Beaufort Gyre Freshwater Experiment:
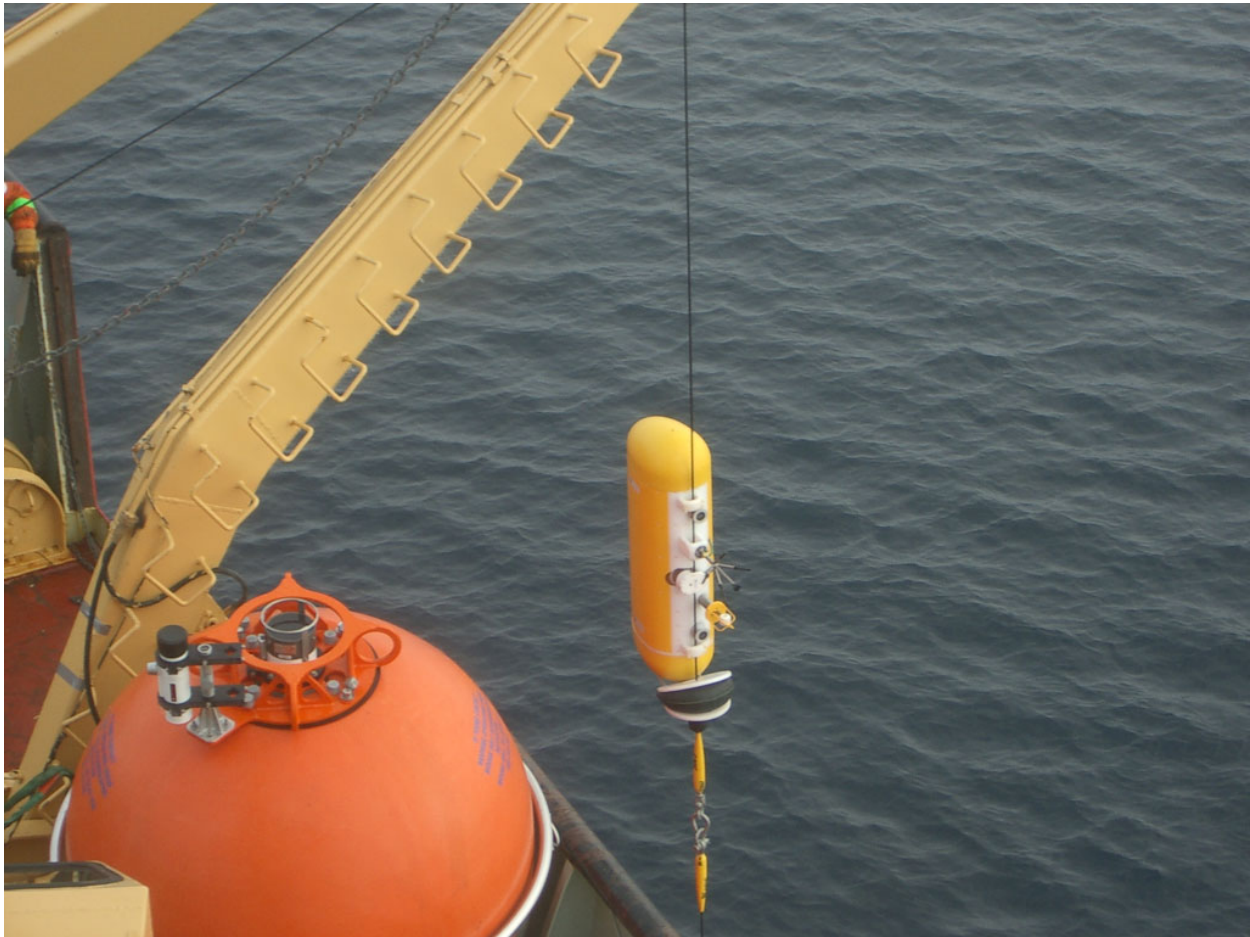# Deployment Operations and Technology in 2003

by W. Ostrom, J. Kemp, R. Krishfield, and A. Proshutinsky

Woods Hole Oceanographic Institution
Technical Report WHOI-2004-1

http://www.whoi.edu/beaufortgyre

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Abstract

The Beaufort Gyre Freshwater Experiment (BGFE) observational program was designed to measure the freshwater content of the upper ocean and sea ice in the Beaufort Gyre of the Arctic Ocean using bottom-tethered moorings, drifting buoys, and hydrographic stations. The mooring program required the development of a safe and efficient deployment method by which the subsurface system could be deployed in waters surrounded by sea ice. This report documents the mooring procedure used to deploy the three BGFE moorings from the CCGS Louis S. St-Laurent, during the Joint Western Arctic Climate Study – 2003 (August 6 – September 7). The technical details of the instrumentation attached to each mooring and the specific deployment parameters are described. Specifics pertaining to the deployment of four surface-tethered drifters in the ice are also documented.

1. Introduction

The major goal of the Beaufort Gyre Freshwater Experiment (BGFE) is to investigate basin-scale mechanisms regulating freshwater content in the Arctic Ocean and particularly in the Beaufort Gyre (BG). Specifically, the variability of different components of the BG fresh water (ocean and sea ice) system will be determined, and the partial concentrations of fresh water of different origin (rivers, Pacific Ocean, precipitation, ice/snow melt, etc) will be assessed. In conjunction with historical data and model studies, an observational program was established in August 2003 to measure freshwater content (in sea ice and in the ocean) and freshwater fluxes in the BG using moorings, drifting buoys, and remote sensing. The observed freshwater content variability in the BG, which acts to integrate the complex contributions from different factors, is expected to be the primary indicator of the ocean's response to climate change.

In particular: (1) links will be identified among accumulation and release of fresh water in the BG and atmospheric, hydrologic, cryospheric and oceanic processes, (2) the regional and temporal variability of relevant processes will be quantified in terms of freshwater fluxes, and (3) the relative importance of each factor that influences freshwater content and flux change under global warming conditions will be determined. The major hypothesis of the project is that the BG accumulates a significant amount of fresh water from different sources under anticyclonic (clockwise) wind forcing, and then releases this fresh water when this forcing weakens or changes direction to a cyclonic (counterclockwise) rotation (Figures 1-3). This accumulation and release mechanism could be responsible for the observed salinity anomalies in the North Atlantic and for a decadal scale variability of the Arctic system as the BG may both filter annual river inputs and pulse freshwater outflows (Proshutinsky *et al.*, 2003).

Support for the BGFE was provided to the principal investigator, Dr. Andrey Proshutinsky, WHOI, by the ARCSS program of the National Science Foundation. However, the project includes collaboration with other US (data sharing), Canadian (hydrographic program), UK (remote sensing) and Russian (historical data analysis) scientists.   In cooperation with Institute of Ocean Sciences (IOS), Canada and Japan Marine Science and Technology Center (JAMSTEC), the Canadian Coast Guard Icebreaker Louis St. Laurent (LSL) was utilized during the Joint Western Arctic Climate Study (JWACS) cruise for the field operations in 2003. The first recovery operations are scheduled onboard the US Coast Guard Icebreaker Healy in 2004. We envision a long-term observational program in the BG to monitor changes in hydrography, ocean circulation, and ice thickness as a contribution to the anticipated NSF SEARCH program.
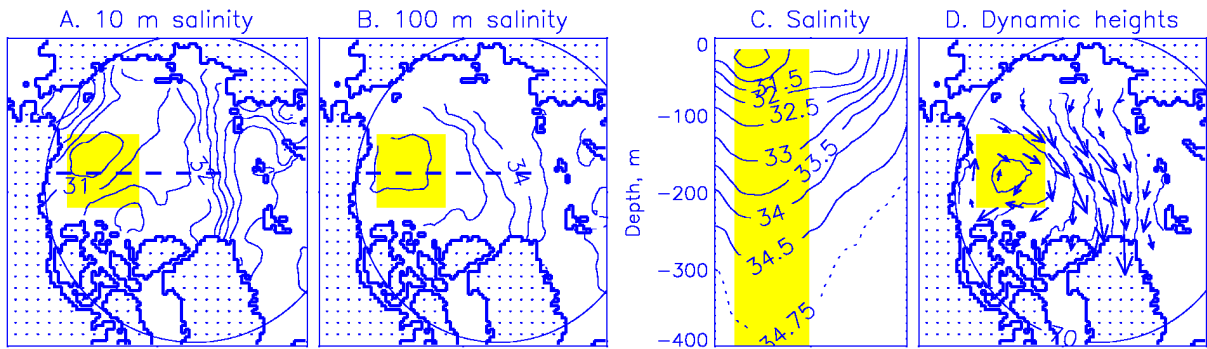
Fig. 1. Winter salinity at 10 (A) and 100 (B) meters. Section C shows the salinity distribution along the dashed line. Dynamic heights relative to 200 db and direction of geostrophic circulation are shown in D. There is a large−scale (1500x1500x0.4 cu. km) anticyclonically rotating lens of fresh water (BG circulation cell) in the Canadian Basin of the Arctic Ocean.
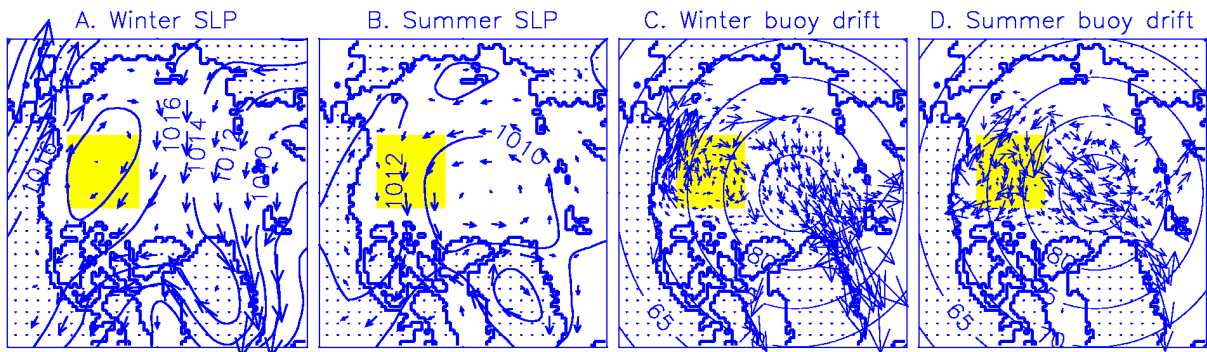
Fig. 2. 1979−1997 winter (A) and summer (B) averaged sea level pressure and geostrophic wind. Seasonal IABP buoy drift is shown in C and D. In winter, the buoy drifts coincide with the anticyclonic wind motion, which generates (by Ekman pumping) a negative salinity anomaly in the BG so that the ocean accumulates potential energy. In summer, this energy supports the anticyclonic geostrophic circulation (Fig. 1D), and drives the buoy drifts against the predominantly cyclonic winds.
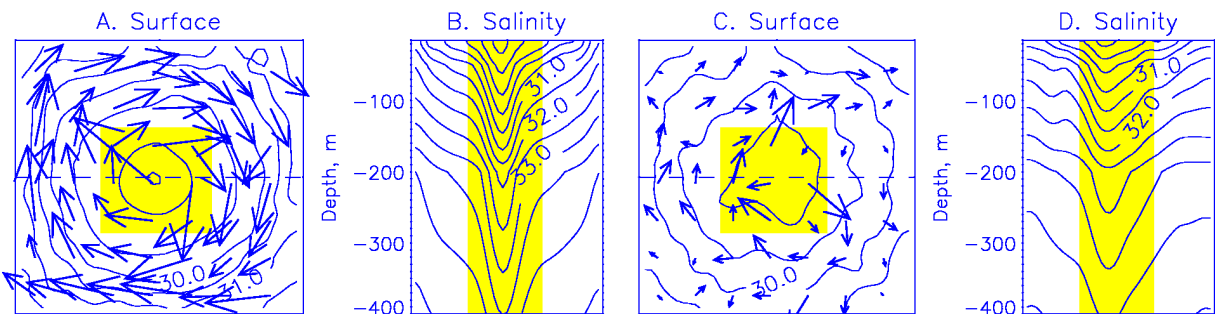
Fig. 3. Results of numerical experiments with a 3−D model in the 2000kmx2000kmx1.5km ideal basin. The basin is initially horizontally uniform but vertically stratified, then it was forced for 9 months by anticyclonic (A and B) and then 3 months by cyclonic (C and D) symmetric winds. (A) and (C) show surface salinity and currents. (B) and (D) show salinity sections along dashed line in (A) and (C)). Anticyclonic winds generate downwelling in the central basin and upwelling along boundaries. Cyclonic winds lead to the upwelling in the central basin and downwelling along boundaries. Anticyclonic forcing (A) is similar to the winter Arctic conditions, and the salinity structure in (B) resembles Fig. 1C. Fig. 3C shows surface salinity and currents after 3 months of cyclonic wind forcing. Circulation pattern of this figure is similar to the ice drift pattern in Fig. 2D (summer ice drift). The circulation is still anticyclonic but is weaker than in winter. Salinity distribution in (D) could be observed in summer when the cyclonic wind forcing leads to the release of freshwater from deep layers to upper layers. Observations are needed in the Beaufort Gyre to test this hypothesis.

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2. Observational program

The major objective of the observational program is to determine freshwater content and freshwater fluxes in the BG during a complete seasonal cycle. Direct measurements from the northern and western regions of the BG regions are few due to usually heavy ice conditions so modern, high-resolution data are needed to fill large spaces in the historical record. As a result, we initiated a program to acquire time series measurements of temperature, salinity, currents, geochemical tracers, sea ice draft, and sea level in the BG using moorings, drifting buoys, shipboard, and remote sensing measurements. The moorings and buoys are designed to precisely measure the variations of the vertical distribution of freshwater content and sea ice draft at representative locations (Figure 4). The hydrographic sections are to examine the variation by radius from the center of the BG. The remote sensing program will characterize the variability of the sea ice thickness (SIT) and sea surface height (SSH) horizontal structure.

Figure 4. BGFE mooring locations (shaded circles) and simulated drift of BGFE ice beacons (triangles indicate deployment location) after one year (crosses) based on IABP monthly mean ice drift velocities (shaded arrows).
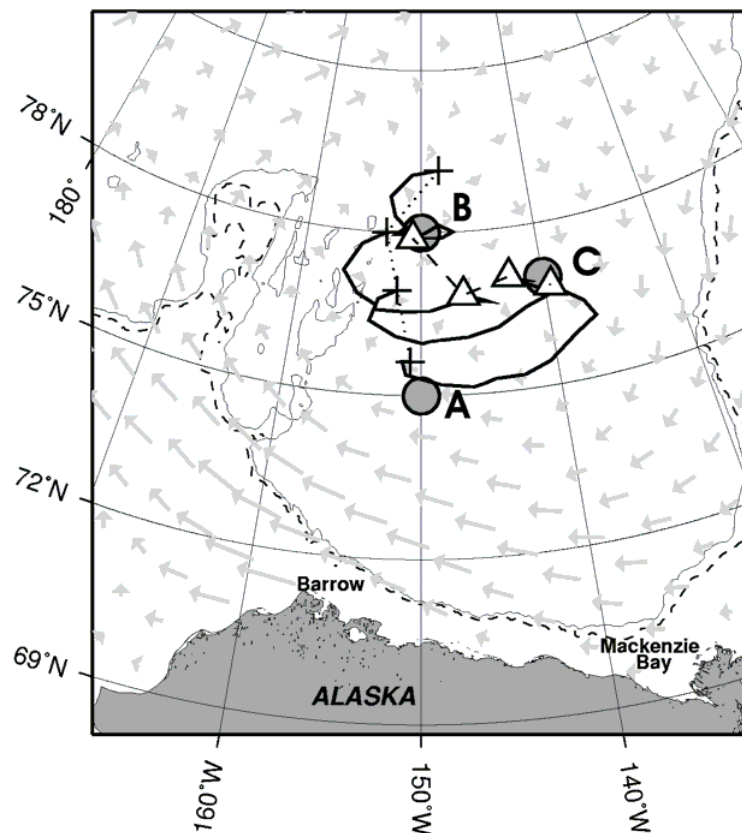
In order to keep costs manageable, the BG circulation system is assumed quasi-symmetrical and only three moorings are currently deployed for our research. Historical hydrographic and ice drift data suggest that the mean center of the BG is located near 78°N, 150°W. On the other hand, I. Rigor determined the centers for different years from IABP drift velocity grids, indicating that the Beaufort Gyre may be located farther south during positive Arctic Oscillation (AO) years. A recent surface salinity section by K. Shimada also indicates the possibility that the BG is located around 75°N. The BGFE moorings are distributed to account for both possibilities. Collaboration with other researchers will allow us to use their observations (North Pole Observatory, Bering Strait, Northern Chukchi Sea, Beaufort Sea) and to analyze their data in conjunction with our investigation.

Both icebreakers and air-supported ice camps were considered as platforms for performing the field deployment and recovery operations, and it was determined that icebreaker operations would be more practical, cost-effective, and safe. Therefore, arrangements were made to deploy our observation system in 2003 from the Canadian Coast Guard Ship Louis S. St. Laurent (Figure 5) on a Joint Western Arctic Climate Study (JWACS) cruise (Chief Scientist: Bon van Hardenberg, IOS) that departed from Kugluktuk, Canada on August 8, and returned on September 5 (Figure 6). Three WHOI scientists were responsible for installing the mooring systems and buoys with help from IOS technicians and Coast Guard personnel: Andrey Proshutinsky, principal investigator, coordinated the effort and conducted ancillary observations, Willie Ostrom lead the deployment operation, and Rick Krishfield prepared the instrumentation and assisted the deployment. More specific information on the cruise (including updates) is included on the BGFE website (http://www.whoi.edu/beaufortgyre).

Figure 5. CCGS Louis S. St. Laurent

In addition to the mooring and buoy deployments, shipboard hydrographic data and water sampling were carried out at 39 sites on the JWACS 2003 cruise, and about the same number will be taken in 2004. The scientific objectives of this program include: (1) identification of water mass characteristics, using multiple hydrographic tracers, and computation of freshwater content from different sources; (2) comparison of observed characteristics with historical data from the region; and (3) separation of the components of halocline water according to their

origin. Temperature, salinity, oxygen, and nutrients, CFCs, carbon tetrachloride, total alkalinity, dissolved inorganic carbon, Tritium/^{3}He and δ^{18}O will be measured. E. Carmack, R. MacDonald and F. McLaughlin from IOS, Canada are responsible for this program. Furthermore, XCTD data along the cruise data were also acquired during JWACS 2003 by K. Shimada, JAMSTEC.
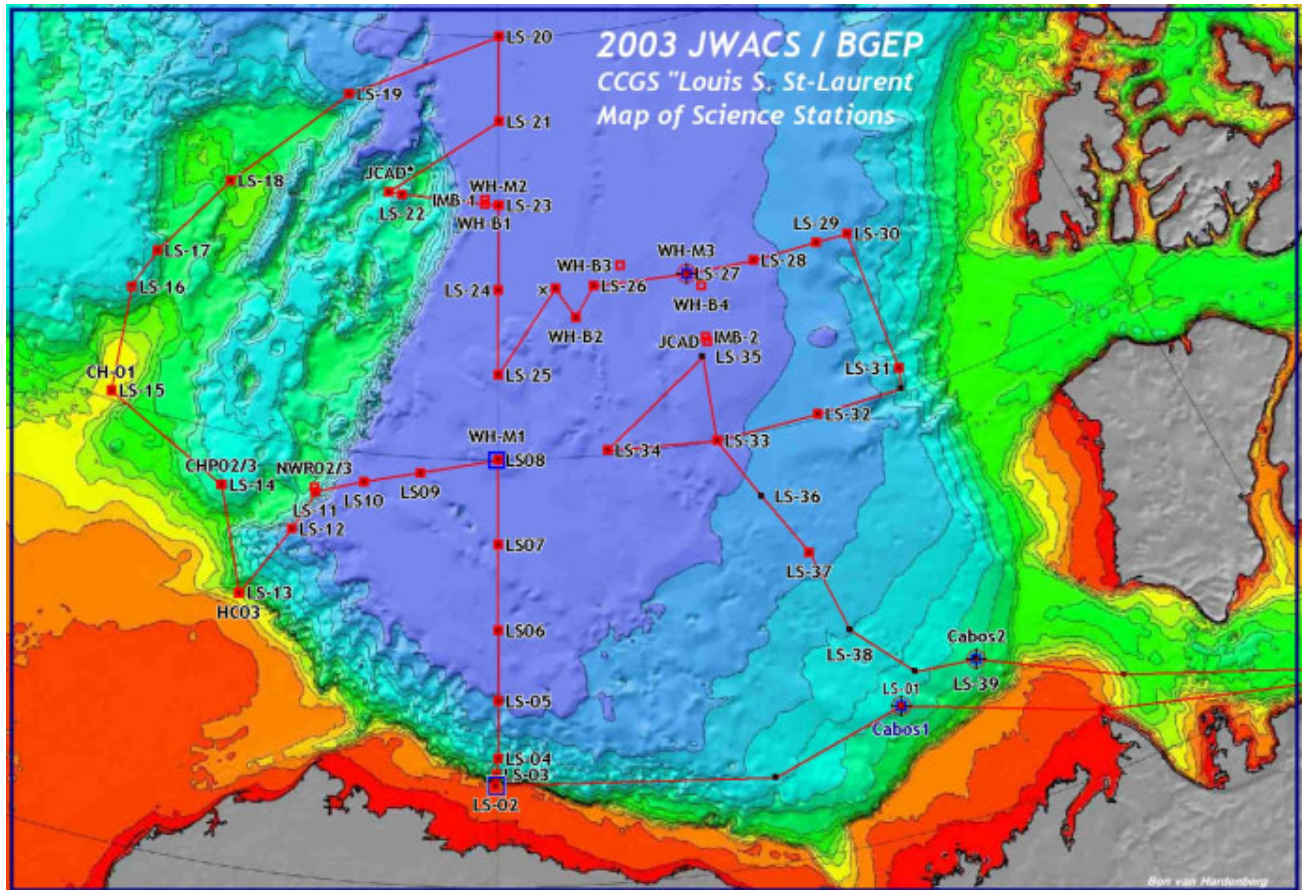
Figure 6. Joint Western Arctic Climate Study (JWACS) 2003 cruise track on IBCAO bathymetry with locations of hydrographic stations (LS), BGFE moorings (WH-M), BGFE buoys (WH-B), and other instrumented systems (Figure by Bon van Hardenberg).

Table 1. BGFE 2003 Deployments During JWACS 2003

(All times = GMT – 6 hours)

Mooring A:

    Deployed August 14, 2003   07:51 75° 00.53' N 150° 00.12' W   begin
                                     12:20 75° 00.39' N 149° 58.752' W dropped
    CTD depth = 3820 m; Sound speed = 1480.1 m/s
    Ship sounder = 3775 m; Sounder II = 3790 m
    Release depth after deployment = 3819 m

Mooring B:

    Deployed August 23, 2003   17:37 78° 01.254' N 149° 51.148' W   begin
                                       22:05 78° 01.491' N 149° 49.378' W dropped
    CTD depth = 3823 m; Sound speed = 1480.4 m/s
    Ship sounder = 3770 m
    Release depth after deployment = 3824 m
    Landing minus drop distance = 48 m (3814-3766 m, transducer at 10 m)

Mooring C:

    Deployed August 26, 2003   15:03 76° 59.49' N 140° 01.54' W begin
                                       19:03 76° 59.254' N 139° 54.229'W dropped
    CTD depth = 3726 m;
    Release depth after deployment = 3733 m
    Landing minus drop distance = 80 m (3723-3643 m, transducer at 10 m)

Buoy 1:

    ARGOS ID = 40298   Ice thickness = 3 m
    Deployed August 23, 2003   09:35 77° 58.5' N   150° 44.6' W   on ice
                                       11:00 77° 58.6' N   150° 42.6' W   off ice

Buoy 2:

    ARGOS ID = 40300   Ice thickness = 2 m
    Deployed August 25, 2003   11:30 76° 51.5' N   146° 41.7' W   ship in position
                                       12:30 76° 51.568' N 146° 39.601'W buoy deployed

Buoy 3:

    ARGOS ID = 40297   Ice thickness = 1.9 m
    Deployed August 26, 2003   07:00 77° 06.5' N   142° 47.5' W   site selected
                                       07:51 77° 06.4' N   142° 47.4' W   off ice

Buoy 4:

    ARGOS ID = 40299   Ice thickness = 2.4 m
    Deployed August 26, 2003   20:30 76° 50.04' N 139° 29.93' W ship in position
                                       22:00 76° 49.9' N   139° 29.3' W   off ice

3. Mooring design

Moorings provide time series of T, S, currents, sea ice draft, and bottom pressure (sea surface heights). A robust, economical system is utilized to obtain high-accuracy, long-term vertical profiles of ocean temperature, salinity and velocity in the BG (Figure 7). Conventional mooring systems containing a McLane Moored Profiler (MMP) are used to sample currents and hydrographic data from 50 to 2050 m with a 54 hours time interval. In addition, an ASL Environmental Sciences 420kHz upward-looking sonar (ULS) provides information about sea ice draft, and a high accuracy bottom pressure recorder (BPR) measures sea level height variability and near bottom T and S. Each mooring consists of a surface flotation package housing an ULS, a mooring cable containing the MMP (5/16" jacketed wire rope, breaking strength 9800 lb.), dual acoustic releases and tether to BPR attached to the anchor. 1/2" Trawler chain (breaking strength > 9800 lb.) is used between the releases and anchor.

The surface floatation package is a 64" syntactic foam sphere with mounting for the ULS and acoustic transponder. It is located at 46 m so that the upper limit of the profiling instrument may be at 50 m. The profiler will travel along a single 2000 m (stretched length) segment of plastic jacketed wire rope with bumper stops at end. Beneath the lower end of the profiler mooring segment, other shots of wire rope and glass floatation balls provide the strength and buoyancy to maintain the 3800 m long mooring system vertically. Dual Edgetech acoustic releases attach the positively buoyant mooring system to the 3800 lb anchor tethering the system to the bottom. A BPR is mounted on the anchor using a specially designed bracket.

In order to ensure that the uppermost MMP bumper is located as close as possible to 50m, adjustment cables shots will be employed to correct the mooring length to the exact depth during deployment. Upon arriving on station to deploy the moorings, a CTD is performed to adjust the depths soundings for the speed of sound. The expected error of the depth estimate can be as large as +/- 20 m. The mooring itself is provided with a lot of buoyancy and should be very rigid. According to a dynamical model of the vertical mooring variation, a 50 cm/s current at 50 m superimposed on a 5 cm/s background depresses the surface buoyancy float only 2 m on the 3800 m long mooring. Assuming a relatively flat ocean bottom, adjustment lengths will be used to adjust the mooring length to within a meter, so the final vertical placement of the uppermost float is expected to fall within +/-10 m of 46 m below the surface.

ICE

Depth 46 m

64" 2500 lb Syntactic Sphere with Acoustic Transponder
1 m 1/2" Trawler Chain
3 ton Miller Swivel
Bumper Stop

1995 m 5/16" JacNil Wire

MMP

Profiling Depth Interval
50.4 m – 2050.4 m

PROFILE AREA

Bumper Stop
10 m 5/16" JacNil Wire
(4) 17" Glass Balls on 1/2" Trawler Chain

500 m 5/16" JacNil Wire
(4) 17" Glass Balls on 1/2" Trawler Chain

500 m 5/16" JacNil Wire
(4) 17" Glass Balls on 1/2" Trawler Chain

500 m 5/16" JacNil Wire
(4) 17" Glass Balls on 1/2" Trawler Chain

100 m 5/16" JacNil Wire

50 m 5/16" JacNil Wire

23.4 m 5/16" JacNil Wire

3 m 1/2" Trawler Chain

(30) 17" Glass Balls on 3/8" Trawler Chain
(7) 4 m shots and (1) 2 m shot

6 x

3 m 1/2" Trawler Chain

Dual Edgetech Releases
with 1/2" Dualing Chain

Pullout Chain

Bottom Pressure Recorder
3800 lb Ww Anchor

Depth
3799 m

HARDWARE DESIGNATION	
(F)	(1) 5/8"SH, (1) 7/8"EL, (1) 3/4"SH
(H)	(2) 5/8"SH, (1) 5/8"SL
(J)	(2) 7/8"SH, (1) 7/8"EL
(M)	(1) 1-1/4"Master Link

SH = Shackle
SL = Sling Link
SS = Stainless Steel
EL = End Link

HARDWARE REQUIRED
per mooring, without spares

(48) 5/8" Anchor Shackles
(2) 3/4" Anchor Shackles
(2) 7/8" Anchor Shackles
(23) 5/8" Sling Links
(1) 1 1/4" Master Link
(3) 7/8" End Link

BEAUFORT GYRE
FRESHWATER EXPERIMENT
MOORING BGFE-"A"
Final Design

Woods Hole Oceanographic Institution
designed by John Kemp & drawn by Betsey Doherty
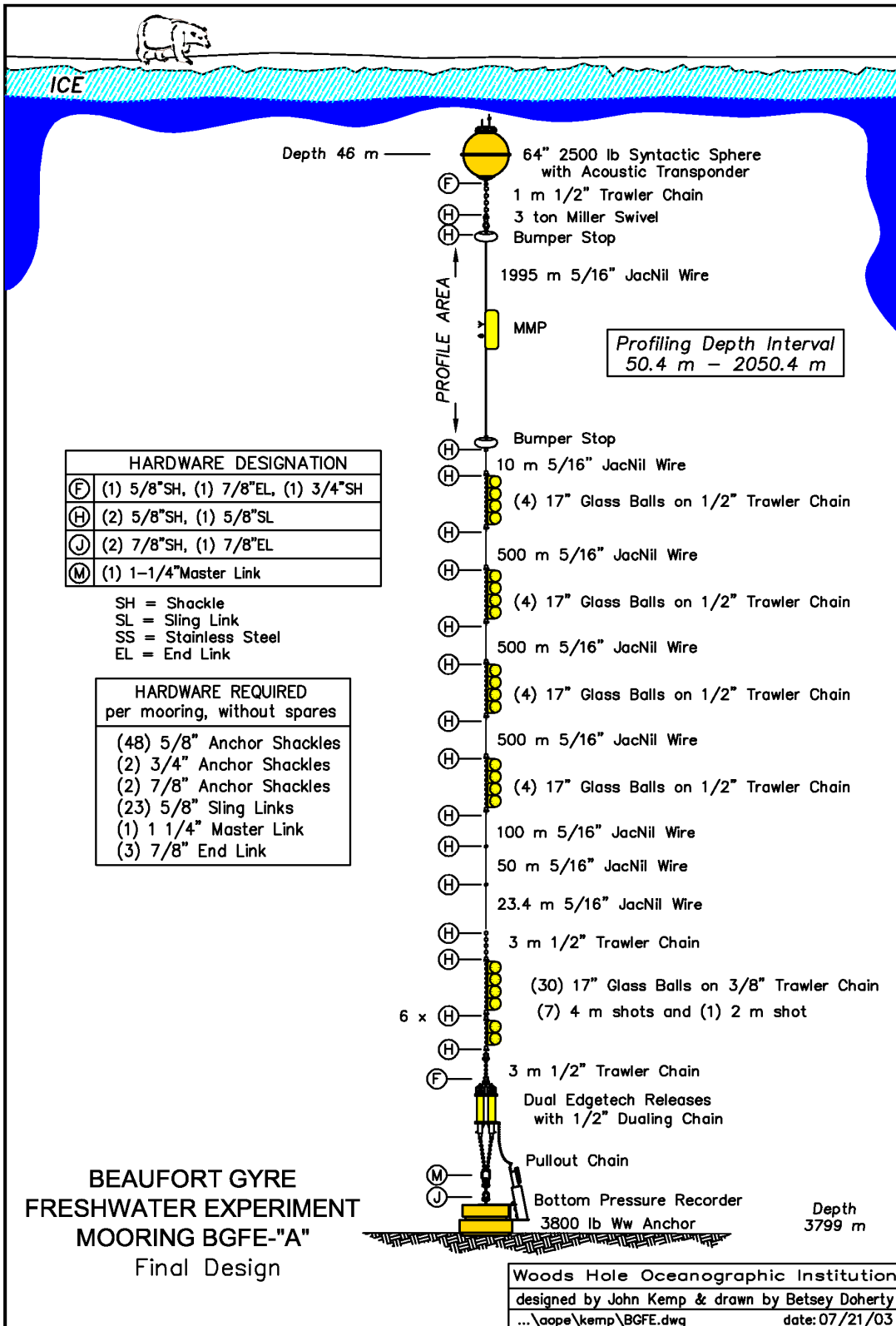...\aope\kemp\BGFE.dwg   date: 07/21/03

Figure 7. Schematic of BGFE moorings

The expected depths at the mooring sites and surrounding grid cells from the ETOPO5, ETOPO2, and IBCAO datasets are reasonably close to the depths determined during JWACS 2003 from CTD casts:

Table 2. Expected versus observed depths at BGFE mooring sites

		ETOPO5	ETOPO2	IBCAO	JWACS
A	75N, 150 W:	3835 3838 3840	3813 3813 3814	3814 3816 3817	
		3829 **3831** 3833	3818 **3819** 3819	3828 **3827** 3826	**3820**
		3824 3826 3828	3823 3823 3824	3830 3829 3828	
B	78N, 150W:	3684 3718 3749	3725 3725 3725	3726 3726 3726	
		3678 **3710** 3742	3726 **3726** 3726	3726 **3726** 3726	**3823**
		3697 3726 3754	3726 3726 3726	3726 3726 3726	
C	77N, 140W:	3684 3683 3681	3703 3703 3703	3704 3704 3704	
		3691 **3690** 3689	3704 **3705** 3705	3708 **3709** 3709	**3726**
		3698 3697 3696	3708 3709 3709	3700 3703 3706	

The length of the BGFE moorings that were deployed were: site A = 3750 m, site B = 3775 m, site C = 3662 m. The difference from the bottom gives the approximate depth of the top sphere. The actual mooring positions and measured water depths for all BGFE mooring are listed in Table 1.

4. Deployment Procedure

The three BGFE moorings were deployed in 2003 using an *anchor first* technique developed by the WHOI - Mooring Operations, Engineering and Field Support Group. The methods of the deployment and recovery of deep-ocean moorings through sea-ice from icebreaker have been used by members of WHOI on the Healy in the Labrador Sea trials, during the Shelf-Basin Interactions Program (SBI), and were employed in the Ross Sea, Antarctica to recover sediment trap moorings during JGOFS.

The standard method for deployment of a mooring of this type would normally be *anchor last*, which minimizes the tension on the mooring segments during the deployment operation. This method begins with the ship positioned down wind from the desired anchor location approximately two and half times, the overall length of the mooring. The top segment of the mooring is deployed first over the stern of the ship, the ship slowly transits towards the anchor drop site as mooring components are connected and passed over the side, and with the entire

mooring towing behind the ship, the anchor is cast over the stern completing the deployment. However, this method requires a large amount of open water to stream the mooring behind the ship so is not practical in ice-covered oceans. Because of the potential for large ice flows existing in the area of the BGFE mooring sites, the following *anchor first* procedure was adopted.

Mooring operations on CCGS Louis S St. Laurent were conducted from the fore deck. The starboard A-frame was rigged with a WHOI Gifford mooring block secured to the A-frame center bale and a vertical chain stopper attached to the adjacent forward bail. A 4 meter length of ½ inch trawler chain was used for the vertical stopper. A ½ inch chain grab was shackled onto the vertical chain stopper approximately 0.5 meters from the deck. A second Gifford block (Figure 8) was secured to a custom fairlead bail welded to the main hatch combing. A 10 ft. LiftAll SN 60 sling was barrel hitched around the base of the ship's starboard bow compressor. A 10" McKissick 5CC snatch block was hooked onto both ends of this sling (Figure 9). The position of the block allowed a 2 ton snap hook with an attached 7/8 inch Sampson stopper line when bent through the block to be in aligned with the windlass capstan.

Figure 8. Gifford deck block

Figure 9. Fair lead block and stopper line

The mooring wire fairlead ran from through the A-frame block down through the deck block and 9 times around the windlass capstan. The mooring wire exiting forward from the windlass capstan was bent around the ship's turning fairlead and redirected aft to a Reel-O-Matic tension reel stand. Figures 10 and 11 show opposing views of the mooring wire fairlead.

Figure 10. Wire fair lead thru deck block to windlass capstan

Figure 11. Wire fairlead windlass capstan to tension cart

The personnel utilized for the safe payout of the mooring wire required: a Boatswain, mooring operations supervisor, windlass operator, two windlass wire handlers, tension cart observer, mooring log recorder and acoustic release technician. The Boatswain's responsibilities were to direct all shipboard deck machinery and maintain communications with the ship's bridge. The correct construction and deployment of the mooring rested upon the mooring operations supervisor. The windlass operator and windlass wire handlers were responsible in maintaining control of the mooring wire rope warped around windlass capstan. The tension cart observer maintained constant visual inspection of the cart's operation.   The responsibilities of the mooring log recorder were to verify and document the mooring components as they were deployed. Because the mooring wire was being manually controlled over the windlass capstan, one of the two acoustic releases attached to the anchor was enabled so that the acoustic release technician could instantaneously send a release command to jettison the 3800 lb. anchor if the payout got out of control.

The mooring deployment commenced following a CTD cast to determine an accurate water depth. The ship's position over the anchor site was maintained during the mooring operation. The mooring anchor was positioned using the starboard crane into the center of the A-frame. The duel acoustic releases were moved along side of the anchor and the release chain was bent through the 1 ¼ inch Master link shackled to the anchor. The ends of the release chain were inserted into the release armatures and the releases were armed. A 3 meter length of ½ inch chain was shackled to the top bale of the duel release tension bar. The starboard crane swung over the acoustic releases and the crane's whip lowered hooking onto the ½ inch chain approximately .5 meters from the chain's free end, using a. 8 ft. LiftAll SN 60 sling barrel hitched through a ½ inch chain grab. The crane whip was hauled in lifting up the chain and duel releases over the top of the anchor. The anchor was suspended off the deck, to allow any existing rotary motion in the linkage's from the release chain and attaching hardware to unwind. The anchor was lowered transferring enough of the anchor's weight onto the deck to stabilize the anchor. The bottom pressure recorder was inserted into its containment tube attached to the side of the anchor. A half clamp bracket was bolted to the acoustic release case closest to the pressure recorder. A Tygon tube incased length of 5/16 inch proof coil chain was shackled to the pressure recorder's top bail. The free end of the chain was shackled to the bracket bolted to acoustic release. Figure 12 details this assembly. When the anchor is released, the recorders will be pulled from the mount by the smaller chain.

Figure 12. BGFE mooring anchor,SeaCat recorders and dual release package

The bridge was notified that the anchor was ready to be lowered over the side. With confirmation to proceed, the crane lifted the anchor up and out board of the ship's starboard side. The anchor was lowered until the chain grab hooked to the ½ inch chain was 1 meter from the deck. The ½ inch chain grab attached to the vertical chain stopper was hooked onto the hanging mooring chain, 0.5 meters from the deck. The crane whip lowered and its chain grab was removed. The next mooring segments to be deployed were the 30 17 inch glass balls bolted onto ½ inch chain. The glass balls were pre-connected into 8 glass balls/8 meter lengths. The crane's

boom shifted inboard and the crane's hook and slung chain grab were hooked between the 6th and 7th glass ball. It was found that this number of glass balls was the maximum manageable number of glass balls that could be lifted inside the A-frame at one time. The crane whip hauled in lifting the glass ball string off the deck and taking on the hanging mooring tension, which allowed the vertical chain stopper to go slack and be removed. The crane boomed down to allow the glass balls to clear the side of the ship. The glass balls were lowered until again the crane whip's chain grab was 1 meter from the deck. The vertical chain stopper was hooked below the crane whip's chain grab. The crane whip lowered transferring the mooring tension to the vertical chain stopper. This procedure was repeated until all 30 glass ball were hanging from the vertical chain stopper.

The first wire shot to be shacked to the free ½ inch chain end of the deployed glass balls was pulled from the tension cart forward around the ship's turning block, up over the top of the windlass capstan and bent around 9 times. The wire was then revved thru the deck and A-frame fairlead blocks and down to the hanging glass balls. The wire rope termination was shackled to the free end of the ½ inch chain. The windlass was hauled in drawing in the wire rope taking the mooring tension away from the vertical chain stopper. The vertical chain stopper's ½ inch chain grab was removed and the A-frame shifted out board as the windlass paid out, allowing the wire rope to be lowered over the side. The windlass wire handler positioned out side of the wire rope bite which ran from the turning block to the tension cart, maintained a consistent grip on the wire so that the wire rope would not slip around the capstan barrel, in order to prevent chaffing on the wire rope's polyethylene jacket. The vigilance of the windlass wire rope handler in laying the wire rope onto the capstan head correctly with ample back tension was critical to the safe lowering of the heavily loaded mooring components. The tension cart observer periodical adjusted the cart's hydraulic valve to maintain an adequate level of additional resistance to the wire rope running to the windlass wire handler and visually checked that the storage wire rope reel was not moving out of alignment. The payout speed of a wire shot was at the maximum speed of the windlass was approximately 25 meters per minute.

When the last wire rope lay became exposed on the storage reel, the windlass speed was reduced and a second wire handler was positioned in front of the tension cart to manually monitor the wire rope as its bitter end came off the reel. Once the bottom end of the wire rope had been removed from the storage reel, the second wire handler firmly gripped the wire just ahead of the wire rope termination and assisted in applying additional back tension pulling against the windlass capstan. A 5/8 inch shackle and 5/8 inch pear ring were connected to the wire rope termination. The windlass capstan slowly paid out and second wire rope handler

holding onto the hardware moved around the turning block up to the capstan wire handler. A snap hook attached to a 7/8 inch diameter Sampson stopper line was connected onto the 5/8 inch pear ring. The Sampson line was drawn tight and secured across the ship's bits. The capstan paid out allowing the stopper line to take on the load held by the capstan wire handler. With mooring stopped off, the empty storage reel was removed and the next wire rope reel installed onto the tension cart. The wire rope termination coming off the top of the storage reel was pulled up around the turning block and shackled to the stopped off termination. The windlass and second wire handlers assumed their positions out side the bite and held back on the mooring wire. The capstan hauled in slightly with the wire handlers taking up the loose slack, the stopper line was removed. A WHOI Velcro canvas cover was wrapped around the hardware joining the two wire shots. The capstan slowly paid out as the two wire handlers applied back tension. While the termination bundle wound around the capstan barrel, the wire helix tended to snap towards the center of the barrel. The wire handlers had to grip the wire very tightly during this phase of the payout in order to prevent the wire rope from getting fouled on the capstan. The canvas wrap shrouding the terminations was removed once it had passed through the two fairlead blocks and reached out board of the A-frame approximately 2 meters from the deck. A 3 ton snap hook shackled to the vertical chain stopper 1 meter from the deck was hooked onto the 5/8 inch pear ring and the windlass paid out allowing the upper termination to be disconnected. A 4 glass ball segment was positioned to the vertical chain stopper and shackled onto the stopped off pear ring. The loose wire rope termination was reattached to the free end of the glass ball chain and the capstan hauled in lifting the glass balls off the deck. Once the tension was off the vertical chain stopper, the snap hook was removed and payout commenced. The McLane moored profiler, MMP was deployed in a similar fashion. The end of the last wire shot was paid out using a 7/8 inch diameter Sampson winch line, where it was stopped off using the vertical chain stopper.

The 64 inch syntactic sphere at the top of the mooring was pre-positioned aft along side the A-frame. A 1 meter ½ inch trawler chain and a 3 ton Miller swivel were shackled onto the sphere's bottom bail. This assembly had a ¼ inch manila line tied to the 5/8 inch pear ring joining the swivel and the ½ inch chain. The line's bitter end was tied to the sphere's equator ring with a slip bowline so that when the sphere was suspended in the A-frame, the line could be easily reached. A 10 ft. LiftAll SN 60 sling was barrel hitched through one of the sphere's lifting bail. The release hook used to deploy the sphere was a Brailer release hook with a 6 ft. LiftAll SN 60 sling shackled with a 5/8 inch shackle to one of the side bail of the hook. This shackle was assembled so that the thumbscrew would protrude away from the release pin. Figure 13 illustrates this assembly.

Once the 1995 meter length of wire rope had been paid out and stopped off onto the vertical chain stopper, the ship's starboard crane swung over the sphere. The 10 ft. sling was barrel hitched onto the crane whip hook .The A-frame shifted inboard so that the hanging wire rope was approximately 0.5 meter away from the side of the ship. The Sampson winch line was passed out board of the A-frame and shackled to the Brailer hook. The sling secured to the Brailer hook was passed through an inboard sphere bail and secured to its release pin. The Brailer release line was passed out board and forward around the A-frame base brings the line inside the A-frame. The sphere was lifted and swung out board of the A-frame.

Figure 13. Brailer release hook and Lift All sling

The ¼ inch manila tag line slip knot tied to the sphere was untied so that the free end of the ½ inch chain and attached swivel could be shackled to the stopped off mooring wire. The crane whip hauled in lifting the sphere, taking the mooring tension from the vertical chain stopper. This stopper was removed. The crane slowly lowered the sphere transferring the hold on the mooring to the Brailer hook and Sampson winch line revved around the windlass. Figure 14 shows the crane whip sling and Brailer hook orientation during this transfer.

The 10 ft. sling was removed and the crane swung clear of the A-frame. The A-frame shifted out board as the windlass paid out lowering the sphere. The Brailer hook release line was carefully tended so that the line was slack during this phase of the operation. Once half the sphere's diameter had been submerged, payout was stopped and the acoustic releases were ranged upon to check the overall length of the mooring relative to the water depth. Upon completion of this test the Brailer hook release line was tied off to an A-frame cleat and the windlass lowered the sphere transferring the mooring tension to the release line, causing the hook to open casting off the mooring. Once the mooring anchor had settled on the sea bottom, the acoustic releases were ranged upon to determine the position of the mooring.

Figure 14. Sling detail: sphere deployment

5. *Moored Profiler*

The McLane Moored Profiler (MMP) is an autonomous, instrumented platform on a conventional mooring tether, which repeatedly traverses that line based on a user defined operation program, acquiring in situ profiles of temperature, salinity and velocity (Morrison et al., 2000). Figure 15 shows the MMP on a mooring wire in a test tank.

The maximum depth rating is 6000 m, and design endurance is over one million meters per deployment. The system software gives the operator great flexibility in defining the sampling schedule, allowing profiles to be interspersed with extended measurements at fixed levels. The along-cable speed of the MMP is approximately 25 cm/s. This speed is determined by the need to minimize energy expenditure to increase the deployment duration. Accurate ballasting of the instrument for the seawater characteristics during the deployment is necessary for proper operation. Using the GDEM interpolations from the EWG summer and winter atlas data, representative profiles for the BGFE mooring locations were selected (Figure 16). The differences between the different seasons and locations is small, so the instruments on different moorings can be ballasted from the same values. The neutral water column values were estimated from the average of the upper (50m) and lower values (2050m) from the representative profiles: neutral depth = 1000 m, neutral temperature = -1.0 °C, neutral salinity = 32.9, and neutral density = 1031.2 kg/m^3.

Figure 15. McLane Moored Profiler

The CTD and current measurement instruments presently employed on the MMP are products of Falmouth Scientific, Inc. The MMPs used for the BGFE are newly manufactured instruments that have been tank tested and dock tested, with factory calibrated CTDs and ACMs. A problem with ACM pressure compensating fluid leaks was detected during the dock tests and repaired. In addition, the heading bias of the ACM compass resulting from the magnetic field of the battery packs was recorded for each MMP by performing spin tests (112 = 18.3°, 113 = 25.4°, 114 = 23.23°). The biases must be subtracted from the measured angles to provide true directions. Eccentricity of the ACM measurement is also a concern, and while measurements were conducted in the lab, post-cruise processing of the data will provide better corrections.
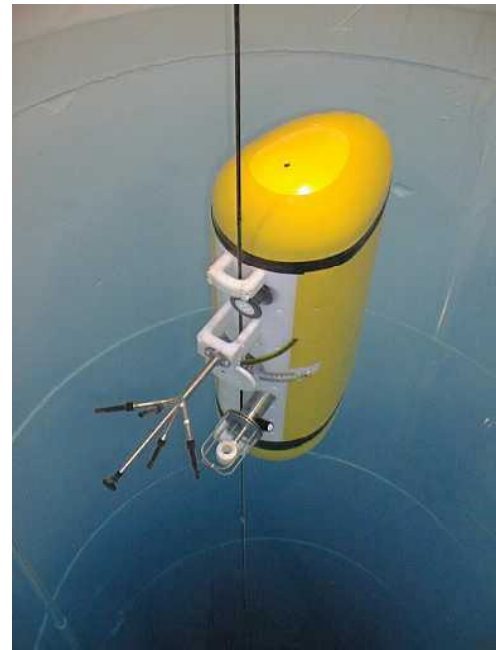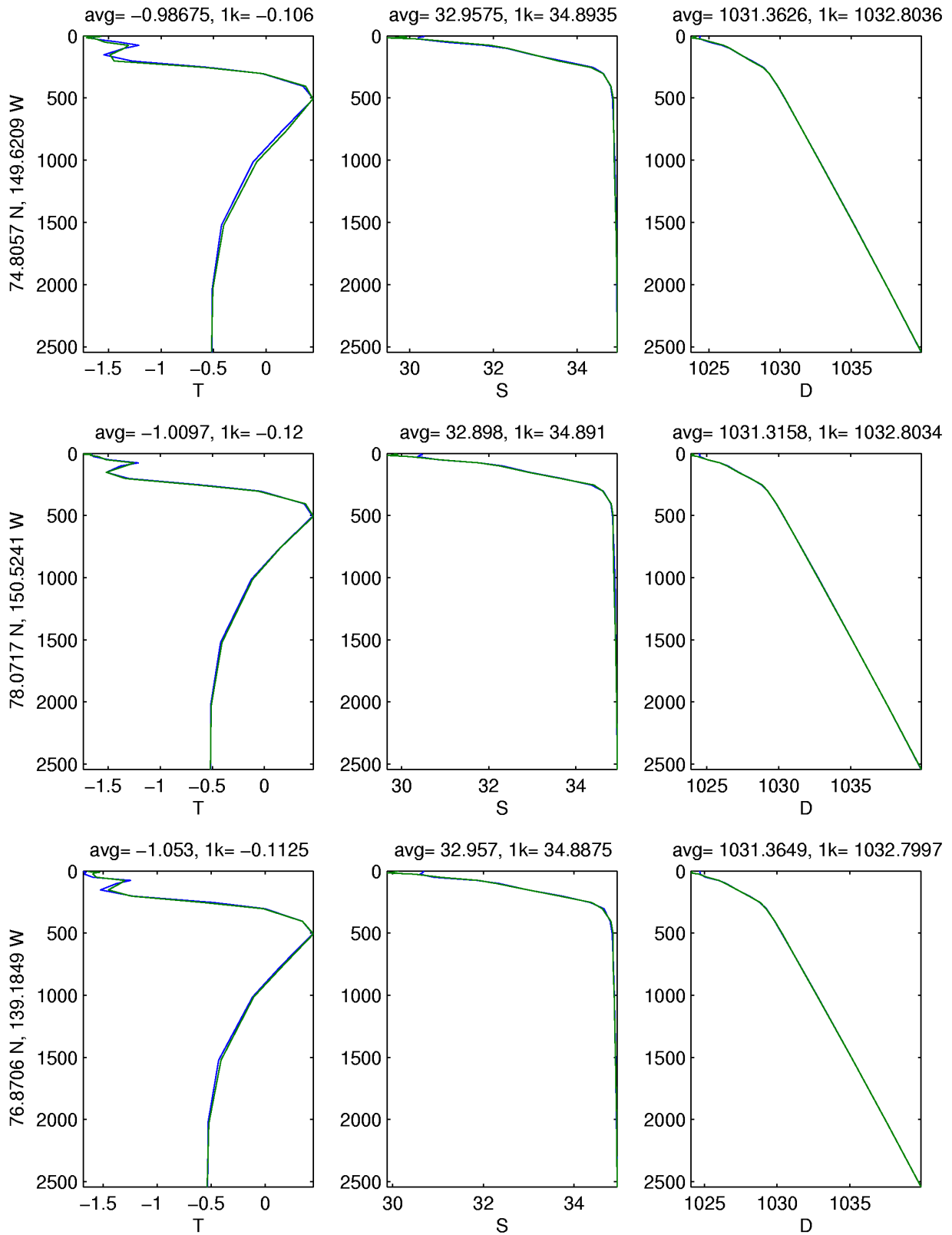
Figure 16. Mean profiles of T, S, and density at mooring locations from winter and summer US/Russian Environmental Working Group Atlas.

The parameters that were used to program the MMPs for the BGFE experiment are selected to ensure a minimum duration of 400 days (800,000 km), and to enable the M2, S2, O1, and K1 tidal constituents to be quantified. Table 3 lists these parameters.

Table 3. MMP deployment parameters

```
BGFE-A (114)      Z| Scheduled start         =    08/15/2003 12:00:00
               Estimated Profile 1 start time:   08/15/2003 18:00:00

BGFE-B (113)      Z| Scheduled start         =    08/24/2003 12:00:00
               Estimated Profile 1 start time:   08/24/2003 18:00:00

BGFE-C (112)      Z| Scheduled start         =    08/27/2003 04:00:00
               Estimated Profile 1 start time:   08/27/2003 12:00:00

    Schedule   I| Profile start interval = 000 06:00:00 [DDD HH:MM:SS]
               R| Reference date/time      =   08/01/2003 00:00:00
               B| Burst Interval           = 002 06:00:00 [DDD HH:MM:SS]
               N| Profiles per burst       =             2
               P| Paired profiles              Disabled
               F| Profiles / file set     =            10

    Stops      S| Shallow pressure         =          30.0 [dbar]
               D| Deep pressure            =        2000.0 [dbar]
               H| Shallow error            =          40.0 [dbar]
               E| Deep error               =         200.0 [dbar]
               T| Profile time limit       =      02:50:00 [HH:MM:SS]
               C| Stop check interval      =            15 [sec]
```

6. Upward Looking Sonar

Upward looking sonar IPS4, (Figure 17) manufactured by ASL Environmental Sciences, are mounted in the uppermost flotation to sample the ice draft with a precision of +/- 0.05 m in acoustic range, or typically +/- 0.3m after conversion to ice thickness. Originally designed at IOS (Melling *et al.*, 1995), the systems determine the return travel time of a 420 kHz acoustic pulse (1.8° beam at –3 dB) reflected from sea ice, or the surface. The "footprint" of the measurement is less than 0.5 m at 30 m operating

Figure 17. Upward looking sonar

depths. A pressure sensor (Paroscientific Digiquartz) is incorporated to measure the sea level changes due to winds and tides, and the vertical changes in the mooring length due to current drag.

The battery pack provides approximately 80 Ah, and the storage capacity is 64 Mbytes. In addition to the travel time, the maximum amplitude and the persistence (duration) of the selected echo may be recorded. To reduce memory requirements, pressure and tilt are recorded less frequently than each travel time (every 20 records), and burst measurements (for ice free periods) less frequently (every 510 records). Software provided by ASL, IpsLink (Version 2.00.04) allows different deployment schemes to be prepared and power and data storage requirements assessed. Parameters selected for the BGFE deployment extend the battery life to a full year using a 2 second ping rate, and leaves sufficient memory to record the amplitude and persistence. Table 4 lists these parameters.

Table 4. Upward looking sonar deployment configurations

```
        BGFE-A Unit '1038' deployed 2003-08-13 02:23:33
        Setting deployment name to 'bgfe03Ax' and number of phases to 1 ...
PASSED
        Setting phase 1 start date set to: 03/08/14/00 ... PASSED

        BGFE-B Unit '1037' deployed 2003-08-21 15:42:23
        Setting deployment name to 'bgfe03Bx' and number of phases to 1 ...
PASSED
        Setting phase 1 start date set to: 03/08/22/00 ... PASSED

        BGFE-C Unit '1036' deployed 2003-08-25 19:44:48
        Setting deployment name to 'bgfe03Cx' and number of phases to 1 ...
PASSED
        Setting phase 1 start date set to: 03/08/26/00 ... PASSED

        Setting phase 1 Ping Interval to 2 ... PASSED
        Setting phase 1 Ping Length to 68 ... PASSED
        Setting phase 1 Lockout to 10 ... PASSED
        Setting phase 1 Maximum Range to 90 ... PASSED
        Setting phase 1 Pressure Interval to 20 ... PASSED
        Setting phase 1 Burst Interval to 510 ... PASSED
        Setting phase 1 Burst Count to 1 ... PASSED
        Setting phase 1 Record Persistence to n ... PASSED
        Setting phase 1 Record Amplitude to y ... PASSED
        Setting phase 1 Minimum Persistence to 8 ... PASSED
        Setting phase 1 Start Amplitude to 200 ... PASSED
        Setting phase 1 Stop Amplitude to 150 ... PASSED
        Looking for confirm phase line from FIRMWARE ... PASSED
        Reading phase confirmation data from FIRMWARE ... PASSED
        Confirming phase 1 ... PASSED
        Confirm deployment set to 'y' ... PASSED
        Erasing Solid State Memory ... deployment started
```

Ice thickness is computed from the difference between the instrument depth and the range to the underside of the sea ice. Depth is determined from the hydrostatic equation, using the pressure measurements adjusted for atmospheric pressure (which must be obtained elsewhere).

The range is corrected for instrument tilt and speed of sound differences (which may be estimated from the uppermost MMP data and open water events).

7. Bottom Pressure Recorder

Precise bottom pressure measurements will be made using Sea-Bird Electronics SBE-16plus temperature and salinity recorders, (Figure 18) with precision Paroscientific Digiquartz (6000 psia) pressure sensors. The resolution of the pressure measurement depends on the sensitivity of the sensor and the resolution of the counter. Integrating the pressure measurements increases the resolution of the pressure measurement, although this may be limited somewhat by sensor drift, recorder time base drift, and background noise.
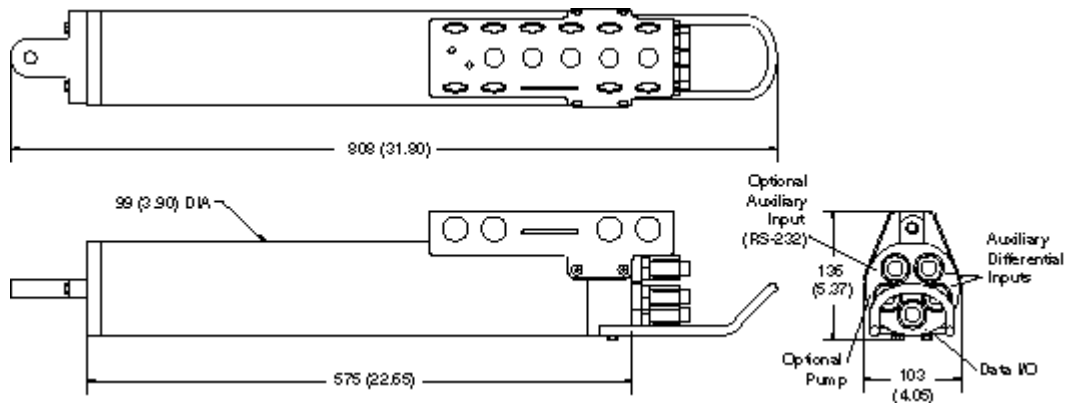

Figure 18. Bottom pressure recorder

Calibration was performed prior to use to observe the error of the measurement, due primarily to the pressure sensor drift and the time base drift of the recorder. Furthermore, the engineer at SeaBird Electronics indicated that there is a startup transient during the warmup of the 6000 psia Digiquartz sensor.   Power considerations do not allow for the measurement to start after the warmup, so the measurement occurs with some transient bias still applied. The error that results is only as large as the variability of the transient bias, which is probably small, but unknown. In order to quantify the combination of all of these uncertainties, each pressure sensor was exercised for a number of days using a dead-weight tester at the approximate pressure that it will be deployed (3800 m), and sensor drift was compared with measurements by a standard.

For the transducer applicable to our application, a measurement integration of 70 seconds should resolve better than 1 mm. At a 25 minute sample rate, the lithium batteries will provide

sufficient power for over a full year (410 days) of measurements. Table 5. lists the bottom pressure recorders battery voltage,sample rate and state up times.

Table 5. Initialization of bottom pressure recorders

```
BGFE-A SBE 16plus V 1.6a  SERIAL NO. 4413    10 Aug 2003  20:48:31
vbatt = 10.7, vlith =  8.7, ioper =  52.1 ma,
waiting to start at  12 Aug 2003  00:00:00

BGFE-B SBE 16plus V 1.6a  SERIAL NO. 4414    23 Aug 2003  18:26:30
vbatt = 10.7, vlith =  8.8, ioper =  53.1 ma,
waiting to start at  23 Aug 2003  21:00:00

BGFE-C SBE 16plus V 1.6a  SERIAL NO. 4415    25 Aug 2003  20:29:48
vbatt = 10.7, vlith =  9.0, ioper =  53.3 ma,
waiting to start at  27 Aug 2003  23:00:00

sample interval = 1500 seconds, number of measurements per sample = 1
Paros integration time = 70.0 seconds
samples = 0, free = 524288
no pump, delay before sampling = 0.0 seconds
transmit real-time = no
battery cutoff =  7.5 volts
pressure sensor = quartz with temp comp, range = 6000.0
SBE 38 = no, SBE 50 = no, Gas Tension Device = no
Ext Volt 0 = no, Ext Volt 1 = no, Ext Volt 2 = no, Ext Volt 3 = no
echo commands = yes
output format = raw HEX
serial sync mode disabled
```

In order to ensure that the measured pressures do not include any mechanical movement due to the mooring, the BPRs are mounted on the anchors (Figure 12).   The SeaCats are tethered to the releases, using chain and mounted and tie-wrapped in an aluminum tube on the anchor for deployment. Upon release of the mooring system, the tether will retrieve the BPRs from the anchor.

8. Surface-tethered drifters

Observations and numerical simulations indicate that the freshwater content variations in the BG due to Ekman forcing should extend far below the surface mixed layer (deeper than 1000~m). Timeseries integrations of the vertical profile data from the moorings will be used to precisely quantify the seasonal changes in the upper ocean freshwater content in the upper 50-2050 m. A gap in the measurements
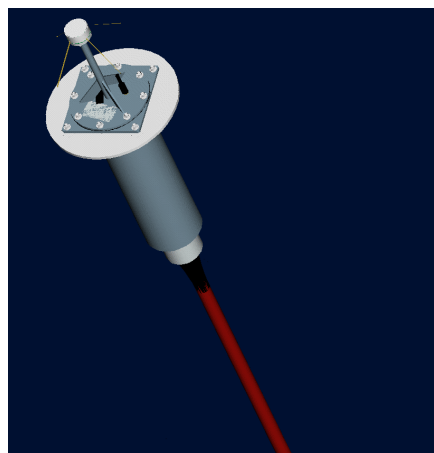

Figure 19. METOCEAN ice-beacon

exists above 50 m below the surface, where the mooring systems terminate in order to avoid interactions with the submerged portions of ice islands or deep pressure ridges. Hence, several economical ice-tethered drifters, (Figure 19) were deployed in August 2003 to provide concurrent T & S data at several discrete depths in the uppermost 40 m.

METOCEAN expendable ice beacons suspend 3 SeaBird MicroCats at 15, 25 and 40 m depths (the deepest MicroCat also has a pressure sensor to determine depth), interrogate each sensor twice per day, and broadcast the data via Argos, which also provides each drifter's location. These ice drift timeseries are immediately made available to the IABP and GTS. The temperature and salinity data are updated daily on the BGFE website.

During the JWACS 2003 cruise, 4 ice beacons were deployed in a radial section through the BG upstream of the moorings, so that the ice drift will transport the buoys past the moorings (Figure 4). Due to relatively thin ice conditions during August, it was difficult to find multiyear icefloes thicker than 2 m. Large icefloes were selected during the cruise from RADARSAT maps and ice reconnaissance flights on helicopter. The actual buoy deployment site was selected after auguring several small holes at different locations, on other sides of consolidated ridges.

Figure 20. BGFE ice beacon deployed from CCGS Louis S. St. Laurent in summer 2003.

Typically, the ice thickness was about 1.5 m, with the bottom half saturated with water. Somewhat thicker ice was generally found in areas surrounded by ridges.

Each ice beacon was completed assembled on the ship, operational, and organized in a pallet box prior to arriving on site. Two sled loads were required during each deployment to transfer the auger and ice beacon to the selected site several hundred meters from the ship. A 10" hole was augured through the multiyear ice floe, and the sensor string (with 30 lb weight) was lowered through the ice by hand. Then a wooden platform was assembled around the buoy to distribute the thermal effect of the ice beacon, and shield the upper ice. Finally, snow was piled on the wood to provide further insulation. The ice beacons have power to obtain measurements for over 1 year, but have no flotation so will eventually melt through the ice and sink. Figure 20 shows a deployed ice beacon.

The ice beacon data are acquired and decoded by Service Argos, according to the manufacturer's equations listed in table 6.

Table 6. Ice beacon data conversion equations

Data Name	Min	Max	Start Byte	Start Bit	Bit Length	Decoding Equation / Comments
Checksum	0	255	1	8	8	Sum of Bytes 2 to 19 Checksum Bytes (Offset = Start Byte, Gain = Byte Length)
Rank	0	15	2	8	4	$y = x$
Time Since Last Observation	0	4095	2	4	12	$y = x$
Battery Volts	6	18.75	4	8	8	$y = 0.05x + 6$
CT1 Temperature (degC)	-5	27.7675	5	8	16	$y = 0.0005x - 5$
CT1 Conductivity (S/m)	0	6.5535	7	8	16	$y = 0.0001x$
CT2 Temperature (degC)	-5	27.7675	9	8	16	$y = 0.0005x - 5$
CT2 Conductivity (S/m)	0	6.5535	11	8	16	$y = 0.0001x$
CT3 Temperature (degC)	-5	27.7675	13	8	16	$y = 0.0005x - 5$
CT3 Conductivity (S/m)	0	6.5535	15	8	16	$y = 0.0001x$
CT3 Depth (dBar)	0	65.535	17	8	16	$y = 0.001x$
SPARE	0	0	19	8	8	None

Message ID 1 of 1

These data and the platform locations derived by Argos are copied to a computer at WHOI and emailed to the PIs on a daily basis, and bi-weekly archives are provided on CD. Table 7 is a sample of the Argos data for an ice beacon several days after deployment.

Table 7. Sample ice beacon Argos-processed data

```
02668 40297  31 12 K 3 2003-08-30 17:40:13   77.353   218.258   0.000  401648073
     2003-08-30 17:33:37  1         58    0.00000E+0    0.33100E+3    0.17200E+2
                          -.14085E+1    0.22966E+1    -.13505E+1    0.23452E+1
                          -.12215E+1    0.24508E+1    0.43480E+2          00
     2003-08-30 17:35:05  1        113    0.10000E+1    0.33300E+3    0.17200E+2
                          -.13600E+1    0.23104E+1    -.13520E+1    0.23457E+1
```

26

```
                            -.12045E+1   0.24507E+1   0.43502E+2           00
2003-08-30 17:36:33  1       213   0.20000E+1   0.33400E+3   0.17200E+2
                            -.14360E+1   0.23063E+1   -.13530E+1   0.23504E+1
                            -.12125E+1   0.24480E+1   0.43520E+2           00
2003-08-30 17:38:01  1        62   0.00000E+0   0.33500E+3   0.17200E+2
                            -.14085E+1   0.22966E+1   -.13505E+1   0.23452E+1
                            -.12215E+1   0.22204E+1   0.43480E+2           00
2003-08-30 17:39:29  1       117   0.10000E+1   0.33700E+3   0.17200E+2
                            -.13600E+1   0.23104E+1   -.13520E+1   0.23457E+1
                            -.12045E+1   0.24507E+1   0.43502E+2           00
2003-08-30 17:40:57  1       217   0.20000E+1   0.33800E+3   0.17200E+2
                            -.14360E+1   0.23063E+1   -.13530E+1   0.23504E+1
                            -.12125E+1   0.24480E+1   0.43520E+2           00
2003-08-30 17:42:25  1        67   0.00000E+0   0.34000E+3   0.17200E+2
                            -.14085E+1   0.22966E+1   -.13505E+1   0.23452E+1
                            -.12215E+1   0.24508E+1   0.43480E+2           00
2003-08-30 17:43:53  1       121   0.10000E+1   0.34100E+3   0.17200E+2
                            -.13600E+1   0.23104E+1   -.13520E+1   0.23457E+1
                            -.12045E+1   0.24507E+1   0.43502E+2           00
2003-08-30 17:45:21  1       222   0.20000E+1   0.34300E+3   0.17200E+2
                            -.14360E+1   0.23063E+1   -.13530E+1   0.23504E+1
                            -.12125E+1   0.24480E+1   0.43520E+2           00
2003-08-30 17:46:49  1        71   0.00000E+0   0.34400E+3   0.17200E+2
                            -.14085E+1   0.22966E+1   -.13505E+1   0.23452E+1
                            -.12215E+1   0.24508E+1   0.43480E+2           00
```

Acknowledgments

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