Moored Current and Hydrographic Measurements from the RAPID WAVE Scotian Line, 2008 to 2018

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Les établissements de l’ancien secteur des Sciences et Levés océaniques dans les régions et à l'administration centrale ont cessé de publier leurs diverses séries de rapports en décembre 1981. Vous trouverez dans l'index des publications du volume 38 du *Journal canadien des sciences halieutiques et aquatiques*, la liste de ces publications ainsi que le dernier numéro paru dans chaque catégorie. La nouvelle série a commencé avec la publication du rapport numéro 1 en janvier 1982.

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Moored measurements of currents, temperature, salinity and bottom pressure made at 6 sites across the Scotian Slope and Rise between October 2008 and May 2018 are summarized with respect to positions and periods; data return, quality and availability; and salient features. The measurements were part of the Western Atlantic Variability Experiment of the Rapid Climate Change program funded by the United Kingdom's Natural Environment Research Council and led by the Proudman Oceanographic Laboratory, in partnership with Fisheries and Oceans Canada (DFO) at the Bedford Institute of Oceanography. The measurement sites were in water depths ranging from 1100m to 3900m near the Halifax Line and its deep-water extension (XHL), where DFO was carrying out hydrographic monitoring which facilitated the field operations and complemented the moored datasets. There were 5 deployments of 9-21 months duration at the 6 primary mooring sites between 2008 and 2014, and 2 additional deployments of 19-24 months duration at 4 of the sites until 2018. The primary instrumentation at each site was an upward-looking Acoustic Doppler Current Profiler (ADCP) at 50 m above bottom (mab), a MicroCAT (MC) temperature-conductivity-pressure recorder at 100 mab, and a bottom pressure recorder (BPR), with additional MCs up to 1100m below the surface at the deepest site during the first 4 deployments. A total of 34 ADCPs, 74 MCs and 34 BPRs returned good data. Example displays of the moored time series, temperature-salinity sections and sea surface temperature composites from the concurrent DFO monitoring, and concatenations with earlier moored time series are provided.

Résumé

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Ce document résume les données sur les courants, la température, la salinité et la pression au fond qui ont été enregistrées entre octobre 2008 et mai 2018 par des instruments amarrés à six sites sur le talus et le glacis néo-écossais selon les positions et les périodes; le retour, la qualité et la disponibilité des données; et les caractéristiques saillantes. Ces données ont été enregistrées lors de l’expérience sur la variabilité dans l’Atlantique Ouest qui a été menée dans le cadre du programme Rapid Climate Change financé par le Natural Environment Research Council du Royaume-Uni et qui a été dirigée par le Proudman Oceanographic Laboratory, en partenariat avec l’Institut océanographique de Bedford de Pêches et Océans Canada (MPO). Les sites d’enregistrement des données se trouvaient à des profondeurs allant de 1 100 à 3 900 m près du transect d’Halifax et de son prolongement en eaux profondes, où le MPO effectuait une surveillance hydrographique qui a facilité les opérations sur le terrain et qui a complété les ensembles de données enregistrées par les instruments amarrés. Il y a eu 5 déploiements d’une durée de 9 à 21 mois sur les 6 principaux sites d’amarrage entre 2008 et 2014, et 2 déploiements supplémentaires d’une durée de 19 à 24 mois sur 4 des sites jusqu’en 2018. Les instruments principaux installés à chacun des sites étaient un profileur de courant à effet Doppler (ADCP) orienté vers le haut à 50 m au-dessus du fond, un enregistreur de la température, de la conductivité et de la pression MicroCAT à 100 m au-dessus du fond et un enregistreur de la pression au fond avec des enregistreurs MicroCAT supplémentaires jusqu’à 1 100 m sous la surface au site le plus profond pendant les 4 premiers déploiements. Au total, 34 ADCP, 74 enregistreurs MicroCAT et 34 enregistreurs de la pression au fond ont enregistré de bonnes données. Le document contient aussi des exemples de séries chronologiques des données enregistrées par les instruments amarrés, des sections de température et de salinité ainsi que des données composites sur la température à la surface de la mer provenant de la surveillance effectuée simultanément par le MPO, de même que des concaténations avec les séries chronologiques des données enregistrées antérieurement par des instruments amarrés.

1. Introduction

This report is intended to be a guide to the moored measurements made in the "Scotian Line" component of the Western Atlantic Variability Experiment (WAVE) funded by the UK Natural Environment Research Council (NERC) as part of its Rapid Climate Change (RAPID) program (e.g., Hughes et al., 2013). The focus is on measurements obtained through the collaboration of the UK Proudman Oceanographic Laboratory (POL) and Fisheries and Oceans Canada's (DFO's) Bedford Institute of Oceanography (BIO) between October 2008 and September 2014. Information is also provided on 2 further deployments of moorings at 4 of the sites between September 2014 and May 2018, and on complementary hydrographic surveys by BIO.

During its primary 2008-14 period, the "RAPID Scotian" (RS) program involved 5 deployments of moorings at 6 sites across the Scotian Slope and Rise between the ~1100 and ~3900m isobaths (Fig. 1). The sites were, in part, on a historical ocean monitoring section referred to here as the Halifax Line (or section) (HL; e.g., Petrie and Drinkwater 1993; Loder et al., 2003) and, in part, on its offshore extension to a water depth of 4700m which was started by BIO in the mid 2000s. The extension is sometimes referred to as the eXtended Halifax Line (XHL), but HL and XHL are used interchangeably here in the names of the stations common to both. Since 1998, BIO has carried out tri-seasonal physical-chemical-biological surveys across the Scotian Shelf and Slope (out to the 2700m isobath) on the HL, as part of the DFO Atlantic Zone Monitoring Program (e.g., AZMP 2010; Hebert et al., 2024). The RS moored measurement program was closely coordinated with the AZMP and its offshore extension - the DFO Atlantic Zone Off-shelf Monitoring Program (AZOMP) – which sampled the outer XHL.

Seasonal hydrographic sampling on the HL was carried out between 1950 and the early 1970s by Canada as a contribution to international monitoring (e.g., de la Ronde, 1972; Drinkwater and Taylor 1982). Only sporadic sampling of the section was carried out between the mid 1970s and late 1990s (e.g., Mann and Needler 1973; Loder et al., 2003), before the initiation of AZMP by DFO in the late 1990s in response to the collapse of the commercial groundfishery off Atlantic Canada.

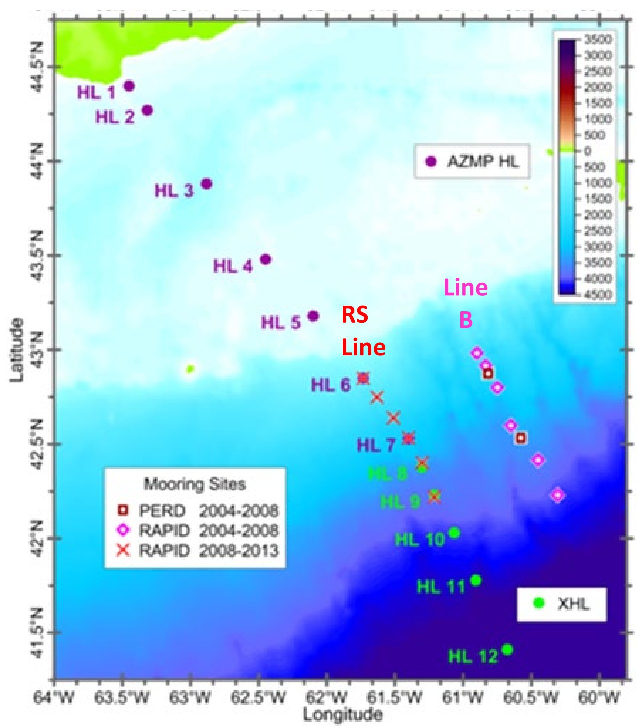


Figure 1. Positions of moorings and standard CTD stations on or near the HL/XHL/RS Line during 2004-18. The core AZMP stations (HL1-7) are shown in **magenta (solid circles)**, and the core AZOMP stations (HL8-12, also referred to as XHL8-12) are shown in **green (solid circles)**. These stations were occupied on most of the cruises when RAPID moorings were deployed or recovered, in addition to CTD profiles taken near the RAPID mooring sites and MC-CTD calibration casts on each cruise. The 6 RAPID-Scotian (RS) mooring sites are indicated by the **red x's**. RS1 is near HL6, RS4 near HL7, RS5 near HL8 and RS6 near HL9. There were moorings at all 6 sites during 2008-2014 and at 4 of the sites during 2014-18 (see Tables 2 & 3). Also shown are the positions of moorings deployed by POL and BIO during 2004-08 on a cross-slope line (corresponding to a satellite altimetry track) referred to by POL as Line B of RAPID WAVE. The moorings deployed by POL on Line B were at 6 sites (indicated by pink open diamonds), and those by BIO as part of a Panel on Energy Research and Development (PERD) program at 2 sites (red open squares, referred to as SS-D and SS-E).

An important finding from analyses of the 1950s-1980s data (Petrie and Drinkwater 1993; Loder et al., 2001, 2003) was that a pentadal period of relatively-cold and -fresh water over the upper Scotian Slope (<1000m) and Shelf had occurred in the early 1960s associated with increased transport of subpolar (Labrador) water around the Tail of the Grand Bank. This anomaly and a more extreme equatorward extension of subpolar water into the Mid Atlantic Bight in the 1880s appear to have been related to the North Atlantic Oscillation having a prolonged period of negative phase (Marsh et al., 1999; Petrie 2007).

Multi-year moored measurements on the Scotian Slope were first made in the late 1970s, ~150 km to the west of the XHL (Smith and Petrie 1982). A moored current and hydrographic measurement program with instruments distributed over the water column at 3 sites near the HL (in water depths of 300, 1100 and 2000m) was carried out during 2000-04 (Loder and Geshelin 2009, 2025). Its results included the finding that the seasonal-mean equatorward flow of subpolar water at depths above 600m at all 3 sites could be disrupted by Gulf Stream (warm-core) rings impinging on the slope, with the equatorward flow at all depths (down to 2000m) reduced during these episodic events. Thus, the upper-ocean circulation in the RS study area is complex, related to variability in the western boundary currents (Labrador Current and Gulf Stream) of the North Atlantic's upper-ocean subpolar and subtropical gyres.

The moored instrumentation on the RS Line – Acoustic Doppler Current Profilers (ADCPs), MicroCAT temperature-conductivity-pressure recorders (MCs) and bottom pressure recorders (BPRs) - was at depths below 1000m. The goal from the RAPID WAVE perspective was to use a novel approach referred to as the "stepping method", involving near-bottom current and density measurements to reconstruct bottom pressure changes on the North Atlantic basin's western boundary (Bingham and Hughes, 2008; Hughes et al. 2013), to obtain estimates of the variability in the Atlantic Meridional Overturning Circulation (AMOC). The AMOC transport estimates at the 42.5ºN latitude of the RS Line would then be used in conjunction with estimates from other latitudes, such as the UK-USA RAPID-MOCHA Line at 26.5ºN (Cunningham et al., 2007) and the Woods Hole Oceanographic Institution Line W at 39ºN (Toole et al., 2011), to help describe and monitor spatial and temporal variability in the AMOC (e.g., Elipot et al., 2013, 2014, 2017; Xing et al., 2025a,b). While the RS measurements were essentially in the Deep Western Boundary Current (DWBC) on the XHL, the derived and measured pressure estimates together with pressure estimates on the basin's eastern boundary allowed estimation of net meridional transport – a very important index for global climate change (e.g., Gulev and Thorne 2021).

The initial RAPID WAVE moorings near 42.5ºN were deployed in 2004 on a Line A across the slope and rise of the southwestern Grand Bank (not shown), and on a Line B along a satellite altimetry track across the Scotian Slope and Rise about 60 km to the east of the HL/XHL (Fig. 1). To complement these and provide current measurements relevant to oil and gas exploration in the area, BIO deployed short moorings with a near-bottom current meter and MC at 2 sites with water depths of 2400 and 3400m (referred to as SS-D and SS-E, respectively) between 2004 and 2008. The RAPID WAVE Scotian Line was then shifted from Line B to be close to (within a few km of) the HL/XHL in September 2008, with the POL-BIO partnership providing efficiencies in equipment, personnel and vessel time, including the availability of high-quality temperature and salinity profiles from AZMP and AZOMP.

The next two sections (§2 and §3) will provide further introductory and summary information on the RS mooring program, and on the complexity of the bottom topography on the HL/XHL, respectively. This will be followed by a brief chronology (in §4) of the various cruises involved in the mooring deployments and recoveries, and then a description (in §5) of the instrumentation used in the moorings together with data return and quality issues. Example displays of the data from the program and complementary datasets will then be provided (in §6), followed by concluding remarks (§7). The mooring diagrams are provided in the Appendix.

2. Overview of RAPID WAVE Scotian Program, 2008-18

Meta information on the 2008-18 POL-BIO RAPID Scotian mooring program is presented in Tables 1, 2 and **3**. There were moorings deployed or recovered on the HL/XHL/RS Line on 8 BIO cruises on the Canadian Coast Guard Ship (CCGS) Hudson between 2008 and 2018. In DFO records, these are designated HUDnnnn-ppp where nnnn refers to the year and ppp to the sequential DFO Atlantic Zone Science cruise in that year (e.g., HUD2008-037), or sometimes just HUD2008037, HUD08037 or cruise 2008-037. Most of these cruises were led by personnel in the DFO AZMP which carried out a hydrographic and biological/chemical survey on the HL and other cross-shelf/slope lines at least twice a year (spring and fall). The RAPID moored measurements were complementary to the AZMP sampling on the HL, and to deeper-ocean sampling on the XHL as part of the AZOMP which led 2 of the cruises. High-quality CTD/bottle profiles were taken near the RS mooring sites as well as at other sites on the HL/XHL/RS Line (Fig. 1). The execution of the RS mooring program would not have been possible without the excellent cooperation of the personnel involved in the AZMP/AZOMP HL/XHL surveys.

There were 7 "deployments" (Deploys 1-7) of multiple moorings on the RS Line, involving 6 different sites between the nominal 1100 and 3900m isobaths (Table 1, Fig. 1). The cruises, sites, deployment and recovery dates, and durations (ranging from 9 to 24 months) are included in Table 1, together with brief comments on the recovered moorings and data.

Table 1. RAPID WAVE Scotian mooring deployments (D #) during 2008-18, with the DFO Atlantic deployment and recovery cruise numbers (Year-ppp), mooring deployment and recovery dates, deployment durations (in months), mooring sites (RS #'s), and comments. The primary instruments on the moorings were Acoustic Doppler Current Profilers (ADCPs); MicroCAT temperature, conductivity and pressure recorders (MCs); bottom pressure recorders (BPRs); and acoustic releases (ARs). 'mab' refers to 'm above bottom'.

D #	Deployment		Recovery		Duration	Sites	Comments
	Cruise	Dates	Cruise	Dates		RS#'s	
1	2008-037	2-3 Oct	2009-048	28-29 Sep	11.9	1, 2, 3, 4, 5, 6	All moorings recovered; Top float at ~101mab at RS1-5; 1 ADCP flooded, 3 with reduced records; 11 good MCs
2	2009-048	30 Sep – 2 Oct	2010-049	16-17 Dec	14.5	1, 2, 3, 4, 5, 6	RS5 not recovered; delayed recovery cruise so some reduced records (2 ADCPs, 4 MCs); 10 good MCs
3	2010-049	18-19 Dec	2011-043	24-26 Sep	9.2	1, 2, 3, 4, 5, 6	RS6 only partly recovered (BPR, ADCP & 2 MCs lost); 10 good MCs
4	2011-043	26-29 Sep	2013-004	5-7 Apr	18.3	1, 2, 3, 4, 5, 6A, 6B	Shifted site (RS6B) for RS6 with separate BPR mooring (RS6A); All moorings recovered; Float moved to ~176mab at RS1-5; No good ADCP at RS2; 15 good MCs
5	2013-004	7-9 Apr	2014-030	21-22 Sep	17.5	1, 2, 3, 4, 5B, 6B	Shifted site (RS5B) for RS5; All moorings recovered; Top float moved to ~201mab at all sites; Deepest MC at ~150mab (by mistake) at all sites
6	2014-030	23-24 Sep	2016-003	11 Apr	18.6	1, 3, 5B, 6B	Reduced array; Top float at ~201mab and deepest MC at ~150mab at all sites; Gap of 6wks before Dpl 7
7	2016-006	21-23 May	2018-008	15-16 May	23.8	1, 3, 5B, 6B	Reduced array; Top float at ~103mab and MCs at ~10 & ~100mab at all sites; RBR BPRs at RS3 & RS6

In Table 2, a complementary summary by RS site is presented, including the range of positions and water depths across the different deployments at each site, the BIO consecutive number (M####) for each mooring, and additional comments. Note the slightly-shifted positions (RS5B, RS6A, RS6B) for RS5 and RS6 in the later deployments due to unrecovered moorings from earlier deployments (see Fig. 3 in next section).

Table 2. RAPID WAVE Scotian mooring sites (RS#, proceeding toward deeper water), deployment (D) #'s at each site, latitude and longitude ranges of the mooring positions, ranges of the water depths for the different deployments, BIO consecutive mooring #'s, and comments. The deployments at nominal sites RS5 and RS6 have been separated into subgroups (RS5 & RS5B; RS6, RS6A & RS6B) because of slightly-shifted positions due to multiple moorings in the water and deployment/recovery considerations. Latitudes & longitudes (from M-Cal software triangulations where available) are shown as minutes in relation to 42°N and 61°W, respectively. Water depths are from BPR measurements where available (see Table 3). *Italics denote questionable depths.*

Site	D #'s	Lat Range, 42°: Decim. minutes	Long Range, 61°: Decim. minutes	Water Depth Range (m)	BIO Mooring (M) #'s	Comments
RS1	1-7	50.96 – 51.26	37.86 – 38.33	1087 – 1113	1696, 1742, 1777, 1804, 1834, 1886, 1942	#1 deepest, #6 shallowest, #7 uncertain
RS2	1-5	44.26 – 44.43	34.42 – 34.61	1690 - 1701	1697, 1743, 1778, 1805, 1835	#2 shallowest
RS3	1-7	39.32 – 39.57	27.31 – 27.7	2287 – 2307, *2253?*	1698, 1744, 1779, 1806, 1836, 1887, 1943	#1 shallowest
RS4	1-5	33.36 – 33.43	22.14 – 22.5	2751 - 2781	1699, 1745, 1780, 1807, 1837	#5 shallowest, #1 deepest
RS5	1-4	23.38 – 23.57	16.57 – 16.84	3417 - 3424	1700, 1746, 1781, 1808	M1746 not recovered
RS5B	5-7	23.83 – 24.26	13.31 -13.63	3455 – 3481, *3396?*	1838, 1888, 1944	Shifted position; complex bathymetry
RS6	1-3	9.69 – 9.91	4.21 – 4.67	3873 - 3880	1701, 1747, 1782	Parts of M1782 not recovered
RS6A	4	12.35	9.17	3860	1810	Separate BPR mooring
RS6B	4-7	10.67 – 10.88	-0.13* – +0.39	3856 – 3865, *3764?*	1809, 1839, 1889,1945	Shifted position; complex bathymetry

* The negative value for longitude minutes for RS6B indicates 60°59.87'.

In Table 3, a more detailed listing with information on all 39 moorings deployed in the RS program is provided, including their specific deployment and recovery dates, best estimates of their positions, and best estimates of the water depths and the instrument depths for each mooring. The primary instruments were an SBE53 bottom pressure recorder (BPR) mounted in the anchor of each mooring, a Teledyne/RDI Sentinel WorkHorse ADCP at 50 m above bottom (50 mab), and a SeaBird SBE37 MicroCAT (MC) recorder that was intended to be at 100 mab on each mooring (but which was mistakenly placed at 150 mab in Deploys 5 and 6). Additional MCs were deployed on some moorings. There were an additional 5 MCs on a tall mooring extending to 1000m below the surface (1000 mbs) at RS6 in Deploys 1-4. Also, a second near-bottom MC was included on most of the moorings in Deploys 5-7, and Aanderaa current meters (RCMs) provided by BIO were included on a few of the moorings in Deploys 1-4. The design diagrams for all of the moorings during Deploys 1-7 are included in the Appendix.

Table 3a. RS1 to RS5. Listing of moorings deployed during the 2008-18 RS program, with their site, deployment (D) #, BIO mooring #, deployment and recovery dates, positions, water depth, and depths of various instruments (MC for MicroCATs, ADCPs, BPR for Bottom Pressure Recorders, RCM for Aanderaa current meters). The listing is organized by site RS# and D# (1 to 7). Positions are from M-Cal triangulations, and water (and BPR) depths from BPR pressure (P) measurements, except in cases noted (e.g., D7*), with decimal minutes of latitude and longitude indicated (relative to 42ºN and 61ºW). ADCP depth is from the water depth and design wirelength (50 mab). MC depths are from MC P measurements in most cases, or from a combination of water depths, other instrument depths and design wirelengths in a few cases. *(The positions, and water and instrument depths indicated italics for D7* are tentative, based on drop positions, soundings and wirelengths.)* (See Table 3b for RS5B to RS6B)

Site	**D #**	**BIO #**	**Dates** (dd/mo/yr-2000)		**Position** (N,W)		**Watr Dpth (m)**	**MC Depths (m)**	**ADCP Depth (m)**	**BPR Depth (m)**	**RCM Dpths (m)**
			Deploy-ment	**Recov-ery**	**(42º) min**	**(61º) min**					
RS1	1	1696	03/10/08	28/09/09	50.96	37.86	1113	1015	1063	1113	
"	2	1742	02/10/09	16/12/10	51.22	37.92	1095	991	1045	1095	
"	3	1777	18/12/10	24/09/11	51.19	37.93	1098	999, 1073	1048	1098	1073
"	4	1804	30/09/11	05/04/13	51.15	38.11	1097	923, 997	1047	1097	1072
"	5	1834	09/04/13	21/09/14	51.17	38.03	1096	897, 946	1046	1096	
“	6	1886	24/09/14	11/04/16	51.26	38.33	1087	888, 937	1037	1087	
“	7*	1942	22/05/16	15/05/18	*51.21*	*38.07*	*1075*	*975, 1065*	*1025*	*1075*	
RS2	1	1697	03/10/08	28/09/09	44.26	34.61	1699	1597	1649	1699	1586, 1592, 1595
"	2	1743	02/10/09	16/12/10	44.43	34.45	1690	1592	1640	1690	
"	3	1778	18/12/10	24/09/11	44.36	34.42	1697	1599	1647	1697	
"	4	1805	29/09/11	05/04/13	44.30	34.48	1701	1602	1651	1701	
"	5	1835	09/04/13	21/09/14	44.31	34.42	1701	1504, 1553	1651	1701	
RS3	1	1698	03/10/08	28/09/09	39.50	27.70	2287	2190	2237	2287	
"	2	1744	02/10/09	16/12/10	39.57	27.41	2289	2191	2239	2289	
"	3	1779	18/12/10	24/09/11	39.32	27.38	2307	2208	2257	2307	
"	4	1806	29/09/11	05/04/13	39.36	27.39	2304	2129, 2204	2254	2304	
"	5	1836	08/04/13	21/09/14	39.36	27.50	2302	2104, 2152	2252	2302	
“	6	1887	24/09/14	11/04/16	39.33	27.31	2307	2108, 2155	2257	2307	
"	7*	1943	22/05/16	15/05/18	*39.39*	*27.35*	*2253*	*2153, 2243*	*2203*	*2253*	
RS4	1	1699	03/10/08	29/09/09	33.36	22.14	2781	2683	2731	2781	
"	2	1745	01/10/09	16/12/10	33.41	22.15	2777	2679	2727	2777	
"	3	1780	18/12/10	24/09/11	33.39	22.25	2773	2674	2723	2773	
"	4	1807	26/09/11	05/04/13	33.43	22.26	2766	2666	2716	2766	
"	5	1837	08/04/13	21/09/14	33.39	22.50	2751	2552, 2601	2701	2751	
RS5	1	1700	02/10/08	29/09/09	23.57	16.57	3424	3326	3374	3424	
"	2	1746	01/10/09	N/r	23.47	16.63	Not recovered			N/r	
"	3	1781	18/12/10	24/09/11	23.53	16.61	3419	3332	3369	3419	
"	4	1808	26/09/11	05/04/13	23.38	16.84	3417	3242, 3317	3367	3417	

Table 3b. *(continued)* RS5B to RS6. Listing of moorings deployed during the 2008-18 RS program.

Site	D #	BIO #	Dates (dd/mo/yr-2000)		Position (N,W)		Watr Dpth (m)	MC Dpths (m)	ADCP Depth (m)	BPR Dpth (m)	RCM Dpths (m)
			Deploy-ment	Recov-ery	42° min	61° min					
RS5B	5	1838	08/04/13	23/09/14	23.83	13.36	3481	3284, 3334	3431	3481	
"	6	1888	23/09/14	11/04/16	24.26	13.63	3455	3251, 3301	3405	3455	
"	7*	1944	22/05/16	16/05/18	*24.22*	*13.31*	*3396*	*3296, 3386*	*3346*	*3396*	
RS6	1	1701	02/10/08	29/09/09	9.81	4.22	3876	984, 1583, 2181, 2680, 3275, 3777	3826	3876	982
"	2	1747	30/09/09	17/12/10	9.91	4.67	3873	979, 1568, 2173, 2675, 3272, 3771	3823	3873	977
"	3	1782	19/12/10	25/09/11	9.69	4.21	3880	885, lost, 2185, 2681, 3280, lost	3830 (lost)	3880 (lost)	883
RS6A	4	1810	28/09/11	07/04/13	12.35	9.18	3860	nil		3860	
RS6B	4	1809	28/09/11	07/04/13	10.83	0.39	3856	998, 1557, 2157, 2657, 3256, 3605, 3756	3806	nil	996
"	5	1839	07/04/13	23/09/14	10.88	0.25	3858	3662, 3710	3808	3858	
"	6	1889	24/09/14	11/04/16	10.69	-0.13$^{\Delta}$	3865	3665, 3715	3815	3865	
"	7*	1945	21/05/16	16/05/18	*10.67*	*0.17*	*3764*	*3664, 3754*	*3714*	*3764*	

*D7, all sites: *Positions, and water depths are for drop positions and from soundings, respectively, although M-Cals are available for RS1 and RS3. Instrument depths for D7 are tentative estimates from the water depths and design wirelengths.*

$^{\Delta}$RS6B, D6: The RS6B Longitude is 60° 59.87'W (or 61° -0.13'W)

Summarizing some key points:

- The primary RS program involved 5 deployments of moorings over the period October 2008 to September 2014, at the 6 nominal sites (RS1–RS6) whose position and water depths ranges are provided in Table 3. The subsequent secondary deployments (#'s 6 and 7) from September 2014 to May 2018 (with a 6-week gap in spring 2016) involved only 4 sites with reduced instrumentation.
- The nominal water depths for the mooring sites were 1100, 1700, 2300, 2800, 3400 and 3900m. The moorings at RS1–RS5 had near-bottom (within 200m) instruments only, with a primary MC intended to be at 100 mab (Table 3, Fig. 2). In contrast, a tall mooring was deployed at RS6 in Deploys 1-4, with MCs at the same approximate depths as the primary one at the other 5 sites; e.g., the top MC in these RS6 moorings was at ~1000 mbs, the same mbs as the primary one at RS1. In Deploys 5-7, the moorings were all short (<201 mab) with near-bottom instrumentation only.
- Nothing was recovered from only one (M1746 at RS5 in Deploy 2) of the 39 deployed moorings, apparently due to an acoustic release failure or tangle. Another mooring (M1782 at RS6 in Deploy 3) was only partly recovered through dragging due to an apparent wire tangle involving the acoustic release and the anchor/mount. There were also a few instrument failures, or premature ends of recording associated with battery failure (to be discussed in §5 for particular types of instruments).
- The primary mooring position for RS6 was shifted by 5-6 km to RS6B in Deploy 4, and the primary position for RS5 shifted to RS5B by 3-4 km in Deploy 5, in both bases to allow dragging for unrecovered equipment from the earlier unsuccessful recoveries. Unfortunately, there was a significant difference in the bottom slope gradient between the original and shifted positions at both RS5 and RS6,

associated with relic topographic features (e.g., cross-slope ridges) from historical continental-slope sediment slumping (see next section). This resulted in differences in the mean current direction between the original and shifted positions (apparent topographic steering) which need to be accounted for in the use of the ADCP data for long-term variability.

- Mooring positions have historically been recorded on BIO mooring logsheets as the drop position of the mooring's anchor from the vessel. This was done for the RAPID mooring deployments. Alternative and potentially better estimates of the settling position of each mooring were available for most deployments from acoustic communication (from various directions) with the acoustic release after the settling, through a process referred to as "M-Cal triangulation". The best-estimate mooring positions in Tables 2 and 3 are from these M-Cal triangulations when they were of good quality (with the estimated water depth from the triangulation being a quality check). In contrast, the latitudes and longitudes in the ODF (Ocean Data Format) files for the RAPID moored measurements in the BIO Archive are for the drop position, with those from the M-Cal triangulation indicated in the Comments in the MC ODF files. The differences are generally small (only 100m or so).
- The best-estimate water depths in Tables 2 and 3 are from BPR measurements where available (as for most moorings). Exceptions are M1782 at RS6 in Deploy 3 in which case the BPR was not recovered, M1809 at RS6B in Deploy 4 in which case the BPR was on a separate mooring (M1810) several km away, and the 4 moorings in Deploy 7 for which the BPR mean pressures were not readily available at the time of this report. The water depths for M1782 and M1809 were estimated from consideration of the mooring depths from the M-Cal triangulations, P measurements from MCs on each mooring, the design wirelengths, and other BPR measurements at the same site.
- The ADCP depths in Table 3, taken as 50 mab in all cases, were estimated from the water depths and the design wire-lengths. P estimates were available from the ADCPs but they were not considered as reliable as the other P and depth information. The MC depths were estimated from the MCs' P measurements in most cases (which were calibrated using data from MC-CTD casts, §5.4), and from a combination of water depth, wirelengths, and other P measurements in the other cases.
- The moorings in Deploys 2-6 were deployed within 1-3 days after recovery (or attempted recovery) of the previous mooring at each site. However, the Deploy 7 moorings were deployed about 6 weeks after the Deploy 6 recoveries, resulting in a significant gap in the merged time series (§6.2).

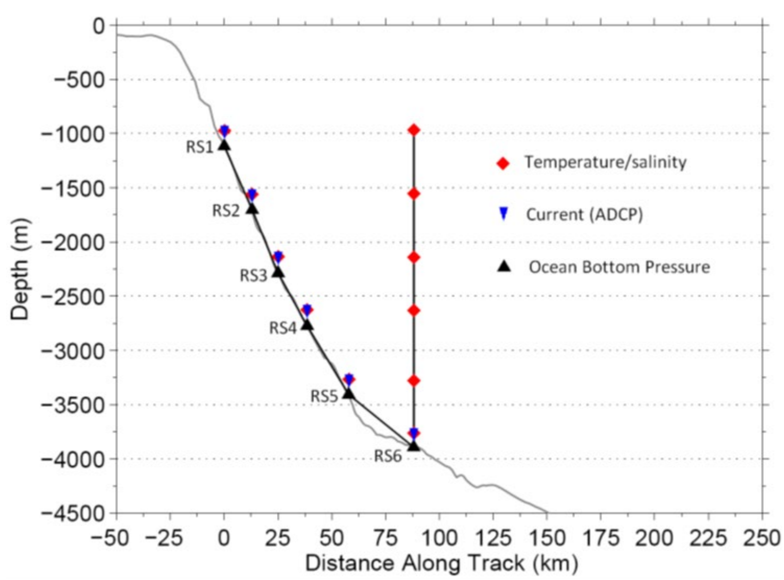


Figure 2. Schematic of the distribution (in the cross-slope vertical plane) of primary instruments deployed on the RAPID WAVE RS Line in Deploys 1-4 (2008-2013). At sites RS1 to RS5, there were 'short' moorings with a BPR (solid black triangle) mounted in the anchor, an ADCP (inverted blue triangle) at a nominal height of 50 mab, and an MC (solid red diamond) at a nominal height of 100mab. At RS6, there was a 'tall' mooring with instruments at the same nominal positions relative to the bottom as at RS1-5, and additional MCs at 5 different heights corresponding to the same nominal depths below the surface as those at RS1-5. The nominal water depths proceeding from RS1 to RS6 were 1100, 1700, 2300, 2900, 3400 and 3900m. However, the actual depths (Tables 2 and 3) differed somewhat in each deployment.

3. Bottom Topography on the HL/XHL/RS Line

Before further discussion of the RS measurement program, it is helpful to discuss briefly the unexpected complex bottom topography on the HL/XHL/RS Line over the Scotian Slope that the RS investigators became aware of just prior to the first RS mooring deployment in 2008. Hydrographic stations across the Scotian Shelf and Slope, including HL6 in ~1050m depth (near RS1) and HL7 in ~2700m depth (near RS4; Fig. 1), had been occupied approximately seasonally from 1950 to the early 1970s (e.g., de la Ronde 1972), as part of ocean monitoring by the Fisheries Research Board of Canada, as a contribution to the International Commission for the Northwest Atlantic Fisheries (ICNAF). Then, in 1998, DFO started the AZMP with seasonal physical/biological/chemical sampling including CTD/bottle profiles at stations HL1 to HL7 on the HL. Thus, HL6 and HL7 are probably the two most oceanographically-sampled sites on the Scotian Slope. Bathymetric information from charts and databases (e.g., used in the topographic depiction in Fig. 1) had not indicated any unusual topographic features at the HL sites. However, Fig. 1 does show an indication of cross-slope indentations and ridges to the east of the HL, in the vicinity of the initial RAPID WAVE Line B.

Between 2000 and 2004, DFO BIO had carried out a moored current measurement program with tall moorings at 3 sites along (near) the HL (Loder and Geshelin 2009, 2025), partly funded by the Canadian Federal Panel on Energy Research and Development (PERD) and several oil and gas companies. These sites were SS-A a few km to the east of HL6 in a water depth of ~1100m, SS-B on the 2000m isobath between HL6 and HL7, and SS-C on the 300m isobath between HL5 and HL6 (Fig. 1). A detailed bathymetric survey (using the CCGS Hudson sounder) over a 4km x 4km area around SS-A had been carried out in fall 2000 as part of the PERD program. It had indicated a limited cross-slope depression of up to 30m depth and ~3km length between HL6 and SS-A, but no further complexity. However, it turns out that papers had been published earlier by BIO colleagues in the Geological Survey of Canada Atlantic (GSCA) on historical sediment slumping on the Scotian Slope (e.g., Piper 1985), but the present investigators (and apparently other physical oceanographers at BIO) were not aware of the details of the resulting features in the vicinity of the HL/XHL.

Shortly before the initial RS deployment cruise in fall 2008, a previously-unavailable (proprietary) high-resolution bathymetric map (Fig. 3) was obtained from GSCA colleagues at BIO (Campbell et al., 2008; also see Philibert et al, 2022, for a recent review), based on newly-developed multi-beam acoustic bathymetric surveying. This map was used in identifying preferred sites for the RS moorings in relation to the HL monitoring sites. The map provided unprecedented resolution of the complex topography in the region, including in the vicinity of Line B where moored measurements had been made during 2004-08. Of particular note are two cross-slope canyons near Line B, and generally less-abrupt features in the area of the HL/RS Line. The latter are apparently a result of historical down-slope slumping of sediment accumulated on the Scotian Slope from de-glaciation events at least many thousands of years ago. As indicated in Fig. 3, this new information was used to shift the RS sites slightly from their initial planned positions to locations where the local topographic gradient corresponds more closely to the larger-scale gradient. The positions of HL6 and HL7 were also adjusted slightly to be away from small-scale bottom slope features and still within 3-6 km of the RS sites (e.g., HL7 was shifted to the top of a small knoll rather than on the knoll's side which explains the differences in water depth observed at the site in earlier surveys).

It appears that the small-scale topographic structure was not a significant factor in the moored measurements at sites RS1 - RS4 (§5.1 and §6.1): successive moorings were re-deployed well within a km of previous ones at each site (Table 2) and the best estimates of water depth for different deployments are within 10-30m of each other for a particular site (possible exceptions are the Deploy 7 moorings at RS1 and RS3 for which the water depths have not been finalized). Similarly, it appears that the small-

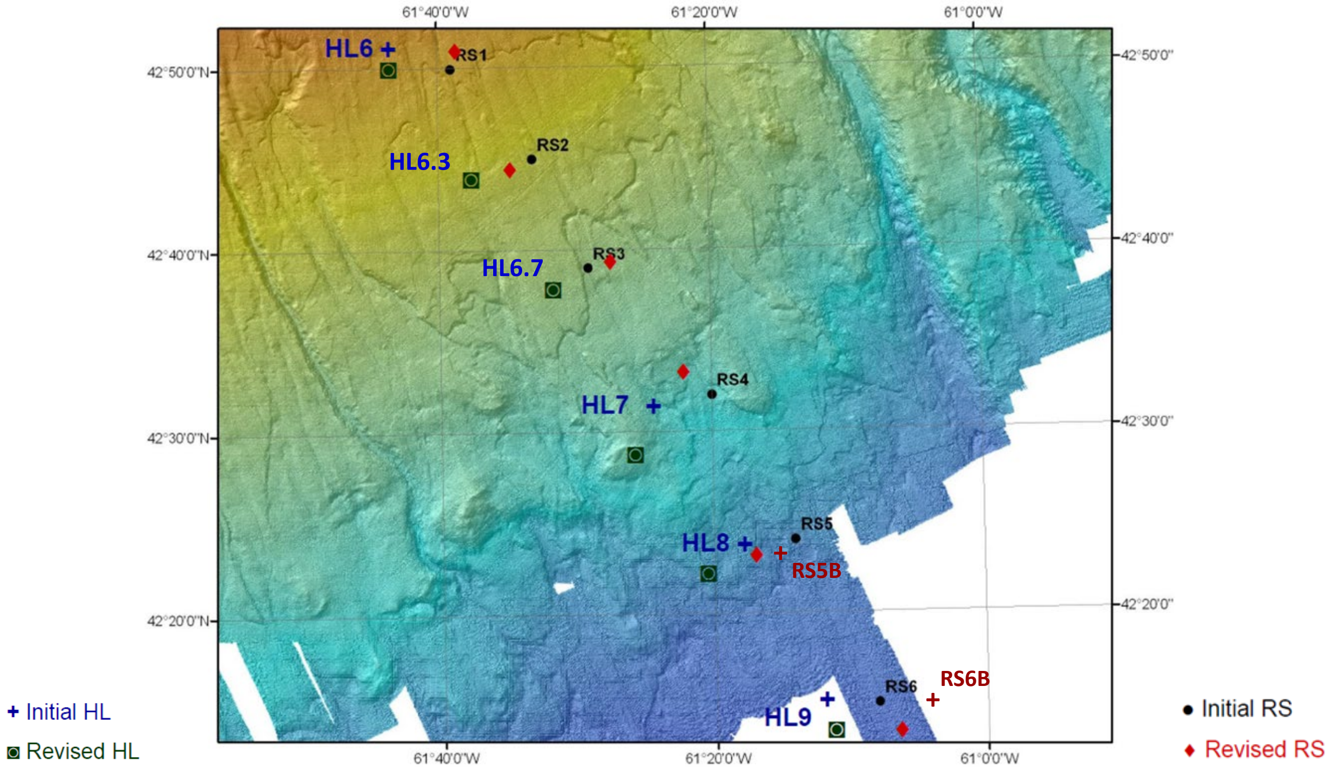


Figure 3. Colour-coded display of the topographic features on the Scotian Slope in the vicinity of the HL/XHL/RS and B Lines. Water depths range from 1050m at HL6 (near RS1), to ~3900m at HL9 and RS6. The planned "Initial" (black dots) and nominal "Revised" (**red diamonds**) positions of the RS moorings, as well as the previous HL/XHL sites (HL6-9; **blue + signs**) and "Revised" and additional CTD profile sites (**green squares with circles,** ◙) in the vicinity of the RS moorings, are shown (approximately). The shifted positions of RS5B and RS6B are also indicated (roughly; **brown + signs**). The topographic rendering is based on high-resolution multi-beam surveying (Campbell et al., 2008). *(Modified from a topographic image provided by the Geological Survey of Canada Atlantic at BIO)*

scale structure was not a factor at RS5 in Deploys 1-4 and at RS6 in Deploys 1-3 (with the pre-deployment shifting of the exact locations of the sites based on the multi-beam topography apparently having helped).

However, because of the need to shift the positions of the RS5 and RS6 moorings to RS5B and RS6B, respectively, due to the unretrieved moorings (M1782 and M1746) at these sites in Deploys 4 and 3, respectively, and because of logistical difficulties (e.g., weather, currents, operational and time constraints) in precise re-positioning at sea, the small-scale topography became a factor in the mean current directions measured subsequently at those sites. At RS5, the record-mean current direction at 58-90 mab was ~230°T in Deploys 3 and 4, compared to ~265°T in Deploys 5 and 6. At RS6, the record-mean current direction at the same height above bottom was ~270°T in Deploys 1 and 2, compared to ~250°T in Deploys 4 and 5. These differences indicate that the very low-frequency flow in at least the bottom 100m was steered to some degree by the small-scale topography (see §5.1 and §6.1 on ADCP data for further discussion).

Implications for the interpretation of the moored current measurements include that (i) it is highly desirable to use the record-mean current direction and the major axis of low-frequency variability in each deployment to determine the effective "along-isobath (or along-slope) direction" for each deployment at each site, and (ii) it will be difficult to determine any changes in the mean flow direction relative to the broader-scale topographic slope from one deployment to another.

4. Mooring Deployment and Recovery Cruises

We next discuss each of the CCGS Hudson cruises on which RS moorings were deployed or recovered (Table 1). In addition to the moorings, the CTD stations on the HL/XHL/RS Line will be noted, since they provide a quasi-synoptic view of the hydrographic structure in the cross-slope vertical plane during each deployment period (see §6.2).

4.1 Hud2008-037, Deployment 1, September-October 2008

This multi-leg AZMP/RAPID cruise was led by chief scientist Dr. Edward Horne (Horne 2008; Hudson 2008). The RAPID mooring work was carried out during the first leg from 28 September to 6 October (Maqueda et al., 2008). First, moorings were successfully recovered from 5 of the 6 RAPID WAVE sites on Line B (B0, B2, B3, B4, B5). Mooring B1 was not recovered, and dragging was unsuccessful.

Then, the 2 BIO PERD moorings, M1666 at SS-D (water depth ~2400m) and M1667 at SS-E (depth ~3400m) which had been deployed in October 2007 (Loder and Geshelin 2025), were also successfully recovered. These were the fourth year-long deployment of short moorings at these sites which together provide a total of 4 years of good T data but unfortunately lower-quality S data.

An MC-CTD calibration cast for the recovered RAPID MCs from the B Line was carried out at site HL11 (depth ~4500m) on 1 October. However, no CTD profiles were taken on the B Line.

The 6 RS moorings (M1696-1701; Appendix) with the primary RAPID instrumentation of 6 ADCPs, 6 SBE53 BPRs and 11 SBE37 MCs (Table 3; also, see §5 for more on the RS instrumentation) were deployed between 2 and 4 October, as planned. In addition, a secondary RBR DR-1050 BPR was mounted on the mooring at each of RS1 and RS6. No pre-deployment MC-CTD calibration cast for the RS Deploy 1 MCs was carried out. However, CTD/bottle profiles for the DFO monitoring programs were taken at HL8 (near RS5), HL9 (RS6), HL10 (~4200m) and HL11 on this first leg, and at HL6 (near RS1) and HL7 (RS4) on the cruise's next leg (on 9 and 10 October). These particular profiles provide only a marginal quasi-synoptic view. No CTD profiles were taken near RS2 and RS3 during this cruise. The CTD #'s, times and positions for these profiles can be found in the DFO cruise report (Horne 2008) and the cruise bridge log (Hudson 2008). Displays of T and S from this and other CTD surveys during the deployment and recovery cruises are provided in §6.2.

Aanderaa current meters (RCMs) were included on 2 of the Deploy 1 moorings at BIO expense (Table 3). On M1697 at RS2, an RCM11 (electromagnetic) and two newer SeaGuard RCMs were included at ~3m intervals for intercomparison purposes (Drozdowski and Greenan 2013), starting at 2m above the MC (which was at 102 mab on this mooring). On M1701 at RS6, an RCM8 (mechanical rotor) was included at 2m above the top MC which was at 2892 mab (or 984 mbs) (see later §5.6 and Table 9 for info on the RCMs).

4.2 Hud2009-048, Deployment 2, September-October 2009

This multi-leg AZMP/RAPID cruise was also led by chief scientist Dr. Edward Horne (Horne 2009; Hudson 2009). The RAPID mooring work was carried out during the first leg from 26 September to 3 October. All 6 RS Deploy 1 moorings were successfully recovered: those at sites RS1-RS3 on 28 October, and those at RS4-RS6 on 29 September. All of the ADCPs, BPRs and MCs provided good data, with the exception of the ADCP at RS5 (M1700) which had flooded shortly after deployment. Also, 3 of the other ADCPs had records of reduced duration due to battery failure. An MC-CTD calibration cast (CTD #13 on this cruise) for the 11 recovered Deploy 1 MCs was carried out near site RS5 (also referred to as HL6.3) on 1 October (Maqueda and Pugh 2009).

The re-deployment (Deploy 2) of the 6 RS moorings (M1742-1747; Appendix) was carried out between 30 September and 2 October, with the same amount of RAPID instrumentation as in Deploy 1 (Table 3), including the secondary RBR DR-1050 BPRs at RS1 and RS6. A BIO RCM11 was again included at the top of the RS6 mooring (M1747) (Table 3). No pre-deployment MC-CTD calibration cast for the RS Deploy 2 MCs was carried out. However, CTD /bottle profiles for the DFO monitoring programs, or to complement the RAPID moorings, were taken near all of the RS sites (with HL6.7 near RS3), as well as at HL8 to HL12 (~4700m). These profiles were taken between 28 September and 2 October, with some before the Deploy 1 mooring recoveries, some after the Deploy 2 placements, and some while no mooring was in the water at a particular site. With these profiles taken irregularly over about 4 days, they provide only a quasi-synoptic view of the cross-slope hydrographic structure (§6.2).

4.3 Hud2010-049, Deployment 3, December 2010

This was a special cruise which had to be shortened and carried out more than 2 months later than planned due to vessel problems and delays with CCGS Hudson in the fall of 2010. It was a single-leg AZMP/RAPID cruise along the HL/RS Line between 15 and 22 December, again led by chief scientist Dr. Edward Horne (Hudson 2010).

With remarkable good-weather fortune in one of the shortest daylight periods of the calendar year, the Deploy 2 moorings at sites RS1 to RS4 were successfully recovered on 16 December. However, the good fortune did not last at site RS5 where it was not possible to communicate with the mooring release and the mooring (M1746) did not surface after repeated blind releases (and was never ever recovered). The mooring at RS6 was then successfully recovered on 17 December. All of the instruments on the 5 recovered moorings provided good data but, unfortunately, the batteries had run out in some cases resulting in records of shorter duration than the deployment period (see Tables 4 and 5 in §5). This was the case for the ADCPs at RS3 and RS5 which only recorded into November (2009), and for the MC at RS4 and 4 MCs at RS6 which only recorded until May-June (2010). The reduced duration of these MC records was apparently due to the addition of pumps which used more battery power than anticipated. All of the recovered MCs were included on one of the MC-CTD calibration casts on 17, 18 or 20 December (CTD #'s 2, 4 and 8 on this cruise; see Hudson 2010) (Maqueda 2010).

The re-deployment (Deploy 3) of the 6 RS moorings (M1777-1782; Appendix) was carried out on 18 and 19 December, with the same amount of primary RAPID instrumentation as in Deploys 1 and 2, but without the secondary (RBR) BPRs. All 11 of the MCs had been included in one of the MC-CTD calibration casts prior to deployment (Maqueda 2010). A CTD/bottle profile was taken at each of the RS mooring sites, as well as at HL9-HL12, providing a quasi-synoptic view of the hydrographic structure on the XHL (§6.2).

4.4 Hud2011-043, Deployment 4, September-October 2011

This two-leg AZMP/RAPID cruise was led by chief scientist Dr. Erica Head (Head 2011; Hudson 2011). The RAPID mooring work was carried out during the first leg from 23 September to 1 October. The Deploy 3 moorings at sites RS1 to RS5 were recovered without incident on 24 and 25 September, with all instruments returning good data.

However, the mooring (M1782) at RS6 did not release on 26 September, presumably due to a release mechanism failure or the BPR having come out of its holder on the mooring anchor during deployment and tangling with the anchor chain (see Appendix for the mooring design). Dragging for the mooring led to the top part of the mooring (including a syntactic foam float, Casabel Iridium beacon, RCM11 and MC) being severed by the dragging wire, although subsequently recovered (the next day) while floating away. Further dragging for the remainder of M1782 was carried out on 12 October during the cruise's second leg, using a longer wire picked up at BIO between legs. Acoustic transponding with the release indicated that it had released, so there was almost certainly a tangle. A long intermediate-depth section of the mooring including 3 MCs (but one lost) was recovered during the further dragging, but unfortunately its lower ~100m section with the BPR, ADCP and 1 MC was not (or never) recovered. However, the recovered Deploy 3 RS6 instruments did yield good data, with the possible exception that the top MC indicated a P/depth about 100m shallower than expected (Table 3); this could have been due to a measurement error in the ~3000 wirelength on this mooring or to the above-mentioned possible tangle during its deployment.

MC-CTD calibration casts for the 7 Deploy 3 MCs recovered on the first leg (including the top one at RS6) were carried out on 27 and 28 September (CTD #'s 7 and 8 on this cruise; Head 2011, Hudson 2011), but none were carried out for the 3 MCs recovered on the second leg (Maqueda and Pugh 2011).

The Deploy 4 moorings at sites RS4 (M1807) and RS5 (M1808) were placed on 26 September (2011), those at RS6 on 28 September, and those at RS1, RS2 and RS3 (M1804-1806) on 29 September (Appendix), all with some design changes from those in Deploys 1-3:

- Sampling/recording intervals on all instruments were set to allow at least an 18-month deployment.
- On the moorings at RS1 to RS5, the top float was shifted higher to ~176mab (from the previous 101mab), in order to eliminate interference of the float with the ADCP sampling (which was upward-looking at 50 mab; see §5.1 on ADCPs).
- On the moorings at RS1, RS3 and RS5, a second MC was included at 175 mab, for redundancy and to assess vertical gradients.
- At RS6, two moorings were deployed:
    - the usual tall mooring (M1809) at a shifted site referred to as RS6B, with the standard ADCP (50 mab) and 6 MCs, and a BIO RCM11 at the top, and an additional MC at 250 mab; and
    - a separate, very short mooring (M1810) with the BPR at a second shifted site (RS6A).

  The shifted sites were chosen to be at least 3 km from the original RS6 site, in order to allow for further dragging for M1782 from Deploy 3. However, unfortunately, the shifted site RS6B ended up being at a location further away where the local bottom (topographic) gradient had a significantly different direction which affected the mean velocity direction at 58-90 mab (see §5.1).

MC-CTD calibration casts for all of the Deploy 4 MCs were carried out on 24, 25 and 28 September (CTD #'s 2, 3 and8; Head 2011; Hudson 2011; Maqueda and Pugh 2011). CTD/bottle profiles were taken near all of the RS mooring sites, as well as at HL9-HL12 and shallower HL sites during the period 24-30 September, thereby providing only a marginal quasi-synoptic view of the hydrographic structure on the HL/XHL/RS Line (§6.2).

4.5 Hud2013-004, Deployment 5, April 2013

This two-leg AZMP/RAPID cruise was led by chief scientist Dr. David Hebert (Hebert 2013; Hudson 2013). The RAPID mooring work was carried out during the first leg from 4 to 12 April. The Deploy 4 moorings at sites RS1 to RS5 were recovered without incident on 5 April and, after a weather delay, the moorings at RS6A and RS6B were recovered on 7 April. All of the primary instruments yielded good and full datasets, with the exceptions that the RS5 ADCP did not return good velocity data and 2 of the MCs from RS6 did not return good P data.

MC-CTD calibration casts for the recovered MCs were carried out on 6, 7 and 8 April (CTD #'s 5, 6 and 8 on this cruise; Hebert 2013, Maqueda and Pugh 2013). While in the vicinity of RS6, acoustic communication was established with the unrecovered release on M1782 (Deploy 3). A command to release was again sent but the release did not come up (consistent with a tangle).

The RS Deploy 5 moorings (M1834-1839; Appendix) were placed without incident on 7 (RS6B), 8 (RS3, RS4 and RS5B) and 9 (RS1 and RS2) April. M1839 was deployed at the shifted position RS6B. In addition, the position of the RS5 mooring was shifted to RS5B (M1838) about 3 km to the east, in order to allow for a dragging operation for the unrecovered (Deploy 2) M1746 at the original RS5 position. A bathymetric survey was conducted at the RS5B site with the Knudsen echosounder, and nothing of significance was noted. However, the ADCP data later recovered from Deploys 5 and 6 at this new site (RS5B) showed a different record-mean direction than at the original RS5 site, indicating a different local bottom-slope direction. This was somewhat analogous to the effect of small-scale (perhaps 0.5-5 km) topography on the mean velocity directions at RS6 and RS6B noted above (Deploys 1 and 2, vs Deploys 4-6; see §'s 5.1 and 6.1).

To reduce costs, only a short mooring (like at the other sites) was deployed at RS6B in Deploy 5 (rather than the previous tall mooring in Deploys 1-4). The same mooring design and instrument positions were intended for all 6 Deploy 5 moorings; namely, a SBE53 BPR mount on the anchor, an ADCP at 50 mab, SBE37 MCs at 100 and 200 mab, and the top float at 201 mab. Unfortunately, a marking mistake was made in the preparation of the wires, and the MCs were attached at 150 and 200 mab on all 6 moorings (Table 3; §5.2). This resulted in a vertical shift in the height of the primary near-bottom MC on the RS moorings from 100 mab in Deploys 1-4 to 150 mab in Deploys 5 and 6. Note that this vertical shift of 50m (relative to the anchor) in the position of the deepest MC was larger than the range of 10-30m in actual water depths at each of sites RS1-RS4, RS6 and RS6B, at RS5 in Deploys 1-4, and at RS5B during Deploys 5 and 6 (Table 2), such that the shift may need to be considered in concatenation of the MC time series for low-frequency variability investigations. Also, the 50m shift is comparable to the water depth difference between site RS5 and RS5B.

All of the deployed MCs were included in the MC-CTD calibration casts during 6-8 April (CTD #'s 5, 6 and 7). CTD/bottle profiles were taken near each of the RS sites (e.g., HL6/RS1 to HL9/RS6) and at HL10 between 5 and 9 April (providing a quasi-synoptic view, §6.2), but not at the deeper HL11 and HL12 sites.

4.6 Hud2014-030, Deployment 6, September 2014

This was a multi-leg AZMP/RAPID cruise led by chief scientist Dr. David Hebert (Hebert 2014; Hudson 2014). The RS mooring work was carried out during the first leg from 19 to 28 September. The Deploy 5 moorings at sites RS1 to RS4 were recovered without incident on 21 September, before rough weather interrupted operations the next day. The moorings at RS5B and RS6B were then recovered on 23 September. All of the ADCPs, BPRs and MCs returned good and full datasets, with the exception of the top MC (at 200 mab) at RS3 which returned only a 12.5-month record (in contrast to 18.5-month records from the others). The shorter record from that MC may have been related to battery consumption associated with it having a Dissolved Oxygen (DO) sensor (although the top MCs at RS1 and RS2 which also had DO sensors did not run out of battery power).

An MC-CTD calibration cast (CTD #17 on this cruise; Hudson 2014) for the recovered MCs was carried out during the night of 25-26 September (Maqueda and Pugh 2014). CTD profiles (most with bottles) were taken at all of the RS/HL mooring sites and at sites XHL10-12 between 21 and 25 September. These stations and the above Deploy 5 mooring recoveries completed the initially-planned 5-deployment RAPID WAVE Scotian mooring program.

Because of the cautious approach of only ~1-year duration for each of Deploys 1-3 (in consideration of earlier mooring losses on Lines A and B), the overall 6-year duration of Deploys 1-5 was shorter than desired. Consequently, a program extension with two 2-year deployments and moorings at only 4 sites was continued, primarily led by BIO with some continued support from POL through existing instrumentation and a small amount of carry-forward funding (thereby extending the RS program duration to nearly 10 years).

Short moorings (M1886-1889) were deployed at RS5B on 23 September and at RS1, RS3 and RS6B on 24 September (Appendix). Each mooring had a BPR in the anchor, ADCP at 50 mab, MCs at 150 and 200 mab, and the top float at 201 mab. Unfortunately, the same wire-marking mistake for the MCs as in Deploy 5 (§4.5) was repeated in Deploy 6 (the mistake was not detected until the post-cruise processing of the Deploy 5 data). An MC-CTD calibration cast (CTD #8) with the to-be-deployed MCs was carried out at HL7 on 21 September (Hudson 2014; Maqueda and Pugh 2014).

4.7 Hud2016-003, Recovery of Deployment 6, April 2016

The recovery of the Deploy 6 moorings was successfully carried out on 11 April during a short first leg (9-12 April) of the spring AZMP cruise led by Dr. David Hebert (Hebert 2016; Hudson 2016a). All of the Deploy 6 ADCPs, BPRs and MCs returned good and full datasets, except that the top MC at each of RS5B and RS6B did not return any good P data (these were the same MCs which had not returned good P data in Deploy 4 – MC#'s 3675 and3680).

No CTD profiles were taken at the RS sites at that time, and a MC-CTD calibration cast for the recovered MCs was not done until May on Hud2016-006 (see below). However, CTD/bottle profiles were taken at sites HL5, HL5.5, HL6 (RS1), HL6.3 (RS2), HL6.7 (RS3) and HL7 (RS4) on 19-20 April but no moorings were in place at that time.

4.8 Hud2016-006, Deployment 7, May 2016

There was a time gap of nearly 6 weeks between the recovery of the Deploy 6 moorings, and the placement of the Deploy 7 moorings during 21-23 May on Hud2016-006 led by Dr. Igor Yashayaev (Hudson 2016b). This cruise, part of AZOMP, first went to the Labrador Sea, and then carried out work on the HL/XHL/RS Line before returning to BIO.

Short moorings (M1942-1945; Appendix) were successfully deployed at RS1, RS3, RS5B and RS6B with a BPR in the anchor, ADCP at 50 mab, MCs at 10 and 100 mab, and the top float at 101 mab. The BPRs at RS1 and RS5B were SBE53s while those at RS3 and RS6B were RBR DR-1050s.

MC-CTD calibration casts for both the recovered Deploy 6 MCs and the to-be-placed Deploy 7 ones were carried out in conjunction with calibration casts for other MCs involved in the Labrador Sea region programs. CTD/bottle profiles along the HL/XHL/RS Line (XHL12 to HL5, including all 6 RS sites) were taken between 21 and 23 May (Hudson 2016b).

4.9 Hud2018-008, Deployment 7 Recovery, May 2018

The Deploy 7 moorings were successfully recovered on 15 May (RS1, RS3) and 16 May (RS5B, RS6B) on Hud2018-018 led by chief scientist Dr. Igor Yashayaev (Hudson 2018). This was again an AZOMP cruise which first went to the Labrador Sea, and then did work on the HL/XHL/RS Line before returning to BIO.

CTD/bottle profiles were taken at the usual HL/XHL/RS sites between 15 and 20 May, as well as at additional deep-ocean sites extending south past 40ºN. However, it is unclear whether MC-CTD calibrations for the recovered RS MCs were carried out (further work is required on this).

A single mooring (M2054) was redeployed at RS5B on 19 May on this cruise, as a minimal follow-on program led by Dr. Igor Yashayaev. This mooring had MCs at 50, 200, 400, 650 and 900 mab, and a Nortek Aquadopp current meter at 100 mab. It was successfully recovered on 6 September 2020 on Hud2020-066.

5. Instrument Summaries, Data Return and Issues

5.1 Acoustic Doppler Current Profilers (ADCPs)

The depths, periods and data return from the Workhorse ADCPs during the 7 deployment periods are summarized in Table 4, by site, mooring and instrument. There were a total of 38 ADCPs deployed during the extended ~10-year period, only 2 of which were not recovered and only 2 others of which did not yield any good data; thus, 34 returned ADCP records. The bin size was 4m in all cases, with bin #1 corresponding to a distance range of 4-8 m from the ADCP head (with a center position 6m from the head). The recording/ensemble interval in all cases was 1 hour, with a ping interval of 36 sec, and 50 (Deploy 7) to 100 (Deploy 1) pings per ensemble depending on the deployment duration.

Three of the ADCP records from Deploy 1 were reduced in length due to battery failure (Fig. 4a), so the number of pings per ensemble was reduced to 70 in Deploy 2. Two of the records during the extended 15-month Deploy 2 were slightly reduced in duration due to battery failure (Fig. 4b). Thus, assuming full records from the (unprocessed) Deploy 7 ADCPs, it is expected that there will be full records from 29 out of the 38 deployed ADCPs, and a 90% overall return rate for good velocity time series from the deployed ADCPs.

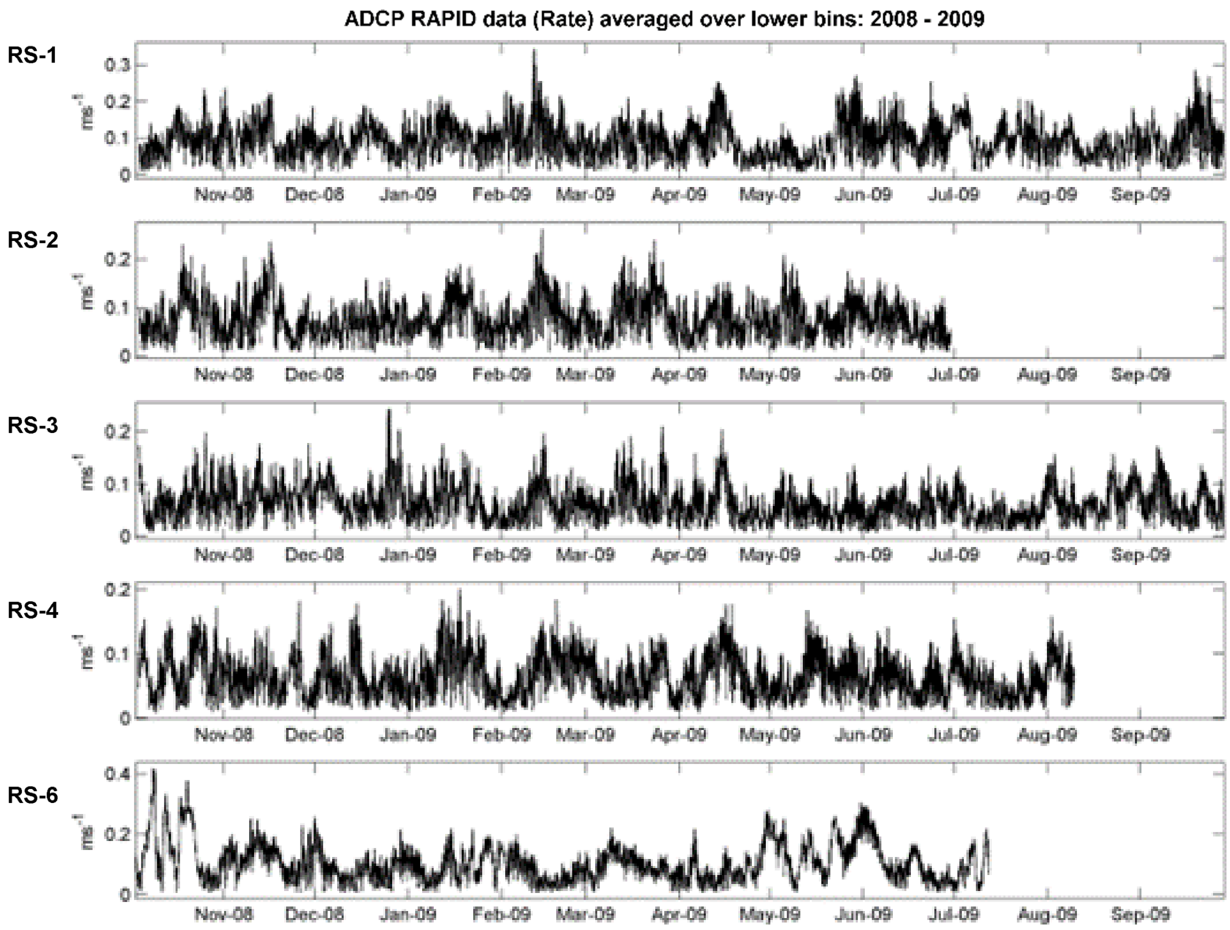


Figure 4a. Time series of Rate (velocity magnitude) vertically averaged over bins near the ADCP, from each of the 5 sites which returned good data during Deploy 1. The reduced duration of the records at RS2, RS4 and RS6 is apparent. The ADCP at RS5 did not return any good data.

By site, there are full records from the 7 deployments at RS1 (so a 100% return rate), and only 1 shortened record (by < 1 month) at RS3 (99% return). For the other two sites where there were also 7 deployments, there were no good data from Deploys 1 and 2 at RS5 (so only 77% return), and a shortened

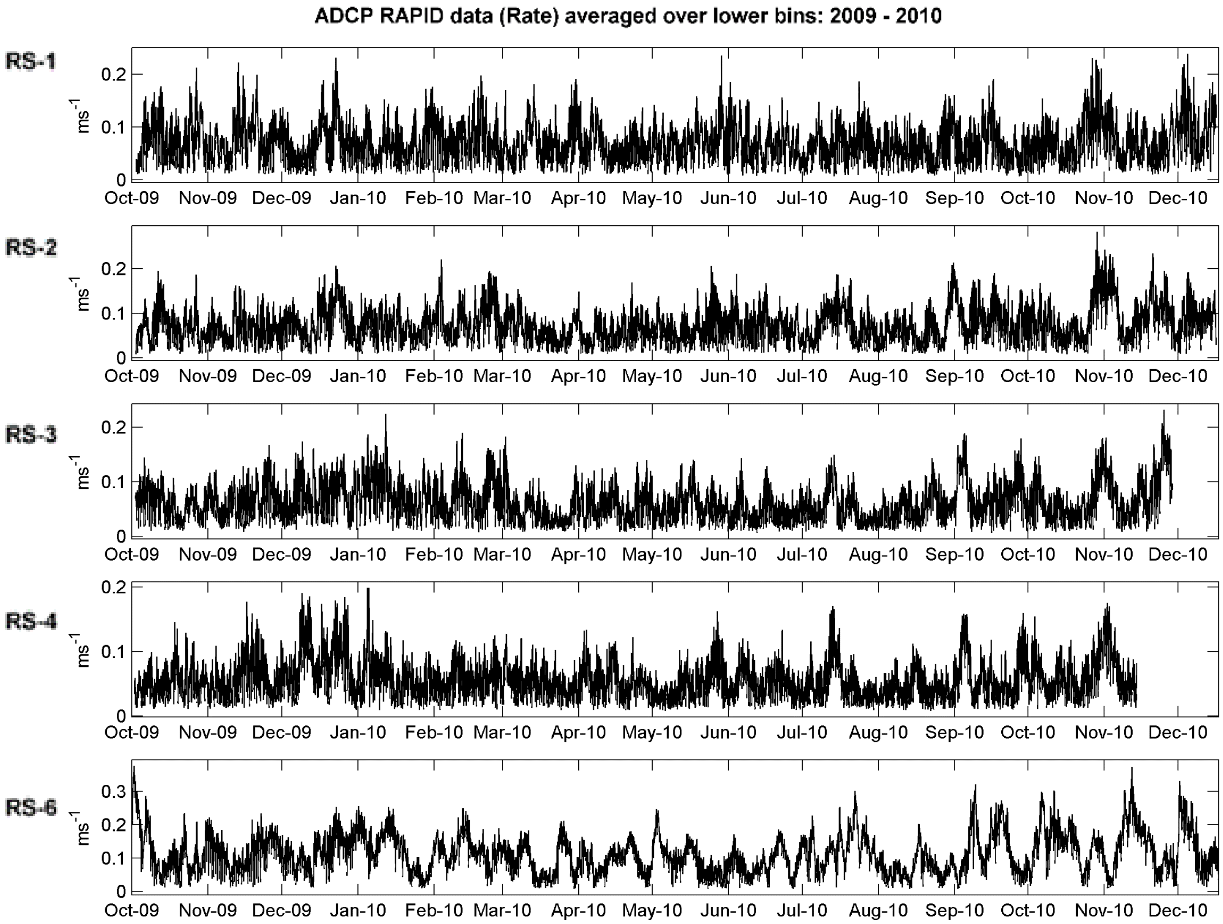


Figure 4b. Time series of Rate averaged over bins near the ADCP, from each of the 5 sites which returned good data during Deploy 2. Note the reduced duration of the records at RS3 and RS4. The mooring at RS5 was not recovered.

Deploy 1 record (by 2 months) and no Deploy 3 record from RS6 (only 90% return). For the two sites with only 5 deployments, there were no good data from Deploy 4 and a shortened (by 3 months) Deploy 1 record at RS2 (so 75% return), and shortened Deploy 1 (by 1.5 months) and Deploy2 (by 1 month) records at RS4 (97% return). However, it should be noted that there is a 6-week gap between Deploys 6 and 7 which could be considered another 6 ADCP-months of missing ADCP data during the overall 9.7-year program at 4 sites (so a further 1% data gap at these sites).

The distance ranges from the ADCP for good velocity data return were somewhat less than expected, ranging from about 60m at RS6 to about 120m at RS1. It appears that this limited range was related to a limited number of scatterers in the lower water column, particularly at the deeper sites. Nevertheless, there were good velocity data in almost all ensembles for the priority interval of 8-36m from the ADCP, or 58-86 mab (bin #'s 2 to 8).

There were two unexpected data degradation problems in some of the ADCP records. The first (of little importance) was that the data from bin #1 at most sites in the early deployments had suspect features from visual inspection and based on the error velocity (the difference between the two estimates of vertical velocity from the pairs of transducers in orthogonal vertical planes). Consequently, the bin 1 velocity data were discarded and not included in the archived files.

The second problem was interference by the top buoyancy float (at 101 mab at RS1-5 in Deploys 1-3) and/or the MC (at 100 mab) affecting the acoustic signal return from bins 10-13 (~94-110 mab) in most cases. This can be seen from the slightly anomalous velocity magnitudes and an increased echo intensity

Table 4a. RS1 to RS5B. Listing of ADCP deployments during the 2008-18 RS program, organized by site (RS#) and deployment (D) #. The other columns indicate the BIO mooring #, ADCP serial #, record start and end dates, ADCP depth, depth range of the centers of 4m bins with good (QC'ed) data, sequential bin #'s (proceeding away from the ADCP) of other bins with mostly good data, and bin #'s with a large quantity of degraded ('bad') data. The ADCP and bin depths are taken from the water depths (Table 3), design wire lengths, and ADCP settings. The bins with QCed and archived (BIO) data are #'s 2-9 in most cases, but only #'s 2-8 in 2 cases*. These QCed data are in the BIO Archive for Deploys 1-5, and are expected to be submitted for Deploy 6. Processing of the Deploy 7 data has not been completed, such that the water depths (from soundings) and bin depths are tentative (*italicized*)**. A question mark (?) indicates uncertain or unknown information. (See Table 4b for RS6 and RS6B)

Site	D #	BIO M #	ADCP Ser #	Start Date	End Date	ADCP Depth	QC'ed Bin Depths	Other 'Good-Data' Bin #'s	'Bad-Data' Bins #'s
RS1	1	1696	11432	03/10/08	28/09/09	1063	1025-1053	14-26	1, 10-13, 27+
"	2	1742	11432	02/10/09	16/12/10	1045	1007-1035	many	1, 10-13, ?
"	3	1777	13592	18/12/10	24/09/11	1048	1010-1038	many	1, 10-13, ?
"	4	1804	11432	30/09/11	05/04/13	1047	1009-1037	1, 10-26	27+
"	5	1834	13983	09/04/13	21/09/14	1046	1008-1036	10-28	1, 29+
"	6	1886	11433	24/09/14	11/04/16	1037	999-1027	10-29	1, 30
"	7	1942	11432	22/05/16	15/05/18	*1025***	*987-1015*	*?*	*?*
RS2	1	1697	10942	03/10/08	30/06/09	1649	1611-1639	14-18	1, 10-13, 19+
"	2	1743	11433	02/10/09	16/12/10	1640	1602-1630	some	1, 10-13, ?
"	3	1778	13873	18/12/10	24/09/11	1647	1609-1637	some	1, 10-13, ?
"	4	1805	11433	29/09/11	05/04/13	1651	*No good data*		
"	5	1835	19080	09/04/13	21/09/14	1651	1613-1641	1, 10-23	24+
RS3	1	1698	11433	03/10/08	28/09/09	2237	2199-2227	14	1, 10-13, 15+
"	2	1744	13153	02/10/09	28/11/10	2239	2201-2229	some?	1, 10-13, ?
"	3	1779	13874	18/12/10	24/09/11	2257	2219-2247	some?	1, 10-13, ?
"	4	1806	13153	29/09/11	05/04/13	2254	2216-2244	1, 10-18	19+
"	5	1836	13873	08/04/13	21/09/14	2252	2214-2242	10-16	1, 17+
"	6	1887	13153	24/09/14	11/04/16	2257	2219-2247	10-16	1, 17+
"	7	1943	13874	22/05/16	15/05/18	*2203***	*2165-2193*	*?*	*?*
RS4	1	1699	11089	03/10/08	09/08/09	2731	2693-2721	?	1, 10-13, many
"	2	1745	13152	01/10/09	14/11/10	2727	2689-2717	?	1, 10-13, many
"	3	1780	10941	18/12/10	24/09/11	2723	2685-2713	?	1, 10-13, many
"	4	1807	12435	26/09/11	05/04/13	2716	2678-2706	1, 10-15	16+
"	5	1837	10941	08/04/13	21/09/14	2701	2663-2691	1, 10-14	15+
RS5	1	1700	11431	*No data*	*Flooded*	3374	*Nil*		
"	2	1746	12491	*No data*	*Not recovered*		*Nil*		
"	3	1781	13893	18/12/10	24/09/11	3369	3335-3359*	?	1, 9-13, ?
"	4	1808	11089	26/09/11	05/04/13	3367	3329-3357	10-14	1, 15+
RS5B	5	1838	13874	08/04/13	23/09/14	3431	3393-3421	10-14	1, 15+
"	6	1888	11089	23/09/14	11/04/16	3405	3367-3395	10-14	1, 15+
"	7	1944	12455	22/05/16	16/05/18	*3346***	*3308-3336*	*?*	*?*

Table 4b. *(continued)* RS6 and RS6B. Listing of ADCP deployments during the 2008-18 RS program.

Site	D #	BIO M #	ADCP Ser #	Start Date	End Date	ADCP Depth	QC'ed Bin Depths	Other 'Good-Data' Bin #'s	'Bad-Data' Bins #'s
RS6	1	1701	11433	02/10/08	12/07/09	3826	3792-3816*	nil	1, 9-12, 13+
"	2	1747	12455	30/09/09	17/12/10	3823	3785-3813	?	1, 10-13, 14?+
"	3	1782	10942	*No data*	*Not recovered*				
RS6B	4	1809	16405	28/09/11	07/04/13	3806	3768-3796	1, 9-13?	14+
"	5	1839	13592	07/04/13	23/09/14	3808	3770-3798	10-14?	1, 15+
"	6	1889	16405	24/09/14	11/04/16	3815	3777-3805	10-12?	1, 13+
"	7	1945	19080	21/05/16	16/05/18	*3714***	*3676-3704*	*?*	*?*

from these bins, as illustrated in Fig. 5 for Deploy 2. Consequently, only data from bins 2-9 (in most cases; vertical interval of 58-90 mab) and bins 2-8 in one case (Table 4) were used and archived. Note however that there were a substantial number of bins above the contaminated ones at the shallower mooring sites (particularly at RS1 and RS2) with useful data (Table 4). (A similar minor contamination issue of a few ADCP bins by a float above the ADCP was later identified in earlier 2004-2010 moored measurements in Orphan Basin; see Loder et al., 2025).

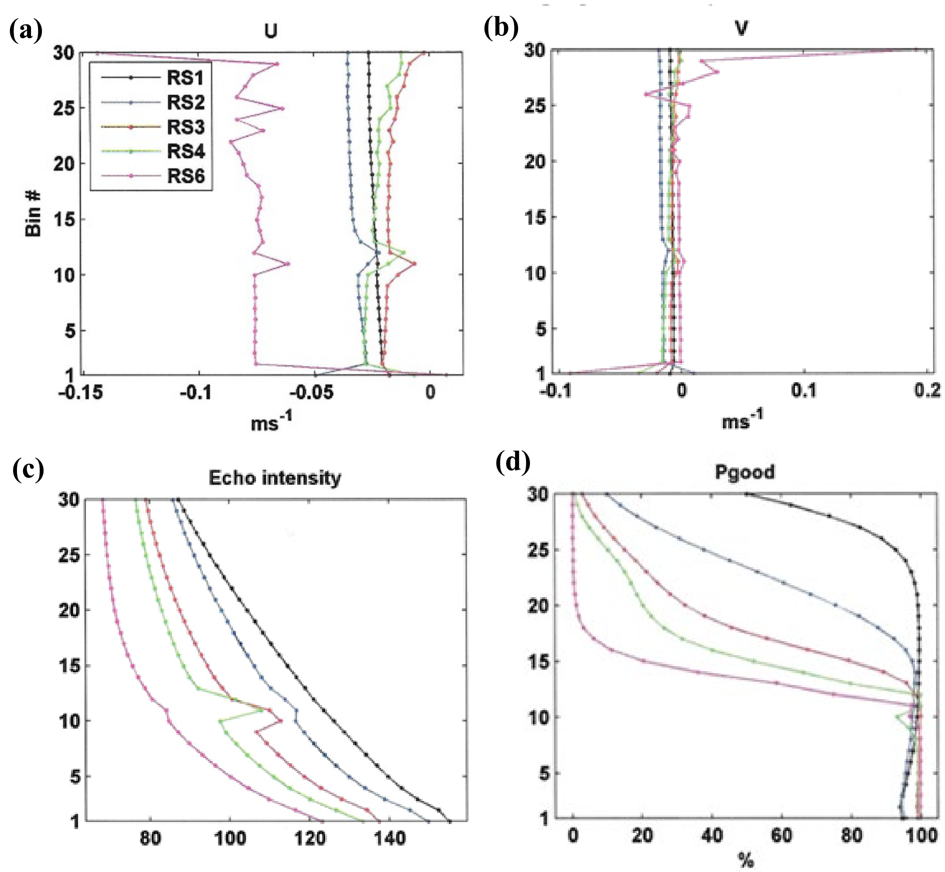


Figure 5. Vertical profiles of record-averaged **(a)** eastward (U) and **(b)** northward (V) velocity, **(c)** echo intensity, and **(d)** percentage of good pings from the recovered ADCPs at the 5 sites during Deploy 2.

As described in §2 and §3, the mooring sites for RS5 and RS6 were changed to RS5B and RS6B by ~3km and ~6km, respectively, in order to allow for dragging for the earlier unrecovered moorings. An attempt was made to place the new mooring sites in similar topography (depth and bottom slope gradient), but this was not completely successful. As a result, the record-mean velocities from the deployments at the shifted sites had different directions, by 20-30°, from those at the original sites. This is illustrated in Fig. 6 which shows progressive vector diagrams (PVDs) for the bin 8 velocity data from the 5 sites with ADCP data from Deploy 4 and from the 6 sites with data from Deploy 5.

The overall differences and similarities in the low-frequency velocities will be discussed in §6.1, in relation to PVDs and time series plots from all of the ADCPs from Deploys 1-6. The primary point to note here is the difference in the direction of the mean flow (overall drift) between site RS5 in Deploy 4 (2011-13) and site RS5B in Deploy 6 (2013-14), by about 30° in this case (**magenta** curve in each panel of Fig. 6). The direction in Deploy 3 at RS5 was similar to that in Deploy 4, and that in Deploy 6 at RS5B similar to that in Deploy 5 (see §6.1 for the PVDs), pointing to the different sites (and local topographies) being the source of the unexpectedly large difference in record-mean velocity directions. A comparable shift in the mean flow direction between sites RS6 and RS6B is described in §6.1. These differences in the local topographic gradient need to be considered in the use of the ADCP data from sites RS5 and RS5B, and sites RS6 and RS6B.

(a)

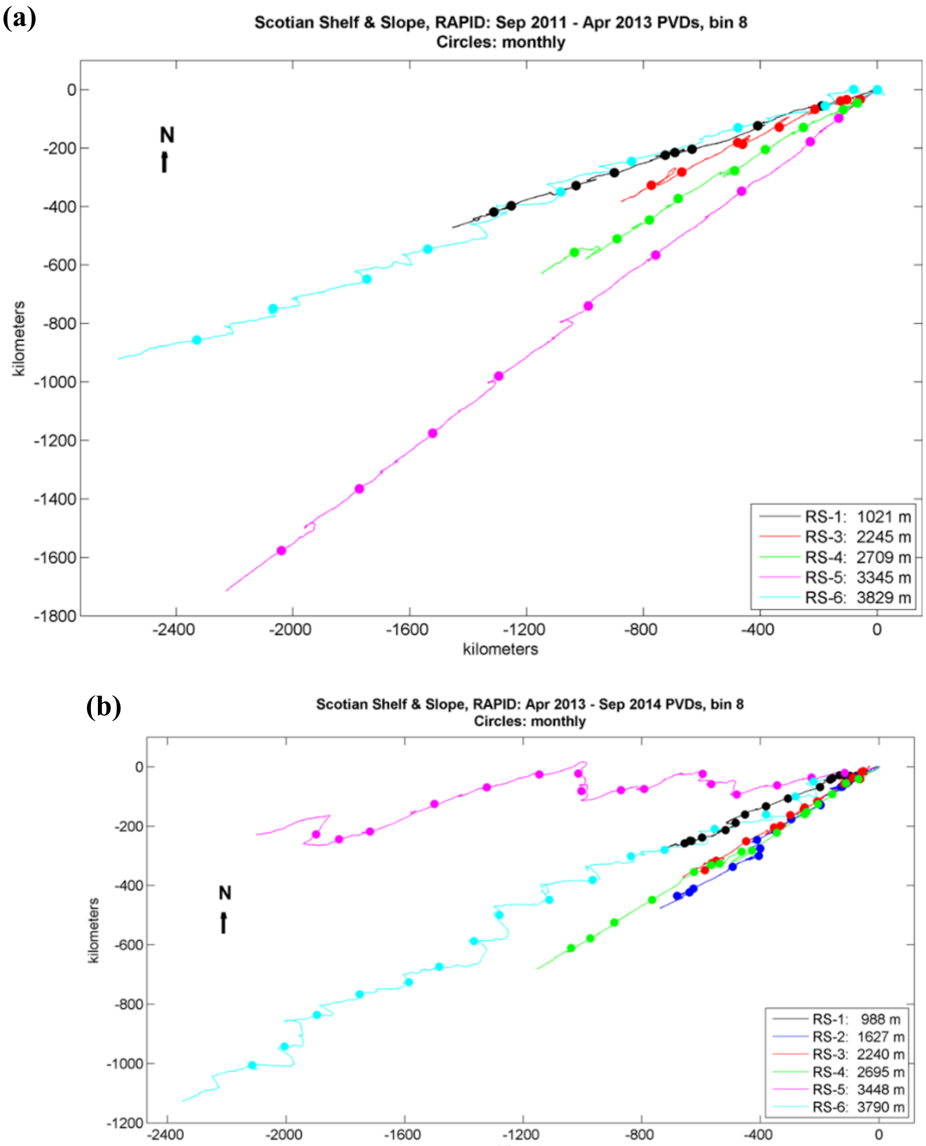


Figure 6. Progressive vector diagrams (PVDs) for the hourly velocity data from bin 8 (centered at 84 mab) from the ADCPs in **(a)** Deploy 4 (5 sites) and **(b)** Deploy 5 (6 sites). Note that the colour coding and space scale are the same in the 2 panels. The depths (mbs) indicated in the legend boxes are not the final ones.

5.2 MicroCAT Temperature, Conductivity and Pressure Recorders (MCs)

In this section, we discuss the MCs and their calibration, data return and other issues. The depths, instrument features, data return periods and some particular issues for the MCs are summarized in Table 5a,b, and their approximate (nominal) heights above bottom at the different sites in the actual deployments in Table 6.

As discussed earlier in relation to Fig. 2, the measurement strategy was to place a primary MC at 100 mab at each of the 6 RS sites, and an additional 5 second-priority MCs on a tall mooring at RS6 at depths corresponding to those of the 100-mab MCs at the other sites (RS1-5). Thus, a total of 11 MCs were used in Deploys 1 and 2. In Deploy 3, MCs were deployed at the same positions, and an additional experimental MC with a Dissolved Oxygen (DO) sensor was added by BIO (at 25 mab at RS1), for a total of 12. In Deploy 4, a total of 15 MCs were deployed, with the additional ones at 175 mab at RS1, RS3 and RS5, and at 250 mab at RS6 (Tables 5 and 6). The additional ones were included to provide more information and some redundancy at key positions, and at limited extra expense since the height of the short moorings was being extended to eliminate float interference with the ADCPs (§5.1).

Concern had arisen about the design of the RS6 mooring during Deploys 1-3, regarding the risk of damage to the BPR in the anchor mount during the deployment of such a tall mooring. Consequently, it was decided in advance to deploy the BPR on a separate short mooring at RS6 in Deploy 4. Separated sites for the BPR mooring (RS6A) and the tall mooring with the ADCP and MCs (RS6B) were chosen (Table 3). Then, with the failed recovery of the lower part of the Deploy 3 mooring at RS6 (apparently due to a chain or wire tangle with the anchor) and consideration of the cost of a tall mooring, it was decided to place only a short mooring at RS6 in Deploy 5 (and also in Deploys 6 and 7). In Deploy 5, the intent was to place MCs at 100 and 200 mab at all 6 sites, and then moorings at only 4 sites in Deploy 6. However, the MCs in these two deployments were mistakenly placed at 150 and 200 mab, resulting in the unintended vertical shift of the primary MCs' position (discussed earlier in §4.5).

There were a total of 67 MCs deployed during the extended 9.7-yr RAPID-BIO program period, only 3 of which were not recovered; thus, there were 64 returned MC records (Table 5). During the primary RS period of 2008-14, there were 43 MCs deployed, with the (same) 3 MCs not recovered: 1 from M1746 (nothing recovered) at RS5, and 2 from M1782 (only partly recovered) at RS6. Five other MCs recovered during 2008-14 had records of significantly reduced length due to battery failure, and 6 others did not return a good P record, as well as 2 more in Deploy 6. These cases of no good P involved 4 MCs: #'s 3675, 3680, 3681 and 3682 – the first 2 of which did not provide good P in any of their 3 deployments, and the last 2 of which did not provide good P data in Deploy 2 (but did in Deploys 4 and 6). In cases of no or unreliable measured P data, a constant P value was specified for the computation of S and density (based on other information on the mooring).

Of the 30 MCs deployed at the primary RS measurement position of 100 (or 150) mab during 2008-14, 28 were recovered with good data, but 2 of these had shortened records during the extended Deploy 2. Overall the good data return rate was high (>90%) for both the primary and other MCs in Deploys 1-5. For the second-priority MCs (21 in total) that were higher on the tall moorings at RS6 during Deploys 1-4, the return rate was lower (Table 5). Two of the (3) lost MCs during the overall program were from RS6 (M1782) during Deploy 3, and 3 of the (5) MCs with records of reduced length were from RS6 (M1747) during the extended Deploy 2. Thus, also considering that there was no tall mooring at RS6 during Deploy5, such that the second-priority MC records (Deploys 1-4) had a total duration of only 4.5 years (compared to 6 years for the primary ones at 100-150 mab in Deploys 1-5), the data from these secondary MCs will probably be of less value than those from the primary MCs.

Assuming that the T and C records from the misplaced MCs at 150 mab in Deploys 5 and 6 can be used (perhaps with some adjustment for vertical gradients) in conjunction with the records from 100 mab in the

Table 5a. Listing of MC deployments at sites RS1 to RS4 during the 2008-18 RS program, organized by site (RS #) and deployment (D) #. The other columns indicate the BIO mooring #, MC Serial #, record start and end dates, MC depth (Dph in m), calibrations applied (R for 'ramped' and F for 'flat', with "pre" & "post" indicating use of pre-deployment and/or post-recovery MC-CTD casts), and other info and comments: Druck (Drk) vs Kistler (Ktr) pressure sensors, nop=no pump, DO=DissolvedOxygen, hi=high. (See Table 5b for RS5(B) and RS6(B))

Site	D #	BIO #	MC Ser #	Start Date	End Date	MC Dph	Cals Applied	Other Info & Comments
RS1	1	1696	6437	03/10/08	28/09/09	1015	R-post	Drk; nop
"	2	1742	2165	02/10/09	16/12/10	991	F-post	Drk; nop
"	3	1777	6433p	18/12/10	24/09/11	999	R-pre&pst	Drk; pump
"	3	1777	9021p	18/12/10	24/09/11	1073	R-pre&pst	Ktr; pump; DO
"	4	1804	6437	30/09/11	05/04/13	923	R-pre&pst	Drk; nop
"	4	1804	3682p	30/09/11	05/04/13	997	R-pre&pst	Ktr; pump
"	5	1834	9021p	09/04/13	21/09/14	897	R-pre&pst	Ktr; pump; DO
"	5	1834	6433p	09/04/13	21/09/14	946	R-pre&pst	Drk; pump
"	6	1886	3709p	24/09/14	11/04/16	888	R-pre&pst	Drk; nop
"	6	1886	3682p	24/09/14	11/04/16	937	R-pre&pst	Ktr; pump
"	7	1942	6433p	22/05/16	15/05/18?	*975?*		Drk; pump
"	7	1942	8263p	22/05/16	15/05/18?	*1065?*		Drk; pump
RS2	1	1697	6434	03/10/08	28/09/09	1597	R-post	Drk; nop; P shifts 2dbar; S hi 0.005 at end
"	2	1743	3680p	02/10/09	16/12/10	1592	F-post	Ktr; pump; P unreliable
"	3	1778	8263p	18/12/10	24/09/11	1599	R-pre&pst	Drk; pump
"	4	1805	3709p	29/09/11	05/04/13	1602	R-pre&pst	Drk; pump
"	5	1835	9410p	09/04/13	21/09/14	1504	R-pre&pst	Ktr; pump; DO
"	5	1835	8263p	09/04/13	21/09/14	1553	R-pre&pst	Drk; pump
RS3	1	1698	6436	03/10/08	28/09/09	2190	R-post	Drk; nop
"	2	1744	3681p	02/10/09	16/12/10	2191	F-post	Drk; pump; P unreliable
"	3	1779	8264p	18/12/10	24/09/11	2208	R-pre&pst	Drk; pump
"	4	1806	6434	29/09/11	05/04/13	2129	R-pre&pst	Drk; nop
"	4	1806	3681p	29/09/11	05/04/13	2204	R-pre&pst	Ktr; pump
"	5	1836	9411p	08/04/13	21/04/14	2104	R-pre&pst	Ktr; pump; DO; shorter record
"	5	1836	8264p	08/04/13	21/09/14	2152	R-pre&pst	Drk; pump
"	6	1887	3681p	24/09/14	11/04/16	2108	R-pre&pst	Ktr; pump
"	6	1887	3710p	24/09/14	11/04/16	2155	R-pre&pst	Drk; pump
"	7	1943	8264p	22/05/16	15/05/18?	*2153?*		Drk; pump
"	7	1943	3713p	22/05/16	15/05/18?	*2243?*		Drk; pump
RS4	1	1699	6468	03/10/08	29/09/09	2683	R-post	Ktr; nop; S hi at end by 0.01
"	2	1745	3675	01/10/09	28/05/10	2679	F-post	Ktr; pump; P unreliable
"	3	1780	8265p	18/12/10	24/09/11	2674	R-pre&pst	Drk; pump
"	4	1807	3710p	26/09/11	05/04/13	2666	R-pre&pst	Drk; pump
"	5	1837	6436	08/04/13	21/09/14	2552	R-pre&pst	Drk; nop
"	5	1837	8265p	08/04/13	21/09/14	2601	R-pre&pst	Drk; pump

Table 5b. *(continued)* Listing of MC deployments at sites RS5(B) and RS6(B) during the 2008-18 RS program.

Site	D #	BIO #	MC #	Strt Date	End Date	MC D(m)	Cals Appld	Other Info & Comments
RS5	1	1700	1696	02/10/08	29/09/09	3326	R-post	Drk; nop
"	2	1746	3676p	*No data*	*Not recovered*			
"	3	1781	8109p	18/12/10	24/09/11	3332	R-pre&pst	Ktr; pump
"	4	1808	2165	26/09/11	05/04/13	3242	R-pre&pst	Drk; nop
"	4	1808	3713p	26/09/11	05/04/13	3317	R-pre&pst	Drk: pump
RS5B	5	1838	8110p	08/04/13	23/09/14	3284	R-pre&pst	Ktr; pump
"	5	1838	8109p	08/04/13	23/09/14	3334	R-pre&pst	Ktr; pump
"	6	1888	3680p	23/09/14	11/04/16	3251	R-pre&pst	Pump; P unreliable
"	6	1888	3713p	23/09/14	11/04/16	3301	R-pre&pst	Drk: pump
"	7	1944	8109p	22/05/16	16/05/18?	*3296?*	??	Ktr; pump
"	7	1944	3714	22/05/16	16/05/18?	*3386?*	??	Drk: pump
RS6	1	1701	6433	02/10/08	29/09/09	984	R-post	Drk; nop
"	1	1701	6435	02/10/08	29/09/09	1583	R-post	Drk; nop
"	1	1701	4617	02/10/08	29/09/09	2181	R-post	Drk; nop
"	1	1701	6432	02/10/08	29/09/09	2680	R-post	Drk; nop
"	1	1701	1785	02/10/08	29/09/09	3275	R-post	Ktr; nop
"	1	1701	6467p	02/10/08	29/09/09	3777	R-post	Ktr; nop
"	2	1747	4614	30/09/09	17/12/10	979	F-post	Drk; nop
"	2	1747	3709p	30/09/09	18/06/10	1568	F-post	Drk; pump
"	2	1747	3710p	30/09/09	19/05/10	2173	F-post	Drk; pump
"	2	1747	3682p	30/09/09	17/12/10	2675	F-post	Ktr: pump; P unreliable
"	2	1747	3713p	30/09/09	04/06/10	3272	F-post	Drk; pump; to 4/6/10
"	2	1747	3714p	30/09/09	25/05/10	3771	F-post	Drk; pump; to 25/5/10
"	3	1782	8110p	19/12/10	25/09/11	885	R-pre&pst	Ktr; pump; P drft 2dbar; depth unexpected
"	3	1782	1785	*No data*	*Not recovered*			
"	3	1782	8111p	19/12/10	25/09/11	2185	F-pre	Ktr; pump; no post cal
"	3	1782	6436	19/12/10	25/09/11	2683	F-pre	Drk; nop; no post cal
"	3	1782	6467p	19/12/10	25/09/11	3280	F-pre	Ktr; pmp; no post cal
"	3	1782	6468p	*No data*	*Not recovered*			
RS6B	4	1809	4614	28/09/11	07/04/13	997	R-pre&pst	Drk; nop
"	4	1809	6435	28/09/11	07/04/13	1557	R-pre&pst	Drk; nop
"	4	1809	4617	28/09/11	07/04/13	2157	R-pre&pst	Drk; nop
"	4	1809	6432	28/09/11	07/04/13	2657	R-pre&pst	Drk; nop
"	4	1809	3675p	28/09/11	07/04/13	3256	R-pre&pst	Pump; P unreliable
"	4	1809	3680p	28/09/11	07/04/13	3605	R-pre&pst	Pump; P unreliable
"	4	1809	3714p	28/09/11	07/04/13	3756	R-pre&pst	3754m fr min P; Drk: pump
"	5	1839	6467p	07/04/13	23/09/14	3662	R-pre&pst	Ktr; pump
"	5	1839	8111p	07/04/13	23/09/14	3710	R-pre&pst	Ktr; pump
"	6	1889	3675p	24/09/14	11/04/16	3665	R-pre&pst	Pump; P unreliable
"	6	1889	3714p	24/09/14	11/04/16	3715	R-pre&pst	Drk; pump
"	7	1945	8111p	21/05/16	16/05/18?	*3664?*	??	Ktr; pump
"	7	1945	8110p	21/05/16	16/05/18?	*3754?*	??	Ktr; pump

Table 6. Nominal Heights Above Bottom (HAB) of the MCs (indicated by X's) in the 7 RS deployments (D1-D7) which returned some good data. Lost MCs are indicated by "nr". The MCs at *150 mab in D5 and D6* were intended to be at 100 mab.

Site	HAB	D1	D2	D3	D4	D5	D6	D7
RS1	200 mab	-	-	-	-	X	X	
"	175 mab	-	-	-	X	-	-	
"	*150 mab*	-	-	-	-	*X*	*X*	
"	100 mab	X	X	X	X	-	-	X
"	25 mab	-	-	X	-	-	-	-
"	10 mab	-	-	-	-	-	-	X
RS2	200 mab	-	-	-	-	X		
"	*150 mab*	-	-	-	-	*X*		
"	100 mab	X	X	X	X	-		
RS3	200 mab	-	-	-	-	X	X	
"	175 mab	-	-	-	X	-	-	
"	*150 mab*	-	-	-	-	*X*	*X*	
"	100 mab	X	X	X	X	-	-	X
"	10 mab	-	-	-	-	-	-	X
RS4	200 mab	-	-	-	-	X		
"	*150 mab*	-	-	-	-	*X*		
"	100 mab	X	X	X	X	-		
RS5/RS5B	200 mab	-	-	-	-	X	X	
"	175 mab	-	-	-	X	-	-	
"	*150 mab*	-	-	-	-	*X*	*X*	
"	100 mab	X	nr	X	X	-	-	X
"	10 mab	-	-	-	-	-	-	X
RS6/RS6B	2900 mab	X	X	X	X			
"	2300 mab	X	X	nr	X			
"	1700 mab	X	X	X	X			
"	1200 mab	X	X	X	X			
"	600 mab	X	X	X	X			
"	250 mab	-	-	-	X			
"	200 mab	-	-	-	-	X	X	
"	*150 mab*	-	-	-	-	*X*	*X*	
"	100 mab	X	X	nr	X	-	-	X
"	10 mab	-	-	-	-	-	-	X

other deployments, the longest potential concatenated MC records over the 2008-18 measurement period should be from RS1 and RS3 with virtually complete records except for the 6-week gap between Deploys 6 and 7. The concatenated records from RS5 will be shorter by 14.5 months (so only ~8.2 years) due to the unrecovered mooring in Deploy 2, and those from RS6 shorter by ~16 months (so only ~8.3 years) due to battery failure (7 months) of the deepest MC in Deploy 2 and the loss (9 months) of the deepest MC in Deploy 3.

During the primary 2008-14 measurement period, the potential MC records at 100-150 mab at RS2 and RS4 are of similar length (~6 years) to those at RS1 and RS3, although there are minor issues with S quality in Deploy 1 at RS2 and RS4 that may need further consideration (Table 5). Unfortunately, the records from RS5 and RS6 are again shorter by 14.5 and 16 months, as discussed above (so lengths of only ~4.8 and ~4.7 years, respectively). Note that the concatenated record lengths in this and the preceding paragraph assume adequate quality data from the various MCs for the scientific questions at hand, which appears to be the case in most (if not all) of the records, but is addressed further below based on the MC-CTD calibration casts.

The MCs were Seabird SBE37-SMs or SBE37-MPs where the P denotes the inclusion of a pump to assist flow through the conductivity cell (noted as "pump" in Table 5). Most were purchased for the program or provided by the UK National Oceanography Center (NOC), with a few provided by BIO. The primary MCs generally had a pump except in Deploy 1. The initially purchased or provided (by NOC or BIO) MCs generally had Druck P sensors (Table 5), but the later ones had Kistler P sensors (e.g., Cunningham et al., 2011).

5.3 Conductivity-Temperature-Depth (CTD) Profiles

As discussed in §2, the RS mooring program would not have been possible without the exceptional cooperation of the personnel involved in DFO's AZMP during 2008-16, and DFO's AZOMP during the extension to 2018. These programs had well-established protocols for the collection of high-quality CTD and bottle data at the standard stations shown in Fig. 1 (when conditions and vessel time allowed), involving laboratory (e.g., salinometer) analyses and high-resolution temperature probes. In many cases, the same CTD system was used on the BIO AZMP surveys, and AZOMP surveys of the XHL and AR7W Line in the Labrador Sea (e.g., Yashayaev and Loder 2016). As described in the next subsection, the MCs were mounted on the CTD rosette on selected casts for calibrations of the former. Also, the CTD profiles at the standard HL/XHL stations and RS sites provide valuable information on the cross-slope and vertical hydrographic structure (§6.3).

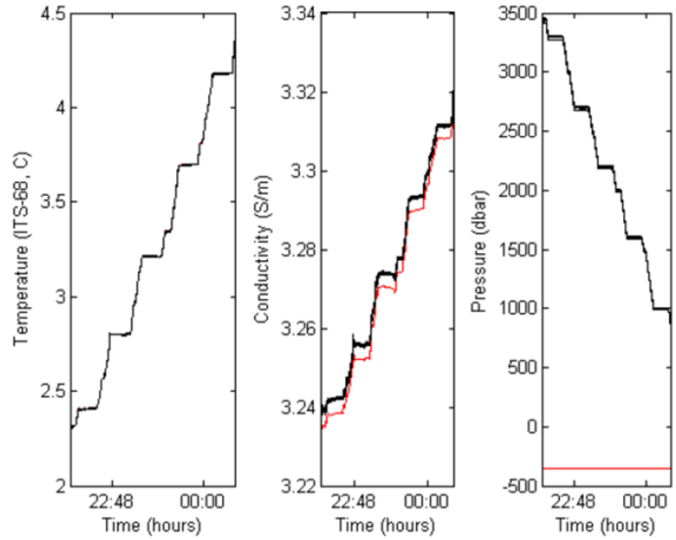
5.4 MC-CTD Calibrations

In most cases the deployed MCs had just been purchased or returned from re-certification from SeaBird prior to deployment. Further at-sea calibrations were carried out on MC-CTD casts prior to deployment for Deploys 3-7, and after recovery of the MCs from all deployments. In these casts, multiple MCs with a typical 15-second sampling rate were attached to the CTD rosette frame as part of a standard CTD downcast at stations like HL7, HL8 or HL9 with depths of ~2700, 3400 or 3900 m, respectively. Then, on the CTD upcast, the MC-CTD package was stopped typically at 5 specified depths for periods of 10-20 minutes in order to collect 40-80 MC readings from waters to which the various sensors had equilibrated. An example of the time series from the multiple MCs on a particular cast is shown in Fig. 7, with the "steps" or plateaus indicating the stop periods. These specified depths were typically 1000, 1600, 2200, 2700 and 3300m, corresponding to the depths of the MCs when deployed on the moorings.

The standard analysis procedure was to take the MC time series of T, C and P from the plateaus, after screening for outliers associated with the sensor equilibration, and pair them with data from the CTD filtered to the MC sampling interval. Standard regression analyses (CTD vs MC) using all of the screened data from all of the plateaus were then carried out, to determine regression coefficients to be applied to the moored MC time series for an optimal calibration.

The calibration (regression) coefficients from the BIO analyses of the MC-CTD casts are shown in Table 7. As mentioned, pre-deployment calibration casts were not carried out for Deploys 1 and 2. Also, post-recovery calibrations were not carried out for the 3 MCs from M1785 at RS6 in Deploy 3 which were recovered on a delayed basis after dragging. The absence of P data from MC #'s 3675 and 3680 (Deploys 2, 4 and 6), and 3681 and 3682 (Deploy 2) is apparent.

Figure 7. Example of MC data from a pre-deployment MC-CTD calibration (up)cast, taken on 24-25 September 2011. The T (left panel), C (centre) and P (right) time series from multiple MCs mounted on the CTD rosette frame are shown, with only small differences among the MCs apparent except for C and P from MC #1696 shown in red (which, consequently, was not deployed). The latter's P sensor was not working and its C values were consistently low. The step structure in each time series reflects the rosette frame being stopped and held at selected depths (P values) for 10-20 minute intervals.



The adjustments for T from these at-sea calibrations were <0.003°C in magnitude in almost all cases, and <0.001°C in most. Exceptions were MC #'s 4614 in Deploy2, 3676 in Deploy 4, and 3675 in Deploy 6 for which the T adjustments were ~0.004°C. Thus, the T data from the MCs can be considered highly reliable. The adjustments for C were 0.002 or less in magnitude in almost all cases (cf typical C value of ~3), and <0.001 in most, with the exceptions of MC #'s 3675, 3680 and 3682 (adjustments of 0.003-0.004). Thus, also considering their lack of P data, the S data from these particular MCs need special consideration. Note however that, with the exceptions of sites RS1-RS4 in Deploys 1 and 2, these MCs were not deployed as the primary ones (at 100-150 mab), and none of the C adjustments for any of the MCs were large.

The magnitudes of the adjustments for P were typically in the 2-10 dbar range. The largest exception was ~42 dbar for MC #1785 in Deploy 1 (this MC was lost in Deploy 3). The other exceptions were MC #3709 in Deploy 2 (11 dbar) and Deploy 4 (13 dbar), and #6435 in Deploy 4 (15 dbar). It appears that uncertainties in the P from one deployment to another, associated with its calibration (including possible drift) and actual difference in water and MC depths of the re-deployed moorings, may be a significant contributor to uncertainty in the S calibration, although these were small in all cases (see below).

Examples of the uncalibrated and calibrated time series are shown in Fig. 8 for 4 MCs in Deploy 3 – the primary MCs (at 100 mab) at RS1 and RS5, and the shallowest and deepest MCs at RS6. For the RS1 and RS5 MCs and the top one at RS6, calibration coefficients are available from both pre-deployment and post-recovery MC-CTD casts. In cases like this (for most of the MCs from Deploys 3-6), the calibration coefficients for a particular time during the deployment were obtained from linear interpolation between the pre-deployment and post-recovery coefficients. We refer to these and others based on linear interpolation in time as "ramped" calibrations. In contrast, when only a pre-deployment or post-recovery calibration was available (e.g., in Deploys 1 and 2) and that calibration is applied for all times in the record, we refer to them as "flat" calibrations. The 4th example shown in Fig. 8, for the deepest MC at RS6 for which a post-recovery calibration cast was not done, is an example of a flat calibration. The differences between the uncalibrated and calibrated values of each of T and C for all 4 MCs are not visible with the resolution of the plots in Fig. 8, although they can be seen in zoomed versions. This is typical of T and C from all for the MCs used during the 2008-18 program.

In contrast, the differences between the uncalibrated and calibrated P values, and between the S values computed from uncalibrated and calibrated data, are generally visible in plots with scales commensurate with the limited variability in each of these variables. The very limited variation in the difference between the uncalibrated and calibrated P values throughout the records for the first 3 MCs in Fig. 8 is consistent with the small differences between the pre- and post-calibration coefficients in Table 7, while the noticeable variation in the S differences for these MCs indicate that small T and C variations can contribute to more noticeable S ones. However, note that the S adjustments for these 3 MCs are much less than 0.01 throughout (§6.2).

The 4th example MC record in Fig. 8, in which the pre-deployment calibration coefficients have been applied throughout the record in a "flat" calibration, shows no obvious variation in the S adjustment during the record, as expected. In this case, the S adjustment of ~-0.005 is somewhat larger in magnitude than in the other cases, but still relatively small.

Table 7a. Deploys 1-3. Linear regression coefficients for the calibrations of T, C and P from the MCs, based on the pre-deployment ("Pre-cal") and post-recovery ("Post-cal") MC-CTD calibration casts on the deployment and recovery cruises (Table 1). "A" represents the slope and "B" the intercept of the regression relation.

Property	Deployment 1 (2008-09)					Deployment 2 (2009-10)					Deployment 3 (2010-11)						
	Ser. #	RS	Appr. Depth	Post-cal		Ser. #	RS	Appr. Depth	Post-cal		Ser. #	RS	Appr. Depth	Pre-cal		Post-cal	
				A	B				A	B				A	B	A	B
T				0.9998	0.0015				1.0003	-0.0004				0.9992	0.0043	0.9991	0.0046
C	6437	RS-1	1000	0.9998	0.0010	2165	RS-1	1000	1.0005	-0.0017	6433	RS-1	1000	0.9989	0.0035	0.9990	0.0034
P				1.0018	0.3751				0.9991	7.1385				1.0022	0.3488	1.0024	0.4642
T				0.9997	0.0010				1.0002	0.0000				0.9993	0.0033	1.0006	-0.0026
C	6434	RS-2	1600	0.9990	0.0038	3680	RS-2	1600	0.9938	0.0207	9021	RS-1	1075	0.9986	0.0049	1.0008	-0.0020
P				1.0017	-5.9090									1.0016	-0.4320	1.0014	0.1359
T				1.0008	-0.0023				0.9999	0.0010				0.9993	0.0036	0.9991	0.0042
C	6436	RS-3	2200	1.0009	-0.0023	3681	RS-3	2200	0.9926	0.0251	8263	RS-2	1600	0.9991	0.0028	0.9992	0.0030
P				1.0014	0.3491									1.0013	0.2871	1.0012	0.2516
T				0.9998	-0.0002				0.9993	0.0037				0.9990	0.0051	0.9991	0.0045
C	6468	RS-4	2700	0.9970	0.0101	3675	RS-4	2700	0.9930	0.0239	8264	RS-3	2200	0.9992	0.0024	0.9992	0.0032
P				0.9989	-6.2386									1.0013	0.1243	1.0013	0.4500
T				1.0007	-0.0006				1.0004	0.0017				0.9992	0.0042	0.9992	0.0044
C	1696	RS-5	3300	1.0017	-0.0050	4614	RS-6	1000	1.0013	-0.0033	8265	RS-4	2700	0.9990	0.0032	0.9993	0.0026
P				1.0026	0.9291				0.9997	-0.6461				1.0011	-0.0334	1.0009	0.2207
T				1.0004	-0.0014				1.0000	0.0004				0.9992	0.0047	1.0000	0.0021
C	6433	RS-6	1000	1.0002	-0.0005	3709	RS-6	1600	0.9997	0.0009	8109	RS-5	3300	0.9994	0.0022	1.0014	-0.0044
P				1.0026	0.1973				1.0075	-1.4050				0.9998	-1.9303	0.9996	-1.7855
T				0.9991	0.0021				0.9999	0.0013				0.9998	0.0019	1.0001	0.0013
C	6435	RS-6	1600	0.9966	0.0112	3710	RS-6	2200	0.9998	0.0005	8110	RS-6	1000	0.9999	0.0003	1.0016	-0.0050
P				1.0002	1.9816				1.0017	-0.0652				0.9994	-0.9239	0.9989	0.0781
T				0.9963	0.0142				1.0000	0.0017				0.9990	0.0049		
C	4617	RS-6	2200	0.9927	0.0250	3682	RS-6	2700	0.9894	0.0355	8111	RS-6	2200	0.9993	0.0021		
P				0.9987	2.6708									1.0008	-2.5377		
T				0.9987	0.0042				1.0001	0.0007				1.0001	-0.0013		
C	6432	RS-6	2700	0.9964	0.0119	3713	RS-6	3300	0.9999	0.0003	6436	RS-6	2700	0.9994	0.0022		
P				1.0011	3.2452				0.9976	0.8288				1.0013	0.5328		
T				1.0004	0.0007				1.0000	0.0015				0.9998	0.0018		
C	1785	RS-6	3300	1.0009	-0.0022	3714	RS-6	3800	1.0000	0.0001	6467	RS-6	3300	0.9996	0.0009		
P				1.0043	27.8180				0.9993	0.2611				0.9998	-1.1046		
T				1.0004	0.0000												
C	6467	RS-6	3800	1.0009	-0.0027												
P				1.0003	-5.5946												

Table 7b. Deploys 4-6. Regression coefficients for the calibrations of T, C and P from the MCs, based on the pre-deployment ("Pre-cal") and post-recovery ("Post-cal") MC-CTD calibration casts on the deployment and recovery cruises.

Deployment 4 (2011-13)						
Ser. #	RS	Appr. Depth	Pre-cal A	Pre-cal B	Post-cal A	Post-cal B
6437	RS-1	925	0.9997	0.0011	1.0002	-0.0010
			1.0005	-0.0013	1.0003	-0.0002
			1.0023	0.5155	1.0023	0.5318
3682	RS-1	1000	1.0000	0.0012	1.0003	0.0000
			1.0032	-0.0105	1.0020	-0.0062
			0.9976	0.0808	0.9976	0.4896
3709	RS-2	1600	0.9997	0.0039	1.0001	0.0020
			1.0010	-0.0028	1.0007	-0.0016
			1.0085	-0.8824	1.0085	-0.6851
6434	RS-3	2125	0.9994	0.0037	1.0001	0.0010
			0.9997	0.0015	1.0000	0.0008
			1.0010	-6.9130	1.0010	-2.9593
3681	RS-3	2200	0.9995	0.0025	1.0002	-0.0001
			1.0005	-0.0015	1.0006	-0.0016
			0.9979	0.6920	0.9978	0.8615
3710	RS-4	2700	0.9993	0.0050	1.0001	0.0020
			1.0002	-0.0002	1.0011	-0.0027
			1.0016	0.4891	1.0014	1.1871
2165	RS-5	3225	0.9998	0.0016	1.0007	-0.0020
			1.0006	-0.0010	1.0010	-0.0022
			0.9990	1.1760	0.9999	13.3020
3713	RS-5	3300	0.9995	0.0045	1.0002	0.0017
			1.0006	-0.0013	1.0008	-0.0018
			0.9969	1.1046	0.9967	1.8267
4614	RS-6	1000	0.9995	0.0046	0.9998	0.0035
			1.0006	-0.0014	1.0000	0.0012
			0.9988	0.7342	0.9986	1.3273
6435	RS-6	1600	1.0001	-0.0001	1.0000	0.0004
			1.0004	-0.0009	0.9993	0.0031
			1.0074	2.6894	1.0077	3.0891
4617	RS-6	2200	1.0000	-0.0003	0.9998	0.0003
			1.0011	-0.0026	0.9999	0.0012
			0.9996	0.0017	0.9996	0.2196
6432	RS-6	2700	1.0000	0.0010	0.9997	0.0015
			1.0010	-0.0027	0.9992	0.0030
			1.0013	0.5084	1.0020	6.7769
3675	RS-6	3300	0.9996	0.0050	0.9995	0.0050
			0.9904	0.0327	0.9921	0.0276
3680	RS-6	3650	0.9999	0.0014	0.9997	0.0026
			0.9926	0.0254	0.9930	0.0242
3714	RS-6	3800	0.9998	0.0025	0.9997	0.0028
			1.0011	-0.0031	0.9999	0.0010
			0.9991	0.7405	0.9992	1.0130

Deployment 5 (2013-14)						
Ser. #	RS	Appr. Depth	Pre-cal A	Pre-cal B	Post-cal A	Post-cal B
9021	RS-1	900	1.0002	0.0008	0.9995	0.0030
			1.0004	-0.0005	0.9982	0.0068
			1.0009	1.5154	1.0017	-0.6001
6433	RS-1	950	1.0003	0.0001	1.0008	-0.0016
			1.0001	0.0004	1.0017	-0.0051
			1.0025	1.2360	1.0029	1.2498
9410	RS-2	1500	0.9989	0.0048	1.0002	0.0003
			0.9971	0.0104	1.0010	-0.0023
			0.9985	0.0244	0.9987	-0.1491
8263	RS-2	1550	1.0002	0.0002	1.0007	-0.0017
			0.9999	0.0009	1.0015	-0.0046
			1.0013	1.2071	1.0015	0.8636
9411	RS-3	2100	0.9989	0.0051	1.0002	0.0004
			0.9967	0.0115	1.0007	-0.0019
			0.9990	0.8016	0.9991	0.5667
8264	RS-3	2150	1.0001	0.0003	1.0007	-0.0015
			1.0000	0.0006	1.0017	-0.0054
			1.0013	1.1455	1.0016	1.4662
6436	RS-4	2600	1.0006	-0.0016	1.0008	-0.0023
			0.9997	0.0017	1.0008	-0.0025
			1.0014	1.3325	1.0016	0.8362
8265	RS-4	2650	1.0001	0.0007	1.0007	-0.0009
			0.9991	0.0036	1.0016	-0.0053
			1.0008	1.1928	1.0010	0.9513
8110	RS-5	3200	1.0002	-0.0001	1.0007	-0.0020
			1.0002	0.0001	1.0019	-0.0057
			0.9993	0.2368	0.9994	-0.3067
8109	RS-5	3250	0.9986	0.0045	1.0008	-0.0020
			0.9968	0.0111	1.0017	-0.0053
			0.9999	-1.5106	1.0000	-2.1861
6467	RS-6	3700	0.9988	0.0045	1.0006	-0.0009
			0.9969	0.0107	1.0013	-0.0042
			0.9997	-0.5101	0.9998	-0.8938
8111	RS-6	3750	1.0001	0.0001	1.0006	-0.0018
			1.0002	0.0001	1.0018	-0.0056
			1.0004	-1.2053	1.0006	-1.9813

Deployment 6 (2014-16)						
Ser. #	RS	Appr. Depth	Pre-cal A	Pre-cal B	Post-cal A	Post-cal B
3709	RS-1	900	0.9999	0.0009	0.9997	0.0020
		900	0.9990	0.0037	1.0020	-0.0061
		900	1.0088	-0.6070	1.0092	-0.1534
3682	RS-1	950	0.9998	0.0016	0.9994	0.0036
		950	0.9993	0.0026	1.0005	-0.0013
		950	0.9979	0.1350	0.9978	0.1609
3681	RS-3	2100	0.9999	0.0017	0.9996	0.0032
		2100	0.9984	0.0059	1.0009	-0.0026
		2100	0.9980	0.4900	0.9981	0.1643
3710	RS-3	2150	0.9999	0.0011	0.9994	0.0033
		2150	0.9991	0.0037	1.0016	-0.0050
		2150	1.0017	0.4062	1.0022	0.2497
3680	RS-5	3200	1.0000	0.0007	0.9995	0.0031
		3200	0.9916	0.0287	1.0098	-0.0312
		3200				
3713	RS-5	3250	0.9999	0.0010	0.9997	0.0017
		3250	0.9991	0.0036	1.0016	-0.0050
		3250	0.9971	1.0031	0.9976	0.2949
3675	RS-6	3700	1.0000	0.0028	0.9995	0.0049
		3700	0.9916	0.0294	1.0091	-0.0282
		3700				
3714	RS-6	3750	1.0000	0.0008	0.9996	0.0028
		3750	0.9991	0.0034	1.0020	-0.0061
		3750	0.9993	0.4951	0.9998	-0.1762

Another set of examples of the application of "ramped" (linear) calibration adjustments is shown in Fig. 9, in this case the uncalibrated and calibrated S records from the 6 primary MCs (at 150 mab) during Deploy 5 (2013-2014). A surprising feature in this set is that the S adjustments are larger at the start of the record than at the end, and in the 0.005-0.01 range in some cases, whereas one might have expected larger adjustments to be needed at the end of the records (after the MCs were deployed for 18 months). This points to the somewhat arbitrary issue of when to apply pre-deployment and/or post-recovery calibrations from MC-CTD casts, considering uncertainties in the small magnitudes of the adjustments and in when inaccuracies in the MC measurements actually developed. As discussed in §6.2, there are small shifts (~0.005 or so) in S between the end of some records and the start of the record from the replacement MCs in a few cases, whose origin has not been resolved. Further consideration of the calibration adjustments in relation to the associated water property changes in T-S space during the re-deployments may be desirable in these cases in particular.

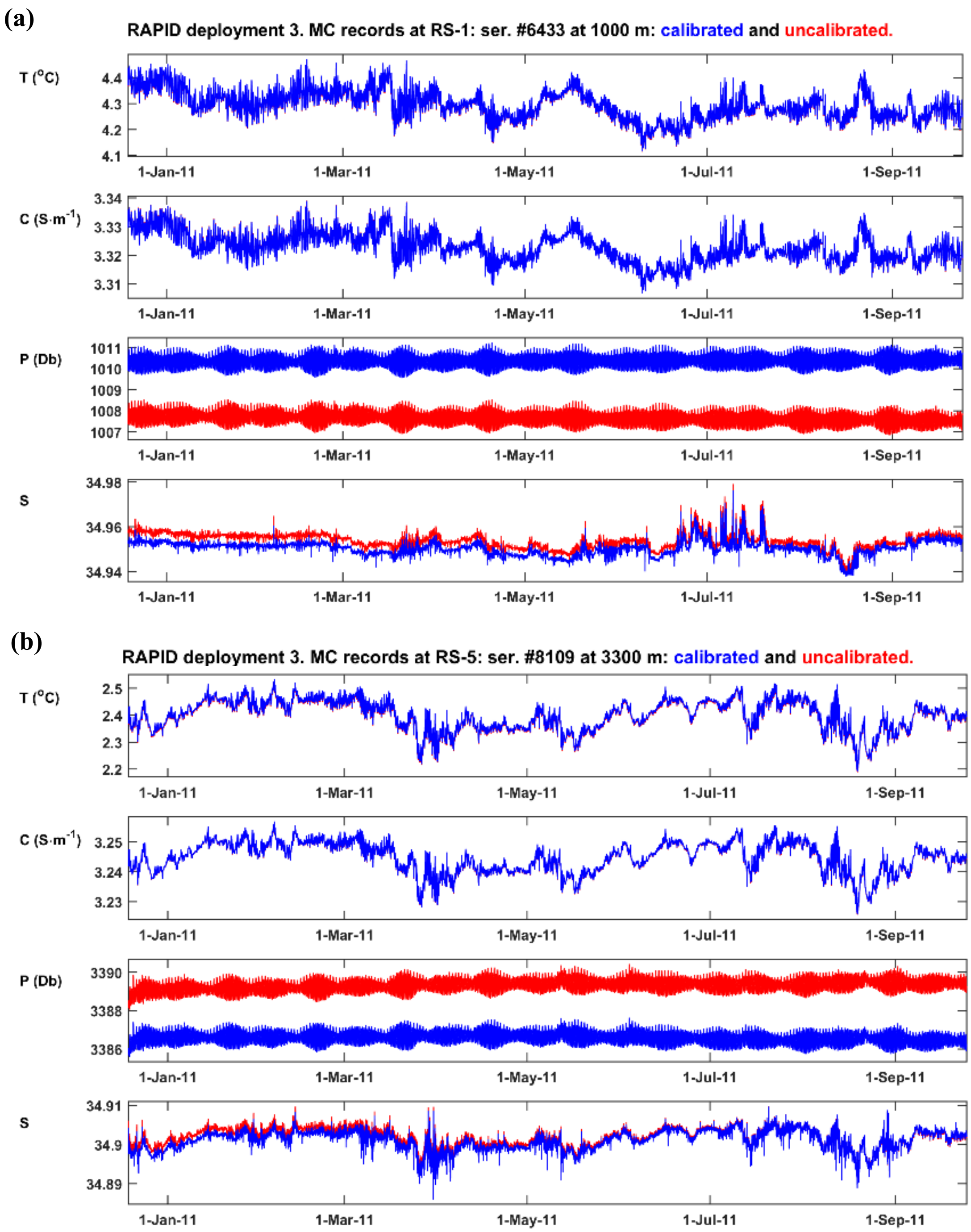


Figure 8. Examples of uncalibrated and calibrated MC time series from 4 of the MCs in Deploy 3 (2010-11): **(a)** MC #6433 at 100 mab at RS1, **(b)** MC #8109 at 100 mab at RS5, (c) MC #8110 at the top of M1782 at RS6, and (d) MC #6467 at ~600 mab at RS6. *See next page for **(c)** and **(d)***. (Note that the deepest MC at 100 mab on M1782 was not recovered.) The 4 panels for each MC correspond to T, C, P and S (from top to bottom). Ramped adjustments using both the pre-deployment and post-recovery calibration coefficients were applied to the first 3 MCs, and flat adjustments based on the pre-deployment calibration to the 4th (because a post-recovery calibration for this MC was not done due to its late recovery). The depths in the subtitles are nominal (see Table 5 for best estimates).

Figure 8. *(continued from previous page)* Examples of uncalibrated and calibrated MC time series from 4 of the MCs in Deploy 3 (2010-11):
(a) MC #6433 at 100 mab at RS1,
(b) MC #8109 at 100 mab at RS5,
(c) MC #8110 at the top of M1782 at RS6, and
(d) MC #6467 at ~600 mab at RS6.
See previous page for (a) and (b) and further information.
The depths in the subtitles are nominal (see Table 5 for best estimates).

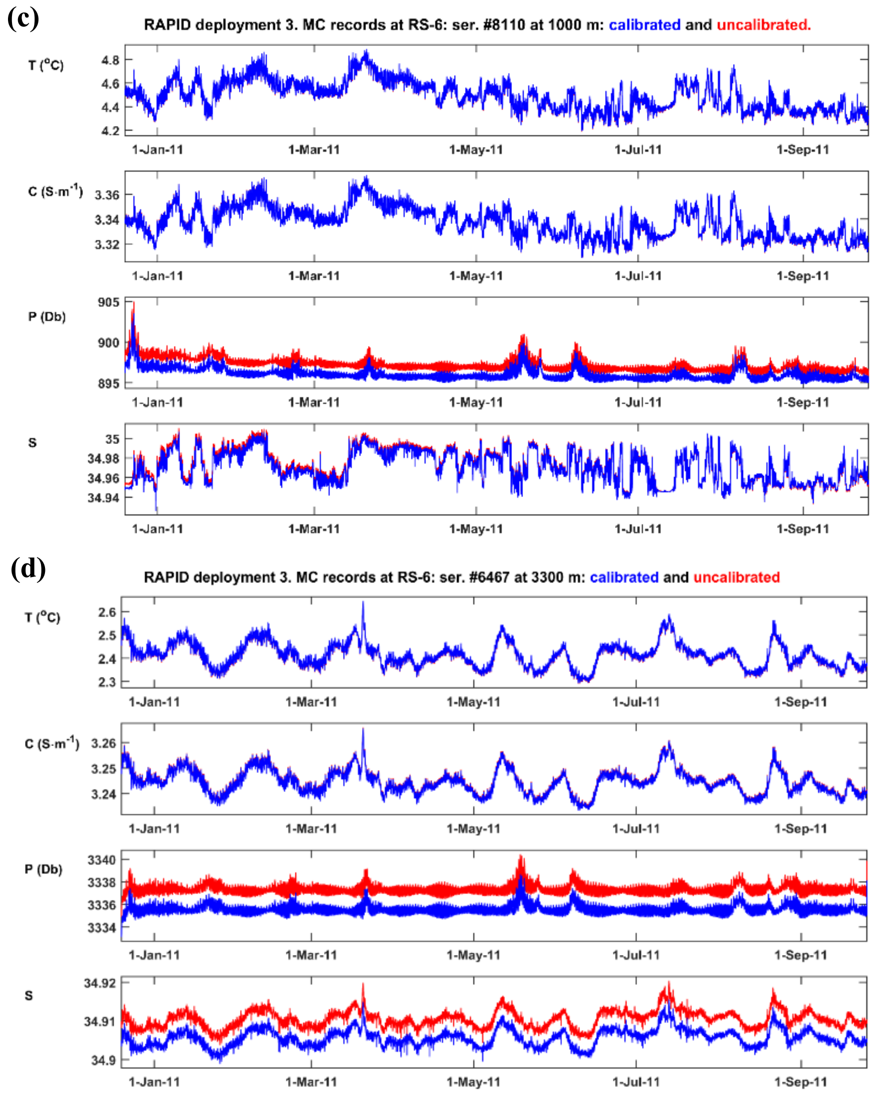
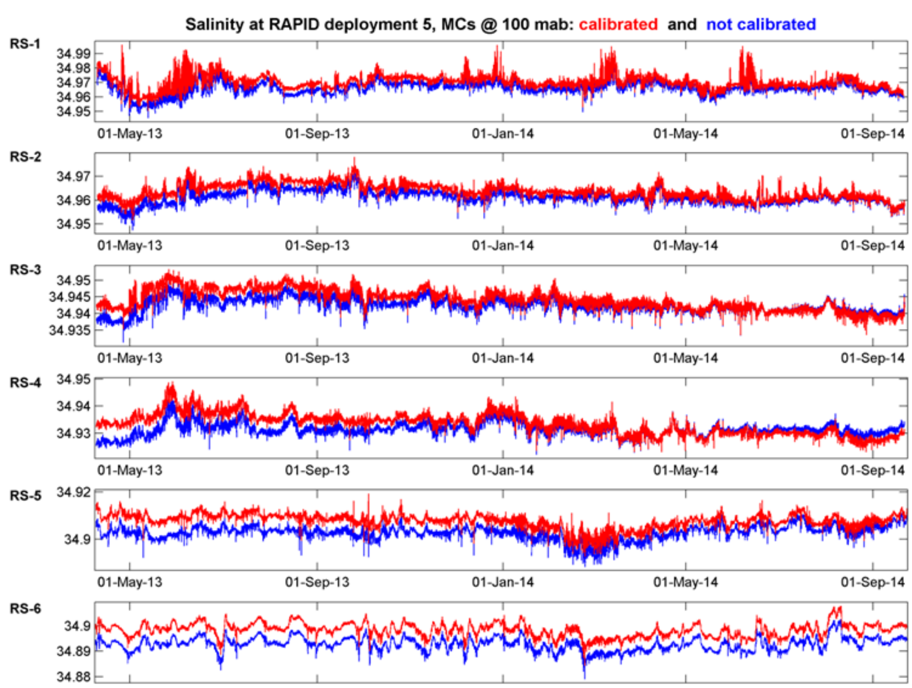


Figure 9. Examples of uncalibrated and calibrated S time series from the primary MCs at 150 mab at the 6 RS sites during Deploy 5 from April 2013 to September 2014. Both pre-deployment and post-recovery calibration coefficients have been used with a linear variation in time ("ramped" adjustments) through the records. The adjustments at the start of the records are typically in the 0.003-0.01 range, and those at the end are generally smaller. (Note that the red and blue colour coding is reversed from in Fig. 8).



5.5 Bottom Pressure Recorders (BPRs)

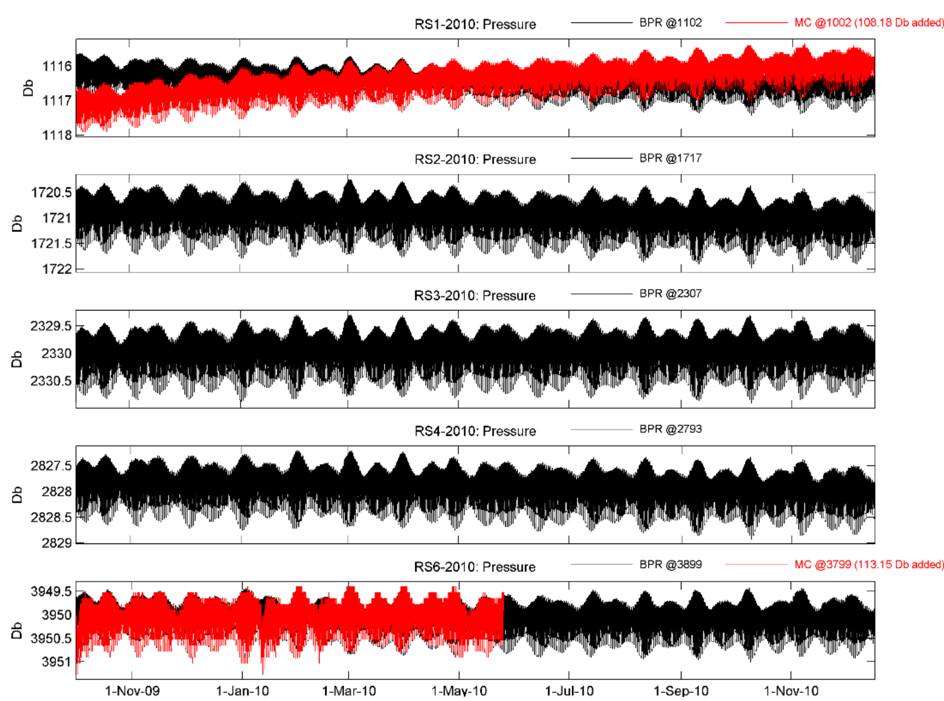
Information on the BPRs deployed during the 2008-18 program is provided in Table 8. The primary instrument was the SeaBird SBE53 (https://www.seabird.com/cms-portals/seabird_com/cms/documents/discontinued-products/manual-53_013.pdf). The less expensive RBR DR-1050 (https://www.manualslib.com/manual/2128354/Rbr-1050-Series.html#manual) was deployed on an exploratory basis in Deploys 1 and 2, but only used as the primary BPR at 2 sites in Deploy 7. In all cases except Deploys 1 and 2 at RS6 and Deploy 4 at RS6A, the primary BPR was deployed in a BIO-developed holder on the mooring anchor. The anchor comprised a stack of 5 train wheels at the tall moorings (RS6 in Deploys 1-3, RS6B in Deploy 4) and a single train wheel on all of the short moorings (Appendix). In Deploys 1 and 2 at RS6, the primary BPR was included in a POL anchor assembly, and in Deploy 4, the RS6 BPR was deployed (without other instrumentation) in a separate very short mooring (M1810 at RS6A). This was done because of difficulties encountered in Deploys 1-3 at RS6 (operational complexity in the deployment of a tall mooring, sometimes in rough weather). Unfortunately, the effect of the operational complexity was realized when M1782 which had been deployed at RS6 in Deploy 3 (in Dec 2010; see §4.3) did not re-surface in multiple recovery attempts (probably due to a tangle of the BPR chain with the anchor). After Deploy 4 at RS6B, only short moorings were deployed there.

The secondary RBR BPRs were included in the POL mooring assembly at RS6 in Deploys 1 and 2, and attached to the acoustic release in other cases (at RS1 in Deploys 1 and 2, and RS1 and RS5 in Deploy 7).

BIO did not have any prior experience with these BPRs, whereas POL did for the SBE53s. Consequently, all of the raw BPR data and related files from Deploys 1-6 were transferred to POL, with the intent that the processed files would be later transferred to BIO. An oversight here was that most of the raw BPR and related files from Deploys 1-5 were not kept at BIO. The files available (at publication time) from the BIO Archive are: the unprocessed (raw) SBE53 records from Deploys 1, 6 and 7; the unprocessed RBR records from Deploys 2 and 7; and the processed (final) SBE53 records from Deploys 1-4 (in the RAPID project archive). The latter are also available from the British Oceanographic Data Centre (BODC).

Examples of the preliminary P data from the 5 recovered SBE53 BPRs in Deploy 5, together with P from the MCs at nominal positions of 100 mab at 2 of the sites, are shown in Fig. 10. Note that offsets to P from the MCs have been applied for display purposes; however, none of the indicated P values are final.

Figure 10. Preliminary P time series from the recovered BPRs from RS1-4 and RS6 during Deploy 2, together with preliminary P from the MCs at nominal positions of 100 mab at RS1 and RS6. The MC time series of P have been offset by 108 and 113 dbar, respectively in order to give approximate agreement with those from the BPRs. Note that none of the P magnitudes are final.



P variability is dominated by the tides and their fortnightly and monthly modulations which need to be removed by filtering in order to examine low-frequency variability, as done in Hughes et al. (2013).

Table 8. Listing of BPR deployments during the 2008-18 RS program, organized by site (RS#) and deployment #. The other columns indicate the BIO #, BPR type and serial #, record start and end dates, and BPR depth.

Site	D	BIO	Model	Serial	Start	End Date	Depth(m)	Comments
RS1	1	1696	SBE53	50	03/10/08	28/09/09	1113	Final at BODC & BIO
"	1	1696	RBR1050	14581	03/10/08	28/09/09	1113	
"	2	1742	SBE53	24	02/10/09	16/12/10	1095	Final at BODC & BIO
"	2	1742	RBR1050	14581	02/10/09	16/12/10	2095	
"	3	1777	SBE53	50	18/12/10	24/09/11	1098	Final at BODC & BIO
"	4	1804	SBE53	24	30/09/11	05/04/13	1097	Final at BODC & BIO
"	5	1834	SBE53	50	09/04/13	21/09/14	1096	
"	6	1886	SBE53	24	24/09/14	11/04/16	1087	
"	7	1942	SBE53	50	22/05/16	15/05/18	*1075?*	*Depth not final*
RS2	1	1697	SBE53	49	03/10/08	30/06/09	1699	Final at BODC & BIO
"	2	1743	SBE53	52	02/10/09	16/12/10	1690	Final at BODC & BIO
"	3	1778	SBE53	45	18/12/10	24/09/11	1697	Final at BODC & BIO
"	4	1805	SBE53	52	29/09/11	05/04/13	1691	Final at BODC & BIO
"	5	1835	SBE53	45	09/04/13	21/09/14	1691	
RS3	1	1698	SBE53	51	03/10/08	28/09/09	2287	Final at BODC & BIO
"	2	1744	SBE53	51	02/10/09	28/11/10	2289	Final at BODC & BIO
"	3	1779	SBE53	48	18/12/10	24/09/11	2307	Final at BODC & BIO
"	4	1806	SBE53	73	29/09/11	05/04/13	2304	Final at BODC & BIO
"	5	1836	SBE53	48	08/04/13	21/09/14	2302	
"	6	1887	SBE53	73	24/09/14	11/04/16	2307	
"	7	1943	RBR1050	14580	22/05/16	15/05/18	*2253?*	*Depth not final*
RS4	1	1699	SBE53	47	03/10/08	09/08/09	2781	Final at BODC & BIO
"	2	1745	SBE53	47	01/10/09	14/11/10	2777	Final at BODC & BIO
"	3	1780	SBE53	66	18/12/10	24/09/11	2773	Final at BODC & BIO
"	4	1807	SBE53	47	26/09/11	05/04/13	2766	Final at BODC & BIO
	5	1837	SBE53	66	08/04/13	21/09/14	2751	
RS5	1	1700	SBE53	46	02/10/08	29/09/09	3424	Final at BODC & BIO
"	2	1746	SBE53	46	*No data*	*Not recovered*		
"	3	1781	SBE53	49	18/12/10	24/09/11	3419	Final at BODC & BIO
"	4	1808	SBE53	23	26/09/11	05/04/13	3417	Final at BODC & BIO
RS5B	5	1838	SBE53	49	08/04/13	23/09/14	3481	
"	6	1888	SBE53	47	23/09/14	11/04/16	3455	
"	7	1944	SBE53	49	22/05/16	16/05/18	*3396?*	*Depth not final*
RS6	1	1701	SBE53	45	02/10/08	12/07/09	3876	Final at BODC & BIO
"	1	1701	RBR1050	14580	02/10/08	12/07/09	3876	
"	2	1747	SBE53	25	30/09/09	17/12/10	3873	Final at BODC & BIO
"	2	1747	RBR1050	14580	30/09/09	17/12/10	3873	Final at BODC & BIO
"	3	1782	SBE53	51	*No data*	*Not recovered*		
RS6A	4	1810	SBE53	25	28/09/11	07/04/13	*3860?*	Final at BODC & BIO
RS6B	5	1839	SBE53	65	07/04/13	23/09/14	3858	
"	6	1889	SBE53	25	24/09/14	11/04/16	3865	
"	7	1945	RBR	14581	21/05/16	16/05/18	*3764?*	*Depth not final*

5.6 Aanderaa Current Meters (RCMs)

BIO has traditionally used Aanderaa current meters (RCMs) for its primary point-source current measurements (e.g., Loder et al., 1990; Drozdowski and Greenan 2013). At the time of RS Deploy 1 in 2008, BIO had largely switched to acoustic Doppler RCM11 meters, but was also still using RCM8s with mechanical rotors in some locations where currents were not expected to be weak. These were in addition to RDI/Teledyne ADCPs which by then were also being widely used at BIO in cases where current measurements over vertical distances of 10s to 100s of m were desired.

With encouragement from the Aanderaa supplier, consideration was also being given to acquiring some of Aanderaa's new-at-the-time SeaGuard (SG) measurement platforms which could accommodate additional sensors. A 1-month deployment of an intercomparison mooring at station HL2 on the inner Scotian Shelf was successfully carried out in May-June 2008, with two SG ZPulse™ multi-frequency Doppler Current Sensor provided by Aanderaa, an RCM11 and RCM8 provided by BIO, and a Doppler Volume Sensor provided by Teledyne/RDI (Drozdowski et al., 2010). A second (longer) BIO-led intercomparison deployment with the two SeaGuards and an RCM11 was then carried out with the addition of these instruments to the RS2 mooring (#1697) in Deploy 1 (Table 9; Drozdowski and Greenan 2012, 2013).

RCM11s were also deployed (piggy-backed) at BIO expense at two other positions in multiple RS deployments (Table 9). An RCM11 with a DO sensor was included at 25 mab on the RS1 mooring in Deploys 3 and 4, for potential use in DO variability investigations at the key AZMP site (HL6) and in concatenating the RS (2008-18) ADCP time series with earlier (2000-04) DFO-PERD RCM time series from this depth at HL6 (site SS-A; Loder and Geshelin 2009, 2025). In addition, an RCM8 was deployed at the top of the tall RS6 mooring in Deploy 1, and an RCM11 was deployed at the top of this mooring in Deploys 2-4 to provide intermediate-depth (~1000 mbs) current information at this deep-water site in the Slope Water complementing the near-bottom ADCP data and MC time series from lower on the mooring.

With various happenings including overcommitments by the lead author, organizational cutbacks, and unexpected complications with the ADCP and MC datasets, the data from the 6 RCM deployments in Table 9 besides those on M1697 have not been finalized. These data may be of value for the evaluation of DO variability and the concatenation of multi-year time series at HL6 (15.5 months), and the evaluation of current variability at an intermediate depth (~1000 mbs) in the Slope Water at RS6 (4.5 years).

Table 9. Listing of RCM deployments during the 2008-18 RS program, organized by site (RS#) and deployment number (D: 1 to 7). The other columns indicate the BIO consecutive mooring #, the type of Aanderaa current meter and its serial #, the record start and end dates, and the water and instruments depths. RCM8s have mechanical rotors and vanes, RCM11s are acoustic Doppler current meters, SeaGuards (SGs) are acoustic Doppler current meters, and DO denotes that the instrument had a Dissolved Oxygen (DO) optode sensor.

Site	D #	BIO #	Instrument		Start Date	End Date	Depths (m)		Notes & Comments
			Type	Ser. No.			Water	RCM	
RS1	3	1777	RCM11	678 DO	18/12/10	24/09/11	1098	1073	Good T & V data
"	4	1804	RCM11	595 DO	30/09/11	05/04/13	1097	1072	
RS2	1	1697	SG	33	03/10/08	28/09/09	1699	1586	Intercomparison study (Drozdowski & Greenan 2012, 2013)
"			RCM11	595 DO	03/10/08	28/09/09	1699	1592	
"			SG	20	03/10/08	28/09/09	1699	1595	
RS6	1	1701	RCM8	1039	02/10/08	12/07/09	3876	982	Frequent rotor stalling
"	2	1747	RCM11	563	30/09/09	06/09/10	3873	977	Good T & V data
"	3	1782	RCM11	679 DO	19/12/10	25/09/11	3883	883	Good T & V data
RS6B	4	1809	RCM11	594 DO	28/09/11	07/04/13	3856	996	

6. Example Data Displays

6.1 Velocity from ADCPs

In this section we briefly discuss some features of the velocity data from the ADCP measurements, referring to the figures in §5.1 and those below,

As expected, there was very little vertical structure in the horizontal velocity from bins 2-9, illustrated in Fig. 11 by the time series of its east (U) component from the lowest 9 bins at RS1 and RS6 in Deploy 5. One can also see the greater variability at high frequencies (e.g., tidal and wind bands) at the ~1100m deep RS1 site than at the ~3900m deep RS6 site, and the contamination (even though slight) of the bin 1 data at RS1. Low-frequency variability on the time scale of months is apparent at both sites, with little (if any) inter-site coherence apparent.

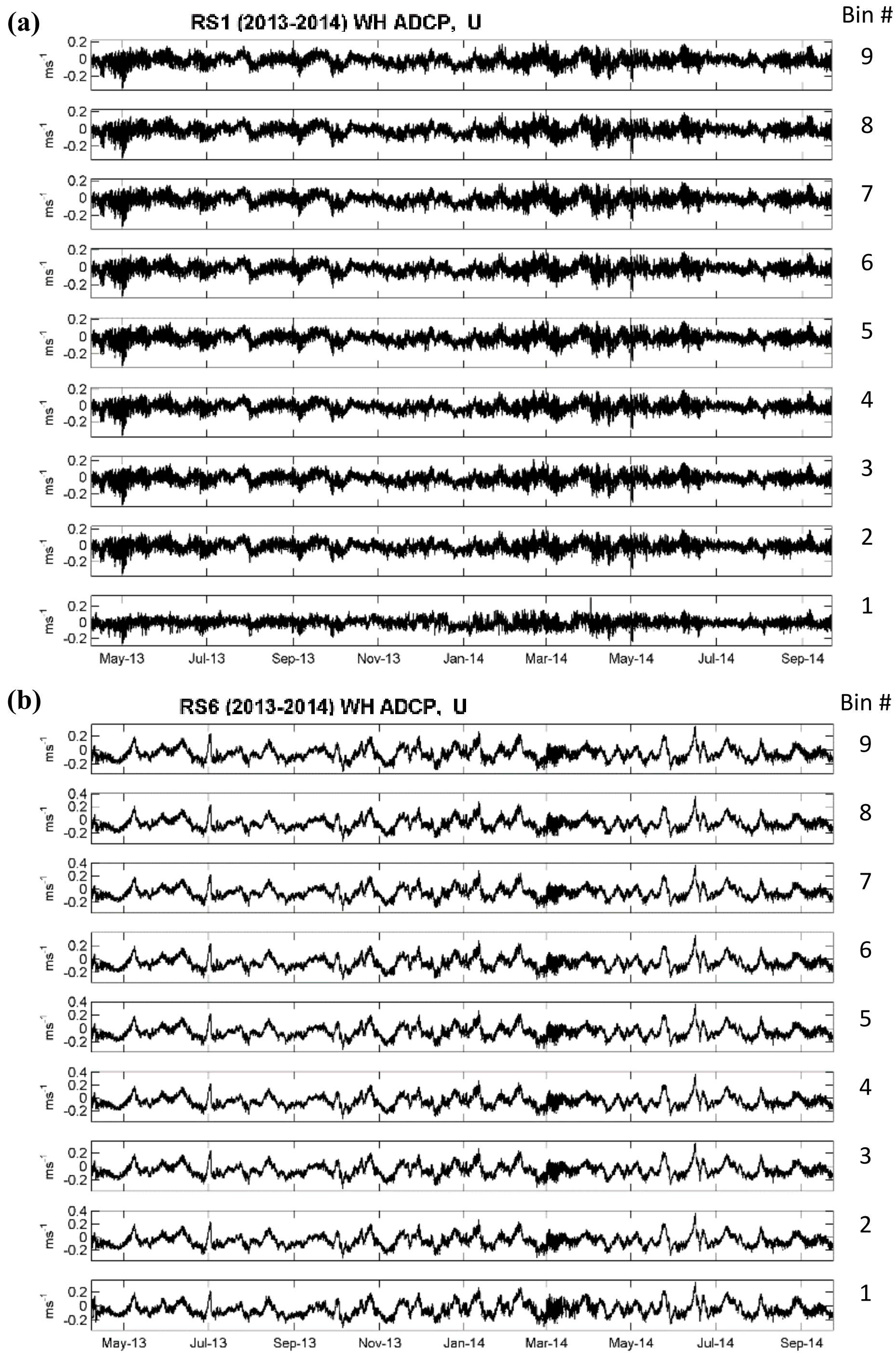


Figure 11. Hourly values of the east component (U, in m/s) of horizontal velocity at sites **(a)** RS1 (M1834) and **(b)** RS6 (M1839) during Deploy 5 from April 2013 to September 2014, in successive bins proceeding away from the ADCP from bin 1 (centered at 56 mab, bottom panels) to bin 9 (centered at 88 mab, top panels).

The velocity magnitudes (Rates), inter-site differences, and data coverage during Deploys 1-5 (2008-14) are indicated in the time series plots of concatenated hourly data from bin 8 in Fig. 12, and in the progressive vector diagrams (PVDs) from bin 8 for Deploys 1-3 and 6 in Fig. 13 (together with those for Deploys 4 and 5 in Fig. 6). The large data gaps from the unrecovered/failed ADCPs in Deploy 4 at RS2, Deploys 1 and 2 at RS5, and Deploy 3 at RS6 are apparent in Fig. 12, as well as the shortened records from battery failures in Deploys 1 and 2. The best temporal coverage during the primary RS deployments during 2008-14 is at RS1, RS3, RS4 and RS6, in that order.

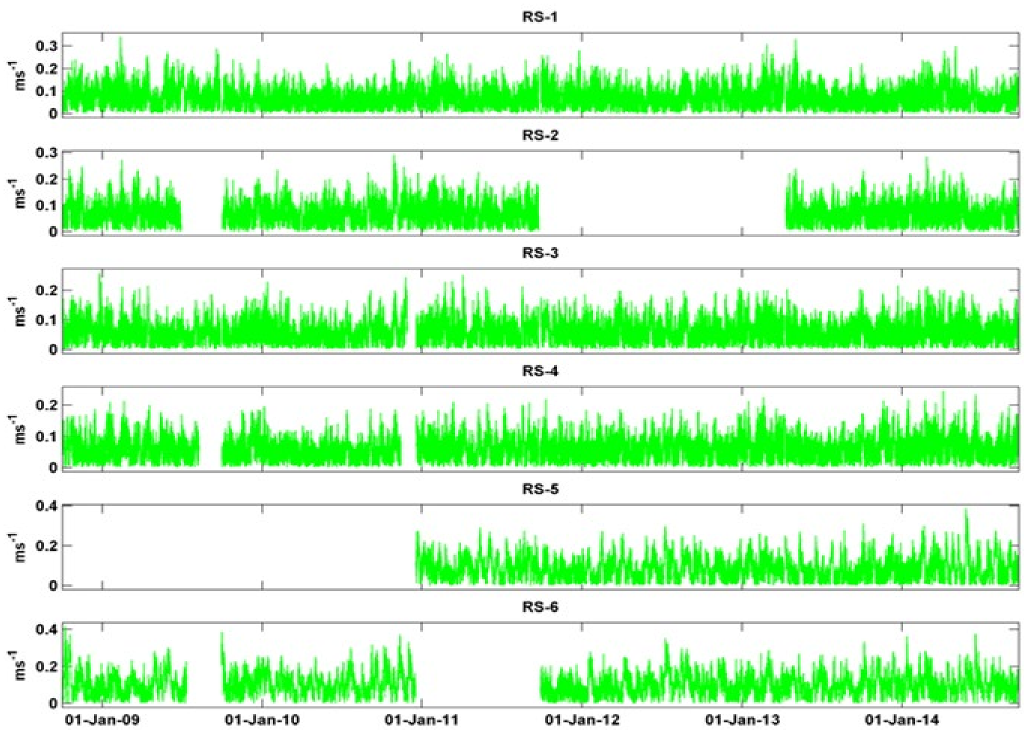
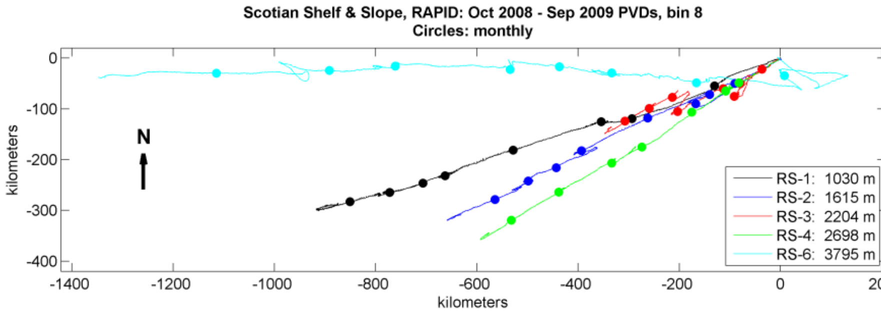


Figure 12. Concatenated time series of Rate from bin 8 (84 mab) at the 6 RS sites during Deploys 1-5 (2008-14). Note the different ordinate-axis scales.

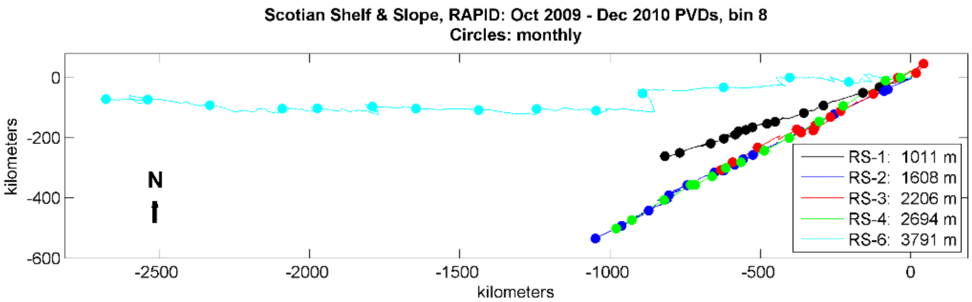
A few things to note from a cursory examination of these figures are:

- Peak current speeds are in the 0.2-0.4 m/s range at all sites, with the highest during 2008-14 at RS5 and RS6 (Fig. 12).
- The record-mean velocity directions are between southwest and west at all sites in all 6 deployments, but have notable inter-deployment differences at RS5 and RS6 in particular (Figs. 6 and 13) . As discussed in §5.1, a major factor in this is the shifted deployment positions at these sites (RS5 to RS5B after Deploy 4, and RS6 to RS6A after Deploy 3). The RS5 directions in Deploys 3 and 4 are similar (230-235°T), and substantially different from those (at RS5B) in Deploys 5 and 6 which are similar (260-265°T) to each other. The RS6 directions in Deploys 1 and 2 are similar (~270°T), and substantially different from those (at RS6B) in Deploys 4-6 (240-250°T). The inter-deployment direction differences at the other 4 sites (RS1-RS4), and at each of RS5, RS5B, RS6 and RS6B are 10° or less.
- The record-mean velocity magnitudes are generally larger at the deeper RS5/RS5B and RS6/RS6B sites (where they are typically 0.05-0.07 m/s), than at the other 4 sites (RS 1-4, where they are typically 0.02-0.04 m/s) (Figs. 6 and 13). Overall, the strongest mean flow is at RS6 and the weakest at RS3.

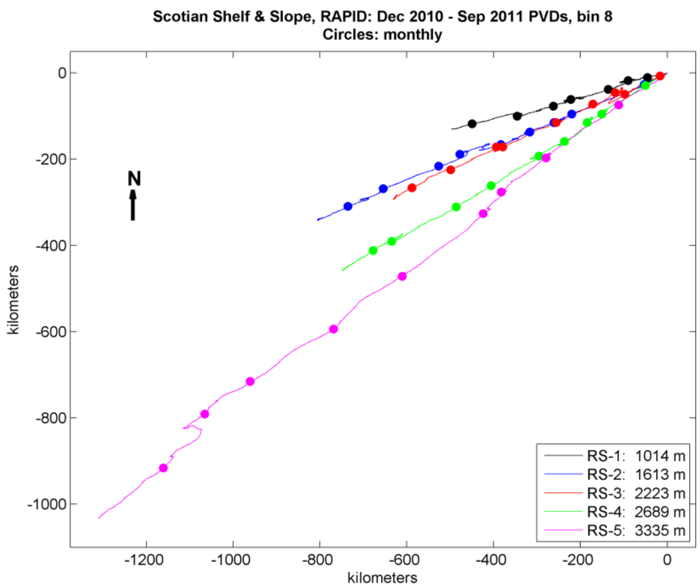
Deploy 1



Deploy 2



Deploy 3



Deploy6

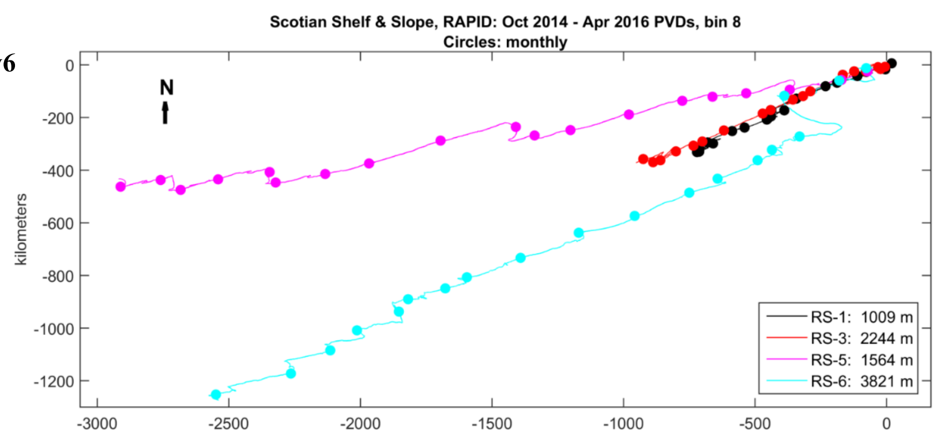


Figure 13. PVDs of hourly velocity from bin 8 (84 mab) of the ADCP at the RS sites during Deploys 1-3 and 6. A common colour coding is used for the different sites in the various panels, but the scales differ. See Fig. 6 for the PVDs from Deploys 4 and 5. The bin depths (mbs) in the legends on the plots are not the final ones in some cases.

- There is a remarkable intermittent and inconsistent sawtooth pattern in the longer-term drift (low-frequency currents) at RS5/5B and RS6/6B in particular (Figs. 6 and 13). The drift at a particular site is approximately along-slope (generally westsouthwestward) for multiple months, but then abruptly changes to a near-perpendicular cross-slope direction which can be upslope or downslope. In some deployments (e.g., Deploy 4), the directions of the cross-slope flow disruptions are the same at RS5/5B and RS6/6B, while in others they are opposite. It is unclear whether these flow disruptions are primarily local features, e.g., related to a GS meander or ring affecting the DWBC, or possibly even related to the complex topography in the general study area (although this seems unlikely). Alternatively, these shifts might be somehow related to episodicity in the flow or position of the DWBC around the Tail of the Grand Bank and Newfoundland Ridge well to the east. Shifts on a similar time scale are apparent in at least some of the concurrent MC T and S series (e.g., Fig. 9), but further investigation is need to determine their inter-relation and origin. Similar features were observed in the 2004-08 BIO moored measurements at sites SS-D and SS-E on the RAPID B Line (Fig. 1; Loder and Geshelin 2025).

Indications of the mid-frequency structure of the along-slope flow, and of the effects of the shifted RS5 and RS6 mooring positions on the the along-slope flow, are provided by the 5-day and 30-day running-mean time series plots in Figs. 14 (for 2008-14) and 15 (for 2008-16), respectively. Note that, for all sites and deployments, the positive along-slope (cross-slope) direction is taken here as 240ºT (330ºT), in consideration of the large-scale shelf-edge and upper-/mid-slope topography. From the relative magnitudes of the along- and cross-slope mid- and low-frequency flows, it can be seen that this is a rough approximation to the direction of the mean and low-frequency flows at sites RS1 to RS5, although the

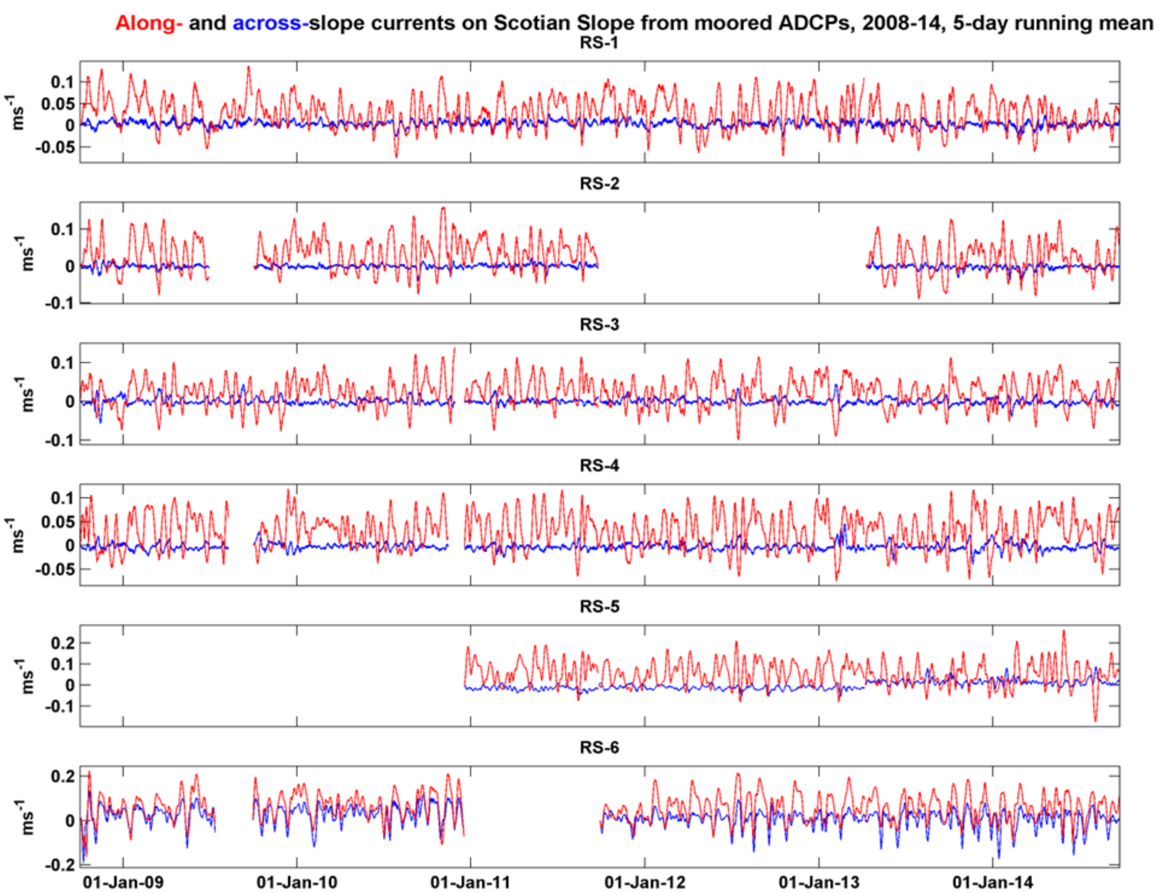


Figure 14. Five-day running means of the along-slope (red) and cross-slope (blue) components of available velocity from bin 8 (84 mab) during Deploys 1-5 (2008-2014). At all sites and in all deployments the positive along-slope direction is taken to be 240ºT. However, it is obvious that this is not a good choice for RS6.

direction of the record-mean velocity does vary from site to site and deployment to deployment, as can be seen in the PVDs (Figs. 6 and 12). In contrast, it can be seen that this along-slope direction choice is not appropriate for the mean-flow direction at RS6. Further, even in the absence of the local small-scale topographic structure discussed in §3, there is of course no reason to expect that the mean and very low-frequency flows at different sites and in different years would primarily be aligned in a single direction, considering potential differing large-scale bathymetric gradient directions on the upper and lower continental slopes (and rise), and large-scale influences (e.g., GS, DWBC and AMOC variability) on the year-to-year mean flow direction.

The effect of of the shifted positions at RS5 and RS6, discussed above in relation to the PVDs, is also clearly apparent in the mean cross-slope flows in Figs. 13 and 14 when a single fixed along-slope flow direction is specified – note the shifts at RS5 in April 2013, and at RS6 between December 2010 and September 2011. Consideration of the effect of these shifts, such as taking the along-slope flow direction to be that of the record-mean velocity or the major axis of low-frequency variability in each deployment at a particular site, is needed in creating merged (across deployments) along-slope current time series for the overall program duration for use in long-term variability analyses.

The filtered time series in Figs. 13 and 14 also indicate significant variability in the along-slope current on the time scale of weeks to months at all sites, which needs to be considered in interpreting seasonal monitoring surveys of hydrographic properties, as discussed by Loder and Geshelin (2009, 2025).

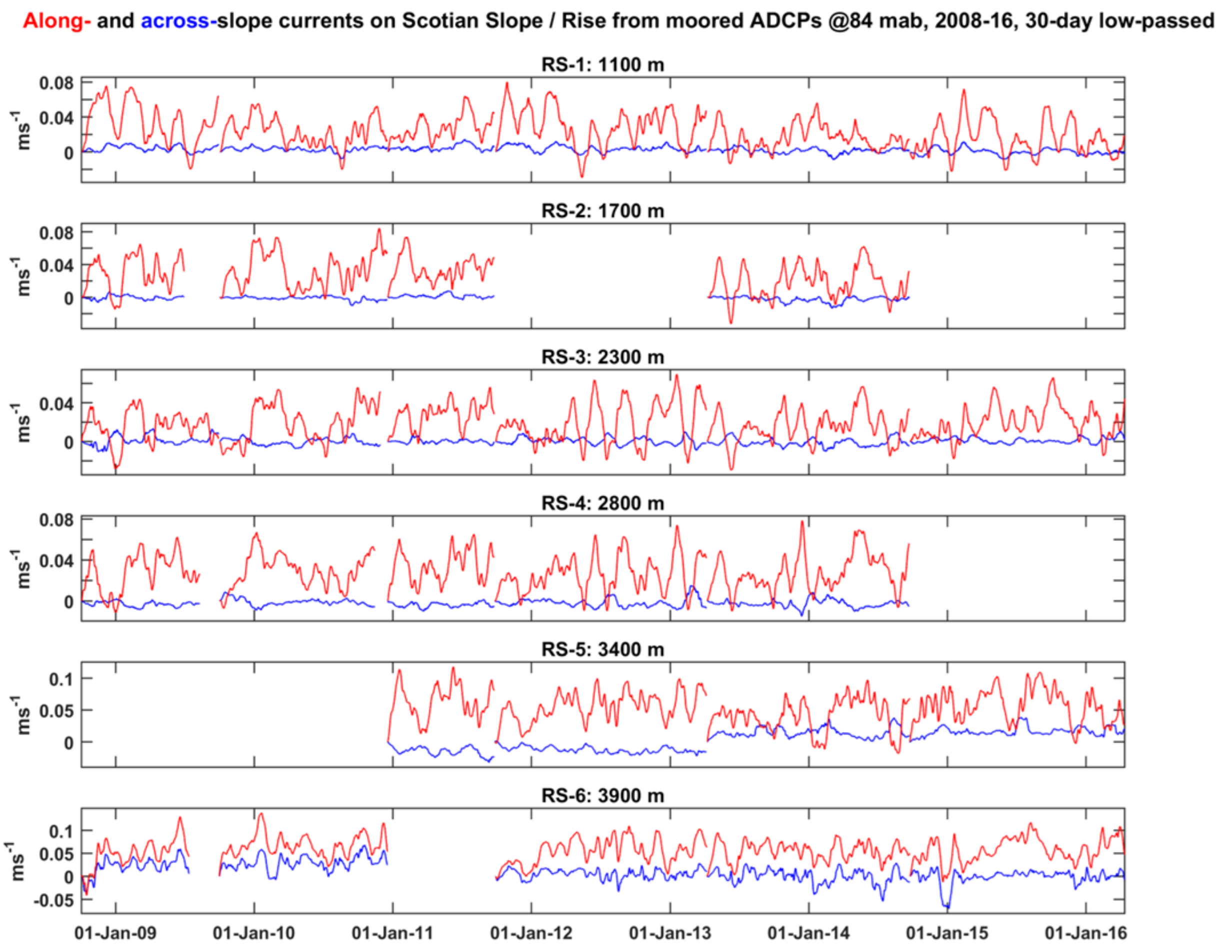


Figure 15. Thirty-day running means of the along-slope (red) and cross-slope (blue) components of available velocity from bin 8 (84 mab) during Deploys 1-6 (2008-2016). At all sites and in all deployments the positive along-slope direction is taken to be 240°T. However, the significantly non-zero cross-slope velocities at RS6 in particular, and also at RS5(B) after April 2013, indicate that this direction is not a good choice for those sites.

6.2 CTD Sections and Sea Surface Temperature

The core AZMP CTD stations adopted in 1998 were HL1-5 over the Scotian Shelf, and HL6 and HL7 over the Scotian Slope (Fig. 1), following from earlier monitoring programs in the 1950s, 1960 and1970s (e.g., Loder et al., 2003). With water depths of 100, 1050 and 2700 m respectively, HL5-7 provided limited cross-slope resolution of the complex frontal structure over the upper slope. Consequently, additional stations were included on occasion on the AZMP surveys such as stations HL5.3 (~300m), HL5.5 (~500m) and HL6.5 (2000m) between HL5 and HL7. In particular, when DFO-BIO-PERD had tall current-meter moorings at sites SS-A (near HL6, 2000-04), SS-B (HL6.5, 2001-04) and SS-C (HL5.3, 2001-04) (Loder and Geshelin 2009, 2025), these additional CTD stations were usually occupied. The core AZMP sampling involved three seasonal occupations of the HL, usually in early April, June (in association with the annual Labrador Sea cruise) and October.

With increased scientific interest in the influence of flows from the Newfoundland-Labrador region on hydrographic and circulation variability over the Scotian Slope and Rise, and in the Slope Water (a mix of waters of subpolar and GS origins), additional offshore stations (HL8-12, Fig. 1) were added to the HL by BIO in the early 2000s, referred to as the XHL. These stations were occupied regularly on the annual Labrador Sea expedition in May-July, with the XHL and AR7W sections and Argo float releases being the primary components of AZOMP. Considering the logistical advantages of moorings on the HL/XHL and previous/ongoing DFO monitoring there, the RAPID WAVE moorings on the B Line (Fig. 1) were moved to the HL/XHL in 2008 and thereafter referred to as the RAPID Scotian (RS) moorings (Fig. 16).

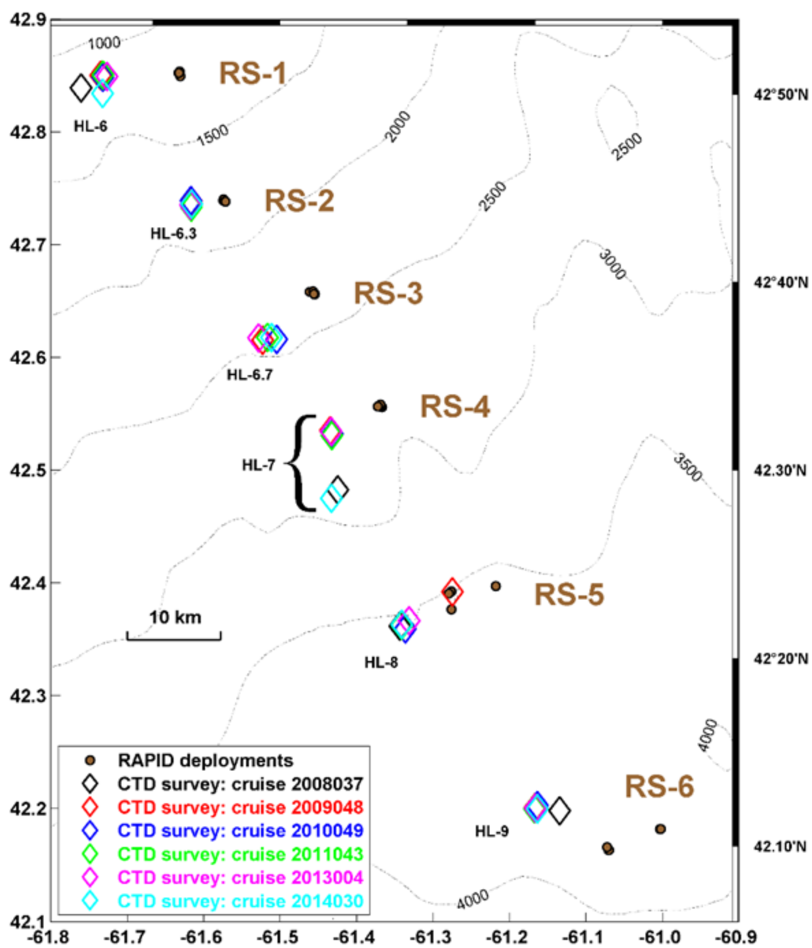


Figure 16. Locations of the RS moorings during the 5 deployments between 2008 and 2014, and of the CTD stations taken on the 6 deployment/recovery cruises (Table 1). See Table 3 for the coordinates of the mooring sites, and Fig. 3 for detail on the topography. Stations HL8 and HL9 are also referred to as XHL8 and XHL9.

The locations of the different RS mooring deployments and the "nearby" CTD profile stations at HL/XHL sites on the 6 RS deployment and recovery cruises during the primary 2008-14 RS observation period are shown in Fig. 16. The shifted positions at RS5 and RS6 are apparent, as well as some differences in the CTD station positions, particularly at HL7/RS4. Recall that the HL6 and HL7 station positions had been selected back in the 1950s, and the HL8 and HL9 positions in the early 2000s, without knowledge of the detailed bathymetry (Fig. 2), and that nominal RS site locations had been chosen in 2008 (Fig. 2) prior to adjustments for the newly-available high-resolution bathymetric map (Fig. 3).

The cross-slope and vertical distribution of T and S from the CTD profiles during the RS deployment and recovery cruises are shown in Fig. 17. Note that, for the upper ocean (perhaps ~1000m), these are only quasi-synoptic since the profiles were taken over a multi-day period and not in directional sequence. However they do indicate the spatial coverage (HL6 to HL10 in all cases, and further on-shelf except in December 2010). They also show the spatial complexity in the S structure down to 2000m or more, associated with eddies, filaments, GS influences and intermittent along-slope flows (e.g., Smith and Petrie 1982; Loder and Geshelin 2009).

With the mooring cruises having been carried out in different seasons, the changes from survey to survey in T and S in the upper 1000m or so in Fig. 17 are associated with a combination of seasonal variability in surface fluxes, interannual variability in Labrador Current and GS influences, and the more-local week-to-month occurrence of eddies, filaments, boluses and smaller-scale structures. The much-smaller changes at depths below 2000m are probably more reflective of DWBC and AMOC variability.

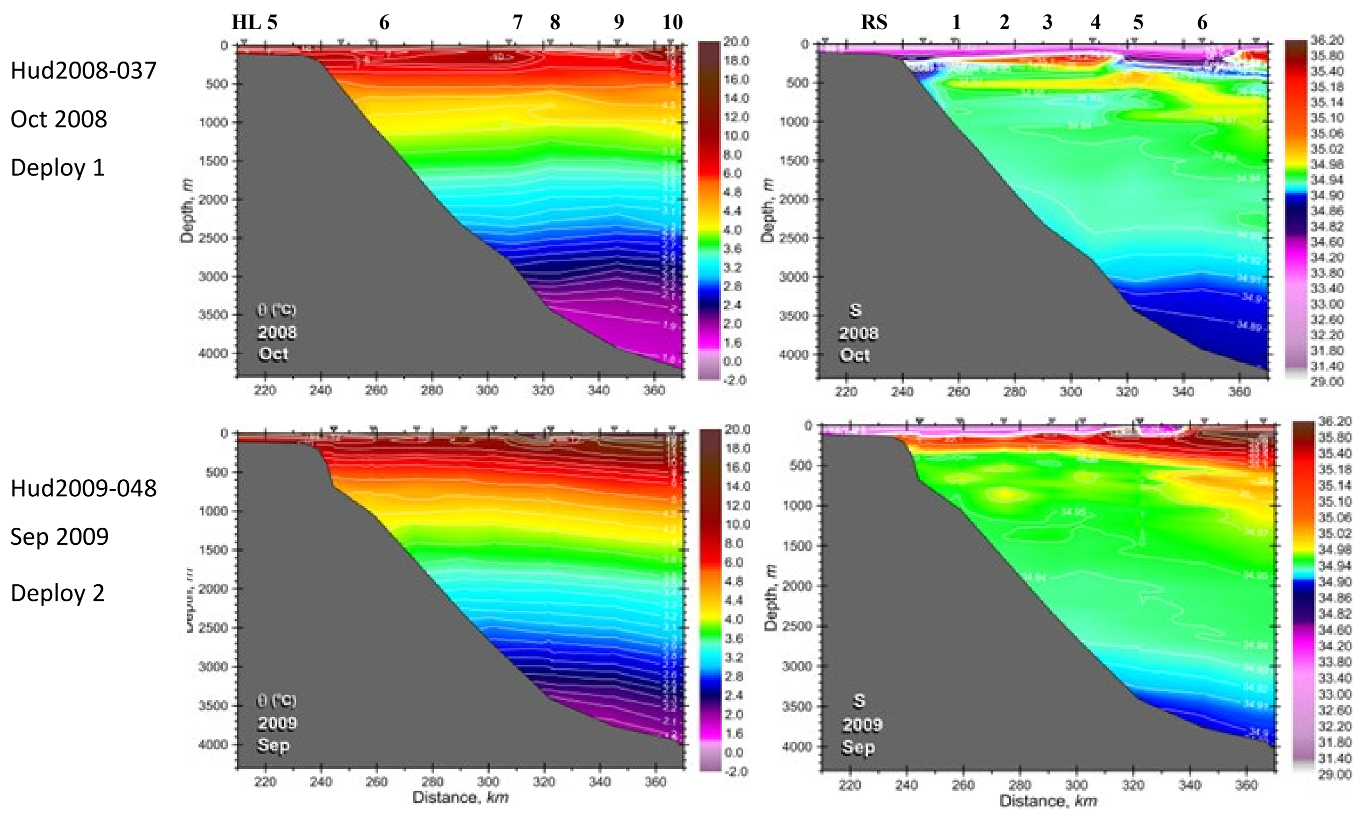


Figure 17. 2008 and 2009. Cross-slope vertical sections (looking NEward) of Potential Temperature (θ, left column) and Salinity (S, right) from CTD profiles taken between HL5 and HL10 during the 6 deployment and/or recovery cruises for the 2008-14 RS moorings. Note the common θ and S scales, and the vertical coverage of 0 to 4300m. HL stations are indicated at the top of the T panels, and RS sites at the top of the S panels (see Fig. 16 for locations). *(Displays courtesy of DFO AZMP and Inna Yashayaeva of DFO BIO.)* *(continued on next page)*

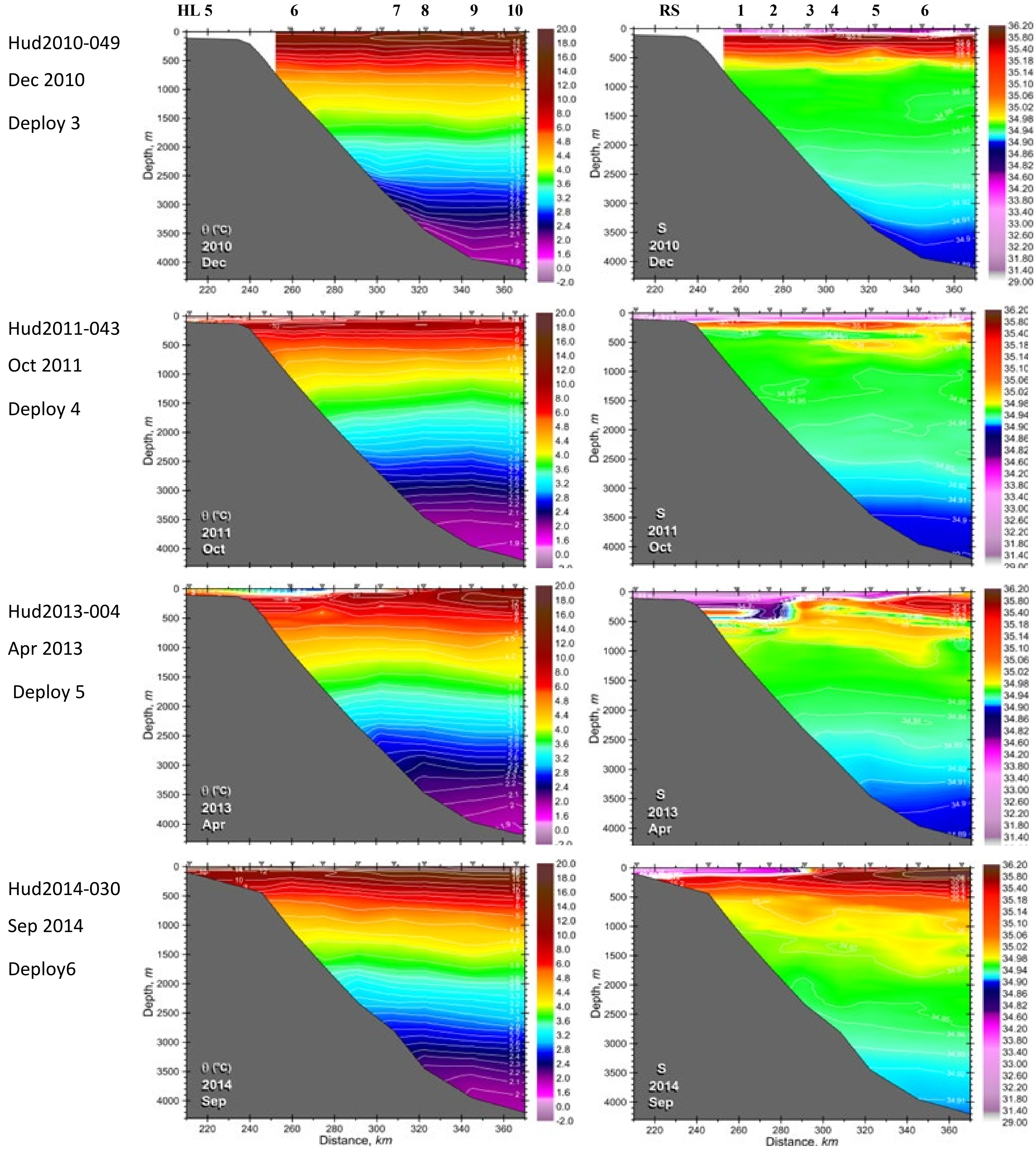


Figure 17. 2010-2014. *(continued from previous page)* Cross-slope sections of θ and S from CTD profiles taken between between HL5 and HL10. *(Displays courtesy of DFO AZMP and Inna Yashayaeva of BIO.)*

Broader and more synoptic views of the hydrographic structure are provided in section plots from the annual AZOMP survey in May-June (Fig. 18) which also include Density (the derived dynamical variable important to circulation). Signatures of the extension of the Labrador Current (relatively low S in the upper 1000m) along the upper slope, Warm Slope Water (relatively high S and low DO) extending shelfward in the upper 500m, the DWBC (Labrador Sea Water and Northeast Atlantic Deep Water with relatively high DO) at depths of ~1500 to 4000m along the mid/lower continental slope and rise, and of baroclinic flows (horizontal density gradients at various depths) can be seen with variability from year to year. While these and other features in the hydrographic properties indicate the spatial and temporal complexity of the ocean dynamics in the region, these hydrographic datasets should be helpful in the interpretation of the moored datasets (hence their display here).

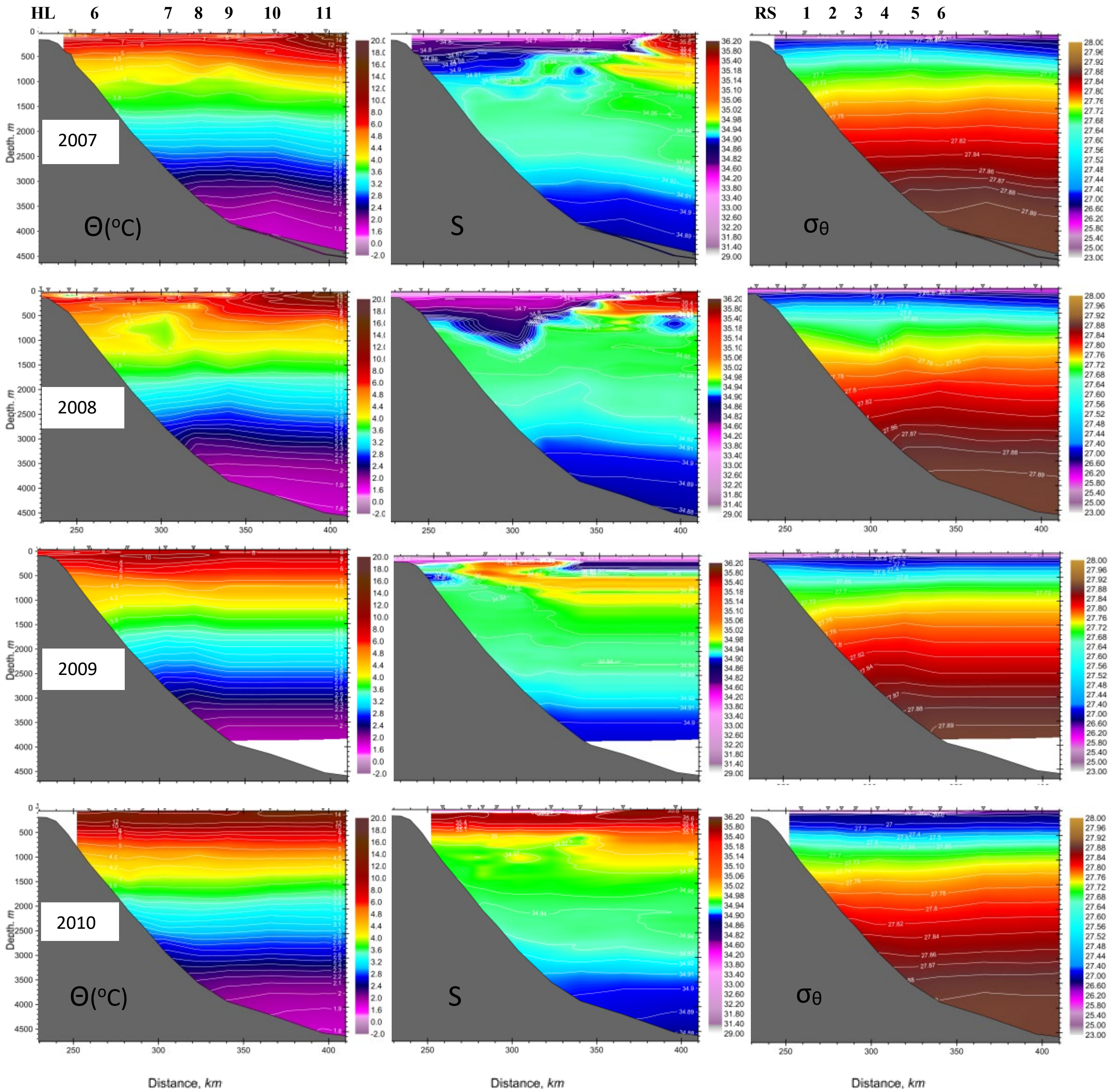


Figure 18. 2007 to 2010. Cross-slope sections of Potential Temperature (θ, °C; left column), Salinity (S; middle) and Potential Density (σ_θ; right) on the HL/XHL in May-June of 7 different years between 2007 and 2014 from DFO BIO AZOMP. The section was not occupied in May-Jun of 2012. CTD stations (with HL #'s in the upper left) are indicated by the inverted triangles along the top of each plot. RS mooring sites are in the upper right. The depth range is 0 to 4700m, and the distance (from the coast) is in km. *(Displays courtesy of DFO AZMP and Inna Yashayaeva of BIO.)* *(continued on next page)*

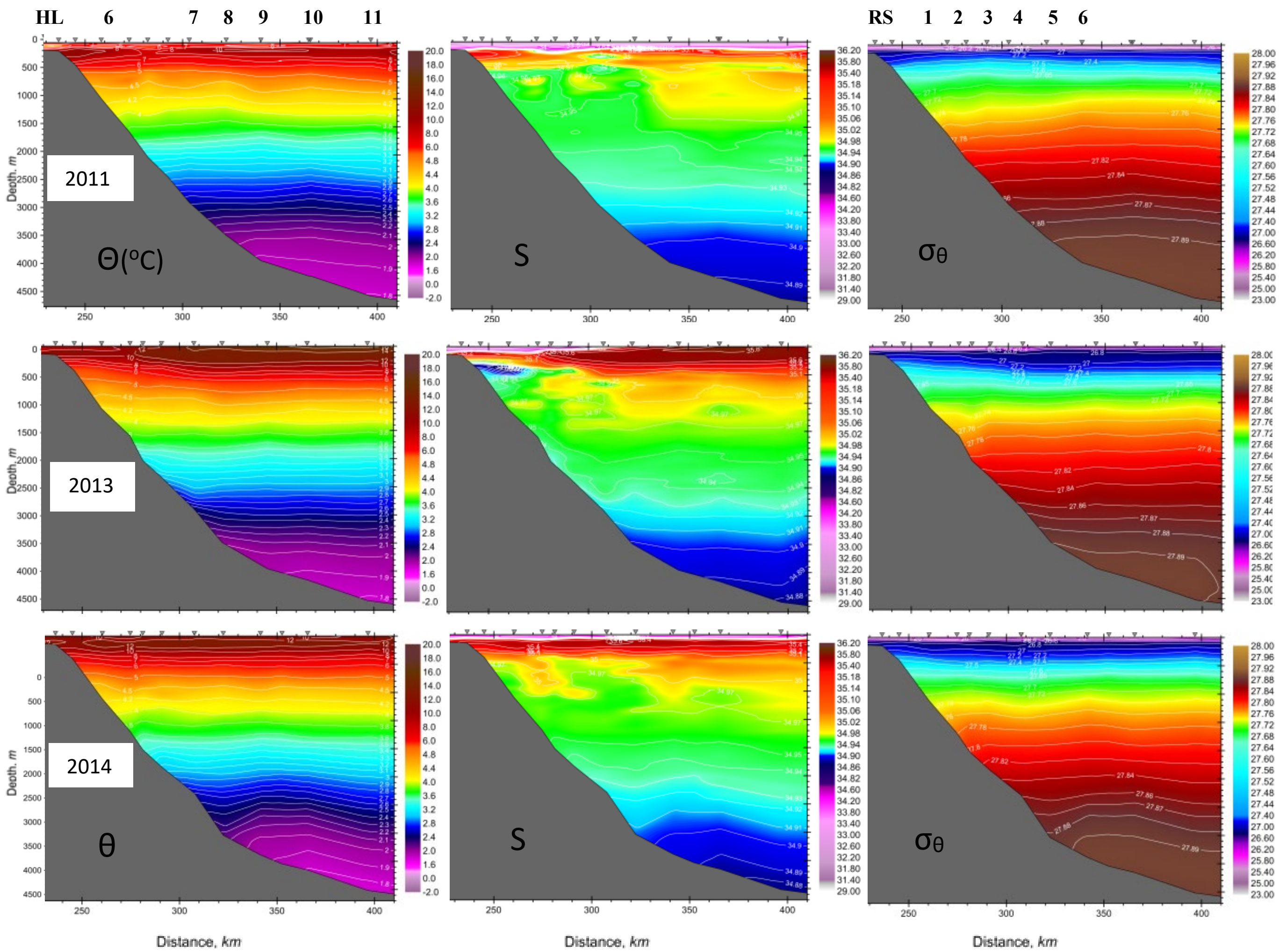


Figure 18. 2011, 2013 and 2014. *(continued from previous page)* Cross-slope sections of θ (°C), S and σ_θ on the HL/XHL in May-June of 7 different years between 2007 and 2014 from the DFO-BIO AZOMP. The section was not occupied in May-Jun of 2012. *(Displays courtesy of of DFO AZMP and Inna Yashayaeva of DFO-BIO.)*

Other datasets that are complementary to the RS moored measurements include Sea Surface Temperature (SST) from satellite infrared imagery (e.g., AZMP 2010; Loder and Geshelin 2009), sea surface height variability from satellite altimetry (e.g., Han et al., 2010; Willis 2010), and Argo floats (Willis 2010).

Very useful SST data products for indicating oceanographic features in the RS Line region associated with the complex interaction of the upper-ocean subpolar (LCE) and subtropical (GS) western boundary currents have been available from AZMP, in the form of monthly and semi-monthly composites from Advanced Very High Resolution Radiometer (AVHRR) imagery. Examples from NOAA AVHRR were used by Loder and Geshelin (2009) in interpreting the 2000-04 moored measurements on the HL, including how GS rings could disrupt the equatorward flow of subpolar water in the upper 600m out to at least the 2000m isobath, and reduce the flow at 2000m depth.

As an illustration of these features and the utility of SST during most of the year (except in summer) for indicating these features, Fig. 19 shows the AZMP monthly SST composites from October 2012 to June 2013, derived from Moderate Resolution Imaging Spectroradiometer (MODIS) data. Also, shown for comparison are the averages of the composites for each month during 1999-2010. The much smoother "climatological" SST patterns confirm the transient nature of the meanders, eddies and other small-scale features in the SST patterns for individual months and individual years. The evolution of features in a particular year can be seen from the monthly composites for the 2012-13 October-June period (Fig. 19).

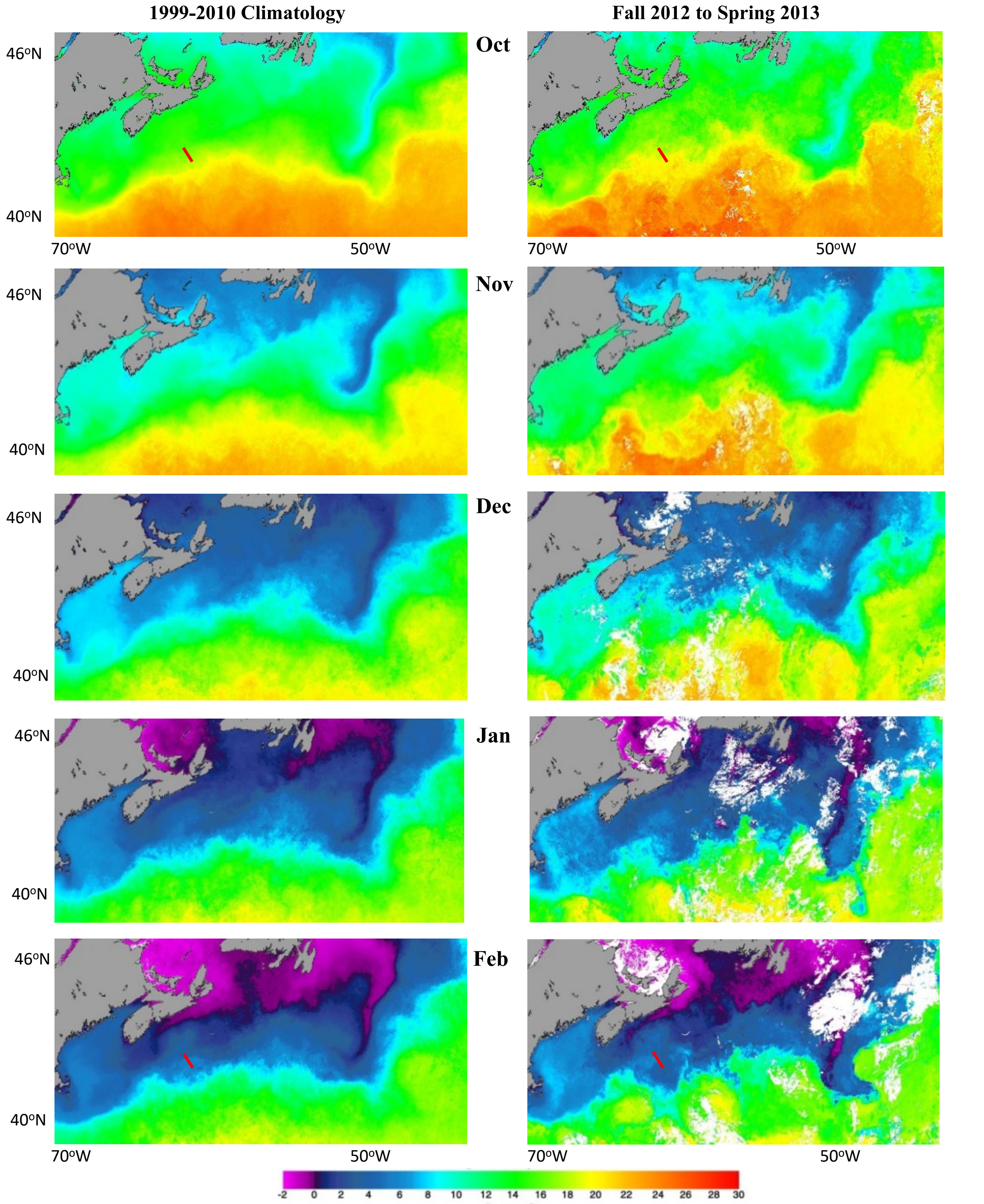


Figure 19. October to February. Monthly composites of SST, derived from MODIS imagery, in the shelf and Slope Water region off Nova Scotia for October 2012 to June 2013 (right column). White areas had too much cloud cover for a monthly mean estimate. A "climatological" mean for each month is shown in the left column, computed as the mean of the individual-year monthly composites during 1999-2010. The short red line \ in the October and February panels indicates the location of the RS mooring line. *(Courtesy of DFO AZMP and the BIO Remote Sensing Group)* *(continued on next page)*

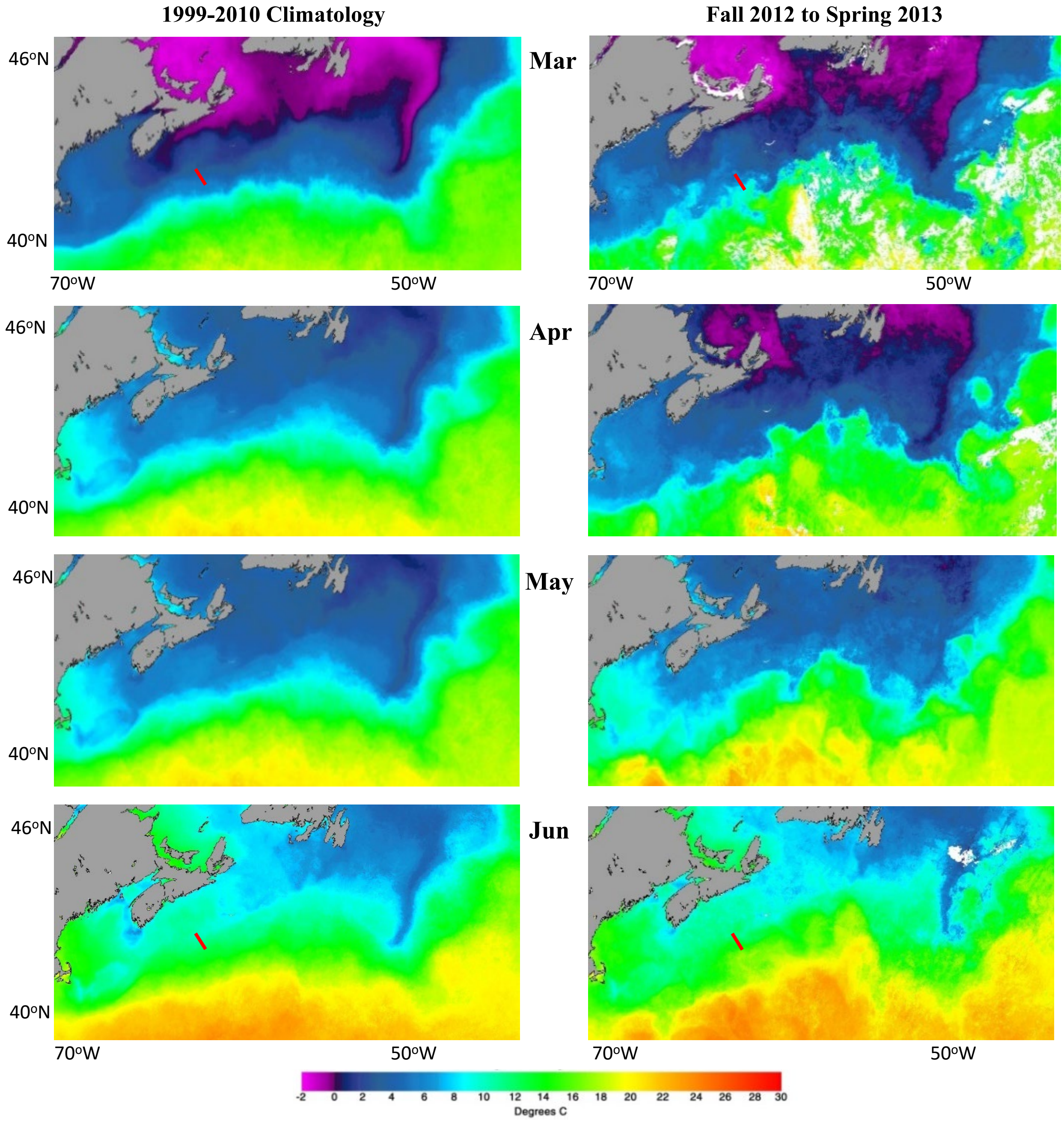


Figure 19. *(continued from previous page)* March to June. Monthly composites of SST, derived from MODIS imagery, in the shelf and Slope Water region off Nova Scotia, for October 2012 to June 2013 (right column). A "climatological" (1999-2000) mean for each month is shown in the left column. The short red line in the March and June panels indicates the location of the RS mooring line. *(Courtesy of DFO AZMP and the BIO Remote Sensing Group; displays downloaded from* http://www.bio-iob.gc.ca/science/newtech-technouvelles/sensing-teledetection/index-en.php*)*.

An illustration of the interannual variability in SST in the RS region during the mooring period, as well as of the frontal and eddy structure in particular months including 2 successive ones , is shown in Fig. 20, which has the monthly AZMP MODIS composites for April and May in each year between 2008 and 2014. The persistence of a 20+ºC winter-spring spatial difference in SST across the frontal zone between subpolar water over the Scotian Shelf and upper slope, and remnant subtropical water offshore is apparent. However, there are year-to-year differences in the complex frontal structure (e.g., Smith and Petrie 1982; Loder and Geshelin 2009, 2025).

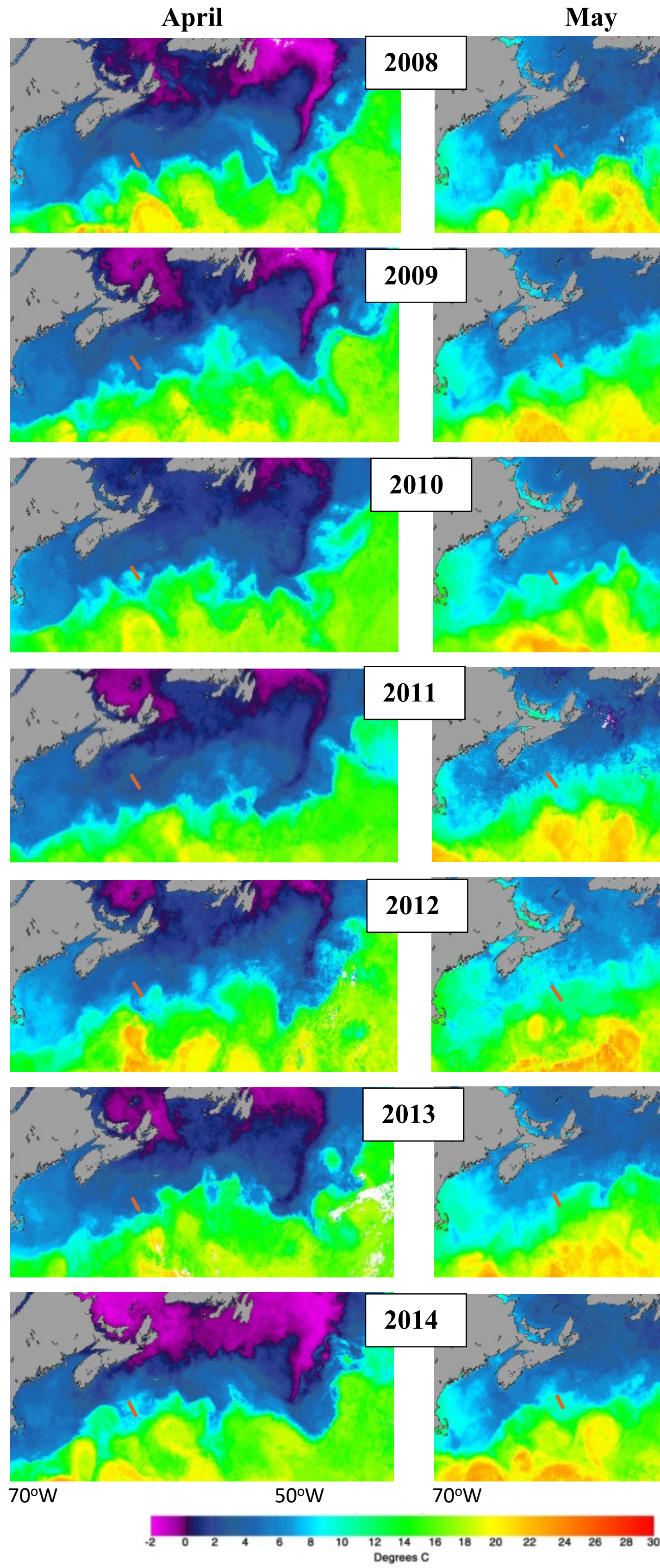


Figure 20: Monthly composites of SST, derived from MODIS imagery, in the shelf and Slope Water region off Nova Scotia, for April (left) and May (right) in each year between 2008 and 2014. *(Courtesy of DFO AZMP and the BIO Remote Sensing Group; downloaded from* http://www.bio-iob.gc.ca/science/newtech-technouvelles/sensing-teledetection/index-en.php).

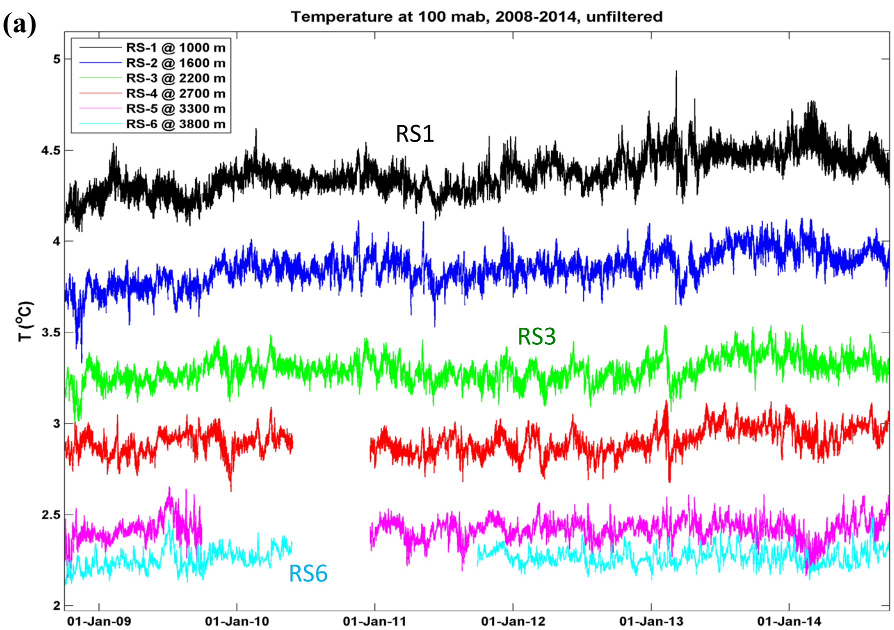
6.3 Temperature, Salinity and Pressure from MicroCats

6.3.1 Concatenated Time Series from Multiple Deployments

The concatenated hourly time series of T and S from the 100 (or 150) mab MCs at all 6 RS sites during Deploys 1-5 are shown in Fig. 21, and the time series after 5-day averaging (to reduce high-frequency variability) are shown in Fig. 22.

In these time series, "flat" or "ramped" adjustments to T, P and C were applied by BIO or POL using all of the available MC-CTD calibration information (§5.4, Table 7). For the Deploy 2 MCs and the 3 RS6 MCs in Deploy 3 not included in post-recovery MC-CTD casts, flat adjustments were applied by BIO. For the other MCs from Deploys 3-6, ramped adjustments were applied by BIO. For the Deploy 1 MCs, ramped adjustments were applied by POL, including removal of small drifts in P (a BIO version for these MCs with flat adjustments only was not used since it resulted in an S shift of +0.01 at RS6 during the Deploy 1-2 re-deployment).

(a)



(b)

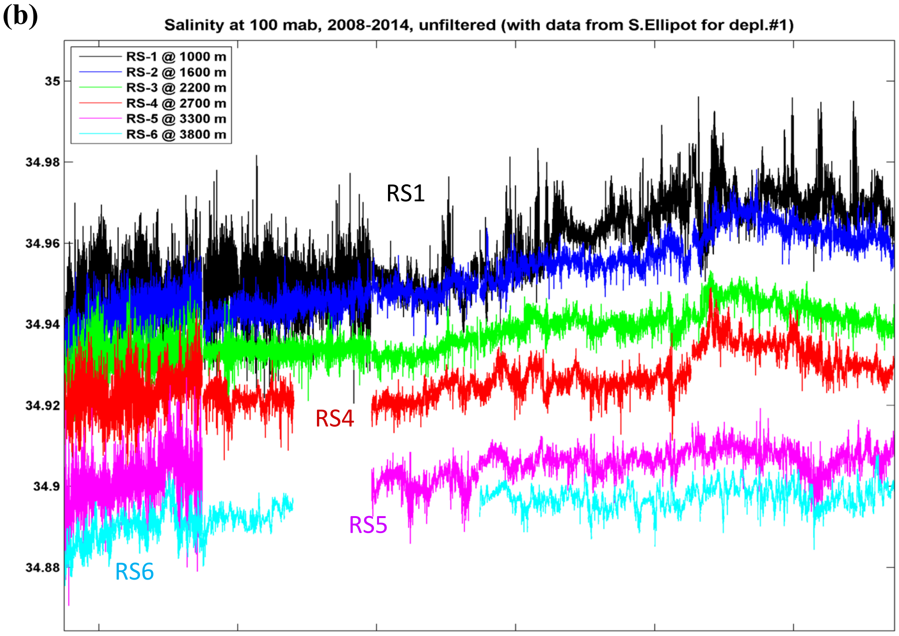
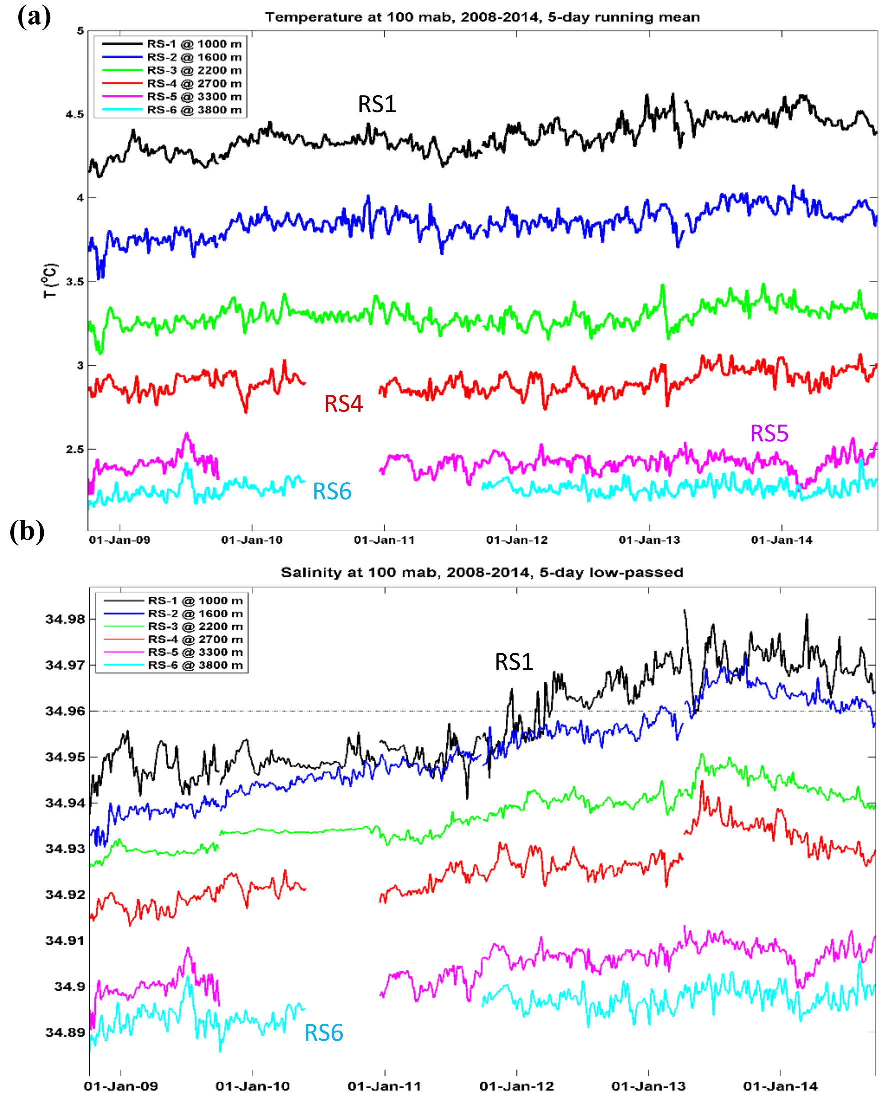


Figure 21. Concatenated hourly time series of **(a)** T and **(b)** S from the primary MCs at 100 (or 150) mab in Deploys 1-5, with colour coding indicating the RS sites. Flat or ramped calibration adjustments were applied by BIO (Deploys 2-5) or POL (Deploy 1) using the coefficients in Table 7 in all cases. The MC depths in the legend boxes are nominal ones (see Table 5 for the final depths).

Figure 22. Filtered (5-day running mean) versions of **(a)** T and **(b)** S from the primary MCs at 100 (or 150) mab in Deploys 1-5 (Fig. 21), with colour coding indicating the RS sites. Flat or ramped calibration adjustments have been applied (see text and Fig. 21 caption). The indicated depths are nominal.



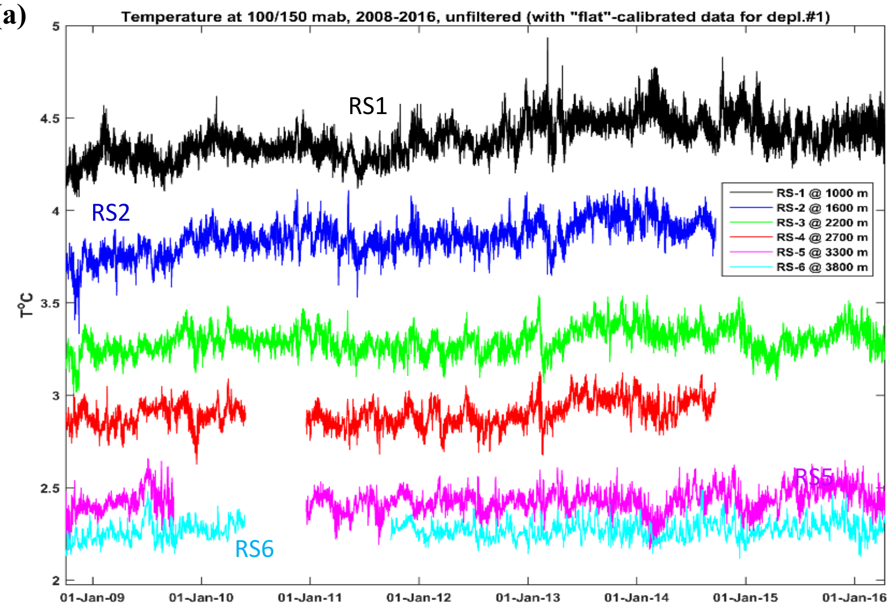
Slight shifts in T or S between the start or end of gaps in the concatenated records remain apparent in some cases at the re-deployment times in October 2009, December 2010, September 2011 and April 2013 (Figs. 21 and 22). The largest T shifts (0.1-0.2°C) are in April 2013 at RS1 and RS2 which can be largely explained by the upward re-positioning of the MCs by about 50m (from 100 mab to 150 mab) between Deploys 4 and 5 (Table 5). Smaller T shifts (<0.1°C) at RS1 in September 2011 and at RS2 in September 2009 cannot be explained by vertical re-positioning, but may be related to calibration uncertainties or actual temporal variability.

The largest remaining re-deployment S shifts have magnitude ~0.01, and occur at RS1 and RS4 in April 2013 (both positive; Fig. 22). Smaller ones (0.003-0.005) of note occur at RS1 in December 2010 (positive), and at RS2 (positive) in April 2013. Those in April 2013 can be at least partly explained by the mistaken vertical re-positioning of the Deploy 5 MCs. It is unclear whether the other very small re-deployment shifts in S are related to actual temporal variability, deficiencies in the MC-CTD calibrations or their applications, or the small differences in the vertical positions of the MCs. Fortunately, these appear to be small relative to the longer-term changes in the study region.

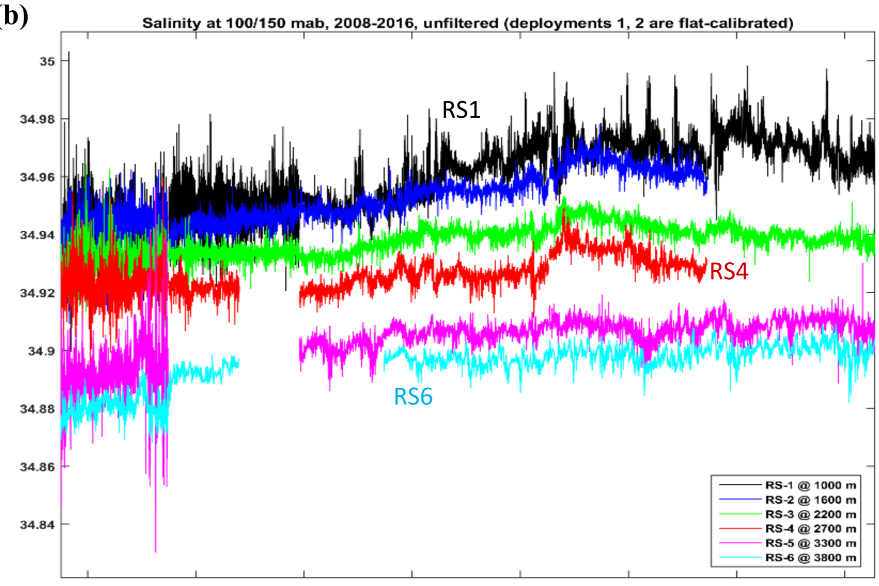
The concatenated hourly time series of adjusted T and S from the 100 (or 150 mab) MCs with the Deploy 6 data from its 4 sites included are shown in Fig. 23, thus covering the fall 2008 to spring 2016 period. Note that these are only preliminary displays since the Deploy 1 data used in these display have the BIO calibration adjustments, rather than the POL adjustments used in the time series in Figs. 21 and 22. As a result, the S values at RS6 during Deploy 1 (October 2008 to September 2009) in Fig. 23b are too low by ~0.01 (compare with Figs. 21b and 22b). Nevertheless, there are overall increases in both T and S at all sites during this ~7.5-year period, although they are only slight at the deeper sites. There is also significant low-frequency variability on time scales of months to years.

Figure 23. Concatenated hourly time series of adjusted **(a)** T and **(b)** S from the MCs at 100 (or 150) mab in Deploys 1-6 (2008-18), with colour coding indicating the RS sites. Flat or ramped calibration adjustments have been applied (by BIO) based on Table 7. Depths are nominal.

(a)



(b)



6.3.2 Time Series from MCs at Multiple Depths

In this subsection with example displays with data from the non-primary MCs included; i.e. time series for multiple vertical positions on the same mooring.

The first set (Fig. 24) is from M1809 at RS6 during Deploy 4 (September 2011 to April 2013). On this mooring there were 7 MCs at RS6, with MCs at the nominal depths of the primary MCs at all sites and an additional one at 250 mab (§5.2, Table 5). The most noticeable features of the variability in the ~1000-3300 m depth range are (i) the limited T (range <0.3°C) and S (<0.02) variability most of the time between ~1600 and ~3300 m, (ii) the larger ranges (<0.5°C for T and <0.05 for S) at ~1000m, and (iii) the occurrence of an event in winter 2012 which caused the depth of the uppermost MC to increase by ~20m and that of the MC at ~2700m to increase by 10m. This event caused the largest T changes in the records at 1000m (<1ºC) to 2200m (~0.3ºC), but this was not solely due to temporal variability in an Eulerian reference frame. Rather, it was apparently associated with a tall eddy passing through site RS6 which caused a short-term increase in P down to 100 mab (~3800 mbs), as a result of the mooring being pushed over by the eddy's currents. The temporary increase in T at ~1000 mbs in contrast to the concurrent decrease in T at greater depths down to at least 3300m is particularly noteworthy. The temporary T decrease at depths of 1600m and greater is consistent with the MCs displaced to greater depths in the presence of decreasing T with depth. The associated increase in T and also in S at ~1000 mbs appears most likely to indicate that the eddy was a remnant of a warm (and relatively saline) Gulf Stream ring, with the change in the water properties due to the eddy dominating over the increased depth of the upper MC. AVHHR imagery is supportive of this but further investigation is needed; e.g., the velocity records from the RCM at the top of this mooring (Table 9) need to be examined. The collective dataset from this mooring should also be useful to the validation of mooring motion models used in mooring design.

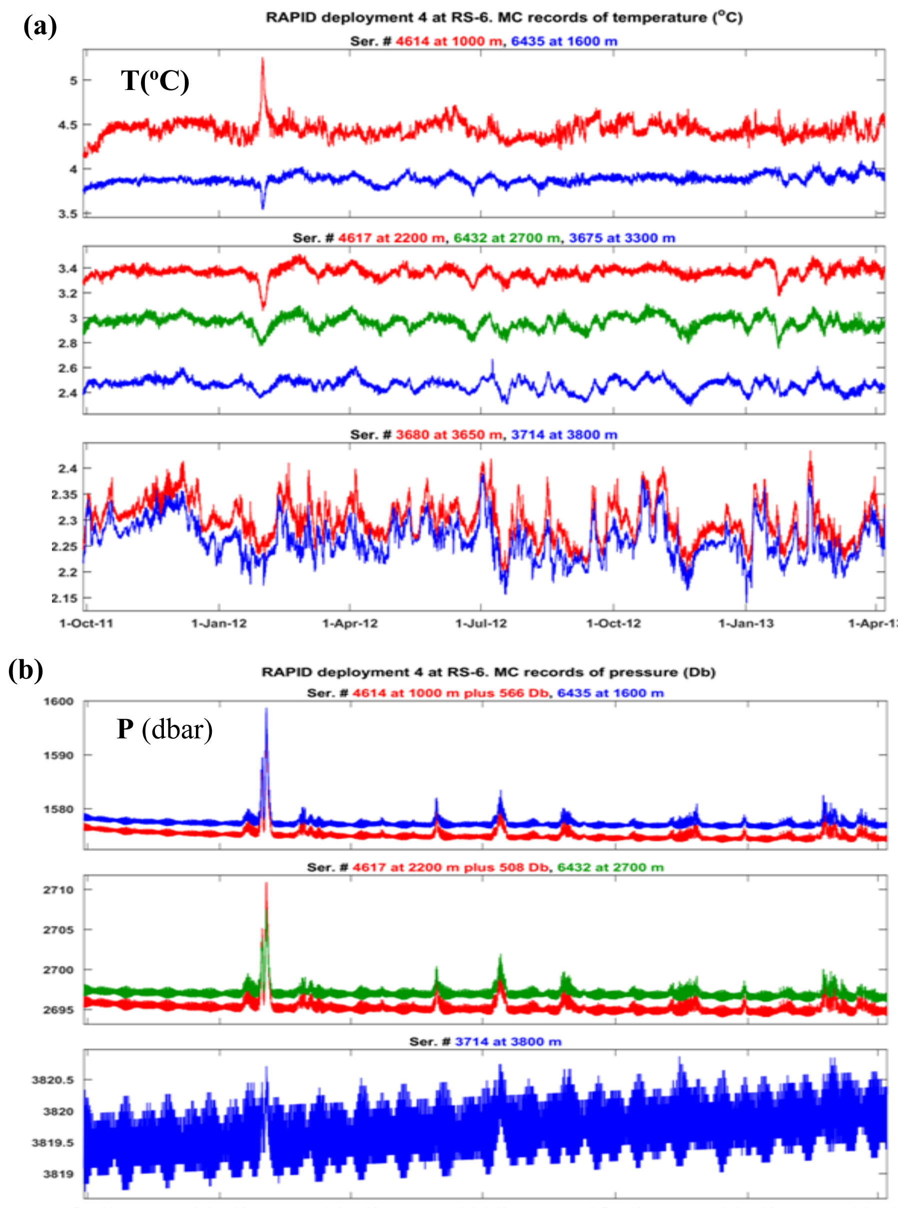
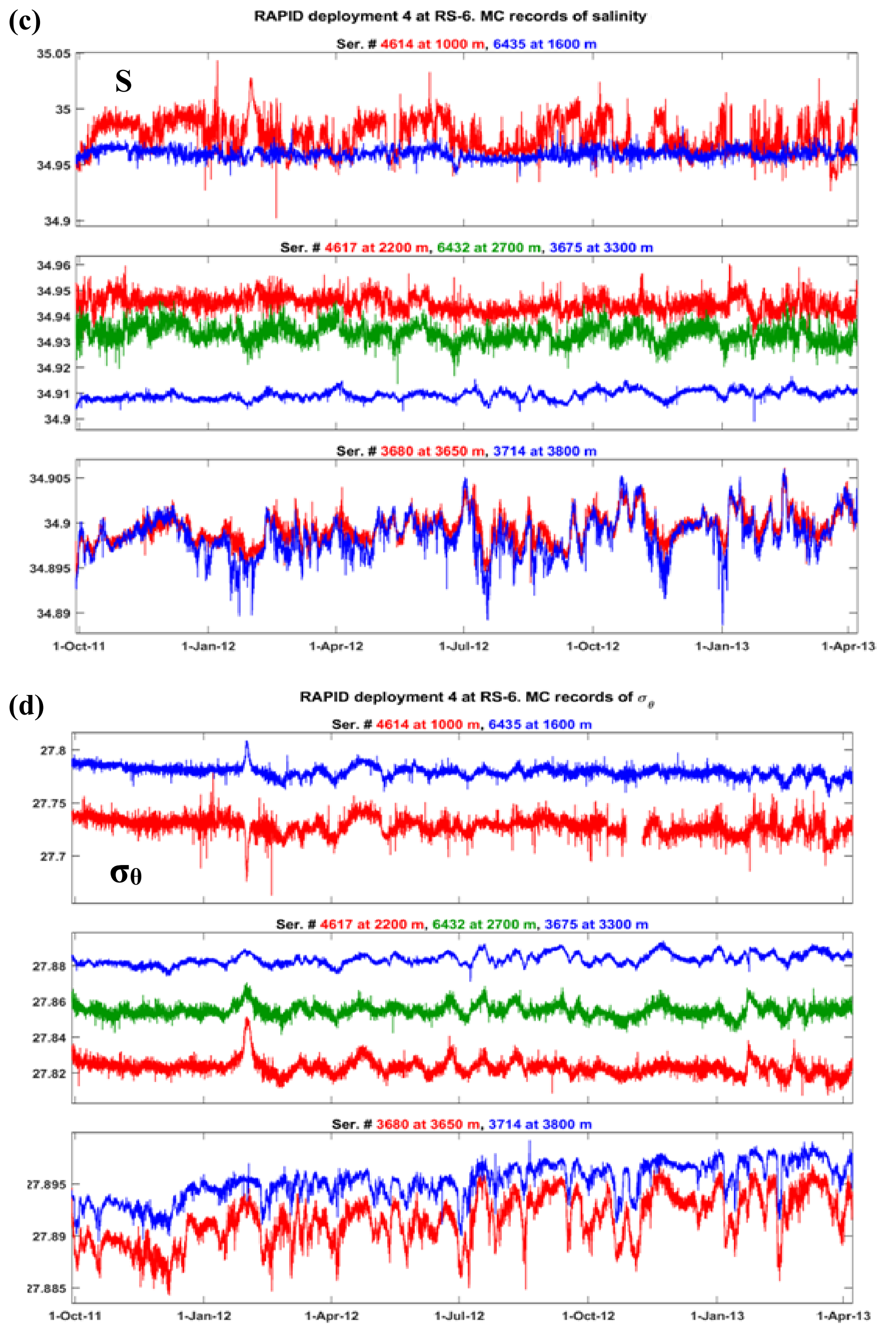


Figure 24. Hourly time series of **(a)** T (ºC), **(b)** P (dbar), (c) S and (d) Density (σ_θ) from the 7 MCs on M1809 at RS6 during Deploy 4 from September 2011 to April 2013. The time series for each variable are displayed using 3 panels in each case, with colour coding (see subtitles) to distinguish the MCs. Two of the MCs did not provide good P data. Some other P records have been offset by amounts indicated above the panel for display purposes (since their depths were signficantly different from each other). The indicated depths (below surface, mbs) above the panels are nominal ones; the actual depths of the MCs are in Table 5. In this deployment the water depth for RS6 was only 3856m rather than the nominal 3900m, so that the actual depths were less than the nominal ones. *(Continued on next page)*

Figure 24. *(continued from previous page)* Hourly time series of (a) T (°C), (b) P (dbar), **(c)** S and **(d)** Density (σ_θ) from the 7 MCs on M1809 at RS6 during Deploy 4. The time series for each variable are displayed using 3 panels in each case, with colour coding (see subtitles) to distinguish the MCs. The indicated depths (below surface, mbs) above the panels are nominal ones; the actual depths of the MCs are in Table 5. In this deployment the water depth for RS6 was only 3856m rather than the nominal 3900m, so that the actual depths were less than the nominal ones.



The T and S variability at 250 mab closely follows that at 100 mab (bottom panels in Fig. 24a,c) with a persistent offset of +0.02-0.05°C in T, and an indication of a small positive offset in S (as expected, Fig. 17) but with a low signal-to-noise ratio.

The second MC set (Fig. 25) is from the moorings at the other sites in Deploy 4 in which a second MC was added at 175 mab at sites RS1, RS3 and RS5 to provide information on vertical structure. The time series of T and S at 100 and 175 mab at these sites are shown, as well as those from the 100 mab MCs at RS2 and RS4. Together, Figs. 24 and 25 show all the MC time series of T and S from Deploy 4.

Somewhat similar to the situation with the 100 and 250 mab records at RS6 (Fig. 24), there is a clear and persistent offset of T at 175 mab relative to that at 100 mab at RS1, RS3 and RS5, but much less so for S. T is typically 0.1-0.2°C higher at 175 mab than at 100 mab at RS1, and 0.05-0.1°C higher at RS3 and RS5. In contrast, there is little noticeable difference in (hourly) S most of the time at all 3 sites in the absence of filtering, such that filtering and further investigation are required. But there is an indication of consistency within 0.005 for S from the two MCs at each of the 3 sites in this deployment, which is re-assuring from the perspective of the performance of these particular MCs and their calibration adjustments. However, it should be noted that there were significant differences between S from the 150- and 200-mab MCs in a couple of cases in Deploys 5 and 6 which appeared to be associated with an inadequate calibration of the second-priority 200-mab MCs rather than the primary 150-mab ones. As discussed earlier, all of the MC S records and calibrations from all of the deployments need further consideration to ensure optimal accuracy for the purposes of resolving the relatively-small deep-ocean S variability on the RS line. However, this does not appear to be the case for the primary MCs from the perspective of density variability, since the latter is most strongly influenced by temperature variability.

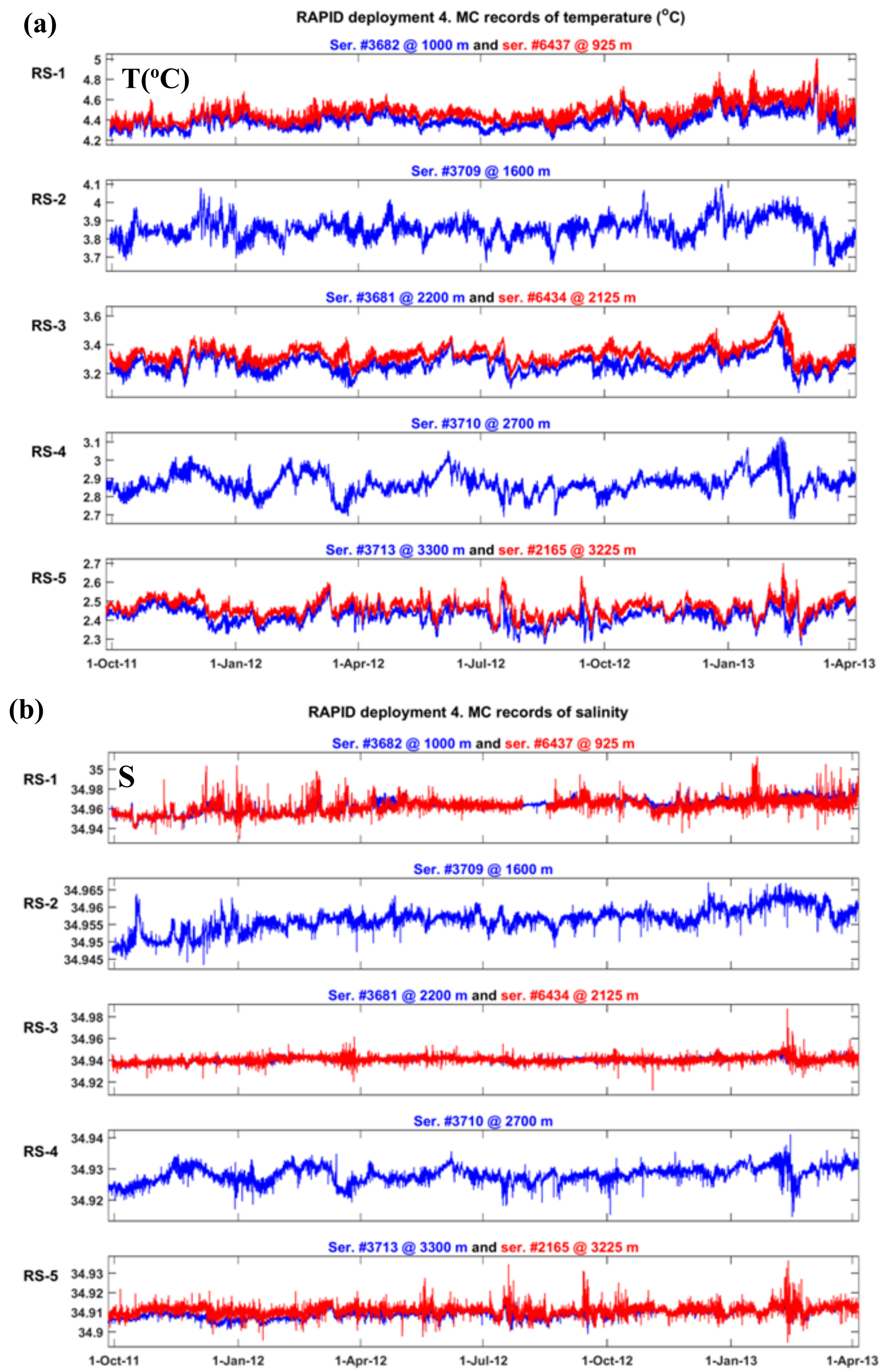


Figure 25. Hourly time series of **(a)** T (°C) and **(b)** S from the MCs at 100 mab (blue) at sites RS1-5 in Deploy 4 and those at 175 mab (red) at sites RS1, RS3 and RS5. The indicated MC depths in the panel subtitles are nominal (see Table 5 for best estimates of these depths).

6.4 Concatenation with Moored Temperature Time Series from Earlier Periods

In conjunction with the historical (back to the 1950s) and ongoing (AZMP, AZOMP) T and S profile monitoring on the HL/XHL/RS line, the 2000-04 BIO moored measurements on the HL (Loder and Geshelin 2009, 2025), and the 2004-08 POL and BIO moored measurements on Line B (Fig. 1), the 2008-18 RS moored measurements should be valuable for describing long-term "climate" variability in the region. In addition, the various moored measurements should be invaluable for further addressing previous concerns regarding the aliasing of high-frequency variability (Mann and Needler 1972). Analyses of the earlier profile datasets have already indicated important decadal-scale variability in the region that affect long-term trends (Petrie and Drinkwater 1993; Loder et al., 2003).

To provide an indication of the temporal and cross-slope coverage of the post-2000 near-bottom moored datasets, Figs. 26 and 27 show the low-pass filtered T series from the different PERD and RAPID programs and mooring sites on the HL/RS and B Lines. Figure 26 shows the T series on the B Line during 2004-08, and those from Deploy 1 (2008-09) at 4 of the RS sites, for the depth range 2200-3800 m. Both programs provide measurements from each of ~2200m (B1, RS3) and ~2700m (B2, RS4) depths, and the 2004-08 SS-E site (~3400m) is on an isobath between the RS5 and RS6 sites. In Fig. 27 the near-bottom T series from shallower PERD and RS sites, including the earlier 2000-04 T series from 2 sites (SS-A, -C) and the 2008-14 T series from all 6 RS sites, are included, covering 14 yrs. The T series from Deploys 6 (2014-16; Fig. 23) and 7 (2016-18) at 4 of the RS sites, and that from the DFO follow-on 2018-2000 mooring at RS5, have not yet been added to this plot. Nonetheless, the nearly 2 decades of moored current and hydrographic measurements at multiple depths between HL6/RS1 (~1050m) and HL9/RS6 (~3900m) provide a unique dataset of low-frequency climate-related variability and of high-frequency variability on the Scotian Slope and Rise, complementing the AZMP/AZOMP profile surveys.

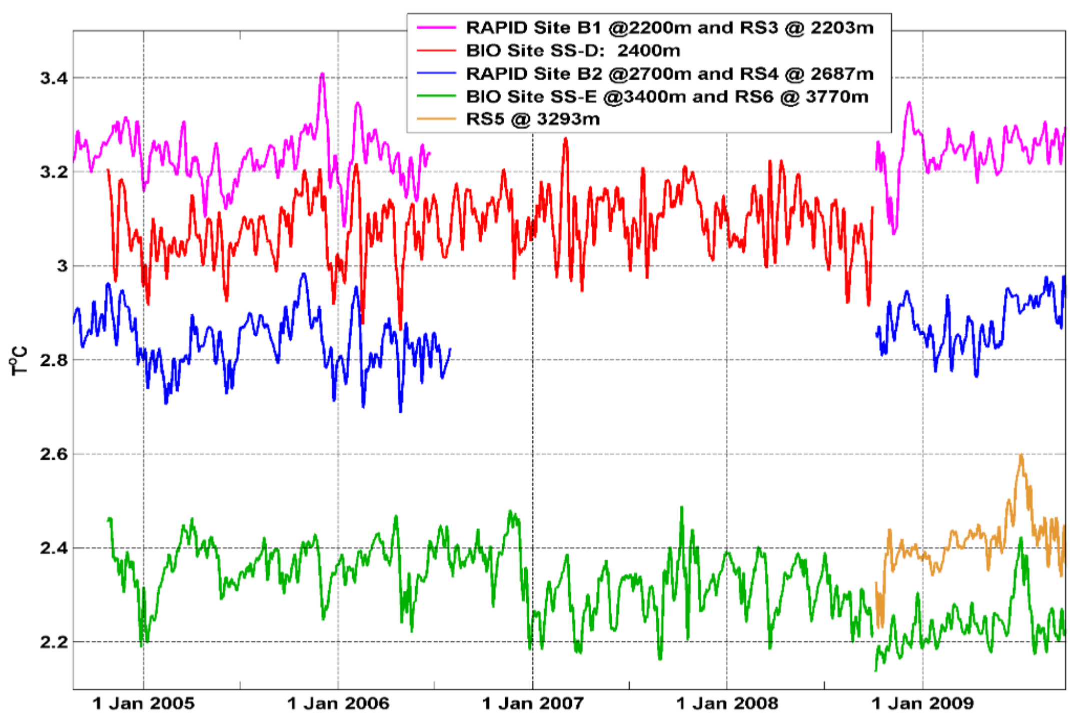


Figure 26. Time series of low-pass filtered T from the near-bottom (≤ 100 mab) zone from moored measurement by POL and BIO on the RS and B Lines during 2004-2009. Site names and nominal instrument depths (below surface) are indicated in the legend box. Colour coding is used to indicate records from similar instrument depths (and also similar water depths), with the notable exception that the 2008-09 T series in the lower right corner (**RS6 at 3770m, green**) should be a different colour than the earlier 2004-08 T series (**BIO SS-E at 3400m**, also **green)**, since the depths are different. This colour-coding error is corrected in Fig. 27.

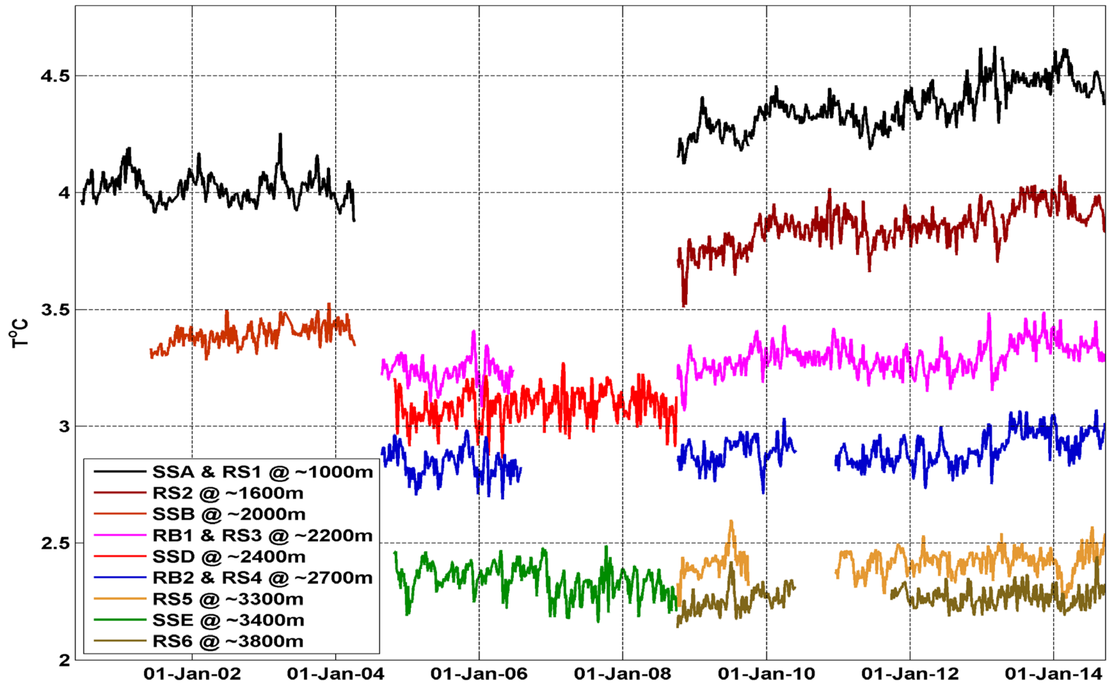


Figure 27. Time series of low-pass filtered near-bottom (≤ 100 mab) T from moored measurements by BIO and POL on the HL/XHL/RS and B Lines during 2000-14. Two sites (SS-A, SS-B) on the HL from the 2000-04 DFO-PERD program have been added beyond those in Fig. 26, and the time series at the 6 RS sites have been extended to 2014. Site names and nominal instrument depths (below surface) are indicated in the legend box (RB1 and RB2 refer to sites B1 and B2 on the RAPID Line B; Fig. 1). Colour coding is used to indicate records from similar instrument (and water) depths. In contrast to Fig. 26, different colours are used here for the 2004-08 SS-E site and the 2008-14 RS5 and RS6 sites which were on different isobaths as indicated. (Figure from Loder et al., 2015) (Data from moored measurements on the RS Line between 2014 and 2020 are not included.)

Going back further, there were two sets of moored measurements at nearby sites on the Scotian Slope, in the late 1960s (Grant and Reiniger 1970, 1971; Smith et al., 1978) and late 1970s (Lively 1979; Smith and Petrie 1982), which included near-bottom instruments in the vicinity of the 1000m isobath. The low-passed T from these and the post-2000 HL/RS measurements up to 2014, together with those from a long-term BIO mooring on the Labrador Slope (outer Hamilton Bank; e.g., Yashayaev and Loder 2016), are shown in Fig. 28.

An increase in near-bottom T on the upper Scotian Slope since the early 2000s is clearly apparent, as well as the relatively-warm (compared to the early 2000s) period of the late 1970s and the relatively-cool 1960s discussed by previous authors based on profile measurements (e.g., Petrie and Drinkwater 1993; Loder et al., 2001, 2003). The clear decadal-scale variation (Fig. 28) indicates that concerns regarding the seriousness of aliasing in the seasonal monitoring surveys of the 1950s-1970s (Mann and Needler 1973), which led to the abandonment of HL monitoring for over 2 decades, were somewhat overstated (in fairness, the level of occurrence of decadal-scale variability in the Northwest Atlantic was not realized in that era). On the other hand, there is no question that the episodic GS meandering and ring influences on the Scotian Slope do pose a serious aliasing issue for the seasonal AZMP/AZOMP sampling of the upper 1000-2000m, for which both moored measurements and satellite imagery (e.g., Figs. 19 and 20).

The value of a combination of moored measurements and regular profiling sampling in monitoring programs (as well as remote sensing in most cases) is also illustrated by the multi-decadal moored T series from the Labrador Slope (Fig. 28). The decadal-scale, and even interannual to a degree, variability apparent there are reflective of much broader-scale variability in the depth of wintertime deep convection in the Labrador Sea (e.g., Yashayaev 2007; Yashayaev and Loder 2016), also of importance to AMOC variability (Rhein et al., 2011).

Of note in the present context is some similarity in the decadal-scale variability on the Labrador and Scotian Slopes, although the moored observations at these two sites by themselves are not adequate to resolve the extent and details of this. For example, whereas the recent paradigm (following Petrie and Drinkwater 1993) has been that the decadal variability in hydrographic properties over the upper Scotian Slope has been related to the volume of subpolar water extending to the west of the Tail of the Grand Bank, the variations in Fig. 28 indicate that HL variability may also be influenced by the properties of the subpolar water, at least on the decadal scale. Further to the apparent complexity and regionality of climate variability in the NW Atlantic, the multi-year cooling of Labrador Sea Water associated with enhanced deep convection has been related to successive winters with a positive North Atlantic Oscillation (NAO) index (Yashayaev and Loder 2016) involving contraction and intensification of the upper-ocean subpolar gyre, whereas the increased extension of cool water west of the Grand Bank has been suggested to be associated with periods of negative NAO related with weakening and spatial expansion (relaxation) of this gyre. Clearly, additional factors are at play, such as variability in the GS affecting the Slope Water and Scotian Slope (e.g., §6.2), and the many factors contributing to the 4-dimensional complexity of the AMOC (e.g., Buckley and Marshall 2016).

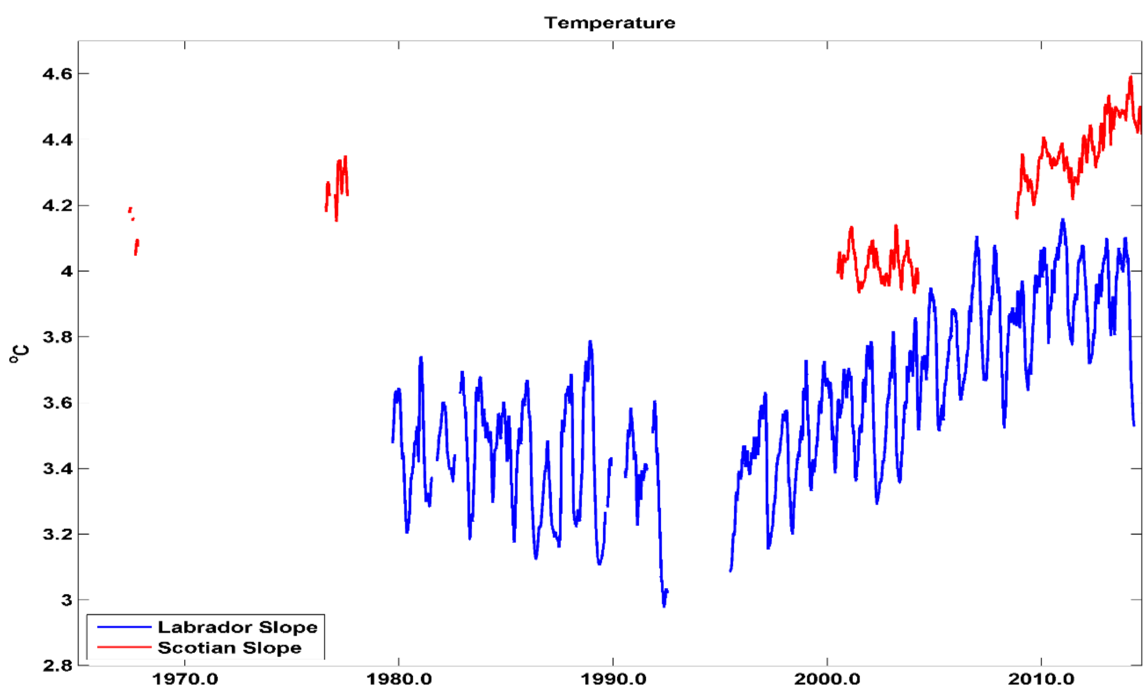


Figure 28. Low-pass filtered near-bottom T from the ~1050m isobath on the Scotian Slope (**red**) and the ~1000m isobath on the Labrador Slope (**blue**). The 1960s observations on the Scotian Slope are from Grant and Reiniger (1970, 1971; described in Smith et al., 1978), the 1970s ones from Lively (1979; described in Smith and Petrie 1982), the 2000-04 ones from Loder and Geshelin (2009, 2025), and the 2008-14 ones from RAPID WAVE. The Labrador Slope observations are from DFO-BIO (AZOMP since 2006) monitoring, described in Lu et al., 2010, and Yashayaev and Loder 2016) (Figure from Loder et al., 2015) (Data from moored measurements since 2014 are not included here.)

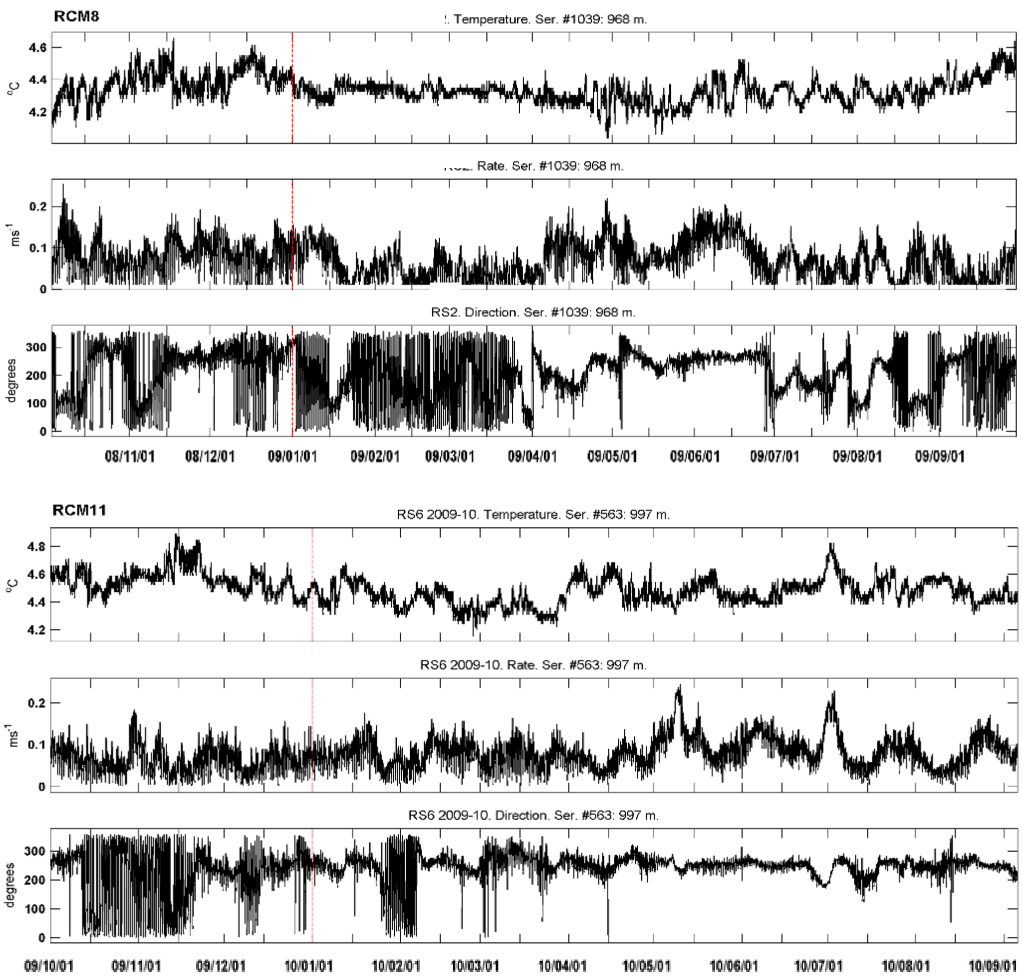
6.5 Temperature and Currents from RCMs on the RS Moorings

As discussed in §5.4, Aanderaa current meters (RCMs) were included on the RS moorings at two positions (Table 9), in addition to those at RS2 in Deploy 1 for a current-meter intercomparison study (Drozdowski and Greenan 2013). The RCM11s at 25 mab at RS1 in Deploys 3 and 4 also provide DO records which have not been evaluated and, together with the ADCP data from 58-90 mab and MC data from 100 mab, information on vertical structure which can be used in identifying adjustments for concatenations with earlier (2000-04) moored measurements at 25 mab (Loder et al., 2009). The RCMs at a nominal depth of 1000m at RS6 in Deploys 1-4 provide 4.5 years of velocity data at an intermediate depth at the outer end of the RS array which should be valuable to both RAPID WAVE estimates of transport and DFO interests in variability in the Slope Water.

The T and velocity records from the nominal 1000 mbs position at RS6 in Deploys 1-3 (Fig. 29) appear to be of good quality with the exception of some rotor stalling of the RCM8 in Deploy 1 during the occurrence of weak currents which occurred much of the time at this position. However, the Direction time series from this RCM8 and the current magnitude (Rate) during the weak-to-moderate current events should be reliable, as well as the Rates and Directions from the acoustic RCM11s in Deploys 2-4.

(a)

(b)



Deploy1

Oct 2008 – Sept 2009

Deploy2

Sept 2009 – Oct 2010

Figure 29a,b. Time series of hourly T (°C, upper subpanels), and velocity magnitude (Rate, m/s, middle subpanels) and Direction (° True, lower subpanels) from the RCMs at the nominal position of ~1000 mbs at RS6 in **(a)** Deploy 1 (RCM8 on M1701), **(b)** Deploy 2 (RCM11 on M1747), and **(c)** Deploy 3 (RCM11 on M1782).

(c)

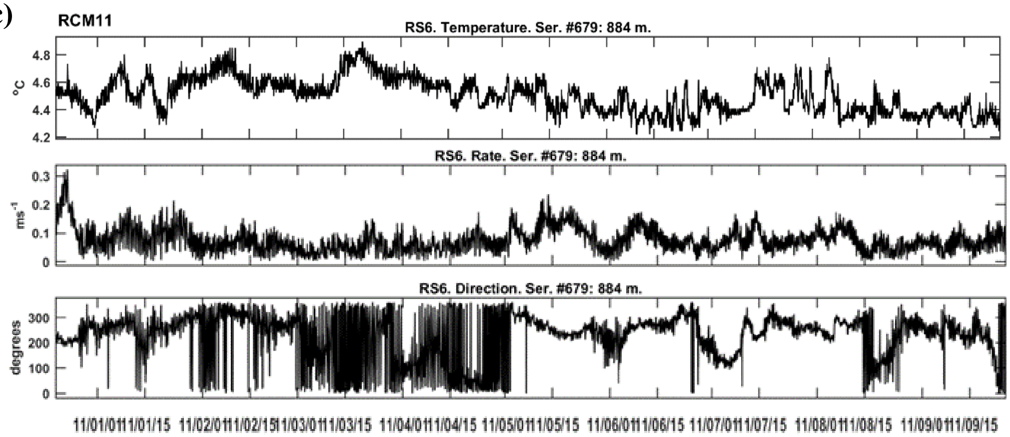


Figure 29c. Time series of hourly T (ºC, upper subpanel), and velocity magnitude (Rate, m/s, middle subpanel) and Direction (º True, lower subpanel) from the RCM11 at the nominal position of ~1000 mbs at RS6 on M1782.

Temperature did not show a persistent seasonal variation (Fig. 29), not unexpected at this depth, especially considering intermittent influences from the GS. Values were in the 4.1-4.9ºC range in all 3 deployments which contrasts the peak value of 5.2ºC in winter 2012 (Fig. 24a) at the top MC at RS6 associated with a warm-core eddy at the site. Thus, that was the most extreme T event observed at this position, during the 4 years with a tall mooring at RS6.

Current speeds at this position (during Deploys 1-3) were typically in the range of 0.05 m/s (or less) to 0.15 m/s, with a westward component most of the time (Fig. 29). The strongest currents (~0.3 m/s) occurred in mid December 2010, during a period of persistent southsouthwestward flow which led to cooler water there. Otherwise the peak current speeds were ~0.2 m/s for a few days on a few occasions in these records, usually associated with a westward flow component. However, there were also periods of days to a few weeks when the flow was generally eastward. Further analysis is clearly required, with the Deploy 4 record included and consideration of the S time series from the MCs below the RCMs.

7. Concluding Remarks

The potential value of the RAPID WAVE moored measurements lies in them providing:

(i) a 10-year time series of AMOC variability at an additional latitude in the North Atlantic, complementing those at other latitudes as part of international climate change studies;

(ii) time series of hydrographic properties and currents in the DWBC and (at depth) in the Labrador Current Extension on Scotian Rise and Slope, complementing those at upstream (e.g., Labrador Slope) and downstream locations;

(iii) an extension of previous moored measurements (with high-frequency sampling) on the HL/XHL, complementing the seasonal AZMP and AZOMP sampling; and

(iv) a moored dataset for validation studies of regional and larger-scale circulation and climate models, in conjunction with other datasets such as those from altimetry, infrared imagery, and AZMP and AZOMP.

Unfortunately, as a result of operational challenges and organizational and personnel changes, the processing of the overall dataset, and especially the data from the reduced program in 2014-18, has been delayed. However, at the time of this report, all of the primary data from the core 2008-14 RAPID WAVE program have been quality-controlled and are (or are in the final stages of being made) available from the BIO Data Archive and the British Oceanographic Data Centre (BODC). These data are also now being used in international AMOC variability studies (Xing et al., 2025a,b), following the initial demonstration of the novel RAPID WAVE approach using the Deploy 1 data (Hughes et al., 2013). Even a decade after the end of the primary mooring period, their potential value (outlined above) should remain, especially with no sustained mooring program on the ScotianSlope in the vicinity of the HL.

It is important to note that processing of some of the moored measurements collected in the 2008-14 primary sampling period, and in the reduced (only 4 short moorings) 2014-18 extension, remains to be completed, or the processed data remain to be made available. In particular, the data from the secondary MCs in the core 2008-14 program are generally of high quality and their quality control has been completed or nearly so, but their availability has been delayed because of very small unphysical (e.g., static instability in the vertical, or S shifts of <0.005 between deployments) features. Examination of these issues in T-S space should allow completion of the quality control. Also, processing of the RCM data from Deploys 1-3 has not been completed, and that for the Deploy 4 RCM data has not started; however, no significant issues are anticipated.

The processing of the ADCP, BPR and MC data from Deploys 6 and 7 is less complete. Overall, the BIO processing of the Deploy 6 (2014-16) datasets is near completion, while that of the Deploy 7 (2016-18) only partly there.

In spite of the limitations of the datasets summarized above and others described in the text, it is still hoped that this report and the references to the supporting documents will help others with the realization of the potential of the RS datasets in conjunction with the complementary datasets and models, whether at BIO, NOC or elsewhere.

8. Acknowledgements

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(An asterisk * indicates that a pdf is available from the BIO Archive at:
\BIODataSvc\ARC\ArchivedDataProjects\Loder\SlopeCurrents\ScotSR_RAPID2008-18 ,
with the filename indicated in ***[green italicized square brackets]*** . A copy can be requested from
DFO.BIODataServices-BIOServicesdeDonnees.MPO@dfo-mpo.gc.ca)

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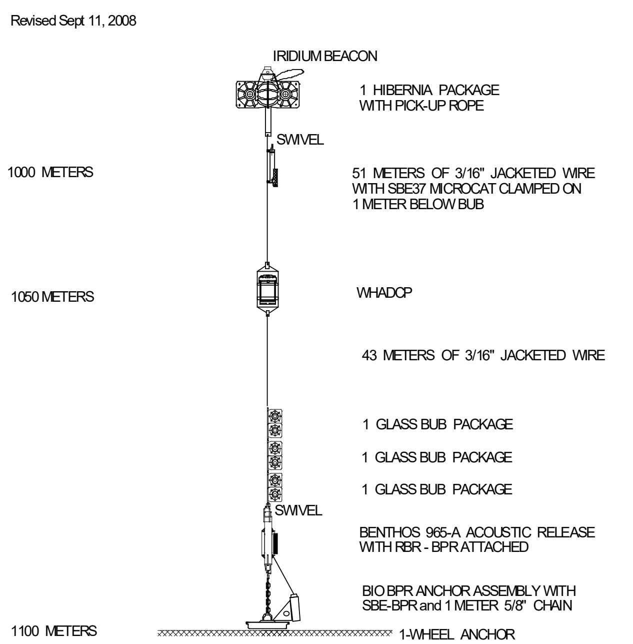
Appendix: Mooring Diagrams

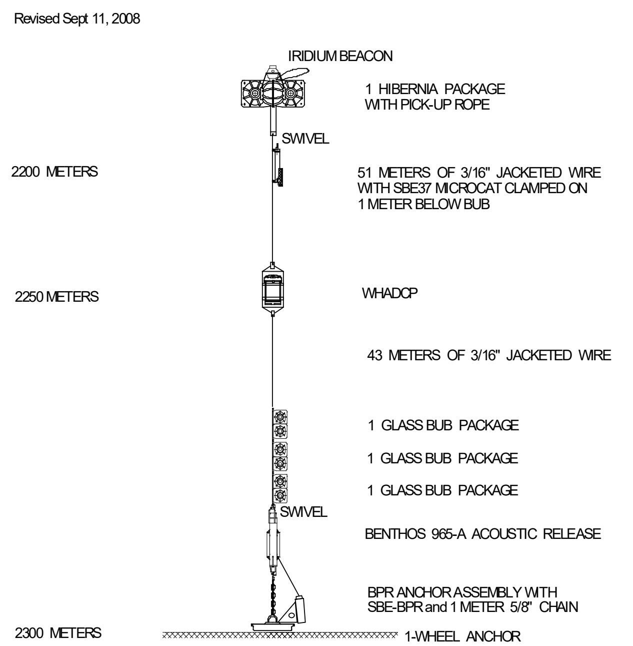
Deployment 1: 2008-2009, RS1 and RS3-5 (M1696 and M1698-1700)

Note: Water and instrument depths are nominal. See Tables 3-5 and 7-9 for instrument serial numbers and actual depths.

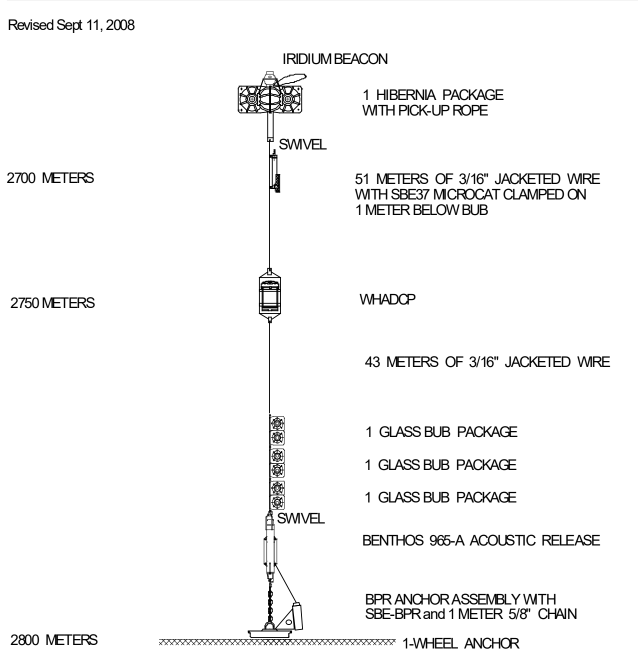
MOORING # 1696 RS1 LODER/POL SCOTIAN SLOPE OCT 2008



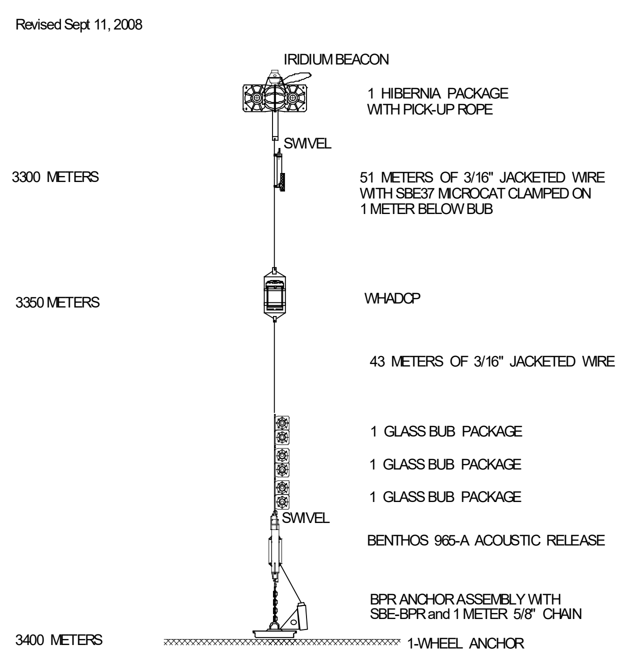
MOORING # 1698 RS3 LODER/POL SCOTIAN SLOPE OCT 2008



MOORING # 1699 RS4 LODER/POL SCOTIAN SLOPE OCT 2008

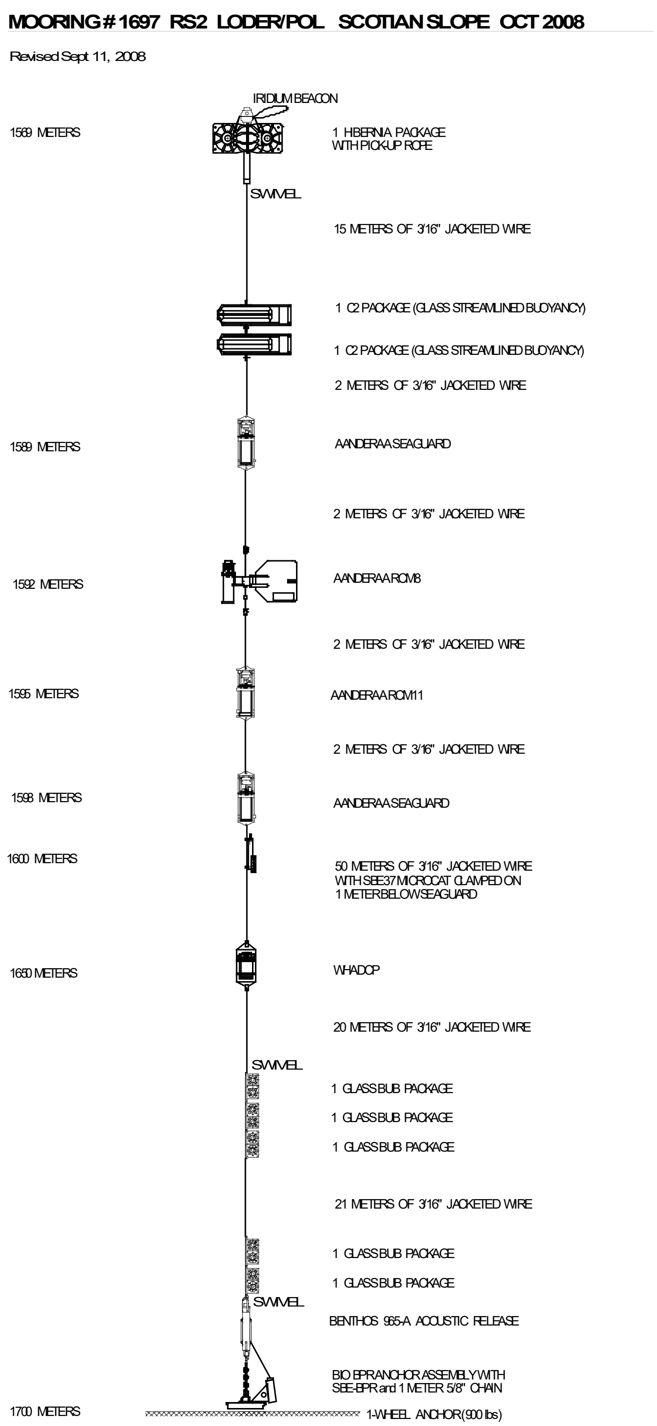


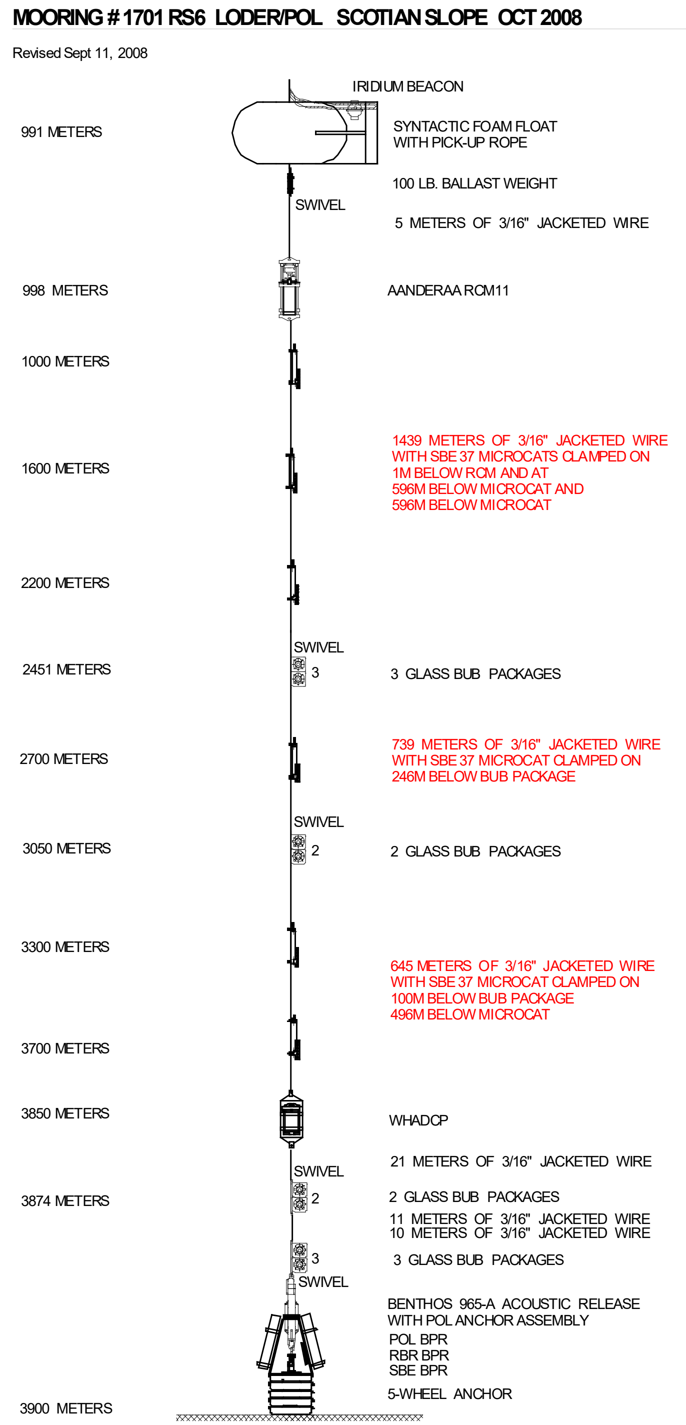
MOORING # 1700 RS5 LODER/POL SCOTIAN SLOPE OCT 2008



Deployment 1, 2008-2009 *(continued)*: **RS2 and RS6** (M1697 and M1701)

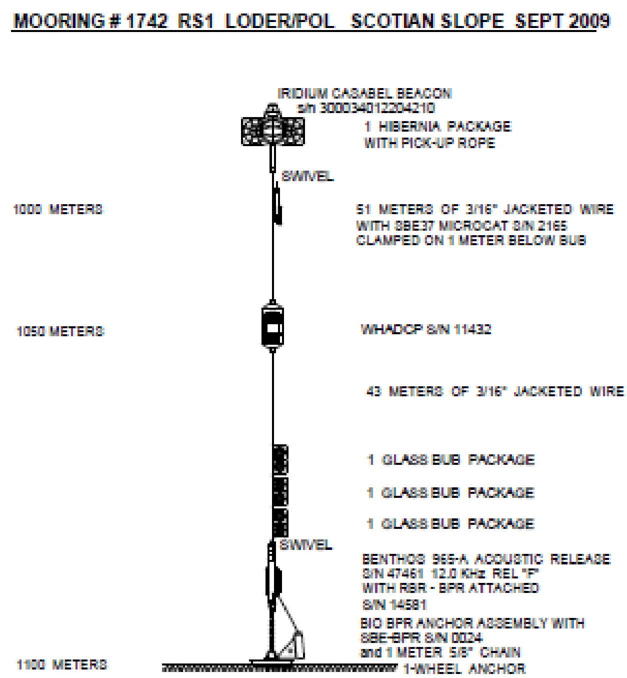
Note: Water and instrument depths are nominal. See Tables 3-5 and 7-9 for instrument serial numbers and actual depths.

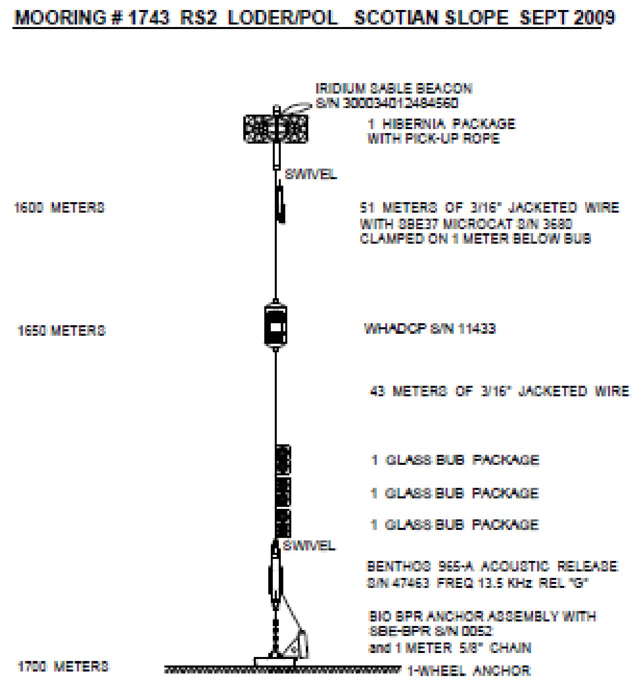


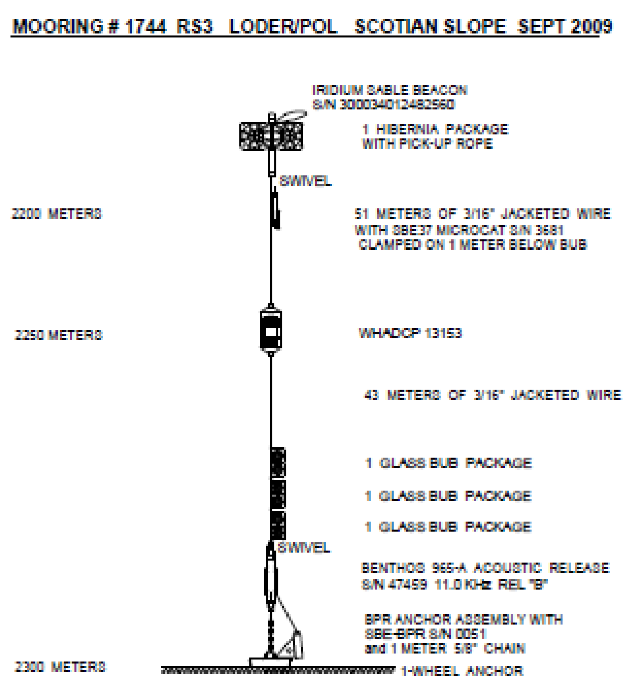


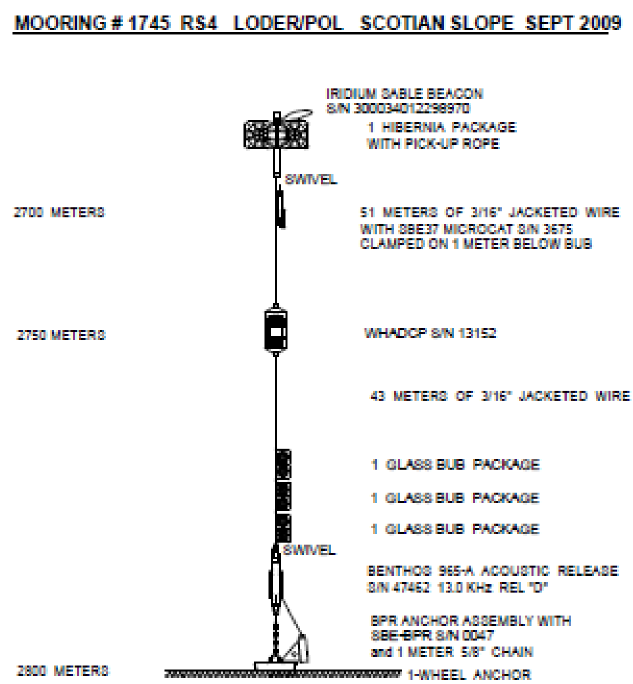
Deployment 2, 2009-2010: RS1 – RS4 (M1742 - M1745)

Note: Water and instrument depths are nominal. See Table 3 for actual depths.



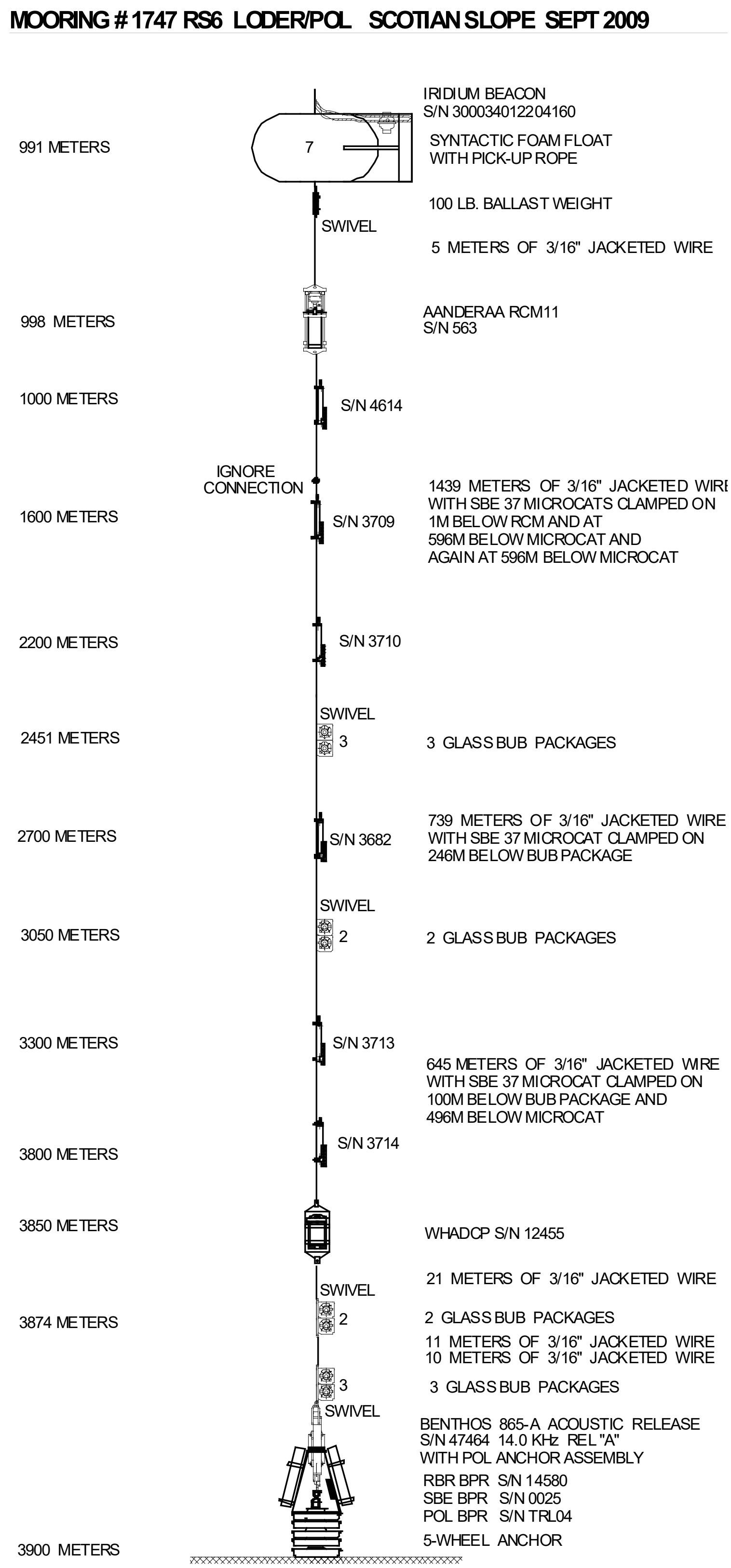


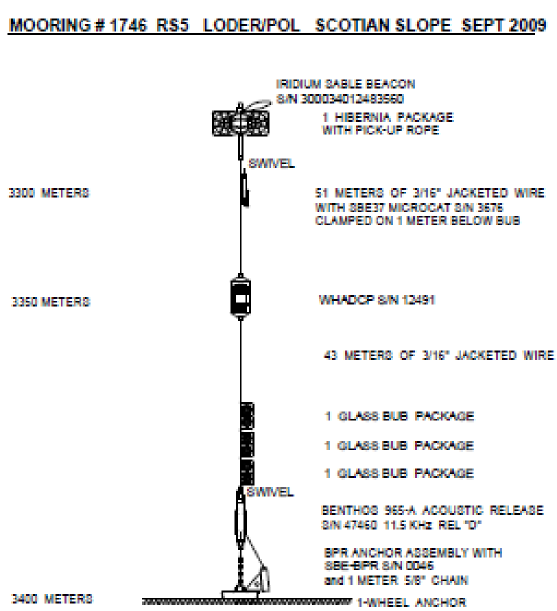




Deployment 2, 2009-2010 *(continued)*: **RS5 and RS6** (M1746 and M1747)

Note: Water and instrument depths are nominal. See Table 3 for actual depths.

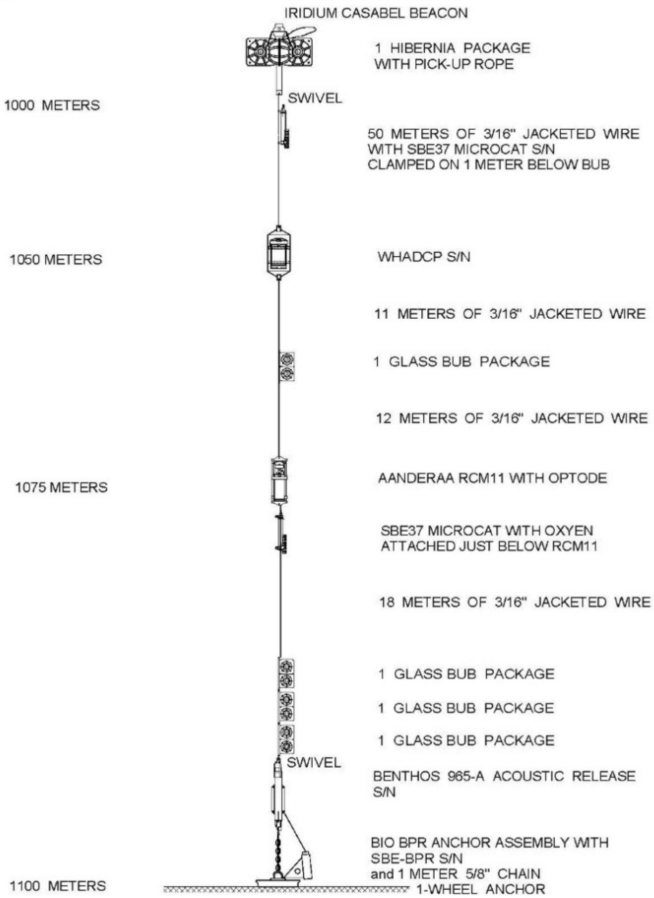




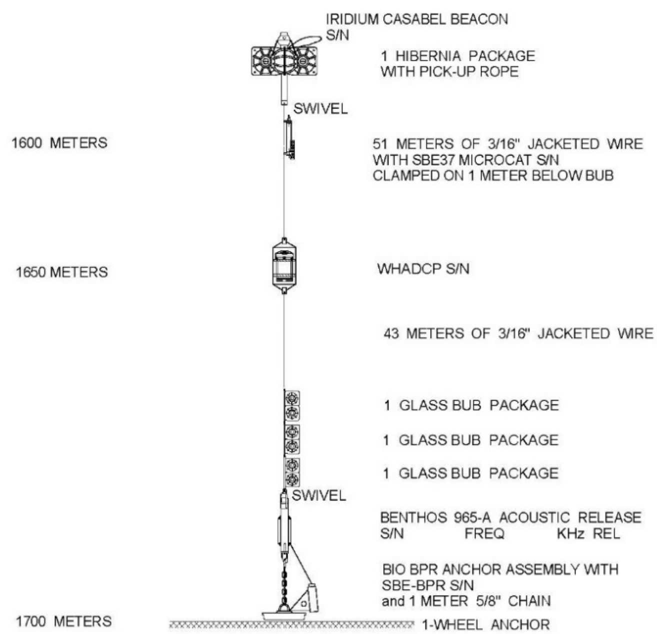
Deployment 3, 2010-2011: RS1 – RS4 (M1777 – M1780)

Note: Water and instrument depths are nominal. See Tables 3-5 and 7-9 for instrument serial numbers and actual depths.

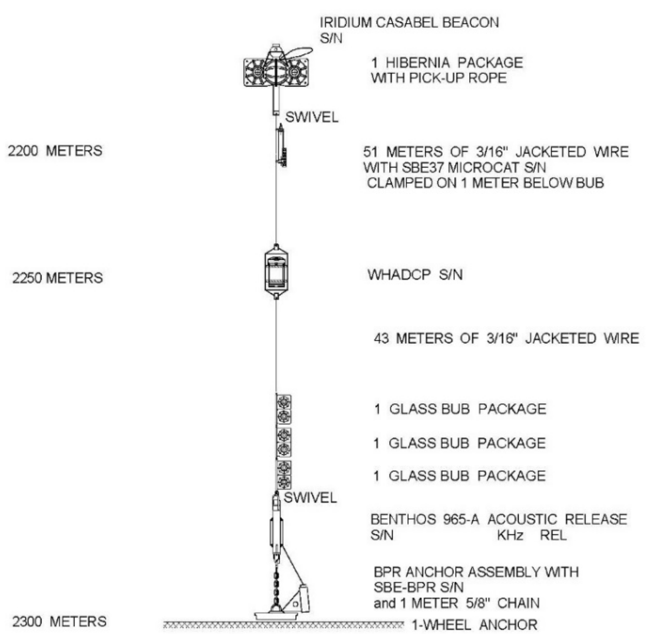
MOORING # 1777 RS1 LODER/POL SCOTIAN SLOPE DEC 2010



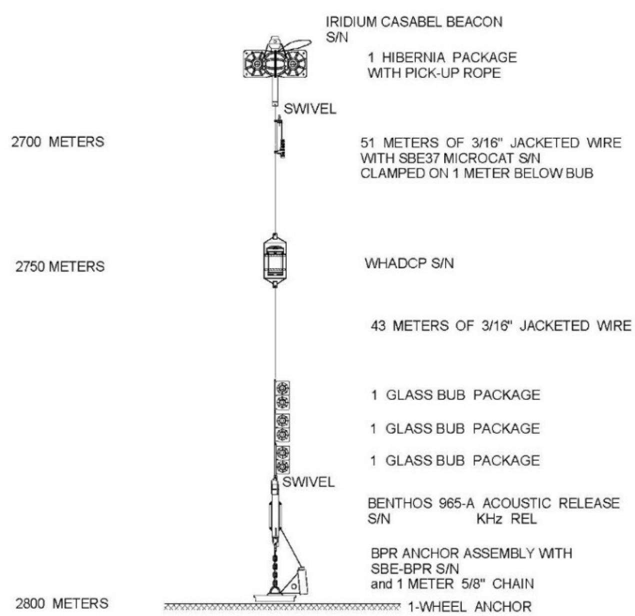
MOORING # 1778 RS2 LODER/POL SCOTIAN SLOPE DEC 2010



MOORING # 1779 RS3 LODER/POL SCOTIAN SLOPE DEC 2010

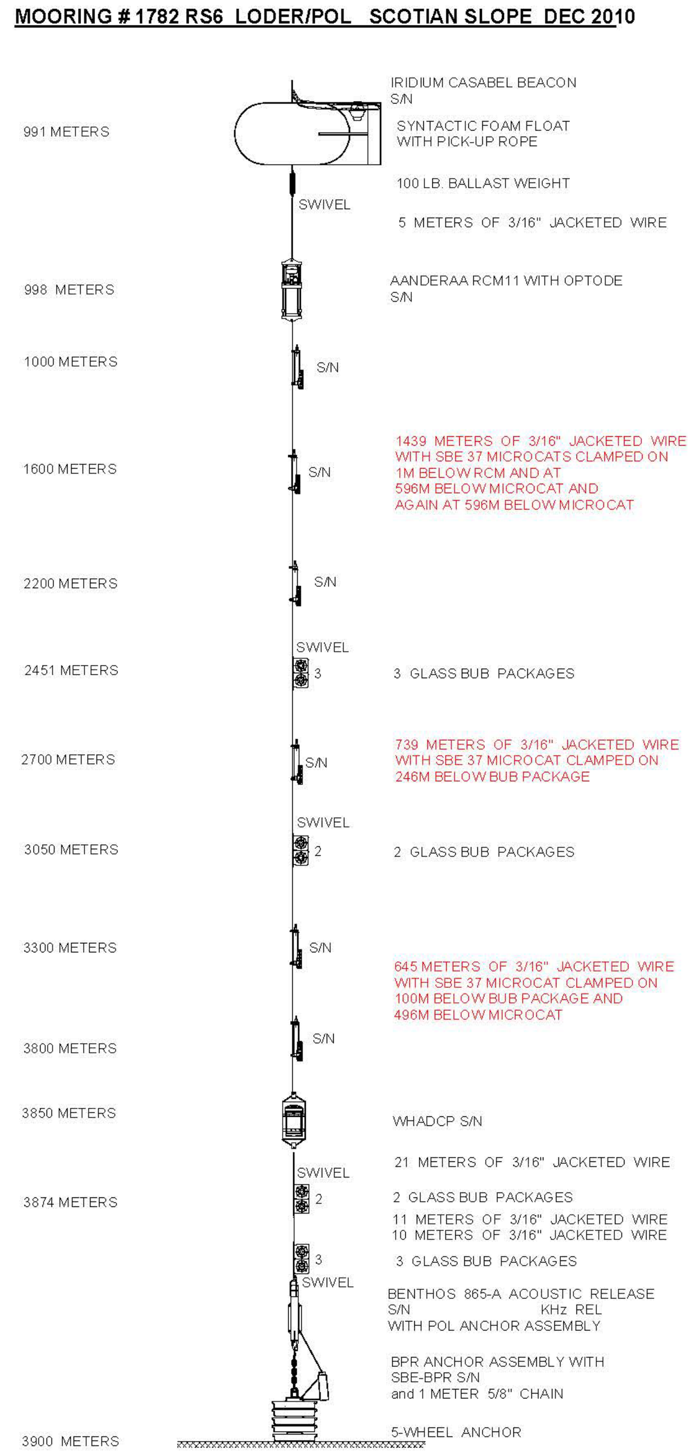


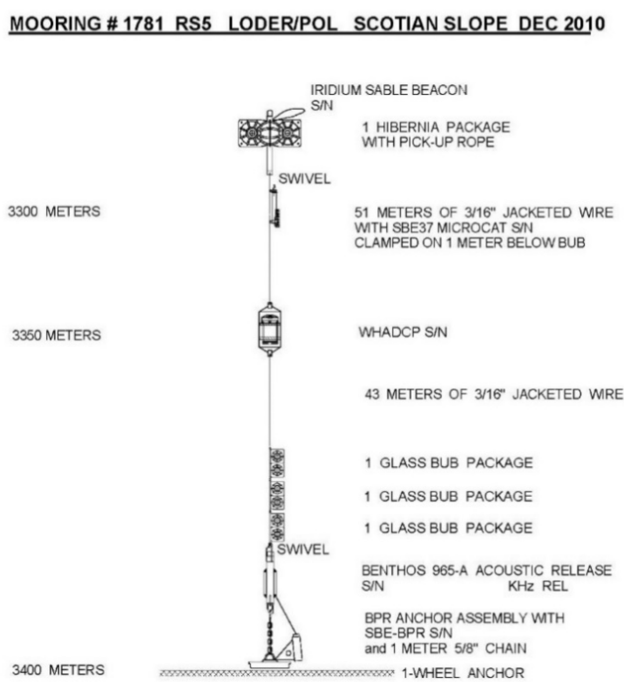
MOORING # 1780 RS4 LODER/POL SCOTIAN SLOPE DEC 2010



Deployment 3, 2010-2011 *(continued)*: **RS5 and RS6** (M1781 and M1782)

Note: Water and instrument depths are nominal. See Tables 3-5 and 7-9 for instrument serial numbers and actual depths.

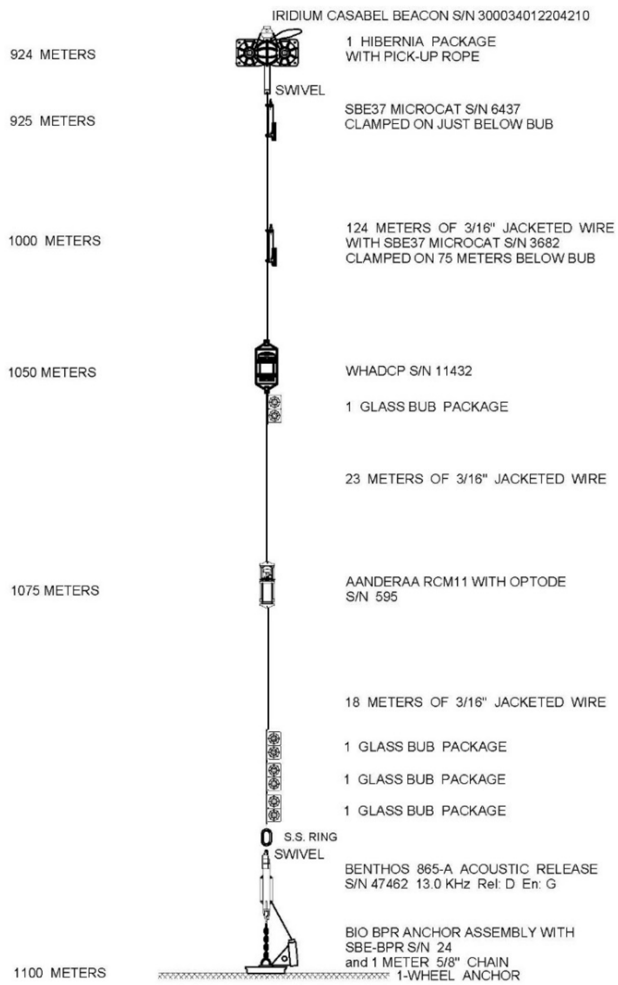




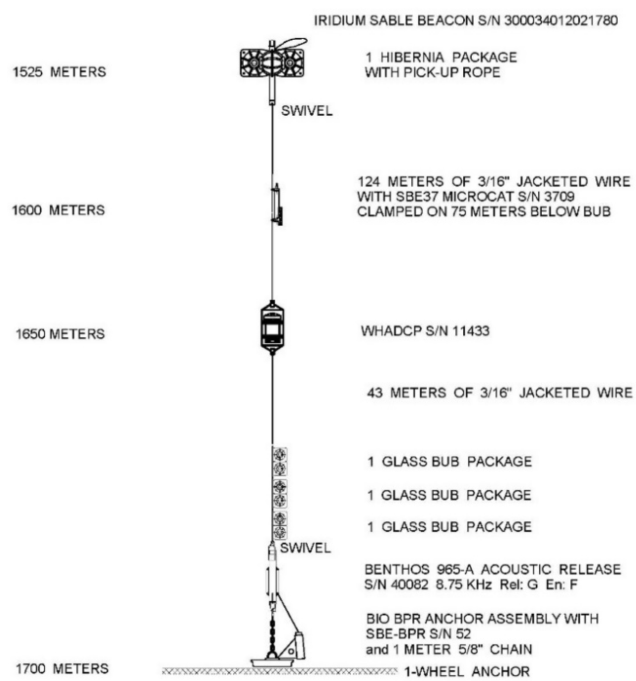
Deployment 4, 2011-2013: RS1 – RS4 (M1804 -M1807)

Note: Water and instrument depths are nominal. See Table 3 for actual depths.

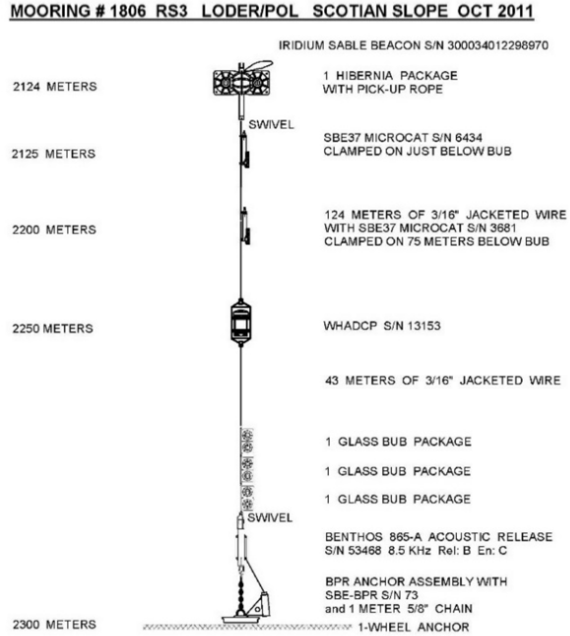
MOORING # 1804 RS1 LODER/POL SCOTIAN SLOPE OCT 2011



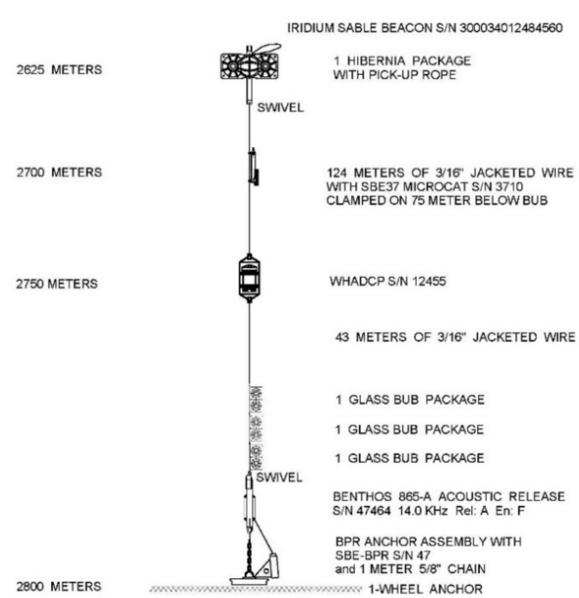
MOORING # 1805 RS2 LODER/POL SCOTIAN SLOPE OCT 2011



MOORING # 1806 RS3 LODER/POL SCOTIAN SLOPE OCT 2011

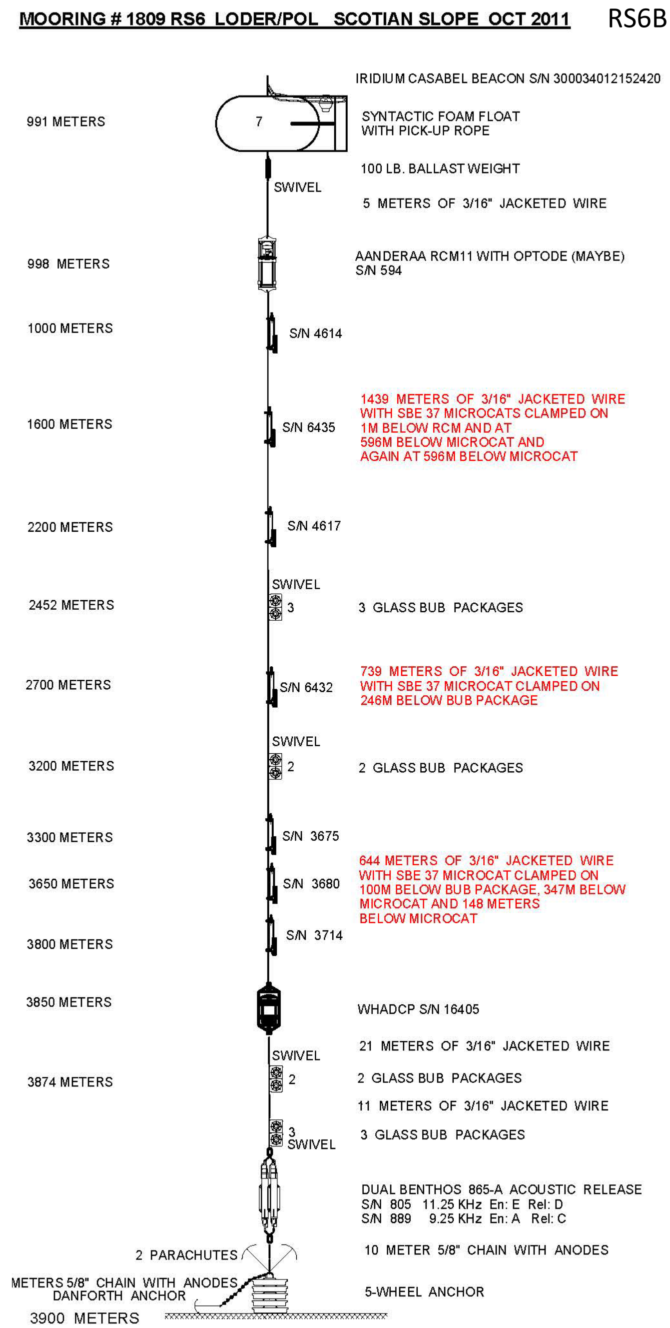


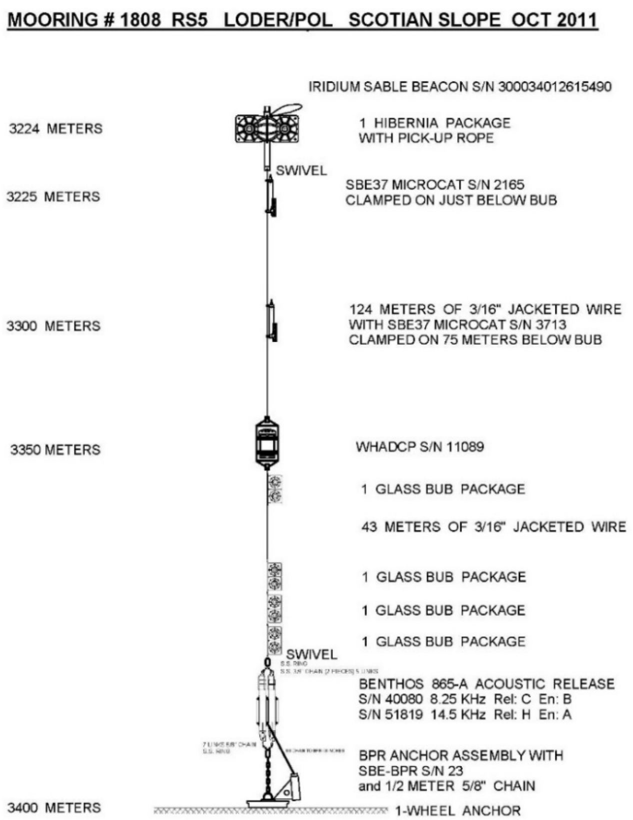
MOORING # 1807 RS4 LODER/POL SCOTIAN SLOPE OCT 2011

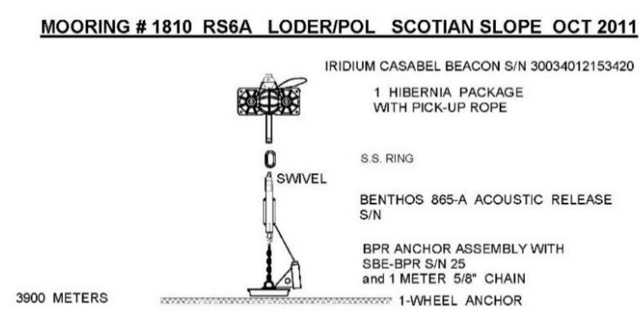


Deployment 4, 2011-2013 *(continued)*: **RS5, RS6A and RS6B** (M1808 – M1810)

Note: Water and instrument depths are nominal. See Table 3 for actual depths.





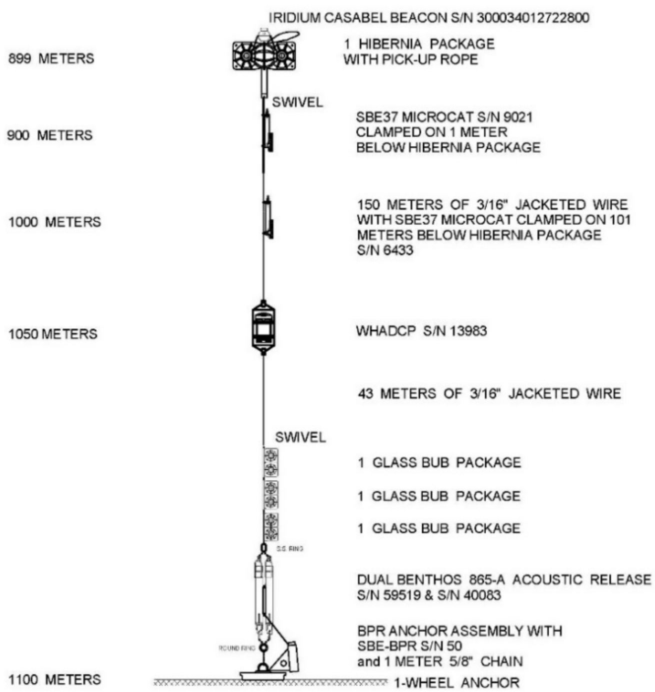


M1810: BPR Mooring

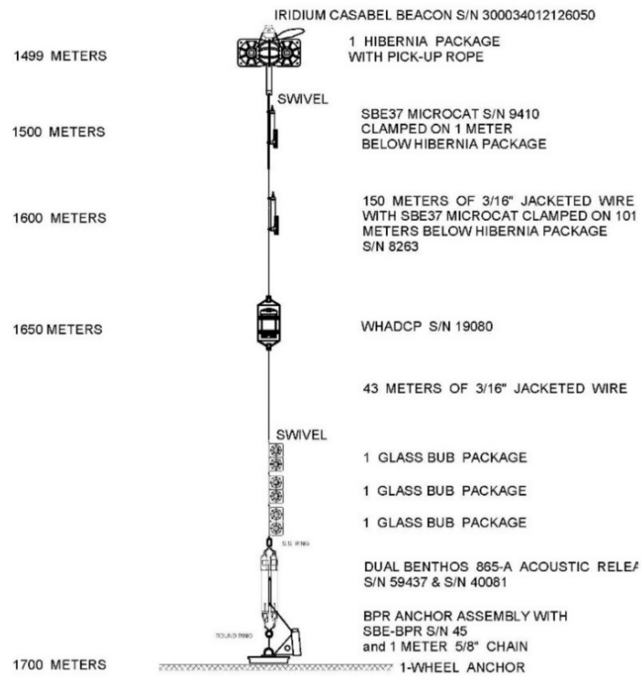
Deployment 5, 2013-2014: RS1 – RS4 (M1834 – M1837)

Notes: Water and instrument depths are nominal. See Table 3 for actual depths.
The deepest MicroCAT on these moorings was mistakenly placed at 150 mab, instead of 100 mab as in the design.

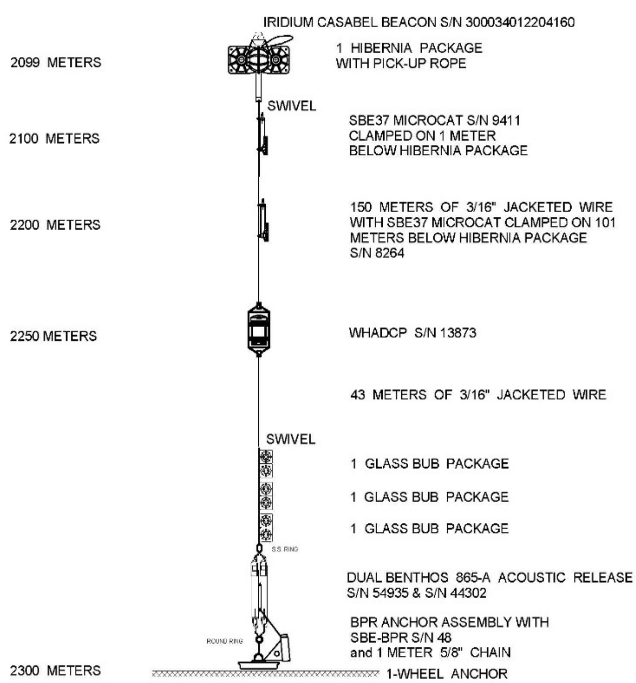
MOORING # 1834 RS1 LODER/POL SCOTIAN SLOPE APRIL 2013



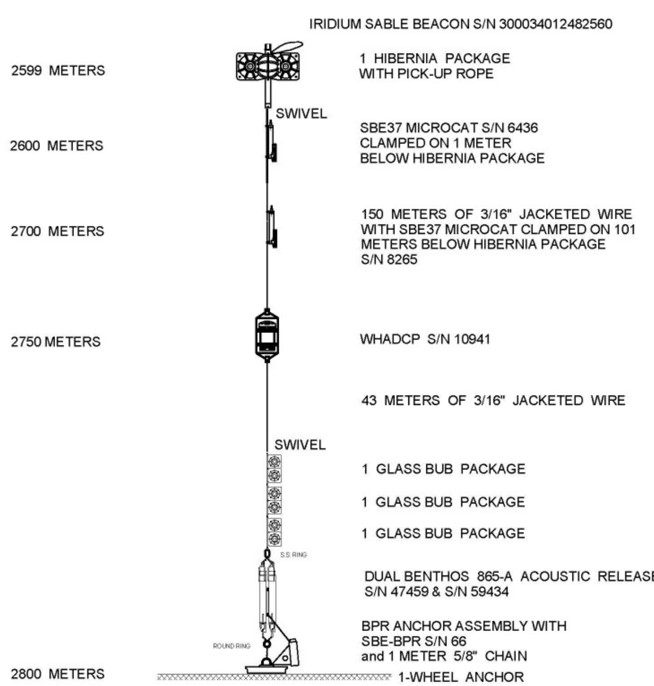
MOORING # 1835 RS2 LODER/POL SCOTIAN SLOPE APRIL 2013



MOORING # 1836 RS3 LODER/POL SCOTIAN SLOPE APRIL 2013



MOORING # 1837 RS4 LODER/POL SCOTIAN SLOPE APRIL 2013



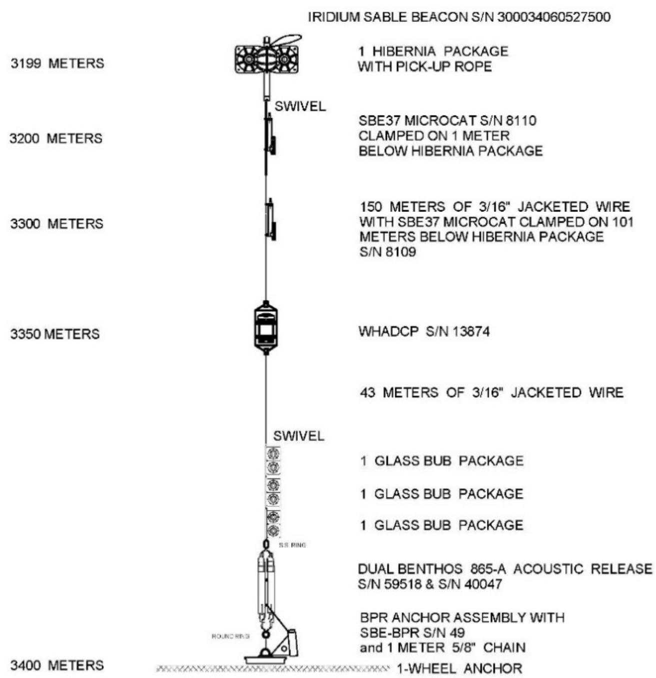
Deployment 5, 2013-2014 *(continued)*: **RS5B and RS6B** (M1838 and M1839)

Notes: Water and instrument depths are nominal. See Table 3 for actual depths.

The deepest MicroCAT on these moorings was mistakenly placed at 150 mab, instead of 100 mab as in the design.

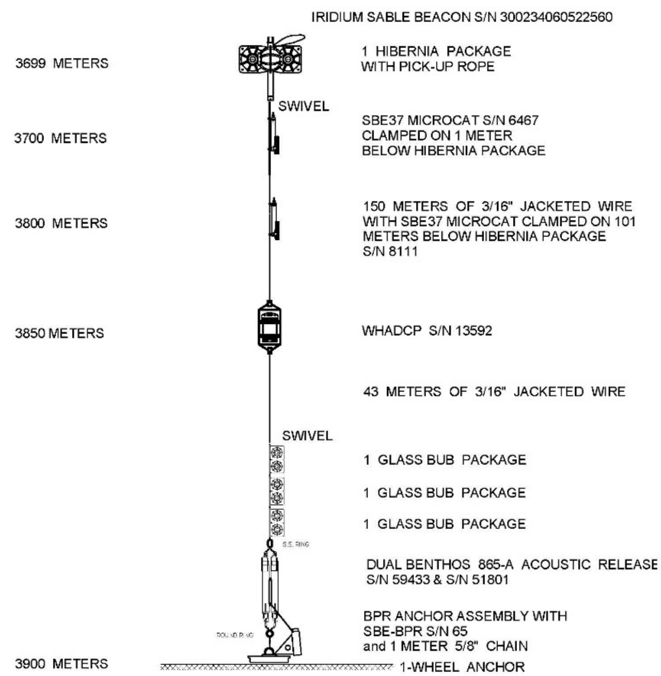
RS5B

MOORING # 1838 RS5 LODER/POL SCOTIAN SLOPE APRIL 2013



RS6B

MOORING # 1839 RS6 LODER/POL SCOTIAN SLOPE APRIL 2013

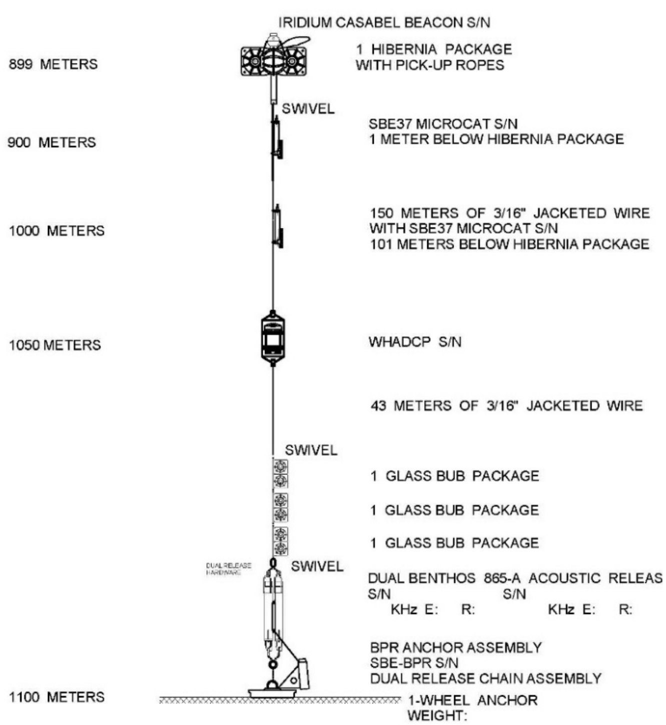


Deployment 6, 2014-2016: RS1, RS3, RS5B and RS6B (M1886 – M1889)

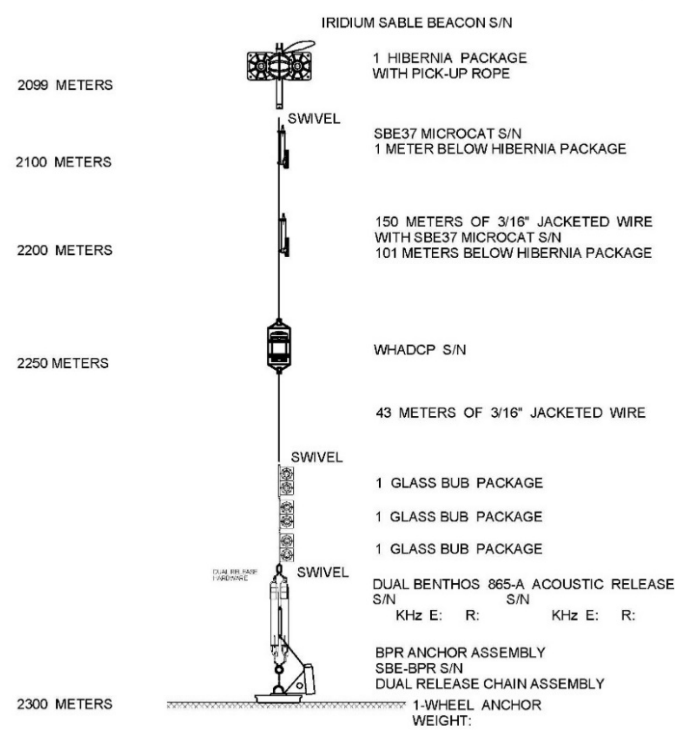
Notes: Water and instrument depths are nominal. See Tables 3-5 and 7-9 for instrument serial numbers and actual depths.

The deepest MicroCATt on these moorings was mistakenly placed at 150 mab, instead of 100 mab as in the design.

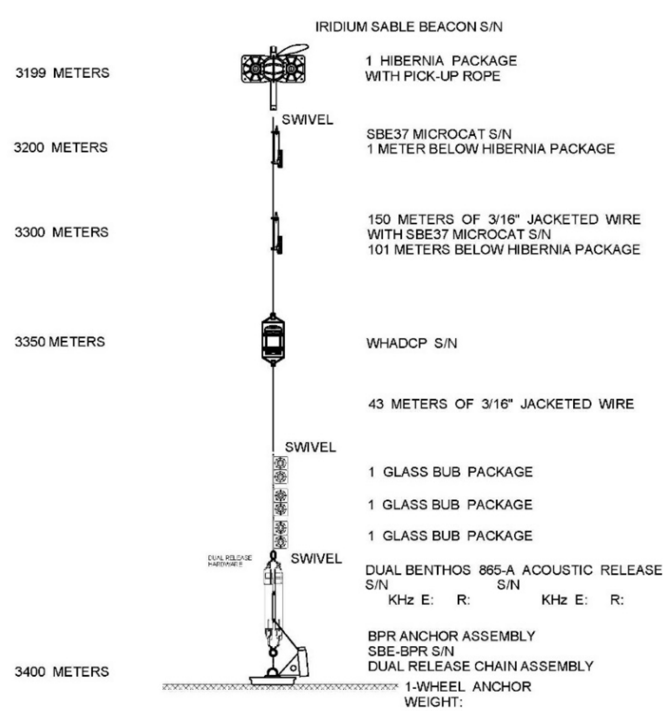
MOORING # 1886 RS1 LODER/POL SCOTIAN SLOPE SEPT 2014



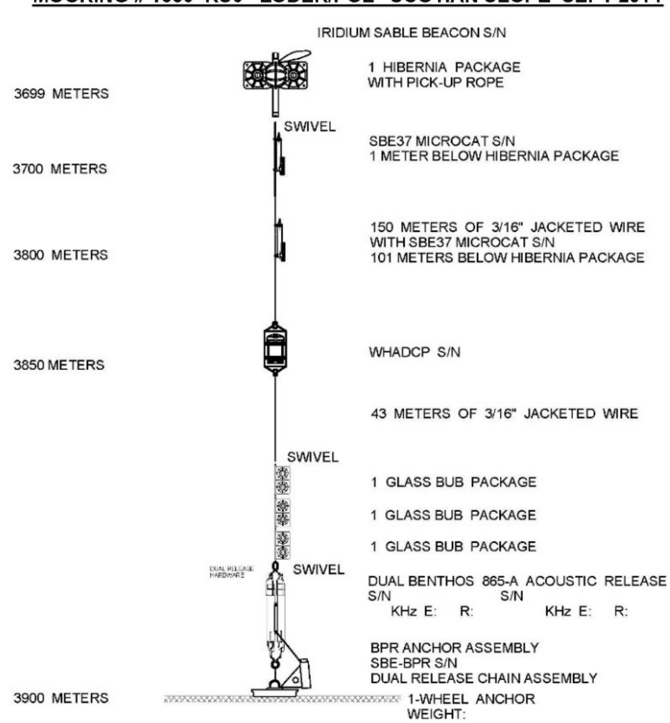
MOORING # 1887 RS3 LODER/POL SCOTIAN SLOPE SEPT 2014



MOORING # 1888 RS5 LODER/POL SCOTIAN SLOPE SEPT 2014



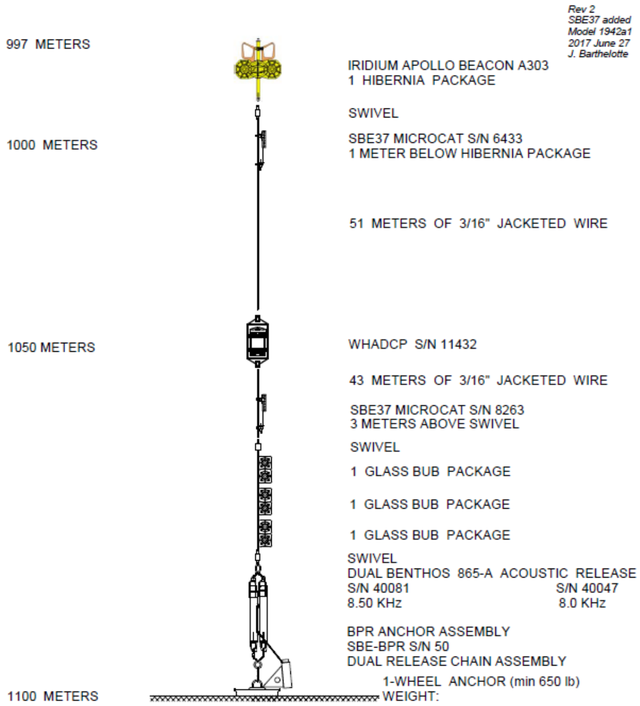
MOORING # 1889 RS6 LODER/POL SCOTIAN SLOPE SEPT 2014



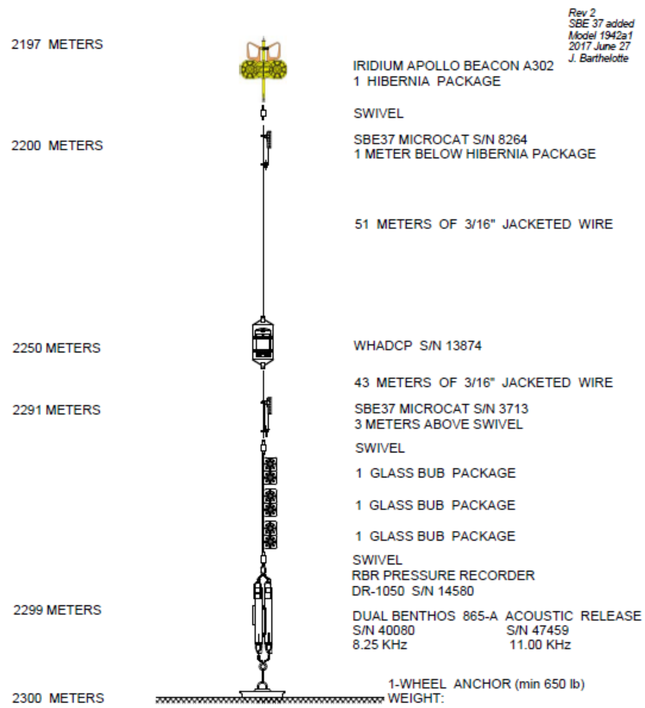
Deployment 7, 2016-2018: RS1, RS3, RS5B and RS6B (M1942 – M1945)

Notes: Water and instrument depths are nominal. See Table 3 for actual depths.

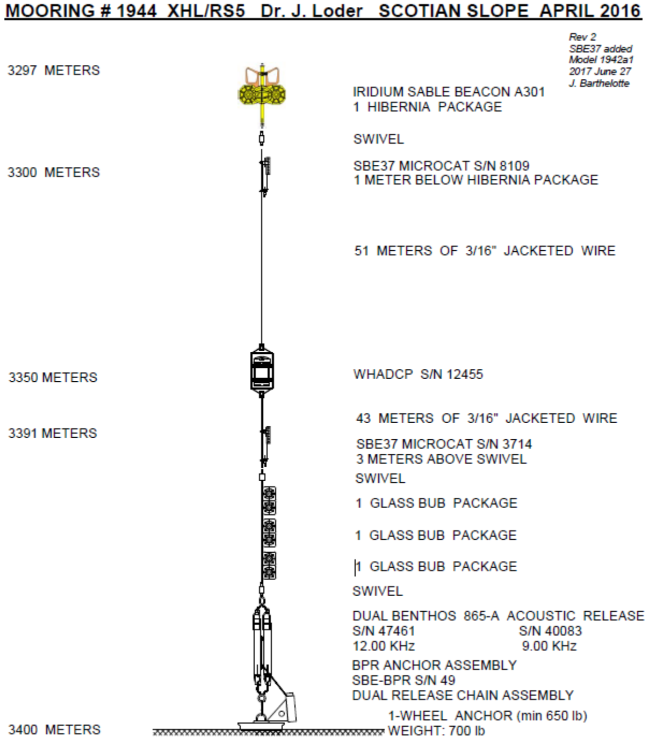
MOORING # 1942 XHL/RS1 Dr. J. Loder SCOTIAN SLOPE APRIL 2016



MOORING # 1943 XHL/RS3 Dr. J. Loder SCOTIAN SLOPE APRIL 2016



MOORING # 1944 XHL/RS5 Dr. J. Loder SCOTIAN SLOPE APRIL 2016



MOORING # 1945 XHL/RS6 Dr. J. Loder SCOTIAN SLOPE APRIL 2016