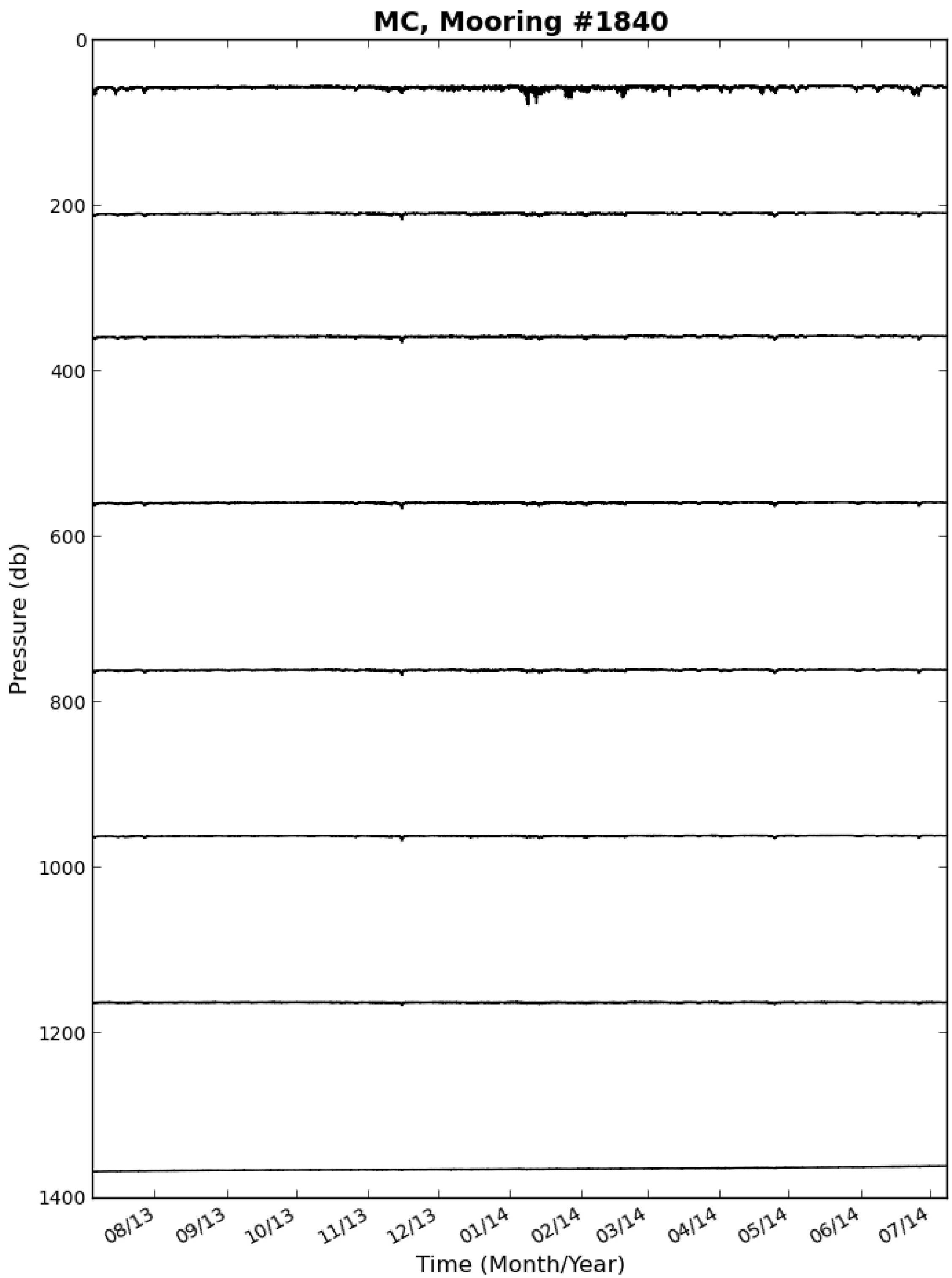


Figure 71 Moored-MC pressure, northern Flemish Cap (NFC).

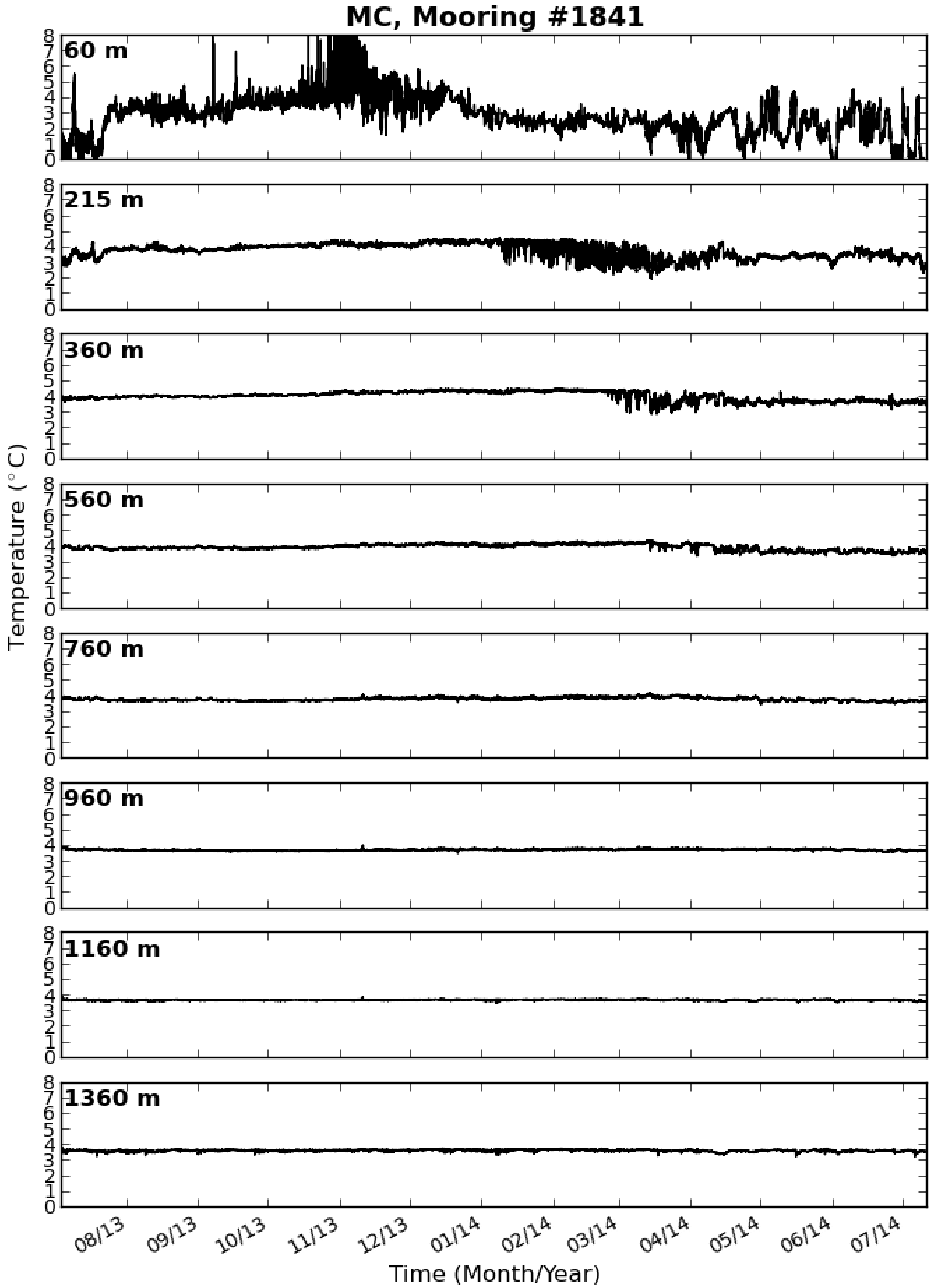


Figure 72 Moored-MC temperature, Sackville Spur(SS).

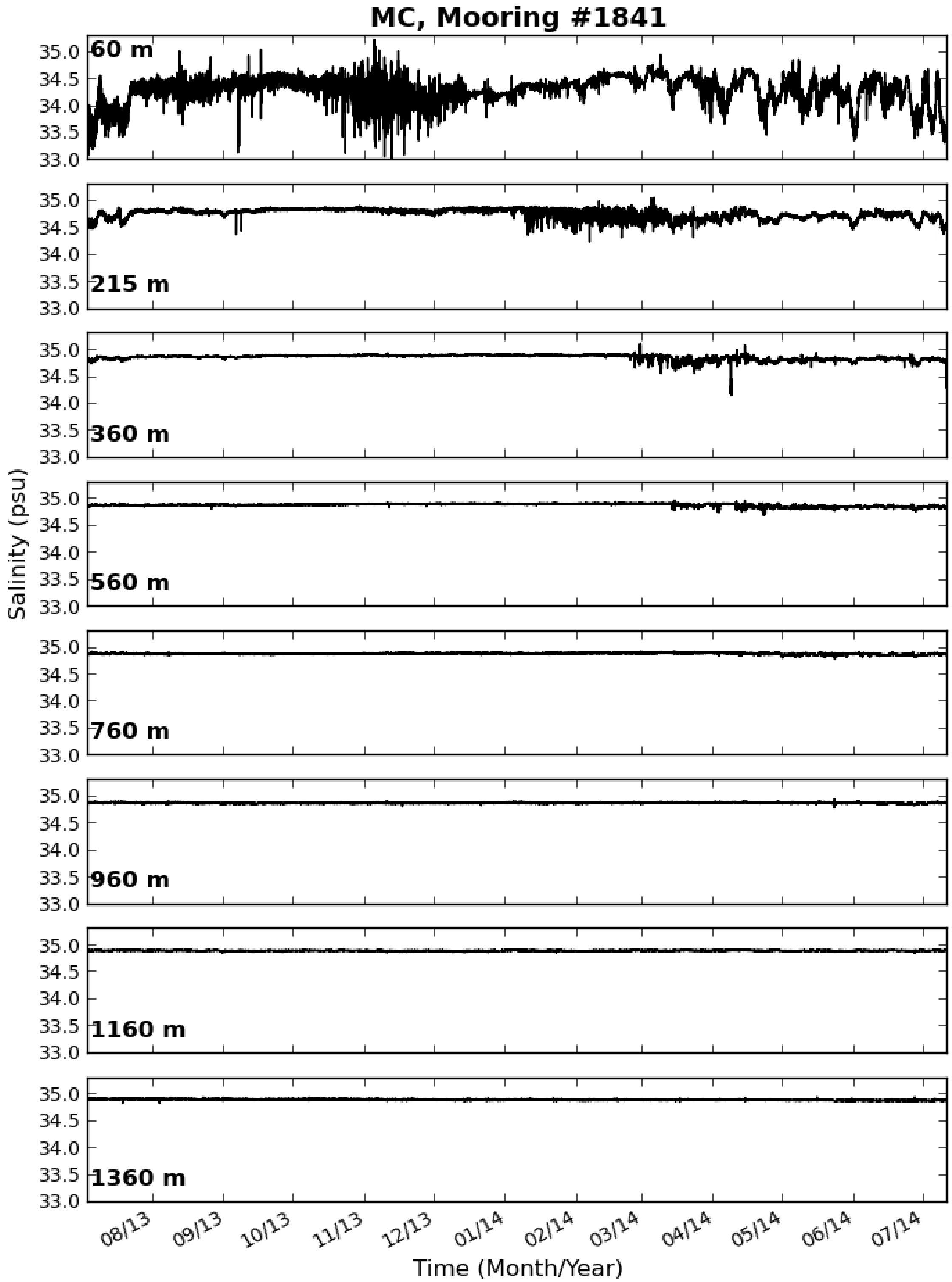


Figure 73 Moored-MC salinity, Sackville Spur (SS).

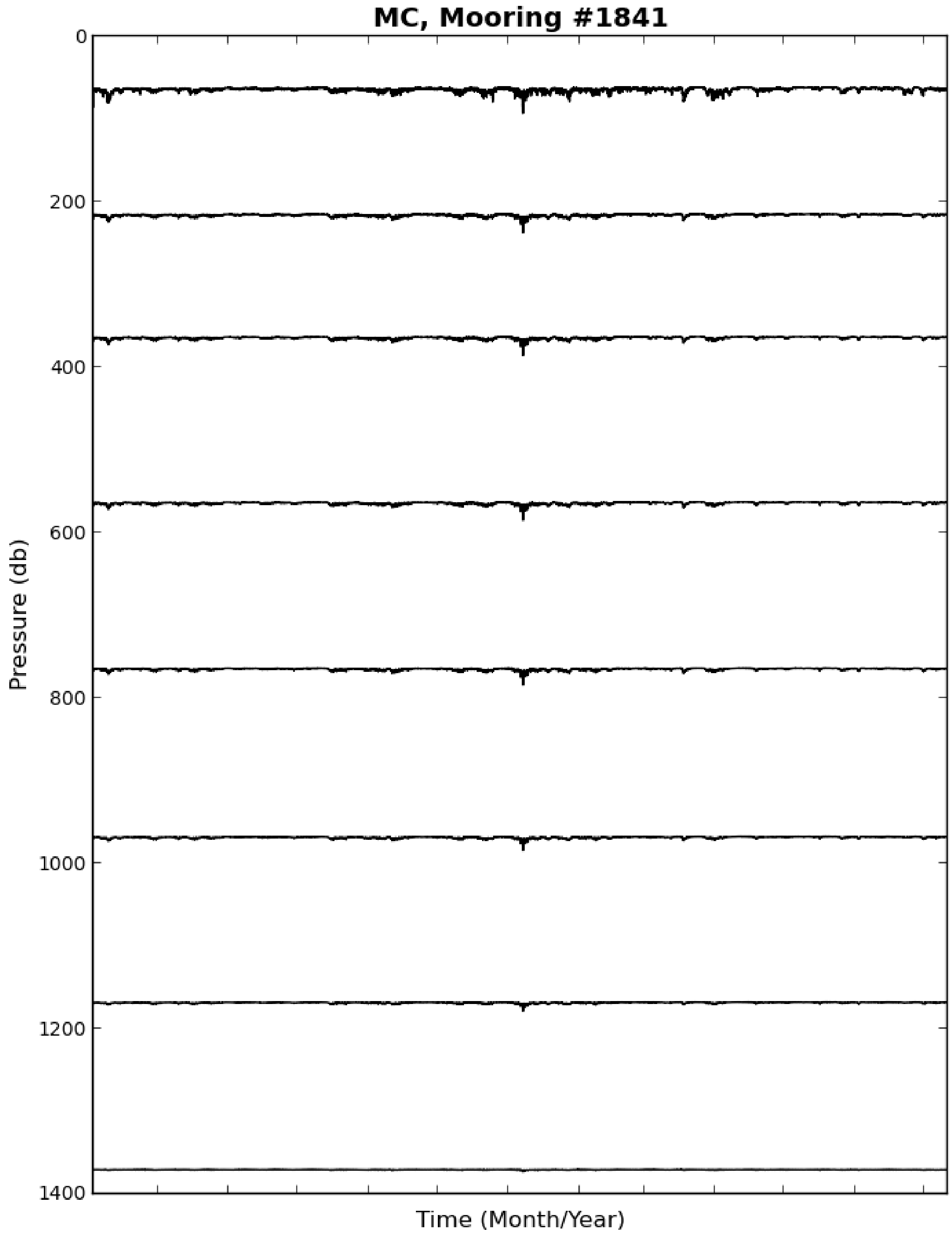


Figure 74 Moored-MC pressure, Sackville Spur (SS).

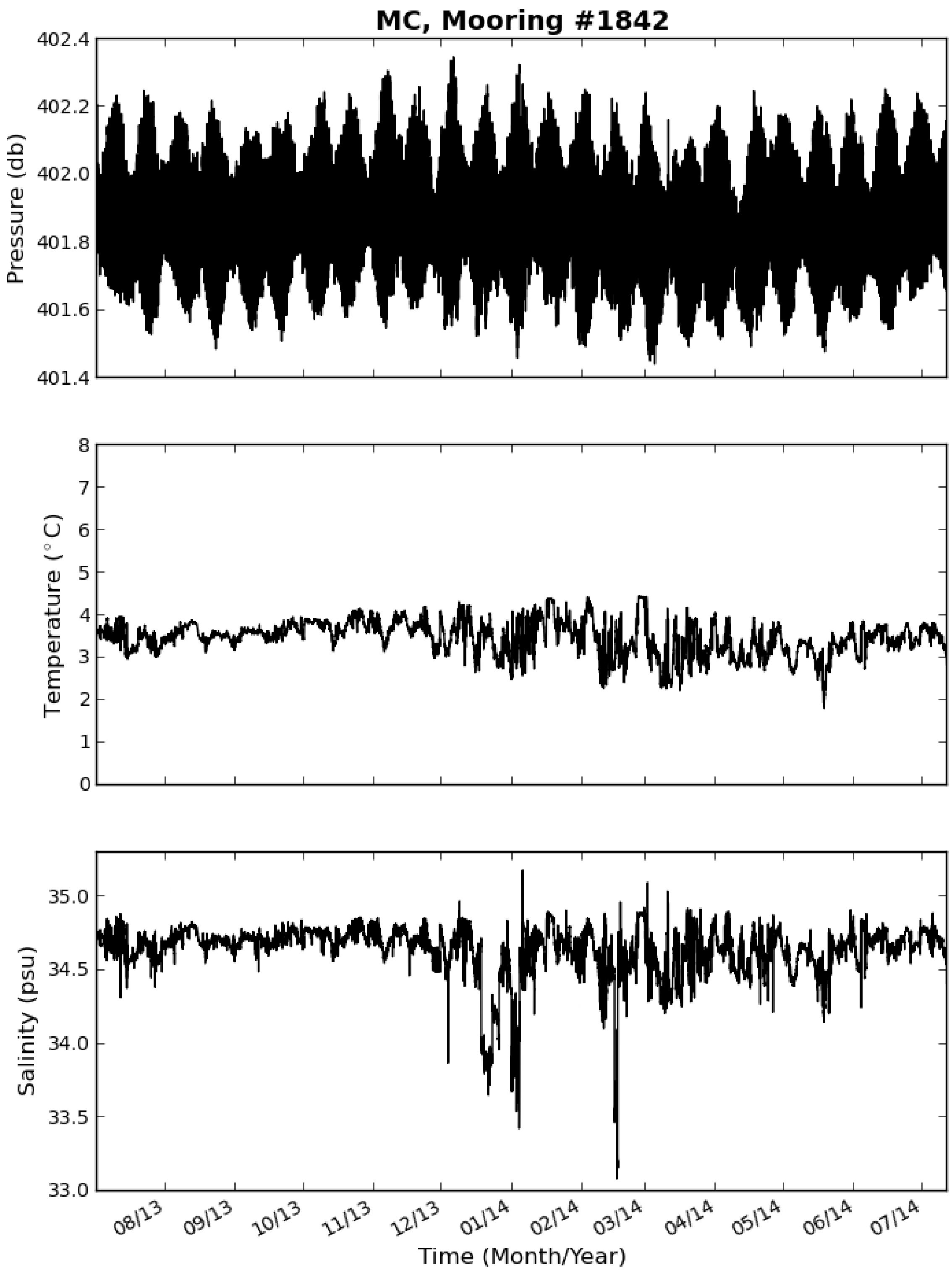
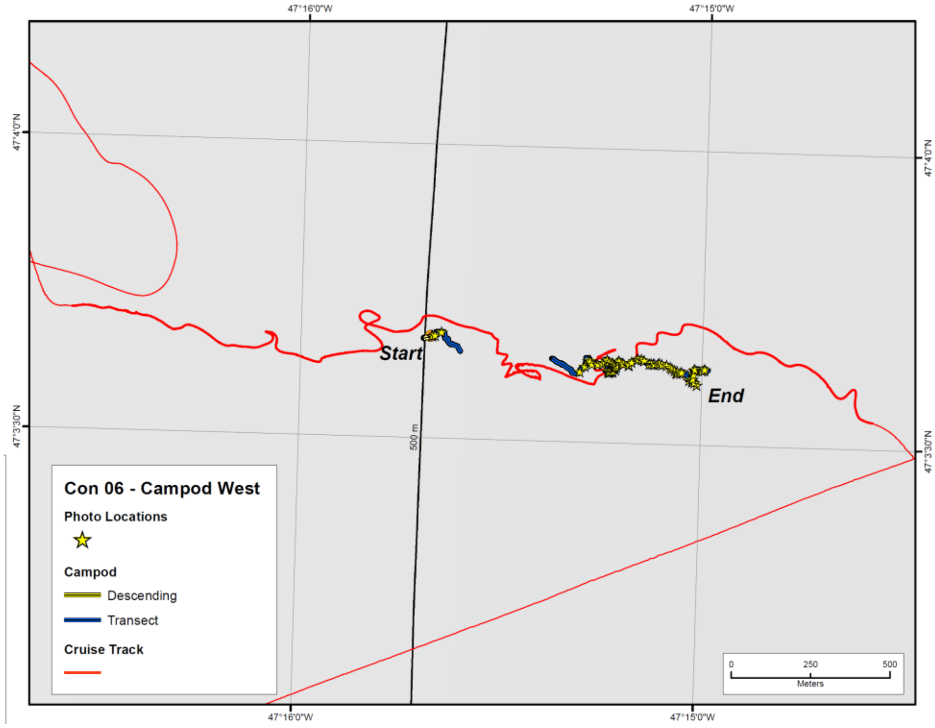
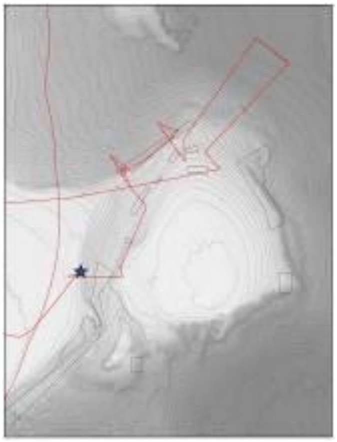


Figure 75 Moored-MC pressure, temperature and salinity, Flemish Pass (FP).

Appendix 8 Benthic Observations

Location 1 **Station: Campod West** **Camera: Campod**





Please note that the Hudson experienced difficulties with Campod cable angle. To ensure proper cable angle the Hudson had to move Campod off the bottom and manoeuver more than usual. When the Hudson engines are running the 'noise' created results in poor trackpoint data.

Also, track point is only available up to 15:15:56 about 30 minutes before the off bottom time. The user may find the ship's cruise track to be a better source of campod location for this transect.

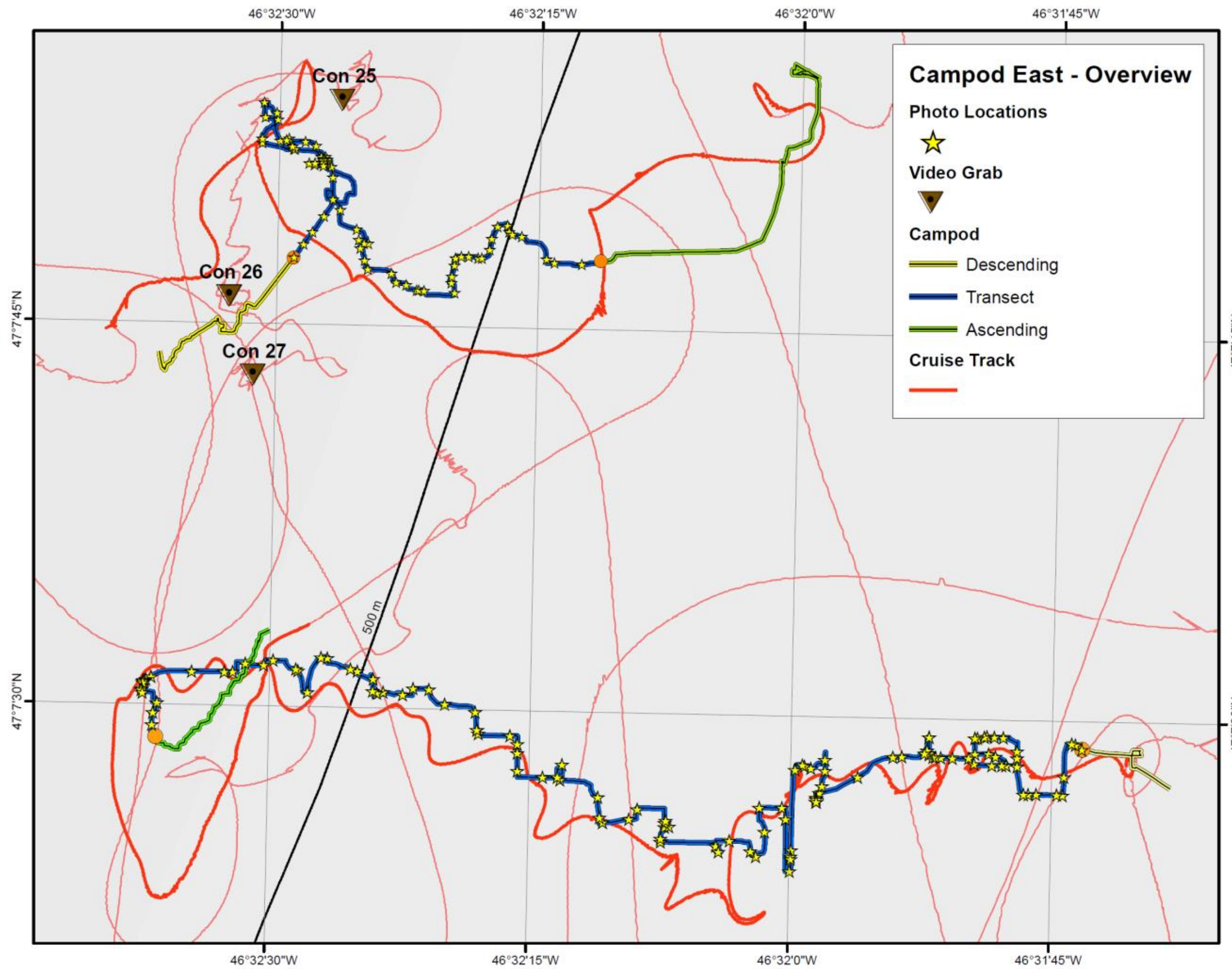
** Note: In this map, cruise track is highlighted from in water, on deck times.

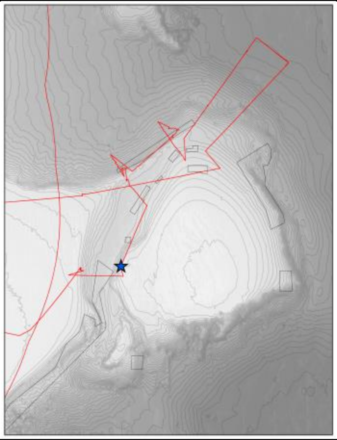
Con 06

Location	*Latitude*	*Longitude*	*Time*
In Water*	N/A	N/A	182134444
On Bottom	47.061225	-47.261244	182140755
Off Bottom*	N/A	N/A	182154716
On Deck*	N/A	N/A	182160320
Time On Bottom (h:mm)	1:40		

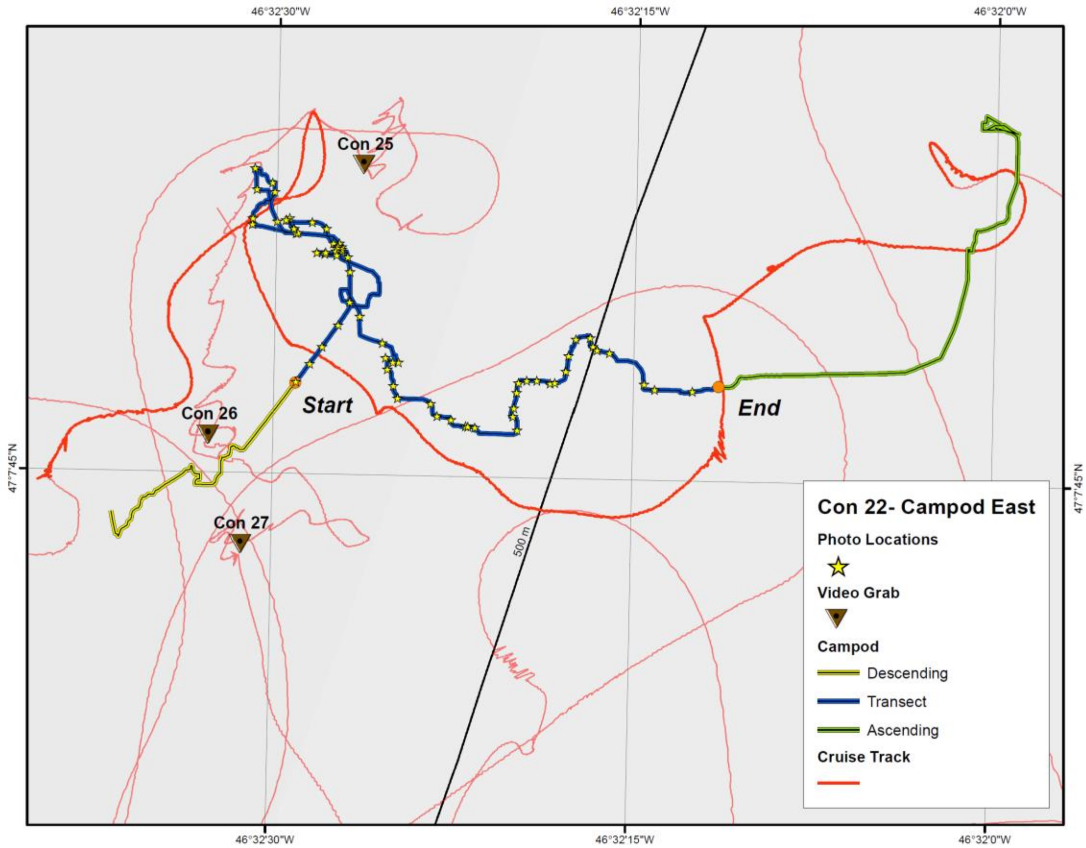
Dive Length – Track Point Line	*Start Depth (m)*	*End Depth (m)*	*Number of Photos*
Approx – 1.1km (*recorded time only)	433	508	110

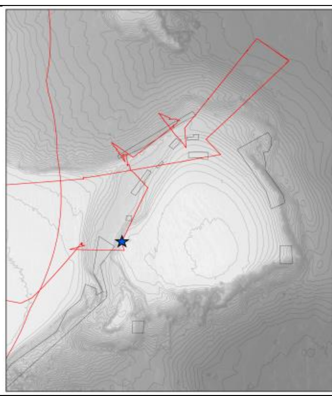
Overview **Campod East** **Camera: Campod**





Location 2 **Station: Campod East** **Camera: Campod**





Con 25 - Sample successful – Asconema collected (2 specimens). No sediment but several rocks with encrusting sponges.

Con 26 - Target – fan-shaped sponge was unsuccessful.

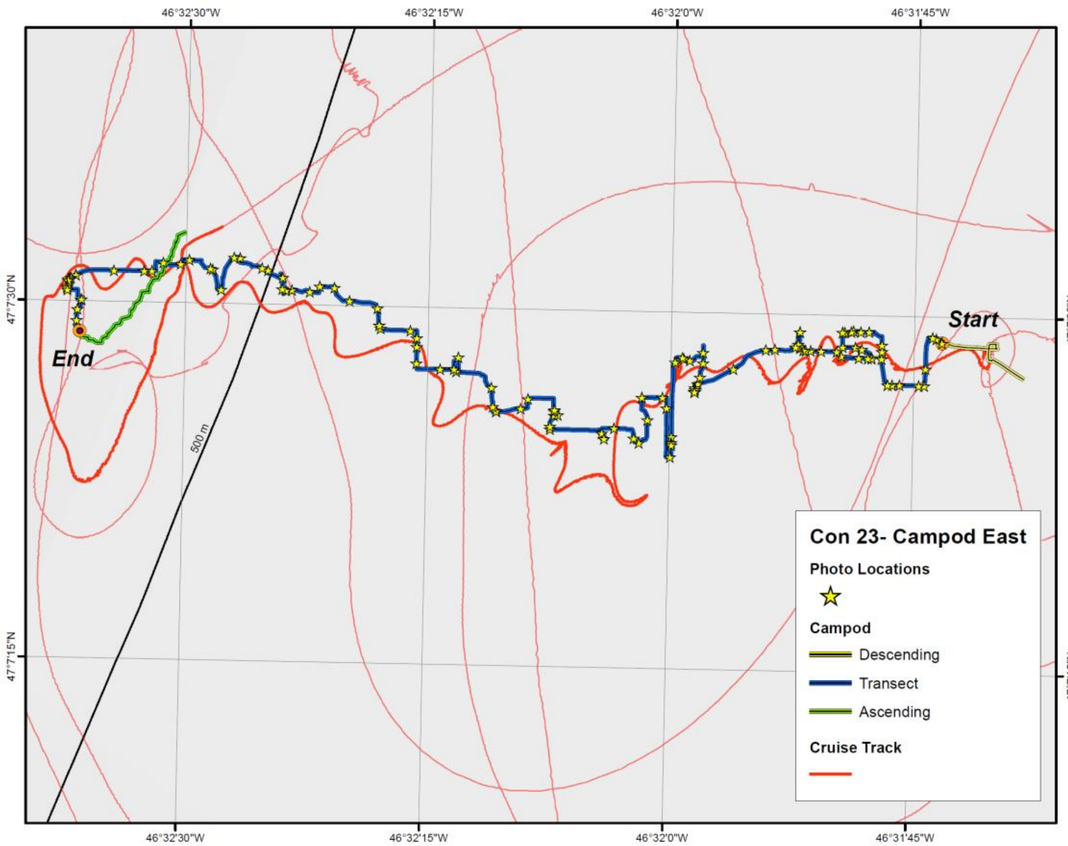
Con 27 – Target – fan-shaped sponge was not successful. Several rocks were collected.

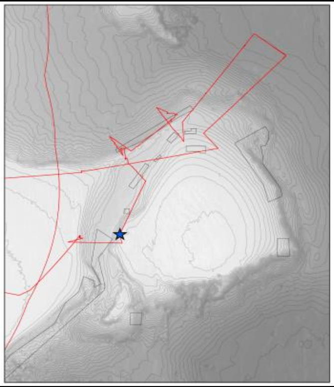
Con 22

Location	*Latitude*	*Longitude*	*Time*
In Water	N/A	N/A	183093005
On Bottom	47.129884	-46.541397	183094503
Off Bottom	47.129911	-46.536496	183102419
On Deck	N/A	N/A	183103937
Time On Bottom (h:mm)	0:39		

Dive Length – Track Point Line	*Start Depth (m)*	*End Depth (m)*	*Number of Photos*
Approx – 1.2km	484	457	72

Location 3 **Station: Campod East** **Camera: Campod**



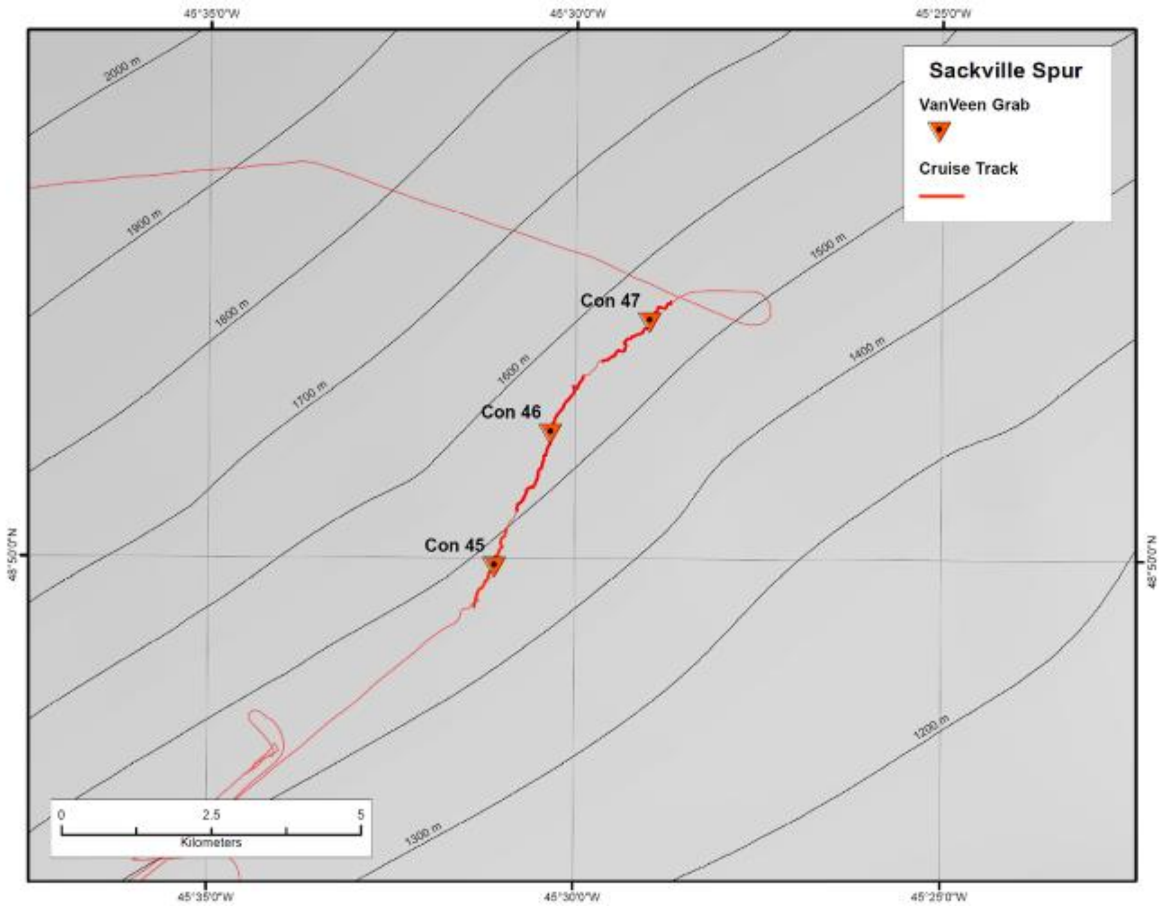


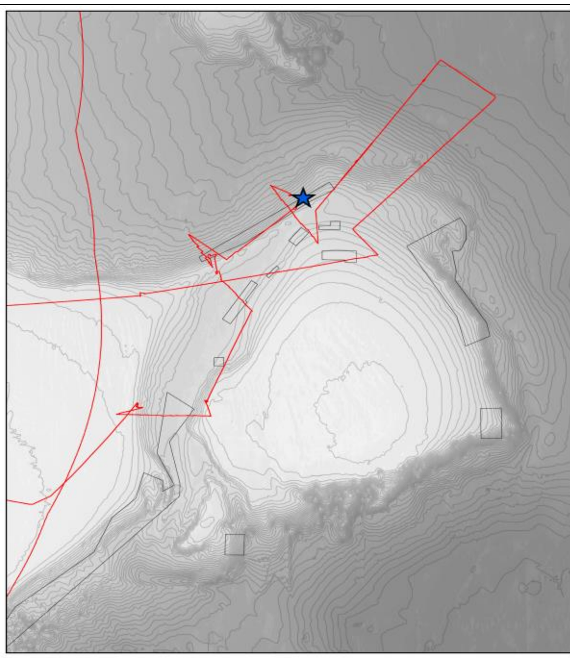
Con 23

Location	*Latitude*	*Longitude*	*Time*
In Water	N/A	N/A	183112356
On Bottom	47.124695	-46.528667	183113624
Off Bottom	47.124644	-46.543443	183131753
On Deck	N/A	N/A	183133030
Time On Bottom (h:mm)	1:41		

Dive Length – Track Point Line	*Start Depth (m)*	*End Depth (m)*	*Number of Photos*
Approx – 2.4km	440	483	131

Location 4 **Station: Sackville Spur** **vanVeen Grabs**



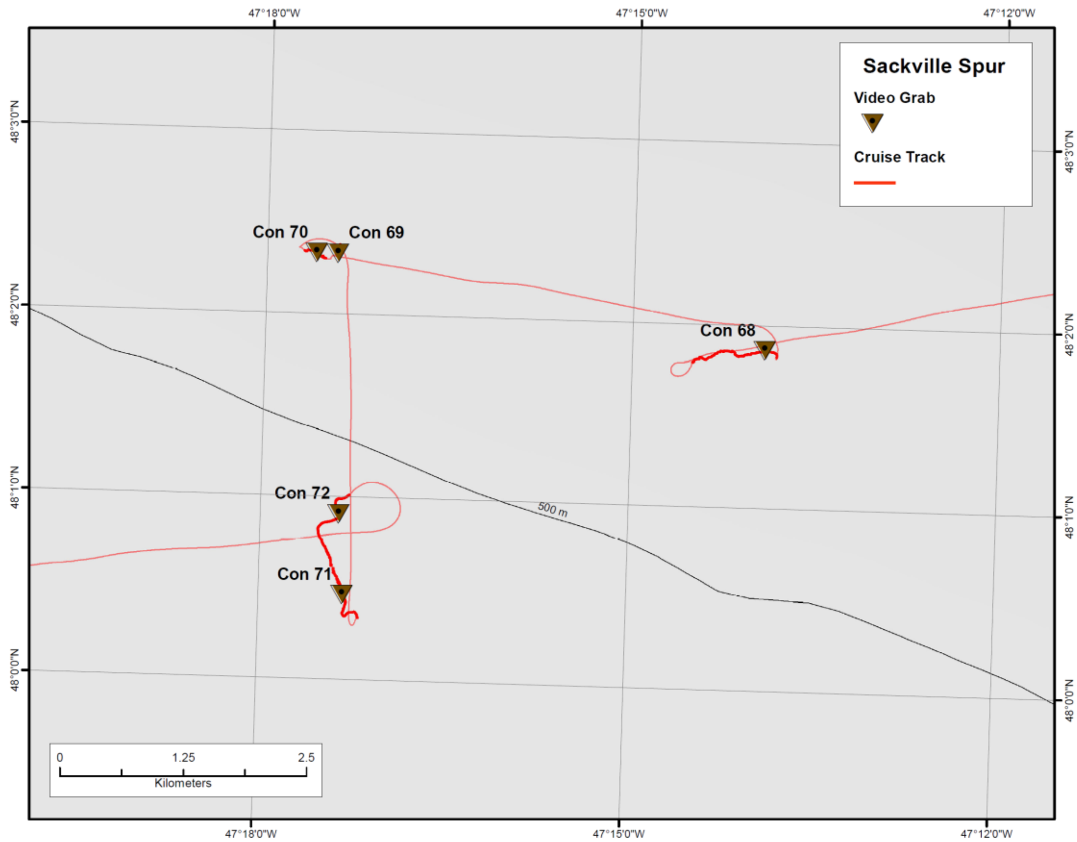


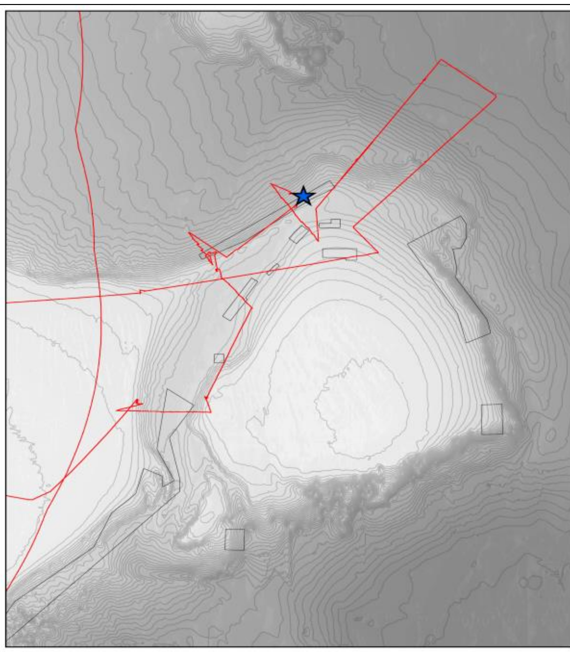
Con 45 – VanVeen successful, small geodia collected.
Depth ~ 1437m

Con 46 – VanVeen successful, no sponge collected but many spicules present in sample (20 litres of sediment)
Depth ~ 1564m

Con 47 – VanVeen successful, no sponge collected but spicules present in sample (17 litres of sediment)
Depth ~ 1575m

Notes taken from cruise database, general table.





Con 68 – Sample not taken – abundant large anemones, sponge is sparse.

Con 69 – Sample not taken – many polymastia and Anthomastus, fairly abundant sponge area.

Con 70 – Sample successful (1/2 grab) – no sponge collected. Sponge not as abundant as in Con 69. Problems with video grab bucket closing properly.

Con 71 – Sample successful – sponge collected. Many finger-like sponges firmly attached to rocks. Other smaller sponges collected.

Con 72 – Targeted an anemone and polymastia. Unsure if sample was successful (notes look incomplete here.)

Biological collections from Video grab and van Veen sediment samples

CON	Collection	Container	Preservative	Genetics
25	Asconema	1L	E	
25	Asconema	small falcon	E	Y
25	Brachiopoda	20ml	E	
25	chiton	20ml	E	
25	Geodia	small falcon	E	Y
25	Hexadella cf. dendritifera	20ml	E	
25	Ophiuroidea	60ml	F	
25	Porifera	20ml	E	
25	Porifera	60ml	E	
25	unsorted taxa	60ml	F	
25	Unsorted taxa on rocks	10L	F	
26	Unsorted taxa on rocks	5L	F	
27	Unsorted taxa on rocks	5L	F	
45	0.5mm	5L	F	
45	1.0mm	10L	F	
45	Didemnidae	20ml	E	Y
45	Didemnidae	20ml	F	
45	Geodia	20ml	E	
45	Hexactinellida	20ml	E	
45	Ophiacantha anomala	60ml	F	
45	Polychaeta	20ml	F	
45	Porifera	20ml	E	
45	spicule clumps	60ml	E	
45	Thenea	20ml	E	
46	0.5mm	5L	F	
46	1.0mm	5L	F	
46	Asbestopluma	20ml	E	
46	Bryozoa	20ml	E	
46	Porifera	20ml	E	
46	Thenea	60ml	E	
46	unsorted taxa	20ml	F	
47	0.5mm	5L	F	
47	1.0mm	5L	F	
70	unsorted taxa	20ml	E	
70	unsorted taxa	60ml	F	
70	unsorted taxa	500ml	F	
71	ascidian/sponge	yellow cup	E	Y
71	Brachiopoda	20ml	E	Y
71	Bryozoa	yellow cup	E	Y
71	Didemnidae	60ml	F	
71	Hydrozoa	yellow cup	E	Y

71	Hydrozoa	yellow cup	E	Y
71	limpet	20ml	E	Y
71	Ophiuroidea	20ml	E	Y
71	Porifera	60ml	E	
71	Porifera	60ml	E	Y
71	Porifera	yellow cup	E	Y
71	Porifera	yellow cup	E	Y
71	Porifera	20ml	E	
71	Psolus	20ml	E	Y
71	Sabellidae	yellow cup	E	Y
71	Sabellidae	yellow cup	E	Y
71	Scalpellidae	20ml	E	Y
71	Terebellidae	yellow cup	E	Y
71	unsorted taxa	5L	F	
72	0.5mm	5L	F	
72	1.0mm	5L	F	
72	Anemone	125ml	F	
72	Anemone	yellow cup	E	Y
72	Anemone	yellow cup	E	Y
72	Anemone	5L	F	
72	Ascidiacea solitary	20ml	E	Y
72	Ascidiacea solitary	250ml	F	
72	Didemnidae	yellow cup	E	Y
72	Didemnidae	250ml	F	
72	unsorted taxa	125ml	F	