METEOR 60 Leg 4

Meridional Overturning Variability Experiment

Fort-de-France - Fort-de-France
16 February 2004 – 06 March 2004

Chapter 1

Participants

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Busack, Michael	IfM-Geomar	Telemetry, MicroCATs
Kanzow, Torsten	IfM-Geomar	Data processing
Karstensen, Johannes, Dr.	IfM-Geomar	ADCP
Koy, Uwe	IfM-Geomar	Moorings, PIES
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Chapter 2

Research programs

The fourth leg of METEOR cruise 60 served a project called MOVE (Meridional Overturning Variability Experiment) which started in January 2000. The long-term observations of fluctuations in the thermohaline circulation of the western Atlantic Ocean were to be continued on a routine base. The array is situated on a zonal section along 16°N between the Antilles Arc in the west and the outskirts of the Middle Atlantic Ridge in the east. Last time the array was exchanged from FS SONNE in June 2003. It comprises moored instruments for recording currents, density, bottom pressure and acoustic tomography signals. It is our long-term goal to observe interannual fluctuations of the thermohaline circulation with integral methods. Results will be intercompared with boundary conditions at higher latitudes. Field observations in the tropical / subtropical North Atlantic Ocean in the frame of the German climate variability (CLIVAR) project B1-4 are accompanied by modeling studies of the structure and the variability of the current system and its relation to atmospheric forcing (http://www.awi-bremerhaven.de/Research/IntCoop/Oce/clivar/projects /projects-index.html). In co-operation with American agencies calibration works for GRACE (Gravity Recovery and Climate Experiment) was planned with high precision bottom pressure recorders. The latter will provide monthly estimates of the earth's gravity field with extraordinary precision.

The prime objective of the cruise leg contained extended maintenance at the mooring sites along 16°N and an extension of the bottom pressure array perpendicular to the section. In addition the re-occupation of this section was conducted to measure the hydrographic stratification and the instantaneous structure of horizontal currents.

Chapter 3

Narrative of the cruise

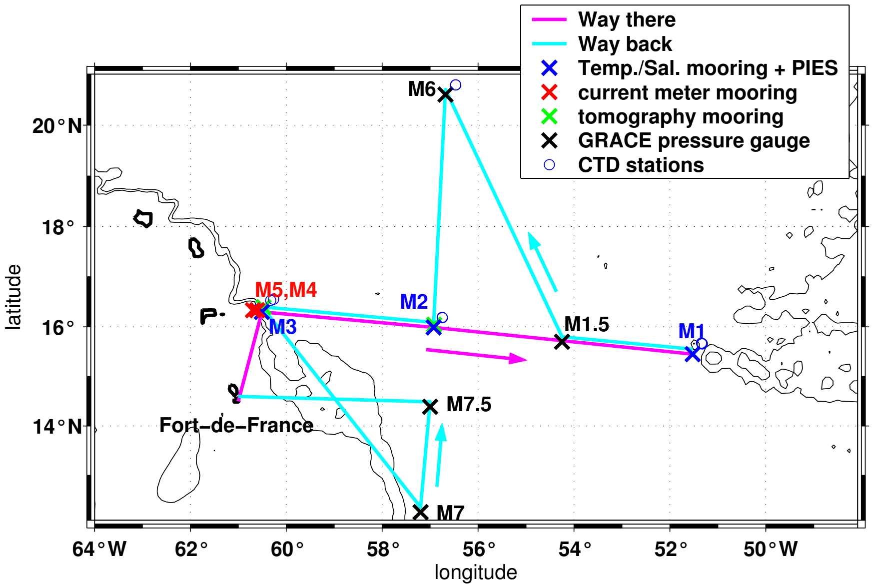


Figure 3.1: Cruise track of 4th leg of cruise METEOR 60. Mooring and CTD stations are also indicated.

FS METEOR left Fort-de-France (Martinique) on 16 February 2004 at 10:30 LT and sailed in northward direction towards the first working area off Guadeloupe, which was reached about 12 hours later. In the following two days four moorings (M3,M3.5,M4,M5), a moored echo sounder (PIES- near M3) and three transponders (near M3.5) were recovered successfully. The

SIO bottom pressure sensor near M3 could not be located though. It turned out that the tomography sound source (M3.5) had not worked at all due to a broken battery wire. A first CTD/lADCP cast was taken. After repairs M3.5 was redeployed as well as a SIO bottom pressure sensor. After completion of the work on 19 February at 2:00 LT in this area FS METEOR moved eastward most of that day towards position M2.

Here a SIO bottom pressure sensor was deployed and the second CTD cast was taken. No acoustic contact could be established with the PIES near M2. Nonetheless, the release command was sent but despite an intense search the instrument could not be located at any time. Three transponders were recovered. During the recovery of mooring M2 the ship drifted over the wire with glas spheres, which got stuck in the propeller. It could not be freed by pulling and after a visual inspection (from a Zodiac) had revealed that the wire was not wrapped around the propeller but was just loosely caught, it got free by itself. The Zodiac crew managed to get hold of the drifting spheres just before dark and re-attached the mooring to the ship. The mooring recovery was thus continued without loss of any instruments. Finally a PIES was deployed near the nominal position of M2.

In the following FS METEOR headed eastward and reached the position of the PIES near M1 on 22 February at 4:00 LT. Data from that PIES was dumped via acoustic telemetry. During the subsequent recovery of mooring M1 the telemetry wire was found cut 20 m below the fishing floats nominally at 40 m and most of those floats plus the 40 m MicroCAT (moored CTD recorder) missing, but the loose telemetry wire above was braided to the remaining wire above subsurface float and thus was held in place. The M1 SIO bottom pressure sensor was successfully recovered and in the following the tomography receiver was lowered from the vessel to 1000 m to try to receive acoustic signals from the sound source 1000 km away at M3.5 without success, even though noise sources had been suppressed on ship by shutting down / reducing generators, compressors, hydraulics, bowthruster and propeller. CTD casts 3-7 were taken in this area with MicroCATs and MTD logger attached to carry out in situ calibration of these devices. A SIO bottom pressure sensor and a PIES were deployed. The PIES whose data had been transferred acoustically could be recovered. This was necessary to install an updated firmware. After a successful test of the telemetry of mooring M1 with the MicroCATs lying on deck, that mooring was deployed on 24 February. Soon afterwards first ARGOS transmissions from all MicroCATs even down to 4000 m could be received. Thus, all electric links including the electrically conducting swivels were obviously working.

After that FS METEOR headed west again and a PIES (M1.5) was deployed half way between M1 and M2 on Feb. 25. Subsequently METEOR sailed on a northwestward track to occupy the northern point of the bottom pressure sensor cross (M6). Here a PIES and a SIO bottom pressure sensor were deployed and CTD casts 8-9 with MicroCATs and MTD loggers attached were taken on 26 February. The next day was spent sailing southward towards M2. Two days later the tomography source was lowered from the vessel near M2 to receive signals from the M3.5 sound source roughly 400 km away. All the vessel's sources of noise were shut down completely. This time the signals from M3.5 were received successfully. In the following, mooring M2 (including MicroCATs as well as the tomography receiver) and three tomography transponders were deployed. CTD cast 10 (without MicroCATs attached) was taken.

Upon heading southward to cover the southern positions of the GRACE bottom pressure cross, it was discovered soon that the essential positions of M7 and M7.5 under the track of the GRACE satellites were located in the exclusive economic zone (EEZ) of Barbados and that the diplomatic clearance had not been requested in due time. So it was decided to carry out mooring works in the west (M3) first and at the same time try to obtain diplomatic clearance for M7 and M7.5 from the Bajan authorities.

In the afternoon of 29 February at 30 km from sound source mooring M3.5, the work boat was deployed to lower a newly built listening device to 1000 m at sufficient distance from METEOR, which moved away 5 nm. Signals from the sound source were successfully received. Since the navigator device needed some reprogramming the sound source mooring M3.5 was recovered again. Subsequently the final CTD cast 11 (with MicroCATs) was taken. The next day (March 1) the POL bottom pressure recorder (near nominal position of M3) was recovered successfully and the MicroCAT mooring M3 was redeployed. Short time afterwards ARGOS signals from the five MicroCATs in the inductive loop were also received. Data from the tomographic test receptions in 30 km were analyzed and the sound source is diagnosed. At night decision was taken to deploy the source and test/prepare two mooring navigators for this purpose. After successful tests with the fully assembled sound source, the current meter mooring M4 was deployed (including the sound source) plus three transponders. Afterwards the sound source transmissions could be received successfully at a distance of 0.5 nm from the mooring.

After a transponder survey METEOR started to steam southeastward towards the positions of M7 and M7.5 with no diplomatic clearance yet obtained. On 3 March at 360 km distance from M4, sound source transmissions were received clearly by a freely floating receiver. On 4 March the diplomatic clearance was issued by the foreign ministry of Barbados in the afternoon. M7 was reached several hours later where a PIES and a SIO bottom pressure sensor were deployed. After deploying the last SIO bottom pressure sensor at M7.5 (between M7 and M2) at noon, FS METEOR started to head back westward to Fort-de-France which was reached one day later.

Throughout the whole cruise thermosalinograph data was acquired for transmission to the Coriolis data centre in Brest, France. In summary, the cruise can be regarded as very successful. The loss of one PIES and one SIO bottom pressure sensor do not affect the overall performance of the ongoing MOVE experiment.

Chapter 4

Preliminary results

4.1 Moorings (T. Kanzow)

The main emphasis of the cruise lay on the service of the MOVE moorings. The basic idea of MOVE is to determine the variability of the deep meridional mass transport across 16°N in the western basin of the North Atlantic as a part of the meridional overturning circulation. In the interior an array of three “geostrophic” moorings (M1-M3) is maintained which captures the meridional flow with a combination of dynamic height and bottom pressure measurements. West of this array, in the triangle over the continental slope, direct current measurements are applied (M3-M5) to capture that part of the deep flow, which passes inshore of M3 (for details see Fig. 4.1). Furthermore acoustic tomography is used to determine deep integrated temperature fluctuations between M2 and M3. The complete set of 6 moorings was recovered successfully. Ultimately 4 moorings were redeployed on the cruise (see Table 4.1). The redeployment of the current meter mooring M5 was renounced since analyzes had shown that its contribution to the transport estimates over the continental slope was negligible. The tomography mooring M3.5 redeployed on 17 February was recovered on 29 February again to make adjustments to the navigators. Due to lack of sufficient spare mooring wire the tomography component was then integrated into the mooring M4, which does not influence its performance.

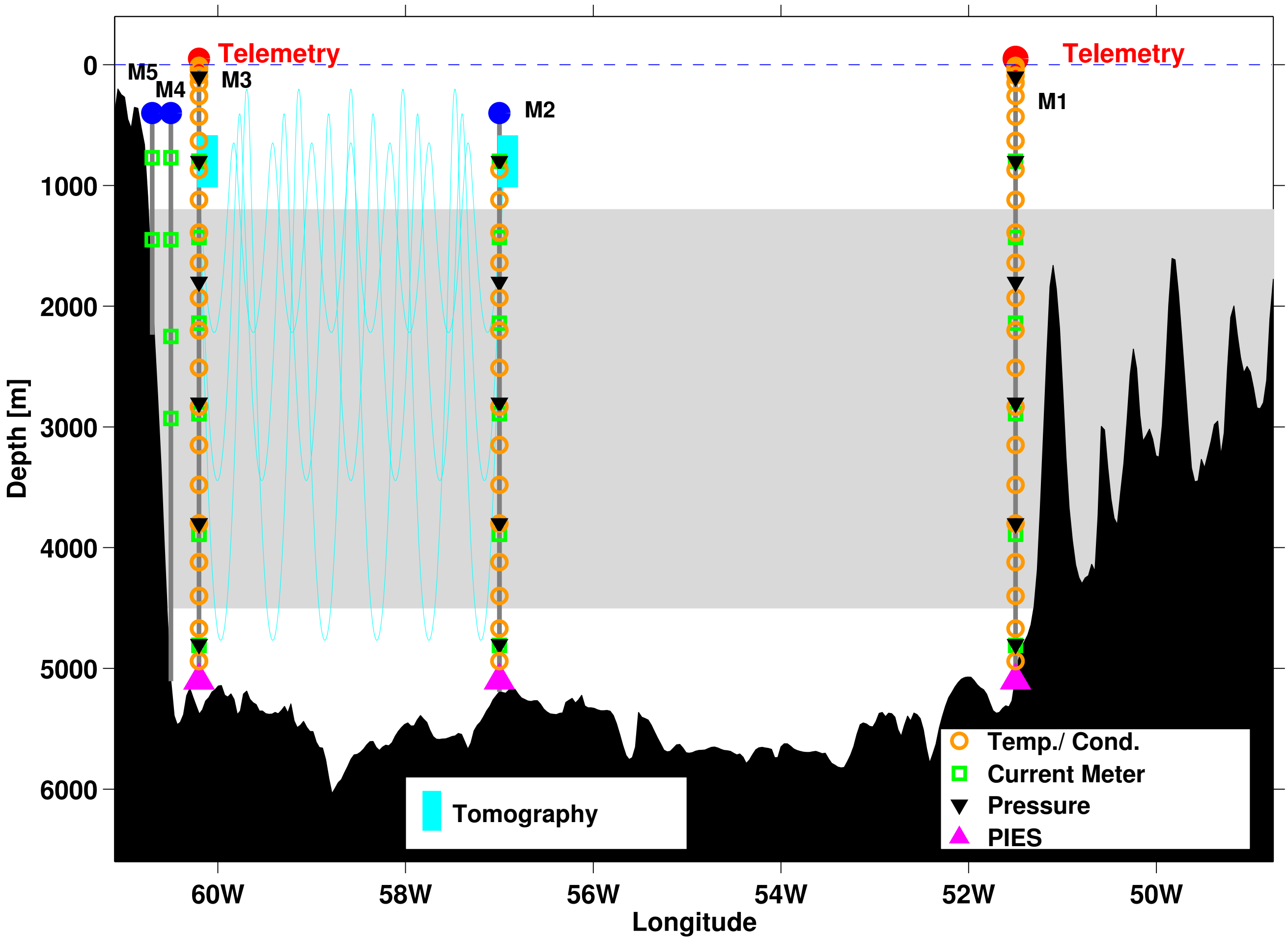


Figure 4.1: MOVE mooring design at 16°N. To maintain lucidity, the tomography mooring M3.5 is not displayed, since it was deployed extremely close to M3. Its tomography sound source has been drawn in as a part of M3 instead.

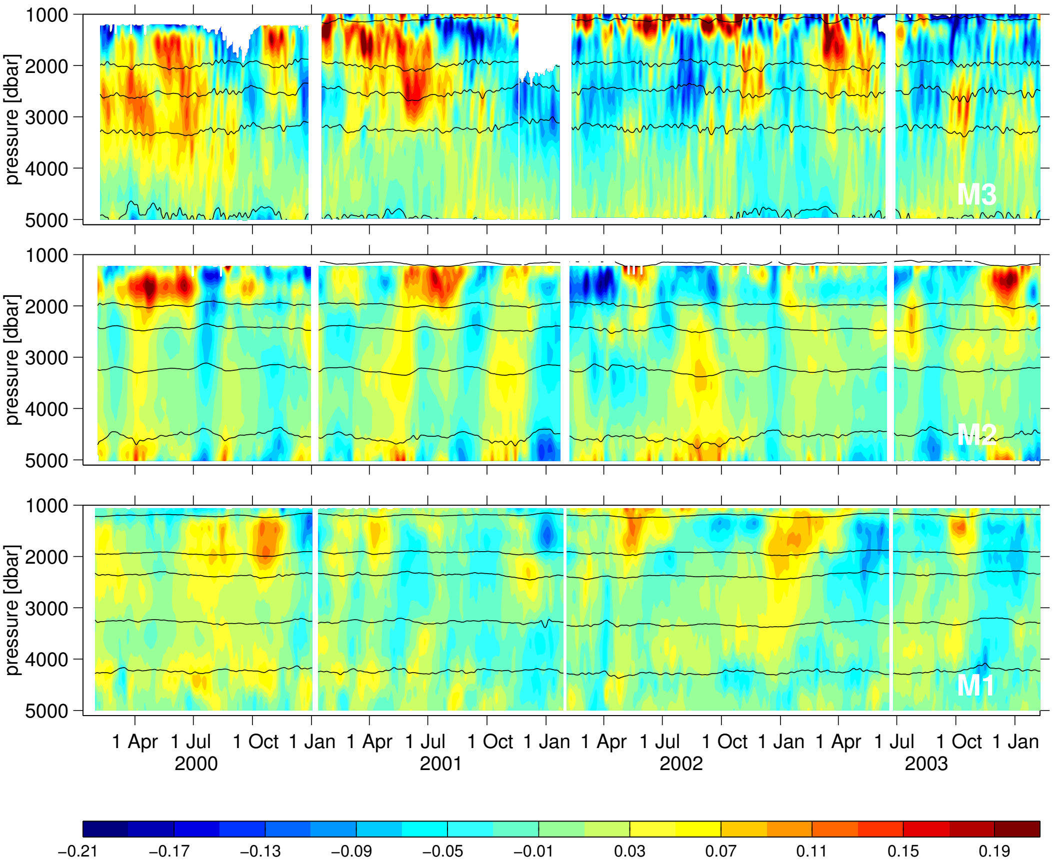


Figure 4.2: Time series of temperature anomalies from MicroCATSs at moorings M3, M2 and M1 since February 2000 (Feb. 2000 - Feb. 2004 mean subtracted) . The data recovered on the METEOR 60-4 leg spans the periods between June 2003 and February 2004. Data gaps result from mooring service works.

Table 4.1: Overview over the mooring work carried out during the METEOR 60/4 cruise

Mooring ID	Period	Latitude	Longitude	Waterdepth [m]	Date deployed	Date recovered
M1	2003-2004	15N 27.00	51W 31.50	4984	23/06/03	22/02/04
M1	2004-2005	15N 27.00	51W 31.30	4970	24/02/04	–
M2	2002-2003	15N 59.20	56W 55.60	4985	25/06/03	20/02/04
M2	2002-2005	15N 59.05	56W 55.50	4985	28/02/04	–
M3	2003-2004	16N 20.30	60W 30.30	4960	27/06/03	18/02/04
M3	2004-2005	16N 20.34	60W 30.51	4929	01/03/04	–
M3.5	2003-2004	16N 20.20	60W 32.80	4100	30/06/03	17/02/04
M3.5	2004-2004	16N 20.15	60W 32.80	4080	19/02/04	29/02/04
M4	2003-2004	16N 20.00	60W 36.45	3010	27/06/03	17/02/04
M4	2004-2005	16N 20.01	60W 36.51	3010	02/03/04	–
M5	2003-2004	16N 20.01	60W 41.75	1600	28/06/03	17/02/04

4.2 MicroCATs (T. Kanzow)

From the 59 MicroCATs that had been deployed on the FS SONNE cruise 172 in June 2003, 56 instruments were recovered. 55 of them acquired data of excellent quality throughout their operation in M1, M2 and M3. Only #952 showed minor problems in conductivity for the last 15 days of the time series. #936, #1716 and #1724 were missing upon recovery. All of the MicroCATs - including #952 - did not show any large deviations relative to the CTD during the calibration casts. For the new deployment period again 59 MicroCATs were deployed but their distribution in the moorings was slightly changed. While during the 4th deployment there had been 10 inductive MicroCATs in M1 and in M3, now there are 13 inductive instruments in M1 but only 5 in M3. The reason for this shift is two-fold: One aim was to extend the telemetry of MicroCAT data to depths of up to 4000m at M1 (so far it had been 1500m). As two of the missing instruments were inductive, and in general inductive instruments were needed in other projects (such as ANIMATE) it was decided to reduce the telemetry depth at M3 from 1500m to 150 m, where data from 5 inductive instruments is transmitted. Correspondingly, the number of serial MicroCATs was increased from 29 to 31. Fig. 4.2 shows temperature anomalies derived from the MicroCAT measurements since the beginning of the MOVE project und February 2000.

The characteristics of the data from the latest deployment period (recovered on this cruise) corresponds well to the preceding data segments at each of the moorings M1, M2 and M3.

4.3 MTD logger (T. Kanzow)

The Mini-Temperature-Depth Loggers (MTD) are used to determine the time variable vertical mooring motions in M1, M2, M3 and M4 to be able to allocate the MicroCAT temperature and conductivity measurements to the correct pressures. Thus the time series shown in Fig. 4.2 are based on the combination of MicroCAT and MTD measurements.

All of the 16 MTD were successfully recovered and all of them had acquired data throughout the duration of the deployment. The MTD are used to determine the time-varying depth of the high precision MicroCATs (conductivity and temperature) in the moorings. The data in the MTD appears to be good except for one instrument: #46 showed an exponential drift of about 18 dbar throughout the deployment period. During the following CTD calibration cast #39 refused to work properly twice, although it had acquired data of good quality while operating in the mooring. So it was decided to not deploy #39 and #46 again. 4 instruments were calibrated twice. MTD #39 and #29 showed a constant pressure during the calibration on CTD #5. It was found to be a connection-problem between the software and the MTD's while starting the instruments. The second calibration on CTD #9 brought out the p-sensors were working right. MTD #20 and #19 went down on CTD #5 and on CTD #9. On CTD #9 plastic screws were mounted for the p-sensor to avoid rust from Aanderaa current meters to fall in. The data showed no difference between the CTD casts #5 and 9#. So one may expect them to work as well with or without these protective screws. MTD #20 and #19 were deployed with these screws in mooring M2. The other MTD were redeployed in a slightly different distribution in the moorings M1, M2, M3 and M4. As in the preceding years especially strong vertical mooring motions of several hundred meters were detected in the DWBC area (Fig. 4.3).

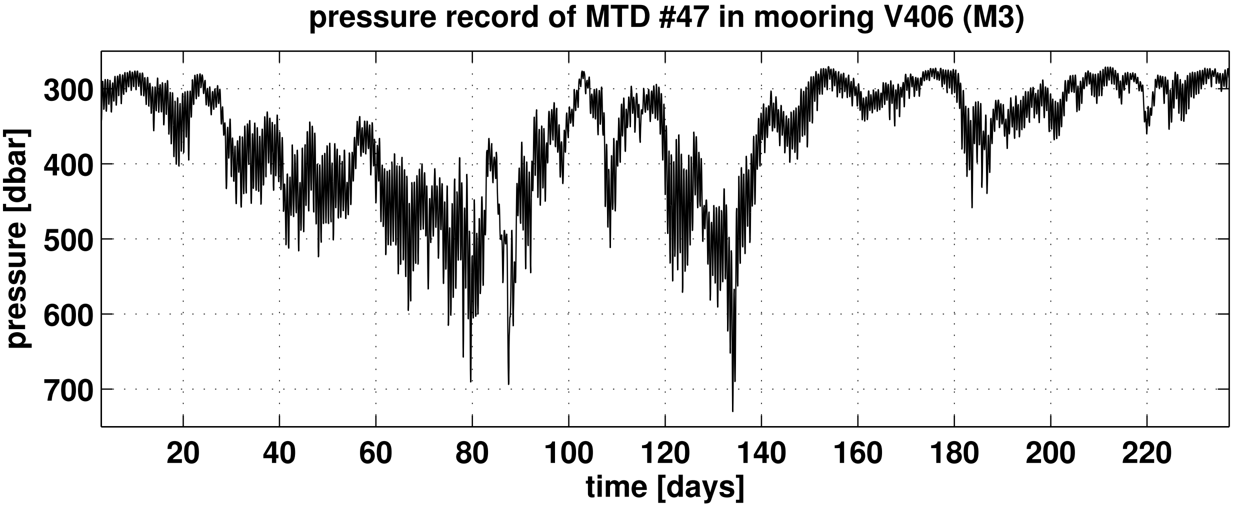


Figure 4.3: Example of a MTD pressure time series: MTD #47 displays deep subduction of mooring M3 during events of strong flow in the Deep Western Boundary Current.

4.4 Bottom pressure measurements (T. Kanzow)

From the difference in bottom pressure fluctuations between the moorings M1, M2 and M3 the zonally integrated meridional near-bottom velocity fluctuations may be derived. An overview over the bottom pressure recoveries and deployments is given in Table 4.4.

From the three Pressure Inverted Echo Sounders (PIES) #012,#002 and #057 that had been deployed near M3,M2 and M1, respectively, #012 and #057 were recovered successfully and had acquired good data throughout the operation since their launch in June 2003. The acoustic communication to PIES #012 was unreliable, so it did not become clear when exactly it released and it was only heard properly with the survey programme when it was already close to the surface. Communication with #57 worked well. PIES #002 could not be recovered. Communication to it could never be established, the RELEASE command could not be confirmed. Furthermore during deployment in June 2003 aboard FS SONNE (cruise 172) the slippage had been folded around one of the tripod's legs by accident. So it was doubtful right from the start if the instrument could get clear of the tripod after release anyway. However, hours after release three successive weak radio signals could be received by the radio direction finder, whether those originated from the PIES never became clear. A search was started immediately, but without success. No further radio pulses were received. #057 showed a surprisingly large exponential drift in the pressure record of about 50 cm whereas normally a drift in the order of 10 cm is seen. As #057 had been deployed for the first time it is expected that its drift rate will be much smaller in successive deployments.

From the two Filloux-type Bourdon tubes #003 and #012 provided by Alan Chave (WHOI) and deployed near M1 and M3 only #003 was recovered and showed reliable data. Communication to #012 failed completely.

The bottom pressure sensor provided by Peter Foden, Proudman Oceanographic Lab. (POL) was recovered. It is essentially a Paroscientific quartz pressure sensor like the one used in the PIES. Communication worked extremely well and the time series recorded looks promising. This instrument was needed in another experiment by POL and thus was not redeployed again.

This time as a contribution to the GRACE satellite mission (gravity recovery and climate experiment) a much larger number of PIES and Chave's Bourdon tubes were deployed in a cross-pattern (see Fig. 3.1) with the one axis being the original MOVE line and the other axis (north-south) being almost orthogonal to it and intersecting it at site M2 (57.0W/16.0N). The east-west extent is about 1000 km while the north-south one spans almost 900 km. All in all 6 PIES - 5 of them with acoustic telemetry option (serial numbers #57 onwards) - and 6 Bourdon tubes where launched.

PIES #57 that had been deployed in June 2003 was the first one with acoustic telemetry option. So prior to recovering it, its detided and daily averaged data was transferred acoustically. The data is encoded as time delays relative to a marker pulse (referred to as "PDT"). The main benefit is the low power consumption of this technique whereas a possible drawback arises as transmission becomes noisy when the vessel moves relative to the PIES. The data was received and stored without larger problems using Benthos 7000 deck unit and the Matlab software FilePDT.m provided by the manufacturer (R. Watts). We then compared the telemetry data to the data stored inside the PIES after its recovery (Fig. 4.4). First of all a reasonable overall agreement both in bottom pressure and travel time was observed. Some data points were missing in the telemetry data and sometimes the succession of days was not correct. This makes the data at times ambiguous. The rms difference between both data sets in terms of bottom pressure was about 0.006 dbar

Table 4.2: Overview over the recoveries and deployments of bottom pressure recorders during cruise METEOR 60-4.

mooring	instrument	latitude	longitude	depth	launch	recovery
M1	PIES #057	15N 27.75	51W 31.90	4980m	19/06/03	23/02/04
M1	SIO-BPR #03	15N 28.00	51W 31.60		22/06/03	22/02/04
M1	PIES #127	15N 27.01	51W 31.60	4965m	23/02/04	
M1	SIO-BPR #03	15N 27.98	51W 31.57		22/02/04	
M1.5	PIES #012	15N 43.10	54W 13.50	5450m	25/02/04	
M2	PIES #002	15N 59.40	56W 55.31	4999m	26/06/03	failed
M2	PIES #123	15N 59.19	56W 56.59	5000m	21/02/04	
M2	SIO-BPR #01	16N 00.17	56W 56.53		20/02/04	
M3	PIES #012	16N 20.51	60W 29.30	5000m	26/06/03	18/02/04
M3	PIES #165	16N 21.30	60W 29.25	5000m	17/02/04	
M3	SIO-BPR #12	16N 21.32	60W 30.3		16/06/03	failed
M3	SIO-BPR #04	16N 21.43	60W 30.39		18/02/04	
M3	POL-BPR	16N 22.29	60W 30.32	4903m	28/06/03	01/03/04
M6	PIES #128	20N 36.51	56W 40.78	5093m	26/02/04	
M6	SIO-BPR #10	20N 36.00	56W 40.78		26/02/04	
M7	PIES #057	12N 15.03	57W 12.04	4451m	05/03/04	
M7	SIO-BPR #02	12N 15.58	57W 11.99		05/03/04	
M7.5	SIO-BPR #07	14N 23.41	56W 59.41		05/03/04	

(or 6 mm). The difference could be explained by vessel movement relative to the PIES during transmission, given its data transmission window of 50 dbar and a window length of 8 seconds in the file telemetry mode. Then, vertical vessel movement of 1.5m is sufficient to account for this discrepancy. This 6 mm difference is more than we can accept as we are interested in the millimeter fluctuations. The newer generation firmware in the telemetry PIES uses a 2 dbar window for pressure data and has a length of 14 seconds. This should ensure that the noise induced by vessel movement should decrease by over one order of magnitude to an acceptable level. This new firmware is being used in all the PIES we deployed, including #057, which was updated during this cruise.

Another concern which became apparent during tests with the file telemetry mode has not been solved yet. Tests with PIES #123 and #165, which had both been deployed for more than 4 days such that they would switch from burst to file telemetry mode, showed that when downloading the data set

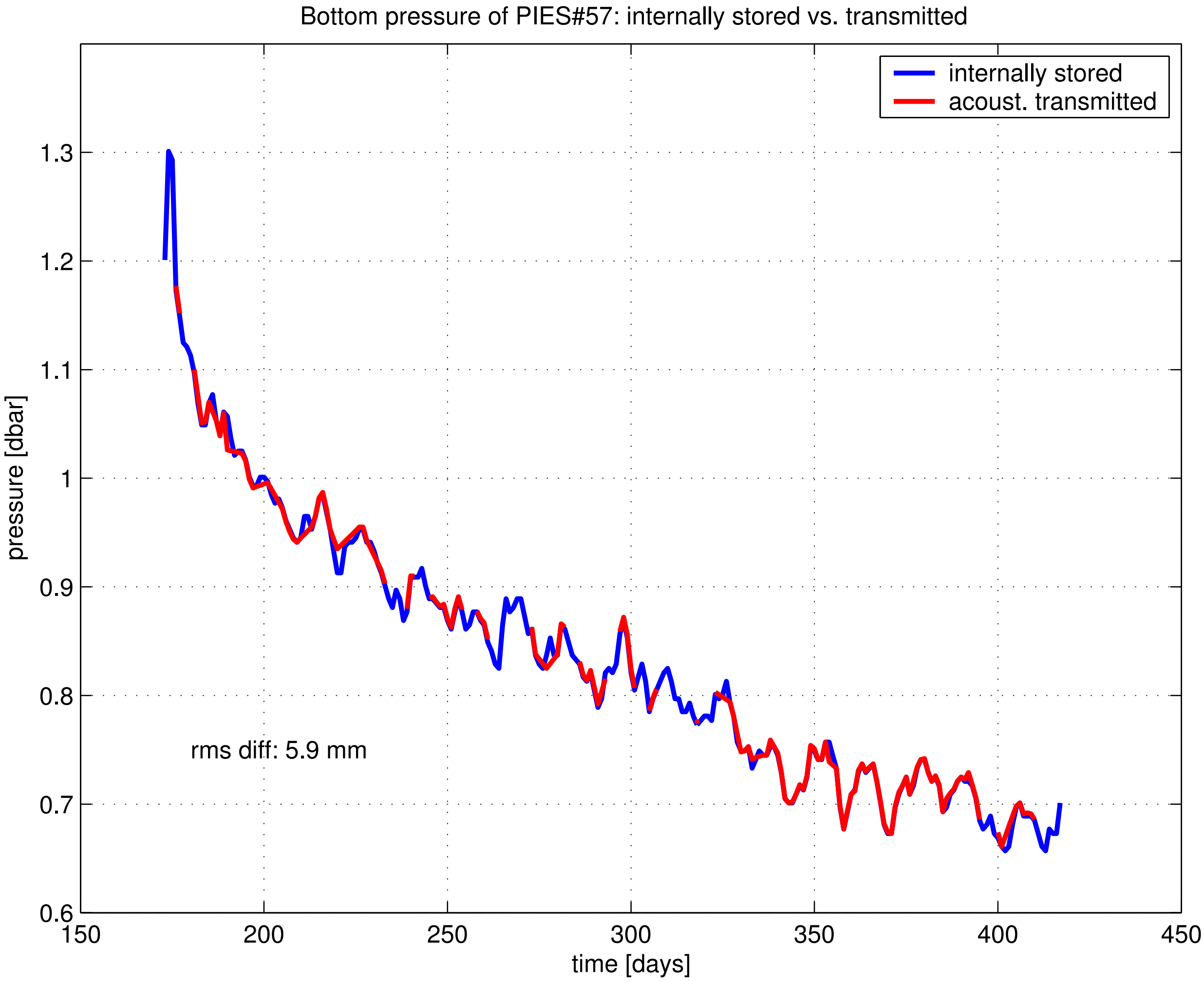


Figure 4.4: Acoustic Telemetry of PIES #057: Bottom pressure time series as received via telemetry (red) and internally stored in the instrument (blue). An rms-difference of 5.9 mm (water column equivalent) is found between both time series

acoustically for the first time, all worked without larger problems. When trying to transfer the data for a second time, the FilePDT.m programme could not receive any signal. All further attempts failed. Of course it would be desirable to download that same data set several times. This could help to overcome problems such as data gaps and ambiguities as seen in PIES #057 and further reduce the noise level. Theoretically (pers. communication R. Watts and G. Chaplin) the file telemetry should work as follows (see also manual "IES model 6.1E - Advanced Acoustic Telemetry Option", revised 04/02/2004): Data is transmitted in blocks of 34 data cycles (days). At the beginning of each block, one data cycle (consisting of pressure, travel time and year day) is transmitted in the MSB (most significant bit format), meaning that the absolute data values (of pressure and travel time) are transferred with limited resolution. MSB data are not exact enough to be used scientifically, but they might be useful to overcome ambiguities of the LSB data described below. The one MSB should be followed by 34 LSB (least significant bit) data cycles, beginning with the most recently acquired and proceeding backward in time. In the LSB format pressure is transferred modulo 2000 decaPascals and IES travel time modulo 0.5 seconds.

As said above, the data is encoded as delays relative to a marker pulse. The marker pulse for MSB has a frequency of 10.0 kHz, whereas for LSB it has 11.0 kHz. The pulses for pressure, travel time and year day have frequencies of 11.5, 12.0 and 12.5 kHz, respectively. This would require 5 frequencies to be received by the deck unit. In our case the DS 7000 has only four channels such that the recently provided PFilePDT.m software was modified only to listen for the LSB data and not receive the MSB 10.0 kHz marker. This should not create any problems, but obviously the programme only received the LSB 11.0 kHz marker where used for the first time to transmit data from PIES #123 and #165. So PIES #057, which only was to be deployed at the very end of the cruise, was operated in the lab for several days, such that file telemetry could be used. When trying to transfer the data for the first time, everything worked reasonably well and the LSB data was received. When trying a second time (after sending the CLEAR command and then again the TELEM command) it could be heard by ear that the PIES was transmitting its data, but the PFilePDT.m programme never received the LSB 11.0 kHz marker. Then it was tried to analyze the pulses that had actually been sent by the PIES: No LSB marker was sent at the beginning of each data cycle, but instead every time a 10.0 kHz MSB marker. What this means is not quite clear to this point and together with R. Watts and G. Chaplin we will try to analyze this problem further. If it should mean that after the first complete file telemetry data transmission (in LSB) during successive attempts only MSB data is sent, then this is a serious bug in the firmware which has to be modified. It is crucial to be able to transfer data in LSB more than once, especially when you intend to keep an instrument deployed for many years but want to dump the data several times inbetween. This is what the telemetry was intended for.

The fact that no LSB marker was sent explains why the PFilePDT.m software got stuck during the recording. We therefore recommend to modify the software such that the software shouldn't wait for a pulses of specific frequencies in a specified succession but that each pulse is recorded in the succession they are received and that the decoding is then applied after the complete data set is transmitted.

4.5 Current meters (C. Begler)

In the mooring deployment M1–M5 of 2003, 26 Aanderaa RCM current meters had been used. The RCMs in M3–M5 are used to determine that fraction of the DWBC transport over the western continental slope, that in M1–M3 give information about the interior dynamics complementary to the geostrophic measurements. All current meters could be recovered, however one instrument from mooring M1 had lost its bottom cap, and thus lost all its data. Some other instruments had not recorded currents near the end of deployment, probably caused by rotor problems (see Table 4.3). The new generation of Aanderaa RCM–9 instruments (based on Doppler-shift-measurements) worked well. In the redeployed mooring design two of the RCM–9 have been inserted in the telemetry-line of M1, since the absence of a vane (which is present in the RCM-8) makes it easier to bypass them with an electric connection. In summary, 22 RCM–instruments were redeployed in the moorings M1, M2, M3 and M4 (see Table 4.4). Fig. 4.5 exemplarily shows current time series recorded at M3. Strong southward flow related to the DWBC prevails over almost the entire length of the records. Only the two near-bottom instruments (moored below 4500m) do not seem to be influenced by its dynamics.

Table 4.3: Recovered Aanderaa current meters in moorings M1-M5

Mooring	Depth	Instrument	S/N	Variables	Comment
M1	771 m	Aanderaa RCM-9	051	U,V,T,C	
M1	1422 m	Aanderaa RCM-8	10662	U,V,T,C	
M1	2123 m	Aanderaa RCM-8	4570	U,V,T,C	bottom lost
M1	2873 m	Aanderaa RCM-8	11621	U,V,T,C	
M1	3872 m	Aanderaa RCM-8	9727	U,V,T,C	
M1	4884 m	Aanderaa RCM-8	9344	U,V,T,C	
M2	803 m	Aanderaa RCM-8	10075	U,V,P,T,C	
M2	1444 m	Aanderaa RCM-8	9345	U,V,T,C	
M2	2145 m	Aanderaa RCM-8	9728	U,V,T,C	
M2	2892 m	Aanderaa RCM-8	9732	U,V,T,C	
M2	3996 m	Aanderaa RCM-8	094	U,V,P,T,C	
M2	4553 m	Aanderaa RCM-8	9831	U,V,T,C	no SPD since 03-Oct-2003
M2	4934 m	Aanderaa RCM-8	11618	U,V,T,C	no SPD since 04-Feb-2004
M3	774 m	Aanderaa RCM-9	054	U,V,T,C	
M3	1423 m	Aanderaa RCM-8	8411	U,V,P,T,C	
M3	2124 m	Aanderaa RCM-8	10663	U,V,T,C	
M3	2877 m	Aanderaa RCM-8	4562	U,V,T,C	
M3	3877 m	Aanderaa RCM-8	8365	U,V,T,C	
M3	4655 m	Aanderaa RCM-8	11442	U,V,P,T,C	PRES defect
M3	4875 m	Aanderaa RCM-8	8349	U,V,T,C	
M4	772 m	Aanderaa RCM-8	10813	U,V,T,C	
M4	1450 m	Aanderaa RCM-8	10815	U,V,T,C	
M4	2255 m	Aanderaa RCM-8	9820	U,V,T,C	no SPD since 22-Jan-2004
M4	2931 m	Aanderaa RCM-8	11617	U,V,T,C	
M5	804 m	Aanderaa RCM-8	10077	U,V,T,C	
M5	1440 m	Aanderaa RCM-8	6160	U,V,T,C	

Table 4.4: Redeployed Aanderaa current meters in moorings M1-M4.

Mooring	Depth	Instrument	S/N	Variables	Comment
M1	1095 m	Aanderaa RCM-9	051	U,V,T,C	
M1	2129 m	Aanderaa RCM-11	293	U,V,T,C	
M1	3877 m	Aanderaa RCM-8	9727	U,V,T,C	
M1	4889 m	Aanderaa RCM-8	9344	U,V,T,C	
M2	805 m	Aanderaa RCM-8	10075	U,V,P,T,C	
M2	1447 m	Aanderaa RCM-8	9345	U,V,T,C	
M2	2147 m	Aanderaa RCM-8	9728	U,V,T,C	
M2	2897 m	Aanderaa RCM-8	9732	U,V,T,C	
M2	3997 m	Aanderaa RCM-8	094	U,V,T,C	
M2	4553 m	Aanderaa RCM-8	10662	U,V,T,C	
M2	4904 m	Aanderaa RCM-8	11618	U,V,T,C	
M3	788 m	Aanderaa RCM-9	054	U,V,T,C	
M3	1437 m	Aanderaa RCM-8	10077	U,V,P,T,C	
M3	2138 m	Aanderaa RCM-8	10663	U,V,T,C	
M3	2890 m	Aanderaa RCM-8	4562	U,V,T,C	
M3	3890 m	Aanderaa RCM-8	8365	U,V,T,C	
M3	4553 m	Aanderaa RCM-8	10502	U,V,T,C	
M3	4877 m	Aanderaa RCM-8	10664	U,V,T,C	
M4	824 m	Aanderaa RCM-8	6160	U,V,T,C	
M4	1436 m	Aanderaa RCM-8	10659	U,V,T,C	
M4	2242 m	Aanderaa RCM-8	11441	U,V,T,C	
M4	2919 m	Aanderaa RCM-8	11617	U,V,T,C	

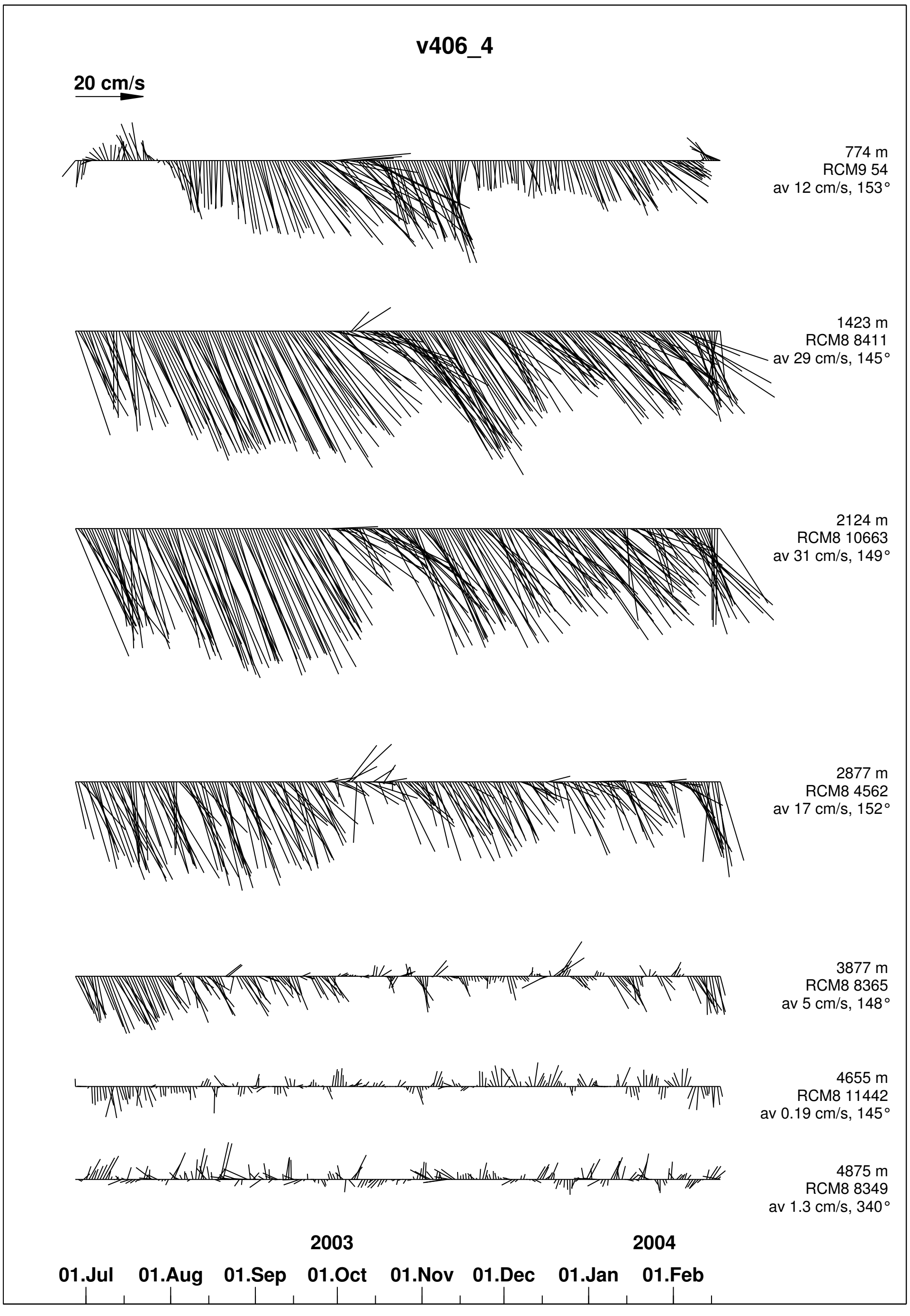


Figure 4.5: Stickplots of recovered current meter data from M3.

4.6 CTD (M. Lankhorst)

4.6.1 Introduction

A total of eleven CTD casts were carried out during METEOR cruise 60/4. The purpose of these was to provide reference data at positions where moorings were to be recovered or deployed, as well as to calibrate MicroCATs and MTD loggers, which were attached to the CTD rosette. As some of the MicroCATs and MTPs were not designed for high pressure, not all CTD casts went to the bottom. Salinity reported by the CTD was calibrated using water sampled with the rosette and analyzed with a laboratory salinometer.

4.6.2 Description of the System

The CTD system used is a SeaBird Electronics, model 911 plus type, referred to as IfM-Geomar serial number 1. A backup system was available but never used. The underwater unit was built into a rosette housing capable of holding 24 water sampler bottles. An lADCP system looking both up- and downward and a Benthos bottom pinger were also installed. Table 4.5 lists sensor model and serial numbers.

Table 4.5: Setup of the CTD system during METEOR cruise 60/4.

Instrument Type	Model No.	Serial No.
CTD deck unit	SBE 11 plus	
CTD underwater unit	SBE 9plus	09P22348-0572
Rosette water sampler	SBE 32	3222348-0291
Temperature sensor	SBE 3plus	03P2920
Conductivity sensor	SBE 4c	042443
Oxygen sensor	SBE 43	430215
Pump	SBE 5T	052603
Pinger	Benthos	
Bottom alarm	mechanic switch	

4.6.3 Calibration Applied to the Data

Pre-cruise laboratory calibrations of the temperature and pressure sensors were available (see below). Both of these yielded coefficients for a linear fit. Salinity was calibrated during the cruise with a Guildline Autosal 8 salinometer. For this purpose, the detected error in conductivity was linearly fitted to the conductivity data itself, and the residuals were linearly fitted to pressure. After this, mean residuals over intervals of 1000 dbar were less than 0.0005, with standard deviations of 0.003. With these corrections applied, a data set was created on board that can be considered final unless the next laboratory calibrations detect changes in the temperature and pressure coefficients. The oxygen sensor must be considered unreliable because no in-situ measurements were carried out during the cruise.

The following pressure (in dbar) correction (laboratory calibration from February 2003) was applied:

```
Coefficients for static correction at temperature T0
PRES(T0)=PCTD(T0)+Pol(PCTD(T0))

 Polynomial degree    is M=1
 Number of data pairs is N=13
 Coefficients, starting at lowest order:
 co(0)=-1.483240e+000
 co(1)=-7.943060e-004
```

The following temperature (in °C) correction (laboratory calibration from November 2003) was applied:

```
Coefficients for correction, TEMP=TCTD+Pol(TCTD)

 Polynomial degree    is M=1
 Number of data pairs is N=16
 Coefficients, starting at lowest order:
 co(0)=-4.044333e-003
 co(1)= 1.621552e-005
```

The following conductivity (in mS/cm) calibration was applied using MatLab:

```
cond = cond_raw + ...
       polyval(coeff_c,cond_raw) + ...
       polyval(coeff_p,press);
```

Table 4.6: Information on all CTD casts during METEOR 60/4, taken from the manually written log sheets.

Station	Cast	Start Time (UTC)	Start Position	Max. Pr.	Notes
99	1	18-Feb-2004 01:26	16°19.84'N 60°31.43'W	4879	clock offset of several minutes
107	2	20-Feb-2004 03:24	15°58.87'N 56°56.64'W	5050	
119	3	22-Feb-2004 19:45	15°28.48'N 51°32.46'W	5050	MicroCats attached
121	4	23-Feb-2004 12:03	15°27.54'N 51°31.87'W	5041	MicroCats attached
125	5	23-Feb-2004 21:15	15°27.88'N 51°31.85'W	3503	MicroCats and mini-loggers attached, only 3500 dbar
126	6	24-Feb-2004 02:20	15°27.60'N 51°31.44'W	990	MicroCats attached, only 1000 dbar
127	7	24-Feb-2004 04:20	15°27.45'N 51°31.49'W	5045	MicroCats and mini-loggers attached
132	8	26-Feb-2004 18:39	20°35.23'N 56°40.14'W	5460	MicroCats attached
132	9	27-Feb-2004 00:19	20°35.33'N 56°39.95'W	4005	Mini-loggers attached, only 4000 dbar
140	10	28-Feb-2004 19:05	15°59.38'N 56°56.89'W	5050	
143	11	01-Mar-2004 00:14	16°21.18'N 60°27.82'W	5171	no lADCP

```
with:
coeff_c = [3.8077e-04  -4.3522e-03]

coeff_p = [-3.6486e-07   9.1812e-04]
```

As a preliminary calibration, it would also have been appropriate to add 0.010 as a constant offset.

4.6.4 Performance and Station Overview

The overall impression of CTD performance is very positive. There were virtually no spikes in the data, nor did the recording computer have problems due to the large amounts of data. Further processing with a laptop (internal name "solo3") and software developed at IfM Kiel (CTDOK using MatLab) was troublesome, as there were different incompatible versions of the software, and as the software was clearly not designed for handling large data files. However, after spending some effort changing versions, the software could be run successfully, but required several hours to process a single profile. Apparently, there is need for improvement, and work on this has been started recently.

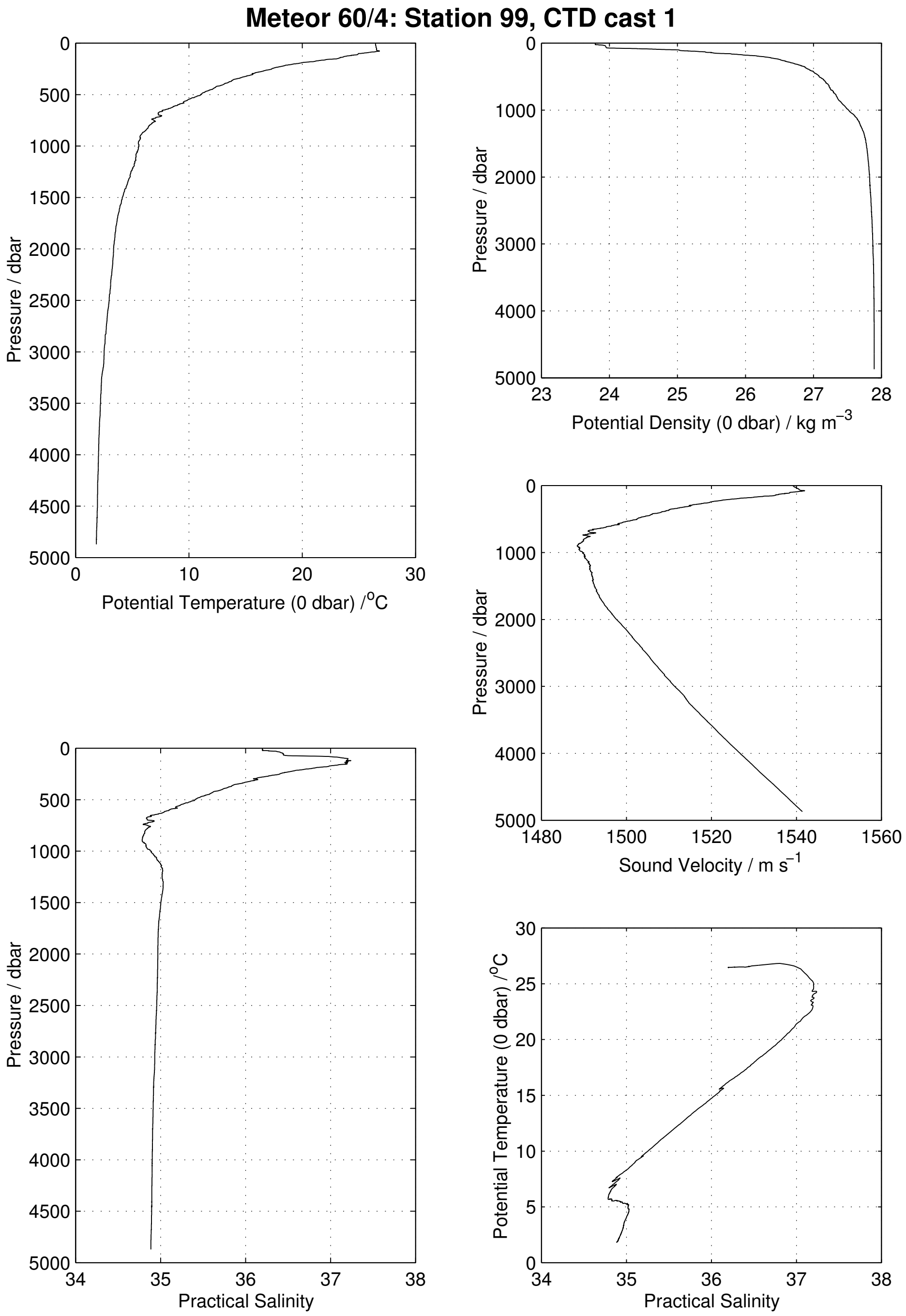
Table 4.6 summarizes the manually written log sheets for the individual CTD casts. During the casts with MicroCAT or logger instruments attached, the probe was halted for ten minutes at various depths during the upcast, which provides calibration points for these devices.

4.6.5 Hydrography

The main features of the hydrography of the area are apparent in plots of salinity versus pressure (Fig. 4.6 highlights this exemplarily in the lower left panel). In most of the casts, the upper 50 m show a fresher layer influenced by tropical rainfall (not in the northernmost stations), followed by a salinity maximum at circa 100 m. From there downward, the profiles feature the linear T-S relationship characteristic of Central Water, until the salinity minimum of Antarctic Intermediate Water is reached at about 800 m. The largest part of the water column, approximately 1200–4500 m, is occupied by the various species of North Atlantic Deep Water, which is the main interest of study in the MOVE project. Below this near the bottom, remainders of Antarctic Bottom Water can be found.

4.7 Calibration of MicroCATs and MTDs (T. Kanzow)

As during the previous cruises related to the MOVE project, all of the recovered and redeployed MicroCATs and MTD were attached to the rosette during CTD casts to carry out in situ calibrations (see Table 4.7 for an overview). This routine is crucial for the high accuracies required in this project. As in the previous years the rms difference between the calibrated CTD and MicroCAT temperatures and conductivities is around 0.005 K and 0.01 mS/cm, respectively, with the individual MicroCATs showing a relatively stable offset relative to the CTD from year to year (i.e., the year-to-year drift of the individual MicroCATs typically displays much lower values than those given above). Thus, by carrying out calibrations prior and after the deployment, the errors of the MicroCATs relative to the CTD can be reduced to less than 0.002 K and 0.002 mS/cm, respectively. As said above, similar calibrations are carried out with the MTD. Here the pressure measurements are of particular importance (see MTD section). The usual differences between the CTD and MTD pressures are below 8 dbar even in the deep ocean (Fig. 4.7). Here again the year-to-year differences of individual MTD relative to the CTD are much smaller than that, such that MTD pressure accuracies of < 2 dbar relative to the CTD should be achievable.



Meteor 60/4: Station 99, CTD cast 1

Figure 4.6: Data from CTD cast 1.

Table 4.7: MicroCATs and MTD logger lowered with the CTD during calibration casts.

CAST	MicroCAT / MTD logger
1	–
2	–
3	**MicoCAT**: 945 953 949 1550 1276 941 910 1280 1268 1269 1279 1277
4	**MicoCAT**: 962 948 960 1718 1721 944 1722 1720 1723 1278 1288
5	**MicroCAT**: 3411 3412 3413 3414 **MTD**: 19 20 22 23 30 46 47 48 52 55
6	**MicroCAT**: 1717
7	**MicoCAT**: 934 939 950 954 959 961 1321 1719 **MTD**: 39 56 57 58 59
8	**MicoCAT**: 0933 0935 0937 0942 0952 0957 0958 1162 1271 1273 1275 1319
9	**MTD**: 19 20 29 33
10	–
11	**MicroCAT**: 0929 0938 0940 0946 1270 1272 1274 1316 1317 1318 1320 1322 1323 2048 2279

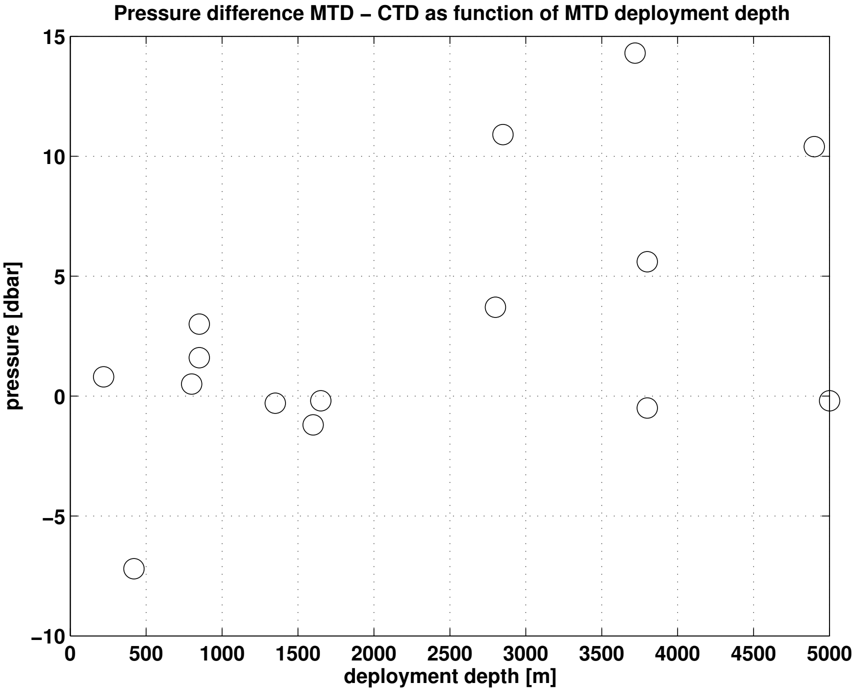


Figure 4.7: MTD calibration: Pressure differences MTD - CTD as a function of MTD deployment depth

4.8 ADCP (J. Karstensen)

4.9 ADCP data

Two types of ADCP were used during the M60/4 cruise: a vessel mounted ADCP (38kHz) mounted in the ships hull acquiring data to about 1000m depth and a lowered ADCP (2 workhorse 300 kHz) mounted on the CTD rosette and acquiring full depth current profiles.

4.9.1 Lowered ADCP (lADCP)

During the cruise 8 single lADCP profiles where acquired (see Table 4.8 and Figure 4.8) while no section sampling was planned. The devices were configured as on SO172 MOVE cruise in 2003 (see end of this section for the master command file). For starting the master/slave devices it is critical to first start the slave as the devices have be correctly synchronized. This was done for all casts properly. Bin size length was 10 m.

Table 4.8: lADCP casts during M60/4. BT: bottom track

St.	Cast	Start Time (UTC)	Start Position	depth	Notes
99	1	18-Feb-2004 01:26	16°19.84'N 60°31.43'W	4879	BT
107	2	20-Feb-2004 03:24	15°58.87'N 56°56.64'W	5050	BT
119	3	22-Feb-2004 19:45	15°28.48'N 51°32.46'W	5050	no BT
121	4	23-Feb-2004 12:03	15°27.54'N 51°31.87'W	5041	BT
127	7	24-Feb-2004 04:20	15°27.45'N 51°31.49'W	5045	no BT
132	8	26-Feb-2004 18:39	20°35.23'N 56°40.14'W	5460	no BT
132	9	27-Feb-2004 00:19	20°35.33'N 56°39.95'W	4005	no BT
140	10	28-Feb-2004 19:05	15°59.38'N 56°56.89'W	5050	no BT

Data processing was carried out with the lADCP package provided by M. Visbeck (Lamont-Doherty, Palisades, NY, USA) (1). The velocities are determined from integrating the shear between up and down cast which, assuming a constant velocity profile during the cast, should cancel out assuming a certain velocity profile. The advantage of using an upward and downward looking instrument is the knowledge of exact velocities at the bottom using the bottom track feature of the downward looking instrument (slave) which further constrains the shear derived velocity profiles.

However, for most casts (except 1, 2, and 4) the bottom was not found. As an additional constraint the vmADCP velocities were used for the upper 1000 m as second boundary condition (except station 1). Navigational information

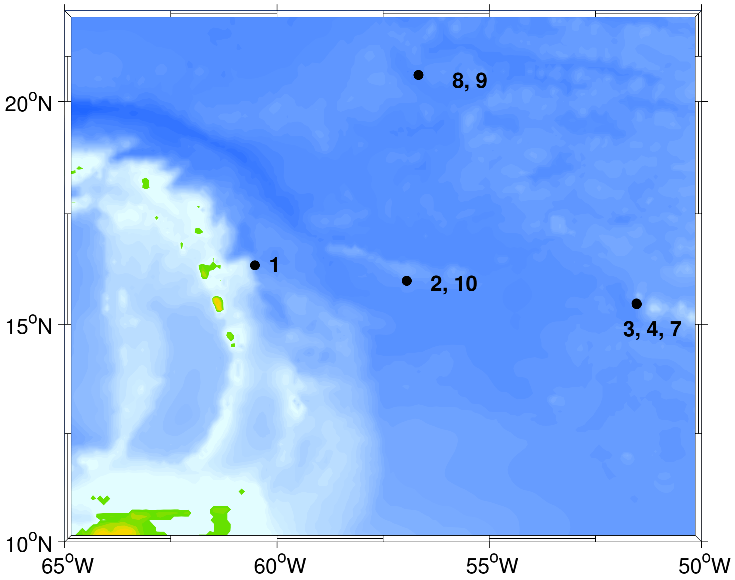


Figure 4.8: Station map of lADCP casts during M60/4.

was extracted from the GPS positions during the casts and considered during the processing procedure. No tidal current corrections were applied. The profiles are shown in Figs. 4.9 and 4.10.

The profiles shown are derived by the shear based estimate without considering the reference velocity measurements from the vmADCP and the bottom velocity (magenta line) as well as derived from the inverse solution considering the velocity constraints (thick black line). Overall there is not a good agreement between the two solutions (shear vs. inverse). Typically the error in velocities obtained (stippled line) exceeds the velocity. Profiles which were recorded at the same location but just a few hours apart (profile 3, 4, 7 and profiles 8, 9) are not very similar in structure. The profile from station 3 shows large velocities of O(0.5m/s) at the bottom which is unrealistic considering the small velocities obtained from the direct bottom track profiles (1, 2, 4). Station 1, near the western boundary, is the only one which shows a reasonable agreement between the shear and the inverse solution. Here velocities are larger than the errors.

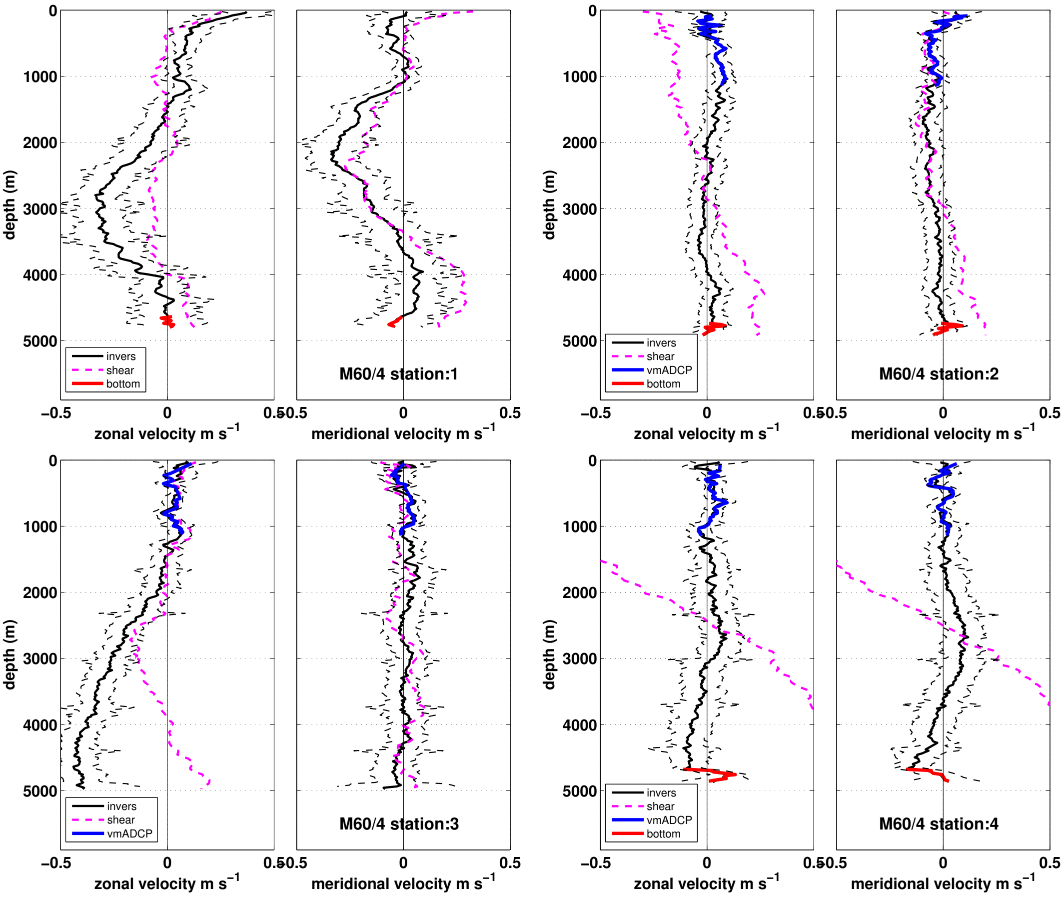


Figure 4.9: Station 1 to 4 lADCP profiles. The vmADCP as well as the bottom velocities are displayed when available. The broken line indicates the uncertainty of the measurement. Processing is based on (1).

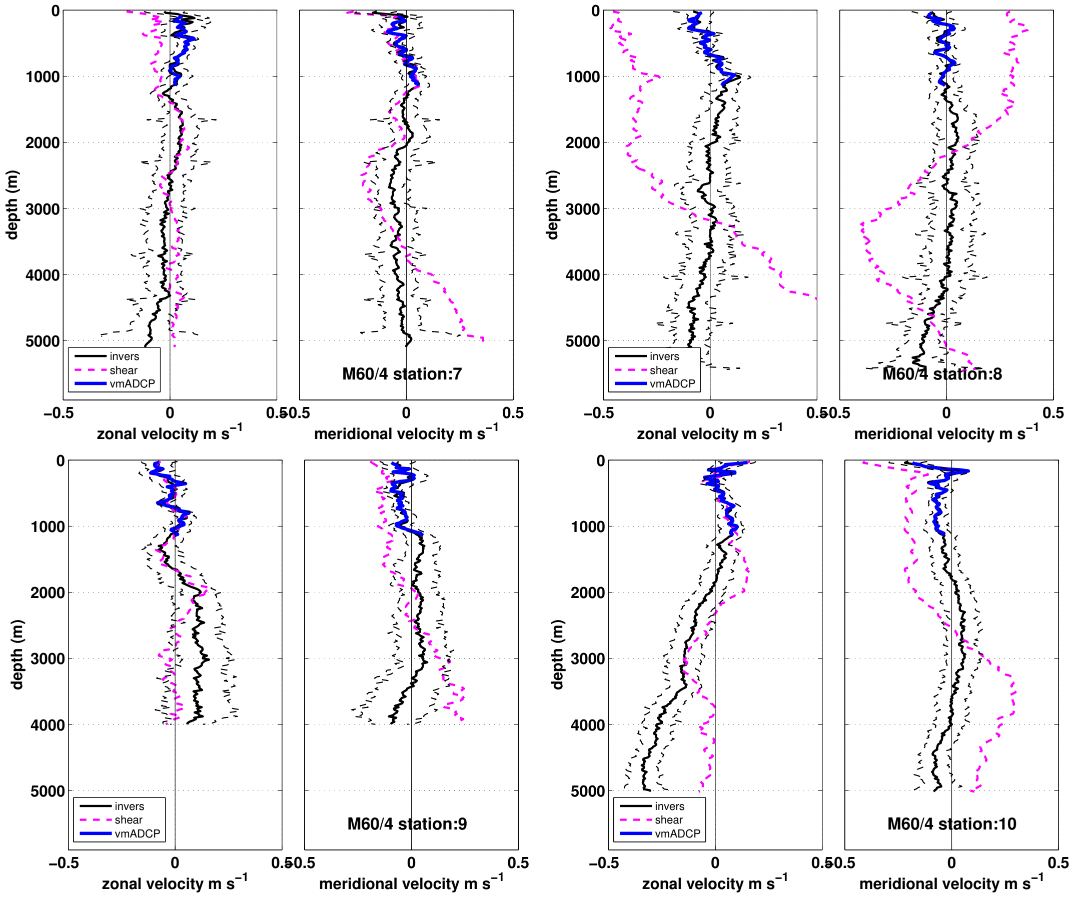


Figure 4.10: Station 7 to 10 lADCP profiles. The vmADCP as well as the bottom velocities are displayed when available. The broken line indicates the uncertainty of the measurement. Processing is based on (1).

4.9.2 Vessel mounted ADCP (vmADCP)

The vmADCP used on M60/4 was the 38 kHz Ocean Surveyor mounted in the ship's hull. The 75 kHz instrument which is permanently installed and normally used on FS METEOR was not ready for operation. The instrument was used with 16m bin length, 70 bins and 2 second ensemble interval. Navigation was fed in from the ASHTECH 3d GPS and the fiber optical gyro (FOG). In particular the quality of the ship heading information can be different between the two instruments while we gave the ASHTECH headings a preference. In case no ASHTECH data was available the FOG heading was used considering the average heading difference between FOG and ASHTECH. A converter was needed to transform some navigational data to be usable for the ADCP. The converter was not working properly during the beginning of the cruise and the data could not be processed. There were certain gaps in the vmADCP data collection during the cruise (Figure 4.11). Beside the aforementioned problem with the navigational data converter at the beginning of the cruise the device was stopped in the EEC of Barbados

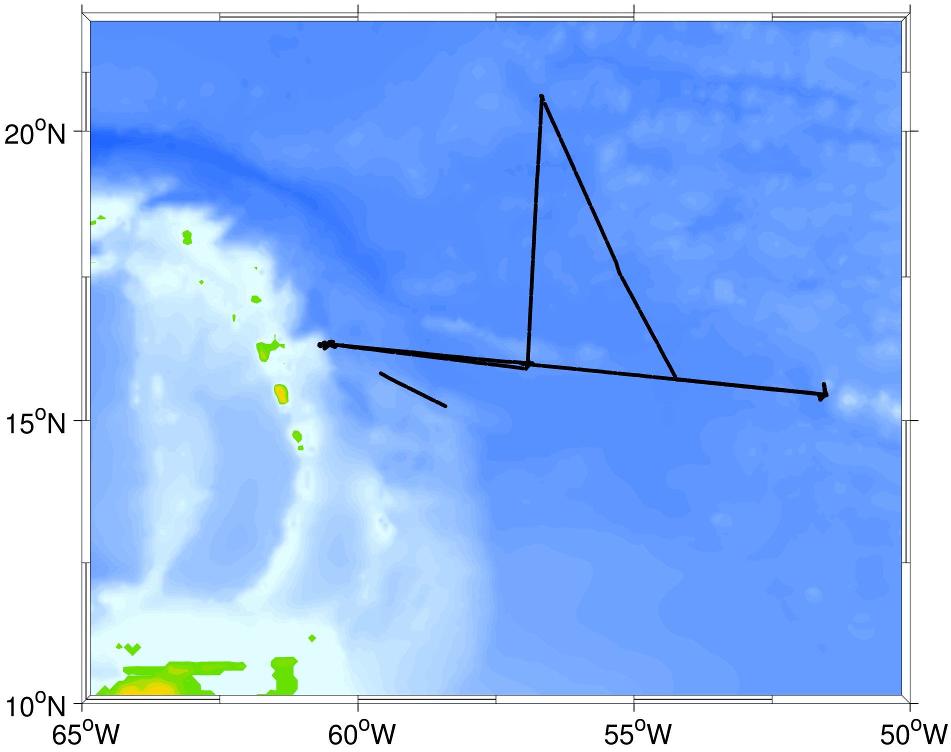


Figure 4.11: Positions of vmADCP data collected during M60/4.

and Martinique.

Removing the mean profile from the data during station work gives a measure of flow variability as well as a lower limit of the accuracy of the data (Figure 4.12). A normal distribution with an average standard deviation of 0.03 m/s in both (u,v) components was found.

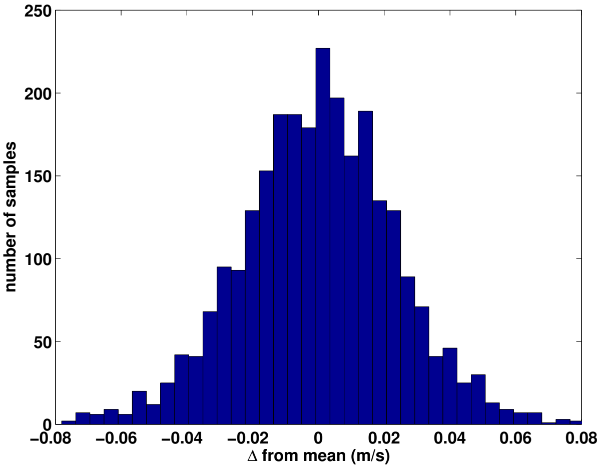


Figure 4.12: Distribution of velocity deviations from their mean for on station data during M60/4.

The data is shown here as a zonal section acquired on the way to the easternmost mooring (Figure 4.13) and two meridional sections acquired on the way to and back from the northernmost PIES position (Figures 4.14 and 4.15). Readily visible are quasi barotropic structures indicating the existence of eddies. In the southward meridional section (Figure 4.15) an eddy diameter of about 3.5°(400km) can be estimated from the data. Along the northward section (Figure 4.14) indications of the same feature are observed. Its wavelength may correspond to that of baroclinic Rossby waves observed in the region (2)

The master control files used durig all casts was:

```
; LADCP *.CMD file made for PALMER-1999/2000 cruise
;by Martin Visbeck modified for Oden cruise 3/1/02
; fuer m60 4 modifiziert 17.02.2004 jk
;  master.cmd
;CR1 retrieving parameter
CR1
;$LMR.TXT will capture all communications to M60_mlog.TXT
$LM60_mlog.TXT
```

```
;ED0000  Depth of transducer
ED0000
;ES35 salinity
ES35
;EX11111   coordinate transformation
;earth coordinates
EX11111
;TE00:00:03.50 time per ensemble, 3.5 second ensemble interval
TE00:00:03.50
;TP00:00.70     time between pings s
TP00:00.70
;EZ0011111  sensor source
; defaults to manual depth setting, uses internal heading,pitch,roll
;uses EC command to set speed of sound
EZ0011111
;EC1500 set speed of sound to 1500m/s
EC1500
;EA00000   heading alignment correction = 0
EA00000
;EB00000   heading bias correction = 0
EB00000
;  RNdm604_ sets deployment name to dm604_
RNdm604_
;CF11101   flow control, serial output disabled
CF11101
;----------  SPECIAL LADCP commands  ----------
;LD111100000  data out (vel,corr,intensity, good,status...)
LD111100000
;LF0500 blank after transmit (0-9999cm),Note:  half of bin length
LF0500
;LP00003  3 pings per ensemble 1 ping per ensemble for anslope
LP00003
;LJ1 receiver gain
LJ1
;LN025 number of depth cells 250 m range covered by 25 bins * 10 m
LN025
; LS1000 bin length (cm)  = 10m
LS1000
; LV250 correlation velocity (cm/s radial)
LV250
; LW1  band width
LW1
;LZ30,220 Amplitude, Correlation Thresholds
LZ30,220
; SI0  master waits 1 ensemble before sending sync pulse
SI0
; SM1 set this instrument to master
SM1
; SA011 master sends pulse before ensemble
SA011
; SW4500 synchronization delay
;        the master waits .5500 s after sending sync pulse
SW5500
;  ----------- END of LADCP commands ----------------
; CK keep parameters as user defaults
CK
; CS start pinging
CS
;$ L close log file
$L
```

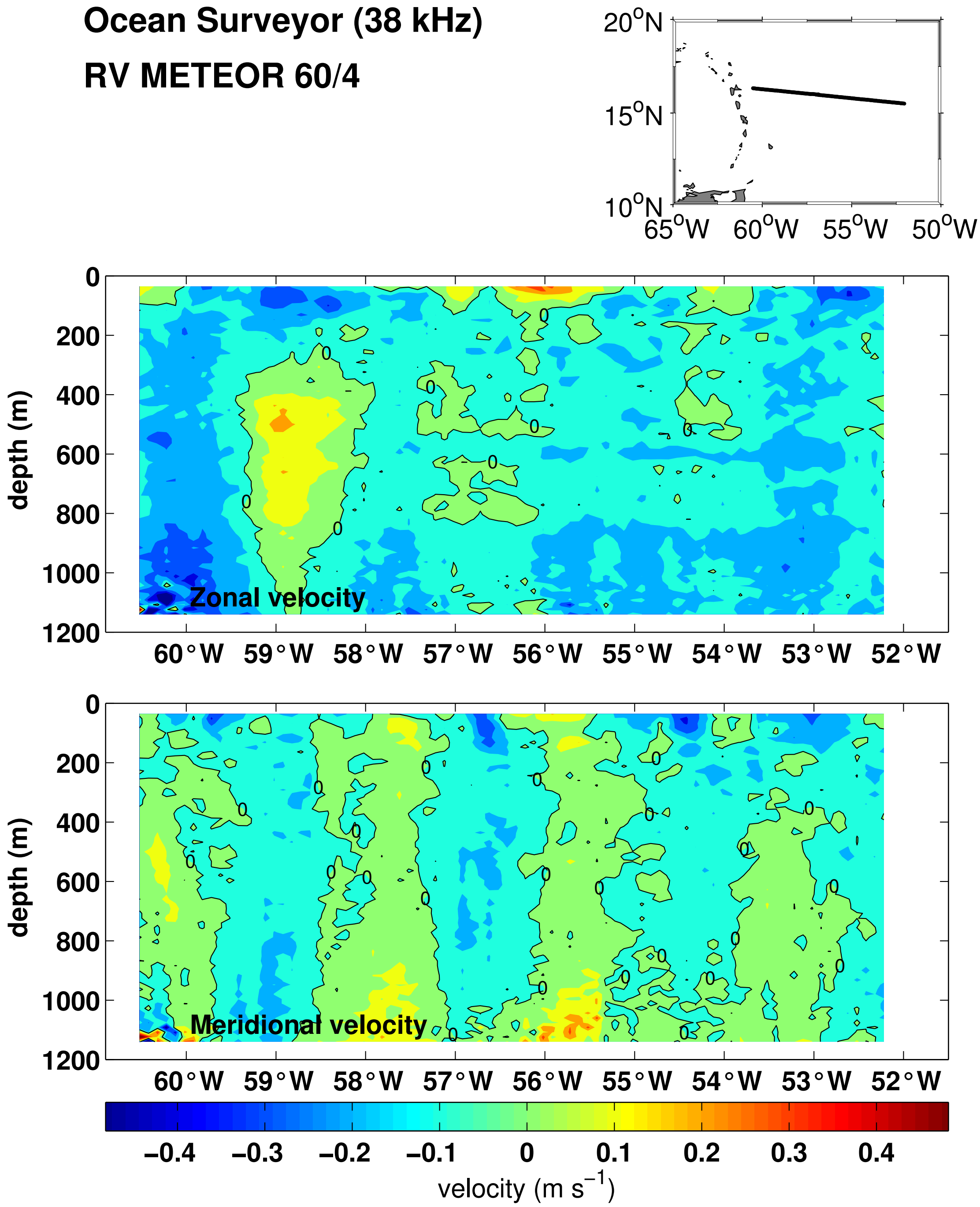


Figure 4.13: Meridional section acquired on the way to the easternmost mooring position (see map for track).

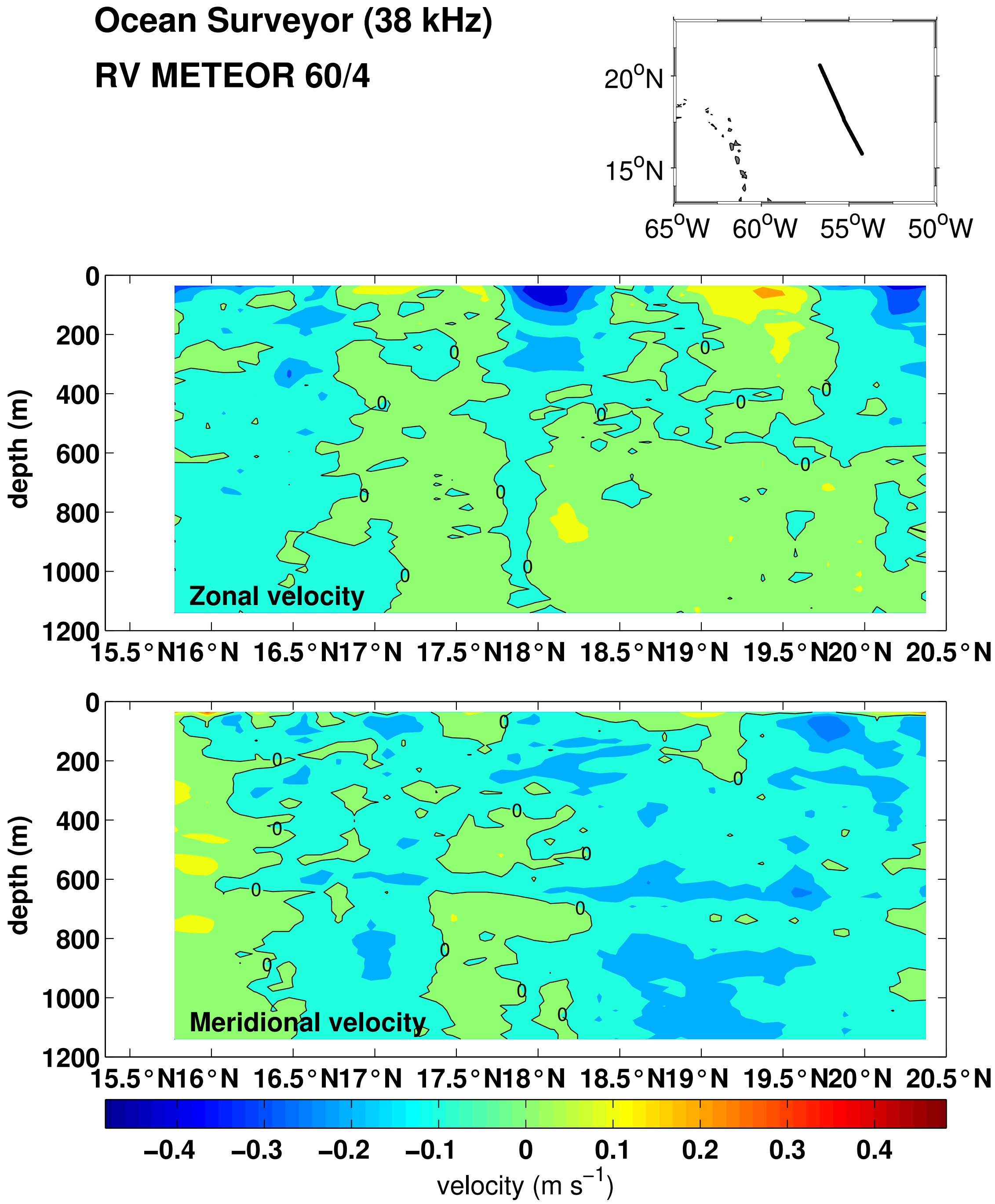


Figure 4.14: First zonal section, acquired on the way to the northernmost PIES deployment position (see map for track).

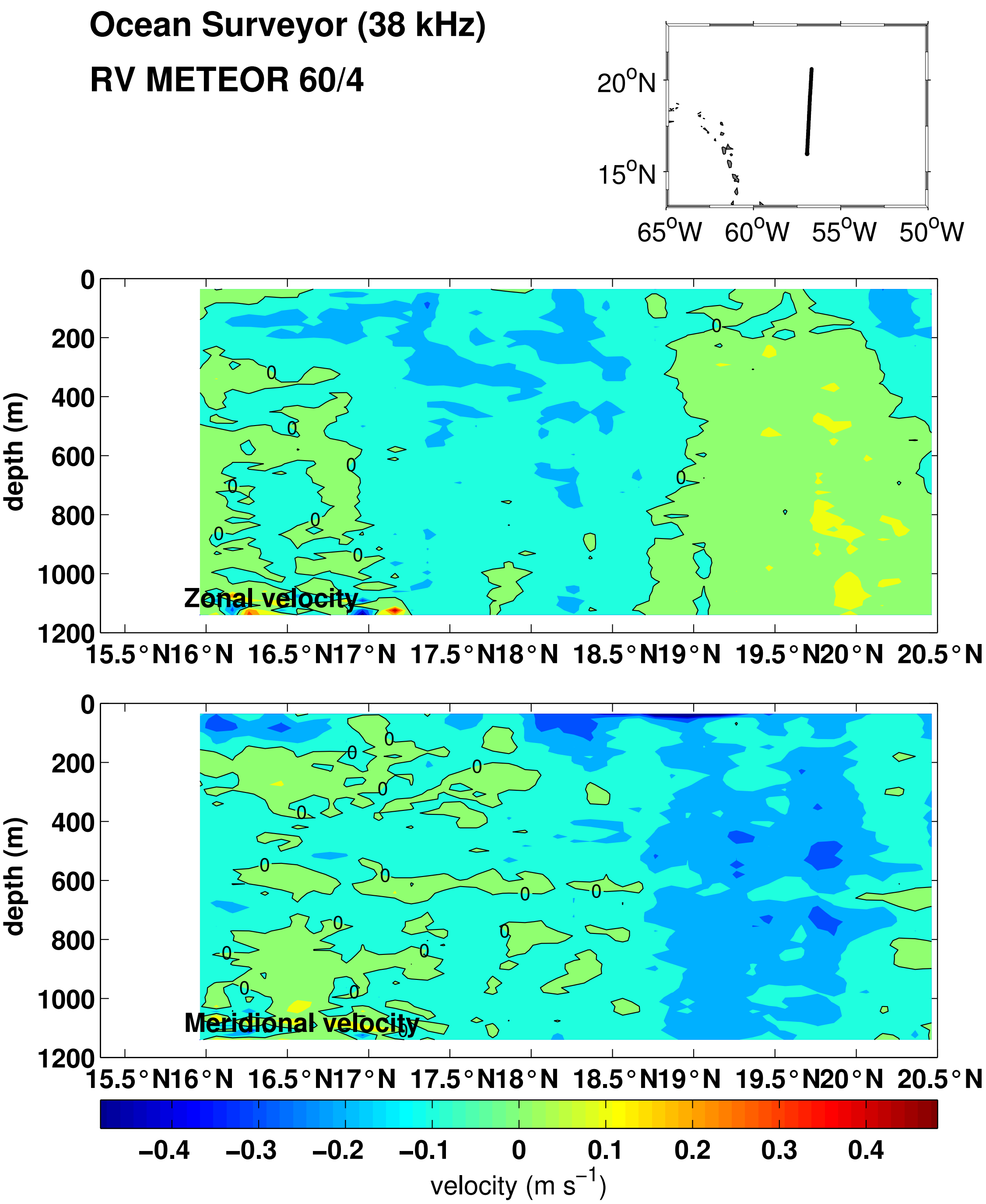


Figure 4.15: Second zonal section, acquired on the way south from the northernmost PIES deployment position (see map for track).

4.10 Tomography (T. Avsic)

The tomographic instruments measure the travel time of different acoustic rays (eigenrays) between a sound source and a receiver (see Figure 4.16). In the *MOVE* mooring array a sound source was moored in M3.5 and a receiver in M2. They were deployed during the FS SONNE cruise 172 in 06/2003. On this cruise first the sound source was recovered on the 17.02.2004. Unfortunately the instrument did not wake up through the SAIL interface and it turned out, that it had no battery power. Powering the system up with external power supply allowed us to communicate with the system. The read out of the internal data showed that there was not one single transmission done by the source. Further investigations showed that the battery cable was clamped between shell and battery. This could only have happened during the assembly of the instrument at *Webb Research* and most probably, during the deployment of the source it was cut due to shocks of movement on deck. The following measurements done by Andrey K. Morozov and Rudolf Link showed that the electronics and also the battery power were okay. The battery cable was changed and the source was lowered at 20m depth to test its full power capability. As many of the ship's aggregates as possible were switched off, so the source could be heard in the bilge of the ship. Sometimes the system reset itself, however this was attributed to high frequency noise penetrating through the SAIL loop. The source was deployed on the 18 February in order to get some first test receptions at the receiver.

The receiver was recovered on the 20 February. Analyzes of the data showed that in fact the source did not work during the last deployment, however very good receptions had been recorded for the last two days (Figure 4.17). The spectrum shows a clear sweeping signal from 200Hz to 300Hz and the correlation shows arriving times of the different rays similar to the predicted times. Converting the data to an audio file let us also hear the signal. This gave us the idea to build a simple and small receiver which can easily be lowered from the ship. John Bailey, Andrey K. Morozov, Rudolf Link and Tom Avsic constructed from some electronic components, one RAFOS hydrophone and a mini-disc recorder an easy-to-use receiver which fits into an Aanderaa shell, which was originally used for carrying batteries of the lowered ADCP. Another receiver with similar electronic components was built in the glass ball of a spare transponder and connected to its transducer. Both systems were lowered together with the much bigger and heavier SeaScan receiver to 1000m depth on the 28 February in order to listen to the 5:54 UTC transmission of the source. None of the systems received the signal. Noise

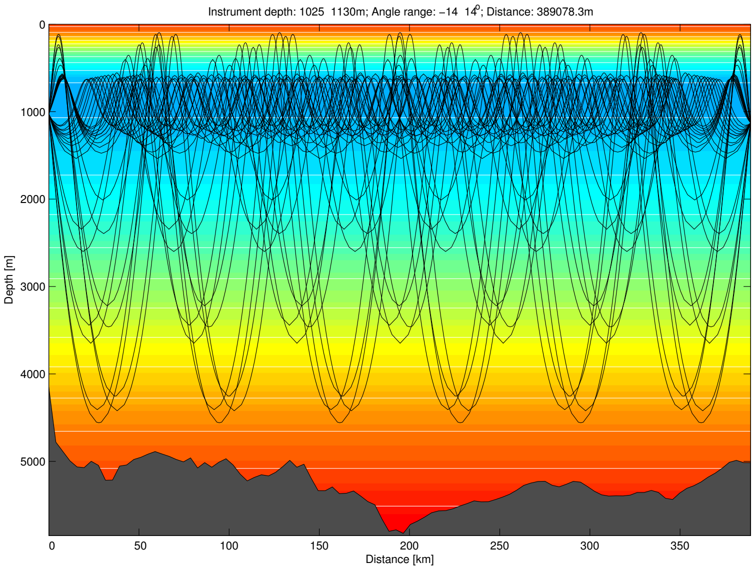


Figure 4.16: Eigenrays between M3.5 and M2 with instruments at 1025 and 1130m.

estimations showed that the noise under the ship was about 20dB higher than in the moored measurement, therefore we expected to be able to record the signal and the suspicion grew that the source had stopped working again. Anyway all of the receiver systems seemed to work correctly. On the same day the receiver was deployed in the mooring M2 and we left for the recovery of the sound source mooring M3.5. This had to be done anyway because the navigator was programmed to make two measurements per hour which would have resulted in a full memory after 6 months. About 30 kilometers before the M3.5 mooring the working boat METEORIT was deployed to listen again to the sound signal with the two small receivers. While the instruments were lowered to approximately 800m depth the ship steamed away to recover the mooring just after the transmission. The instrument on deck again could not be woken up. Measuring the battery power gave a value of 0.3V. This time a faulty connector was the cause for this. However reading out the internal data showed that the source worked fine including the transmission before recovery. Again this happened due to movement shocks, necessitating easy-to-use receivers for testing whether the moored source was still working or not.

Analysing the recorded data on the two mini-disc recorders showed also that the source was working, however estimates of the source level lead to uncertain results. The results showed however, that the receiver with the RAFOS

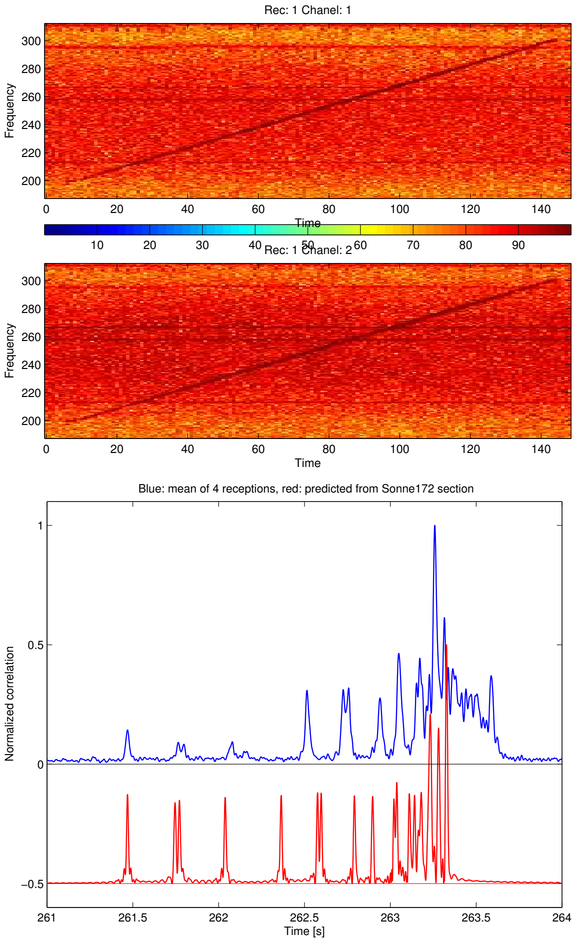


Figure 4.17: Upper panel: Spectrogram of the first record of the sound source reception at M2. The sweep signal from 200Hz to 300Hz in 135s is clearly visible. Lower panel: Normalized mean correlation of all four receptions (blue) together with the theoretically predicted correlation derived from the SONNE 172 CTD section (red, shifted by -0.5).

hydrophone (named *Altoids*) was more appropriate for listening the source. The transponder also received the signal, but it was pervaded with loud hitting noise. After testing the whole electronics of the sound source and another in-water-test at 20m depth, the source was deployed in the M4 mooring. Another listening with the Altoids receiver was carried out at 800m depth and at about 1km distance to the mooring. The Altoids was attached to the winch by a rubber rope of about 3m length. The signal was clearly recorded on the mini-disc and also the noise seemed to be strongly reduced compared to the previous records.

While the ship steamed to the bottom pressure site M7, it stopped again at about 360km distance to the sound source. This time the Altoids was attached to 800m rope which had two Benthos balls, a watch-dog and a radio signal at the top. Directly above the Altoids were two rubber ropes of 1.5m length. The Altoids was deployed from the ship and the ship steamed away about 4nm. After recovery the signal was clearly seen in the spectrum. Also the correlation showed clear arrivals of different rays (Figure 4.18). This time the record level was chosen to be very good, however sometimes it sounded like the two rubber ropes hit each other. The setting on the mini-disc recorder were: hydrophone connected to *Mic In*, record level 14, record mode *mono*.

4.10.1 Atomic clocks

The receiver and the sound source were equipped with *ORCA* atomic clocks. The manufacturer specifies the drift to be less than 10^{-9}. The drift of the source clock could not be measured, because it did not work without power supply, however the drift of the receiver's clock was 35ms in 241days. This corresponds to 1.68×10^{-9}.

4.10.2 Transponder

Six TR6000 transponders for mooring navigation (three at both moorings) were recovered and redeployed. All six instruments were released after their one and a half year deployment. The burning time of the release wire was about 10 min, which is the same as was found one year before after the 6 month deployment. The ascending time was between 60min and 75min. The transponder locations were determined by a survey. See the Table 4.10.2 for transponder positions.

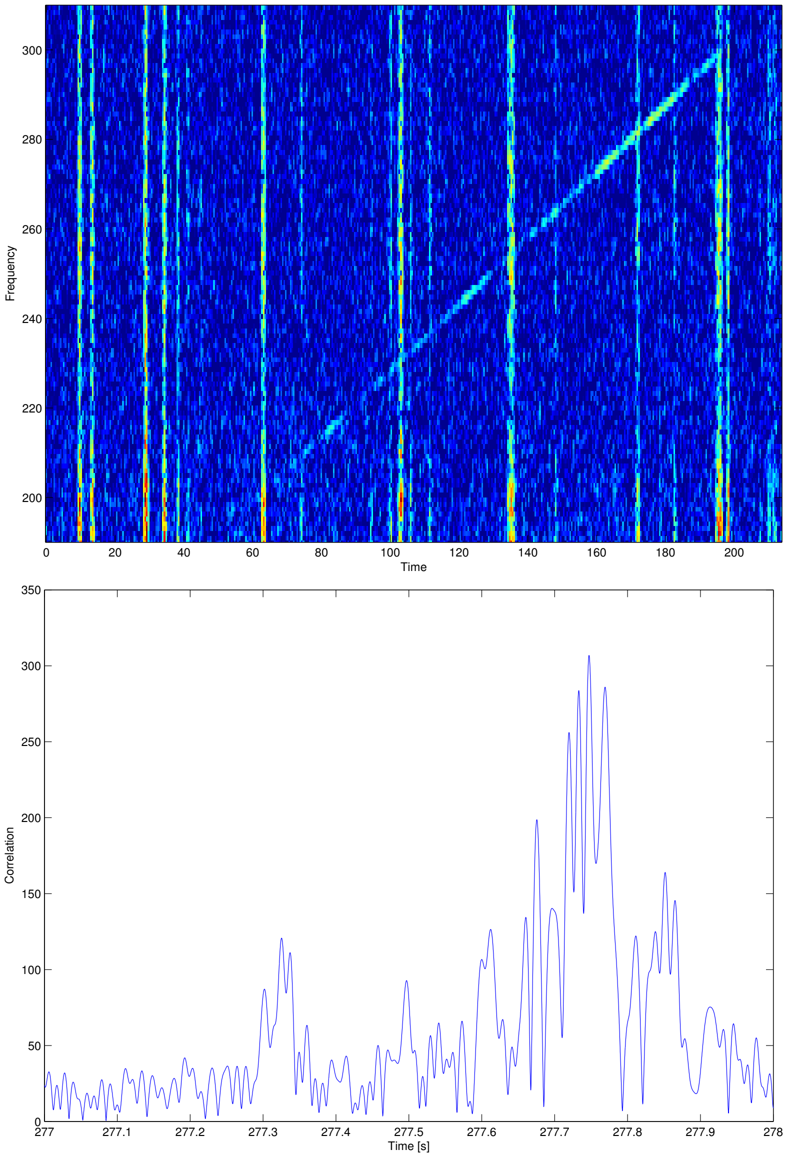


Figure 4.18: Upper panel: Spectrogram of Altoids record 360km away from the sound source. Lower panel: Associated Correlation.

Table 4.9: Location of transponder positions (including error estimates) based on an acoustic survey

		rx [kHz]	tx [kHz]	rel.code	latitude	longitude	depth	error
M2	XP-1	10.0	11.5	A	15°N 58.386	056°W 56.975	4991m	± 6.5m
M2	XP-2	10.0	12.0	D	15°N 58.387	056°W 54.164	4970m	± 7.5m
M2	XP-3	10.0	12.5	F	16°N 00.653	056°W 55.606	4930m	± 6.6m
M4	XP-1	10.0	11.5	A	16°N 19.013	060°W 38.330	2367m	± 6.5m
M4	XP-2	10.0	12.0	B	16°N 19.045	060°W 35.224	3327m	± 3.5m
M4	XP-3	10.0	12.5	F	16°N 21.814	060°W 36.011	3141m	± 5.8m

4.10.3 Altoids Tomography Receiver

The Altoids tomography receiver is a simple receiver used for recording hydrophone data from a Benthos hydrophone to a minidisk recorder. The receiver was built primarily to test the operation of the Webb Research sound source.

The Benthos hydrophone (as used on RAFOS floats) is coupled to the Altoids amplifier through a shielded cable. The amplifier provides 80dB of gain with a band pass between 100 - 500 Hz. A pair of 9-volt batteries serves as continuous power supply for up to 2000 hours. The amplified output terminates with a 3.5mm phone connector. The phone connector plugs into the standard input jack of a minidisk recorder. With the recorder set to mono mode, 138 minutes of recording time is available. After a recording is made, playback into a computer's microphone input to capture the recording to a .WAV file. The .WAV file can then be read into Matlab for analysis.

Testing of Altoids has shown that ship generated noise in the water is the most serious problem encountered. Deployment from a small boat or float mooring and moving the ship away from the receiver solves the noise problem. The second source of noise is surface noise. Lowering Altoids to a depth of about 1000 meters provides a quiet environment for the receiver. Empirical testing with the minidisk recorder has shown that using the microphone input with the input level set to a value of 14 works best.

4.10.4 Self noise estimation on the SeaScan-ERATO R10 and the Altoids receiver

The self noise of both receivers were measured by Andreas Pinck and Rudolf Link by a shortcut through the input pins of the amplifier. The measured voltage at the amplifier's output was assumed to be the noise produced by the amplifier itself. Both amplifiers were stored in their metal HF-shieldings to prevent noise due to electro-magnetic-smog on the ship. The Altoids amplifier still showed some 50Hz output which must have originated from radiation outside the amplifier. This 50Hz signal was subtracted from the measurement. The voltage read at the oscilloscope was about 5mV peak to peak at the Altoids and 30mV at the ERATO system. The gain of the Altoids is fixed to 80dB where the measurement on the ERATO was made at 104dB (18dB+56dB+80*.375dB). Converting the 30mV reading to a gain of 80dB gives:

$$30mV/10^{\frac{104-80}{20}} = 1.9mV \tag{4.1}$$

Further more the peak to peak voltage needs to be converted to an effective voltage to make it comparable with other noise measurements on this cruise:

$$Altoids@80dB : 5mV/2 * \frac{1}{\sqrt{2}} = 1.75mV \tag{4.2}$$

$$ERATO@80dB : 1.9mV/2 * \frac{1}{\sqrt{2}} = 0.65mV \tag{4.3}$$

According to this measurement, the ERATO system would produce about 3 times less noise than the Altoids system.

4.10.5 Noise estimation on the SeaScan-ERATO R06 receiver

The 250Hz noise level in the ocean can be estimated on a SeaScan-ERATO receiver by the following formula:

$$NL1 = -SH - DI + Vrms \tag{4.4}$$

where SH is the sensitivity of a single hydrophone (SH = -202dB) and DI the directivity of hydrophone (DI = 6dB). Vrms is the root-mean-square voltage output of the hydrophone during the noise measurement of the receiver converted to dB. It can be calculated from receiver's data by:

$$Vrms = 20 * log10(RMS * Q) - Gp - Gf - GAIN * .375 \tag{4.5}$$

where RMS is the rms noise value saved by the receiver. Q is 1.22/1000 according to AD Conversion 13bits ref 5V ($2 * 5/2^{13} = 1.22mV$), Gp = 56 due to fixed gain preamplifier, Gf = 18 due to band-pass filter and GAIN the value of the auto adjusting amplifier which is also saved by the receiver.

Using the last few receptions from the moored receiver R06 (M2), when the signal of the sweep sound source in M3.5 had been successfully received, lead to noise estimates between 82 to 83dB on channel 1 and 75 to 79dB on channel 2. When the same receiver was lowered directly from the ship to 1000m depth the noise level was 100dB on channel 1 and 85dB on channel 2. Systematically higher noise levels on channel 1 seemed to be a problem caused by the receiver, however the noise on both channels was much higher during the lowered measurements. Reasons for that could be the noise of the ship (even though we tried to power down many noise sources in the ship) and the up and down movement of the receiver in the water due to high waves at the surface.

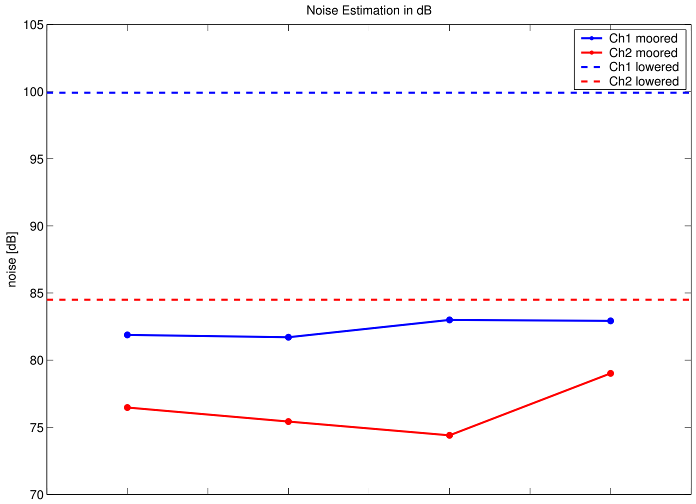


Figure 4.19: Noise Level during moored and lowered receptions.

4.10.6 Source level estimation from the moored SeaScan-ERATO R06 system

The Source Level SL of the sound source can be estimated from the record of the receiver moored 400km away from the source. Basically the following formula was used:

$$SL = SNR + NL + 20 \times log10(r) + a \times r/1000 - Gc \tag{4.6}$$

where SNR is the Signal to Noise Ratio, NL the Noise Level, $20 \times log10(r)$ loss due to distance, $a \times r/1000$ attenuation and Gc gain due to correlation. The SNR was calculated through the correlated data, therefore the Gc has to be subtracted. NL was already calculated in the previous section. The distance r was 383897 m. Additional formulas are:

$$SNR = 20 \times log10(\frac{corr_{ray}}{corr_{noise}}) \tag{4.7}$$

$$Gc = 10 \times log10(B \times T) \tag{4.8}$$

$$a = 0.115 \times 10^{-3} \times (\frac{0.435 \times f^2}{0.64 + f^2} + \frac{36 \times f^2}{5000 + f^2}) \tag{4.9}$$

where $corr_{ray}$ is the value of the correlation of a single ray and $corr_{noise}$ the rms value of noise in the correlation. B is the bandwidth ($100Hz$) and T the duration ($135s$) of the signal. So the attenuation coefficient a for $250Hz$ is 0.036, NL was found to be $82-83dB$ on channel 1 and $75-79dB$ on channel 2. The SNR was calculated with the -13 ray. It seemed that the earlier ray had more attenuation due to small structures in the surface layer or possible reflections at the sea surface. Unfortunately the -13 ray was rather weak in the last record, therefore it was not used in this calculation. The SNR varied from $23-28$ dB on both channels which gave a Source Level of $183-189$ dB on channel 1 and $189-194$ dB on channel 2 (Figure 4.20).

4.10.7 Modified tomography receiver R10 test on 20/21.02.2004

The SeaScan receiver R10 was modified to be able to receive the 200-300Hz sweep signal. The filters were changed and the buffer size increased to 1MB by its manufacturer. Set up this way a task was run in the laboratory on the SYS01 system. The other components were: SS16, CK30, INT16, HYD03, Sharp MiniDisc SN:90212663 and Hi-Tex LX-38 stereo speakers. The signal was simulated by the MD-Player with its speakers lying on the hydrophone. The volume was turned to maximum on the recorder and to 1/4 at the speaker's amplifier. The task was:

```
120 Par
```

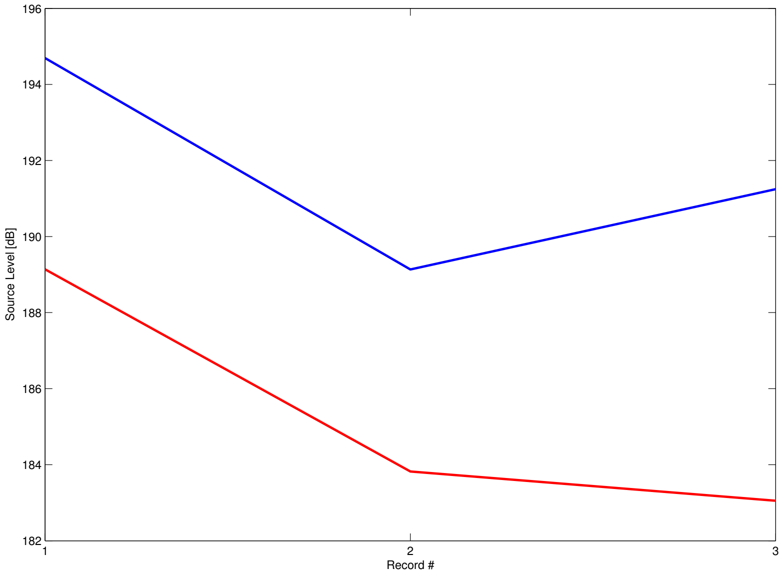


Figure 4.20: Source Level during moored receptions, red channel 1, blue channel 2.

```
    240 Nav 2
    295 Rx 0 0 18750
```

```
Start time  : 19.02.2004 20:20:00 UTC
End time    : 20.02.2004 18:00:00 UTC
Periodicity : 10min
```

Over all, the system received 129 times the signal from the MD-Player and made 258 navigations as expected. During the first record, the MD-Player was not switched on yet, however all other records showed a proper signal in spectrum and correlation and were properly saved on the instrument's hard disk.

4.10.8 Power consumption of Sweep Sound Source

```
Basic values

Standby current     :       1.5mA                   1.5mAh
Clock recalibration :   ca. 1.2A for 12min          0.24Ah
Transmission        :       3.0A for 140sec         0.1167Ah
```

```
For one year:

Standby                                             13.14Ah
Clock recalibration interval 24h                   87.6Ah
Overall consumption without transmission           100.74Ah

Battery pack 45V - 22 slices (11Ah each)            232Ah
Capacity for transmission:                         131.26Ah

Maximum of transmissions:                         1125 = 3 per day
```

4.10.9 12.0kHz PIES#002 received @ navigation of tomography receiver in mooring M2

Mooring navigations of four measurements in group have been repeated every 6 hours on following times: 0:15:00, 0:25:00, 0:35:00, 0:45:00, 0:55:00, 1:55:00, 2:55:00, 3:55:00, 4:55:00, 5:15:00. The 4 navigations were carried out in a 13s interval.

The PIES deployed near M2 was supposed to do its acoustical travel time measurement every 10 minutes starting at 00:00:00. However on the 14 November 2003 at 12:25:52 it was first seen in the navigation data. It was continuously detected earlier in the navigation data, suggesting a constant clock drift of the PIES. The clock drift was estimated to be 3.078s per day (running too fast). The clock was already drifted 253 seconds (12:30:00-12:30:52 and assuming 5s of travel time between PIES and navigator) when it was first seen in the data. 253/3.086 = 81.9 suggest that the clock started to drift 82 days before the 13 November 2003, which is the 24 June 2003 and one day before its deployment. On the 17 October 2003 the PIES was last seen in the navigation data, suggesting that the time between his first and last ping of a single measurement was 50s. It can be ruled out that the received signal was the *RELEASE* signal of the PIES. Most likely it was its usual travel time measurement with 4 ping 16.5s apart. This is also supported by the interval structure of the receptions in the navigation data (Fig. 4.21).

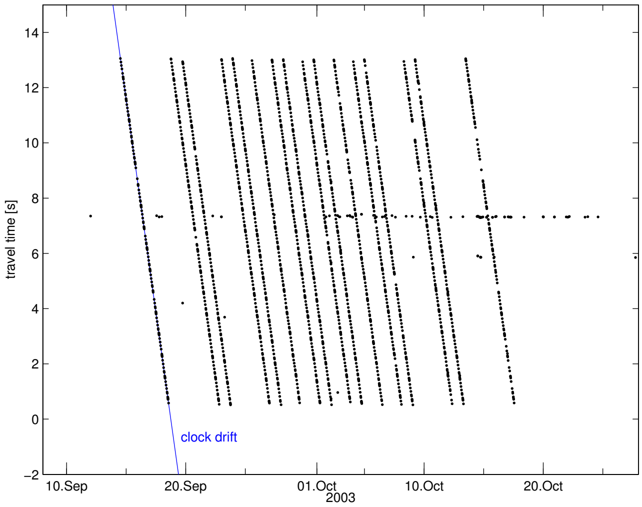


Figure 4.21: Navigation data for the 12.0kHz signal.

4.10.10 Tasks

The sound source was programmed to transmit two times a day the 200-300Hz and 135s long sweep signal. The transmission times are 05:54:52 and 17:54:52 UTC. Clock recalibrations were set to 24:00:00 UTC with one day period. Also the receiver was programmed to listen two times a day for 150s. The schedule is 05:59:10 and 17:59:10 UTC. The clock in the receiver is recalibrating at 17:00:00 UTC with a one day period.

Navigations of the sound source mooring were started to navigate at 01:40:00 and 02:10:00 UTC with a period of 2 hours. The navigations of the receiver were set to 05:45:00, 05:55:00, 06:05:00 and 06:15:00 UTC. The period here is 6 hours.

Sound source task

```
Start day = 426, Period0 = 1 days, Period1 = 1 days
Number of tasks = 2
Task Hour Minutes Seconds
0  5  54  52
0  17  54  52
```

Receiver task

```
Navigation Task after 17:00 Calibr.

 0424:12:20:00          StartTime
 0424:16:00:00          StopTime
 0000:00:10:00          Periodicity

   600 Nav 4                                   0:10:00


Receive Task, M2 Move Experiment

 0424:17:30:00          StartTime
 1154:17:30:00          StopTime
 0000:12:00:00          Periodicity

   900 Nav 4                                   0:15:00
  1200 Par                                     0:20:00
  1500 Nav 4                                   0:25:00
  1750 Rx  0  0  18750                         0:29:10 SS@ 0:24:56 (54:56)
  2100 Nav 4                                   0:35:00
  2400 Par                                     0:40:00
  2700 Nav 4                                   0:45:00
```

M4 mooring navigator #I4 task

```
 Start on day = 426  hour = 23  minute = 40
 Measurement interval,  minutes = 120
 Scheduler is ARMED BUT NOT ACTIVE
```

M4 mooring navigator #I6 task

```
 Start on day = 427  hour = 02  minute = 10
 Measurement interval,  minutes = 120
 Scheduler is ARMED BUT NOT ACTIVE
```

4.11 DVS data (J. Karstensen)

Underway data was collected by a number of sensors and distributed via the DVS (Datenverteilungssystem). Data was recorded every ten seconds stored on hard disc and later a DVD was created from the data. A subset of all parameters – those often required for supporting analysis – was extracted from the original files and written into a MatLab *.mat structure 'dvs'. No interpolation in time was performed. The following variables are available:

```
%         dvs.jul     Julian Days [days]
%         dvs.lat     Latitude    [decimal degrees]
%         dvs.lon     Longitude   [decimal degrees]
%         dvs.cog     Course over Ground [degrees]
%         dvs.sog     Speed over Ground  [m/s]
%         dvs.dep     Hydrosweep Depth   [m]
%         dvs.tws     True Wind Speed    [m/s]
%         dvs.twd     True Wind Direction [degrees]
%         dvs.rws     Relative Wind Speed [m/s]
%         dvs.rwd     Relative Wind Direction [degrees]
%         dvs.ate     Air Temperature  [degrees C]
%         dvs.hum     Humidity  [%]
%         dvs.apr     Air Pressure  [hPa]
%         dvs.tem     Temperature [degrees C]
%         dvs.sal     Salinity
```

4.11.1 Measured variables

Overall there was no suspicious data. The Thermosalinograph (TSG) did not record data during some hours on the 22. February due to problems in restarting the device after a total power outage. The meteorological system was serviced from a representative of the DWD (Deutscher Wetterdienst) during the cruise and can be considered as high quality. TSG sample 1.5 m below surface and is a SBE21 device. The meteorological sensors are installed at the following height (all above NN): wind at 40.1 m, air pressure at 10.6 m, humidity 28.3 m, air temperature at 28.3 m, water temperature (PT100, other than TSG) at 2.1 m depth, radiation at 40.5 m.

By analyzing TSG samples with the salinometer, M. Lankhorst determined a too high salinity of the TSG and proposed a correction:

$$salinity_{true} = salinity_{TSG,measured} - 0.08$$

The overall meteorological conditions during the cruise where not exceptional (Figure 4.23 to 4.22) and typical for the region with westward trade wind. Air and surface water temperature decreased towards the open Atlantic, while salinity increased. In particular at the eastern most position there was a drop in temperature and an increase in salinity with accompanying high surface water density. There was always a high pressure system with daily modulation. The radiation variables show the typical daily variations. Only a few daytime drops in short-wave radiation can be seen as a result of a few clouds.

4.11.2 Derived variables

Another set of variables was derived from the aforementioned: surface density, sensible and latent heat flux, wind stress. The heat fluxes are derived using the Fairall et al. (1996) parameterizations, the wind stress is based on the Smith (1988) algorithm. Surface density was high at the easternmost part of the section as very saline (and colder) water was found here. The sensible heat flux was always negative (ocean loses heat) as surface water was warmer than air temperature. Latent heat was high and typical for the evaporative trade wind region.

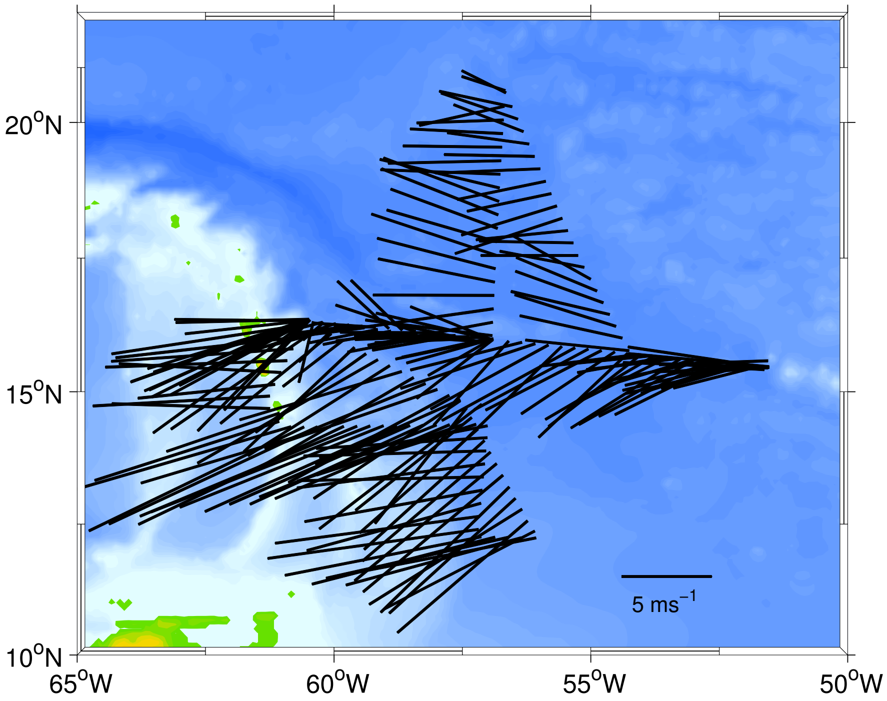


Figure 4.22: Wind vectors during the M60/4 cruise.

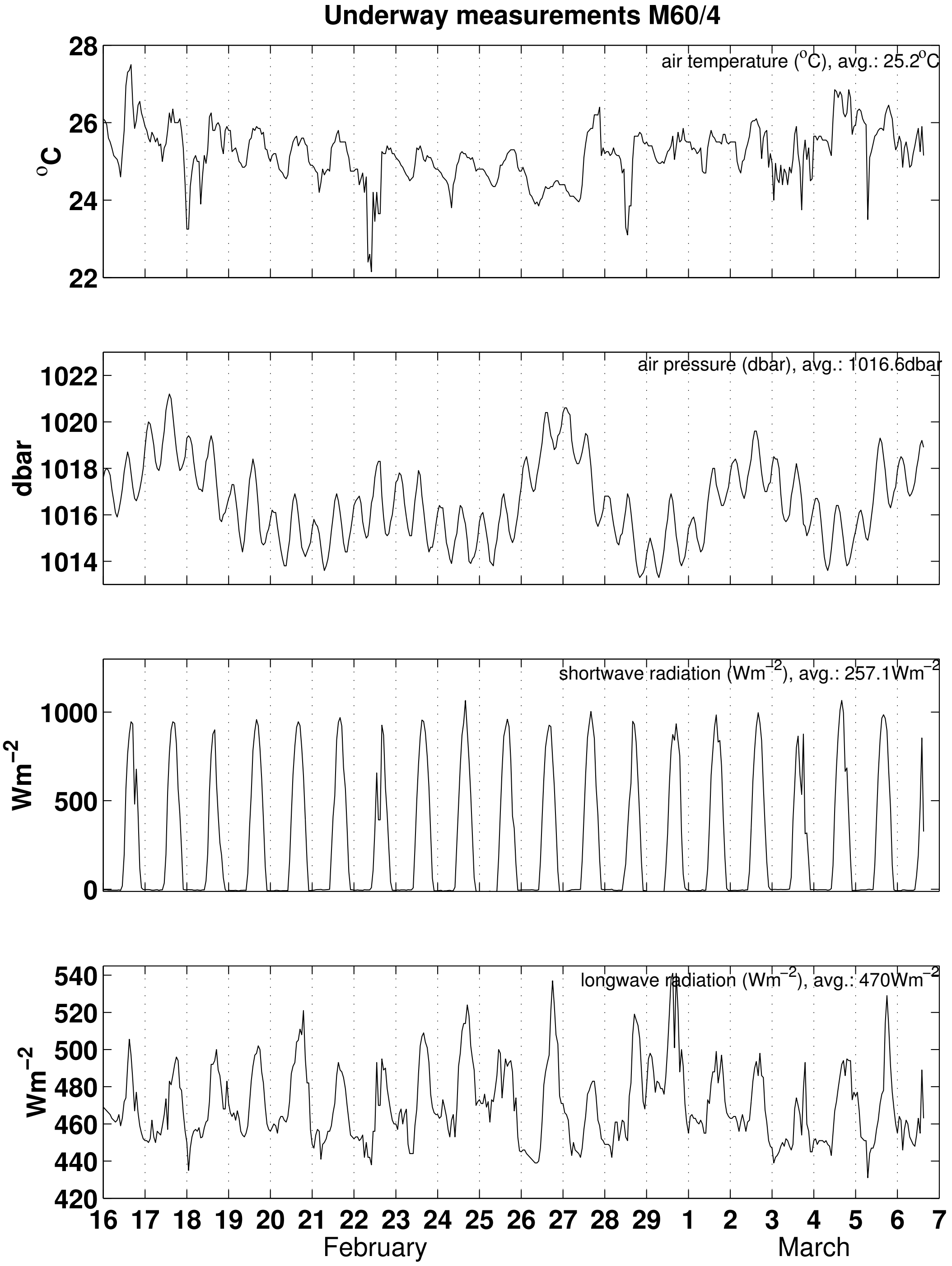


Figure 4.23: Underway measurements collected via the DVS system and interpolated through full hour values. From top to bottom: Air temperature, air pressure, short-wave radiation, long-wave radiation.

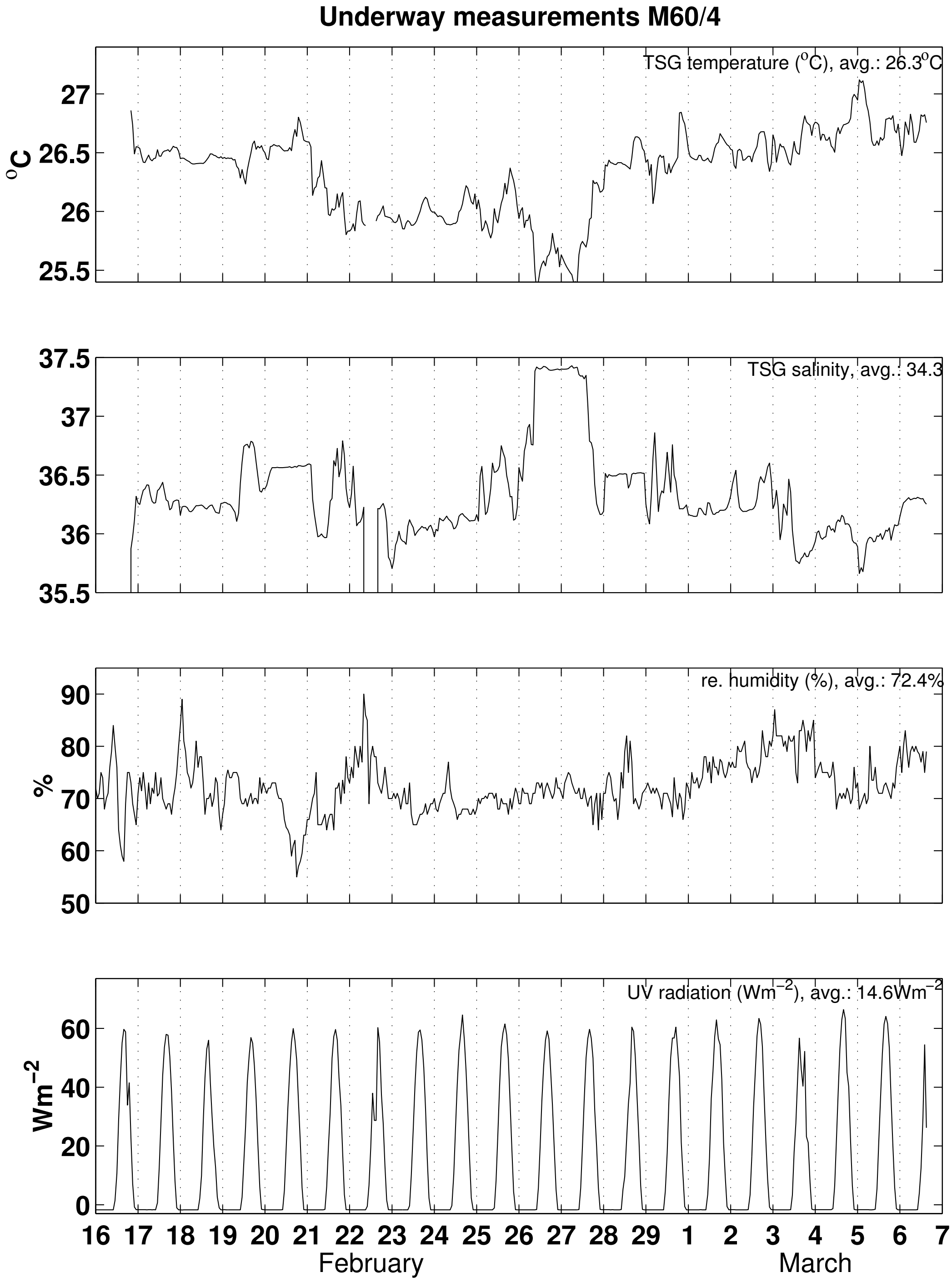


Figure 4.24: Underway measurements collected via the DVS system and interpolated through full hour values. From top to bottom: TSG temperature, TSG salinity (uncorrected), relative humidity, ultraviolet radiation.

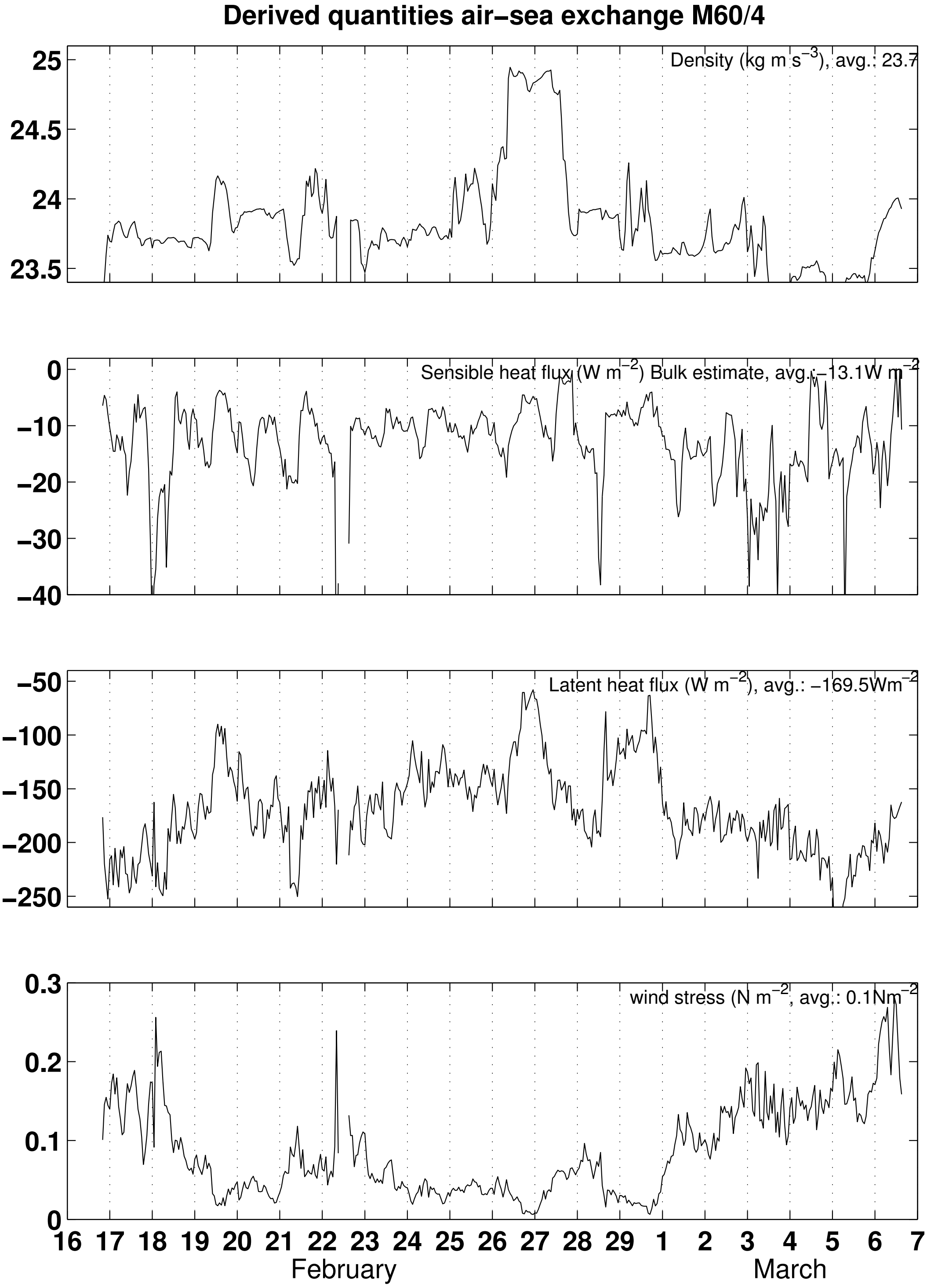


Figure 4.25: Derived quantities from the DVS data - value for every full hour is shown. From top to bottom: water density (derived from TSG temperature and salinity), sensible heat flux, latent heat flux, wind stress

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