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Spatial Variability of Bottom Turbulence over a Linear Sand Ridge Mooring Deployment and AUTOSUB AUV Survey Cruise Report

R/V RRS *Challenger*, Cruise Number 146

Broken Bank, North Sea, U.K., 17 – 28 August 1999

Cruise Report

by

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Technical Report

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Approved for Distribution:

Timothy K. Stanton, Chair

Department of Applied Ocean Physics and Engineering

Abstract

Two successful AUTOSUB deployments were carried out during August 1999 as part of the AUTOSUB Thematic Program project titled "Spatial Variability of Bottom Turbulence over a Linear Sand Ridge", funded by the Natural Environment Research Council (NERC), U.K. The AUTOSUB Autonomous Underwater Vehicle (AUV) was deployed and used to survey flow patterns at a location near the Broken Bank, southern North Sea, U.K. The AUV was equipped with acoustic flow and turbulence sensors and its surveys aimed at mapping the spatial variation of flow and turbulence near the bed and over topographic features.

Three instrumented bottom mounted frames were also deployed, around the AUV survey area, for a period of approximately 5 days. The purpose of this array was to gather information on the temporal variability of the flow and turbulence near the seabed and to identify the important terms that drive circulation around the bank.

Additional data were gathered including CTD casts, seabed samples and acoustic images of the seabed (side-scan sonar).

The purpose of this data collection was to help identify the flow patterns around ridges and to understand the mechanisms controlling the maintenance and evolution of such features.

This report describes the operations carried out by researchers from the University of South Carolina, Woods Hole Oceanographic Institution, Southampton Oceanography Centre and the AUTOSUB Team on the R.V. RRS Challenger during the period 17th – 28th August 1999.

Table of Contents

List of Figures

List of Tables

I. Introduction

Theoretical work on the development and maintenance of sandbanks, combined with existing data on peak tidal flows in the sandbanks of the southern North Sea, suggest that the bottom stress expected in the swales between the banks is of the order of $1N/m^2$ and increases by a factor of order 2 over the crest of the bank. Despite this large spatial variation of stress, previous measurements were either limited to single points only or averaged over the entire wavelength of the shoals. Thus observations sufficient to constrain the spatial variability of bottom turbulence produced by models are virtually non-existent and our understanding on the development and maintenance of such linear features is limited.

The development of the AUTOSUB, an autonomous underwater vehicle (AUV), provided a unique opportunity for the spatial mapping of flow and turbulence over uneven topography as these encountered over ridges. The AUV was used during August 1999 to measure the spatial variation of turbulence over the sandbank in the southern North Sea.

The objectives of the mission were:

(1) to spatially map bottom stresses in tidal flows over a linear ridge; and

(2) to use the measurements to understand the role of bottom stress in controlling the bedform scale flow and sediment transport processes that maintain the sandbank.

Stationary-, ship- and AUV-borne observations were collected during a few-day period over Broken Bank, a tidally dominated sand ridge situated 100km offshore of the East Anglian coast, UK (Figure 1). The bank is typical of those found in the region; it is 41km long and 5km wide and has an asymmetric cross-section with steep northeastern slopes and more gently sloping stoss sides.

This report describes the activities that took place during the cruise number 146, onboard the R/V RRS Challenger during August 1999. The participants of the cruise were:

Scientific Team

Dr. George Voulgaris (Chief Scientist), University of South Carolina, SC, USA & SOC
Dr. John H. Trowbridge, Woods Hole Oceanographic Institution, MA, USA
Dr. Eugene Terray, Woods Hole Oceanography Institution, MA, USA
Dr. Adonis Velegrakis, School of Ocean and Earth Science, SOC
Mr. John Davis, School of Ocean and Earth Science, SOC
Mr. Doros Paphitis, School of Ocean and Earth Science, SOC

AUTOSUB Team, Ocean Technology Division, SOC

Mr. Peter Stevenson, Mr. Miles Pebody, Mr James Perrett and Mr Andy Harris

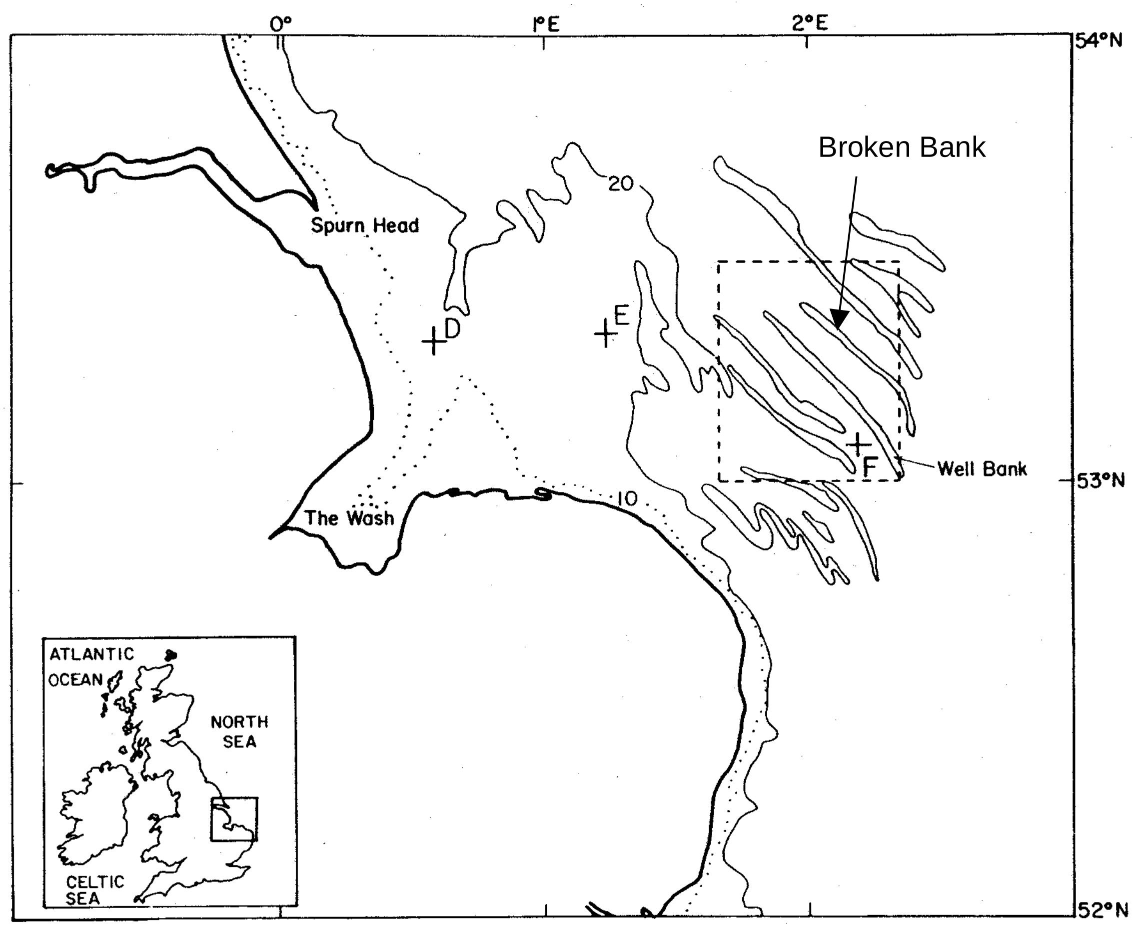

Figure 1. Area of activities during R/V RRS Challenger Cruise Number 146.

II. The Deployment Cruise

II-1. Cruise Chronology

August 17. The R/V Challenger departed Southampton Dock at 1630 (all times are GMT) on August 17th, 1999. After a steaming of approximately 28 hours the vessel arrived at the location of the experiment on August 18, 1999.

August 18. At 1000am a meeting was held between the scientists, the bridge officers and the deck crew to discuss the deployment of the bed frames and AUTOSUB and the procedures that should be followed during these operations. We arrived to the site at approximately 2030. Prior to deploying any of the instrumented bed frames a side-scan sonar reconnaissance survey was carried out to identify the bed conditions (i.e., types and size of bedforms). Particular attention was paid on deploying the benthic boundary layer system (AQUILA tripod) at a location not influenced by flow separation processes around large waveforms. The survey was carried out overnight over the bank and at the swales around it.

August 19. We began deployment at 0604 starting with the AQUILA tripod at location $02^{o}11.6$'E, $53^{o}17.7$'N (crest of the bank). The tripod mooring consisted of a ground line attached to a ballast weight of approximately 150kg. The tripod was put on the bed and then the ground line was released. Unfortunately, during the deployment great tension was applied to the deployment line and we suspected that the tripod was overturned. We decided to recover and repeat the deployment. This occurred at 0800 and the tripod was deployed on site. Then we proceeded with the deployment of the remaining frames. At 0850 we deployed the bottom frame A, which was equipped with an upward looking ADCP and a pressure sensor. The frame was deployed at location $02^{o}10.0$'E, $53^{o}16.2$'N during a smooth operation. Next we proceeded to location $02^{o}04.8$'E, $53^{o}20.6$'N where the third bed frame (B), carrying a pressure sensor was deployed at 1010. The AUTOSUB team performed adjustments and tests of the vehicle prior to launching. At 1345 all operations were ceased due to adverse weather conditions.

August 20. AUTOSUB was launched at 0545 for a compass calibration run and for a pre-determined test run along a transect perpendicular to the main axis of the bank. The AUV failed to dive and at 0805 the AUV mission was abandoned and the vehicle was recovered. During recovery the vehicle collided with the side of the ship. This results in slightly damaging the front panel of the AUV. Also, the DopBeam sensor was affected by the impact and was pushed inwards. Following recovery, CTD casts were carried out at locations along and across the bank; later a side scan sonar survey was commenced at approximately 1400. While the survey was underway, tests were carried out on the AUTOSUB vehicle to identify the causes of the mission failure. The problem was found to be faulty batteries and all batteries were replaced. Repeated side-scan sonar surveys were carried out throughout the course of the night.

August 21. AUTOSUB was launched at 0800 for a calibration mission. The vessel was following the AUV in order to be within telemetric transmission range for carrying out tests and downloading/uploading commands from the ship to the AUV and vise versa. The calibration/test mission was successful and the AUV was recovered at 1530. Then sampling of the seabed was carried out at various locations around the bank. The sampling was completed at approximately 2050 and the AUV was launched for its first scientific mission at 2140.

August 22. AUTOSUB survey in an autonomous, terrain-following mode was well underway and the ship headed for a pre-scheduled meeting with the AUV at approximately 0909. During the course of the day side-scan sonar and shipborne ADCP surveys were carried out along a transect (B) north of the AUV deployment area. The surveys were interrupted at pre-determined intervals for meeting and checks of the AUV operational status.

August 23. AUTOSUB's 1^{st} mission was completed successfully and the AUV was recovered at 12:00. After data downloading a battery change was carried out while CTD casts were collected during the period 1200 to 1700. The AUTOSUB was ready and redeployed for a 2nd mission at 2100. Side-scan sonar and ship-borne surveys were carried continuously in parallel with the AUV surveys.

August 24. Side-scan sonar and shipborne ADCP surveys were obtained throughout the day with interruptions for meeting and checking on the AUV.

August 25. The bed frame (B) with the pressure sensor was recovered at 0928. Following the recovery and while waiting for next slack water side-scan sonar survey was underway. The bed frame (A) with the ADCP was recovered at 1500 while the AQUILA tripod was recovered at approximately 1600. Finally the AUV was recovered at 1800. Side-scan sonar survey was continued during the night.

August 26. The survey was finished at 0500 and the ship started sailing back to Southampton.

August 27. Arrived at Southampton Oceanography Centre dock.

A synoptic outline of the main events that took place during the cruise is shown in Table 1.

II-2. Shipboard Data Systems

The Challenger was equipped with Trimble GPS4000 for navigation and a SIMRAD EA500 echosounder. All navigational and depth data were pre-processed and recorded onboard the ship's data logging system.
The recorded navigational data showing position of the ship for each day of the cruise are shown in Figure 2.

Also a hull mounted Acoustic Doppler Profiler (ADCP, 75KHz) system was operated during the cruise.

Data from the ADCP and navigation were retrieved by the NERC RVS technical support person and stored in a CD that became available to us at the end of the cruise.

Table 1. R.R.S. CHALLENGER CRUISE 146/99: Timetable of events

All scientific operations during cruise 146/99 were carried out around Broken Bank (Southern North Sea, see Figure 1) in vicinity of 53° 18' N, 02° 09' E. Time in GMT.

Date	Julian Day 99	Time (BST)	Event
17/08/99	229	14:00	SBE. Commence singling up.
		16:30	FAOP.
18/08/99	230	20:35	Sidescan survey.
19/08/99	231	05:33	Complete sidescan survey.
		06:04	Deployed 3 moorings: 02 11.6 E. 53 17.7 N AQUILA Tripod. 02 10.0E. 53 16.2 N ADCP & Pressure bed frame. 02 04.8 E. 53 20.6 N Pressure sensor bed frame.
		13:48	Ceased operations due to adverse weather.
20/08/99	232	05:37	AUTOSUB launched.
		07:57	AUTOSUB recovered; failure to initiate mission.
		09:07	Commenced CTD casts along a transect.
		14:18	Completed CTD casts.
		15:41	Started sidescan survey.
21/08/99	233	05:30	Completion of sidescan survey.
		08:19	AUTOSUB launched. Calibration mission.
		15:33	AUTOSUB recovered. Calibration mission successful.
		16:38	Commenced sea bed sampling along transect line.
		20:51	Seabed sampling is completed.
		21:40	AUTOSUB launched. 1st Mission.
22/08/99	234	01:21	Commenced ADCP and sidescan survey.
23/08/99	235	12:06	AUTOSUB recovered, end of 1st mission.
		13:05	Commenced CTD casts along a transect.
		17:27	Completed CTD casts.
		18:00	Shipborne ADCP and sidescan survey.
		21:04	AUTOSUB launched. 2nd mission.
25/08/99	236	09:36	Pressure sensor bed frame recovered.
		10:35	Shipborne ADCP and sidescan survey.
		14:50	ADCP and pressure bed frame recovered.
		15:37	AQUILA tripod recovered.
		16:43	Shipborne ADCP and sidescan survey.
		18:18	AUTOSUB recovered. End of 2nd Mission.
		18:48	Shipborne and ADCP and sidescan survey.
26/08/99	237	05:24	Complete survey. Science mission completed. ETA 271400 L. Proceeded to Southampton.

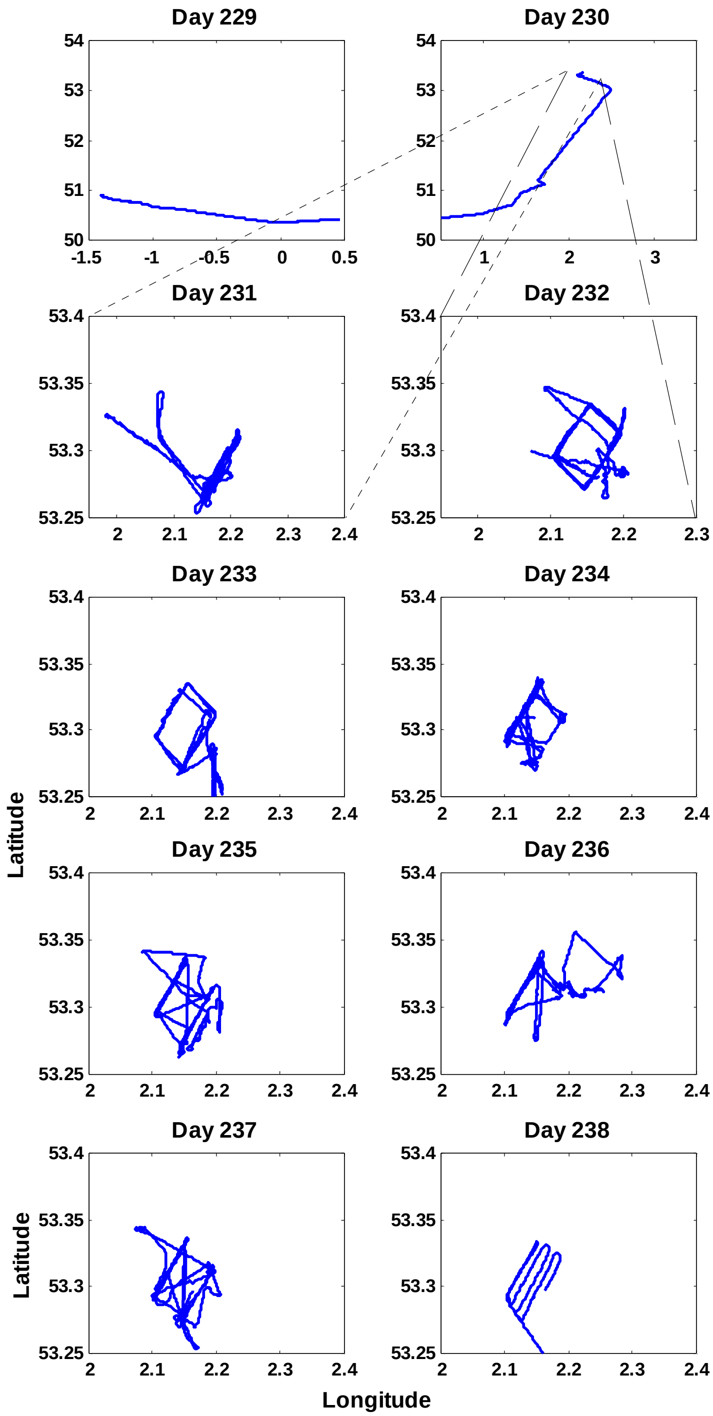

Figure 2. Plots showing the position of the ship for each day of the cruise (positions during days 229 and 230 indicate sailing toward the experimental site).

III. The Bed Frames

III-1 Summary Description

The experimental area was around the middle part of the Broken Bank. In this area three bed mounted frames were deployed carrying a variety of instrumentation. The basic strategy of the deployment was to: (i) obtain pressure gradients along and across the main axis of the bank; (ii) measure the temporal variability of the tidal flow on both the crest and the swale of the bank; (iii) measure benthic boundary layer processes including turbulence and sediment resuspension; and finally (iv) obtain measurements of flow concurrently with the AUV data collection for intercomparison purposes.

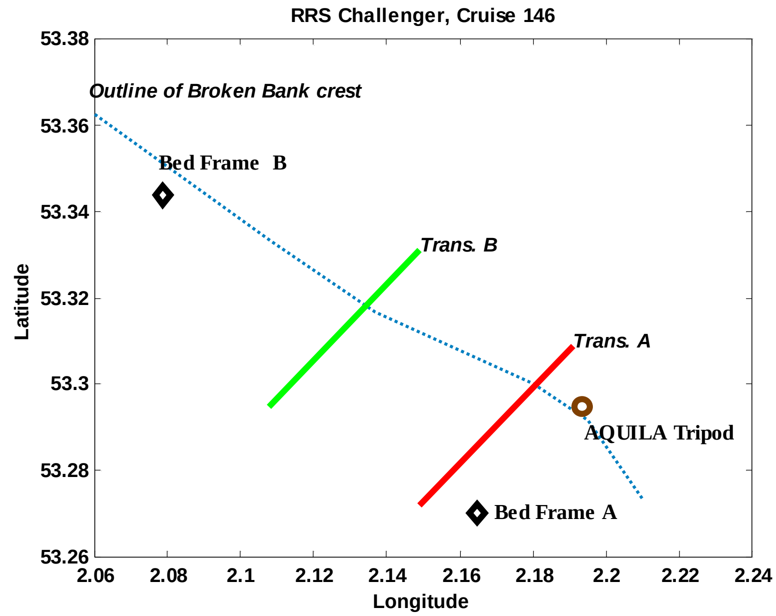

Figure 3. Diagram showing the experimental layout and the relative position of instrument (bed frames) deployment locations and AUTOSUB and ship survey lines (Transects A and B, respectively).

All bed frames were attached to surface buoys and the lines to the buoys were used for both deploying and recovering. Mr. John Humphery (Proudman Oceanographic Laboratory, UK) designed the moorings.

A schematic diagram of the deployment configuration is shown in Figure 4. A bed frame (B) with a pressure gauge was deployed near the crest of the bank at the northern end. Some 8km to the south the AQUILA tripod was deployed on the top of the bank with another pressure gauge and also a Laser In-Situ Scatter Transmissometer (LISST) system installed on it. At a transverse direction and in the swale of the bank a bed frame (A) was deployed with an upward looking ADCP (600KHz) and a pressure gauge. In addition to the above described moorings, two main transects were established for the monitoring of the spatial variability of the flow. Transect A (see Figure 2) was the main transect were the AUTOSUB vehicle was collecting data at a fixed elevation above the sea bed. Transect B was established for the collection of shipborne ADCP data with the vessels onboard installed ADCP system. In addition, sonar images of the seabed were collected repeatedly over different times of the tidal cycle along the two main transects.

III-2 Benthic Boundary Layer Frame (AQUILA Tripod)

Bottom boundary layer measurements were obtained by deploying an instrumented tripod (AQUILA) that was developed by the University of Southampton. The tripod was deployed on 19th August 1999 at 06:04 GMT. The deployment location was 2°11.6103' E and 53°17.6938' N (see Figure 2).

The tripod was equipped with various sensors for measuring flow and sediment characteristics within 2 meters of the seabed. The instrument suite included a SIMRAD Mesotech Altimeter (Model 807, 200KHz) for monitoring the seabed elevation. The Altimeter has an operational range between 0.37 and 5.00m with a resolution of 7.62mm. Flow conditions were measured using three 2 - axis Alec Electronics Co, electromagnetic current meters (ACM200-V) and 1 NorTek Acoustic Doppler

Table 2. List of sensors installed on the AQUILA tripod frame and their elevation in relation to the altimeter. Sensor height above bed can be calculated as the difference between the altimeter reading and the relative position of the altimeter and the individual sensor.

Instrument	Elevation above Deck (Z_{deck}, cm)	Height above altimeter (dz_{alt}, cm)
Altimeter	195	0
ADV	27	-168
Emcm# 3 (#1)	172	-25
Emcm# 4 (#2)	143	-52
Emcm# 5 (#3)	81	-114
OBS#1	213	+18
OBS#2	105	-90
OBS#3	52	-143
LISST-100	205	+10
Pressure (on Data Logger)	226	+31
Temperature	226	+31
Conductivity	226	+31
Pressure Gauge (range 200m)	199	+4

Velocimeter (ADV, 10MHz). Turbidity levels were measured using 3 Seapoint Optical Backscatter Sensors, (OBS). Conductivity and temperature of the water was measured with a Falmouth Scientific, Inc., OEM CT-sensor that consists of an inductive conductivity sensor (range: 0-64mmho/cm (0-6.5S/m); accuracy: ± 0.25mmho/s (0.0025S/m)) and a platinum temperature sensor (range: -5 to 35 Celsius; accuracy ± 0.050 Celsius). A C100 KVH Industries, Inc. compass and a pitch and roll sensor were installed on the system. All data were synchronized and logged onboard a data logger developed by WS Ocean Systems. All data were recorded at 5Hz except the ADV sensor that was recorded at 25Hz. The system was recording every half an hour for 15 minutes. 312 bursts were collected of which bursts 0 to 7 and bursts 309 to 311 where collected on board the vessel and thus will not be considered in the data analysis. The first good burst corresponds to a start time of 19th August 1999 at 08:36:30 (Julian time: 231.3587) while the last good burst had a start time of 25th August 1999, at 15:06:30 (Julian time: 237.6295).

Table 3 lists the commands that were used to program the system and the gain that was used for some of the sensors.

Table 3. Setup commands used during the deployment of the AQUILA tripod frame.

CA262143	% Activate all channels 111111111111111111
CH004095	% Channels for header 000000110100001010
CB261615	% Channels for burst 111111110111101111
PA56	% Serial port inputs ADV=5; KVH=6
GF6.3	% Set gain on OBS1 to 3
GF7.3	% Set gain on OBS2 to 3
GF8.3	% Set gain on OBS3 to 3
AD1	% Warm-Up period 1s
AHI15	% Header Interval 15min
AHS1	% Header Scan Rate 1s (1Hz)
AHL30	% Header Duration 30min
ABI30	% Burst Interval 30min
ABS5	% Burst Scan Rate 5Hz
ABL4505	% No of scans 15min of data + warm-up (5Hzx60sx15min)+(5Hzx1s)
AM	% Units of time are in minutes
AU0	
LAUT	% Set Filename to AUT
SS1	% Save the above set-up as no 1.
RD17.08.99	% Set Date on System's Clock
RT09.00.00	% Set Time on System's Clock
AO	% Start Logging immediately (No programmed logging)

In addition to the instrumentation that is an integral part of the AQUILA tripod, a self-recording Laser In-Situ Scatter Transmissometry (LISST-100, Range (1.5 to 250 microns), manufactured by Sequoia Sci. and owned by the University of South Carolina, was installed on the tripod frame. Assigning values to the logging parameters M, B and N sets the LISST data logger. The instrument was set to take 60 (parameter N) samples with a time interval of 5 (parameter B) seconds in between them (each sample will be the average of 16 scans) and then wait (sleep) for 10 minutes. This resulted in sampling data for 5 minutes every 15 minutes. 417 bursts were collected in total of which the first 10 were while the sensor was out of the water. The good data comprise a total of 407 bursts with the first burst initiated on 19th August 1999 at 08:00 (Julian time: 231.3333) while the last burst was initiated on 23rd August 1999 at 13:00 (Julian time 235.5417). The last burst collected was some 2 days before the recovery of the tripod. The reason was that the data logger was full of data. Also an accurate pressure gauge (SBE 26 SEAGAUGE V3.0a SN 0047; pressure sensor serial number = 52421; range = 45 psi) was installed for measuring pressure variations during the tidal cycle (see futher Figure 9).

The arrangement of the instruments on the AQUILA tripod as well as their relative location and elevation above the seabed is shown in Figure 4.

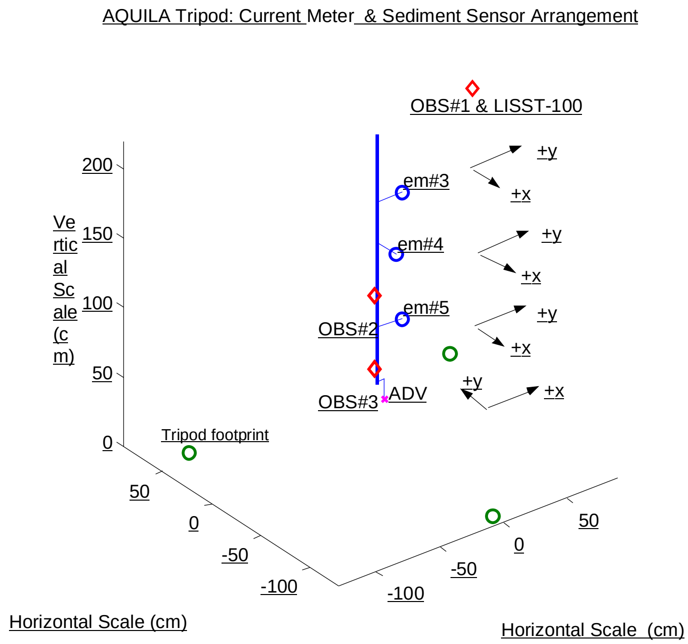

Figure 4. Three-dimensional diagram showing the location of the sensors and the sensor defined orientation. Raw velocity data were converted into the frame coordinate system that coincides with that of the ADV sensor.

The data collected were calibrated into physical units except data from the OBS sensors that are given in counts (no calibration exists for the OBS sensors). The mean values of horizontal component of velocities, recorded by the flow meters, along the frame coordinate system are shown in Figure 5. Noticeably, the mean values from the electromagnetic current meters show an offset, which is more obvious for the y component (Fig. 4, bottom panel). On the other hand the mean values obtained with the ADV sensor show a tidal variation around zero. The em sensor 2 appears to have the minimal offset amongst all the em sensors.

Figure 6 shows the mean water depth as recorded by the pressure sensor together with the intensity of the return signal from the 3 beams of the ADV sensor (middle panel) as well as the correlation coefficient between transmitted and received signal (bottom panel). The intensity of the return echo depends on the amount and size of backscatterers present in the water column and in some cases this can be used as a proxy for the amount of

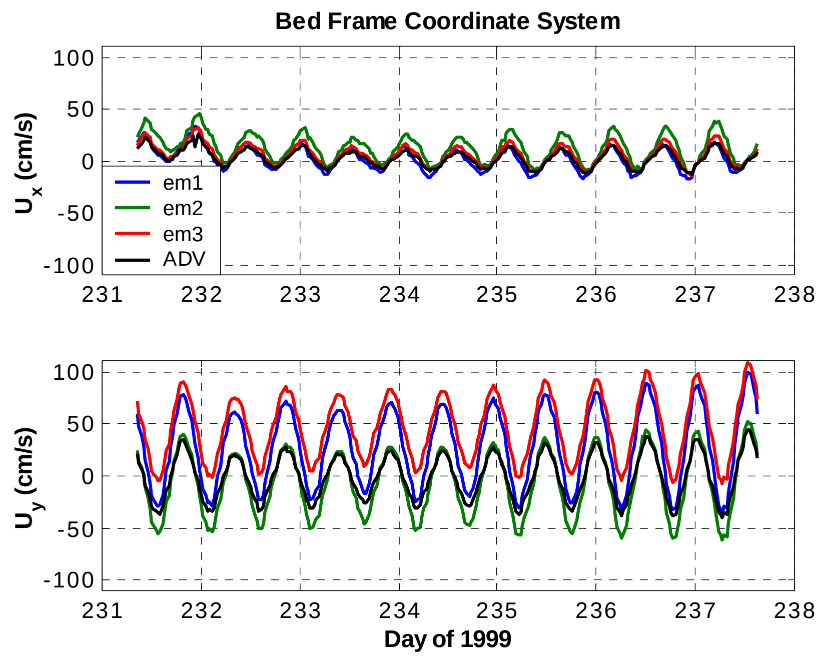

Figure 5. Time-series of the two horizontal components (x and y) of mean velocity as recorded from the velocity measuring sensors.

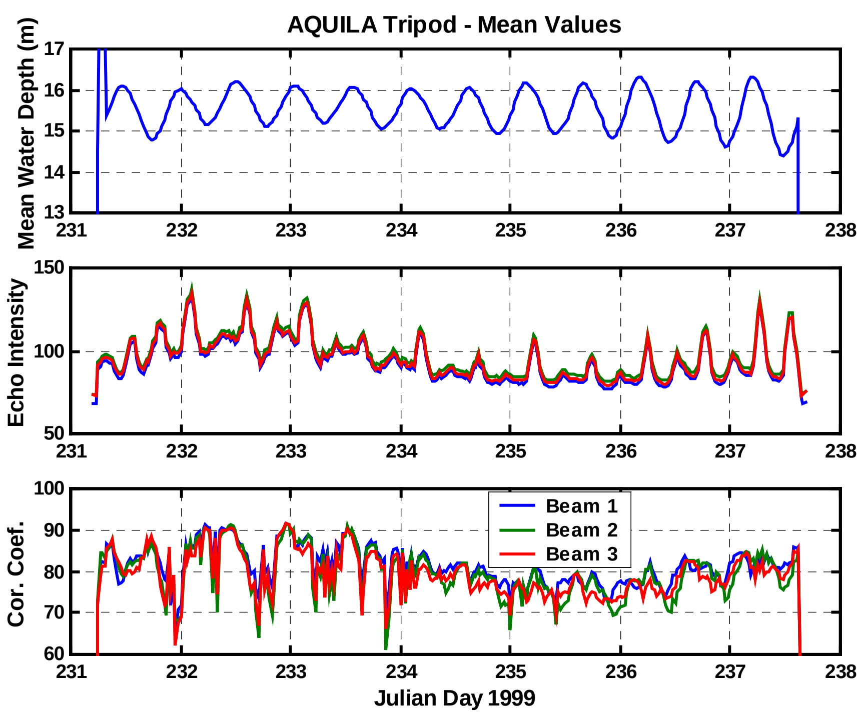

Figure 6. Mean water depth at the deployment location (top) and intensity of the return echo (middle) and correlation coefficient (bottom) for each of the beams of the ADV sensor

sediment being in suspension in the water column. In general high returns denote good quality of flow measurements. The correlation coefficient throughout the deployment was above 60%. In general it is noticeable that both the return echo strength and the correlation coefficient are higher during the first half of the deployment period. This coincides with periods of higher wave activity and thus more sediment set in suspension and acting as the backscattering particles.

The OBS records (sensors 1, 2 and 3, being at approximately 2, 0.5 and 1m above the bed respectively) are shown at the top three panels of Figure 7. Sensors 2 and 3 exhibit a very similar response that is mainly due to their proximity to the seabed while sensor 1 is approximately 2 m above the sea bed and its response differs from that of the other two sensors. The elevation of the frame above the seabed seems to remain constant for the majority of the deployment period. There are two exceptions: (i) at time just before day 232 there is a decrease in distance of approximately 8cm, and (ii) toward the end of the deployment (after day 236.2) where a settlement over 30cm occurred. The latter is of a great magnitude to be real (a 30cm settlement will had caused the ADV sample volume to be on the seabed and the ADV data should had been corrupted).

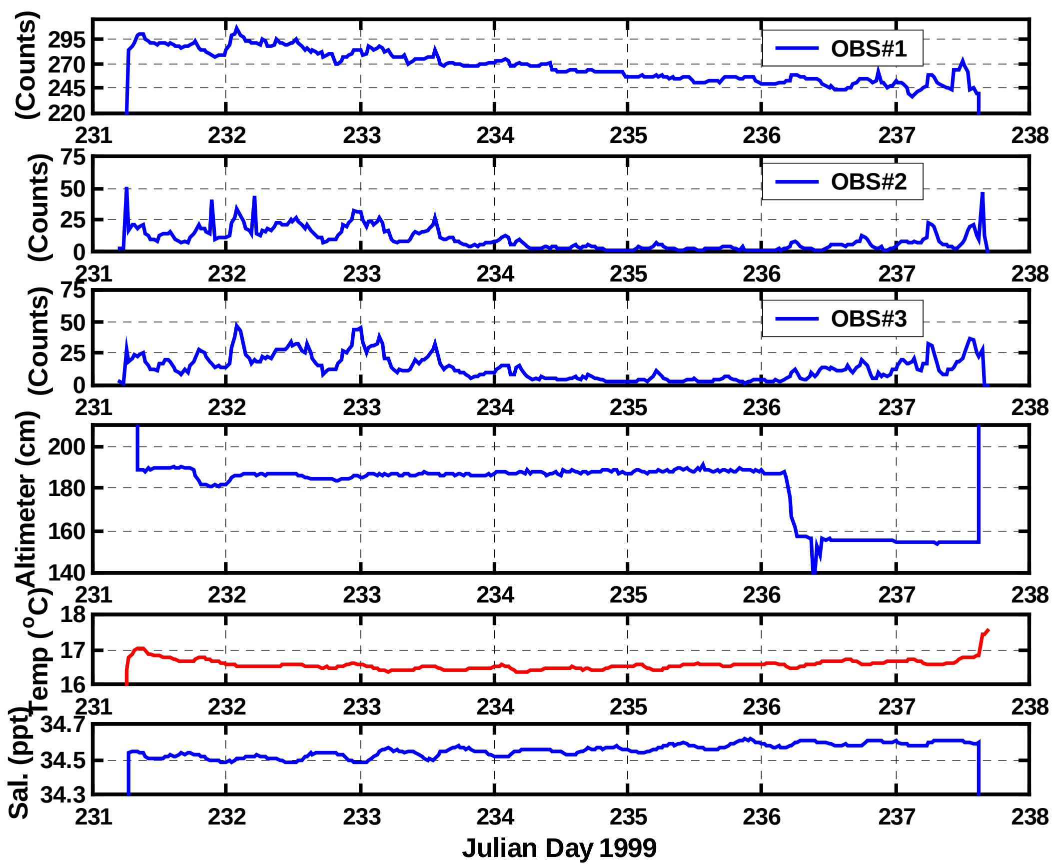

Figure 7. Time-series of burst-averaged values from the OBS sensors (in counts), the altimeter, temperature and salinity as collected by the AQUILA tripod

A closer examination of the raw altimeter data revealed that this was due to an apparent malfunction of the sensor that kept jumping values by approximately 30cm (see Figure 8). Thus the burst averaged altimeter data were corrected for this malfunction. Also in Figure 5 the raw records of temperature and salinity are shown. The temperature during the deployment period was approximately 16.6 degrees while the salinity varied between 34.5 and 34.6ppt.

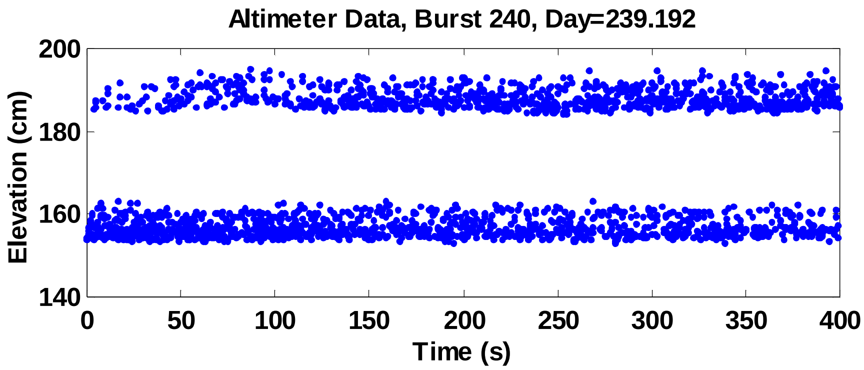

Figure 8. Time-series of raw altimeter data showing abrupt changes of elevation recorded by the sensor. The values around 190 cm are in agreement with the values from previous bursts when the sensor was operating correctly. These values (upper cluster) are used to calculate the elevation of the sensors

III-3 Bed Frame A

The first bed frame (A) was deployed on 19th August 1999 at 08:50 and at location 2°09.88'E and 53°16.22'N. An upward-looking RDI BroadBand ADCP Workhorse, 600MHz and a Seagauge Pressure Gauge (SBE 26 SEAGAUGE V3.1 SN 0044 Pressure sensor serial number 61469; range = 300 psia) were installed on it. The ADCP was configured to record velocities over range 100 bins with bin size of 0.25m. The ensemble interval was set to 3 minutes. It started collecting data on the 18/08/99 at 05:00:00 and while the frame was still onboard the vessel. The data collected cover a range from 1.88m to 26.63m above the seabed and are shown in Figure 9. The mean water depth was approximately 32m. The pressure recorded at the same location every 3 minutes and waves every hour. The mean pressure time-series and the wave-induced standard deviation are shown in Figures 10 and 11, respectively.

III-4 Bed Frame B

The second bed frame (B) was deployed on 19th August 1999 at 10:10 and at location 2°04.73'E and 53°20.63'N. A Seagauge Pressure Gauge (SBE 26 SEAGAUGE V3.1 SN 0043; pressure sensor serial number = 52423; range = 45 psia) was installed on it measuring mean pressure every 3 minutes and waves every 1 hour. The mean pressure time-series and the wave-induced standard deviation are shown in Figures 10 and 11, respectively.

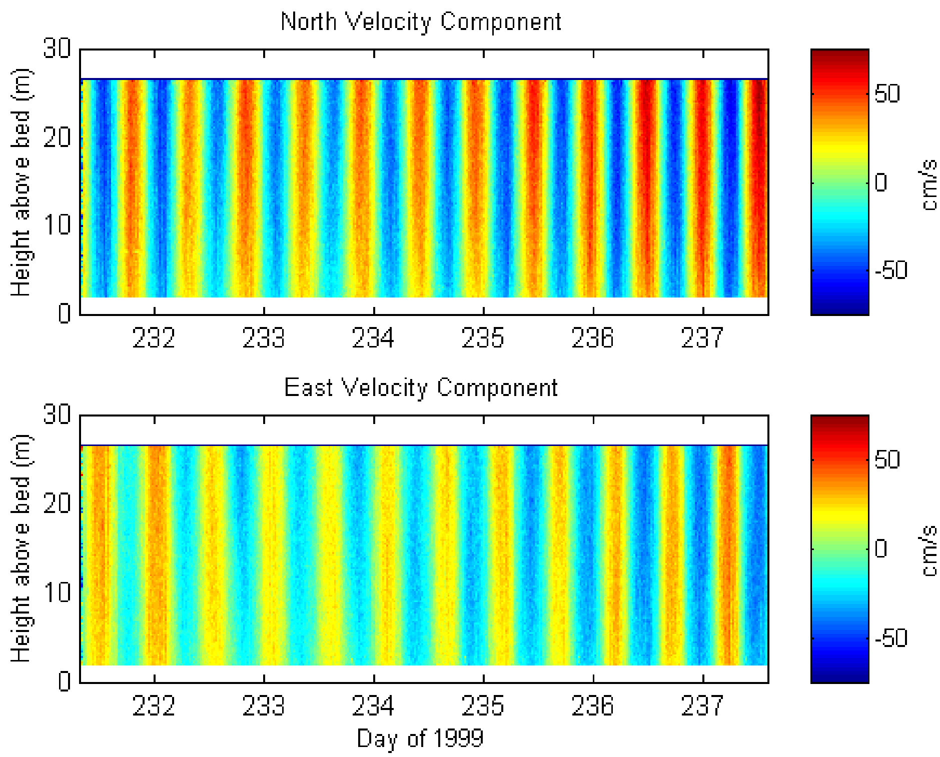

Figure 9. Time-series of ADCP data collected at the location of bed frame A.

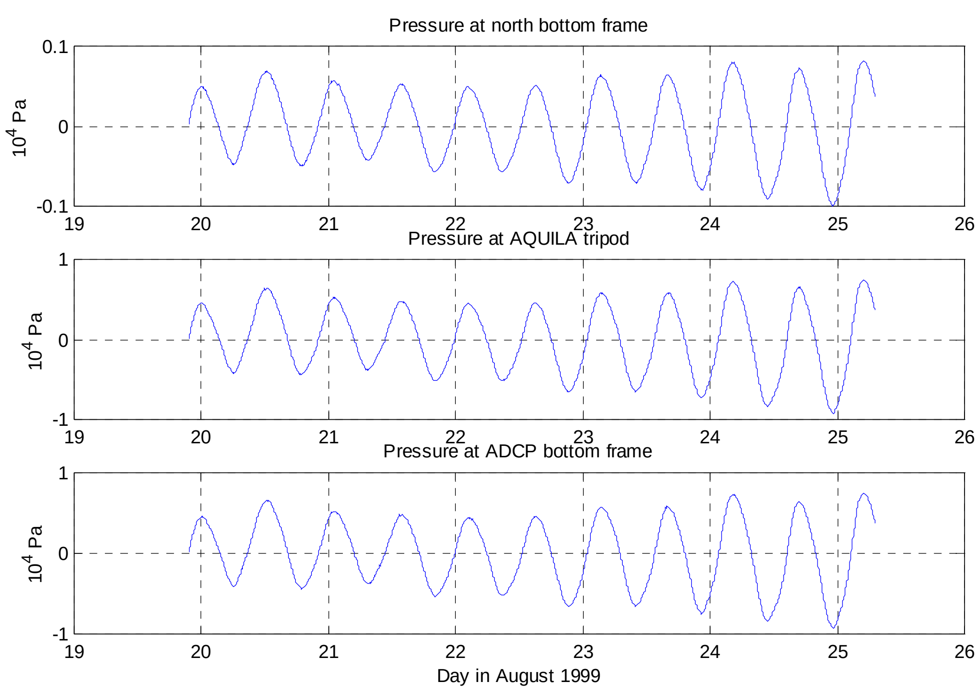

Figure 10. Pressure (in Pa) as recorded by the three pressure gauges deployed in the locations shown in Figure 3. Data points shown are every 3 minutes (top: bed frame B; middle: AQUILA tripod; bottom: bed frame A).

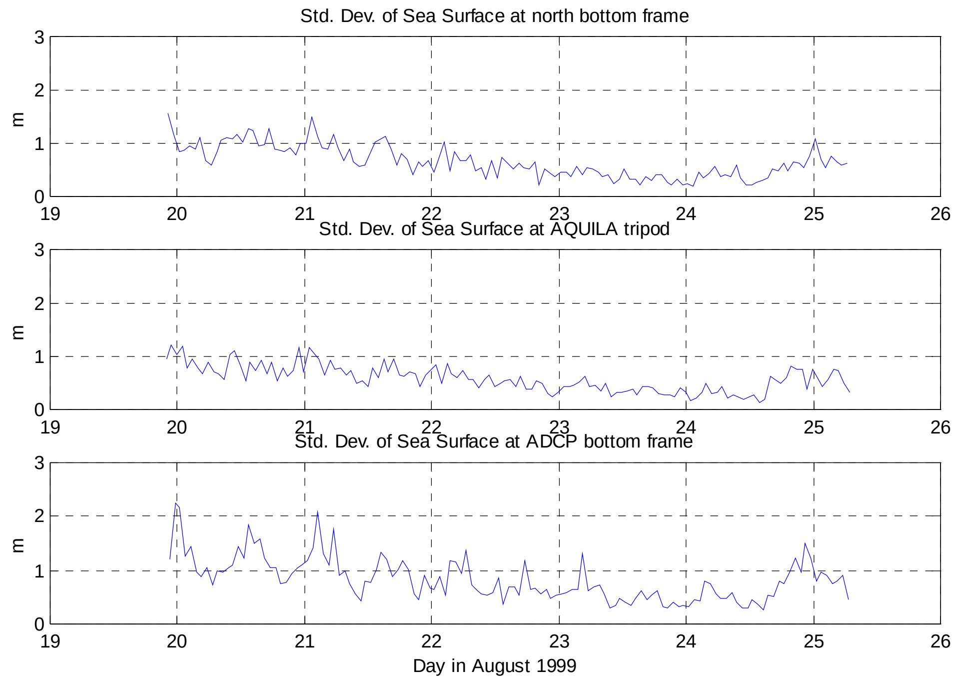

Figure 11. Standard Deviation of sea surface, inferred from records of pressure for a period of 3 minutes obtained every 3 hours at the locations shown in figure. The std deviations were estimated from the spectra of the burst data applying correction for depth attenuation using linear wave theory (top: bed frame B; middle: AQUILA tripod; bottom: bed frame A).

IV. The AUTOSUB Surveys

The AUTOSUB vehicle was used during August 1999 to measure the spatial variation of turbulence over the sandbank in the southern North Sea. The objectives of the mission were: (1) to spatially map bottom stresses in tidal flows over a linear ridge; and (2) to use the measurements to understand the role of bottom stress in controlling the bedform scale flow and sediment transport processes that maintain the sandbank. Instrumentation on the AUV included: (1) the standard AUTOSUB instrument suite consisting of an ADCP (200KHz), CTD, Transmissometer, Altimeter, GPS, Perssure sensor and (2) instruments that we supplied for this project consisting of an Acoustic Doppler Velocimeter ADV, a 1200KHz Broadband ADCP and a single-axis pulse-Coherent Doppler sonar, which were used to measure the near bed (0.4 to 4m) flow. A schematic diagram of the instrument load of the AUV is shown in Figure 12.

The vehicle was programmed to collect data along a 5km long transect running perpendicular to the main axis of the bank and at a height 4m above the seabed. Side-scan sonar analysis revealed that the AUV was collecting flow measurements over a bed with of varying morphology (from sand waves with a height of 1 m and length of 15m to wave induced ripples and flat bed). The ambient tidal flow speed varied between 0 and 60cm/s and was aligned with the major axis of the bank. On average the AUV covered 11

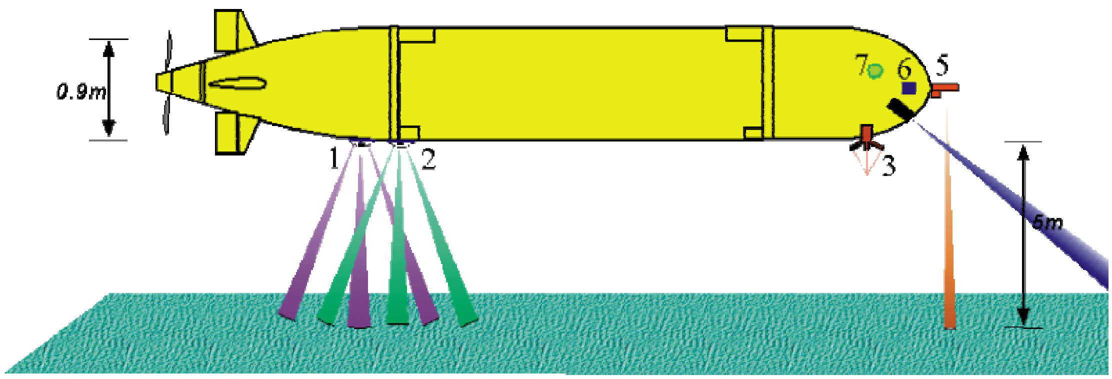

Figure 12. Schematic diagram showing the instrument load of the AUTOSUB vehicle during the cruise. The instrument load consisted of: (1) a 1200 KHz BB ADCP for measuring near bed flow and bottom tracking ; (2) a 300 KHz BB ADCP - vehicles bottom tracking system; (3) an Acoustic Doppler Velocimeter (ADV) for measuring the 3-D flow/turbulence; (4) a forward looking Sonar for bathymetry and assisting the terrain following navigational procedure; (5) a 1.75MHz acoustic beam for flow measurements; (6) a CTD and Transmissometer package; and (7) a pressure sensor for measuring depth below sea surface.

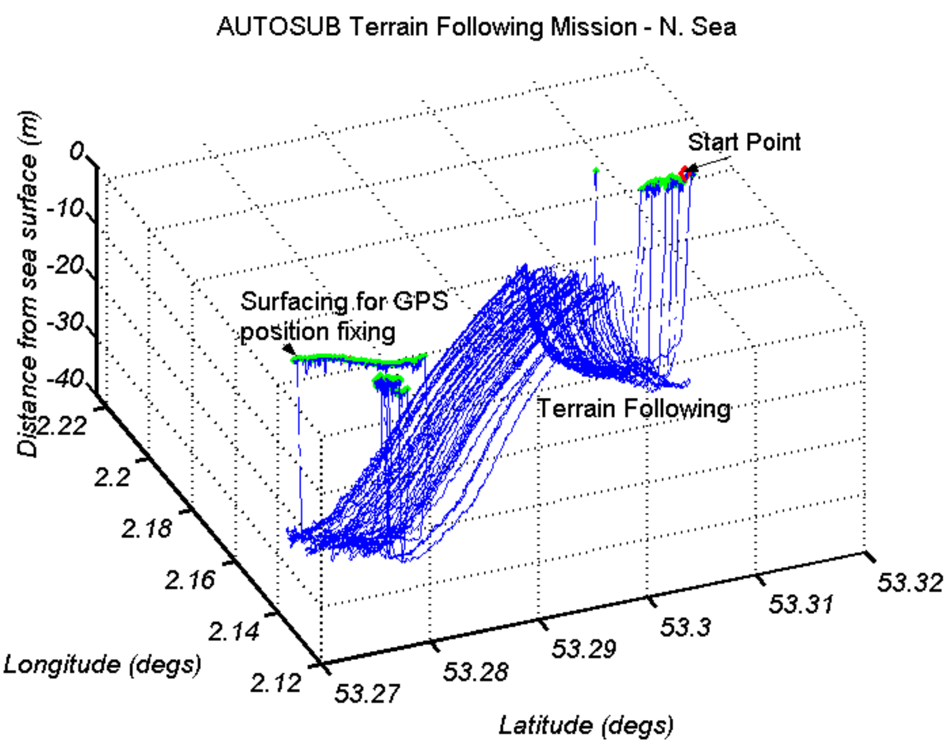

Figure 13. Diagram showing the 3-D location of the vehicle during on of the missions. The vehicle was "flying" at approximately 4m above the sea bed following the bottom bathymetry. Surfacing locations for GPS fixing can be clearly seen in the diagram.

transects per tidal cycle for a total period of over 70 hours with one change of batteries between data collection periods. In total 2 successful missions were carried out that covered the periods from August 21st, 1999, 21:40 (Julian time: 233.9028) to August 23rd, 1999, 12:06 (Julian time: 235.5) and from August 23rd, 1999, 21:04 (Julian time: 235.87) to August 25th, 1999, 18:17 (Julian time: 237.7618).

Data from the AUTOSUB standard instrument suite were recorded onboard the vehicles controller/data logger and were supplied to us by the AUTOSUB team. Our instruments were self-logging. The 1200 KHz ADCP was programmed to log internally raw water velocities along the acoustic beams and bottom tracking velocities every 1s (1Hz). The bin resolution was 20cm. The Acoustic Doppler Velocimeter (ADV) sensor was self-recording the 3 components of the flow (along, across vehicle main axis and vertical) at a rate of 16.6667Hz. ADCP and ADV collected data during both missions. The Dop-beam sensor was operational only during the second mission and it recorded acoustic data along its axial beam at a frequency of 200Hz. Special analysis of the signal has to be carried out to convert the collected data into axial velocities along the acoustic beam.

V. The CTD Survey

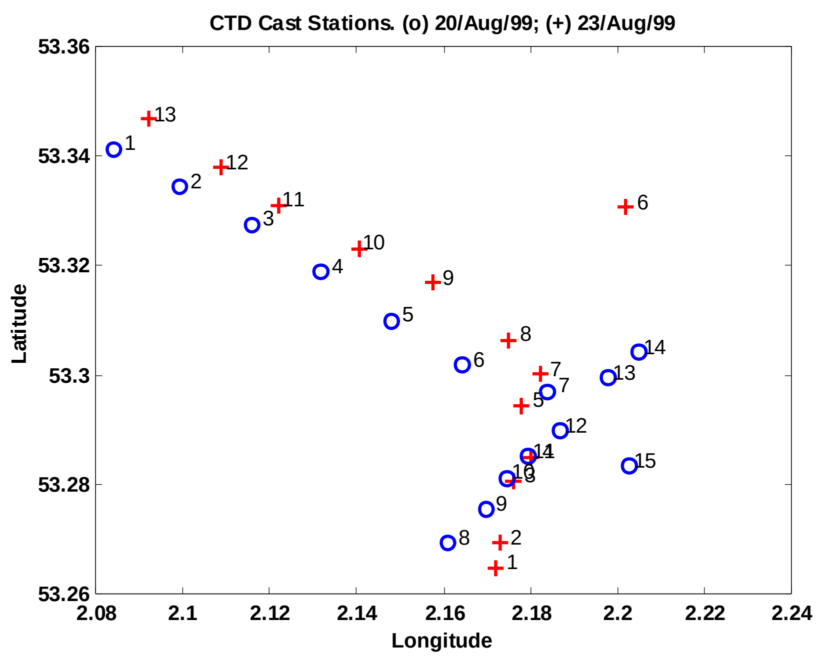

Figure 14. Diagram showing the locations of the CTD cast data collected during 20th and 23rd August 1999 (crosses and circles, respectively). The numbers indicate station as listed in Tables 3 and 4.

Conductivity, temperature and depth measurements were obtained at locations along and across the Broken bank at two different days: August 20th and 23rd, 1999, respectively. The objective of the CTD casts was to identify any vertical stratification and any horizontal gradients in the density of the water that might be driving mean flows. A

Falmouth Scientific Inc., model MCTD-MBP-D instrument was used for the casting. The locations of each cast are shown in Figure 14 while the details of each cast station deployments are listed in Tables 4 and 5. Plots of the individual casts are attached as Appendix A.

Table 4. Locations and time of CTD casts for 20th August 1999. Time in GMT.

Instrument:	Falmouth Scientific Inc, MCTD-MBP-D			
Station No	Latitude	Longitude	Water Depth*	Cast Time
1	53° 15.88’	2° 10.32	35.5	10:10:12
2	53° 16.16’	2° 10.37	32.5	10:35:22
3	53° 16.84’	2° 10.57’	29.5	10:52:44
4	53° 17.10’	2° 10.81’	24.0	11:13:36
5	53° 17.66’	2° 10.68’	18.0	11:36:37
6	53° 19.84’	2° 12.11’	15.0	12:33:04
7	53° 18.01’	2° 10.93’	27.5	13:07:26
8	53° 18.38’	2° 10.50’	27.5	13:24:06
9	53° 19.01’	2° 09.45’	32.0	13:46:53
10	53° 19.39’	2° 08.43’	32.5	14:09:28
11	53° 19.86’	2° 07.32’	31.0	14:32:27
12	53° 20.28’	2° 06.53’	32.0	14:51:34
13	53° 20.80’	2° 05.54’	30.0	15:14:31

Table 5. Locations and time of CTD casts for 23rd August 1999. Time in GMT.

Instrument: Falmouth Scientific Inc, MCTD-MBP-D.				
Station No	Latitude	Longitude	Water Depth*	Cast Time
1	53° 20.48’	2° 05.04’	14.0	14:09:02
2	53° 20.06’	2° 05.96’	13.0	14:27:52
3	53° 19.65’	2° 06.95’	13.0	14:42:34
4	53° 19.13’	2° 07.91’	14.0	14:57:25
5	53° 18.60’	2° 08.89’	14.5	14:29:08
6	53° 18.11’	2° 09.86’	17.0	14:43:22
7	53° 17.82’	2° 11.03’	16.5	15:43:23
8	53° 16.16’	2° 09.66’	36.0	16:11:42
9	53° 16.52’	2° 10.18’	34.0	16:41:59
10	53° 16.87’	2° 10.48’	30.0	16:56:05
11	53° 17.11’	2 °10.76’	24.5	16:10:41
12	53° 17.39’	2° 11.22’	19.5	17:27:22
13	53° 17.97’	2° 11.88’	36.4	17:49:42
14	53° 18.26’	2° 12.29’	38.5	18:08:20
15	53° 17.00’	2° 12.17’	18.0	18:31:25

VI. Sea Bed Sampling

Seabed sediment samples where collected using a Van-Veen sampler (grab). The sampling took place on 21st August 1999 along the two main experimental transects (A and B, see Figure 2). The locations of the samples are listed on Table 5 and their relative position is also shown in Figure 15.

Table 6. Location of Sea Bed Samples

Station No	Latitude	Longitude	Water Depth (m)
1	53° 18.44’	2° 11.31’	38.5
2	53° 18.11’	2° 10.82’	21.5
3	53° 17.84’	2° 10.60’	16.5
4	53° 17.43’	2° 10.32’	22.0
5	53° 17.16’	2° 09.92’	27.0
6	53° 16.80’	2° 09.39’	35.0
7	53° 16.63’	2° 09.32’	36.0
8	53° 16.39’	2° 08.88’	36.5
9	53° 17.70’	2° 06.35’	34.5
10	53° 18.39’	2° 06.98’	33.5
11	53° 18.86’	2° 07.52’	18.0
12	53° 19.12’	2° 07.86’	13.0
13	53° 19.32’	2° 08.03’	25.0
14	53° 19.69’	2° 08.61’	35.0

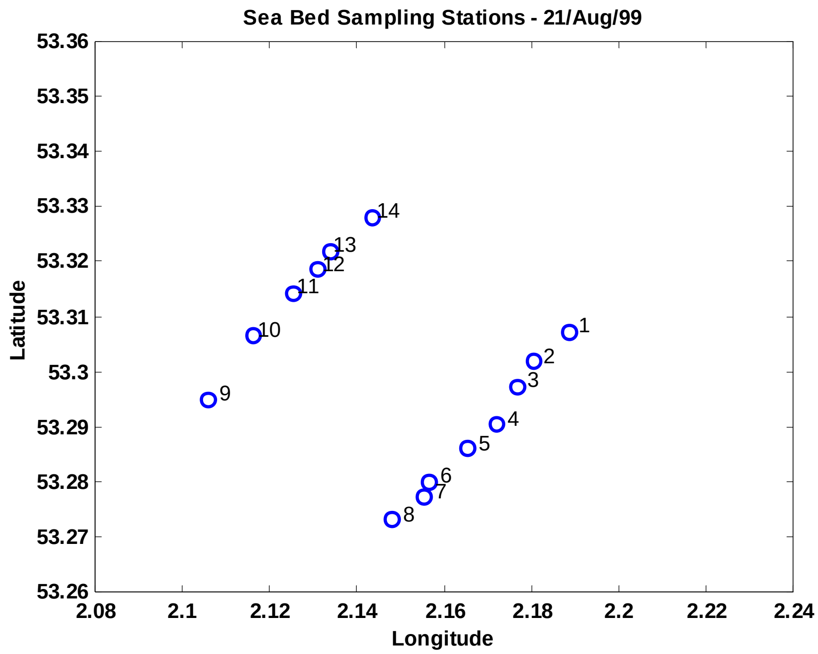

Figure 15. Locations of sea bed grab samples obtained along two transects oriented perpendicular to the main axis of the Broken Bank.

VII. Bed Imaging

A Dual Frequency (114KHz & 414KHz) Geoacoustics Side-Scan Sonar was used with an Octopus digital recorder and a Dowty 3710 thermal linescan printer

Both frequencies were used during the operation: (i) the lower frequency was used during the bad weather conditions (force 5-6); and (ii) the higher frequency was utilized during calm weather. The triggering time used was 135 ms and the sweep time 133 ms (giving a slant range of 100 m each side). Good quality records were obtained during the calm weather surveys.

Several surveys took place. The first survey (18-19 August) was a reconnaissance site survey over the areas of the proposed sites for the deployment of the bottom-mounted instrumentation. The next survey took place on the 20th and 21st of August and consisted of repeated surveys along transects A and B during a complete tidal cycle. On the 22nd of August, repeated surveys took place along transect B over a complete tidal cycle. On August 23rd, transect A was repeatedly surveyed during the time of the AUTOSUB maintenance.

Acknowledgements

The moorings were designed by John Humphery at the Proudman Oceanographic Laboratory who provided the hardware-frames A and B.

We are indebted to Steve Lentz, Department of Physical Oceanography, Woods Hole Oceanographic Institution who generously provided the 3 pressure gauges that were installed on the three bed frames. Also Janet Fredericks was instrumental in preparing the pressure gauges and ADV sensor installed on the AUTOSUB. Craig Marquette prepared the pressure gauges.

We are grateful for the skills and assistance of the Captain, officers and the deck crew of the R/V RRS Challenger.

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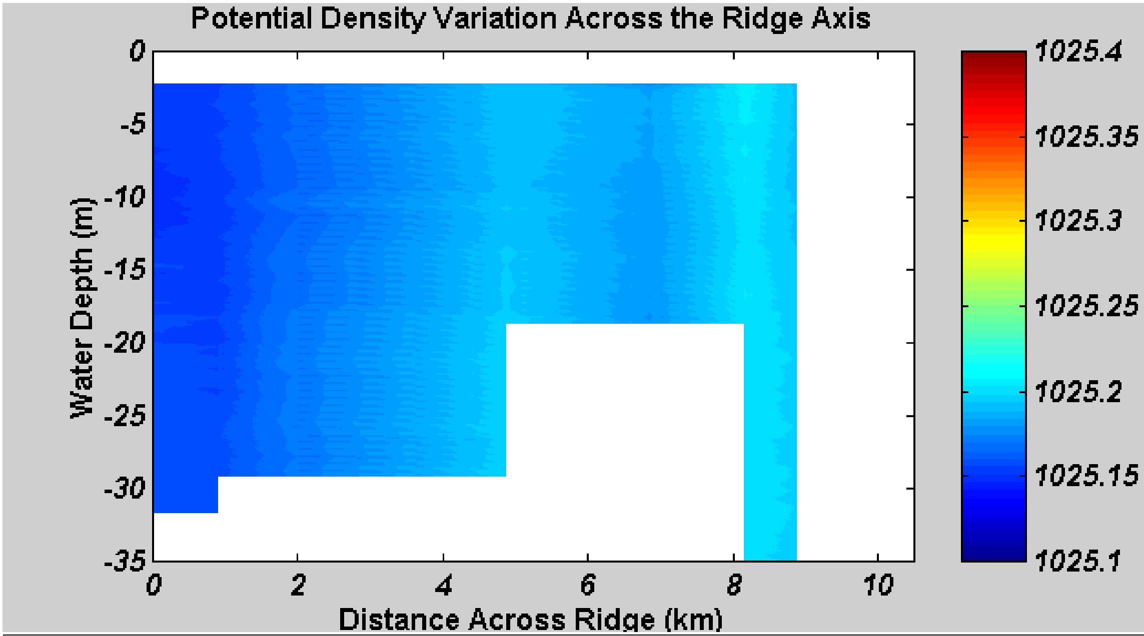
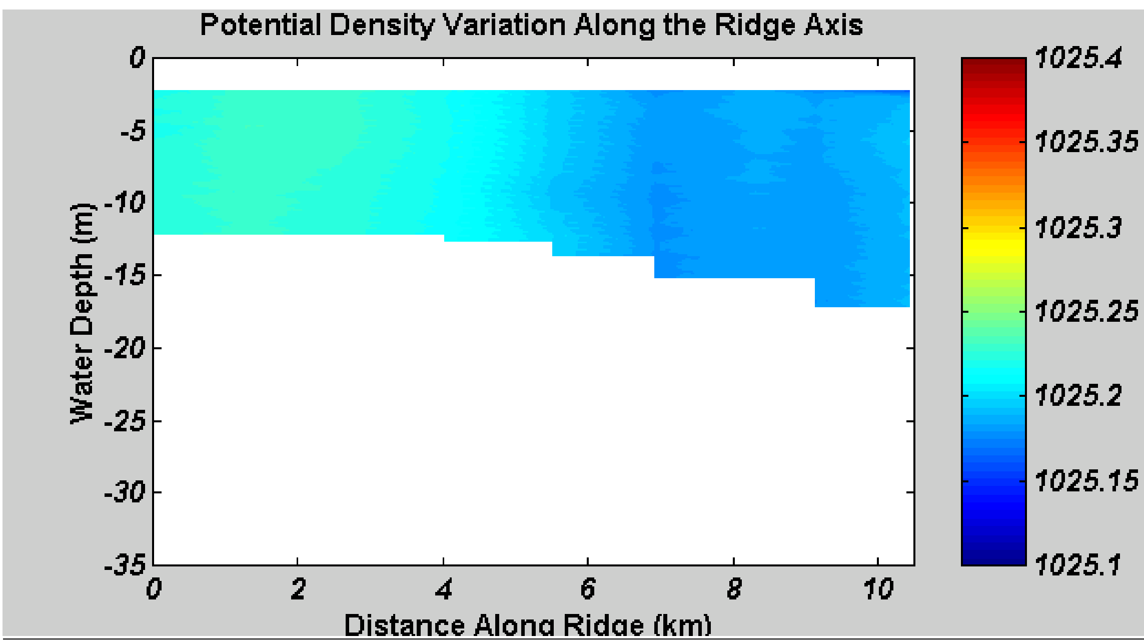
APPENDIX A

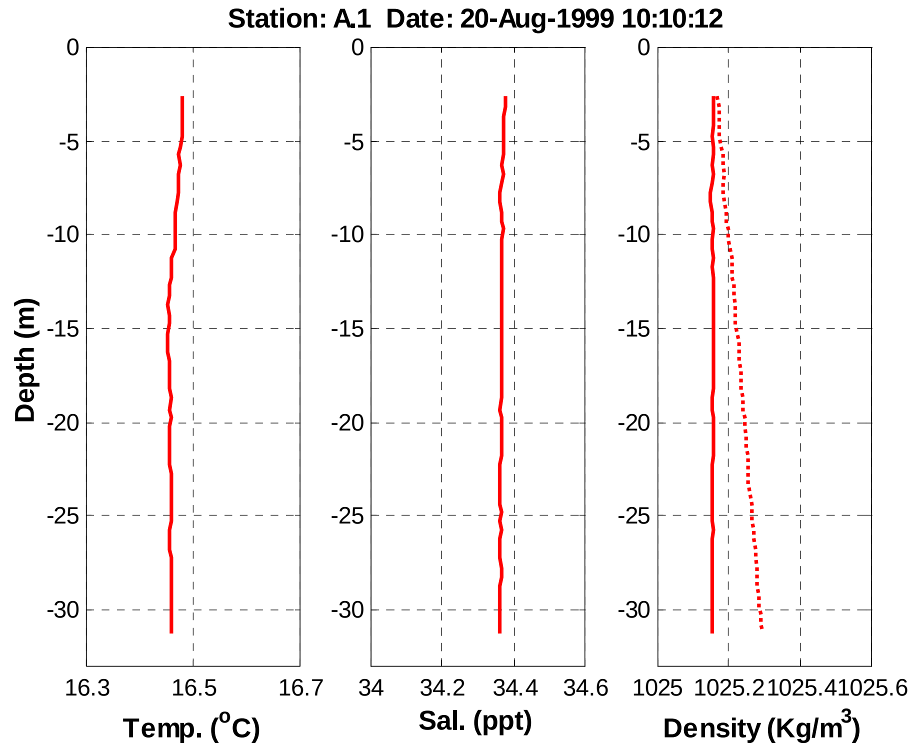
CTD – CASTS

The raw data were collected with a sampling rate 2Hz; The data shown in the Appendix are the downcast data only and they are depth averaged into bins of 0.5 m.





Synoptic diagrams of potential density variation across (top panel) and along (bottom panel) the sand bank axis for the 23rd August 1999 CTD survey (see Figure 14 in page 21). These diagrams were constructed using the raw data shown in this Appendix.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-15
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-25
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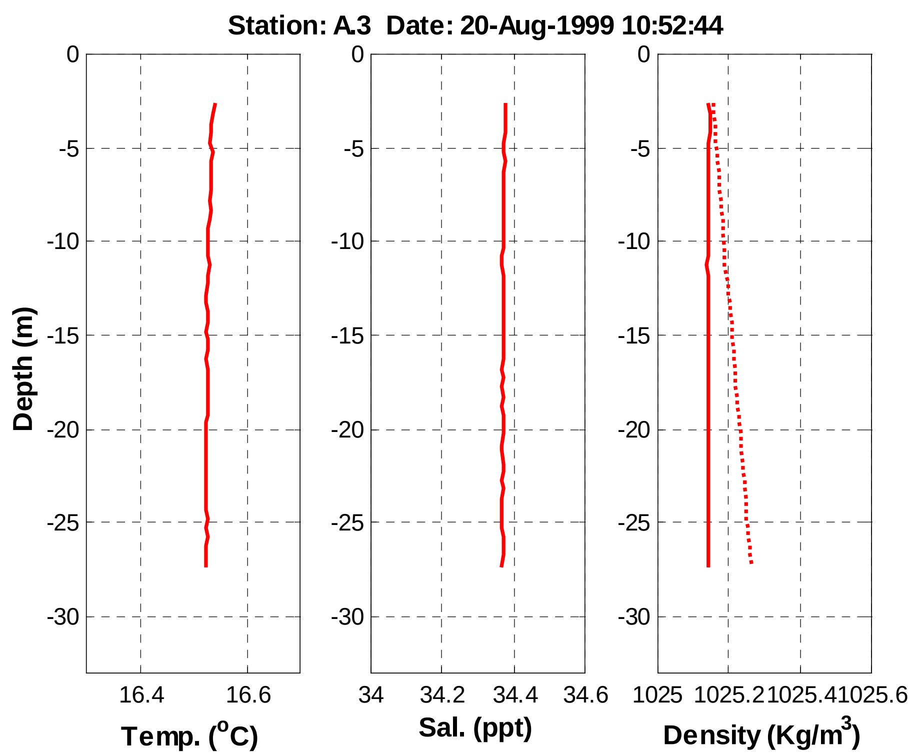
16.3
16.5
16.7
Temp. (°C)
34
34.2
34.4
34.6
Sal. (ppt)
1025
1025.2
1025.4
1025.6
Density (Kg/m3)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Temp. (°C)
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Sal. (ppt)
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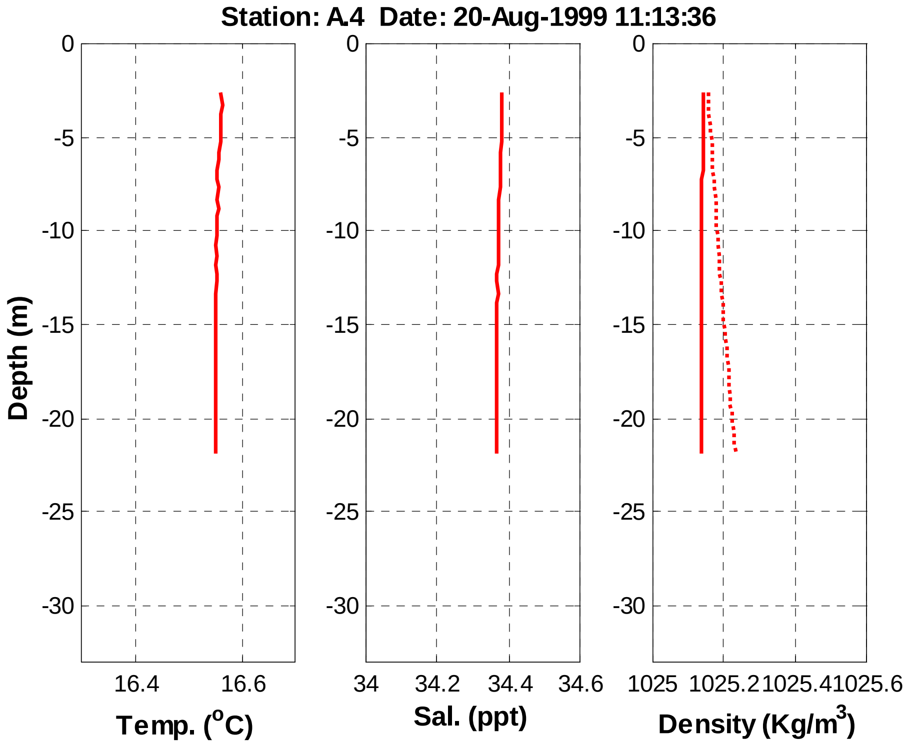
1025.2
1025.4
1025.6
Density (Kg/m3)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16.4
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Temp. (°C)
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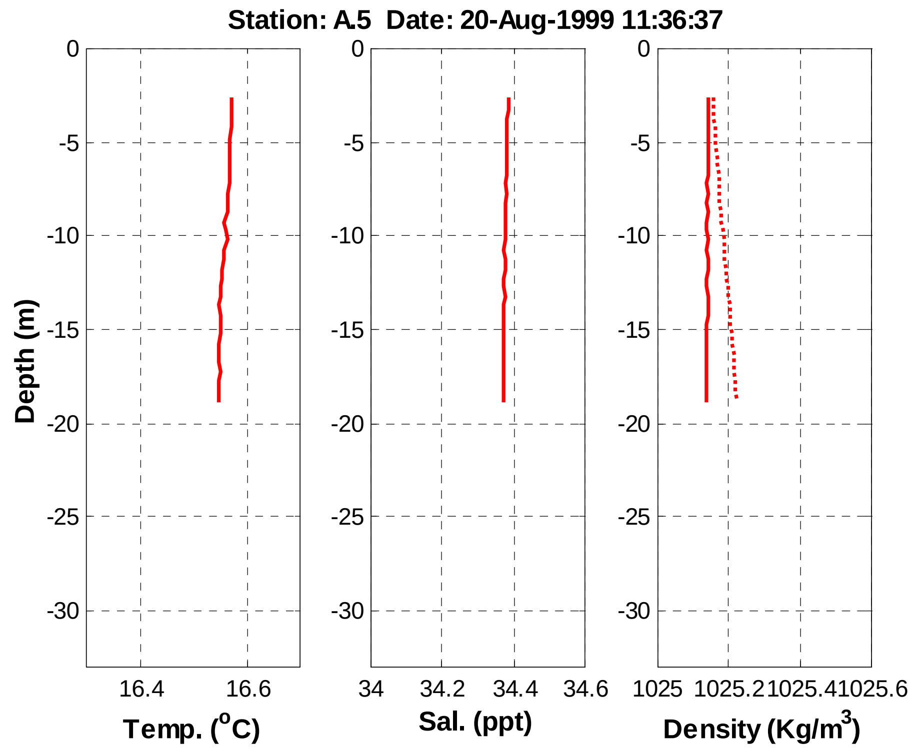
Sal. (ppt)
1025
1025.2
1025.4
1025.6
Density (Kg/m3)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-30
16.4
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Temp. (°C)
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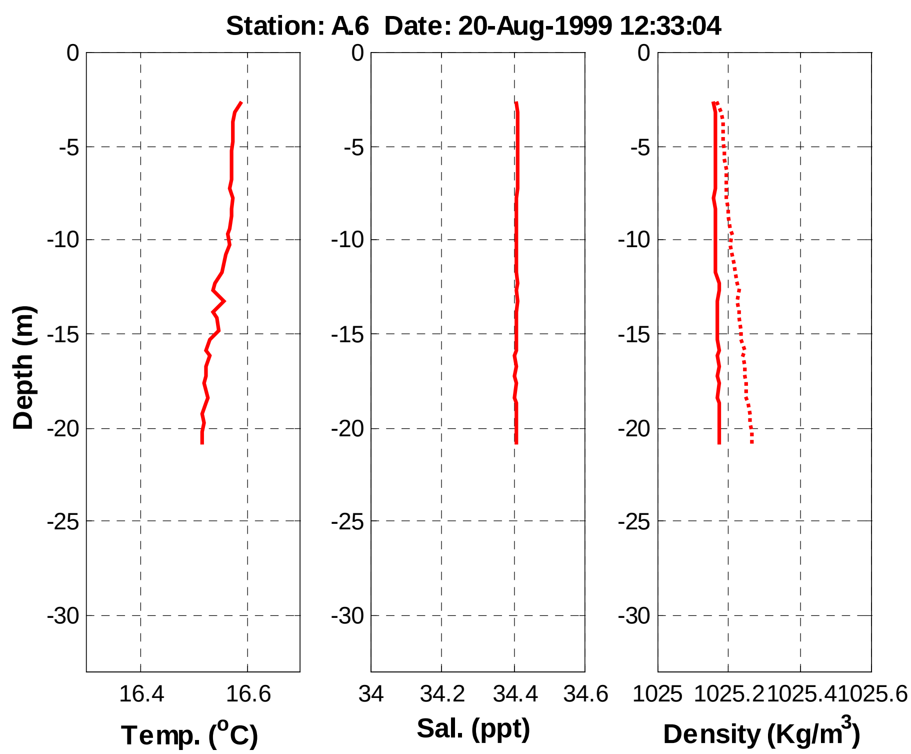
34.6
Sal. (ppt)
1025
1025.2
1025.4
1025.6
Density (Kg/m3)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-20
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-30
16.4
16.6
Temp. (°C)
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34.2
34.4
34.6
Sal. (ppt)
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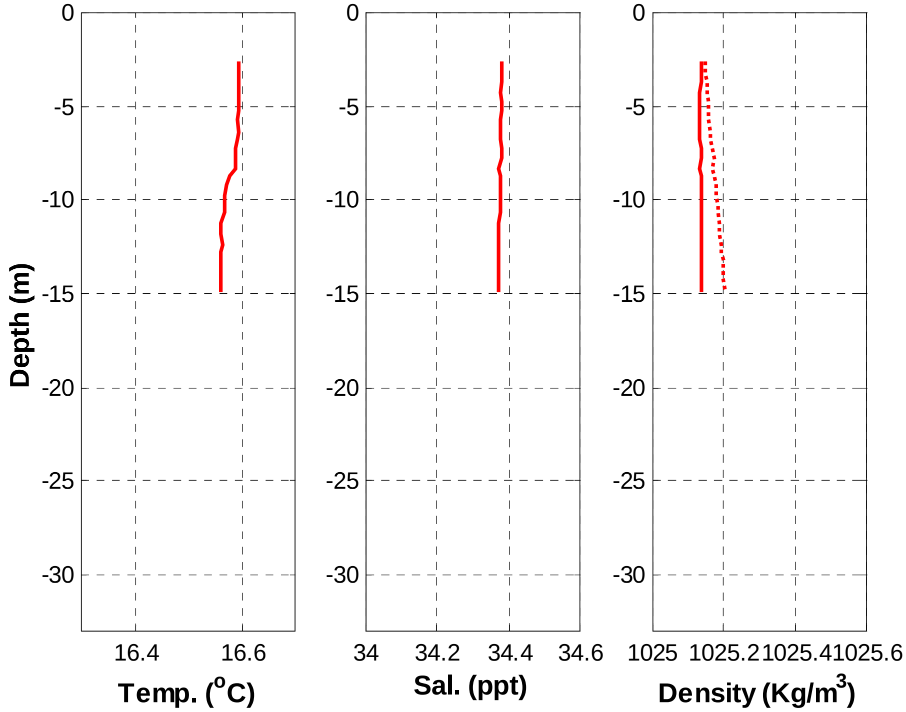
1025.2
1025.4
1025.6
Density (Kg/m3)

Station: A.7 Date: 20-Aug-1999 13:07:26



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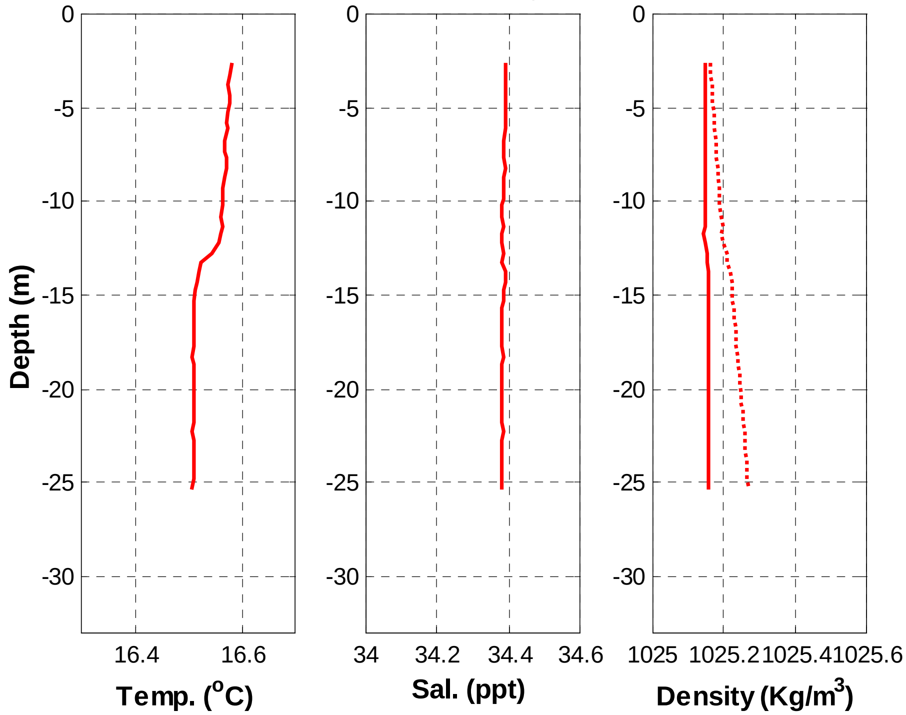

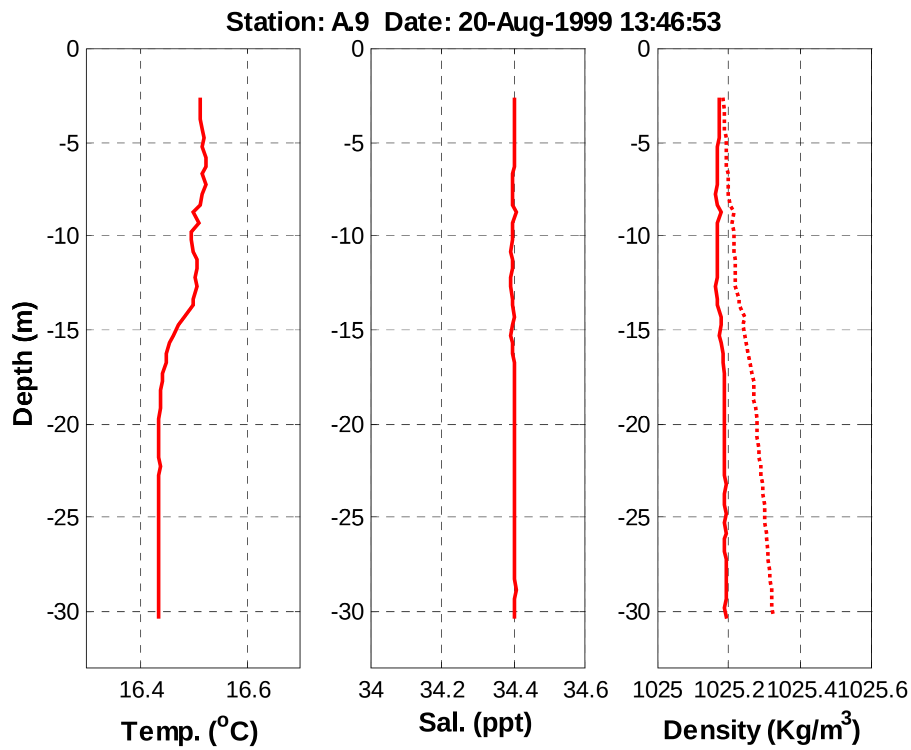
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Temp. (°C)
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Sal. (ppt)
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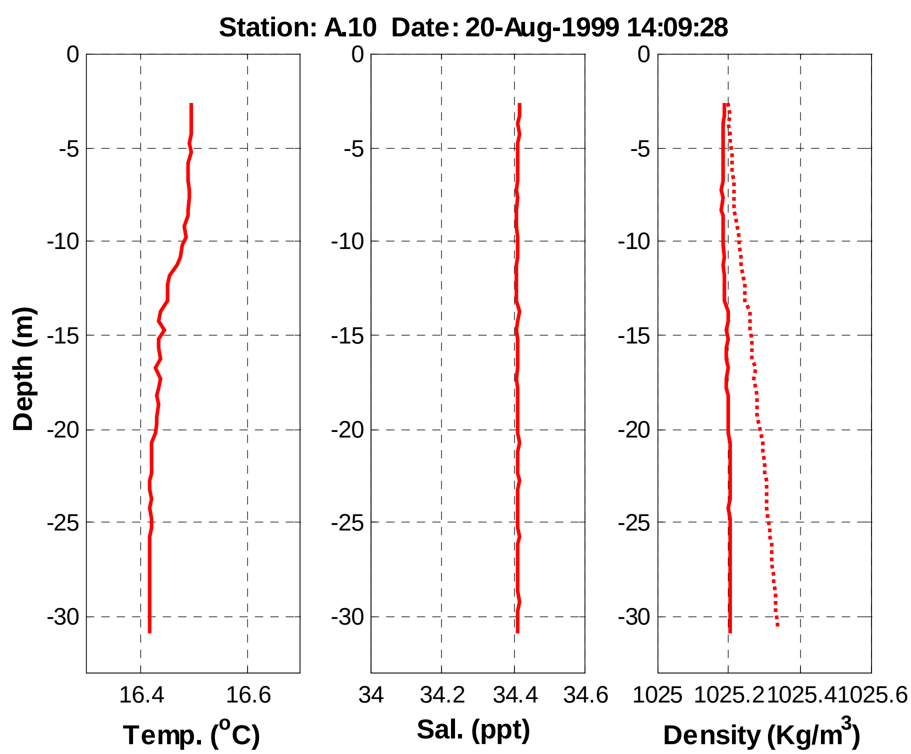
1025.4
1025.6
Density (Kg/m3)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Temp. (°C)
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Sal. (ppt)
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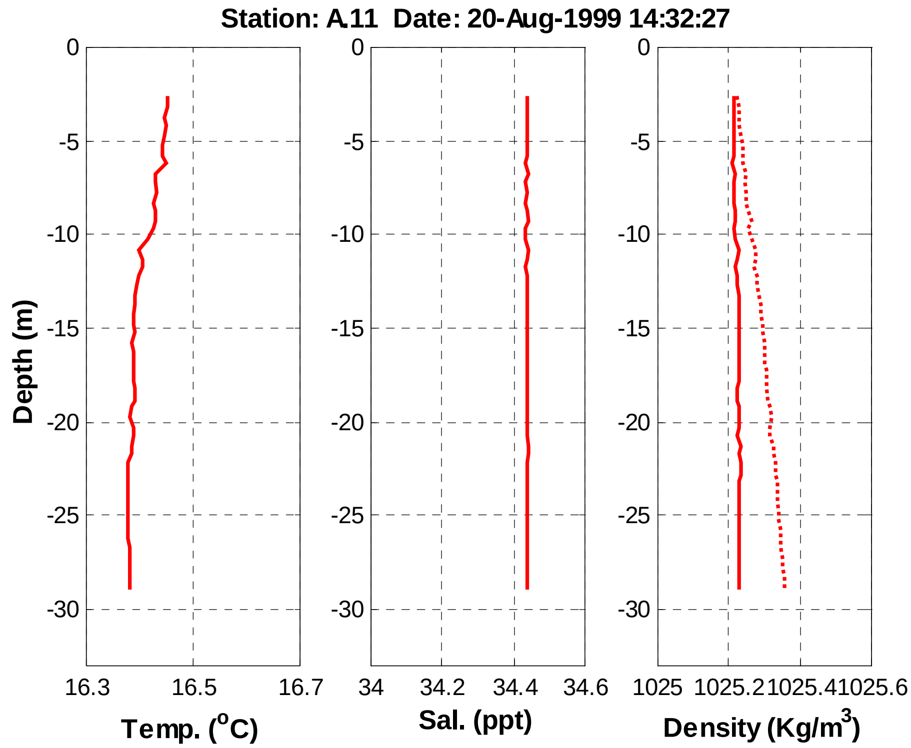
1025.4
1025.6
Density (Kg/m3)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Temp. (°C)
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34.4
34.6
Sal. (ppt)
1025
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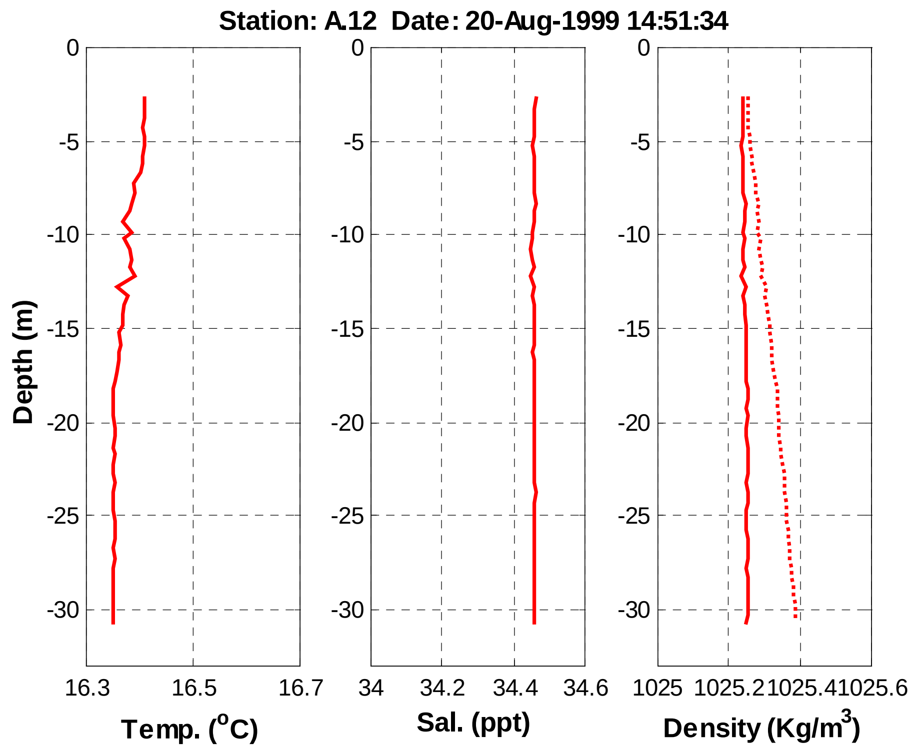
1025.4
1025.6
Density (Kg/m3)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Sal. (ppt)
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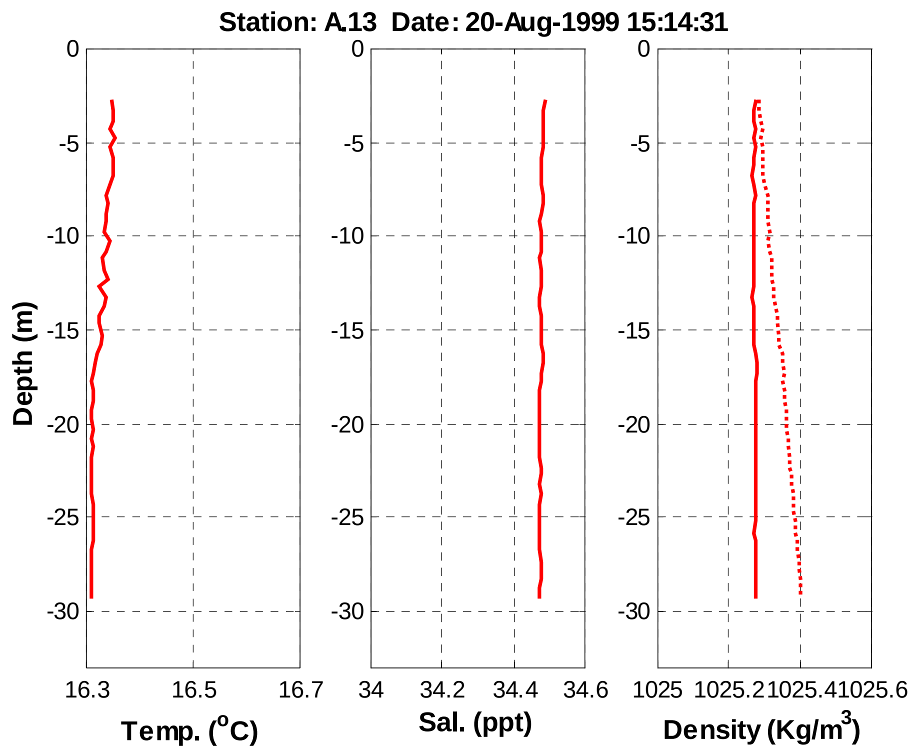
1025.4
1025.6
Density (Kg/m3)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Sal. (ppt)
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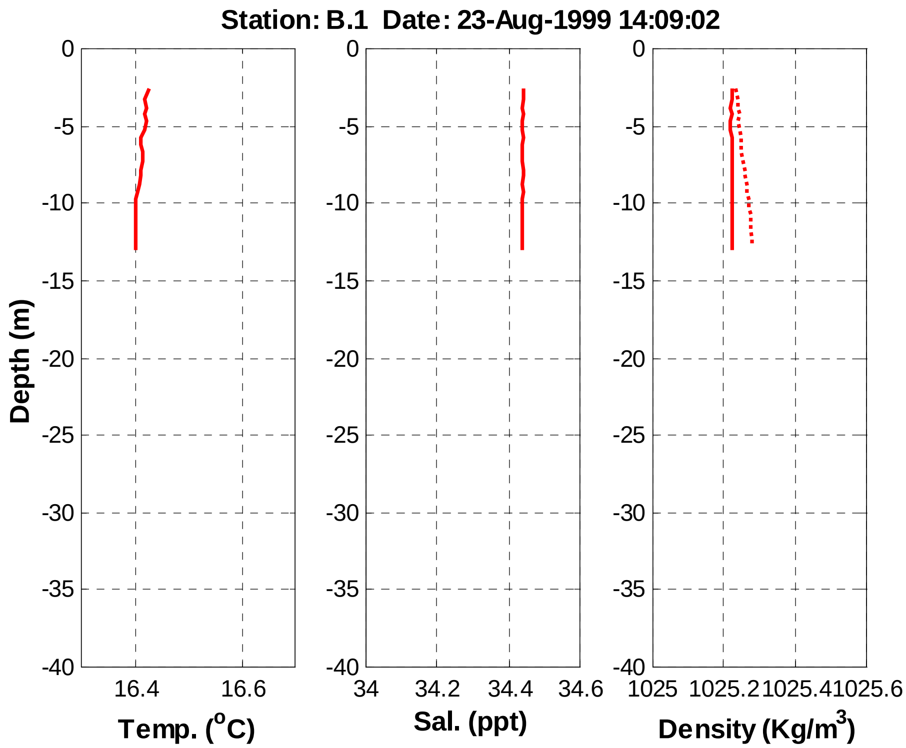
1025.4
1025.6
Density (Kg/m3)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Temp. (°C)
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Sal. (ppt)
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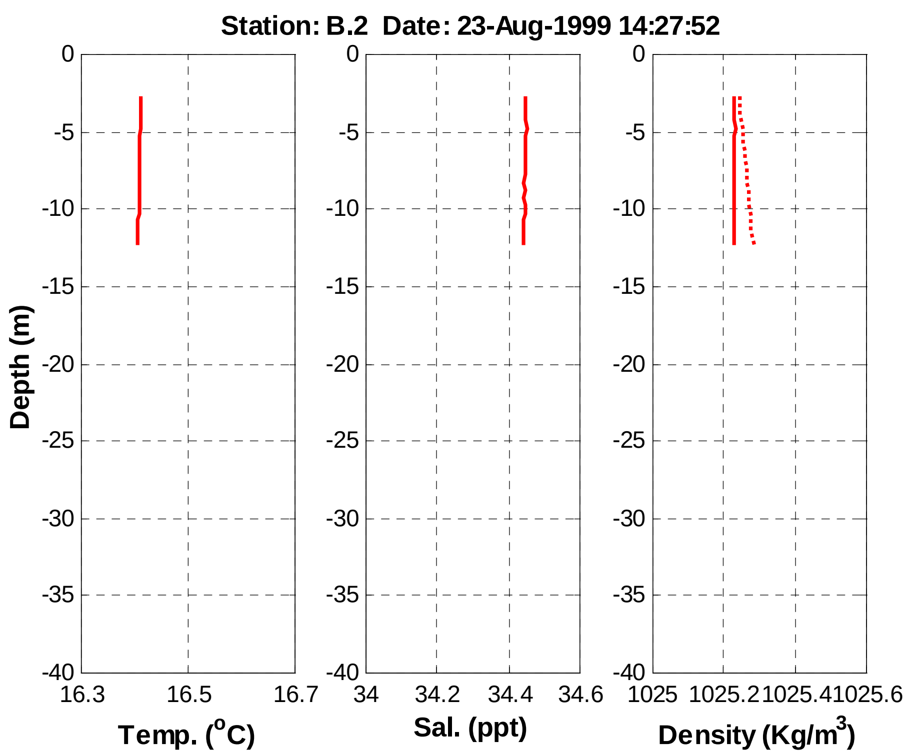
1025.6
Density (Kg/m3)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Sal. (ppt)
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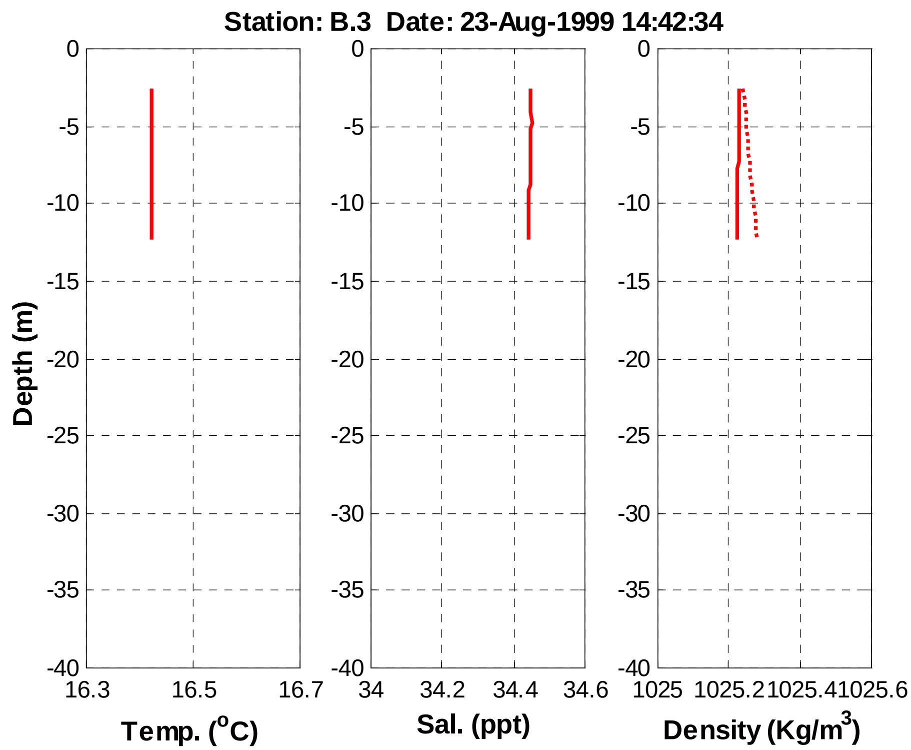
1025.4
1025.6
Density (Kg/m3)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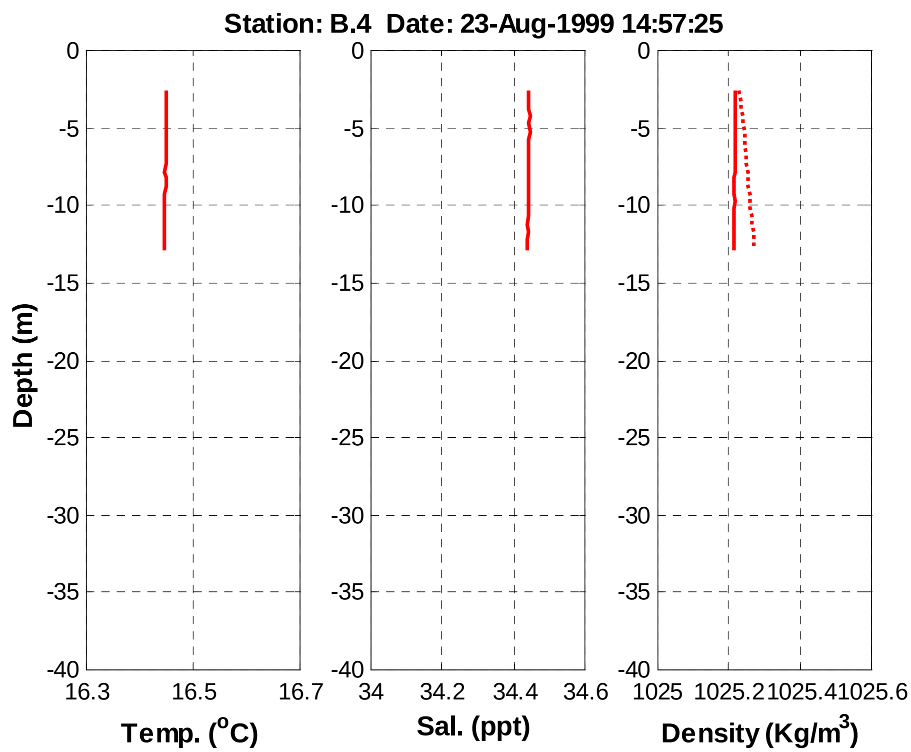
Density (Kg/m3)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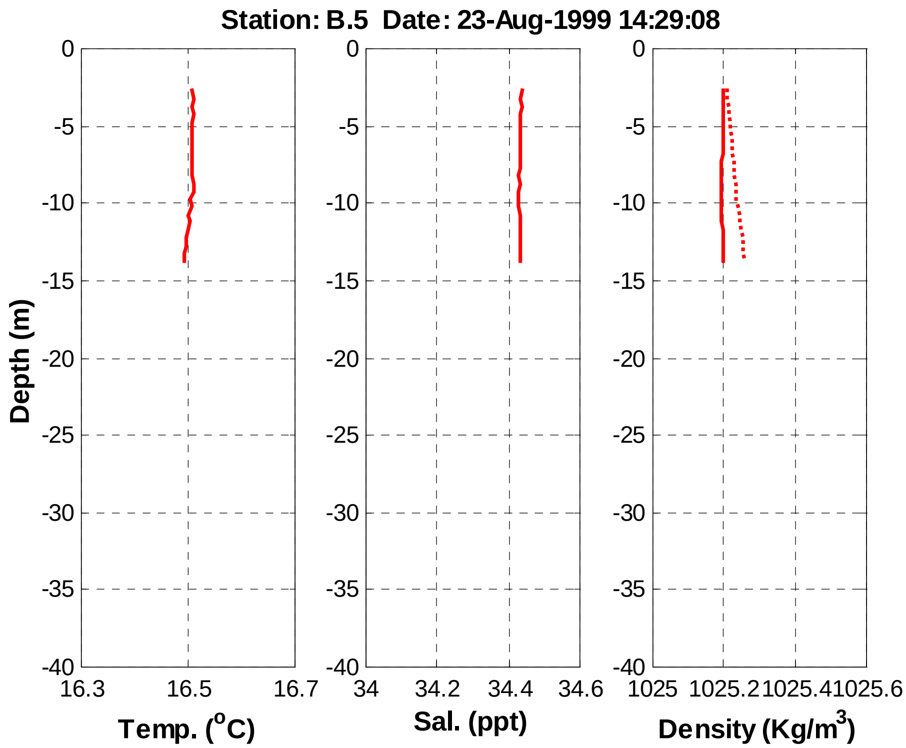
Density (Kg/m3)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Sal. (ppt)
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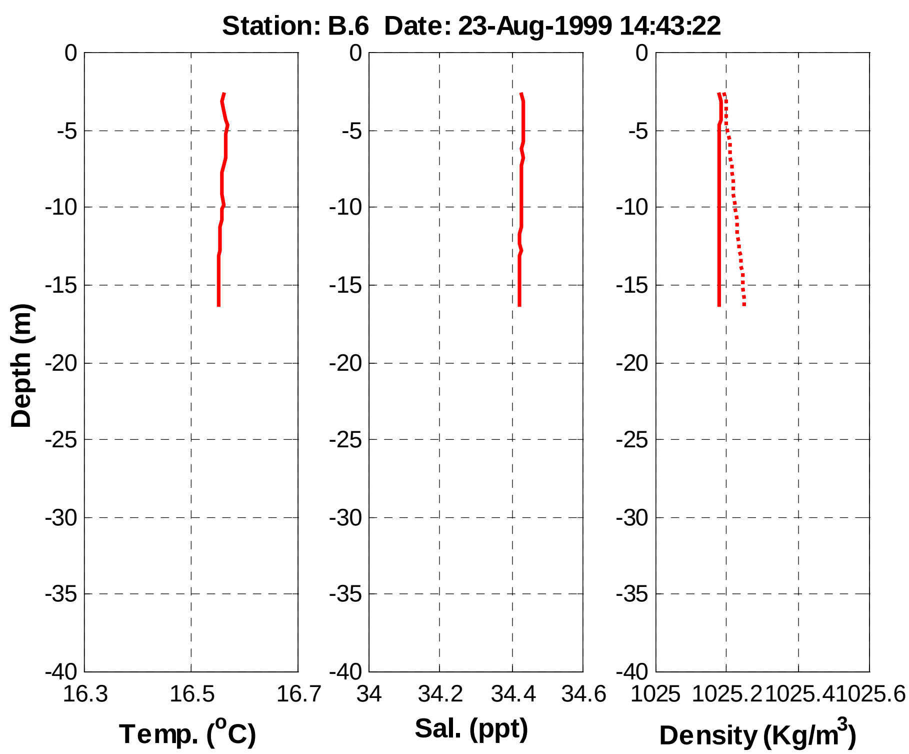
Density (Kg/m3)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Temp. (°C)
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Sal. (ppt)
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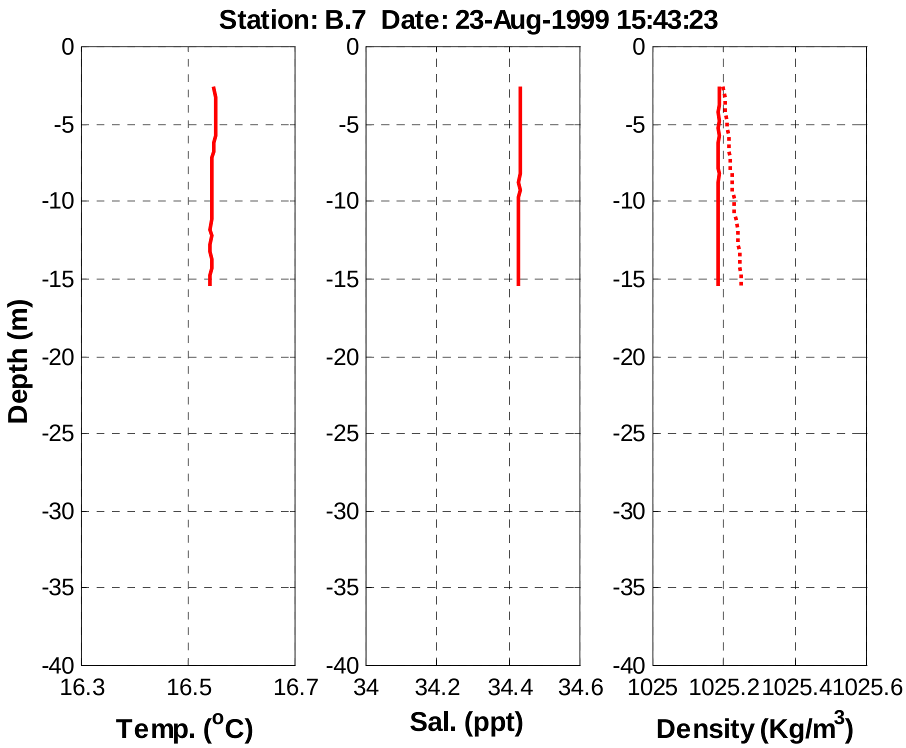
Density (Kg/m3)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Temp. (°C)
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Sal. (ppt)
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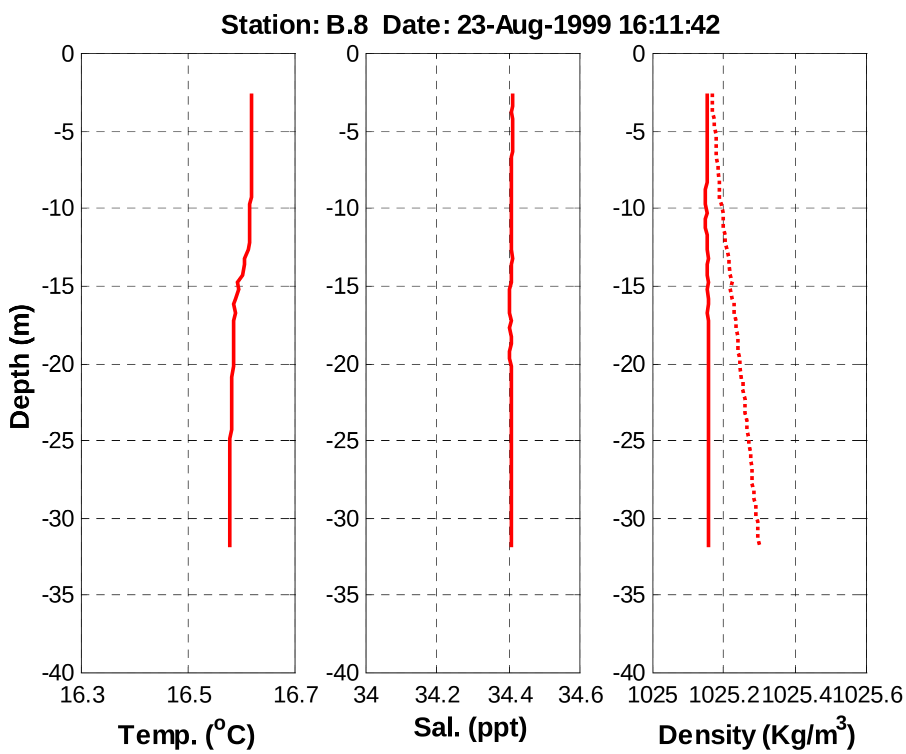
1025.4
1025.6
Density (Kg/m3)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Temp. (°C)
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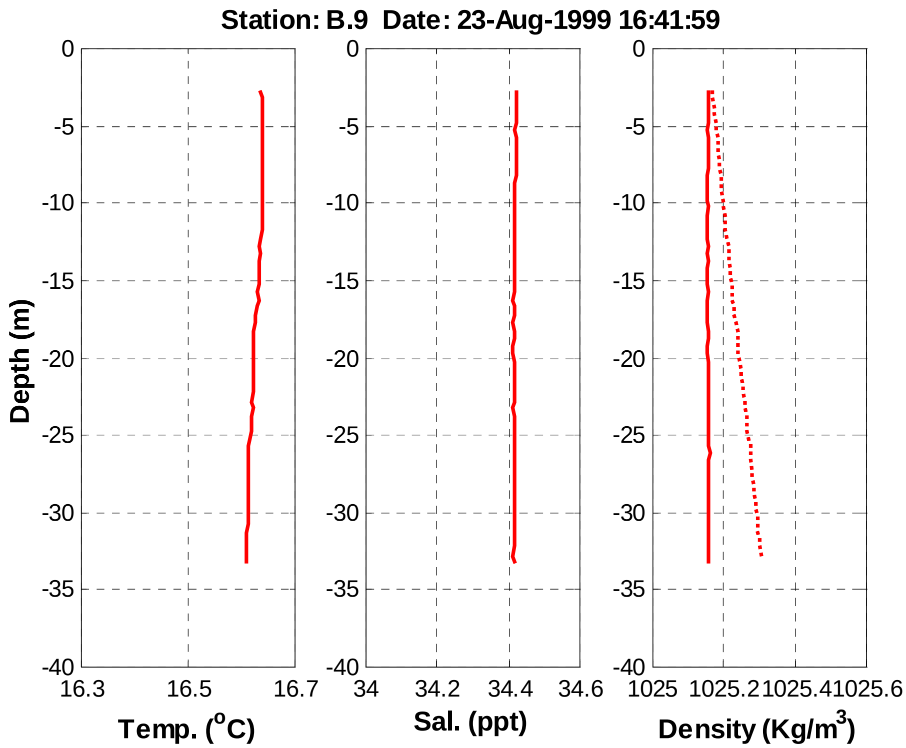
Density (Kg/m3)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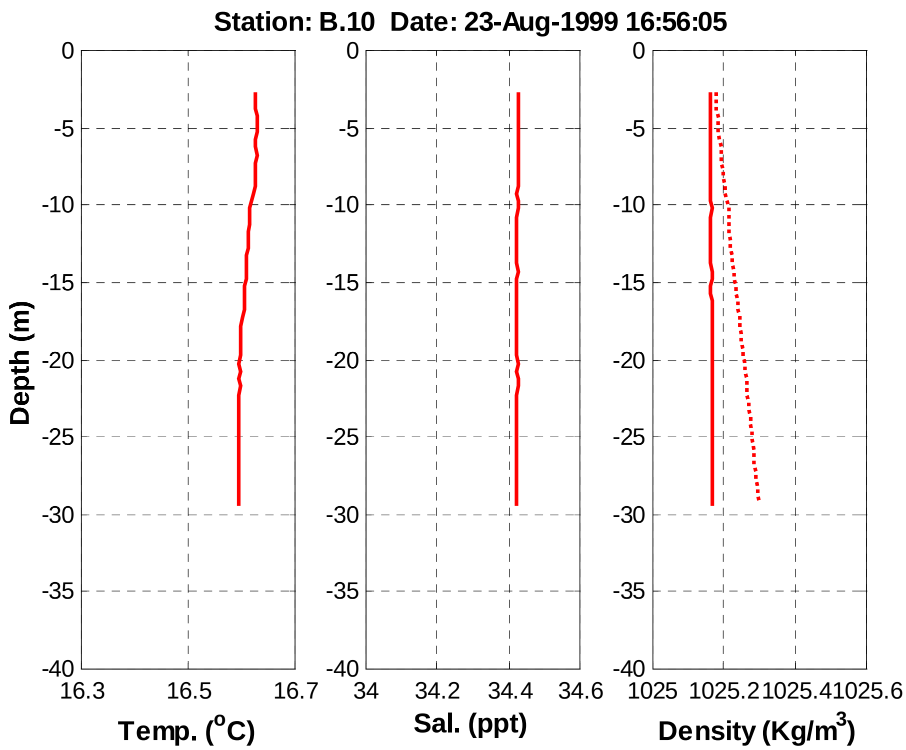
Depth (m)
Temp. (°C)
Sal. (ppt)
Density (Kg/m3)
0
-5
-10
-15
-20
-25
-30
-35
-40
16.3
16.5
16.7
34
34.2
34.4
34.6
1025
1025.2
1025.4
1025.6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Depth (m)
Temp. (°C)
Sal. (ppt)
Density (Kg/m3)
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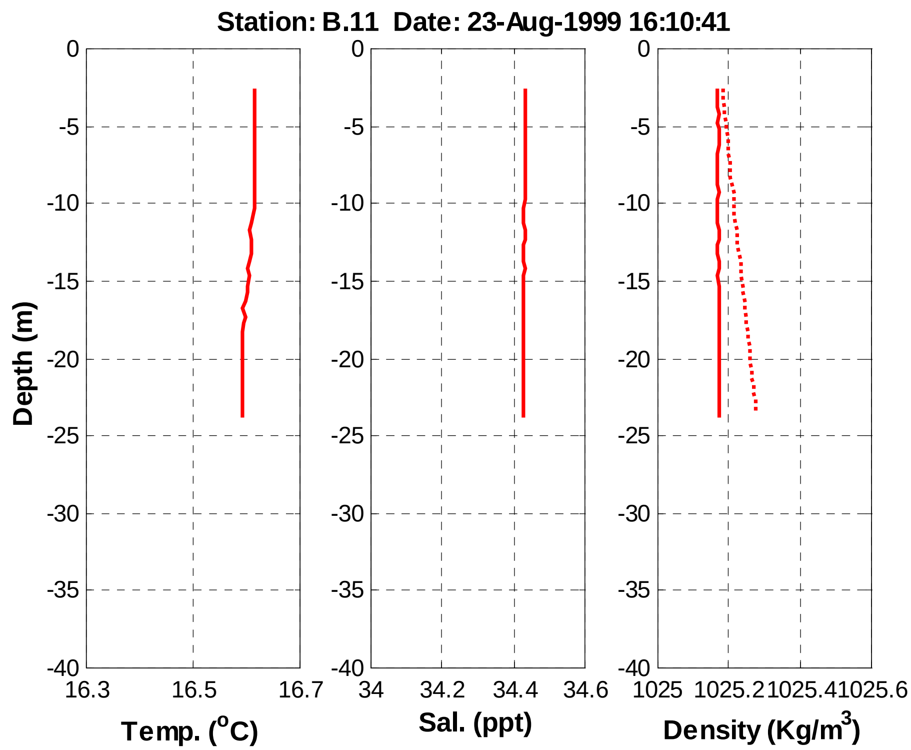
-10
-15
-20
-25
-30
-35
-40
16.3
16.5
16.7
34
34.2
34.4
34.6
1025
1025.2
1025.4
1025.6


Station: B.11 Date: 23-Aug-1999 16:10:41
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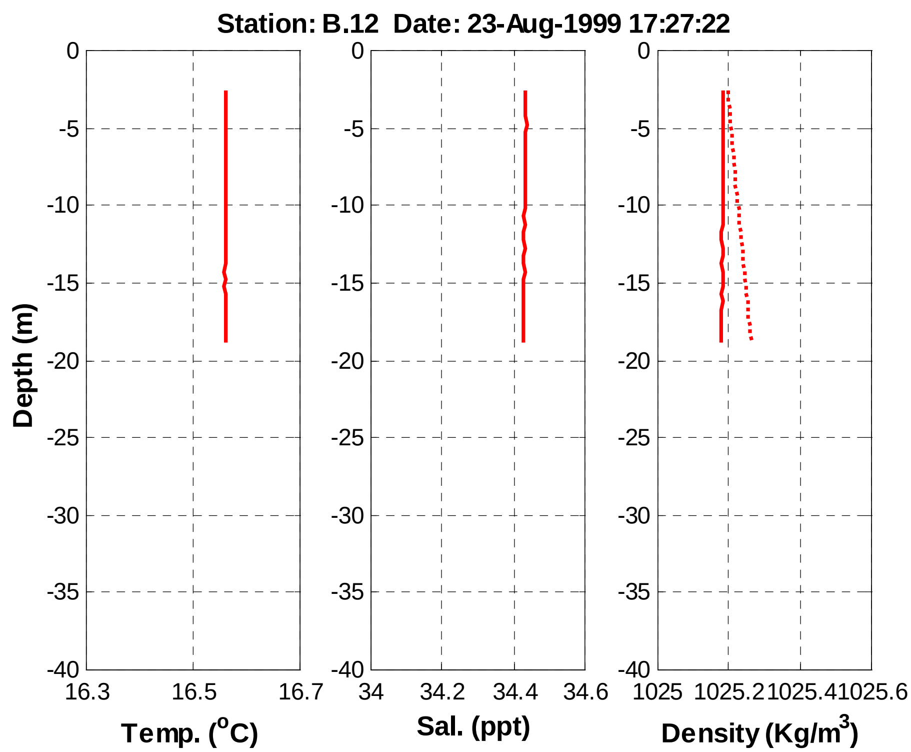
-15
-20
-25
-30
-35
-40
16.3
16.5
16.7
Temp. (°C)
34
34.2
34.4
34.6
Sal. (ppt)
1025
1025.2
1025.4
1025.6
Density (Kg/m³)


Station: B.12 Date: 23-Aug-1999 17:27:22
Depth (m)
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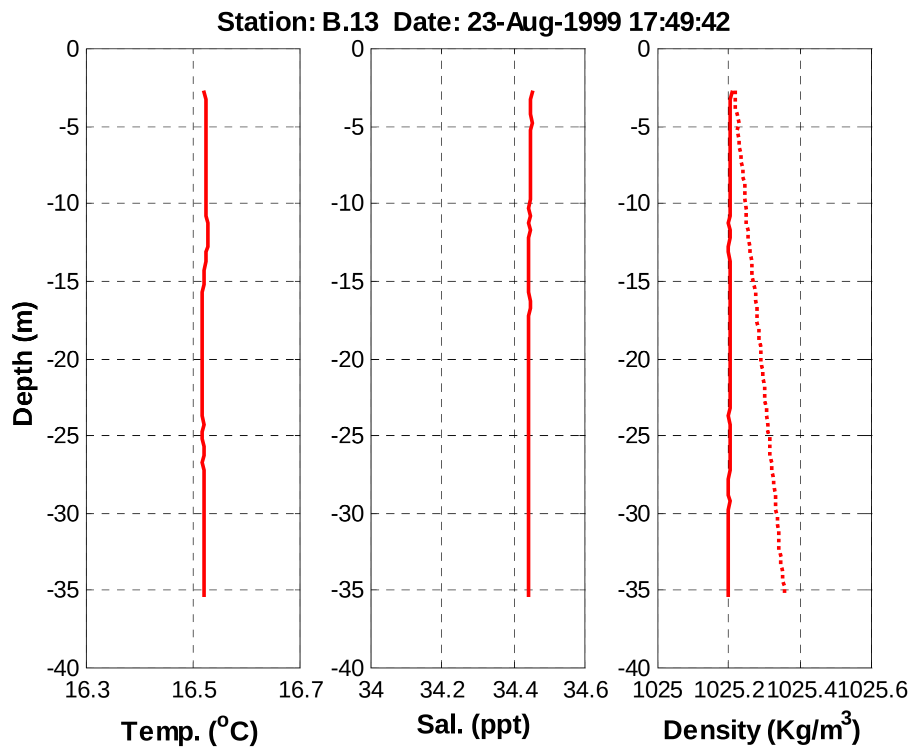
-10
-15
-20
-25
-30
-35
-40
16.3
16.5
16.7
Temp. (°C)
34
34.2
34.4
34.6
Sal. (ppt)
1025
1025.2
1025.4
1025.6
Density (Kg/m³)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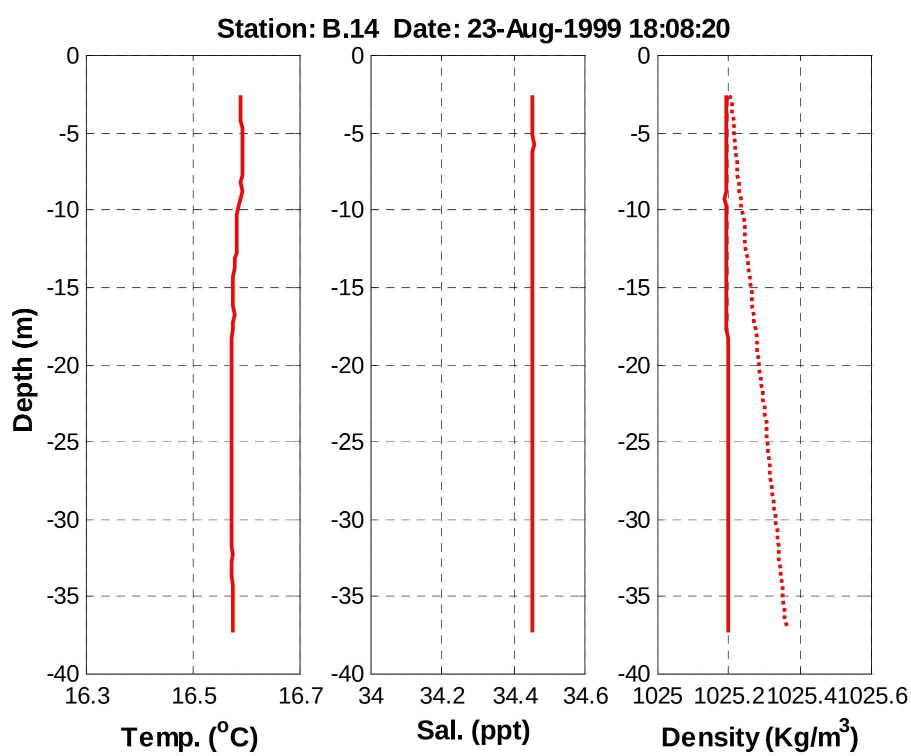
-10
-15
-20
-25
-30
-35
-40
16.3
16.5
16.7
Temp. (°C)
34
34.2
34.4
34.6
Sal. (ppt)
1025
1025.2
1025.4
1025.6
Density (Kg/m3)


Station: B.14 Date: 23-Aug-1999 18:08:20
Depth (m)
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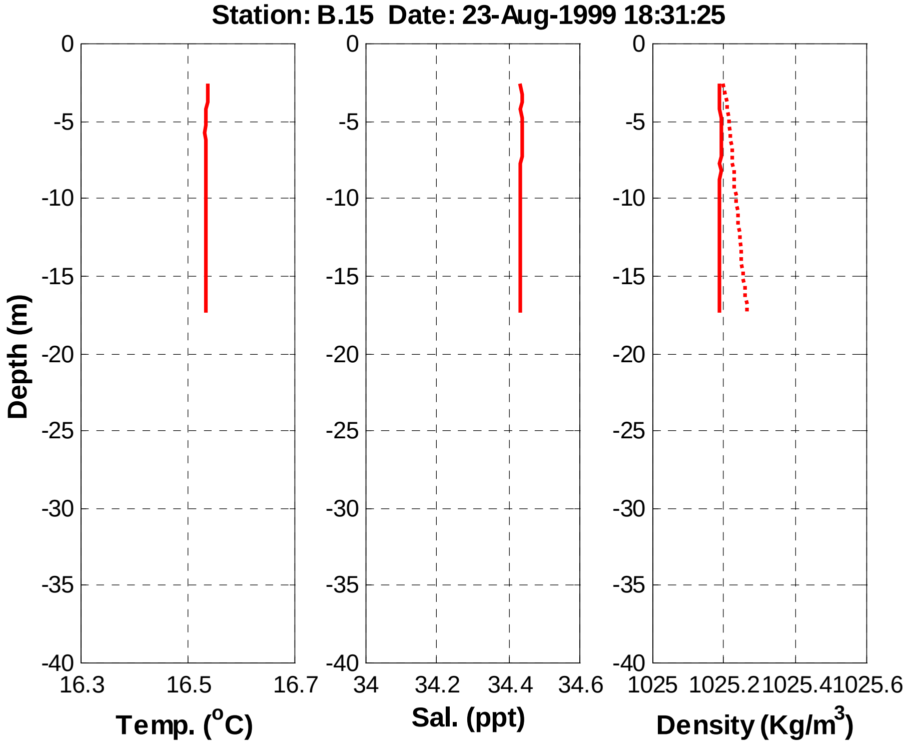
-10
-15
-20
-25
-30
-35
-40
16.3
16.5
16.7
Temp. (°C)
34
34.2
34.4
34.6
Sal. (ppt)
1025
1025.2
1025.4
1025.6
Density (Kg/m3)


Station: B.15 Date: 23-Aug-1999 18:31:25
Depth (m)
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-10
-15
-20
-25
-30
-35
-40
16.3
16.5
16.7
Temp. (°C)
34
34.2
34.4
34.6
Sal. (ppt)
1025
1025.2
1025.4
1025.6
Density (Kg/m3)

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16. Abstract (Limit: 200 words)

Two successful AUTOSUB deployments were carried out during August 1999 as part of the AUTOSUB Thematic Program project titled "Spatial Variability of Bottom Turbulence over a Linear Sand Ridge," funded by the Natural Environment Research Council (NERC), U.K. The AUTOSUB Autonomous Underwater Vehicle (AUV) was deployed and used to survey flow patterns at a location near the Broken Bank, southern North Sea, U.K. The AUV was equipped with acoustic flow and turbulence sensors and its surveys aimed at mapping the spatial variation of flow and turbulence near the bed and over topographic features.

Three instrumented bottom mounted frames were also deployed, around the AUV survey area, for a period of approximately 5 days. The purpose of this array was to gather information on the temporal variability of the flow and turbulence near the seabed and to identify the important terms that drive circulation around the bank.

Additional data were gathered including CTD casts, seabed samples and acoustic images of the seabed (side-scan sonar).

The purpose of this data collection was to help identify the flow patterns around ridges and to understand the mechanisms controlling the maintenance and evolution of such features.

This report describes the operations carried out by researchers from the University of South Carolina, Woods Hole Oceanographic Institution, Southampton Oceanography Centre and the AUTOSUB Team on the R.V. RRS Challenger during the period 17th–28th August 1999.

17. Document Analysis a. Descriptors

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Acoustics
Currents

b. Identifiers/Open-Ended Terms

c. COSATI Field/Group

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