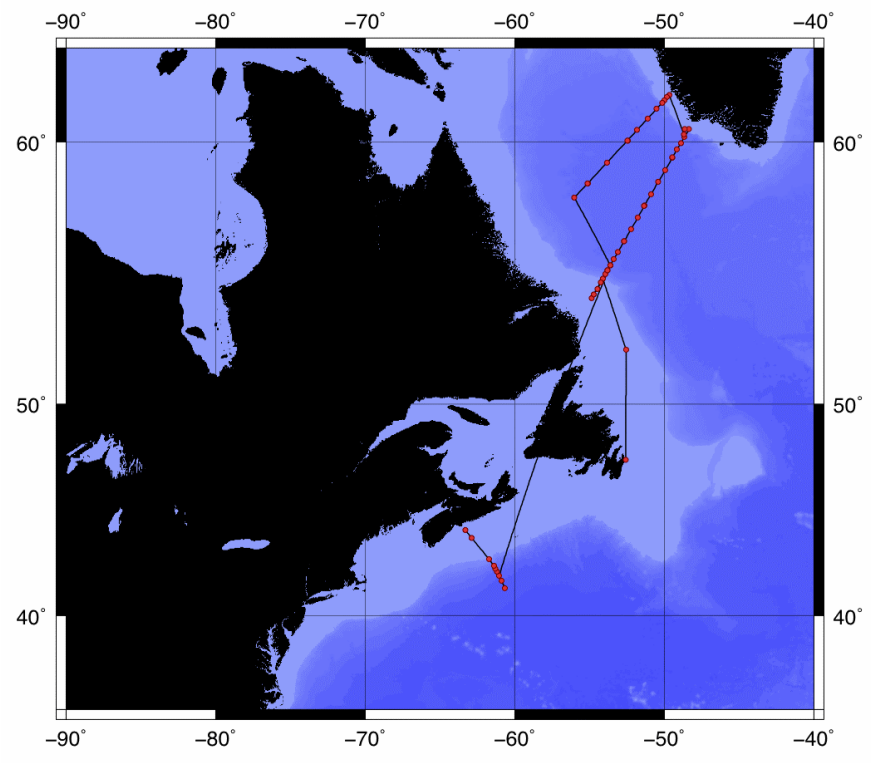
CRUISE REPORT: AR07W

(Updated NOV 2012)



Highlights

Cruise Summary Information

WOCE Section Designation	**AR07W**
Expedition designation (ExpoCodes)	**18HU20070510**
Aliases	**HUD2007-011, HUD2007011, 18HU07011, 2007011**
Chief Scientists	**Ross Hendry / BIO**
Dates	**2007 MAY 10 to 2007 MAY 27,**
Ship	***CCGS Hudson***
Ports of call	St. John's, NL, CAN - Dartmouth, NS, CAN
Geographic Boundaries	61° 32.32' N 63° 19.39' W 48° 21.34' W 41° 24.49' N
Stations	27
Floats and drifters deployed	5 APEX floats deployed
Moorings deployed or recovered	1 deployed, 1 recovered

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Links To Select Topics

Shaded sections are not relevant to this cruise or were not available when this report was compiled.

Cruise Summary Information	Hydrographic Measurements
Description of Scientific Program	**CTD Data:**
Geographic Boundaries	Acquisition
Cruise Track (Figure): PI CCHDO	Processing
Description of Stations	Calibration
Description of Parameters Sampled	Temperature Pressure
Bottle Depth Distributions (Figure)	Salinities Oxygens
Floats and Drifters Deployed	**Bottle Data**
Moorings Deployed or Recovered	Salinity
	Oxygen
Principal Investigators	Nutrients
Cruise Participants	Carbon System Parameters
	CFCs
Problems and Goals Not Achieved	Helium / Tritium
Other Incidents of Note	Radiocarbon
Underway Data Information	**References**
Navigation Bathymetry	
Acoustic Doppler Current Profiler (ADCP)	
Thermosalinograph	
XBT and/or XCTD	
Meteorological Observations	**Acknowledgments**
Atmospheric Chemistry Data	
Data Processing Notes	

CRUISE REPORT

HUDSON 2007011

LABRADOR SEA

WOCE LINE AR7W

A. CRUISE NARRATIVE

1. Highlights

a. WOCE Designation:	WOCE Line AR7W
b. Expedition Designation:	HUD2007011 or 18HU07011 (ISDM format)
c. Chief Scientist:	Ross Hendry Ocean Sciences Division Department of Fisheries and Oceans Bedford Institute of Oceanography PO Box 1006 Dartmouth, NS, Canada B2Y 2A4 Ross.Hendry@dfo-mpo.gc.ca
d. Ship:	CCGS Hudson
e. Ports of Call:	May 10, 2007 St. John's, NL, Canada May 27, 2007 BIO, Dartmouth, NS, Canada
f. Cruise Dates:	May 10 to May 27, 2007

2. Cruise Summary Information

a. Cruise Track

A cruise track is shown in Figure A.2.1. The ship's position at 0000 UTC on each day of the cruise is indicated with a date label. The World Ocean Circulation Experiment (WOCE) cruise station summary (SUM) file outlines the science operations conducted during the cruise.

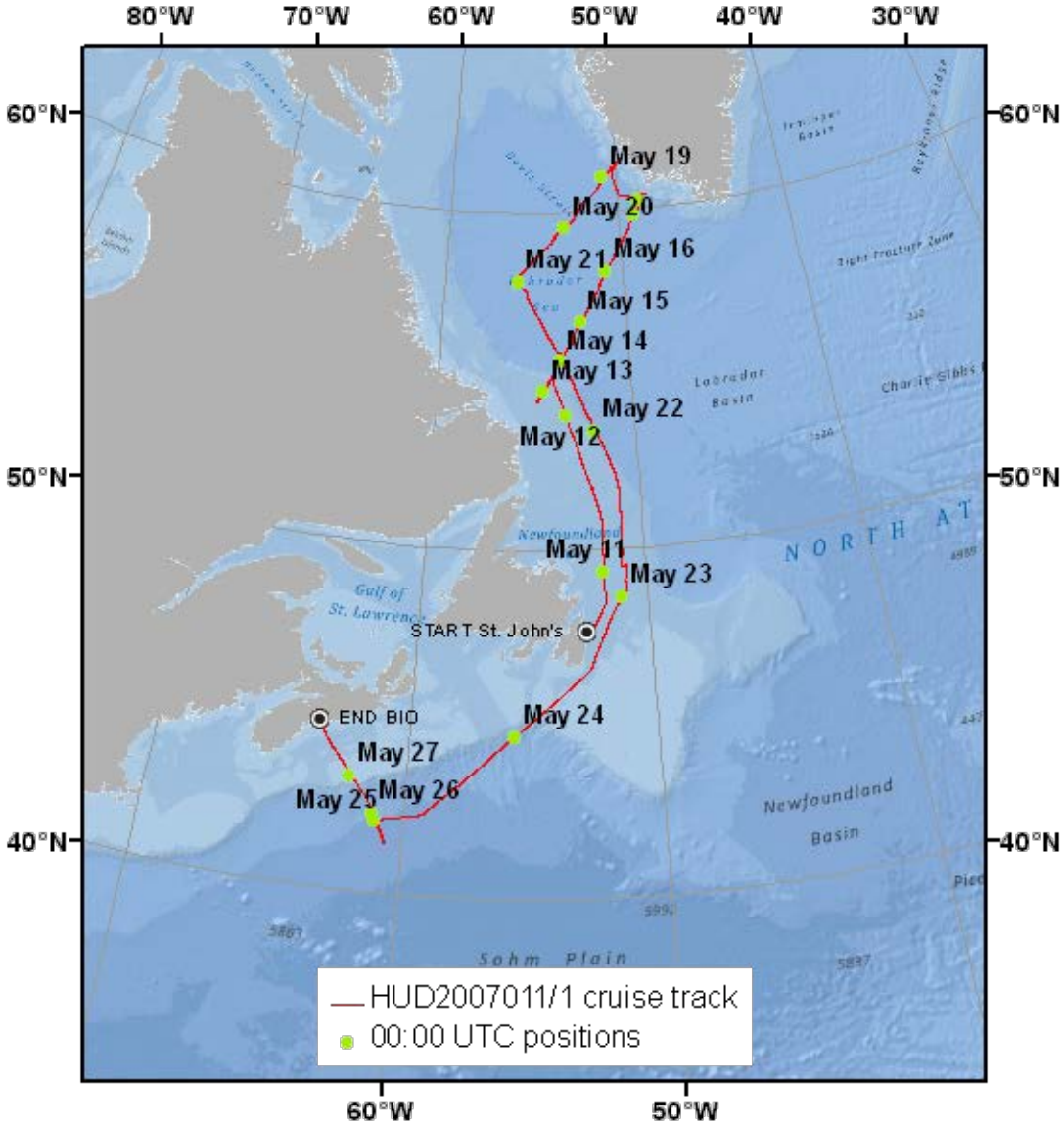

Figure A.2.1 Cruise track for HUD2007011/1 showing the ship's position at 00:00 UTC from 11–27 May 2007.

b. Total number of stations occupied

The AR7W Labrador Sea section, part of the northern Labrador Sea L2 section, and the extended Halifax Section were occupied during the HUD2007011 mission. The L2 station positions were derived from positions of Hudson 97009 stations L2_01 to L2_19. The combined effort of this survey, Spring 2007 Atlantic Zone Monitoring Program surveys, and an early-May HUD2007007 line across Orphan Basin provide a comprehensive assessment of the

oceanographic conditions in the Canadian sector of the Atlantic Ocean. HUD2007011 CTD station positions are shown in Figure A.2.2. Table A.2.1 lists the science operations.

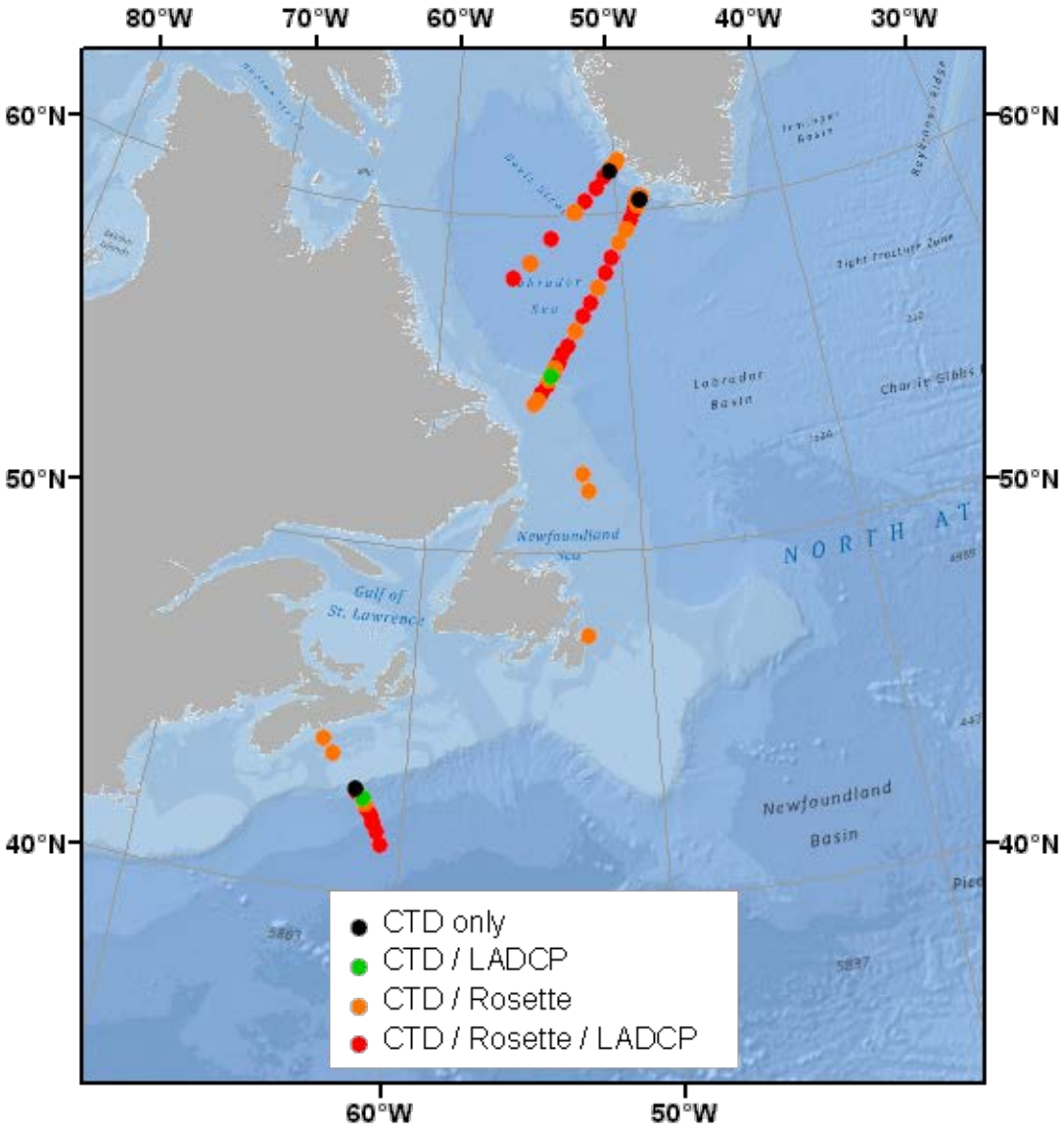

Figure A.2.2 HUD2007011/1 stations involving some combination of CTD, Rosette, and LADCP.

Cast Type	Number of Operations	Detailed Division	Operation Numbers
Rosette & CTD	27	23 of the 28 regular AR7W Sites (L3 line) plus sites 4.5, 8.5, 25.3 and 25.7	Table A.2.2
	12	Partial occupation of L2 line	186, 189, 192, 196, 197, 201, 204, 207, 211, 214, 219, 222 (Table A.2.3)
	11	Halifax Line	228, 233, 238, 241, 245, 248, 250, 251, 254, 257, 261 (Table A.2.4)
	7	Biology Casts not included in other tables	35, 63, 96, 145, 210, 218, 225
	1	Station 27	3
	2	Transit Stations	8, 9
	1	Aborted	227
Moorings	1	Release Test	7
	1	Recovery	28
	1	Deployment	29
Floats	5	APEX floats deployed	65, 113, 183, 234, 240
Biology	40	200 micron net tows	2, 5, 11, 15, 19, 22, 26, 33, 41, 46, 53, 61, 73, 81, 95, 110, 122, 131, 144, 152, 159, 166, 170, 174, 177, 181, 185, 188, 191, 194, 199, 203, 206, 208, 213, 216, 221, 224, 256, 260
	14	200 micron net tows for egg production rate measurements	6, 12, 34, 47, 62, 82, 111, 132, 153, 171, 178, 195, 200, 217
	38	76 micron net tows	1, 4, 10, 14, 18, 21, 25, 32, 40, 45, 52, 60, 72, 80, 94, 109, 121, 130, 143, 151, 158, 169, 173, 176, 180, 184, 187, 190, 193, 198, 202, 205, 209, 212, 215, 220, 223, 259
	7	Multi-net tows	226, 232, 236, 242, 246, 249, 252
Chemistry	11	I-129 surface	48, 54, 74, 83, 112, 123, 146, 154, 172, 175, 179
	9	I-129 profile	42, 97, 133, 160, 222, 228, 233, 241, 245
	20	Inert gas samples	64, 74, 83, 154, 172 (Table A.3.1)
Other		Vessel-mounted ADCP	No number assigned
	94	XBT Deployments	Table B.4.1

Table A.2.1 Science operations conducted on HUD2007011/1.

Along AR7W (Table A.2.), L2 (Table A.2.3), and the Halifax Section (Table A.2.4) the stations were full-depth WHP small volume rosette casts with up to 24 rosette bottles. Water samples were analyzed for CFCs, total inorganic carbon (TIC), total alkalinity, oxygen, salinity, nutrients (nitrate, phosphate, and silicate), total organic carbon (TOC), and bacterial abundance.

Chlorophyll was analyzed at depths less than 200 m at most stations. Samples were collected for iodine-129 (129I) on selected casts. At five stations along the AR7W (L3) line water samples were collected for shore-based analysis of dissolved Ar, Kr, Xe, and N2.

AR7W Site Number	2007011 Deep Cast Operation Number
1	Not sampled due to ice
2	Not sampled due to ice
3	Not sampled due to ice
4	Not sampled due to ice
4.5	16
5	17
6	20
7	23
8	13
8.5	24
9	27
10	36
11	42
12	48
13	54
14	64
15	74
16	83
17	97
18	112
19	123
20	133
21	146
22	154
23	160
24	172
25	182
25.3	168
25.7	167
26	179
27	175
28	Not sampled due to ice

Table A.2.2 AR7W (L3) sites and rosette and CTD operation numbers for HUD2007011/1.

L2 Site Number	2007011 Deep Cast Operation Number
20	186
19a	189
19	192
18	196
17	197
15.5	201
14	204
13	207
12	211
10	214
8	219
6.5	222

Table A.2.3 L2 sites and rosette and CTD operation numbers for HUD2007011/1.

HL Site Number	2007011 Deep Cast Operation Number
2	261
3	257
5.5	254
6	251
6.5	250
7	248
8	245
9	241
10	228
11	233
12	238

Table A.2.4 Halifax Line sites and rosette and CTD operation numbers for HUD2007011/1.

c. Floats and Drifters deployed

Nine APEX profiling floats (Teledyne Webb Research, E. Falmouth, MA) equipped with SBE-41 temperature-conductivity sensors (Sea-Bird Electronics, Inc., Bellevue, WA) were deployed as a Canadian contribution to the international Argo project (see Figure A.2.3 below). This effort was jointly supported by Fisheries and Oceans Canada and the Canadian Ice Service of Environment Canada. Eight floats were deployed in the Labrador Sea and one float was deployed on the offshore Halifax Line. Table A.2.5 gives details of the float deployments. Launch locations are shown in {mooring figure} below.

On 4 May 2007 Sea-Bird issued a notice that there was a problem with the Druck pressure sensors used in SBE-41 CTDs on Argo floats that could cause a progressive negative offset in measured pressure and the eventual failure of these sensors and recommended that float users stop float deployments and return the affected CTDs to Sea-Bird for repair. A considered decision was made to proceed with our planned deployments and accept any resulting premature failures. The time frame for the resolution of this issue was several months at a minimum and it was felt that the benefits of ensuring continued coverage by taking advantage of the deployment

opportunities on our annual Labrador Sea mission outweighed the potential costs of reduced float lifetime. All nine floats deployed were equipped with APF9a controller boards which compensate for negative pressure drifts by using atmospheric pressure as a reference. A single float equipped with an older model APF8 controller board originally scheduled for deployment failed pre-launch tests and was replaced with an APF9 float carried as a spare. The APF8 controller truncates negative pressures to zero and the reported pressures are in error by the amount of any negative drift.

Float		WMO	Event	Launch Position		Start Time	Launch Time
Type	SN			N. Lat	W. Lon	UTC	UTC
APEX-SBE APF8C	3269	4901075	65	56° 31.2'	052° 41.4'	14 May 2007 37:00	14 May 2007 02:00
APEX-SBE APF8C	3270	4901076	113	58° 15.0'	050° 57.5'	15 May 2007 09:00	16 May 2007 40:00
APEX-SBE APF8C	3271	4901077	183	60° 15.6'	048° 42.1'	17 May 2007 54:00	18 May 2007 15:00
APEX-SBE APF8C	3272	4901078	234	41° 47.8'	060° 54.5'	25 May 2007 59:00	25 May 2007 54:00
APEX-SBE APF8C	3274	4901080	240	42° 14.6'	061° 11.9'	25 May 2007 05:00	25 May 2007 54:00

Table A.2.5 APEX float deployments on HUD2007011/1.

d. Moorings deployed or recovered

The Aanderaa current meter mooring near station L3-8 on the AR7W line was once again serviced on May 13, 2007. Mooring #1601 was recovered successfully in moderate sea conditions. The RCM8 appeared to have worked properly and all mooring tackle was in good condition. The replacement mooring #1640 was deployed successfully.

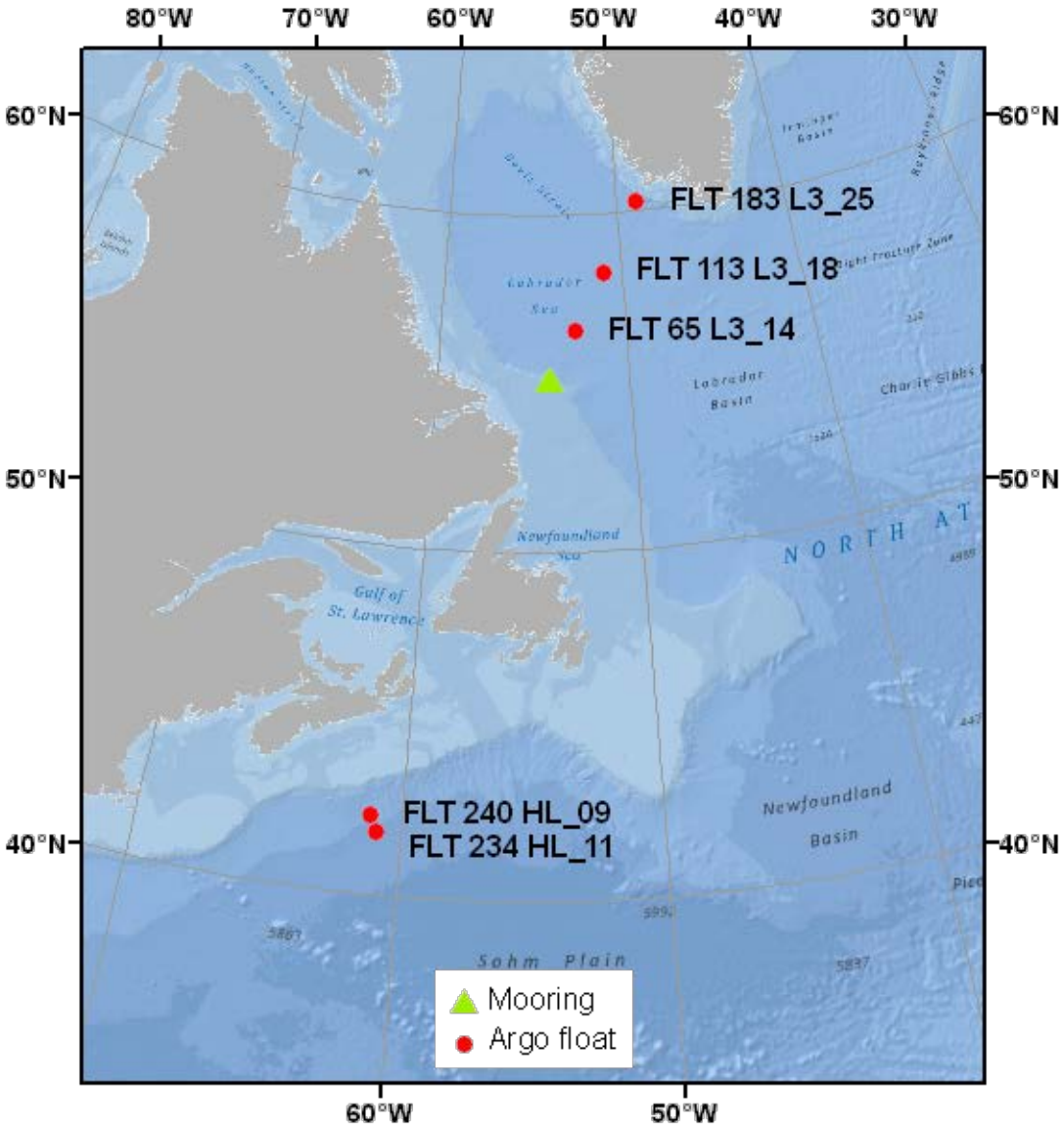

Figure A.2.3 HUD2007011/1 float deployment locations (red-filled circles) and mooring locations (green-filled triangle). A mooring was recovered and redeployed at the same location.

Recovery of M 1601:

Position	55º 07.20' N 54º 05.31' W	Standard mooring consisting of one current meter positioned 20m above bottom along AR7W on the Labrador Slope (12-month deployment) at 1030 m depth.

Deployment of M 1640:

Target position Deployment position Post-cruise position	55º 07.2' N 54º 05.4' W 55º 07.1' N 54º 05.3' W 55º 07.7.145' N 54º 05.5.282' W	Standard mooring consisting of one current meter positioned 20m above bottom along AR7W on the Labrador Slope (12-month deployment) at 1019 m depth.

A new software package called M-Cal (Mooring Calibrator) V 1.04 was used for the first time. M-Cal is a subset of a program called WorkBoat by James Illman of Software Engineering Associates. This enables the user to position the mooring once on the bottom. A computer is linked to the ship's navigation as well as, in this case, to the Benthos DS7000 deck unit. As the ship travels near the mooring, M-Cal transponds to the acoustic release and measures the time interval between the send and reply pulses. This information combined with the navigation data enables the program to calculate the position of the release. As more and more data is gathered, the position continually updates. M-Cal also calculates a depth for the release.

This software is of great use if a mooring is off location for some reason. As M-Cal gives a position and not just a slant range, locating the mooring is much quicker. Transponding to a release only gives a slant range and not a direction. A ship has to randomly travel to minimize this slant range which could be time consuming. We did not have the opportunity on this mission to fine tune the program with inputs as "the speed of sound in water" for this location and the "turn around time of the acoustic release". However, as M-Cal saves the calibration, these inputs can be changed later to create a more accurate position.

M-Cal was used to log slant ranges from the ship to the acoustic release along with position and depth information from the navigation data stream during a post-deployment positioning survey. This permitted a later refinement of the deployment position and added to our knowledge of the local bathymetry.

3. List of Principal Investigators

Name	Affiliation	Responsibility
Kumiko Azetsu-Scott	BIO Kumiko.Azetsu-Scott @dfo-mpo.gc.ca	Chemistry program coordination
Carina Gjerdrum	Canadian Wildlife Service, Environment Canada Carina.Gjerdrum@ec.gc.ca	Sea bird program
Roberta Hamme	University of Victoria rhamme@uvic.ca	Inert gas measurement program
Glen Harrison	BIO Glen.Harrison@dfo-mpo.gc.ca	Associate senior scientist, Biological program coordination
Erica Head	BIO Erica.Head@dfo-mpo.gc.ca	Macrozooplankton distribution, abundance and metabolism
Ross Hendry	BIO Ross.Hendry@dfo-mpo.gc.ca	Senior scientist
Paul Kepkay	BIO Paul.Kepkay@dfo-mpo.gc.ca	Dissolved organic carbon, colloid chemistry, plankton respiration
Bill Li	BIO Bill.Li@dfo-mpo.gc.ca	Pico-plankton distribution and abundance, bacterial abundance and productivity
Robert Pickart	Woods Hole Oceanographic Institution rpickart@whoi.edu	Lowered ADCP
John Smith	BIO John.Smith@dfo-mpo.gc.ca	Radioisotope sampling program
Igor Yashayaev	BIO Igor.Yashayaev@dfo-mpo.gc.ca	CTD/XBT program coordination

Table A.3.1 List of Principal Investigators (see Section 7 for addresses)

4. Scientific Programme and Methods

4.1 Physical–Chemical Programme

a. Narrative

The physical and chemical program on Hudson 2007011 continued an annual series of measurements in the Labrador Sea that began in 1990 as a contribution to the World Climate Research Programme and has evolved into a multidisciplinary regional monitoring effort. The broad goal is to regularly measure the physical and chemical properties of the Labrador Sea and adjacent North Atlantic areas to monitor interannual and long-term changes and better understand the mechanisms that cause these changes. A particular focus is on changes in the intensity of winter overturning of surface and intermediate-depth waters and the resulting formation of Labrador Sea Water with varying temperature and salinity properties. This overturning is part of the thermohaline circulation that plays a role in the global climate system. Convection also transfers atmospheric gases such as oxygen and carbon dioxide from the surface layers to intermediate depths. The resulting oceanic storage of anthropogenic carbon reduces the rate of increase of carbon dioxide in the atmosphere but also increases the acidity of oceanic waters. The physical-chemical investigations are part of a larger multidisciplinary effort seeking a better understanding of interannual and long-term changes in regional ecosystems.

Hudson 2007011 program elements included:

1. CTD profile measurements of pressure, temperature, salinity, dissolved oxygen, fluorescence, and light intensity at a fixed set of stations (AR7W/L3 line) spanning the Labrador Sea from Hamilton Bank on the Labrador Shelf to Cape Desolation Island on the West Greenland Shelf;

2. Associated measurements of salinity, dissolved oxygen, nutrients (nitrate/nitrite, phosphate, silicate), CFCs, dissolved inorganic carbon, alkalinity, Oxygen-18, and Iodine-129 from discrete water samples from a rosette sampler on the CTD package;

3. Similar physical and chemical measurements along part of the northern Labrador Sea L2 line occupied on Hudson 97009 to provide expanded geographical coverage of the Labrador Sea;

4. Similar physical and chemical measurements at Station 27 on the Newfoundland Shelf and on the Halifax Line on the Scotian Shelf in support of the Atlantic Zone Monitoring Program (AZMP);

5. Similar physical and chemical measurements on the Scotian Slope in support of an expanded offshore monitoring program and a joint study with the UK Proudman Oceanographic Laboratory;

6. Recovery and redeployment of a current meter mooring providing near-bottom current and temperature measurements on the Labrador Slope in 1000 m water depth;

7. Current measurements from a ship-mounted acoustic current profiler;

8. Current measurements at CTD stations from a lowered acoustic current profiler (Woods Hole Oceanographic Institution);

9. Temperature profile measurements from Expendable Bathythermographs (XBTs) at selected points between CTD stations;

10. Autonomous float deployments as part of the Canadian Argo Program and the international Argo Project;

11. Collection of water samples along the AR7W line for shore-based analysis of dissolved inert gases to quantify the physically-driven disequilibrium of gases during water mass formation. (University of Victoria).

The physical-chemical-biological programs described here and in more detail in Section 4.2 below were tightly coupled. Additional dedicated biological CTD stations to a maximum depth of 200 m were occupied at selected sites throughout the mission.

Station 27 off St. John's was occupied as a contribution to the AZMP. The CTD cable showed bird-caging after the occupation of Stn 27 and was reterminated. Three ring nets and a release test were next carried out at station Transit_01 en route to the western end of the AR7W line, but the CTD failed at the start of the upcast of ROS Event 8 and was recovered without tripping any

bottles. The transit was resumed while the CTD cable was reterminated and the system performed normally at ROS Event 9 at site Transit_02 later the same day.

The Labrador Sea station work went as planned except that sea ice prevented access to stations L3_01 to L3_04 on the Labrador Shelf and L3_28 on the West Greenland shelf. An extra station L3_4.5 was made at the ice edge on the Labrador Shelf. Operations on the L3 line included 27 full-depth CTD casts, 4 shallow CTD casts, 57 ring net hauls, 81 XBT drops, 3 float deployments, and the recovery and deployment of the Labrador Slope mooring.

Ice conditions required a transit northward from the AR7W line to the L2 line that was well seaward of the West Greenland shelf so we were unable to occupy requested biological stations on the shelf between L3 and L2 lines.

The positions of L2 stations occupied on HUD2007011 were based on a multi-line survey designed for Hudson 97009. We planned to occupy as much as the L2 line as possible while leaving enough time for the priority Halifax Line. No ice was found near L2_16 and the ship steamed about 14 nm shoreward of the most-eastward Hudson 97009 site L2_19 to begin the line at site L2_20 in 110 m depth early on May 18. We enjoyed an ice-free time window but daily Cape Farewell ice charts from the Danish Meteorological Institute showed the distance from the L2 West Greenland shelf stations to the leading edge of the northward-moving seasonal sea ice decreased from 45 nm on 18 May to 25 nm two days later. We were forced to steam at reduced speed during 18–20 May because of initially high swell and then a period of 35-kt winds, and time constraints made it necessary to break off work on the L2 line late on 20 May at LRO Event 222, site L2_06.5. Operations on the L2 line included 12 full-depth CTD casts, 2 shallow CTD casts, and 25 ring net hauls.

Net hauls and a shallow CTD cast were carried out at the L3_11 site to monitor any changes in biological activity during the week since original 14 May occupation.

Ice conditions made it necessary to return to the offshore end of the Halifax Line via Cape Race rather than by the shorter route through Belle Isle Strait and the Gulf of St. Lawrence. A blown fuse associated with a short in the sea cable ended LRO Event 227 HL_10 at 1000 m on the downcast; the station was repeated as Event 228 after a retermination of the CTD cable. An extra station at HL_5.5 was made in support of the offshore survey but inner shelf stations HL_4 and HL_5 were not occupied due to time constraints. The combined Halifax Line/offshore Halifax Line (HL) coverage included 11 full-depth CTD casts, one shallow CTD cast, 7 Multinet hauls with 5 sampling levels down to 1000 m (HL_6–HL_12), and 3 vertical ring net tows (HL_2–HL_3). Apex profiling floats were deployed at stations HL_9 and HL_11.

The weather was favourable for much of the mission, although conditions were marginal during some of the first operations on the Labrador side of the AR7W line. Steaming speed was occasionally reduced but operations were not stopped at any point for weather. Conditions were especially fine during the long transit from the southern Labrador Sea to the Halifax Line and the ship was consistently able to run at 14 kt during daylight hours.

We are indebted to Captain Todd Gilmore and the officers and crew of CCGS Hudson and to Ship's Technician Mr. Richard Malin for the support they provided to the science program on Mission 2007011.

Summary log (all times are UTC)

09 May 2007 12:00 WHOI LADCP power problems fixed but instrument is not communicating.
09 May 2007 12:00 It was reported that two CTD cable reterminations were needed on the prior HUD2007007 Orphan Basin mission.
10 May 2007 12:00 Fire and boat drill St. John's.
10 May 2007 13:40 Cast off from HMCS Cabot, 220 Southside Road, Pier 27, St. John's.
10 May 2007 15:32 Bird-caging of CTD cable noted after Stn 27 occupation. CTD cable reterminated.
10 May 2007 22:15 Loose ice, small pieces.
11 May 2007 11:52 Event 7 release test on hydro wire.
11 May 2007 12:19 ROS Event 8 Transit_01 downcast only, no bottles tripped (electrical problem). CTD cable reterminated.
11 May 2007 15:45 ROS Event 9 Transit_02.
12 May 2007 06:00 At mooring site. Winds 35 kt with forecast for 40-50 kt by 08:00. Interrogated Mooring 1601 release but elected to pick up stations to west and wait for better weather before carrying out mooring operations.
12 May 2007 08:59 ROS Event 13 L3_08. Two bottles with lanyards hooked to same release point failed to fire.
12 May 2007 11:38 Delay before NET Event 10 L3_08 to remove block from hydrographic winch and rethread wire through sheave after wire slipped out. Problem with wire-out display caused further delay.
12 May 2007 15:00 Start ROS Event 16 L3_04.5 at ice edge off Labrador coast.
12 May 2007 20:45 WHOI LADCP repaired following L3_04.5 using boards from NWAFC LADCP; installed in CTD package before L3_05 (approximately 4 h delay). No data collected because of problems with connecting cable. Cable was replaced before following LRO Event 20 L3_06.
12 May 2007 23:00 Encountered trawler working across L3_06 site; occupied station ~3 nm south of target position to avoid wait.
13 May 2007 08:00 Night watch reported difficulties drawing samples because of early-morning rough weather. Slowed ship during sampling. CTD frame shifted off pedestal, creating a potentially dangerous situation. Now strapping CTD frame down before sampling. Ship will stay on station until freons have been sampled.
13 May 2007 13:15 Back on site for recovery of Mooring 1601 (Event 28) and deployment of replacement Mooring 1640 (Event 29). Both operations successful. Total time 3 h 15 m including post-deployment survey.
14 May 2007 08:00 Problems with VMADCP. Deck unit is timing out and resetting. Data loss while resetting.
17 May 2007 07:43 Start of L3_25.3. WHOI LADCP connector unplugged at LADCP. Someone had rerouted cable leaving insufficient slack to accommodate raising of CTD package on legs. Reattached and taped connector. Since LADCP had not been charging no LADCP data were collected at L3_25.3.

17 May 2007 16:34 Start ROS Event 175 at planned position of L3_27 taking advantage of ~8 nm shoreward bight in ice edge. Unable to reach L3_28 site. Occupied L3_26 ~7 nm northwest of ice-covered planned position in 1100 m water depth.

18 May 2007 08:00 Transit to L2 line via waypoint offshore position L2_16 to avoid ice; thus unable to occupy requested biological stations on shelf between L3 and L2 lines. No ice near L2_16 so proceed inshore towards L2_20.

18 May 2007 10:05 Start ROS Event 186 at L2_20 on the West Greenland shelf in 110 m depth.

19 May 2007 10:01 End of LRO Event 207 L2_13. Westerly winds increasing, speed reduced to 8 kt on transit to L2_12.

19 May 2007 17:38 End of LRO Event 211 L2_12. Westerly winds 30/40 kt, speed reduced to 6-8 kt on transit to L2_10.

20 May 2007 07:14 End of Event 214 L2_10 LRO. Westerly winds 25/35 kt, speed reduced to 6-8 kt on first 2 h of transit to L2_08, increased to 13 kt during remaining 3.5 h of transit.

20 May 2007 11:21 Break off L2 line at LRO Event 222 L2_6.5 and begin steam to offshore Halifax Line via Cape Race.

21 May 2007 01:10 Divert to SE on SAR call. False EPIRB alarm, cancelled after ~30 minutes.

21 May 2007 10:25 Slow to evaluate ice conditions, then run south to Event 225 reoccupation of L3_11 NETS/LRO to monitor any changes in biological activity during the week since original 14 May occupation.

22 May 2007 02:15 Reduce speed to 11 kt 02:15 to 06:30.

22 May 2007 18:30 Slow to 11-12 kt and jog ~10 nm to east to avoid ice tongue.

22 May 2007 21:45 Reduce speed to 11-12 kt 21:45 to 03:00 23 May.

23 May 2007 03:00 Reduce speed to 9 kt 03:00 to 07:15 (sunrise).

23 May 2007 12:00 Cape Race waypoint; set course to HL_12.

24 May 2007 15:00 Alter course to HL_10; at present location it is the same distance to HL_10 and HL_12. This will give chemists more time between casts to run freons, at some cost in steaming time.

24 May 2007 20:55 MNT Event 226 HL_10. Most of the guide rollers on the winch used for multinet casts are seized. The conductor cable is wearing grooves in the horizontal rollers. Raised block supported by foredeck Hiab crane so that the cable runs free of the horizontal rollers.

24 May 2007 23:05 LRO Event 227 HL_10. Fuse blew at ~1000 m on downcast. Short in sea cable diagnosed. Reterminated cable and redid station as Event 228.

25 May 2007 16:54 LRO Event 238 HL_12. At ~3600 m on upcast retaining screws on metering block sheave cheeks were noted to be backing out. Tightened screws and continued upcast. Stopped again to apply Locktite and retighten screws. The sheave bearing seemed to run rough after retrieval but the unit was left in service since no replacement was available.

26 May 2007 06:00 On the first two combined CTD/multinet stations, the multinet cast went first following the practice for combined ring net/CTD stations which is required because ring net and CTD casts are both carried out from the winch room and CTD sample drawing would delay the start of ring net operation. For LRO Event 241 HL_9 and subsequent combined CTD/multinet stations we changed the order of operations so the CTD preceded the multinet cast. This allowed rosette water samples to be drawn while the ship remained on station for the multinet operation and also let the chemists begin the freon analyses and free up the freon sampling syringes for use on the next station. It was noted that ring net operations could not

be carried out on the foredeck because the ring net clamps would damage the conductor cable on the multinet winch.

26 May 2007 08:15 Slight delay before Event 246 HL_8 MNT to replace a malfunctioning block.

27 May 2007 10:50 Tied up alongside at BIO. Disembark Leg 1 scientific staff. There was a 2-day Leg 2 with three new science personnel to service moorings at Halifax Line Station 2 and on eastern Georges Bank that was deemed to be part of HUD2007011 for administrative convenience. The ship left BIO at 16:00 UTC 27 May 2007 and returned to BIO at 11:45 UTC on 29 May 2007.

b. Radioisotope Sampling Program — John Smith

Water samples were collected for 129I in support of an ongoing study of transit times in the North Atlantic Deep Western Boundary Current using paired 129I and CFC-11 measurements. Priority features for sampling were the Denmark Strait Overflow Water in the Labrador Sea and the deep boundary current on the extended Halifax Line. Water samples were collected for 129I from near surface rosette bottles at 11 stations on the L3 (AR7W) line. Ice conditions prevented the occupation of stations at sites L3_01, L3_03, and L3_28 where surface samples had been requested. Requested surface samples at sites L3_07 and L3_09 were apparently missed in the confusion of mixed mooring and CTD operations at the start of the occupation of AR7W. Multiple-depth sampling of 129I was carried out at five deep stations on the L3 section, at the most westward station on the L2 line, and at the four offshore stations on the Halifax Line. (Figure A.4.1.1). Table A.4.1.1 lists the 21 operations that included 129I sampling.

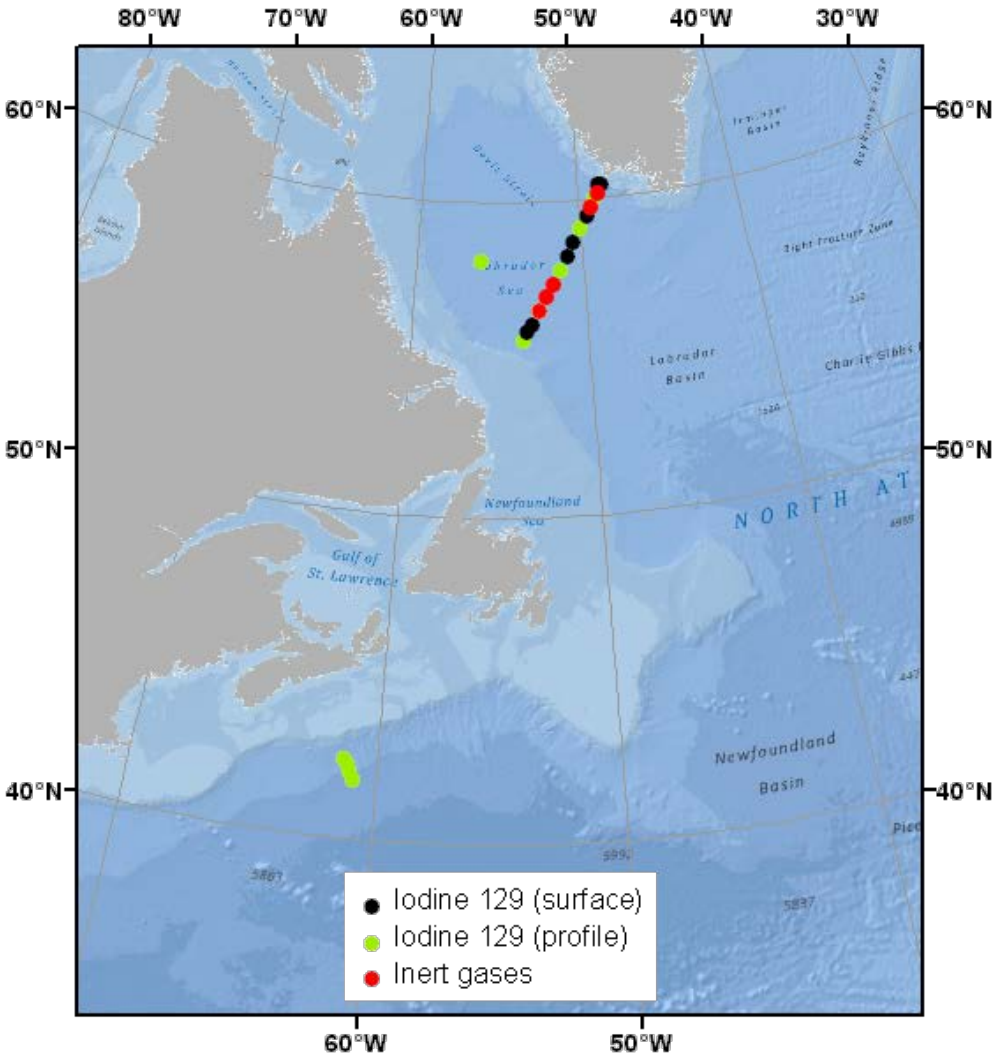

Figure A.4.1.1 HUD2007011/1 stations that sampled for Iodine-129 (green-filled circles) and inert gases (red-filled circles).

Station	Event	Latitude	Longitude	Time	IDs
L3_11	42	55.6100	-53.6100	14 May 2007 01:12	17
L3_12	48	55.8400	-53.3900	14 May 2007 06:09	1
L3_13	54	56.1200	-53.1000	14 May 2007 11:27	1
L3_14	64	56.5100	-52.7000	14 May 2007 19:32	22
L3_15	74	56.9600	-52.2300	15 May 2007 02:31	1
L3_16	83	57.3800	-51.7900	15 May 2007 08:33	1
L3_17	97	57.8000	-51.3400	15 May 2007 15:12	21
L3_18	112	58.2200	-50.8800	15 May 2007 21:58	1
L3_19	123	58.6400	-50.4200	16 May 2007 03:47	1
L3_20	133	59.0600	-49.9400	16 May 2007 09:31	20
L3_21	146	59.4800	-49.4700	16 May 2007 16:36	1
L3_22	154	59.7500	-49.1700	16 May 2007 21:06	1
L3_23	160	59.9800	-48.8900	17 May 2007 01:37	19
L3_24	172	60.1800	-48.6800	17 May 2007 11:51	1
L3_27	175	60.4500	-48.3600	17 May 2007 16:33	1
L3_26	179	60.4400	-48.6500	17 May 2007 19:19	1
L2_06.5	222	58.0900	-56.0300	20 May 2007 21:12	18
HL_09	241	42.2400	-61.2000	26 May 2007 00:06	8
HL_08	245	42.3800	-61.3000	26 May 2007 05:50	4
HL_10	228	42.0300	-61.0600	25 May 2007 02:22	9
HL_11	233	41.7800	-60.9100	25 May 2007 08:16	6

Table A.4.1.1 Iodine 129-related operations on HUD2007011/1.

c. Inert Gas Sampling Program — Roberta Hamme

Water samples were collected for dissolved inert gases at five stations along the L3 (AR7W) line (Table A.4.1.2, see also Figure A.4.2.2) with the aim of sampling the core of the different water masses in the area (LSWnew, LSW2000, LSW1994, surface, DSOW, NEADW, and ISW). See attached table for cast and sample numbers. The usual sampling order for these bottles was CFCs, DOC, oxygen, inert gases, DIC etc... The Niskins were sampled out of the usual order of deepest first, so that the deepest Niskin that inert gases would be collected from was sampled first, then other non inert gas Niskins were sampled until the next inert gas Niskin was ready to be sampled. In this way, the time the water in the Niskin was exposed to a headspace before the inert gas samples were drawn was reduced as much as possible. These samples will be analyzed for dissolved Ar, Kr, Xe and N2 using an isotope dilution IRMS method (Hamme & Severinghaus, 2007). The goal of this work is to quantify the physically-driven disequilibrium of gases during water mass formation. Theoretical work and samples from the deep Pacific suggest that these gases (as well as CO2, O2, CFCs, etc.) can not maintain equilibrium with the atmosphere during the rapid cooling and high wind speeds driving bubble-mediated gas exchange that occur during convective episodes. It is our intention to sample for these gases in multiple years to study interannual variability in this disequilibrium.

Station	Event	ID	Latitude	Longitude	Time	Pressure dbar
L3_14	64	309687	56.5092	-52.7035	14/05/2007 19:32	1068
L3_14	64	309686	56.5092	-52.7035	14/05/2007 19:32	1280
L3_14	64	309684	56.5092	-52.7035	14/05/2007 19:32	1731
L3_14	64	309683	56.5092	-52.7035	14/05/2007 19:32	1971
L3_14	64	309682	56.5092	-52.7035	14/05/2007 19:32	2213
L3_15	74	309716	56.9565	-52.2267	15/05/2007 02:31	239
L3_15	74	309715	56.9565	-52.2267	15/05/2007 02:31	361
L3_15	74	309714	56.9565	-52.2267	15/05/2007 02:31	510
L3_15	74	309712	56.9565	-52.2267	15/05/2007 02:31	870
L3_16	83	309744	57.3765	-51.7931	15/05/2007 08:33	3
L3_16	83	309743	57.3765	-51.7931	15/05/2007 08:33	35
L3_16	83	309741	57.3765	-51.7931	15/05/2007 08:33	140
L3_22	154	309898	59.7517	-49.1706	16/05/2007 21:06	2460
L3_22	154	309897	59.7517	-49.1706	16/05/2007 21:06	2620
L3_22	154	309896	59.7517	-49.1706	16/05/2007 21:06	2770
L3_22	154	309892	59.7517	-49.1706	16/05/2007 21:06	3199
L3_22	154	309891	59.7517	-49.1706	16/05/2007 21:06	3259
L3_24	172	309957	60.1767	-48.6792	17/05/2007 11:51	240
L3_24	172	309956	60.1767	-48.6792	17/05/2007 11:51	338
L3_24	172	309955	60.1767	-48.6792	17/05/2007 11:51	460

Table A.4.1.2 Inert gas sampling on HUD2007011/1.

4.2 Biological Program

a. Narrative

The biological program conducted as part of cruise 2007011, with some modifications, was a continuation of studies began in 1994 to describe the large-scale (spatial and temporal) variability in plankton biomass, productivity and biogenic carbon inventories in the Labrador Sea.

The program has consisted of essentially four elements:

1. a phytoplankton biomass/primary productivity program conducted by Jeff Anning (for Glen Harrison),

2. a microbial program conducted by Tim Perry (for Bill Li),

3. a mesozooplankton program (Erica Head), and

4. a dissolved organic carbon program conducted by Jay Bugden (for Paul Kepkay)

The ultimate aim of these studies is twofold:

1. to provide a description of the inventories in and export of biogenic carbon from the Labrador Sea, their turnover rates and variability in space and time as part of Ecosystem Research Division's (ERD) continuing climate studies and

2. to provide a description of plankton life-cycles and productivity in the Labrador Sea and its influence or contribution to ecosystems downstream in support of ERD's ecosystem-related research.

In addition to the Labrador Sea study, phytoplankton, mesozooplankton and nutrient samples were collected along the extended Halifax Section in support of ERD/OSD obligations to the Atlantic Zone Monitoring Program (AZMP) and the new climate component.

A pelagic bird survey was carried out by Carina Gjerdrum, Wildlife Biologist - Seabird Issues with Environment Canada's Canadian Wildlife Service (Dartmouth, NS) supporting CWS's work on seabird issues. The goal of this survey was to gather data on the offshore distribution and abundance of marine birds in order to identify and minimize the impacts of human activities at sea on birds. These data will provide critical, and currently unavailable, information for environmental assessments for offshore developments, and will help identify areas where birds are at high risk from oil pollution, and other human activities.

b. Zooplankton Sampling — L. Harris / E. Head

The zooplankton sampling is part of an ongoing program, the aim of which is to investigate the distribution, abundance and life history of the major zooplankton groups found in the Labrador Sea and its associated shelf systems. Particular emphasis is placed on the copepod species of the Calanus genus, which dominate the zooplankton in this region.

A total of 78 vertical ring net tows were taken at 40 stations (Figure A.4.2.1) (Station 27, Transit_01, 25 on the L3 line including two occupations of L3_11 separated in time by about one week, 11 on the L3 line, and 2 on the Halifax Line). Tows were made from 100 meters to the surface using a 0.75 m diameter 200 µm-mesh □ring net at 40 stations and a 0.33 m diameter 76 µm-mesh ring net at 38 stations. At Station 27 and on the Halifax Line tows were from the bottom to the surface. See Table A.4.2.1 below for net event numbers.

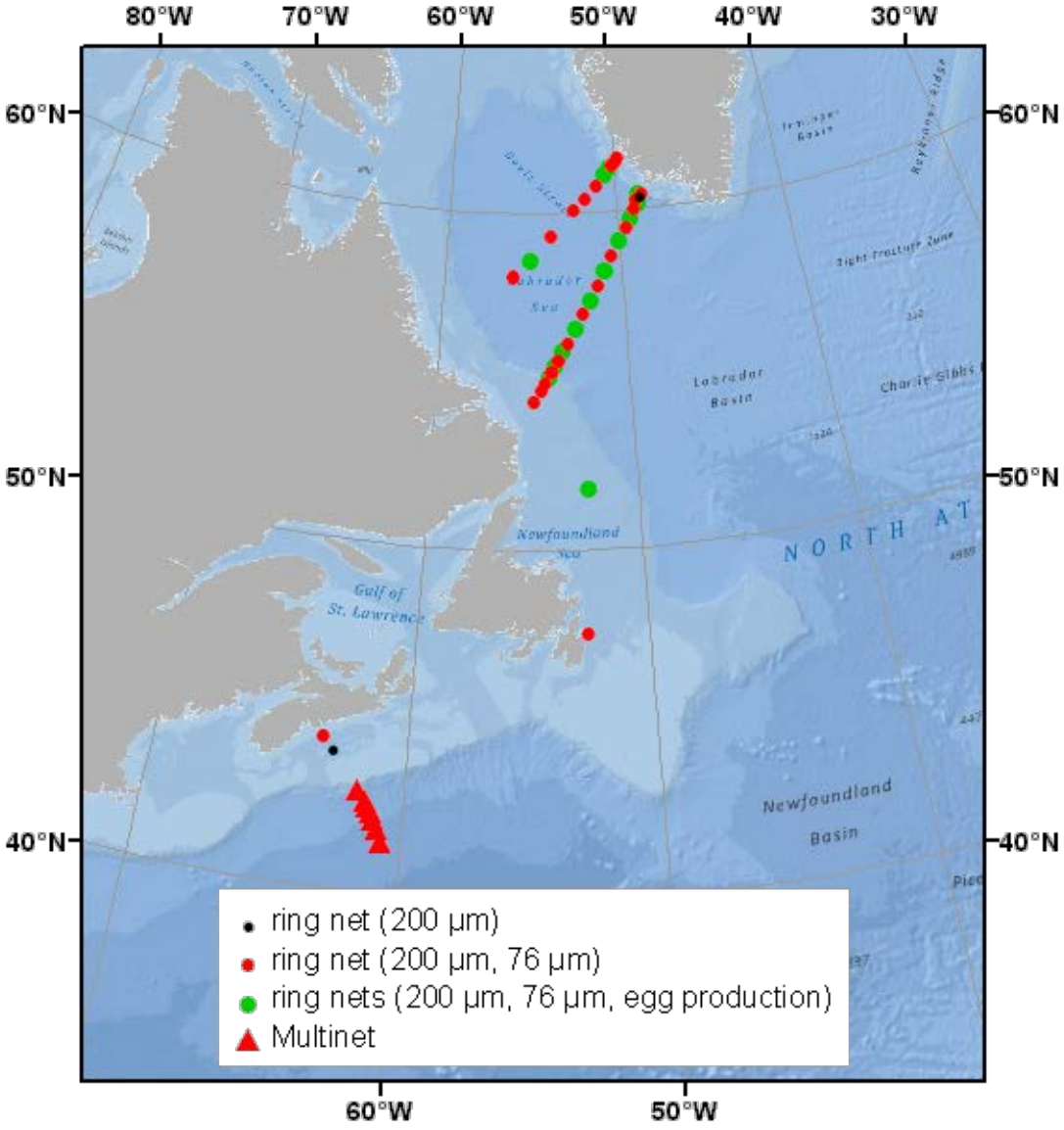

Figure A.4.2.1 HUD2007011/1 ring net (circles) and multi-net (red triangles) locations.

Station	Ring Net 200µ	Ring Net 76µ	Egg Production	Multi-Net 200µ
STN27	Y	Y		
Transit_01	Y	Y	Y	
L3_08	Y	Y	Y	
L3_04.5	Y	Y		
L3_06	Y	Y		
L3_07	Y	Y		
L3_09b	Y	Y		
L3_10b	Y	Y	Y	
L3_11b	Y	Y		
L3_12b	Y	Y	Y	
L3_13b	Y	Y		
L3_14b	Y	Y	Y	
L3_15b	Y	Y		
L3_16b	Y	Y	Y	
L3_17b	Y	Y		
L3_18	Y	Y	Y	
L3_19	Y	Y		
L3_20	Y	Y	Y	
L3_21	Y	Y		
L3_22	Y	Y	Y	
L3_23	Y	Y		
L3_25.7	Y			
L3_24	Y	Y	Y	
L3_27	Y	Y		
L3_26	Y	Y	Y	
L3_25	Y	Y		
L2_20	Y	Y		
L2_19a	Y	Y		
L2_19	Y	Y		
L2_18	Y	Y	Y	
L2_15.5	Y	Y	Y	
L2_14	Y	Y		
L2_13	Y	Y		
L2_12	Y	Y		
L2_10	Y	Y		
L2_08	Y	Y	Y	
L2_06.5	Y	Y		
L3_11b2	Y	Y		
HL_10b				Y
HL_11b				Y
HL_12b				Y
HL_09b				Y
HL_08b				Y
HL_07b				Y
HL_06b				Y
HL_03b	Y			
HL_02b	Y	Y		

Table A.4.2.1 Net-related operations on 18HU2007011/1.

c. Measurements of Copepod Reproduction Rates — L. Harris / E. Head

Egg production rates of Calanus finmarchicus, the dominant copepod species, were measured at 10 stations on the L3 Line, 3 stations on the L2 Line and at the Transit_01 station. See Figure A.4.2.1 and Table A.4.2.1 above.

d. Depth Distribution of Calanus finmarchicus in the Slope Water off the Scotian Shelf — L. Harris / E. Head

The vertical depth distribution of *Calanus finmarchicus* in the Slope Water off the Scotian Shelf was investigated. At 7 stations, HL 6-12, five depth strata (1000–800, 800–600, 600–400, 400–200, 200–0 m) were sampled using a square 0.5 x 0.5 m multi-net fitted with five 200 μm-mesh nets. See Figure A.4.2.1 and Table A.4.2.1 above.

e. Total Organic Carbon — Jay Bugden / Paul Kepkay

In order to better understand the cycling of carbon in the Labrador Sea, it is necessary to examine the pool of total organic carbon (TOC). Obtaining a profile of TOC concentration in the water column can help determine the fate of organic carbon. Elevated concentrations of TOC at depth are indicative of transport of carbon to the deep ocean, which basically removes it from the effects of biological re-mineralization. This can result in the long term storage of organic carbon in the deep ocean. Such information can be applied to models that track the fate of carbon in the environment and its potential effects on climate change.

During CCGS Hudson cruise 2007011 TOC depth profiles were collected from stations of the AR7W line as indicated in Table A.4.2.2 below.

Station	TOC Profile
AR7W site 1	Not sampled due to ice
AR7W site 2	Not sampled due to ice
AR7W site 3	Not sampled due to ice
AR7W site 4	Not sampled due to ice
AR7W site 4.5	X
AR7W site 5	X
AR7W site 6	X
AR7W site 7	X
AR7W site 8	X
AR7W site 9	X
AR7W site 10	X
AR7W site 11	X
AR7W site 12	X
AR7W site 13	X
AR7W site 14	X
AR7W site 15	X
AR7W site 16	X
AR7W site 17	X
AR7W site 18	X
AR7W site 19	X
AR7W site 20	X
AR7W site 21	X
AR7W site 22	X
AR7W site 23	X
AR7W site 24	X
AR7W site 25	X
AR7W site 26	X
AR7W site 27	X
AR7W site 28	Not sampled due to ice

Table A.4.2.2 TOC sampling on 18HU2007011/1.

f. Primary Production Measurements — Jeff Anning

Water samples for photosynthesis-irradiance (P-I) experiments were collected from the rosette at 12 stations (Table A.4.2.3). For each incubation experiment, 33 aliquots were inoculated with 14C labelled sodium bicarbonate and then incubated at in situ temperatures at 30 light levels (+ 3 dark bottles) for approximately 3 hours. At the end of the incubation period the cells were harvested onto GF/F glass fibre filters for later counting in a scintillation counter. On one occasions (L2-12), a parallel P-I incubation from a single depth was done using the stable isotopes 13C/15N instead of the radioisotope, for comparison. Duplicate chlorophyll, duplicate particulate organic carbon, one HPLC, and one Absorption Spectra sample were collected for each incubation experiment.

Station	Event	Lat.	Long.	Date	Time	Depth	ID
Transit_02	9	52.282	-52.557	May 11 2007	16:12	1	309450
Transit_02	9	52.282	-52.557	May 11 2007	16:12	30	309446
L3_4.5	16	54.350	-54.867	May 12 2007	15:11	1	309490
L3_10b	35	55.417	-53.817	May 13 2007	19:16	1	309564
L3_10b	35	55.417	-53.817	May 13 2007	19:16	30	309560
L3_14b	63	56.500	-52.700	May 14 2007	18:57	1	309671
L3_14b	63	56.500	-52.700	May 14 2007	18:57	30	309667
L3_17b	96	57.800	-51.334	May 15 2007	14:36	1	309756
L3_17b	96	57.800	-51.334	May 15 2007	14:36	30	309752
L3_21b	145	59.467	-49.467	May 16 2007	15:57	1	309862
L3_21b	145	59.467	-49.467	May 16 2007	15:57	30	309866
L3_24	172	60.167	-48.667	May 17 2007	13:43	1	309961
L3_27	175	60.433	-48.350	May 17 2007	16:49	1	309974
L3_27	175	60.433	-48.350	May 17 2007	16:49	30	309978
L2_19	192	61.367	-50.000	May 18 2007	13:37	1	310051
L2_19	192	61.367	-50.000	May 18 2007	13:37	30	310055
L2_12b	210	60.050	-52.450	May 19 2007	14:16	1	310153
L2_12b	210	60.050	-52.450	May 19 2007	14:16	30	310157
L2_08b	218	58.583	-55.117	May 20 2007	14:05	1	310219
L3_11	225	55.600	-53.617	May 21 2007	13:06	1	310276
L3_11	225	55.600	-53.617	May 21 2007	13:06	30	310280

Table A.4.2.3 Photosynthesis/Irradiance incubations conducted on 18HU2007011/1.

g. Bacterial Abundance and Production of Microbial Plankton Tim Perry / Glen Harrison

At every depth at every station on the L3 line and stations sampled on the HL line a sample was collected for bacterial counting by flow cytometry. On the L2 line a surface sample was collected for the stations sampled.

Water samples were collected from all depths at 7 stations on the L3 line and incubated for between 3–24 hours after inoculation with 3H-labelled leucine (Table A.4.2.4). The cells were collected by centrifugation and prepared for scintillation counting back on shore.

Station	Event	Lat.	Long.	Date	Time
L3-24	36	60.1984	-48.7379	May 20 2007	04:39
L3-27	45	60.4459	-48.3736	May 21 2007	18:04
L3-18	94	58.2306	-50.8711	May 22 2007	04:50
L3-14	135	56.5711	-52.6720	May 24 2007	22:55
L3-11	163	55.5882	-53.6434	May 25 2007	16:50
L3-7.5	174	55.0521	-54.1364	May 25 2007	00:12
L3-08	177	55.0977	-54.0867	May 25 2007	03:08

Table A.4.2.4 Microbial production incubations were conducted at the above stations.

h. Stable Isotope Studies of Carbon and Nitrogen (nitrate and ammonium) Utilization by Phytoplankton

Glen Harrison

This work represents a continuation of research begun in 1994 to determine the primary productivity (in terms of carbon and nitrogen) of phytoplankton in the Labrador Sea. On this particular mission, stations were selected along the L3 and L2 lines to determine productivity inside and outside of the high phytoplankton biomass zone (determined from satellite ocean colour) off the coast of Greenland (Figure A.4.2.2).

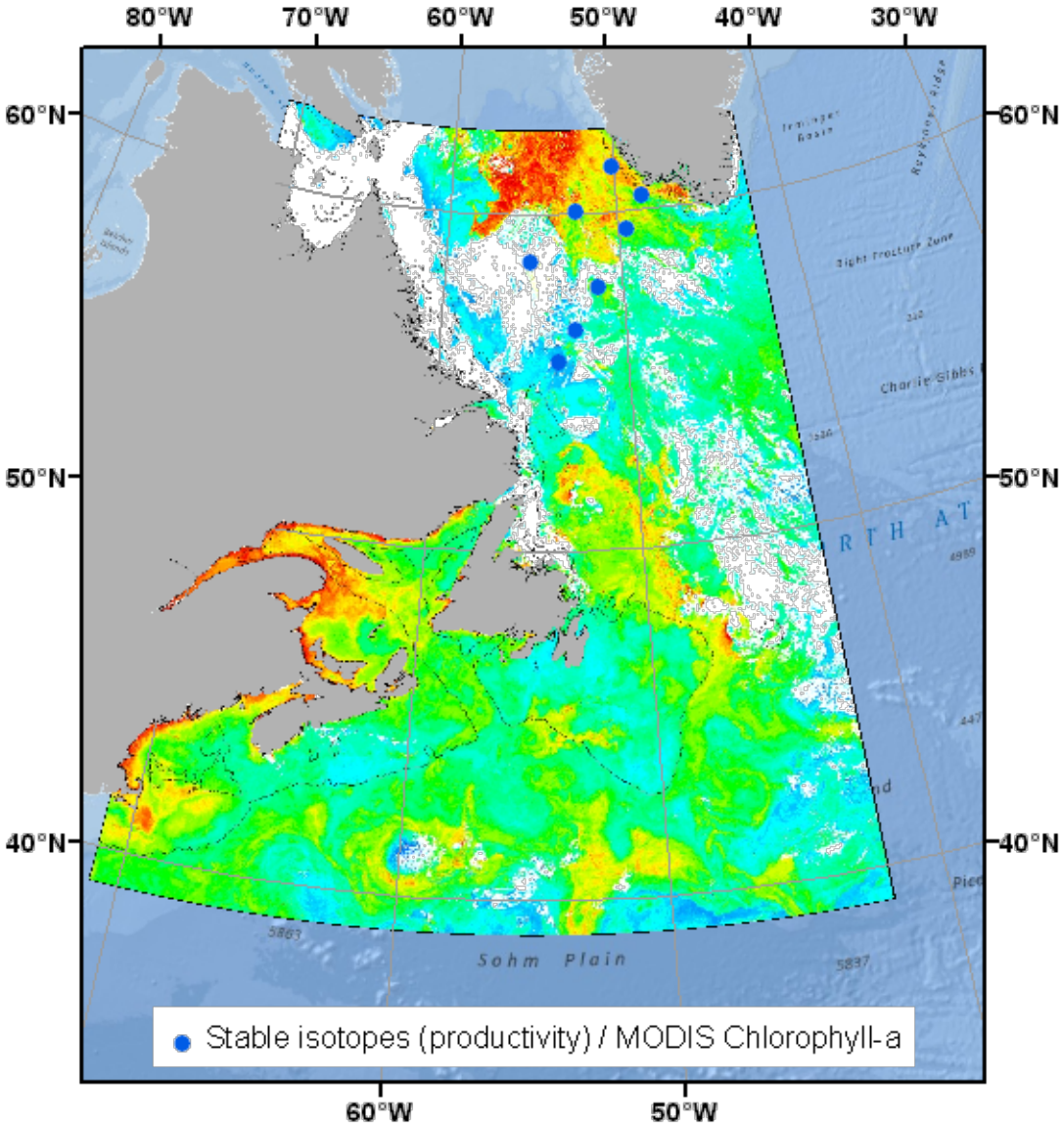

Figure A.4.2.2 Stable isotope productivity stations (filled blue circles) and surface chlorophyll concentrations from a composite 1–15 May 2007 MODIS satellite ocean colour image.

Carbon dioxide (CO_2), nitrate (NO_3), and ammonium (NH_4) utilization rates from eight depths in the photic zone (i.e. the 1% light level ranging from 25–60 m) were determined using stable isotope tracer (^{13}C and ^{15}N) methods. Incubation experiments were carried out in on-deck "simulated in-situ" incubators. A total of 8 experiments were conducted (Table A.4.2.5). In

addition to isotope tracer experiments, particulate organic matter (nitrogen and carbon) were determined at the productivity depths, samples were collected in surface waters for determination of natural C and N isotope abundance, and ammonium concentrations were measured at 11 depths in the upper 200 m.

Date	Site	Event	Photic Depth (m)	*15*N / *13*C	POC / PON
14 May 2007	L3_14	63	50	x	x
15 May 2007	L3_17	96	30	x	x
16 May 2007	L3_21	145	40	x	x
17 May 2007	L3_27	175	40	x	x
18 May 2007	L2_19	192	25	x	x
19 May 2007	L2_12	210	30	x	x
20 May 2007	L2_08	218	50	x	x
21 May 2007	L3_11	225	60	x	x

Table A.4.2.5 Stable isotope productivity stations on 18HU2007011/1.

i. Pelagic bird survey — Carina Gjerdrum

Background

Our primary objective for the pelagic monitoring program is to map the relative abundance and distribution of pelagic birds in Atlantic Canada. We rely on ships-of-opportunity to carry seabird observers to offshore areas throughout the region, and prioritise areas that can be surveyed across multiple seasons and years. These data will provide critical, and currently unavailable, information for environmental assessments for offshore developments, help identify areas where birds are at high risk for oil pollution and other human activities, identify critical marine habitat, and allow us to monitor trends in abundance and distribution of marine birds.

Protocol

The main objective of our protocol is to ensure that observers conducting surveys at sea from a moving platform are recording data in a consistent, unbiased fashion that permit subsequent conversion into seabird densities. This protocol is consistent with methods used elsewhere in the world, making these data comparable to other geographic areas.

Surveys are conducted while looking forward from the bridge, scanning ahead to a 90o angle from either the port or starboard side, limiting observations to a transect band 300 m wide from the side of the platform. A survey consists of a series of ten-minute observation periods, which are exclusively dedicated to detecting birds at sea. We conduct as many consecutive ten-minute observation periods as possible, regardless if birds are present or not, and try to ensure consistent coverage throughout the day. Observations can only be conducted when the platform is travelling at a minimum speed of 4 kt (7.4 km/h) and a maximum of 19 kt (35.2 km/h). We do not conduct observations when visibility is poor (i.e., when the entire width of the 300 m transect is not visible due to rain or fog).

We scan the transect continuously by eye, to count and identify birds present in air or on water. Binoculars are used to confirm the species identification, and other details, such as age, moult, carrying fish, etc. We continuously record all birds observed on the sea surface throughout the ten-minute period, and estimate their distance from the platform. Flying birds are not recorded continuously throughout the 10-minute period, as this would overestimate bird density. Instead, we record flying birds using instantaneous counts, or “snapshots”, at regular intervals throughout the observation period. The number of snapshots conducted depends on the speed of the platform.

General results

From 9–27 May, 479 ten-minute observation periods were conducted from the bridge of the CCG Hudson. During this time, I counted 3031 birds from 7 different families (Table A.4.2.6). In general, birds were widely distributed throughout the survey area, although higher densities occurred within 120nm off the east and southeast coast of Newfoundland (Figure A.4.2.3).

Family	Species		Number observed
Procellariidae	Northern Fulmar	*Fulmarus glacialis*	455
	Sooty Shearwater	*Puffinus griseus*	8
	Greater Shearwater	*P. gravis*	239
	Manx Shearwater	*P. puffinus*	1
Hydrobatidae	Leach's Storm-petrel	*Oceanodroma leucorhoa*	819
	Wilson's Storm-petrel	*Oceanites oceanicus*	5
	Unknown Storm-petrel	*Oceanodroma* or *Oceanites*	22
Sulidae	Northern Gannet	*Morus bassanus*	29
Anatidae	Unknown duck		1
Scolopacidae	Red-necked Phalarope	*Phalaropus lobatus*	3
	Red Phalarope	*P.fulicaria*	6
Laridae	Long-tailed Jaeger	*Stercorarius longicaudus*	1
	Parasitic Jaeger	*S. parasiticus*	4
	Pomarine Jaeger	*S. pomarinus*	7
	Unknown Jaeger	*Stercorarius* spp.	1
	Unknown Skua	*Catharacta* spp.	1
	Unknown Tern	*Sterna* spp.	3
	Sabine's Gull	*Xema*	4
	Herring Gull	*Larus argentatus*	24
	Iceland Gull	*L. glaucoides*	15
	Glaucous Gull	*L. hyperboreus*	11
	Lesser Black-backed Gull	*L. fuscus*	1
	Great Black-backed Gull	*L. marinus*	11
	Black-legged Kittiwake	*Rissa trydactyla*	161
	Unknown Gull	*Larus* spp.	1
Alcidae	Dovekie	*Alle alle*	207
	Black Guillemot	*Cepphus grylle*	3
	Thick-billed Murre	*Uria lomvia*	372
	Common Murre	*U. aalge*	211
	Unknown Murre	*Uria* spp.	118
	Razorbill	*Alca torda*	11
	Atlantic Puffin	*Fratercula arctica*	256
	Unknown Alcidae	Alcidae	7
Unknown songbirds			13
Total number observed within transect			**3031**

Table A.4.2.6 Numbers of birds observed within the 300 m-wide transect during the spring 2007 Labrador Sea survey.

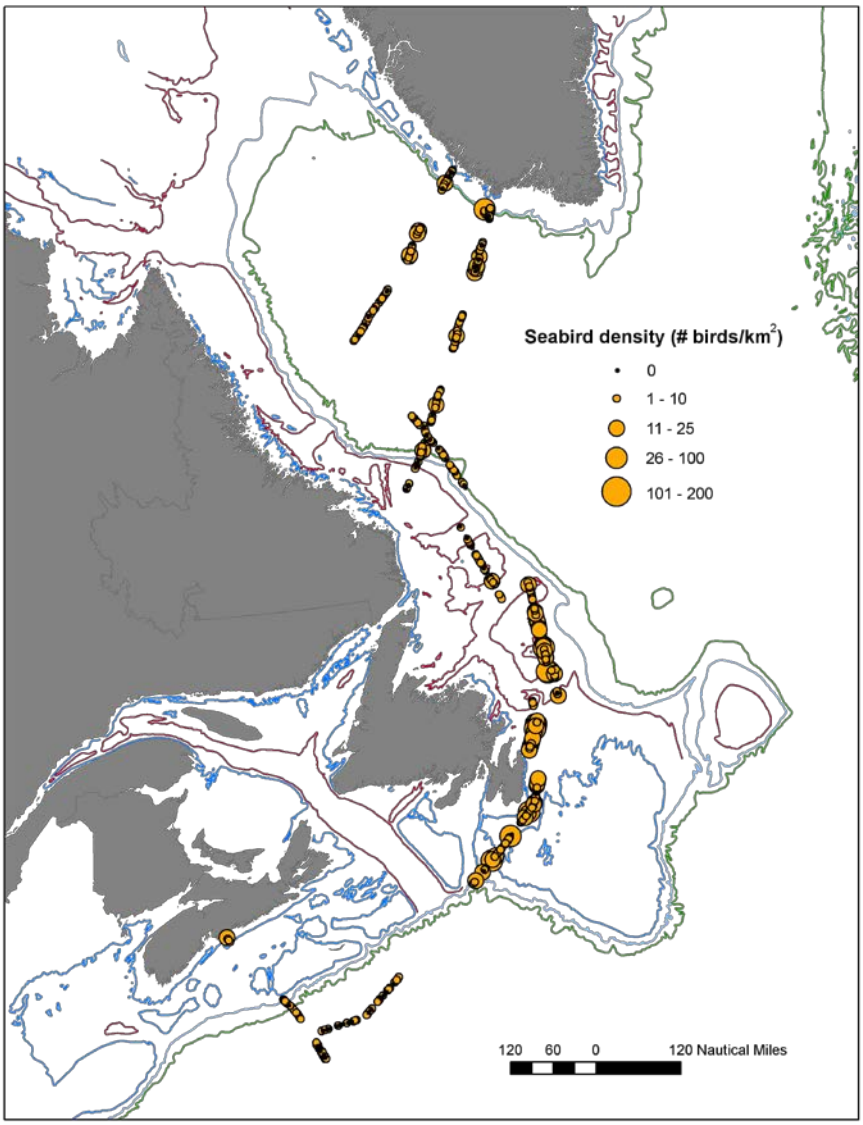

Figure A.4.2.3 Bird densities (number of birds/km^2) observed during spring 2007 Labrador Sea surveys.

Species from the family Alcidae (Auks) were the most abundant group observed (39%), 59% of which were murres. Thick-billed Murres were seen on the Grand Banks of Newfoundland and on both crossings of the Labrador Sea, compared to Common Murres, which were only observed off Newfoundland. Atlantic Puffins were also abundant off the coast of Newfoundland, close to breeding colonies. Dovekie were most common in the Labrador Sea, although small numbers were also observed south of the Avalon Peninsula.

Northern Fulmar were observed throughout the survey area and were common ship-followers on the Labrador Sea transects, where as many as 1500 were counted around the vessel at one time. Greater Shearwaters were only observed south of Newfoundland where they have recently arrived from their breeding grounds in the southern hemisphere. Leach's Storm-petrels were especially numerous off the northeast coast of Newfoundland in an area with relatively high amounts of drift ice. Black-legged Kittiwakes were the most commonly encountered gull in the

survey, and often followed the vessel with the fulmars. Arctic-breeding gulls such as Iceland, Sabine's, and Glaucous Gulls were also encountered.

Acknowledgements

Our work could not occur without the generous support of DFO scientists and staff, and the Coast Guard officers and personnel. Thank you for giving me the opportunity to join this cruise.

5. Major Problems and Goals Not Achieved

No major problems were encountered on Hudson 2007011. Reasonable weather conditions and equipment performance allowed all primary scientific goals to be met. Ice conditions prevented access to the four most inshore AR7W station positions on the Labrador Shelf and the most inshore AR7W station on the West Greenland Shelf. Weather conditions on the L2 line limited steaming speed, resulting in reduced sampling relative to the initial plan in order to protect higher priority Halifax Line stations.

6. Other Incidents of Note

No major science equipment problems were encountered. Minor delays were associated with:

1. electrical failures of the CTD cable that required replacement of the connector at the sea unit end and two reterminations, including one mechanical retermination

2. repairs of the Woods Hole Oceanographic Institution Lowered Acoustic Doppler Current Profiler deployed with our CTD package

3. difficulties with the Interocean winch on the foredeck used for multinet tows. Some of the guide rollers on the winch were seized and sustained damage due to chafing of the cable before the problem was identified and allowances made. The damaged rollers need to be replaced as part of a general maintenance service.

Problems with instrumented blocks appeared late in the mission. The sheave in the block used for foredeck deployments of the multinet seized at site HL_8 after four deployments on the offshore Halifax Line. The spare block/sheave then used for CTD deployments from the Winch Room caused problems beginning at site HL_12. Flexing or vibration of the block caused the set screws holding the flanges of the sheave together to back out and rub against the arms of the block. The cast had to be stopped at several points on the up cast to reseat the set screws. After the station the bearing of this sheave was found to be running rough. A replacement sheave installed in the same block for the following station at site HL_9. developed identical problems at site HL_7. At the end of this station, the block taken out of service on the multinet was combined with a third replacement sheave. At the following station at site HL_6.5, the same problem with backing out of the set screws presented itself. The screws were reseated after applying sealing compound and the same block and sheave served well for the remaining relatively shallow stations. These issues should be reviewed on shore. There is no explicit life-cycle management of our instrumented blocks and this may be part of the issue.

A failure of the power supply for the lower deck branch of the ship's network meant that the GP Laboratory lost network connectivity. Normal operations depend on two-way communication between the GP Laboratory and the Computer Laboratory for information on operational status and data transfer, but the failure late in the mission was inconvenient rather than critical.

Latency in network communication made it impractical to maintain real-time access to a networked science data base to record and distribute metadata. An upgrade in network speed from 10 Mbit/sec to 100 Mbit/sec might alleviate this issue.

7. List of Cruise Participants

Name	Responsibility	Affiliation
Jeffrey Anning	Primary production	OSD, BIO
Carol Anstey	Nutrients, Oxygen	ERD, BIO
Kumiko Azetsu-Scott	Inorganic Carbon and CFC program, Inorganic Carbon	OSD, BIO
Richard Boyce	Salinity, Moorings	OSD, BIO
John (Jay) Bugden	Total Organic Carbon	ERD, BIO
Michael Dunphy	CTD, XBT	Evans Computer
Eva Falck	Oxygen	University of Bergen
Carina Gjerdrum	Sea bird observer	CWS, EC
Roberta Hamme	Inert Gases	University of Victoria
Leslie Harris	Zooplankton	ERD, BIO
Glen Harrison	Biology program, Associate Chief Scientist	ERD, BIO
Adam Hartling	VMADCP, ADU5, CTD	OSD, BIO
Ross Hendry	Chief Scientist	OSD, BIO
Jeffrey Jackson	Data management, CTD	OSD, BIO
Richard Nelson	CFCs	ERD, BIO
Timothy Perry	Bacteria	ERD, BIO
Clark Richards	CTD, XBT	Dalhousie University
Brian Robinson	Inorganic Carbon	BDR
Robert Ryan	CTD maintenance, CTD	OSD, BIO
David Slauenwhite	CFCs	BDR
Jorge Urrego Blanco	CTD, XBT	KNMI
Igor Yashayaev	XBT program, CTD, XBT	OSD, BIO

BIO	Bedford Institute of Oceanography PO Box 1006, Dartmouth, NS, Canada, B2Y 2A4
BDR	BDR Research Ltd. Box 652, Station 'M', Halifax, NS, Canada, B3J 2T3
EC, CWS	Environment Canada, Canadian Wildlife Service 45 Alderney Drive, Dartmouth, NS, Canada, B2Y 2N6
ERD, BIO	Ecosystem Research Division, Fisheries and Oceans Canada, BIO
Evans Computer	Evans Computer Applications Limited 6424 Norwood Street Halifax, NS, Canada B3H 2L3
KNMI	Royal Netherlands Meteorological Institute PO Box 201, 3730 AE De Bilt, The Netherlands
OSD, BIO	Ocean Sciences Division, Fisheries and Oceans Canada, BIO
University of Victoria	School of Earth and Ocean Sciences, University of Victoria PO Box 3055 Stn CSC, Victoria, BC, Canada V8W 3P6

B. UNDERWAY MEASUREMENTS

1. Navigation and Bathymetry — Jeff Jackson

The primary Science navigation aid on HUD2007011 was the Ashtech ADU5 attitude determination and real-time differential GPS system (Section B.5). NMEA strings were broadcast at approximately 0.6-second intervals on a multiplexed serial data stream originating at a PC on the bridge and available at distribution units throughout the ship. Other navigation aids included the ship's Sperry SRD-31 Doppler Speed Log and dual Raytheon Anschütz Marine Standard 20 Gyro Compass Systems whose NMEA strings were broadcast at approximately 1-second intervals.

AGCNAV is a PC-based display and waypoint setting software package, developed at the Atlantic Geoscience Centre [now Geological Survey of Canada (Atlantic)] at BIO. This software graphically displays ship position, waypoints, course, speed, etc. at the various science working areas. This has been the standard software package for years now and we used it again on this mission.

New to the navigation acquisition arena is the Geological Survey of Canada (GSC) Survey Suite navigational software. This is a Microsoft Windows-based package which grabs every NMEA string broadcast over the network and adds a date/time stamp to every data record acquired. It was tested on this cruise and it seemed to work without any problems. It is easier to configure and operate than AGCNAV. The only negative observation that can be made is that it does not have a waypoint viewer.

Raytheon PTR Dual Frequency Sounders (10 kHz/12 kHz) and Raytheon Line Scan Recorders were sited in the Winch Room and Forward Laboratory for the science program. The sounders were connected to Hudson's ram-mounted transducer which has a 15° beam width. The transducer offset is 6 m with the ram up and 8 m with the ram down. The Winch Room system was operated in 12 kHz mode at station locations to collect bathymetric data and display the output of the acoustic beacon mounted on the CTD package frame. The sweep rate of the recorder was adjusted throughout the course of data collection to aid in identifying the bottom signal. These sounders do not provide digital output.

Output from the ship's ELAC LAZ 4420 dual-frequency navigation echo sounder was logged with the other navigation data. This system was operated from the bridge by the officer of the watch as a ship's navigation aid and is normally set to 30 kHz. We had requested that it be operated in 12 kHz mode when this did not interfere with normal ship's operations. Unfortunately we did not establish an explicit protocol for logging changes in system configuration and so had to diagnose the operating mode after the fact. In high-frequency mode the ELAC sounder lost bottom at depths greater than about 400 m while underway at normal cruising speeds, but provided useful bottom information in 1000-m water depths during a reduced-speed post-mooring-deployment survey. The system is not powered for deep-sea sounding and performance was very dependant on sea state. Incomplete notes indicate a switch to 12 kHz on the morning of 15 May 2012, after which intermittent coherent bottom traces were recorded in 3500 m depths. In ideal conditions during the transit from the end of the L2 line to

the southern Labrador slope on 21 May 2012 clean bottom traces were returned from 3000 m depths. The system appears to have been changed to high-frequency mode late on 21 May 2012 as the ship entered water depths less than 2000 m over the Labrador slope. Low-frequency mode was apparently used from early on 24 May 2012 to mid-afternoon on 26 May 2012 when the ship was transiting deeper waters en route to the offshore end of the Halifax Line, but no useful bottom information was received during this period. High-high-frequency mode was apparently used for the remained of the mission.

2. Vessel Mounted Acoustic Doppler Current Profiler Adam Hartling

Hudson is equipped with a Teledyne RDI Ocean Surveyor II vessel mounted acoustic Doppler current profiler (ADCP) system consisting of a 75 kHz phased array transducer assembly mounted in a well in the ship's hull and a deck unit and computer located in the forward lab.

The transducer assembly is mounted on a ram penetrating the ships hull that can be lowered if necessary. The transducer remained in the retracted position for the duration of the cruise. It was determined during sea acceptance testing that lowering the transducer did not effect the operation of the system. The transducer is located approximately 6 m below the waterline.

The system is capable of collecting bottom-track data to 1000 m and profile data to 650 m. Setup includes 100 8-m bins. The Ocean Surveyor was set to operate in the narrow-band single ping mode with 3 s ensemble time. Position, heading, pitch and roll data are provided by the ADU5 attitude determination unit at a 1 Hz rate. Ships gyro heading data are connected directly to the OSII deck unit. The Ocean Surveyor also includes a temperature sensor for sound speed calculations.

The WinADCP software package is used monitor profile data in real time. WinADCP is set to display time series of short-term averaged profile and attitude data. The VmDas software package is used to deploy the OSII and log raw data, VmDas option files, and intermediate and processed files. Data are backed-up on an external hard-drive. The data back-up includes only raw data and VmDas option files.

All NMEA strings are logged during data collection. The gyro heading is included with the raw data. Raw data are processed in real time for a short-term average of 30 s and a long-term average of 300 s.

The data will have to be reprocessed using gyro heading during periods with low quality or no attitude solution. Raw data can be reprocessed using VmDas.

A significant increase in the noise floor is caused by bow thrusters while on station, during high sea states, or during travel at speeds in excess of 12 kt in rough conditions. The increase in noise floor results in a significant decrease in data quality and reduction in profile range.

3. Continuous Flow Multisensor Package (CFMP) Jeff Anning

Water from approximately 4 m was continuously pumped to the forward lab. The temperature, conductivity and fluorescence were measured and logged every 30 s. The temperature and

conductivity were measured with Sea-Bird sensors and the fluorescence by a WET Labs flow-through fluorometer. Incident Photosynthetically Active Radiation was measured with a Li-Cor Spherical Quantum Sensor and these data were merged with the sea water parameters. Exact time and positions were provided by the ship's GPS and logged with the other data.

4. XBT measurements — Igor Yashayaev

A total of 94 Expendable Bathythermographs (XBT) were deployed on the mission (Figure B.4.1.1). Deployment details are provided in Table B.4.1.1.

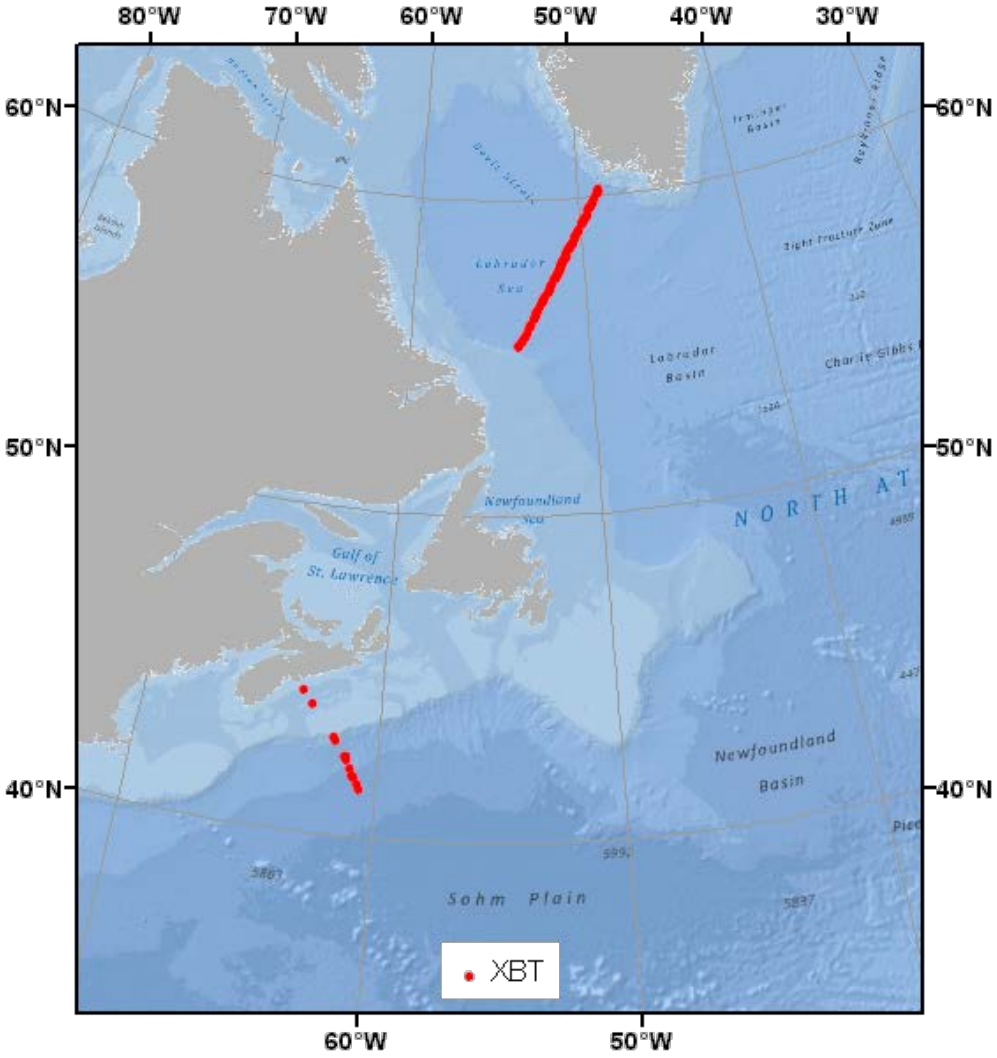

Figure B.4.1.1 XBT deployments during HUD2007011/1.

Event	Station	Latitude	Longitude	Time
30	L3_09-10	55.3193	-53.9309	13 May 2007 17:35
31	L3_09-10	55.3605	-53.8961	13 May 2007 17:48
37	L3_10-11	55.4613	-53.7383	13 May 2007 22:43
38	L3_10-11	55.5028	-53.6847	13 May 2007 23:31
39	L3_10-11	55.5652	-53.6479	13 May 2007 23:59
43	L3_11-12	55.6735	-53.5157	14 May 2007 04:05
44	L3_11-12	55.7604	-53.4589	14 May 2007 04:41
49	L3_12-13	55.9125	-53.3036	14 May 2007 09:13
50	L3_12-13	55.9900	-53.2378	14 May 2007 09:49
51	L3_12-13	56.0355	-53.2031	14 May 2007 10:06
55	L3_13-14	56.1751	-53.0239	14 May 2007 15:32
56	L3_13-14	56.2546	-52.9668	14 May 2007 15:56
57	L3_13-14	56.3261	-52.9151	14 May 2007 16:18
58	L3_13-14	56.3992	-52.8590	14 May 2007 16:40
59	L3_13-14	56.4745	-52.7805	14 May 2007 17:03
66	L3_14-15	56.6056	-52.6120	14 May 2007 22:56
67	L3_14-15	56.6781	-52.5405	14 May 2007 23:36
68	L3_14-15	56.7454	-52.4683	15 May 2007 00:05
69	L3_14-15	56.7802	-52.4315	15 May 2007 00:15
70	L3_14-15	56.8162	-52.3946	15 May 2007 00:26
71	L3_14-15	56.8867	-52.3214	15 May 2007 00:48
75	L3_15-16	57.0321	-52.1515	15 May 2007 05:33
76	L3_15-16	57.0895	-52.1017	15 May 2007 06:01
77	L3_15-16	57.1472	-52.0493	15 May 2007 06:30
78	L3_15-16	57.2308	-51.9727	15 May 2007 06:55
79	L3_15-16	57.3130	-51.8973	15 May 2007 07:19
84	L3_16-17	57.4486	-51.7229	15 May 2007 11:37
85	L3_16-17	57.4689	-51.6973	15 May 2007 11:47
86	L3_16-17	57.5171	-51.6378	15 May 2007 12:10
87	L3_16-17	57.5583	-51.5936	15 May 2007 12:23
88	L3_16-17	57.5892	-51.5621	15 May 2007 12:32
89	L3_16-17	57.6242	-51.5269	15 May 2007 12:43
90	L3_16-17	57.6638	-51.4873	15 May 2007 12:54
91	L3_16-17	57.7029	-51.4477	15 May 2007 13:06
92	L3_16-17	57.7392	-51.4087	15 May 2007 13:16
93	L3_16-17	57.7729	-51.3691	15 May 2007 13:27
98	L3_18	57.8415	-51.3493	15 May 2007 18:14
99	L3_18	57.8806	-51.3115	15 May 2007 18:33
100	L3_18	57.9192	-51.2766	15 May 2007 18:52
101	L3_18	57.9557	-51.2428	15 May 2007 19:12
102	L3_18	58.0037	-51.1848	15 May 2007 19:27
103	L3_18	58.0186	-51.1648	15 May 2007 19:32
104	L3_18	58.0612	-51.1068	15 May 2007 19:46
105	L3_18	58.0958	-51.0584	15 May 2007 19:57
106	L3_18	58.1314	-51.0116	15 May 2007 20:08
107	L3_18	58.1548	-50.9827	15 May 2007 20:16
108	L3_18	58.1835	-50.9403	15 May 2007 20:25

(con'd)

Event	Station	Latitude	Longitude	Time
114	L3_18-19	58.2996	-50.8914	16 May 2007 00:59
115	L3_18-19	58.3715	-50.7839	16 May 2007 01:22
116	L3_18-19	58.3976	-50.7439	16 May 2007 01:31
117	L3_18-19	58.4378	-50.6816	16 May 2007 01:44
118	L3_18-19	58.5033	-50.5923	16 May 2007 02:06
119	L3_18-19	58.5213	-50.5686	16 May 2007 02:11
120	L3_18-19	58.5674	-50.5067	16 May 2007 02:26
124	L3_19	58.7161	-50.3983	16 May 2007 06:34
125	L3_19	58.7548	-50.3551	16 May 2007 06:46
126	L3_19	58.7908	-50.3120	16 May 2007 06:57
127	L3_19	58.8628	-50.2160	16 May 2007 07:20
128	L3_19	58.9298	-50.1235	16 May 2007 07:42
129	L3_19	58.9931	-50.0351	16 May 2007 08:03
134	L3_20-21	59.1211	-49.8808	16 May 2007 12:33
135	L3_20-21	59.1718	-49.8216	16 May 2007 12:57
136	L3_20-21	59.2013	-49.7846	16 May 2007 13:14
137	L3_20-21	59.2343	-49.7454	16 May 2007 13:33
138	L3_20-21	59.2575	-49.7177	16 May 2007 13:46
139	L3_20-21	59.3059	-49.6560	16 May 2007 14:02
140	L3_20-21	59.3380	-49.6196	16 May 2007 14:12
141	L3_20-21	59.3687	-49.5836	16 May 2007 14:21
142	L3_20-21	59.4212	-49.5192	16 May 2007 14:38
147	L3_22	59.5753	-49.4128	16 May 2007 19:09
148	L3_22	59.6237	-49.3426	16 May 2007 19:24
149	L3_22	59.6816	-49.2592	16 May 2007 19:43
150	L3_22	59.7025	-49.2282	16 May 2007 19:50
155	L3_22-23	59.8046	-49.0985	16 May 2007 23:44
156	L3_22-23	59.8629	-49.0357	17 May 2007 00:05
157	L3_22-23	59.9227	-48.9698	17 May 2007 00:25
161	L3_23-24	60.0337	-48.7664	17 May 2007 04:10
162	L3_23-24	60.1034	-48.7074	17 May 2007 04:31
163	L3_23-24	60.1470	-48.6734	17 May 2007 04:43
164	L3_23-24	60.1687	-48.6555	17 May 2007 04:50
165	L3_24-25	60.2329	-48.6008	17 May 2007 05:09
229	HL_10	42.0302	-61.0653	25 May 2007 05:19
230	HL_11	41.8400	-60.9421	25 May 2007 06:20
231	HL_11	41.7844	-60.9076	25 May 2007 06:37
235	HL_11-12	41.7520	-60.8787	25 May 2007 12:10
237	HL_12	41.4149	-60.6695	25 May 2007 15:07
239	HL_09	41.5564	-60.7223	25 May 2007 20:34
243	HL_09	42.2604	-61.2208	26 May 2007 04:24
244	HL_08	42.3783	-61.2824	26 May 2007 05:03
247	HL_08	42.3898	-61.3011	26 May 2007 10:00
253	HL_06	42.8524	-61.7445	26 May 2007 20:57
255	HL_05.5	42.9515	-61.8259	26 May 2007 22:12
258	HL_03	43.8832	-62.8915	27 May 2007 04:47
262	HL_02	44.2654	-63.3141	27 May 2007 08:16

Table B.4.1.1 XBT deployments during HUD2007011/1.

5. Ashtech ADU5 Attitude Determination Unit — Adam Hartling

The Ashtech ADU5 is a real-time attitude determination system and Differential Global Positioning System (DGPS) that provides motion corrections for the Ocean Surveyor II (OS-II) vessel-mounted ADCP.

The ADU5 uses differential carrier phase measurements from an array of four GPS receivers (Antennas) to compute heading, roll, and pitch in real-time at a 5 Hz update rate.

Position and velocities are computed only for Antenna 1. The remaining antennas provide carrier phase data for attitude determination. Antenna 1 is a Beacon antenna providing differential position when in range of a base station. Beacon corrections were available for all but the most northeast portion of the cruise.

Antenna separations in a normal multipath environment determine the level of solution accuracy. The fore-aft antenna separation of 3 m provides potential heading accuracy of 0.2 degrees. The port-starboard antenna separation of 1 m provides potential pitch-roll accuracy of 0.6 degrees.

User configurable data are output on two serial ports. Output Port A is not used. Output Port B, 115200, 1 Hz update rate, provides position and attitude data for the Ocean Surveyor II. NMEA strings used include GGA, VTG, and PASHR, AT2 (heading, pitch, roll).

When the receiver is searching for the ambiguities or when a valid solution has not been found, a code phase estimate of heading appears in the PASHR, AT2 string and pitch and roll are displayed as exactly 0.00. Heading may also be displayed as 0.00 if no estimate is available. The PASHR, AT2 string contains a quality flag which indicates the quality of the solution. When either of these situations exist, the attitude reset flag is set to 1 in the attitude output message (a 0 for the attitude reset flag indicates a good attitude solution).

If noisy or bad satellite measurement data were received by the ADU5 the Kalman filters sometimes get lost. This results in no valid solution. This often is the result of high multipath interference. BRMS and MRMS fields in the PASHR, AT2 string will exceed maximum noise levels, and the PDOP will become large. For a good solution PDOP should be less than 6.

Solution quality was monitored on a daily basis with the aid of the Teledyne RDI VmDas and WinADCP software packages used to log and monitor the OSII ADCP current profile data.

6. Meteorological measurements — Ross Hendry

The officer of the watch enters standard meteorological data into the ship's log book at regular intervals. On occasion we have transcribed these logged values for local scientific use but there is no standard protocol for doing this.

Since April 2003 Environment Canada (EC) has maintained an AXYS Technologies Inc. Automated Volunteer Observing Station (AVOS) on board Hudson that measures a suite of meteorological variables. Data are stored on an EC-maintained personal computer on board Hudson. Normally these measurements are automatically forwarded at regular intervals onto the

Global Telecommunication System (GTS) of the World Meteorological Organization. The GTS data then become available at http://www.sailwx.info/shiptrack/shipposition.phtml?call=CGDG but there are significant data gaps which include the entire period of HUD2007011.

Wind speed and direction are operationally monitored with a Young Model 05103 Wind Monitor (R. M. Young Company, MI, USA) mounted on the starboard side of the upper platform on Hudson's antenna mast 26 m above sea level. The Wind Monitor is connected to a Young Model 06206 Marine Wind Tracker located on the bridge. The Marine Wind Tracker provides NMEA $WIMWV (Wind Speed and Angle) strings which are captured, time-stamped, and logged at 1-second intervals by the Geological Survey of Canada (GSC) Survey Suite navigation logging system.

Wind direction reported by the Wind Monitor is the direction relative to the ship's heading from which the wind is blowing, zero degrees when the wind is on the bow, and increasing clockwise when viewed from above. The manufacturer of the Model 05103 Wind Monitor notes that the wind direction potentiometer has a 5° dead band between 355 and 360 degrees. In the Hudson installation the NMEA output directions actually show a dead band between approximately 175 and 180 degrees.

Relative wind direction is converted to geographic direction by adding the ship's heading provided by the ship's gyro compass system as NMEA $HEHDT (Heading – True) strings. Wind speed and direction in a geographic reference frame are then computed by the vector addition of the wind velocity in the ship reference frame and the ship's velocity over ground provided by the Ashtech ADU5 (Section B5) as NMEA $GPVTG strings (Track Made Good and Ground Speed).

The 1-second geographic vector wind values were bin averaged in 60-second bins to provide a uniform 1-minute time series. A 5-minute time series was then produced by smoothing the 1-minute vector time series with a 5-point convolution filter with relative weights [1 4 6 4 1] and sub-sampling the smoothed time series (Figure B.6.1).

Sustained winds with speeds above 35 kt were encountered during the last half of 12 May 2007; with a maximum 44 kt 1-minute average wind speed recorded at 1719 UTC. A second period of sustained winds with speeds of more than 35 kt occurred during 20–21 May 2007.

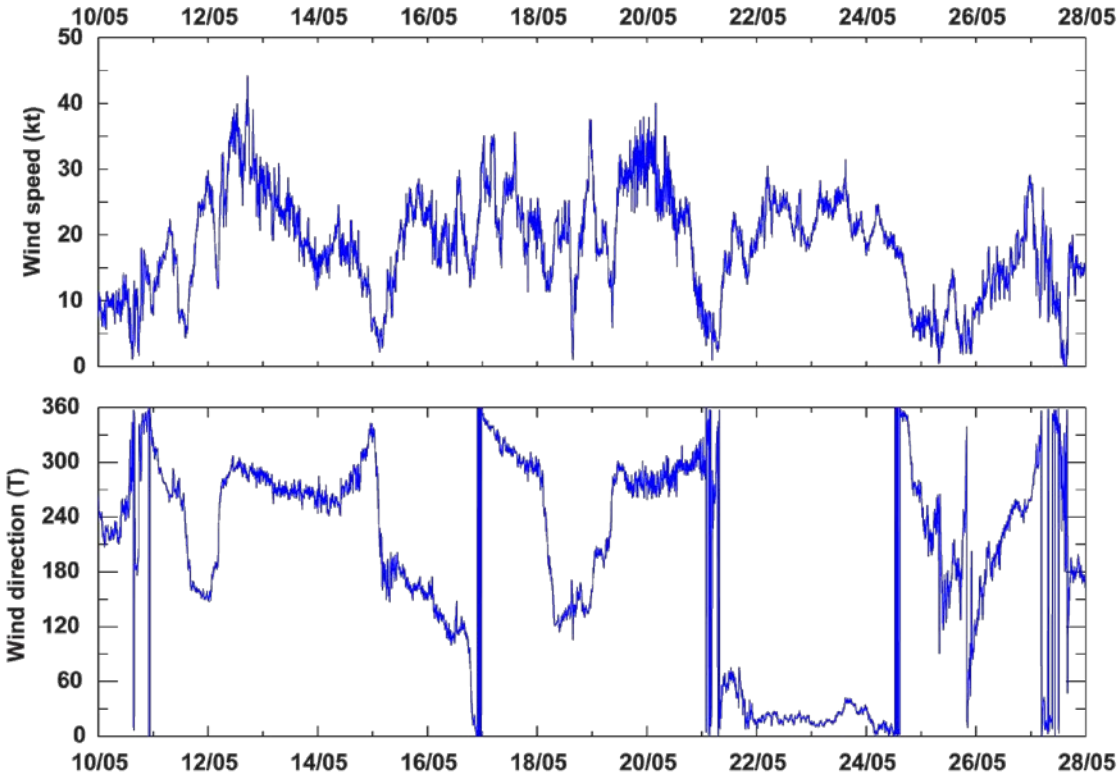

Figure B.6.1 Five-minute vector average wind speed (upper) and direction (lower) at 26 m height.

C. HYDROGRAPHIC MEASUREMENTS -DESCRIPTIONS, TECHNIQUES AND CALIBRATIONS

1. CTD Measurements — Ross Hendry / Bob Ryan / Igor Yashayaev

a. Description of equipment and technique

CTD measurements on HUD2007011 were made with a Sea-Bird Electronics, Inc. 911plus CTD equipped with dual SBE 3 temperature and SBE 4 conductivity sensors and dual SBE 43 dissolved oxygen sensors. The SBE 9plus sea unit was mounted vertically within a custom-designed CTD/Rosette frame that accommodates 24 10-L sampling bottles.

The CTD used on HUD2007011 was configured for the preceding mission HUD2007007 with TC sensor pairs with local designations TC-09 (temperature sensor TS-09 and conductivity sensor CS-09) and TC-10 (temperature sensor TS-10 and conductivity sensor CS-10). Pre-cruise calibrations of TS-09 and CS-09 carried out in the BIO Standards Laboratory during 14–16 March 2007 showed a mean temperature error of 0.3 ± 0.3 mK and a mean salinity error of -0.0009 ± 0.0014. TS_10 and CS_10 had been sent to Sea-Bird for evaluation and were returned by Sea-Bird with a new replacement conductivity cell and new Sea-Bird calibrations dating from 11–12 April 2007 Temperature sensor TS-10 failed on HUD2007007 and a new pairing TC-11 consisting of temperature sensor TS-08 with 12–13 March 2007 BIO pre-cruise calibrations (-0.4 ± 0.3 mK) and conductivity sensor CS-10 was used for the last part of HUD2007007 and all of HUD2007011. Post-cruise BIO calibrations carried out during 16–18 January 2008 showed a mean temperature error of -0.8 ± 0.3 mK and a mean salinity error of -0.0059 ± 0.0016 for TS-09/CS-09 and a mean temperature error of -0.9 ± 0.2 mK and a mean salinity error of 0.0008 ± 0.0008 for TS-08/CS-11.

Additional analog sensors included a Chelsea Technologies Group Ltd. AquaTracka III Fluorometer, a WET Labs, Inc. CDOM WETStar Fluorometer, and a LI-COR Biosciences LI-193SA Irradiance PAR Sensor. An SBE 35 Deep Ocean Standards Thermometer was also included in the CTD package. A Teledyne Benthos 2110-2 Altimeter was installed in the rosette package and interfaced with the SBE 911plus for bottom detection. Details of the CTD configuration are provided in Appendix 3.

A free-running Teledyne Benthos BFP-312 bottom finding pinger and a self-contained Teledyne RDI 150 kHz Broadband Lowered Acoustic Doppler Current Profiled (LADCP) belonging to the Woods Hole Oceanographic Institution were also installed on the rosette.

All the pressure cases as well as the sample bottles were mounted vertically to improve the package's stability as it descends through the water column. In the centre of the frame is an aluminum tube, which contains at its upper end a 24-position Sea-Bird SBE 32 Carousel Water Sampler. The frame itself is subdivided into four quadrants. One quadrant holds the LADCP in a shortened pressure case. Another quadrant contains the SBE 9plus pressure case and the WetStar fluorometer. The third quadrant contains the battery pack for the LADCP, the altimeter, and the pinger. The last quadrant contains the dual CTD sensors and pumps. The WETStar Fluorometer and LI-COR PAR Sensor have limited depth ranges and are only deployed on shallow casts.

They are mounted together in a removable rack to facilitate the change-over from shallow to deep casts.

The CTD package was deployed from Hudson's enclosed winch room with a Hawboldt Industries Model SPR 43-3640 winch loaded with 7000 m of 0.3125" diameter single-conductor double-armoured cable manufactured by Rochester Wire & Cable. The conductor cable is led out over an 18" diameter ODIM Brooke Ocean Instrumented Metering Sheave (IMS) mounted at the end of a telescoping boom. A quick-change mechanism allows switching blocks between the IMS and a mechanical sheave used for the hydrographic winch located inboard of the CTD winch which is used for vertical net tows. The IMS comprises the sheave block, a computer-based display, and a remote winchroom display. The IMS measures cable tension, scope, speed, and inclination. The Lab Unit and Remote Displays are equipped with inter-system communications features for sending commands and messages to the winch operator.

b. Sampling procedures and data processing techniques

The rosette frame and CTD were deployed with a lowering rate of 60 m/min (40 m/min in the upper 200 m). The package was recovered at a rate of 75 m/min depending on the wire tension.

Microsoft Windows based Sea-Bird Seasave V5_37d was used for CTD data acquisition, conversion, and real-time display. IMS software was used for communication with the winch operator and for providing CTD readout to the metering block display.

In-house JAVA-based CTD Data Acquisition and Processing System version 1.3.4 (Hum, 2007) provided a wrapper for downloading and processing CTD data from the SBE 9plus. Data processing modules from Sea-Bird SBE Data Processing Version 5.37e and in-house BIO processing modules were applied to the raw CTD data files to produce output in several different formats for further analysis. The DATCNV (data conversion) module converts the raw data file to engineering units, and stores the converted data in a .CNV file. DATCNV also creates a water bottle [.ROS] file from the raw [.BL] data file containing CTD scan numbers corresponding to bottle trips. The ROSSUM (bottle summary) module converts the .ROS file to a water bottle summary [.BTL] file. Sea-Bird modules split data in .CNV files into upcast and downcast files, and translate binary data to ASCII format. The in-house SeaODF module reads the final .CNV file, and creates an Ocean Data Format [.ODF] file. ODF_IGOSS appends an IGOSS station record to a [.IGS]. QProBtl creates a [.QAT] file for each [.BTL] file. The [.QAT] file is an ASCII, comma delimited file containing the same data as the [.BTL] file in a different format. Calib appends merged data from the [.ODF] and [.QAT] files to a calib.txt file. All the raw and processed data files associated with the station are then transferred to the ship's file servers for archive and subsequent access and distribution to various users on the vessel.

CTD temperature values are reported in the IPTS-68 scale. CTD salinity values are calculated using the IPSS-78 algorithm.

2. Salinity — Rick Boyce

a. General

A total of 594 valid salinity samples were returned from 542 of 1051 rosette bottle trips. Figure C.2.1 shows the bottle positions and salinity sampling arrangements for the three lines occupied on HUD2007011/1. No samples were taken at Station 27, Transit_02, or shallow biology casts at the same sites as physics casts. Salinity samples were analysed for 319 of 515 bottles (62%) on AR7W physics casts, 126 of 221 bottles (57%) on L2 physics casts, and 97 of 184 bottles (53%) on Halifax Line physics casts. Replicate salinity samples were drawn from 48 bottles, including two samples from each of 44 bottles and three samples from 4 bottles. The distinction between normal and delayed replicates in Figure C.2.1 is discussed below. Sample bottles delivered for analysis included one broken sample bottle and 10 other empty or partially empty sample bottles, all with valid ID labels. The positions of these bottles are highlighted in Figure C.2.1 and labelled "salinometer log comment".

b. Description of equipment and technique

Salinity samples were analyzed using a Guildline Autosal 8400B salinometer (Guildline Instruments Limited, Smiths Falls, ON), serial number 60968. Samples were drawn into 200 mL bottles. Once the sample bottle was rinsed three times and filled to the shoulder, the neck and threads of the bottle were dried using paper towel and a new dry cap was installed. Once the bottles reached room temperature, the caps were retightened. The drying of the neck of the bottle and installing a dry cap has been a technique used since HUD2000009 to avoid salt crystals forming under the cap.

The salinometer cell was filled and rinsed numerous times with sample water before readings were recorded. When three consecutive readings of conductivity ratio agreed to within 0.00001, that value was recorded on the log sheet and entered into the ODIN database (Isenor, 2002).

c. Data processing

Once conductivity ratios, sample IDs and standards had been entered into the database an ODIN module computed salinities following the IAPSO PSS78 standard using the water sample conductivity ratio and bath temperatures. Any changes in the salinometer readings between successive standardizations were assumed to have occurred as a linear drift of the instrument. Thus, the program applied a correction to the ratios, which varied linearly with the samples analyzed. An offset was also applied if the initial standardization was different from the quoted value given on the ampoule label.

d. Laboratory and sample temperatures

Full cases of samples were taken from the winch room to the Drawing Office where they were left for a period of at least 10 hours to equilibrate to room temperature before being analyzed. The temperature in this area ranged from approximately 23º to 25ºC. The bath temperature was maintained at 24ºC for all samples.

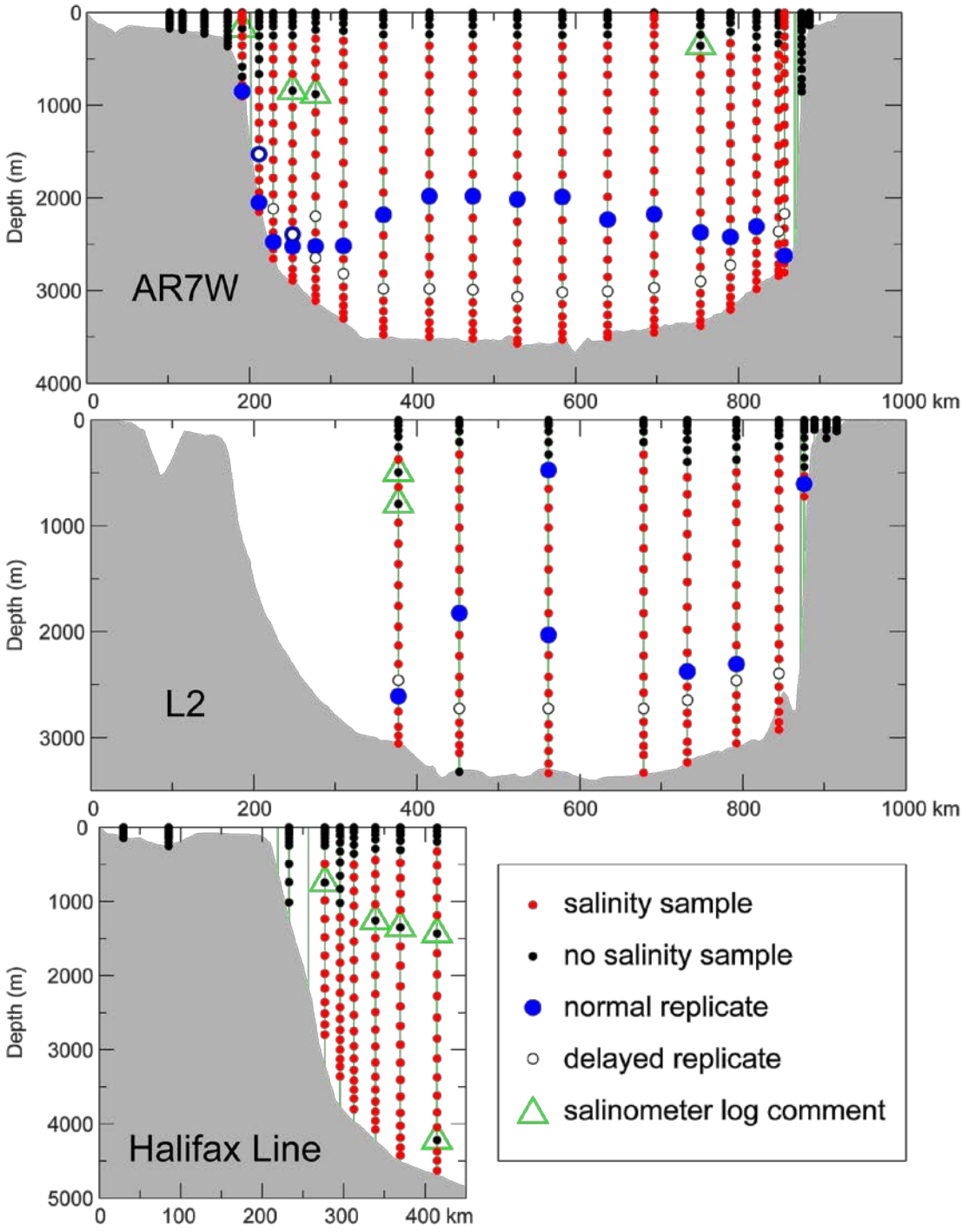

Figure C.2.1 Bottle depths and salinity sampling for the three sections occupied on HUD2007011/1.

e. Replicate Analyses

Replicate salinity samples were drawn from 48 of the 542 rosette bottles from which salinity samples were drawn. Two replicates were drawn from 44 bottles and three replicates from 4 bottles. The normal practice is to analyse the salinity samples as soon as practical after they have

equilibrated to laboratory temperature but the analyses of about half the replicate samples drawn on HUD2007011 were deliberately delayed to investigate the degradation of stored samples. Statistics of the signed (second sample minus first sample) differences between the 26 normal replicates are shown in Table C.2.1. 25 of the 26 signed differences in salinity lay within the range [-0.0014 0.0006], with the only exception giving a maximum 0.0187 that was screened out of the calculations of the mean, standard deviation, and 95% confidence interval in Table C.2.1 using the cutoff criteria in Table C.2.1 defined by median ± 9* (median absolute deviation). The mean value of the difference between normal replicates was not significantly different from zero at 95% confidence.

The 26 delayed replicate pairs that included a normal delayed sample showed a mean increase in the salinity of the delayed sample of 0.0016 with 95% confidence limits [0.0009 0.0023] assuming all the replicate pairs are independent. Note however that 4 of these 26 pairs are not completely independent because they were derived from triplicate samples that included two delayed samples sharing a common normal sample. The delay between station end time and nominal sample analysis time (defined as mid-watch for the salinometer operator) for the 26 delayed samples paired with normal samples in the above calculation varied from 3.6 to 11.2 days with median 8.2 days. For comparison, the 568 salinity samples that were analyzed without an intentional delay were run with a maximum delay of 3 days and a median delay 0.8 days.

Statistic	Value
Number of bottles sampled	542
Number of replicate pairs	26
Minimum	-0.0014
Maximum	0.0187
Median	0.0000
Median absolute deviation	0.0003
Cutoff	[-.0027 .0027]
Outliers	1
Mean (N = 25)	-0.0001
Standard Deviation (N = 25)	0.0005
95% Cl for mean (N = 25)	[-.0002 .0002]

Table C.2.1 Salinity replicate statistics

f. Standards Used

The salinometer was standardized during the mission using IAPSO standard water, Batch P147 dated June 6, 2006 with K15 value 0.99982 and salinity 34.993. Standardization checks were performed at the beginning and end of the 8 salinometer runs (involving between 11 and 87 samples) except for Run 9 (36 samples) where only a beginning standardization check was done.

g. Performance of the Autosal salinometer

Overall the salinometer worked well during the mission. The lab temperature was stable during all runs which is an important factor when trying to optimize the performance of the instrument. Historically the Autosal was setup in the General Purpose (GP) lab onboard Hudson. Air temperature was difficult to control in this area. For this mission the Autosal was installed in the

Drawing Office where the operator can control the ambient air temperature much better than in the GP lab.

3. Oxygen — Eva Falck / Carol Anstey

a. General

A total of 835 oxygen samples including 37 replicates were returned from 798 of a total of 1051 rosette bottle trips (76%). Samples were taken at 11 levels for both Station 27 and Transit_02. No oxygen samples were collected from shallow biology casts at the same sites as physics casts. Oxygen samples were analysed for 444 of 515 bottles (86%) on AR7W physics casts, 184 of 221 bottles (83%) on L2 physics casts, and 148 of 184 bottles (80%) on Halifax Line physics casts.

b. Sampling procedures

Sub-samples were drawn from 10 L bottles attached to a 24-bottle Rosette Sampler. Oxygen sub-samples were drawn after chlorofluorocarbon (CFC) and total organic carbon (TOC) samples. The oxygen sampling bottles were 125 mL Iodine flasks with matched custom ground stoppers (Levy *et al.*, 1977). The flask volumes were predetermined gravimetrically (volume data saved to titration program). The matched flasks and stoppers are etched with identification numbers.

Each oxygen sub-sample was drawn through a silicone tube attached to the spigot of the Rosette bottle. The flask was thoroughly rinsed and filled to overflowing; the flow was then allowed to continue until two to three flask volumes overflowed. The sampling tube was slowly retracted with continuous low flow to ensure that no air was trapped in the flask. The flask stopper was also rinsed. The draw temperature of each sample was taken. This method deviated from previous years where the CTD recorded temperature was used as draw temperature. Samples were oxidized immediately with the addition of 1.0 mL each Alkaline Iodide and Manganous Chloride. The flask stopper was carefully inserted to avoid introducing air. The flask was then thoroughly shaken. The resulting precipitate was allowed to settle for approximately 30 minutes before analysis once the bottles reached the GP lab.

c. Analysis equipment and technique

The oxygen samples were analyzed using an automated procedure developed by the Ocean Data Facility of the Scripps Institute of Oceanography (SIO/ODF, 1999). This procedure is a modified Winkler titration from Carritt & Carpenter (1966). The oxygen in seawater is made to oxidize iodide ion to iodine quantitatively in the presence of an alkaline solution of manganese (II) ion. Once the resulting precipitate has settled, it is dissolved by the addition of 1.5 mL of 5M sulphuric acid. Dissolved oxygen content is determined by an automated Thiosulphate titration using the UV (350nm) absorption of the tri-iodide ion for end-point detection. A Potassium Iodate solution was used as the working standard. The temperatures of the samples (taken from the CTD wet deck sheets), potassium iodate and thiosulphate (taken by temperature probe integrated with titration system) are logged in the program for each determination to allow for temperature related volume corrections.

Standards, titre, acid and pickling agents were prepared just before the cruise. The second lot of Alkaline Iodide used had developed a colloidal black precipitate during cruise storage. The reagent was filtered through cleaned glass wool before use. This removed most of the precipitate but not all. Its presence did not seem to affect the titrations.

d. Replicate analysis

Replicate samples were drawn from 37 rosette bottles, about 5% of the 798 bottles that were sampled for oxygen. Adjusted sample standard deviations for 32 screened replicate pairs are plotted for each day of analysis in Figure C.3.1 below. The average standard deviation (precision) for the screened replicate samples is 0.009 mL/L.

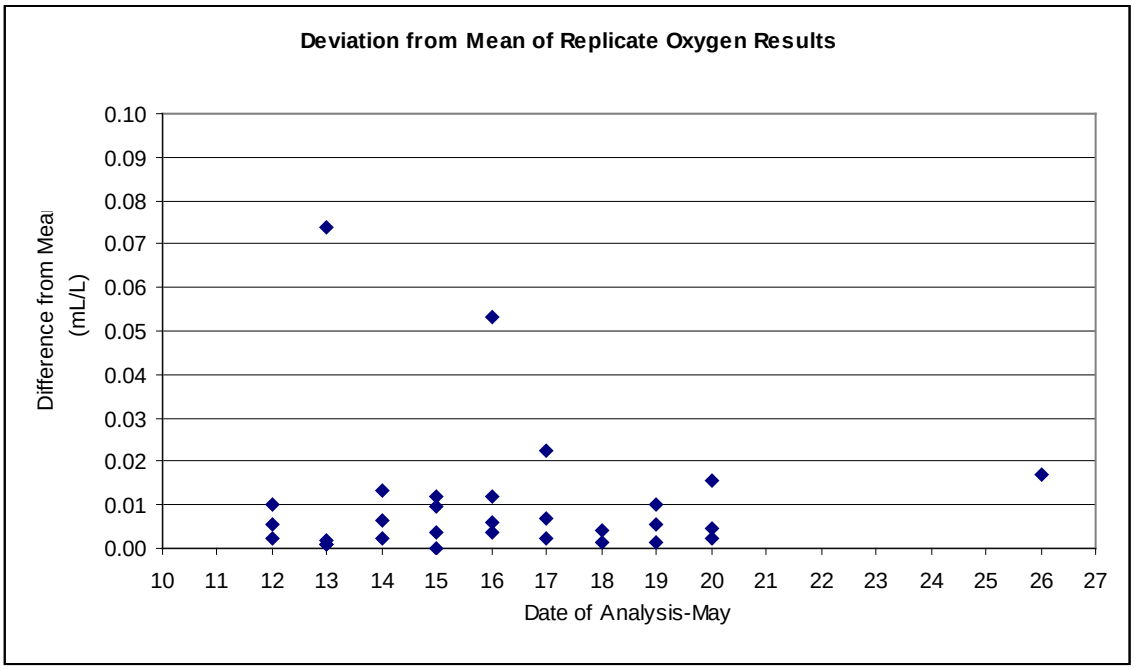

Figure C.3.1 Difference from mean of the analysis of each replicate pair vs. date of analysis.

e. Standards and blanks

Standards are determined by the titration of 10.0 mL volume of KIO3 solution. Blanks are determined by titration an initial 1.0 mL volume of KIO3 followed by addition and titration of a second 1.0 mL volume. The blank is the difference between the two volumes. The usual protocol followed is to obtain at least three replicate standards and blanks within ±0.0003. Many standardization replicates did not agree this closely. Standardizations were run at the beginning of each calendar day instead of before each batch of samples due to a shortage of reagents. The oxygen analysis software allows the operator to edit out any individual blank or standard titration considered an outlier. The average values of valid standards and blanks for each set of titrations are used by the analysis program to compute oxygen concentration. The individual titration volumes and auxiliary information are stored for possible re-processing. The means of the daily accepted standard and blank values are plotted in Figure C.3.2 and Figure C.3.3 below.

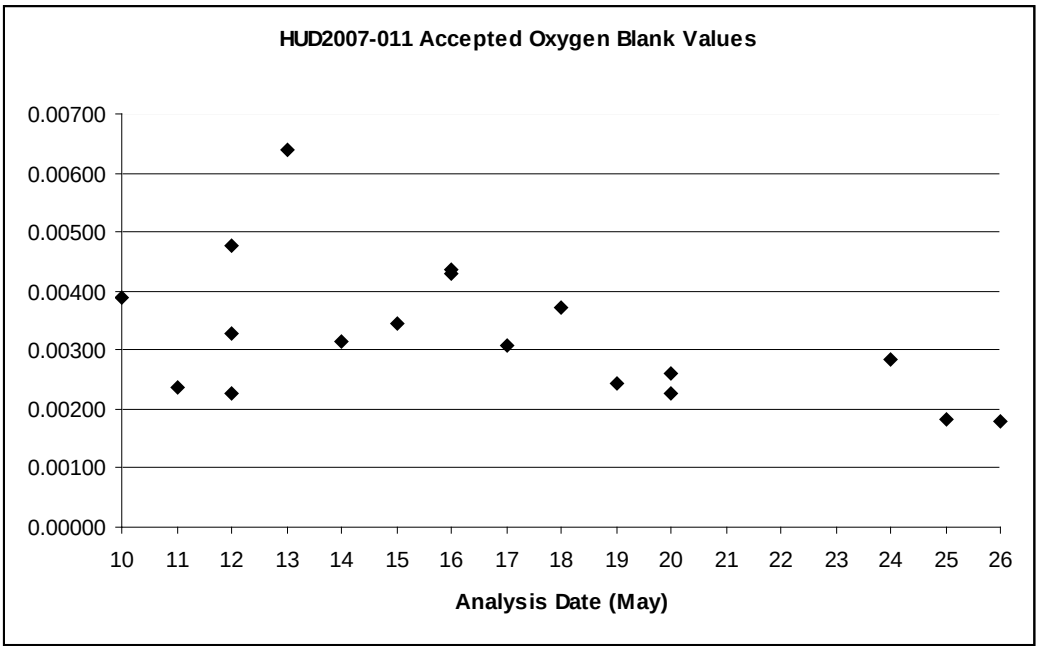

Figure C.3.2 Accepted values for oxygen blanks for each analysis day.

The blank values in Figure C.3.2 have an overall average of 0.00327 mL and overall average deviation (mean absolute difference from the sample mean) of 0.00089 mL.

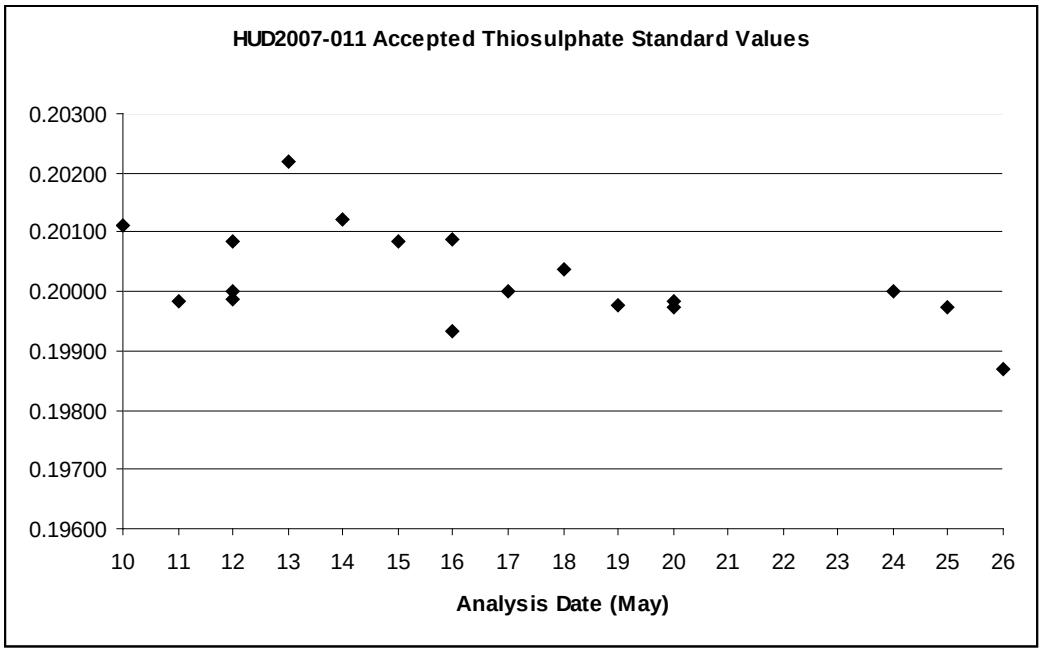

Figure C.3.3 Accepted values for thiosulphate standards for each analysis day.

The thiosulphate standard values in Figure C.3.3 have an overall average of 0.20024 N and overall average deviation of 0.00065 N.

f. Comments

A log book was kept with a daily record of raw data results and any problems encountered. Analysis of the samples posed few technical problems. There was a substantial decrease in bubbles forming in the reagent lines as compared to last year. This was probably due to cooler and less erratic lab temperatures. Results from standard and blank calibrations were not as precise as earlier years. Protocol calls for precision to be ±0.0003; this was rarely achieved. There was a shortage of reagents prepared as the L2 line was added without letting the lab know prior to loading the Hudson. Calibrations were done only once a day when the next day's data collection file was set up and as few as possible in order to conserve reagents. A computer or 'systems' crash occurred a few times. The reason this happens has not yet been determined. Fortunately this resulted in the loss of only a few samples. The Dosimats both worked smoothly. It was noted last year that the thiosulphate Dosimat failed to stop dispensing several times when the flushing function was invoked. This problem did not reoccur for this cruise.

Samples were drawn by experienced and well-trained winch room personnel. Problems with switched stoppers or bubbles in the samples were not noted. It was noted that the Alkaline Iodide dispenser may not have been delivering 1.0 mL May 18 as it needed cleaning.

3a Further remarks on Oxygen — Ross Hendry

a. Introduction

This section briefly discusses the precision and accuracy expected of dissolved oxygen from bottle samples measured by shipboard titration. It then reviews the oxygen replicate statistics and looks at the variability of blanks and standards and the statistics of the residuals of bottle minus corrected CTD oxygen values as a function of the blanks and standards used to calculate the bottle oxygen concentrations. The final conclusion is that most of the variability in blanks and standards does not represent changes in reagent concentrations but comes from some other source. This has implications for the potential accuracy of our CTD oxygen calibrations.

b. Review of oxygen titration chemistry

The following is based on Culberson (1991) and Dickson (1996).

The dissolved oxygen concentration of a sample in mL/L at the temperature at which the oxygen in the sample was fixed by the pickling reagents is [Eq. 8 in Culberson (1991)]

$$O2 = \frac{\frac{(Vx - Vblk,dw)\cdot VIO3\cdot NIO3\cdot 5.598}{(Vstd - Vblk,dw)} - DOreg}{(Vbot - Vreg)/1000} \qquad \text{Eq. 1}$$

where

Vx = thiosulfate titer of sample (cm^3)
Vblk,dw = thiosulfate titer of pure water blank (cm^3)
VIO3 = volume of iodate standard (cm^3)
NIO3 = normality of iodate standard (=6·times the molarity)
5.598 = number of mL of oxygen gas (STP) per molar milliequivalent of O2 gas
Vstd = thiosulfate titer of standard (cm^3)
Vbot = volume of sample bottle (cm^3)
Vreg = volume (2 cm^3) of sample displaced by reagents
DOreg = absolute amount of oxygen added with reagents, 0.0017 mL (Murray *et al.*, 1968)
O2 = oxygen concentration in sample (mL/L)

The number of moles of dissolved oxygen in a sample is [Eq. 10, 13 in Dickson (1996)]

$$n(O2) = \frac{1.5\cdot(Vx - Vblk,dw)\cdot VIO3\cdot MIO3}{(Vstd - Vblk,dw)} - DOreg \qquad \text{Eq. 2}$$

where

MIO3 = molarity of iodate standard
n(O2) = moles of dissolved oxygen

c. Precision and accuracy goals

Carpenter (1965) found that the modified Winkler technique is capable of an accuracy of 0.1% (0.006 mL/L at a mid-range value of 6 mL/L). Culberson (1991) reiterated that "Carpenter's (1965) modification of the Winkler technique is reproducible (2 standard deviations) to ±0.010 mL/L" but "Achieving this level of precision ... requires scrupulous attention to detail."

The WOCE Hydrographic Program (WHP) provided a possible working definition of accuracy as "the standard deviation of interlaboratory reproducibility" and set formal one-time-survey bottle oxygen measurement goals of 0.1% precision and <1% for reproducibility (WHPO, 1994), (Table 2.5). They noted that "Some laboratories presently achieve 0.5% accuracy, which is recommended for WOCE measurements." For the reference oxygen concentration this gives a standard-deviation precision goal of 0.006 mL/L as above and an inter-laboratory standard-deviation reproducibility of 0.03 mL/L. Dickson (1996) characterized the initial target World Ocean Circulation Experiment (WOCE) precision and accuracy criteria as demanding a maximum within cruise precision (1 standard deviation) of 0.5 µmol/kg and an overall inter-cruise/interlaboratory range of bias less than 2.0 µmol/kg for concentrations up to 400 µmol/kg, again about 0.1% and 0.5% respectively.

The WHP goals were meant to be operationally achievable and were guided by a 1991 intercomparison (Culberson *et al.*, 1991). The intercomparison reported that three of the four participating groups achieved replicate precisions (1 standard deviation) of 0.004–0.005 mL/L or about 0.08% excluding the few outliers with differences > 0.05 mL/L. The internal consistency of the standard titrations on the intercomparison cruise as measured by the intra-institutional relative standard deviation based on replicated titrations varied from 0.06% to 0.15%. After an adjustment of the outlier iodate standard of one of the groups, the range between the highest and lowest oxygen values of common samples analyzed by the four participating institutions in the 1991 intercomparison never exceeded 0.6%.The recommended 0.5% relative error goal quoted above allowed for about this level of inter-laboratory variability. The Woods Hole Oceanographic Institution group in the study claimed an accuracy of about 0.02 mL/L or about 0.3% (Knapp *et al.*, 1990).

d. Influence of draw temperature on bottle oxygen

The density of each sample at the time of pickling is needed to convert volumetric oxygen concentrations (mL/L) to mass concentrations (µmol/kg) (Culberson, 1991). The temperature of each sample was measured with a hand-held digital thermometer just after the sample was drawn from a Rosette bottle to allow the calculation of sampling density. Some deep samples had warmed from in situ values by more than 4°C at the time the oxygen sample was drawn, giving a relative decrease in potential density from in situ conditions of about 0.05%.

e. Hudson 2007011 precision statistics

The replicate statistics from Section C.3 above give no significant bias and a standard deviation of 0.009 mL/L or 0.15% associated with random errors in sample drawing and sample titration. This is close to but slightly larger than the hoped-for 0.1%. Both oxygen analysts were experienced in shipboard oxygen analyses. Winch room personnel responsible for drawing

oxygen samples included both experienced staff and first-time student volunteers. It might be expected that the new trainees would not be as proficient in drawing samples as the more experienced watchstanders. Inexperienced watchstanders and occasional periods of rough weather could both have influenced the scatter in replicate samples.

f. Hudson 2007011 accuracy statistics: Influence of blanks and standards

Neglecting the DOreg term in Eq. 1 which is of order 0.2% of the first term in the numerator, the fractional change in oxygen concentration can be expressed to first order as a sum of fractional changes of sample, standard, and blank titres

$$\frac{\partial O2}{O2} \approx \frac{\partial Vx}{(Vx - Vblk,dw)} - \frac{\partial Vstd}{(Vstd - Vblk,dw)} + \frac{(Vx - Vstd)\,\partial Vblk,dw}{(Vx - Vblk,dw)(Vstd - Vblk,dw)}. \qquad \text{Eq. 3}$$

The median values of Vx–Vblk,dw, Vstd–Vblk,dw, and Vx–Vstd were approximately 0.80 mL, 0.60 mL, and 0.20 mL respectively. The numerical values of the coefficients of δVx, δVstd, and δVblk,dw in Eq. 3 based on these median values are 1.25, −1.67, and 0.42 respectively, all with units mL-1. A titration volume variability δVx of about 0.0012 mL is associated with δVx /(Vx–Vblk,dw) equal to the 0.15% fractional replicate standard deviation.

The term

$$Nthio = \frac{VIO3 \cdot NIO3}{(Vstd - Vblk,dw)} \qquad \text{Eq. 4}$$

in Eq. 1 is the normality of the thiosulfate titration solution (approximately 0.2 N) at the temperature of standardization. Eq. 1 can be also be written as

$$O2 = \frac{(Vx - Vblk,dw) \cdot Nthio \cdot 5.598 - DOreg}{(Vbot - Vreg)/1000} \qquad \text{Eq. 5}$$

and Eq. 3 as

$$\frac{\partial O2}{O2} \approx \frac{\partial Vx}{(Vx - Vblk,dw)} - \frac{\partial Vblk,dw}{(Vx - Vblk,dw)} + \frac{\partial Nthio}{Nthio}. \qquad \text{Eq. 6}$$

The second and third terms of Eq. 6 account for changes in dissolved oxygen concentration associated with random and systematic changes in the measured blanks and standards. Average values of accepted blanks and standards associated with each run were used to calculate the oxygen concentrations from that run, so only the first terms of Eq. 6 contributes to intra-run variability in measured oxygen concentration.

Discrete batches of samples analyzed on Hudson 2007011 are identified by 20 sequential run numbers between 9 and 28. Runs 1–8 refer to the previous mission Hudson 2007009. One of the Hudson 2007011 runs (Run 13) analyzed blanks and standards but there were no associated samples. New blanks and standards were determined for 17 of the 19 runs where samples were analysed. Runs 12 and 17 used blanks and standards from Runs 11 and Run 16 respectively. Between 5 and 103 sample titrations were performed for Runs 9–28, excluding Run 13.

Blanks

Blanks obtained for Runs 9–28 including Run 13 with no samples are plotted against run number in Figure C.3a.1 An average of about 4 blanks per run were flagged by the operators as unacceptable and excluded from the run statistics. Run-mean values based on between 2 and 4 individual accepted values per run varied from 0.00180 to 0.00639 mL. Intra-run blank standard deviations varied from 0.00002 to 0.00087 mL with an overall rms value of 0.00036 mL. Since each blank depends of two titrations, the random error in blank determinations should be $\sqrt{2}$ times the random error in an individual titration. Intra-run standard errors of the mean varied from 0.00001 to 0.00051 mL with an overall rms value of 0.00021 mL.

Figure C.3a.1 shows that changes in the run-mean blank were large relative to the intra-run standard deviations. The standard deviation of the run-mean blanks was 0.00117 mL or about 3 times the rms intra-run standard deviation. Using this value for $\delta V_{blk,dw}$ and the quoted median value of $V_x - V_{blk,dw}$, the second term on the right hand side of Eq. 6 gives a fractional change in dissolved oxygen of about 0.15%. Note that a similar calculation using the third term on the right hand side of Eq. 3 gives a lower fractional change in dissolved oxygen of about 0.05% directly associated with blanks because more of the variability due to blanks is absorbed in the second term.

Standards

Two batches of potassium iodate with different normalities were used for the combined Hudson 2007009 / Hudson 2007011 oxygen analyses. The first batch with normality 0.0120985 was used for Runs 1–18 and the second with normality 0.0120774 was introduced for the analysis of Run 19 and used for the remainder of the mission. Two batches of thiosulfate solution were also used, with the second being introduced at the start of Run 20. This meant that Run 19 gave the only standardization of the first thiosulfate batch with the second iodate standard. The SIO/ODF Oxygen Titration Manual (SIO/ODF, 1999) cautions against changing the iodate and thiosulfate solutions on the same day and recommends that to maintain continuity three standardizations should be done with a new batch of either solution before changing the other solution.

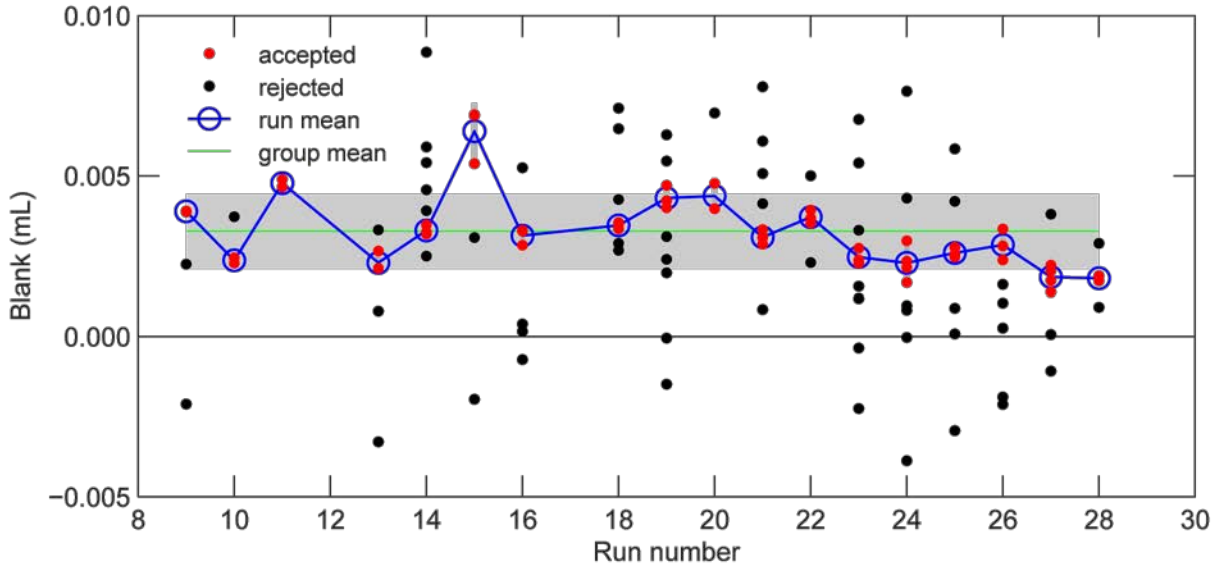

Figure C.3a.1 Hudson 2007011 oxygen titration blanks. About 60% of the individual blanks were flagged by the operators as unacceptable and excluded from the run statistics. Individual accepted (51 values) and in-range rejected (66 of a total of 76) blanks are shown. Also shown are mean values (blue circles) and standard deviations (vertical grey bars) of all accepted individual blanks for a run and the mean (green line) and standard deviation of the 18 run-mean blanks (horizontal grey bar).

Individual values and two grouped means of the thiosulfate volumes needed to titrate 9.9365 mL of the two potassium iodate solutions corrected to 20°C are plotted against run number in Figure C.3a.2. Group 1 comprises Runs 9–18 and Group 2 Runs 20–27. Run 19 is not included in either group since the titration volume is depends on the concentrations of both thiosulfate and potassium iodide and Run 19 used thiosulfate from the first batch and potassium iodate from the second batch. Individual accepted (50 values) and in-range rejected (41 of a total of 58) standards are shown. Most of the rejected values are positive outliers, as are 16 of the 17 rejected values that are out of range of the plot limits. Hansen (1999) noted that most sources of systematic oxygen titration error result in an increased oxygen content.

The mean run-mean values of thiosulfate volume for the two groups are 0.60209 and 0.60326 mL. There was a moderately significant increase in volume of 0.00116 mL or 0.19% of the Group 1 mean, $t(16) = 1.42$, $p < 0.088$. Since the normality of the second iodate batch was about 0.17% lower than the normality of the first batch, the titration of a given volume of the second batch would require about 0.17% less thiosulfate of a given normality than a titration of the same volume of the first batch. The observed increase in volume for the second group implies that its normality is less than the normality of the first batch.

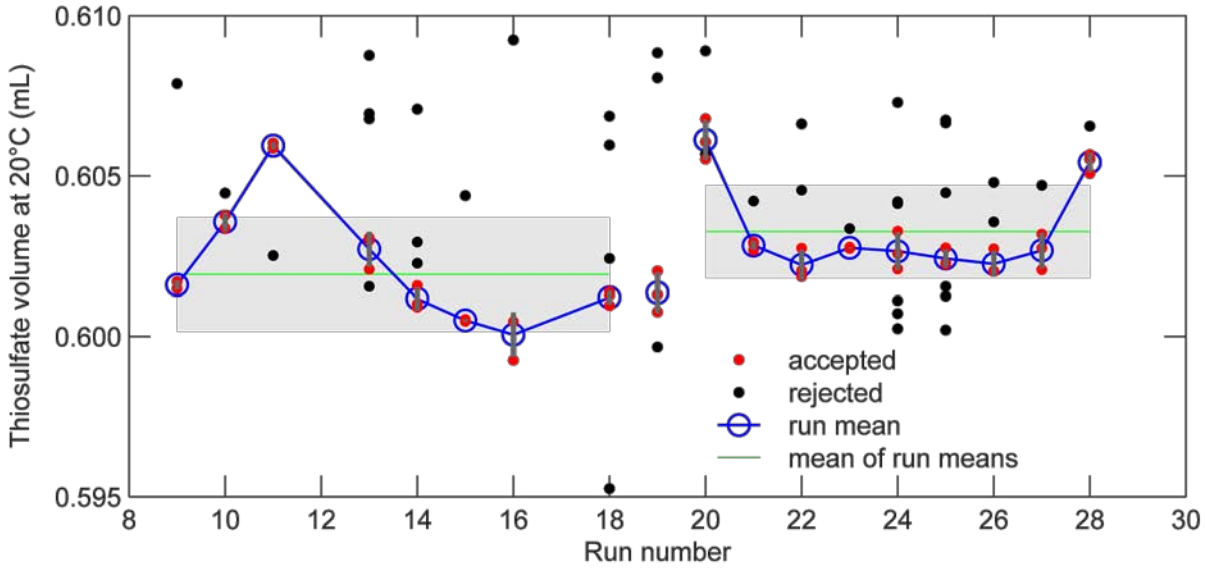

Figure C.3a.2 Hudson 2007011 oxygen titration standards. About 54% of the individual standards were flagged by the operators as unacceptable and excluded from the run statistics. Individual accepted (50 values) and in-range rejected (41 of a total of 58) standards are shown. Also shown are mean values (blue circles) and standard deviations (vertical grey bars) based on between 2 and 4 individual accepted values for a run and the overall means (green lines) and standard deviation (horizontal grey bars) for all accepted standards for Runs 9–18 and 20–28 which used the same batches of potassium iodate and thiosulfate.

The mean run-mean values of thiosulfate volume for the two groups are 0.60209 and 0.60326 mL. There was a moderately significant increase in volume of 0.00116 mL or 0.19% of the Group 1 mean, $t(16) = 1.42$, $p < 0.088$. Since the normality of the second iodate batch was about 0.17% lower than the normality of the first batch, the titration of a given volume of the second batch would require about 0.17% less thiosulfate of a given normality than a titration of the same volume of the first batch. The observed increase in volume for the second group implies that its normality is less than the normality of the first batch.

The intra-run standard deviation of thiosulfate volume varied from 0.00002 to 0.00069 mL with an overall rms value of 0.00042 mL or 0.07%. Note however that the statistics are based on very few values: 4 of the 18 runs had only two valid standards and the remaining 14 runs had three valid standards. The intra-run standard error of the mean varied from 0.00001 to 0.00040 mL with an overall rms value of 0.00024 mL. These values are similar to the intra-run blank statistics.

Changes in run-mean volume for Group 1 describe a roughly sinusoidal pattern with a standard deviation of 0.00192 mL, about 5 times the rms intra-run standard deviation. Group 2 shows less scatter except for high values for Runs 20 and 28. The Group 2 standard deviation is 0.00145 mL, about 3 times the rms intra-run standard error of the mean. The variance of the first group is 1.8 times the variance of the second group but with little statistical significance; $F(7,8) = 1.42$, $p = 0.223$. The rms standard deviation is 0.00170 mL. The standard deviations of thiosulfate volume and the quoted median value of Vstd–Vblk,dw correspond to fractional change in dissolved oxygen of about 0.2–0.3% (second term on the right hand side of Eq. 6).

g. Thiosulfate normality

Thiosulfate normalities corrected to 20°C calculated from individual standard titrations and run-mean blanks using Eq. 4 are plotted against run number in Figure C.3a.3. Run 19 shared the first batch of thiosulfate with Runs 9–18 so in principle it could be included in the first group but the grouped means in Figure C.3a.3 exclude Run 19 as in Figure C.3a.2. The overall pattern of change in Figure C.3a.3 mirrors that in Figure C.3a.2 with a change in sign since changes in standards dominate the changes in thiosulfate normality. Run 20 is less of an outlier in Figure C.3a.3 than in Figure C.3a.2 because the relatively high Run 20 blank partially compensates for the high Run 20 thiosulfate volume.

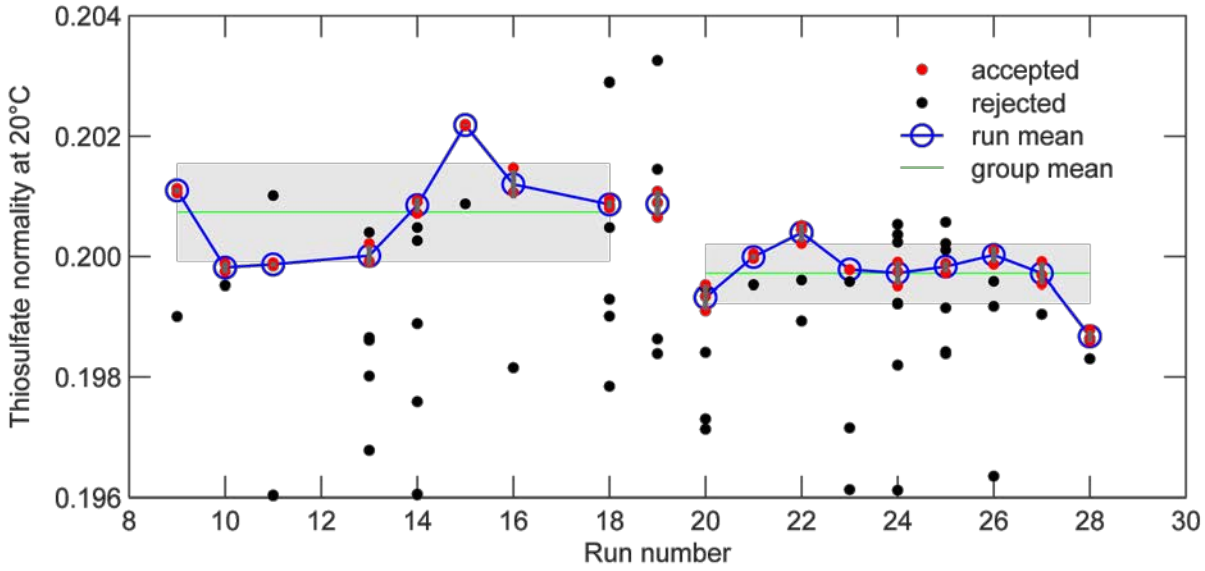

Figure C.3a.3 Hudson 2007011 thiosulfate normality from standard titrations and run-mean blanks. Individual accepted (50 values) and in-range rejected (53 of a total of 58 values) are shown. Also shown are mean values (blue circles) and standard deviations (vertical grey bars) of all accepted individual values for a run and the means (green lines) and standard deviations (horizontal grey bars) for Runs 9–18 and 20–28 which used common potassium iodate and thiosulfate solutions.

The mean values of the two groups (excluding Run 19) are 0.20074 N and 0.19972 N and the standard deviations are 0.00081 N and 0.00048 N or 0.2–0.4% of the group means. Standard 95% error limits for the mean values of thiosulfate normality are [0.20008 0.20140] N and [0.19935 0.20008] N or about ±0.3% and ±0.2% for Groups 1 and 2 respectively. The Group2 mean is significantly less (-0.51%) than the Group 1 mean, $t(16) = -3.19$, $p < 0.003$. The overall rms intra-run standard deviation in thiosulfate normality is 0.00014 N or about 0.07% of the mean for the 18 runs including Run 19.

The normality of a thiosulfate solution is expected to decrease gradually with age as a result of air oxidation and other chemical and bacteriological reactions (Green, 1965). In Green's study of the solubility of oxygen in seawater, periodic standardizations of a 0.2 N sodium thiosulfate solution stored in a tightly stoppered brown bottle showed no detectible change in concentration over a 4-month period. If changes do occur, well-defined trends might be expected if all systems were working well. Periodic standardizations of a given batch of thiosulfate are meant define its initial normality and monitor any changes as they occur. The intra-group variability in Figure

C.3a.3 does not fit such a model. Large random changes are problematic because they mask any gradual change in normality if such change occurs and in any case limit the precision of any estimate of the mean value of normality.

h. Comparison with CTD oxygen

The CTD used on Hudson 2007011 was equipped with dual SBE43 dissolved oxygen sensors. Sea-Bird (2007) notes that the "SBE43 is a polarographic membrane oxygen sensor having a single output signal of 0 to +5 volts, which is proportional to the temperature-compensated current flow occurring when oxygen is reacted inside the membrane." The sensors used on the cruise had serial numbers 430042 (primary) and 430133 (secondary). Both sensors were serviced and recalibrated by the manufacturer in late-2005 and early-2006. In the case of secondary Sensor 430133 this included the replacement of the spar assembly.

CTD oxygen concentrations were derived following Owens & Millard (1985) described in Sea-Bird (2007) as

$$Oxygen(mL/L) = Soc \cdot \left(V + V_{offset}\right) \cdot Oxsat(S,T) \cdot e^{(tcor*T)} e^{(pcor*P)} \qquad \text{Eq. 7}$$

where V is CTD oxygen voltage, S, T, and P are CTD salinity, temperature, and pressure, Oxsat(S,T) is the oxygen saturation concentration in seawater and Soc, Voffset, tcor, and pcor are calibration coefficients. The 2005–2006 calibrations referred to above were created using oxygen saturations following Weiss (1970). Since 2008, Sea-Bird (2008) has recommended the use of the updated oxygen saturation algorithm of Garcia & Gordon (1992). The differences in the two versions of oxygen saturation (Garcia & Gordon – Weiss) for Hudson 2007011 bottle samples ranged between approximately −0.04 mL/L and 0.01 mL/L with an rms difference of about 0.02 mL/L.

Bottle oxygen values were manually screened for gross outliers prior to the analyses discussed below. The first step used differences of bottle oxygen values and cruise values of CTD oxygen based the manufacturer's calibrations. Additional outliers were identified with a criterion based on the median absolute deviation of these differences for each sensor and cast. This quality control step removed about 9% of downcast values and 3% of upcast values. Larger differences between bottle and downcast CTD oxygen values are expected because the bottle samples are taken on the up casts and there may be temporal changes in dissolved oxygen between the down and up casts. The manufacturer's calibrations from 2005–2006 gave CTD oxygen that was biased low, with mean differences for approximately 700 quality-controlled differences of about 0.4 mL/L and 0.2 mL/L for the primary and secondary SBE43 sensors respectively [Table C.3a.1]. The corresponding standard deviations were about 0.08 mL/L and 0.05 mL/L.

CTD oxygen voltage, salinity, temperature, pressure, and oxygen saturation at pressures corresponding to the Rosette samples were refit to bottle oxygen values following Eq. 7 using Weiss (1970) for consistency with results also shown in Table C.3a.1. Separate fits were done for down and up casts, since hysteresis effects related to sensor time lags are not included in the correction model. Outlying residuals from an initial regression were flagged by a robust

screening criterion based on the median absolute deviation of the residual values for each sensor and cast. The reported results are from a second regression that excluded about 6% of downcast values and 1% of upcast values that had been identified as outliers. The local fits had negligible biases of at most ±0.002 mL/L. Both sensors gave downcast residual variances larger than the corresponding upcast residual variances. The secondary sensor gave the best performance. The increased primary sensor residuals are partly explained by jumps in the output of the primary sensor at the start of the upcasts of Events 13 and 16. The primary sensor also showed larger differences between down- and up-cast oxygen voltage profiles.

S/N	Source	Soc volt^{-1}	Voffset volt	tcor °C^{-1}	pcor dbar^{-1}	rms mL/L
430042	29 Dec 2005	0.3679	-0.4993	0.0012	1.35E-04	0.411(dn)
						0.465(up)
430133	21 Jan 2006	0.3660	-0.6451	0.0001	1.35E-04	0.163(dn)
						0.193(up)
430042	primary dn	0.3979	-0.5099	0.0011	1.30E-04	0.061
430042	primary up	0.3909	-0.4496	0.0008	1.25E-04	0.049
430133	secondary dn	0.3765	-0.6560	0.0013	1.33E-04	0.038
430133	secondary up	0.3719	-0.6221	0.0022	1.31E-04	0.031

Table C.3a.1 CTD oxygen calibration coefficients from the manufacturer and from fits to bottle oxygen values for both down and up casts and rms differences between corrected CTD and bottle oxygen values.F:\D\Data\AR7W\ar7w_2007\data\oxygen\oxygen_calibration_2007011.xls Worksheet coefficients A6:G15

Figure C.3a.4 plots residual bottle minus locally-calibrated CTD oxygen vs bottle oxygen run number for the best-fitting secondary sensor upcast case. Run-mean differences range from −0.05 to 0.03 mL/L with an overall mean value of −0.002 mL/L. About 41% of the residual variance is related to changes in run-mean values, with the remained due to intra-run variability. The expected changes in bottle oxygen attributable to variations in run-mean blanks and standards from Eq. 1 above are also shown in Figure C.3a.4. The changes due to the sum of these effects are similar to the changes in run means. The fitting procedure minimizes the average squared difference between bottle oxygen and CTD values with no reference blanks and standards. It appears that almost half of the variability in run-mean bottle minus corrected CTD oxygen is related to bottle oxygen offsets associated with variability in run-mean standards and blanks.

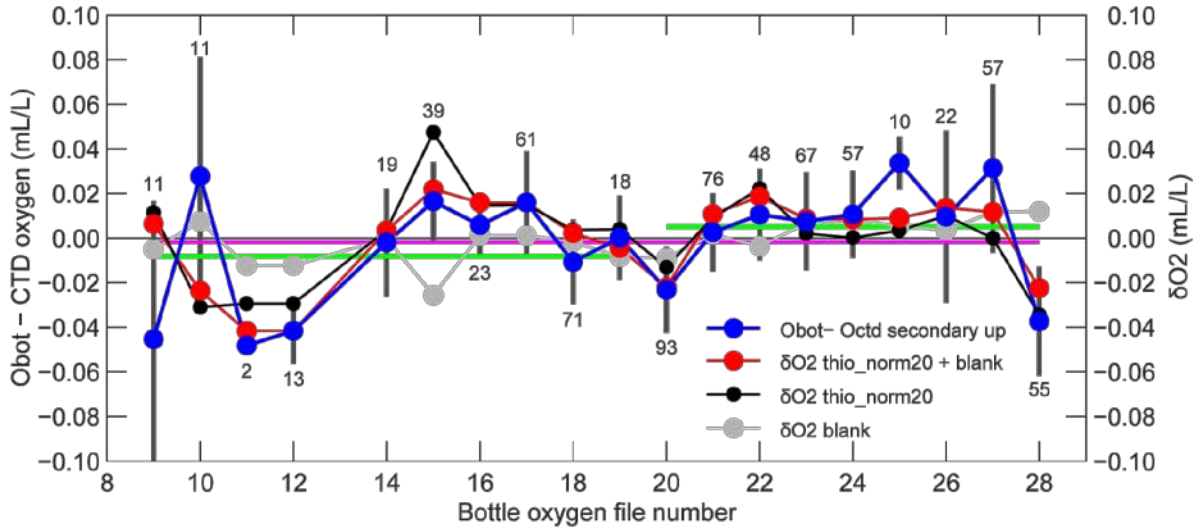

Figure C.3a.4 Run-mean values of differences between bottle and calibrated secondary upcast CTD oxygen as a function of run number (blue). The number of valid comparisons for each run is appended. Vertical lines represent one-standard-deviation error bars. The overall mean (magenta line) and the means for the extended Group 1 including Run 19 and Group 2 (green lines) are also shown. The expected differences associated with run-mean blanks and standards and their sum as discussed above are also shown.

The means of the 10 run-mean residuals for extended Group 1 including Run 19 and the 9 values for Group 2 were −0.008 mL/L and 0.005 mL/L respectively, with associated standard deviations 0.027 mL/L and 0.023 mL/L. Neither of the group means differs from zero with any high significance. The difference in mean values of 0.013 mL/L or about 0.2% of a nominal 6.6 mL/L oxygen concentration is also not different from zero with any high significance, $t(17) = 1.15$, $p < 0.132$. Any real difference in the mean bottle oxygen values for the two groups is masked by high variability in the run-mean values.

To emphasize the relative variability, the group-mean differences were removed. This is equivalent to changing the bottle oxygen values by subtracting the group-mean differences from each group. The results in Figure C.3a.5 emphasize the similarity between bottle minus corrected CTD oxygen and the expected changes in bottle oxygen attributable to variations in run-mean standards and blanks. The adjusted group mean values are zero by construction. The overall standard deviation was reduced slightly to 0.024 mL/L. The first two cases involving Runs 9 and 10 stand out as exceptions. Both cases involved samples from a single station.

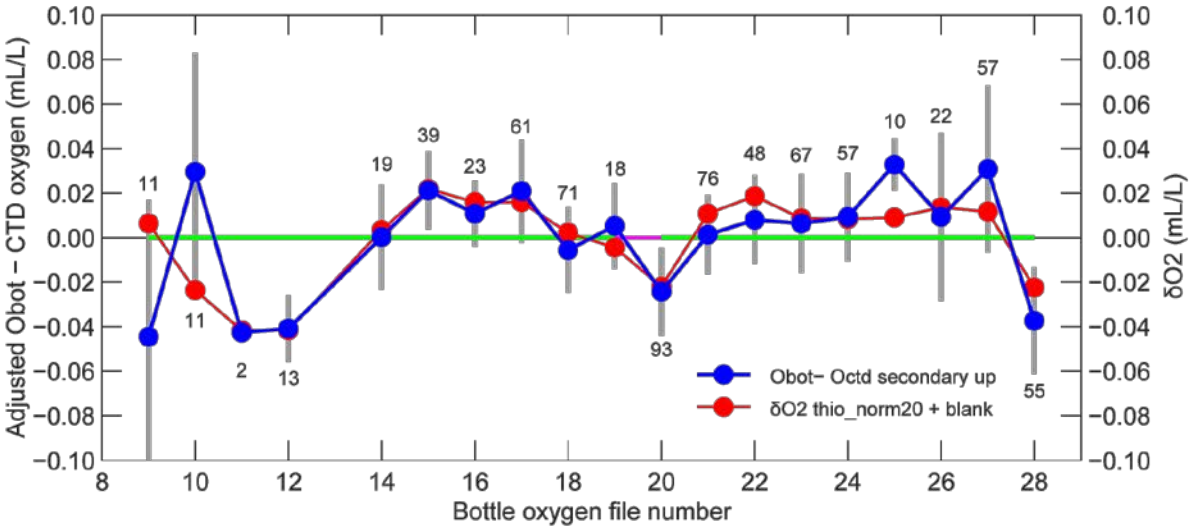

Figure C.3a.5 Run-mean values of differences between adjusted bottle oxygen values and calibrated secondary upcast CTD oxygen as a function of run number (blue) as in Figure C.3a.4. The overall mean (magenta line) and group means (green lines) are zero by construction. The sum of the expected differences associated with run-mean blanks and standards is repeated from Figure C.3a.4.

Figure C.3a.6.shows a scatter plot and regression line for the values from the two time series in Figure C.3a.5. The slope of the regression line 0.82 is not significantly different from unity at the 95% confidence level. A regression using only the 14 cases with at least 14 valid bottle − CTD oxygen values (excluding Runs 9–12 and 25) gave a tighter fit R2 = 0.76, t(12) = 6.24, p < 0.000 and a regression slope of 1.11, also not significantly different from unity at the 95% confidence level.

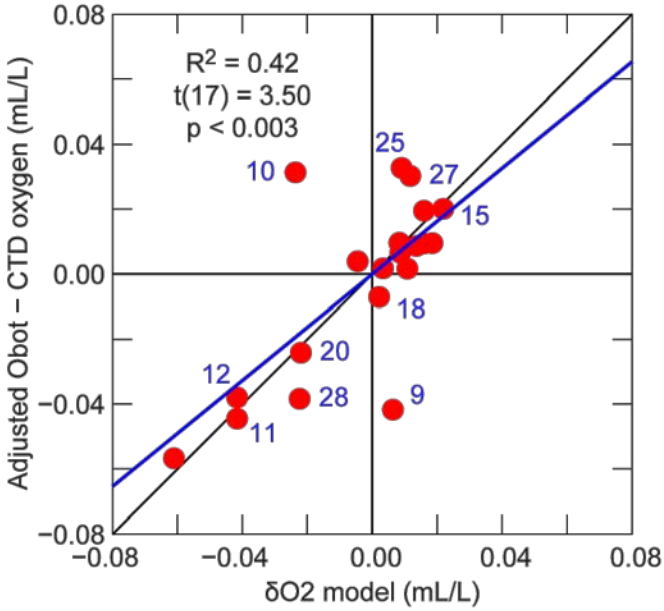

Figure C.3a.6 Scatter plot of run-mean values of differences between adjusted bottle oxygen values and calibrated secondary upcast CTD oxygen and the sum of the expected differences associated with run-mean blanks and standards from Eq. 6 above. Selected points are labelled with run number.

As a final step, fits to the CTD oxygen model were redone with bottle oxygen values recalculated using the mean of all run-mean blanks and the means of run-mean thiosulfate concentrations from extended Group 1 and Group 2 respectively for the associated samples. The results in Table C.3a.2 show that the residual variance was reduced for all cases by about 60% compared to the results in Table C.3a.1. The rms residual for the best-fitting was 0.027 mL/L. The slope, offset, and temperature coefficients are highly correlated so although the values of the coefficients changed slightly the fitted CTD oxygen values were essentially unchanged.

S/N	Source	Soc volt^{-1}	Voffset volt	tcor °C^{-1}	pcor dbar^{-1}	rms mL/L
430042	primary dn	0.3975	-0.5053	0.0009	1.30E-04	0.064
430042	primary up	0.3904	-0.4450	0.0006	1.24E-04	0.050
430133	secondary dn	0.3754	-0.6477	0.0012	1.32E-04	0.035
430133	secondary up	0.3714	-0.6184	0.0020	1.30E-04	0.027

Table C.3a.2 CTD oxygen calibration coefficients from fits to bottle oxygen values recalculated with an overall-mean blank and group-mean thiosulfate concentrations for both down and up casts and rms differences between corrected CTD and bottle oxygen values.

i. Summary

The replicate statistics from Section C.3 above give no significant bias and a standard deviation of 0.009 mL/L (0.15% of 6 mL/L) associated with random errors in sample drawing and titration. This is close to but slightly larger than the hoped-for 0.1%. Both oxygen analysts were experienced in shipboard oxygen analyses. Winch room personnel responsible for drawing oxygen samples included both experienced staff and first-time student volunteers. It might be expected that the new trainees would not be as proficient in drawing samples as the more experienced watchstanders. Occasional periods of rough weather could both have influenced the scatter in replicate samples.

About 54% of the individual standards and 60% of the individual blanks were flagged by the analysts as unacceptable and excluded from the run statistics. This is typical of results in recent years but is troubling in that it suggests a lack of stability in the standardization process. A significant amount of time and general frustration could be saved if the sources of this variability could be identified and better controlled. Run-mean standards and blanks showed large variability relative to expected changes in reagent concentrations over the cruise period. It has been suggested that the use of deionised water from Hudson's reverse osmosis system in the standardization procedure is a possible source of contamination and it is agreed that laboratory-grade deionised water should be brought to sea for this purpose.

Corrected upcast CTD oxygen voltage from the best-performing secondary oxygen sensor based on quality-controlled bottle oxygen gave residual rms values of 0.031 mL/L or about 0.5%. Only 60% of this variance (0.25 mL/L rms) appears to be associated with random errors in sample drawing and analysis, with the remaining 40% (0.20 mL/L rms) associated with systematic errors in run-mean standards and blanks. A CTD calibration model that averages over all stations will tend to average out this systematic variability. A CTD calibration model that allows for time dependence could reduce the residual variance in a fitting procedure but introduce errors in the CTD values by projecting run-mean bottle oxygen offsets onto the calibrated CTD oxygen.

The effects of hysteresis associated with sensor time lags are not included in the Sea-Bird (2007)calibration model. Preliminary results for the 2007 data set using the revised model described in Sea-Bird (2008) are promising, but more comprehensive support of our sea-going oxygen measurement effort may be needed to fully realize the potential improvement in the accuracy of our CTD oxygen data.

4. Nutrients — Carol Anstey

Description of equipment and technique

Samples were analyzed for silicate, phosphate, and total nitrate (nitrate plus nitrite) using a Technicon Autoanalyzer II. The chemistries were standard Technicon for Seawater Analysis (Silicate 186-72W, Phosphate 155-71W, Nitrate/Nitrite 158-71W) except for Phosphate which has been modified by separating the Ascorbic Acid (4.0 gm/L from the Mixed Reagent. This modification was achieved by introducing the modified Mixed Reagent instead of water at the start of the sample stream at 0.23 mL/min. and introducing Ascorbic Acid into the stream between the two mixing coils at 0.32 mL/min (Strain & Clement, 1996).

Sampling procedure and data processing technique

Duplicate nutrient samples were drawn into 30 mL HDPE (Nalge) wide-mouth sample bottles from the 10 L Rosette bottles. The sample bottles were pre-washed in 10% HCl, rinsed three times with Alpha-Q (deionized water) and oven dried at >100°F.

A sample run included six Calibration Standards, analyzed in duplicate, at the beginning and end. The standards, wash water and blanks were made up in 33 ppt NaCl (Sigma, ACS Reagent.) The second most concentrated Calibration Standard was used as a Check Standard every 16 samples followed by blanks as a baseline check. The standards were checked against an Intercalibration Reference Material MOOS-1 for nutrients produced by NRC, Ottawa. [http://www.nrc-cnrc.gc.ca/obj/inms-ienm/doc/crm-mrc/eng/MOOS-1_e.pdf]

The raw analog data was converted to digital data, processed and concentrations calculated, including statistics, by an in-house Pascal 7.0 program (AAII) on a PC. Chart recordings, hard copy and disk copies of the data were archived.

Note that samples are stored at 4°C and allowed to warm to ambient lab temperature before analysis.

Replicate analysis

A total of 1942 duplicate samples were analyzed for HUD2007011. Samples were analyzed as soon as possible after collection. Any samples collected off watch were kept refrigerated (~4ºC) and analyzed within eight hours of collection.

There were no technical problems encountered during this cruise. All sample runs were excellent: stable baselines and very good calibration RMS – ‘fit to curve’. Only the phosphate baseline for May 26, 2007 analysis was unstable. This was soon addressed by changing the pump tubes and an extra acid cleaning of the phosphate heater to remove molybdate build up. There were some problems during the first few analyses with air bubbles slipping into the flow cells causing erroneous air peaks. This was fixed by tilting the colorimeters by 20º. The air peaks did not interfere with the final voltage data as the program has been written to edit these out. Since the problems encountered last year on HUD2006019, we have been able to replace old equipment. The nitrate and phosphate colorimeters have been replaced with rebuilds from Pulse Instrumentation. The voltage regulators replaced with new. Data was still being collected using

the last spare IO board. The search for a replacement is ongoing. Last year's problems with white Azo-dye precipitate continuously building up in the nitrate line and the degassing of the ascorbic acid reagent for silicate forming bubbles which would get caught in the flowcell were not encountered. The high, and difficult to regulate, lab temperatures which may have contributed to these problems last year were much more stable and cooler. Average lab temperatures stayed between 22ºC to 26ºC as compared to sometimes 35ºC last year. This was probably due to cooler temperatures outside. Fans were still used to help cool the whole lab along with keeping portholes and deck doors open during calm weather.

The data quality parameters, determined with check standards, MOOS-1 Intercalibration Reference Standard and RMS offset from the calibration curve, came well within accepted values. Frequent flushing of the system with 1N HCl followed by Alpha-Q water helped to prevent sample flow problems and build-up of molybdate coating of the flow cells. Table C.4.1 summarizes the QC/QA MOOS-1 results.

QC/QA MOOS-1		Silicate µM	Phosphate µM	NO2+NO3 µM
Accepted Values	from	25.00	1.490	22.80
	to	27.00	1.630	24.60
Analytical Results		26.54	1.595	25.30
		26.09	1.641	24.99
		26.00	1.607	24.94
		25.52	1.572	23.99
		25.67	1.562	24.07
		26.50	1.624	25.18
		26.61	1.624	25.23
		26.20	1.614	25.27
		26.36	1.621	25.90
		26.13	1.624	24.05
		26.10	1.607	24.16
		26.15	1.611	23.92
		26.31	1.620	24.35

Table C.4.1 Summary of nutrient QC/QA MOOS-1 data for HUD2007001/1.

RMS offset from the predicted calibration curve is a measure of how acceptable the calibration was for a specific analysis run. There is no firm cutoff for 'good' or 'bad' data. Table C.4.2 lists acceptable limits for RMS fit determined by averaging 34 runs of data deemed to be acceptable by peak shape, stability of the baseline and precision between duplicates.

	Silicate µM	Phosphate µM	NO2+NO3 µM
Mean (n = 34)	0.115	0.042	0.089
Std. Deviation	0.115	0.020	0.043
Maximum	0.695	0.111	0.271
Cruise Average	0.102	0.013	0.074

Table C.4.2 RMS offset from curve nutrient data for HUD2007001/1.

Table C.4.3 gives RMS offsets from the predicted calibration curve for individual analysis runs.

Analysis Date	Silicate µM		Phosphate µM		NO2+NO3 µM	
	initial	final	initial	final	initial	final
10 May 2007	0.038	0.047	0.009	0.010	0.040	0.014
11 May 2007	0.052	0.094	0.013	0.013	0.038	0.050
12 May 2007	0.044	0.054	0.009	0.013	0.023	0.108
13 May 2007	0.008	0.059	0.008	0.006	0.053	0.010
14 May 2007	0.027	0.015	0.008	0.008	0.042	0.024
15 May 2007	0.012	0.107	0.009	0.014	0.021	0.133
16 May 2007	0.048	0.070	0.005	0.008	0.020	0.008
17 May 2007	0.075	0.042	0.014	0.008	0.055	0.054
18 May 2007	0.029	0.031	0.024	0.012	0.032	0.019
19 May 2007	0.211	0.520	0.014	0.025	0.117	0.345
20 May 2007	0.016	0.061	0.010	0.012	0.026	0.047
21 May 2007	0.040	0.019	0.007	0.011	0.050	0.027
24 May 2007	0.061	0.045	0.010	0.010	0.011	0.081
25 May 2007	0.036	0.360	0.011	0.019	0.031	0.222
26 May 2007	0.051	0.489	0.022	0.023	0.064	0.294
27 May 2007	0.486	0.013	0.023	0.011	0.279	0.021

Table C.4.3 RMS values for individual nutrient analysis runs for HUD2007001/1.

Precision is a measure of the variability of individual measurements and in the following analysis two categories of precision are determined: field and analytical precision. Analytical precision is based on the pooled estimate of the standard deviation of the check standards over the course of a complete autoanalyzer run and is a measure of the greatest precision possible for a particular analysis. Field precision is based on the analysis of replicate water samples taken from a single rosette sample bottle and has an added component of variance due to subsampling, storage and natural sample variability.

Both categories of precision are determined by computing the variance ($\sigma 2$) of each replicate set, where i is the index of the replicate set. In the case of analytical (field) precision, a replicate set consists of all the check standards (duplicate samples). Given p replicate sets and n samples within any replicate set, the mean standard deviation ($\overline{\sigma}$) is determined from

$$\overline{\sigma} = \sqrt{\frac{\sum_{i=1}^{p}(n-1)_i \sigma_i^2}{\sum_{i=1}^{p}(n-1)_i}}$$

The precision P expressed in percent is based on the mean concentration (M) of the check standards (analytical precision) or water samples (field precision) and is given by

$$P = \frac{\overline{\sigma}}{M} \times 100\%$$

Table C.4.4 indicates the detection limits and field precisions obtained for this cruise. The detection limits are three times the standard deviation of the blank values. Robust estimates of field precision are derived as outlined above by excluding standard deviations greater than 9 times the median absolute deviation (MAD) of the replicate standard deviations also reported in Table C.4.4. The excluded outliers accounted for about 2% of the samples for each of the three nutrients.

	Silicate	Phosphate	NO2+NO3
Number of Samples	971	971	971
Number of Duplicates	1942	1942	1942
Mean concentration (µM)	9.30	0.937	13.51
Median concentration (µM)	8.80	1.006	15.57
MAD of replicate standard deviations (µM)	0.02	0.002	0.03
Field Precision (µM)	0.04	0.006	0.07
Field Precision (%) based on median values	0.5%	0.6%	0.4%
Detection Limit (µM)	0.29 ±0.14	0.02 ±0.01	0.10 ±0.04

Table C.4.4 Detection limits and field precision for nutrients on HUD2007001/1.

The nutrient detection limits noted in Table C.4.4 are an average of all analytical runs for the cruise. Individual daily detection limits were applied to the corresponding daily data sets.

Note that all results in this report are given in volume units µmol/L or µM. In some earlier reports the analytical precision and detection limits were converted to mass units µmol/kg using a standard density of 1 024.43 kg/m3 corresponding to salinity 33 and temperature 15°C.

Means of duplicate measurements and densities based on CTD salinity values and the average ambient lab temperature (22–26ºC range) were used to compute the values in mass units given in the HUD2007011 SEA file.

5. Dissolved Inorganic Carbon in Seawater — Kumiko Azetsu-Scott

a. Description of equipment and technique

The total dissolved inorganic carbon content of seawater is defined as the total concentration of carbonate ion, bicarbonate ion and unionized species of carbon dioxide. Before analysis, the sample is treated with acid to convert all ionized species to the un-ionized form, which is then separated from the liquid phase by gas purging and subsequently measured using a coulometric titration technique. This involves the reaction of carbon dioxide gas with a dimethysulfoxide solution of ethanolamine to produce hydroxyethylcarbamic acid. The acidic solution is titrated with hydroxide ion formed by the electrolytic decomposition of water. The progress of the titration is followed through colorimetric measurement of the absorbance of a pH indicator dye (thymolphthalein) in the ethanolamine solution.

A known volume of seawater is dispensed into a stripping chamber from a pipette of known volume and temperature controlled to within 0.4°C. It is then acidified with ten percent of its volume of a 10% solution of carbon dioxide-free phosphoric acid. The solution is stripped of carbon dioxide gas by bubbling with a stream of nitrogen gas directed through a glass frit. The carrier gas exiting the stripper passes through a magnesium perchlorate trap to remove water vapour and acidic water droplets. The gas stream is then directed into the coulometric titrator where the total amount of carbon dioxide gas is quantified.

b. Sampling procedure and data processing techniques

Samples for total inorganic carbon were collected and analyzed from selected levels on full-depth casts at Station 27, at all sites occupied on the AR7W line except L3_12 (no bottles were available for TIC measurements), on L2-line stations 6.5, 8, 10, 12, 13, 14, 15.5, 18, 19, 19a, and 20, and on Halifax Line stations 2, 3, 6, 7, 8, 9, 10 and 11. Ice conditions prevented the occupation of L3 stations 1–4 and 28.

Samples are drawn from the rosette immediately following the drawing of the oxygen samples in order to minimize exchange of carbon dioxide gas with the head space in the sampler. This exchange will typically result in a loss of carbon dioxide. It is desirable that the samples be drawn before half the sampler is emptied and within ten minutes of recovery. Clean borosilicate glass bottles are rinsed twice with 30–50 mL of the sample. The bottle is then filled from the bottom using a length of vinyl tubing attached to the spigot of the sampler. The sample is overflowed by at least a half of the volume of the bottle (typically 250 mL). A head space of 1% is left to allow for expansion without leakage.

Theoretically, the coulometer should give a direct measurement of the amount of carbon titrated based on calculations using the Nernst equation. In practice, the coulometer's calibration is checked using Certified Reference Materials obtained from the Scripps Institute of Oceanography, La Jolla, California. These samples are treated in the same manner as a seawater sample. Values are reported in units of μmol/kg. The overall precision of the analysis should be at least 1.5 μmol/kg for samples with concentrations in the range of 1800-2300 μmol/kg.

6. Alkalinity — Kumiko Azetsu-Scott

a. Description of equipment and technique

The total alkalinity of seawater is defined as the number of moles of hydrogen ion equivalent to the excess of proton acceptors (bases formed from weak acids with dissociation constants of less than K=10-4.5) over proton donors (acids with K>10-4.5) in a one kilogram sample. An automated potentiometric titration system is used to determine this quantity. During the course of the titration the pH is measured using a Ross combination electrode standardized using a Hansson seawater buffer. A known volume (~37 mL) of sample is measured in a calibrated, thermostated pipette and dispensed into an open cup. The alkalinity of the sample is estimated from its salinity and acid equivalent to 0.7 of this amount is added and the pH measured. A further three aliquots of acids are added to bring the titration to 90% completion. The Gran Function F3 (Stumm & Morgan, 1996) is then applied to these points to obtain a more refined estimate of the alkalinity. Five additional aliquots are then added to complete the titration.

b. Sampling procedure and data processing techniques

Samples for alkalinity were collected using the same procedures and from the same bottles as for Dissolved Inorganic Carbon (Section 5b).

The pH values for the last five points of the titration are used to evaluate the Gran Function F1 from which the final estimate of the equivalence point is obtained. Hydrochloric acid used in the titrations is calibrated is two ways, against a standard solution of sodium borate using an acid base titration and against potassium iodate using an iodometric titration with sodium thiosulphate. In addition, the calibration is checked using Certified Reference Materials obtained from the Scripps Institute of Oceanography, La Jolla, California. Values are reported in units of μmol/kg.

7. Halocarbons — Rick Nelson / Brian Robinson

a. Description of Equipment and technique

The series of halocarbon compounds that are analysed includes the chlorofluorocarbons CFC-12, CFC-11, CFC-113 and the halocarbons carbon tetrachloride and methyl chloroform. The analyses are carried out on two identical purge and trap systems developed at the Bedford Institute of Oceanography. Water samples are injected into the systems directly from the syringes used to collect the samples. The sample pipette is rinsed with a minimum of two volumes of water before the sample passes into the purge chamber that is held at 80°C. The halocarbons are purged from the sample for four minutes with ultra high purity nitrogen at a flow rate of 80 mL/min. The purged gasses are trapped in a Porapak-N trap that is cooled to a temperature of less than 10°C. The halocarbons are then desorbed by heating the trap to 170°C. A Varian 3300 Gas Chromatograph equipped with a 75 m DB 624 megabore column and electron capture detection is used for the separation and quantification of the halocarbons.

b. Sampling procedure and data processing techniques

Due to the length of time required for a single sample analysis (approx. 25 min) and the frequency at which the deep stations were sampled, it was not possible to collect halocarbon samples at all stations during the cruise. Station 27 was sampled at a single depth. On the AR7W

line halocarbons were sampled at selected depths on all primary stations except for L3_21 and L3-27. On the L2 line, samples were taken at stations 6.5, 8, 10, 12, 14, 15.5, and 18. All Halifax Line stations were sampled.

Samples are collected directly from the rosette using 100 mL syringes to avoid contact of the sample with the atmosphere. The syringes are rinsed three times before they are filled. To prevent contamination, the CFC samples are the first samples collected from the bottles. The samples are then stored in a water bath of continuously flowing surface seawater until analysis. The analysis of the samples is always completed within 24 hours after they have been drawn. The purge and trap system is also susceptible to contamination whenever it is open for maintenance and repairs. For this reason, blanks are run after the system has been open until a stable baseline can be achieved.

Chromatograms are analyzed using a commercial software package. Concentrations of the various components are evaluated from baseline-corrected peak areas. Calibration is carried out using working gas standards made up at Brookhaven National Laboratories. These standards have been calibrated in turn against a standard air sample ALM-64975 provided by the Climate Monitoring and Diagnostics Laboratory (CMDL) of NOAA in Boulder Colorado. Standard volumes are corrected for lab temperature and pressure. Results are reported in units of pmol/kg of seawater. Clean air samples are also analyzed at several stations as a check on the standardization.

8. Sampling for radionuclides (Iodine-137) John Smith

Water samples for shore-based analysis of Iodine-129 were collected in 1 L plastic bottles at the stations and water depths indicated in Table A.4.2.1. The bottle and cap were rinsed once, the bottles filled allowing a head space for expansion and capped, and the caps then sealed with black electrical tape. The samples were stored at ambient temperature in the chemistry container located on the main deck.

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E. APPENDICES

Appendix 1 Operation Notes Report

NOTE NUMBER	ENTRY TIME	PERSONNEL NUMBER	NOTES	CRUISE NUMBER	OPERATION ID
1	25 May 2007 02:18	104	CTD termination problem. Cast was stopped at 1300 and brought back on board for repairs.	2007011	227

Appendix 2 Mooring Logs

Placement

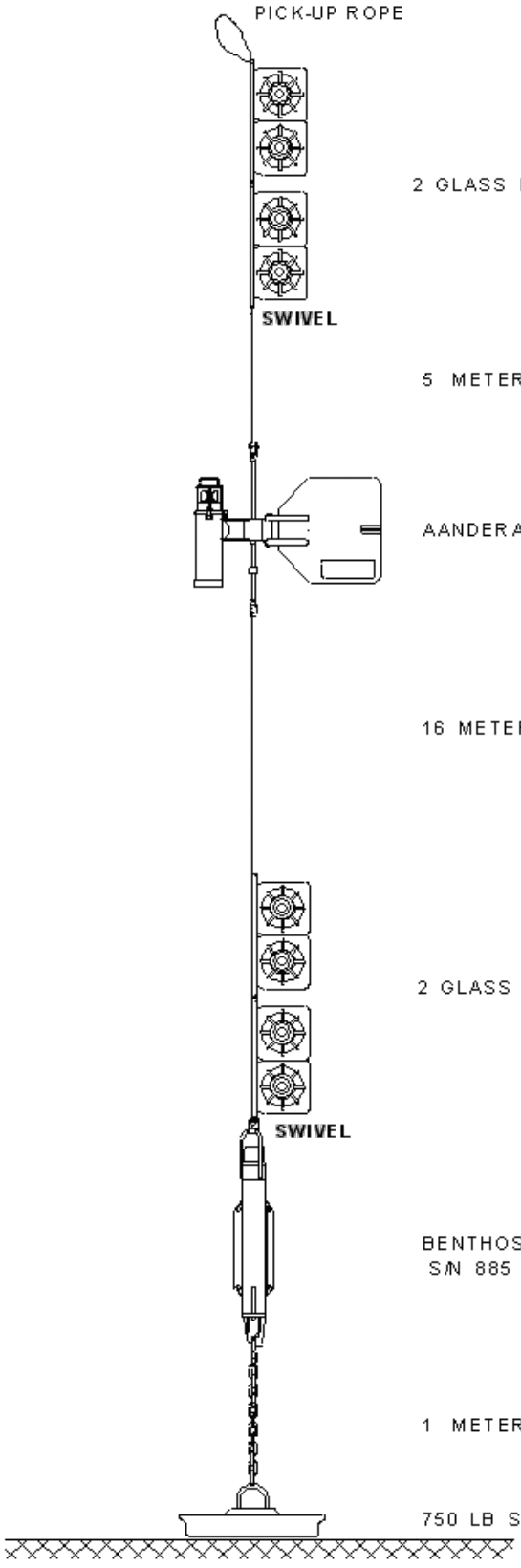
Mooring No. 1601
Geographic Area: Labrador Sea Intended Duration: 1 Year
Ship: CCGS Hudson Cruise No: 2006-019 Date: May 26, 2006
Sea State: 1 Weather Conditions: Calm, clear

Notship # N060874 Date Made May 31, 2006 Date Cancelled May 15, 2007
All Areas: Tel: 902-564-7751 or 1-800-686-8676
Fax: 902-564-2446 Email: notshipssyd@mar.dfo-mpo.gc.ca
Latitude: 55º 7.20' N Longitude: 054º 5.31' W Time of Fix: 1104 Z
Depth: Raw: 556 fathoms Corrected: 1030 meters
Main Float: Type: BUB Packages Markings: Yellow
Beacon: Type: None I.D. # n/a
Mooring Line: Type: 3/16" galvanized jacketed Colour: Yellow
Release: Type: Benthos 965A S/N: 885 Release Code: "C" 9.25 kHz

Placement Log

Time (Z)	Instrument	Remarks
1102	Floats	Floats in water.
1104		Anchor dropped 55º 07.2036' N 54º 05.4142' W.
		Sounding 556 fathoms (sounder speed 1473 m/s).
		A survey was performed using the Benthos deck unit, ship's position and sounder to position the mooring.

MOORING # 1601 CLARKE LAB SEA MAY 2006



Recovery

Mooring No. 1601
Ship: CCGS Hudson Cruise No: 2007-011 Date: May 13, 2007
Mooring Tech: R. Boyce
Type of Nav: GPS
Sea State: 2 Weather Conditions: Wind 20 Kt. 4 m swell
Cancel Notship: Yes Y No

Recovery Log

Time (Z)	Instrument	Remarks
1315		On site. Mooring Calibration successful (MCal).
1316		Release command sent. No apparent response.
1317		Release command sent. No apparent response.
1321		Release command accepted.
1325		Slant range 629 meters.
1331		Indicated on surface.
1336		In sight off starboard quarter.
1337		ELAC sounder switched from 0-5000 m to 0-2000 m.
1351		Manoeuvring to grapple mooring.
1353		Hooked on HIAB crane.
1355		RCM 4154 on board. Rotor spinning.
1358		Hauling on mooring winch.
1400		4 BUB packages and release on deck. End of recovery.

Performance

Include below if the mooring was successful or not, any corrosion, Guard buoys missing, release operation, partial recovery, mooring not in original position, dragging, any equipment damaged or any other information.

Mooring No: 1601

Successful mooring deployment and recovery.
All mooring tackle and instrumentation in good shape.
RCM 4154 appeared to have worked with the correct amount of data.

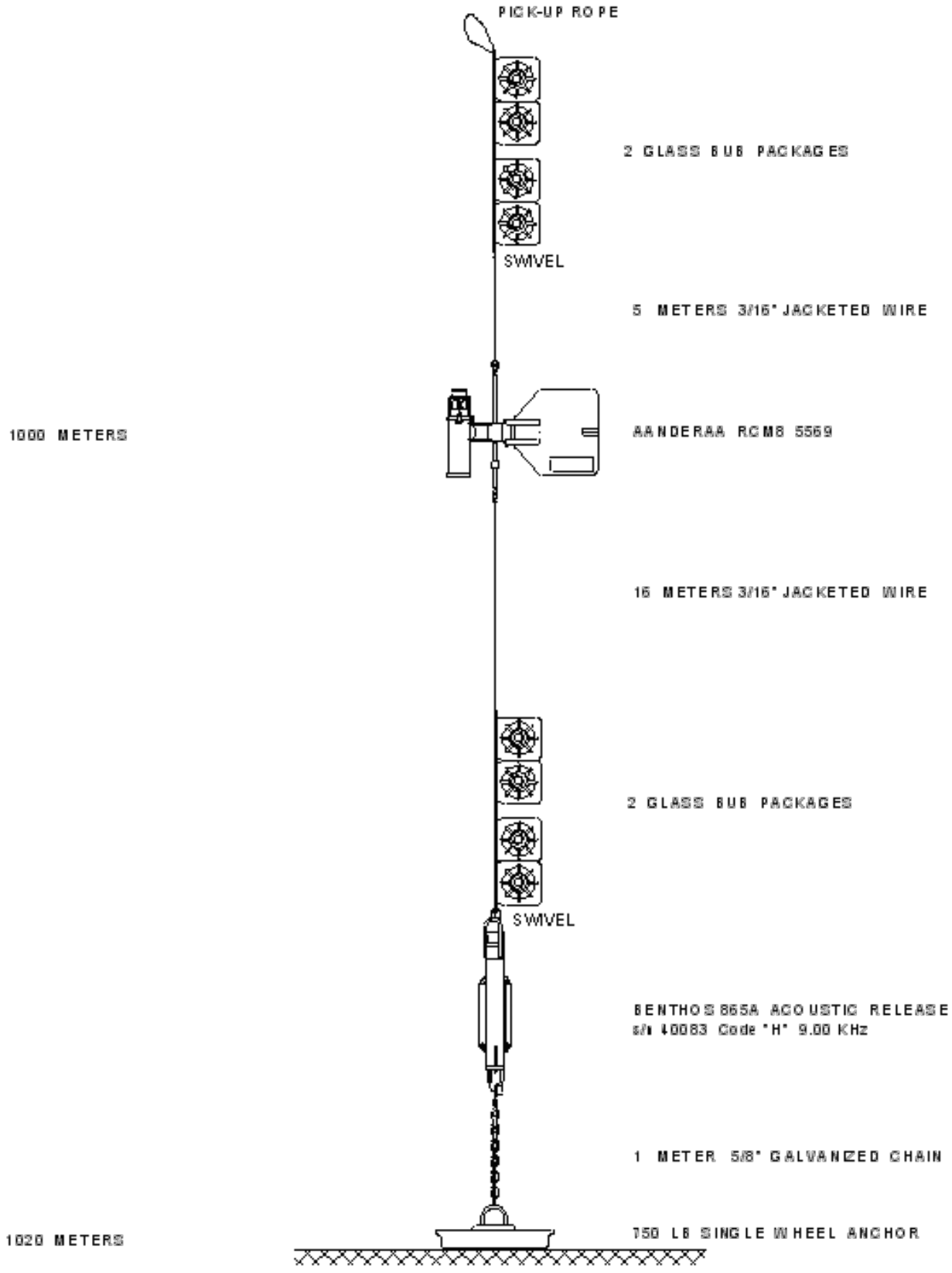
Placement

Mooring No. 1640
Geographic Area: Labrador Sea Intended Duration: 1 Year
Ship: CCGS Hudson Cruise No: 2007-011 Date: May 13, 2007
Sea State: 2 about 4 m swell Weather Conditions: Wind 20 kt, partial cloud
Mooring Technician: R. Boyce Navigation Inst. DGPS
Notship # N070509 Date Made May 15, 2007 Date Cancelled
All Areas: Tel: 902-564-7751 or 1-800-686-8676
Fax: 902-564-2446 Email: notshipssyd@mar.dfo-mpo.gc.ca
Latitude: 55º07.1427' Longitude: 054º05.3383' Time of Fix: 1511Z
Depth: Raw: 550 fathoms Corrected: 1019 meters
Main Float: Type: BUB Packages Markings: Yellow
Beacon: Type: None I.D. # n/a
Mooring Line: Type: 3/16" galvanized jacketed Colour: Yellow
Release: Type: Benthos 865A S/N: 40083 Release Code: "H" 9.00 kHz

Placement Log

Time (Z)	Instrument	Remarks
1420	RCM 5569	On deck, rotor spinning.
1430	Anchor	Lashed outboard.
		Westerly winds.
		Upwind = east to west
1511		Anchor away 55º 07.1' N 54º 05.2' W.
1523		On bottom.
		Start mooring calibration and logging (MCal).
1530		Locked on calibration.
		Preliminary position from MCal.
		55º 07.1' N 54º 05.3' W
		Based on 1489 m/s gives
		Depth 1026 m, rms 32 m.
1630		End of survey. End of deployment.

MOORING #1640 HENDRY LAB SEA MAY 2007



Appendix 3 CTD Initial Setup Information

Channel Designation	Parameter	Model Number	Serial Number	Calibration Date	System Number
Frequency 0	Temperature – Primary	SBE3	3P2298	29 Jun 2006	TS09
Frequency 1	Conductivity – Primary	SBE4	41873	13 Jul 2006	CS09
Frequency 2	Pressure – SBE9plus				
	s/n 9P15349-0475	410K-105	69009	05 Dec 1996	PP06
		Modulo 12P	362	31 Jan 1997	
Frequency 3	Temperature - Secondary	SBE3	3P2303	12 Apr 2007	TS10
Frequency 4	Conductivity - Secondary	SBE4	41874	11 Apr 2007	CS10
Voltage 0	Altimeter	2110-2	222	18 May 1999	AL01
Voltage 1	Fluorometer Chelsea	AquaTracka Mk 3	88172	10 Feb 1997	FL01
Voltage 2	Oxygen	SBE43	430042	29 Dec 2005	OX01
Voltage 3	Oxygen	SBE43	430133	21 Jan 2006	OX02
Voltage 4	Irrandiance (PAR)	LI-193SA	SPQA280	27 Mar 2003	IR02
		PN 90310	0002-CH1	17 Apr 1998	LA01
Voltage 5	Fluorometer, WetLabs	CDOM WETStar	WSCD-987P	18 Aug 2003	FL07
Voltage 6	Free	Free	Free		
Voltage 7	Free	Free	Free		

F. MANUFACTURERS

Aanderaa Data Instruments AS
Nesttunbrekka 97
N-5221 Nesttun Norway
http://www.aadi.no

Ashtech OEM
510 DeGuigne Drive
Sunnyvale, CA 94085 USA
http://ashtech-oem.com

Chelsea Technologies Group Ltd
55 Central Avenue
West Molesey, Surrey, KT8 2QZ UK
http://www.chelsea.co.uk

Guildline Instruments Limited.
21 Gilroy Street
Smiths Falls, ON K7A 4S9 Canada
http://www.guildline.com

LI-COR Biosciences
4647 Superior St.
Lincoln, NE 68504 USA
http://www.licor.com

ODIM Brooke Ocean
461 Windmill Road
Dartmouth, NS B3A 1J9 Canada
http://www.brooke-ocean.com

Rochester Wire & Cable
751 Old Brandy Rd.
Culpeper, VA 22701 USA
http://www.rochestercables.com

Sea-Bird Electronics, Inc.
1808 136th Place NE
Bellevue, WA 98005 USA
http://www.seabird.com

Software Engineering Associates
2316 Delaware Ave Suite #266
Buffalo, NY 14216-2687 USA
http://www.seanav.com

Teledyne Benthos
49 Edgerton Drive
North Falmouth, MA 02556 USA
http://www.benthos.com

Teledyne RD Instruments
14020 Stowe Drive
Poway, CA 92064 USA
http://www.rdinstruments.com

Teledyne Webb Research
82 Technology Park Drive E.
Falmouth, MA 02536-4441 USA
http://www.webbresearch.com

WET Labs, Inc.
PO Box 518
Philomath, OR 97370 USA
http://www.wetlabs.com

G. CONTENTS

CCHDO Data Processing Notes

Date	Person	Data Type	Action	Summary
2012-04-16	*Jeff Jackson*	CTD	Submitted	to go online
	Detailed Notes 1 dbar binned CTD files in CCHDO CSV file format			
2012-04-16	*Carolina Berys*	CTD	Website Updated	Available under 'Files as received'
	Detailed Notes File 18HU20070510_CTD.zip containing CTD data, submitted by Jeff Jackson on 2012-04-16, available under 'Files as received', unprocessed by CCHDO.			
2012-10-10	*CCHDO Staff*	BTL	Website Update	Available under 'Files as received'
	Detailed Notes The following files are now available online under 'Files as received', unprocessed by the CCHDO. 18HU20070510.exc.csv AR07W_2007do.pdf			
2012-10-10	*Bob Key*	BTL/CrsRpt	Submitted	to go online
	Detailed Notes 1. All of the data labeled NITRAT are actually NO3+NO2. This is noted in the header text, so if the column header is corrected, then the header text should be edited accordingly. 2. I ran all parameters of each cruise through QC. Many flags have been altered relative to the original submissions. In several cases I went back to the PI and got updates (mostly CTD calibrations).			
2012-11-20	*Jeff Jackson*	SUM	Submitted	to go online
	Detailed Notes Station Summary File			
2012-11-20	*Jeff Jackson*	CrsRpt	Submitted	to go online
2012-11-21	*Jeff Jackson*	SUM	Submitted	Minor change to Station Summary file.
2012-11-27	*Jerry Kappa*	CrsRpt	Processed	Final PDF ready to go online
	I've placed 1 new version of the cruise report: ar07w_18HU20070510do.pdf into the directory co2clivar/atlantic/ar07w/ar07w_18HU20070510/ It includes summary pages and CCHDO data processing notes as well as a linked Table of Contents and links to figures, tables and appendices. It will be available on the cchdo website following the next update script run.			