

## **METEOR Cruise 41, Leg 3**

**Vitória - Salvador  
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Cruise Report of the  
Physical Oceanography Group on Board

by

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### **5 Preliminary Results**

#### **5.3 Marine Geoscience M41/3**

##### **5.3.1 Physical Oceanography**

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### **Introduction**

The World Ocean Circulation Experiment (WOCE) will terminate its observational phase by the end of 1998. This unique oceanographic campaign compassed planning, implementation and coordination of a global network of hydrographic observations and now aims at extensive modeling studies during its analysis, interpretation and synthesis phase in the years to come. The hydrographic work during M41/3 was part of the Deep Basin Experiment (HOGG et al., 1996), a subprogram in Core Project 3 of WOCE. Furthermore, the physical oceanography group on board assisted to collect water samples for other parties on the METEOR, including supplements to the WOCE Hydrographic Program (WHP) tracer network.

The equatorward flow of Antarctic Bottom Water (AABW) in the South Atlantic is part of the global thermohaline circulation, jointly with fluxes of Antarctic Intermediate Water (AAIW) and North Atlantic Deep Water (NADW). The Rio Grande Rise at a nominal latitude of 30° S represents a natural barrier for the spreading of Antarctic Bottom Water between the Argentine and the Brazil Basin. It is intersected by two deep channels: The Vema Channel (originally called Rio Grande Gap) and the Hunter Channel (ZENK et al., 1993; ZENK et al., 1998). Estimates based on geostrophy and results from moored current meters have demonstrated that more than half of the bottom water export between the two neighboring basins is achieved through the deep Vema Channel (SPEER & ZENK, 1993; HOGG et al., 1998). According to these long-term observations the total northward transport of

Antarctic Bottom Water amounts to  $6.9 \times 10^6 \text{m}^3 \text{s}^{-1}$ . The contribution of the Hunter Channel ( $2.3 \times 10^6 \text{m}^3 \text{s}^{-1}$ ) is not insignificant (ZENK et al., 1998) but was beyond the scope of this cruise.

At a number of locations, WOCE observations have demonstrated a tendency towards increasing bottom water temperatures. In fact, a systematic temperature increase of 30 mK was observed by the METEOR in the Vema Channel near the sill between January 1991 and December 1992. Comparable changes of bottom water properties were never observed before in the Vema Channel since the availability of the first highly accurate CTD records in 1972. The trend towards higher bottom water temperatures has also been documented in comparable, yet unpublished WOCE observations of Brazilian and English groups. According to the latest visit in spring of 1996 the upward trend appeared to be stopped, however, at the end of our cruise we had to revise this view.

During M41/3 the physical oceanography group aimed at a new survey of the bottom water properties and distribution by (i) starting a long-term record of variability of water mass characteristics at the sill of the Vema Channel with moored instruments and (ii) enlarging the set of highly accurate hydrographic data during cruises. The latter is also expected to serve as an improved input for modeling efforts. Monitoring of bottom water properties will provide more insight into its fluctuations which for a long time have been assumed to be negligible.

### **Methods, data acquisition and reduction**

A number of observational tools were applied during the cruise. The backbone for hydrographic observations was a CTD (conductivity, temperature, depth (pressure)) recorder in combination with a rosette sampler carrying 21 bottles. An inventory of all CTD stations is given in Tab.X1. Locations of CTD stations are displayed in Figs.X1 and X2. The bottle set was used on 25 stations yielding over 500 water samples. Because of the application of a lowered Acoustic Doppler Profiler (IADCP), to be described later, we used no mechanical bottom finder. Instead, bottom approaches were monitored by a pinger.

Our CTD system (Neil Brown MKIIB, IfM no. NB3) was provided by the IfM based *Zentrallabor für Meßtechnik*, a German WOCE unit maintaining high quality instruments including their reliable calibration. The CTD probe was last calibrated in temperature immediately prior to cruise M41/3 on 11/12 March 1998. A post-cruise calibration was performed in summer 1998.

We made every effort to calibrate all CTD stations while still on board. 42 salinity twin samples, a subtotal of all the rosette samples, were analyzed by an Autosal salinometer (IfM no AS6). For standardizing we used batch No P129. The resulting 21 pairs of check values were systematically taken from the deepest part of the profiles, i.e. about 25 m above the ground (near-bottom, NB), and from the mixed layer (ML) at the 10 m level. The inter-twin standard deviations of salinity amount to  $\pm\{0.0009, 0.0019, 0.0015\}$  for  $\{\text{NB, ML, all}\}$  levels. Comparable sampling noise during the CTD data acquisition at constant depth while firing bottles is of a similar

order  $\pm\{0.0007, 0.0027, 0.0017\}$ . Quasi-time series of salinity corrections are shown in Fig.X3. Mean salinity corrections for {NB, ML, all} levels ( $\{+1.8, +9.3, +5.5\} \times 10^{-3}$ ) are included. No systematic calibration drift could be recognized. Fig.X4 contains corrections as a function of salinity readings. Here, we found a dependence on salinity (conductivity) which needs to be considered in the final calibration. Assuming all ML values taken at the surface, all NB values sampled at 4000 dbar and salinity decreasing linearly with pressure  $P_{CTD}$  we can infer a crude preliminary correction for raw salinities  $S_{CTD}$ :

$$S_{corrected} = S_{CTD} + (B \times P_{CTD} + A) \quad (1)$$

with  $B = -1.85 \times 10^{-6} \text{ dbar}^{-1}$  and  $A = 9.2 \times 10^{-3}$ . In the following text and figures (with the exception of Appendix 1) no salinity correction is applied in this report. Since corrections are relatively tiny, they would not be recognizable in the majority of the salinity graphs shown in this document. Final salinity values are subject to a more careful post-cruise CTD calibration.

Lists of all CTD casts with observed *in situ* temperatures, potential temperatures and salinities at standard depth/pressure values are given in Annex X1. Here, preliminary salinity corrections according to (1) have been taken into account.

The latest version of the processing and data reduction software package CTDOk, administered by Thomas Müller of IfM, was used on a Personal Computer. The processing includes the following sequential software modules: Inspection and graphic editing by hand, maximum lowering speed check to detect pressure spikes, dynamic pressure correction, despiking by a median argument, monotonizing with respect to pressure, minimum lowering speed check, low pass filter run with 19 weights, pre-cruise fine-tune calibration, static pressure-offset correction, interpolation on 2 dbar steps and storage for plotting and export in MATLAB binary files (\*.mat).

During earlier WOCE cruises the same CTD probe was used repeatedly in the Vema Channel and for WHP section work. According to our earlier experiences and after the application of all corrections and the post-cruise calibration, an absolute accuracy of better  $\pm 2 \text{ mK}$  in temperature,  $\pm 0.003$  practical salinity units (PSU), and  $\pm 3 \text{ dbar}$  in pressure can be expected.

The refurbished on-track observational system DVS of the METEOR was used to collect quasi-continuous near-surface temperature from two sensors of the ship's meteorological station. It was found that the portside thermometer reading lies systematically  $\{0.149 \pm 0.050\} \text{ K}$  below the starboard thermometer of the ship (Fig.X5). Both sensors are mounted 4 m below the surface. An *ad-hoc* comparison with CTD data from the surface (according to Tab.X1) indicates the portside DVS temperature to be systematically lower by  $0.3 \text{ K}$  (see Fig.11b).

Between 21 April and 5 May we collected 34 twin water samples for a calibration check of the ship's thermosalinograph which data also are fed to the DVS system.

From the resulting 17 salinity check values we inferred a calibration equation that is valid for April / May 1998:

$$S_{\text{corrected}} = D \times S_{\text{ThermosalinographDisplay}} + C \quad (2)$$

with  $D = 1.0054$  and  $C = -0.0211$ . Four samples of these were collected on passage. Although the latter are supposed to be of slightly lower quality, all samples were equally treated by the indicated least square linear fit (Fig.X6).

Preliminary depth profiles for sections were exported from the *DVS* data bank as well. Due to varying numbers of outliers, depth values were clipped by plausible extrema and subsequently low pass filtered.

Until Sta. 229, the CTD/rosette sampler was supplemented by a *lowered* broadband Acoustic Doppler Current Profiler (BB IADCP) which was kindly provided by Jürgen Fischer from IfM Kiel. We expect the obtained vertical current profiles to deliver valuable information on shear as an indicator for enhanced mixing in the benthic boundary layer of the Vema Channel and its northward extension. Due to a technical problem the last IADCP station (no 229) failed to deliver currents. After successful repair, the instrument was not remounted on the rosette sampler. The IADCP log is given in Tab.X4.

In addition to the well known problem of the near bottom interference layer, our IADCP measurements suffered from a lack of scattering particles in the intermediate depth ranges of this 'blue water' environment. The dramatic decrease of the received signal amplitude can be seen in the vertical profile of target strength (Fig.X7a, profile 212) below 1000 m. However, the signal strength recovers over the deepest 600 m of the profile, apparently owing to an increase of sediment particle concentration on the Vema Sill.

Fig.X7b depicts the raw vertical velocity component (bin 3) over the total duration of the cast. The lowering speeds of  $1 \text{ ms}^{-1}$  during downtrace and  $1.2 \text{ ms}^{-1}$  during uptrace are generally recovered. However, there is a large data gap between, say, ensemble 700 and 1100 (the bottom-nearest point was approached around ensemble 1300). During uptrace a similar behavior is observed and there are additional periods of near-zero vertical velocities during water sampling stops. These data gaps are also visible in the raw data northward velocity component (Fig.X7c). Near the bottom (around ensemble 1300) the (earth) velocities are predominantly northwards as expected in the deep trough of the Vema Channel.

The standard procedure to derive relative velocities is to differentiate individual IADCP profiles vertically, then to average overlapping profiles in depth cells and integrate the resulting mean shear profile from a reference level (FISCHER & VISBECK, 1993).

The IADCP is a self-contained instrument without pressure sensor. Its depth is determined by integrating the measured vertical velocity in time. The large data gaps prevented us from calculating reference velocities from time integrals of the baroclinic velocities by our software package so that the data require additional

post-cruise processing. (The set of processing programs had been kindly provided by J Fischer.)

Relative northward velocities (referenced to the deepest point at 4362 m) are displayed for the deep part of the profile in Fig.X7d (downtrace), and X7e (uptrace). Northward velocities show maximum values between 100 to 200 m above the bottom. They are consistent with earlier findings from moored current meters in the Vema Channel and from numerical modeling. This nose shaped velocity profile with pronounced shear layers above and below the maximum is typical for bottom boundary currents (MERCIER & SPEER 1997; ZENK et al., 1998).

The *vessel mounted* Acoustic Doppler Current Profiler (VM ADCP) operated routinely. It covered approximately the upper 250 m layer. Unfortunately its data flow is still not yet integrated by the ship's own DVS data bank.

For topographic surveys we used the multi-beam echosounder Hydrosweep of the METEOR. In the subsequent data processing we were kindly supported by the ship's system operator V. Gebhardt. Of special interest were details of the topography of the Vema Sill where IfM mooring V389 was deployed (see Tab.X2, Fig.X8). This area had already been surveyed with Hydrosweep in 1991 during METEOR cruise 15. Fig.X9 shows blow-ups on identical scales of both independent observations from the eastern side of the Vema Sill. They were obtained with the same hardware but with significantly different Hydromap software versions. As expected, both maps agree excellently in region with steep topography. In fact, the slope of the shown eastern wall can exceed 25 %. Less agreement in the details can be found on the ground plateau with its minimal slopes. Inaccuracies in depth estimates can shift isobaths horizontally by a few kilometers.

At the beginning of the cruise, on Sta. 209 we deployed a current meter mooring (IfM no V389) on the sill of the Vema Channel. Logistical and operational details are given in Fig.X8 and Tab.X2. The current meter rig is designed for a two-year record of temperature and speed fluctuations. The moored CTD recorder (MicroCat by Sea Bird, Inc.) has a sampling capacity of over three years. The start of a long-term record of temperature variability of Antarctic Bottom Water with great accuracy was a major goal of the physical oceanography group on board.

### **Hydrographic conditions in the central South Atlantic**

Here we discuss the water mass stratification on two orthogonal sections at 9° W and 24° S. We assume the involved selection of hydrographic stations to be representative for the central subtropical South Atlantic. The sections (see Fig.X1) are short in comparison with the WHP network (SIEDLER et al., 1996). Related WOCE sections A9 and A14 are located on 19° S and 9° W. They were occupied in 1991 and 1995 by METEOR (M15) (SIEDLER & ZENK, 1992) and the French research vessel L'ATALANTE.

For the general descriptions of distinctive water masses we depict their characteristic potential temperature salinity ( $\theta/S$ ) properties in Fig.X10. For this purpose we have plotted all interpolated ( $\sigma_t = 2$  dbar) CTD data from the two sections in one diagram.

Tropical surface water (TW) with  $\theta > 20^\circ\text{C}$  at the top of Fig.X10 shows a tendency to split. Colder, more fresher water was encountered on and to the East of the Middle Atlantic Ridge in the Angola Basin. Its counter part with warmer and saltier surface conditions in the Brazil Basin can be better recognized in Fig.X11. This figure shows the near-surface T/S record from the thermosalinograph ( $\tau = 10$  min) on four sections. The higher variability in T/S in the western (Fig.X11b) and the southern (Fig. X11a) regions reflects a number of fronts, more frequently encountered in the open Brazil Basin than in the Angola Basin (Fig.X11b). The frontal structure of surface parameters appears caused by the Brazil Current Front (BCF) as part of the inner recirculation in the Brazil Basin.

The colder surface waters ( $\theta < 25^\circ\text{C}$ ) on  $9^\circ\text{W}$  and on its cross point with the  $24^\circ\text{S}$  section can be interpreted as a signal of the far reaching Benguela Current southwest of the Benguela Angola Front (Fig.X12). Densities, i.e.  $\sigma_t$  values, at the surface of the central South Atlantic of  $\{(24.3 - 24.5), (24.7 - 24.9)\} \text{ kg m}^{-3}$  are typical ranges for the {Brazil, Angola} Current regime in May 1998. Here we note that two subtropical surface water types are separated by a line west of the Middle Atlantic Ridge. The crest region itself has the same T/S properties as the eastern side of the Ridge.

We return to the CTD derived  $\theta/S$  diagram in Fig.X10. At temperatures between approximately  $10^\circ$  and  $16^\circ\text{C}$  we find a tight  $\theta/S$  relation which in our case is characteristic for South Atlantic Central Water (SACW) of the main thermocline. Farther down in the water column it is replaced by Antarctic Intermediate Water (AAIW) with its salinity low at  $< 34.5$  (BOEBEL et al., 1997). The next salinity extremum ( $> 34.86$ ) belongs to the North Atlantic Deep Water (NADW) (ZANGENBERG & SIEDLER, 1998). After crossing the equator it erodes Circumpolar Deep Water (CDW) splitting this lower saline water mass into an upper CDW and a lower CDW type (REID et al., 1977). Towards the West of our  $24^\circ\text{S}$  section the deepest part of the water column ( $\theta < 2.0^\circ\text{C}$ ) is occupied by the Antarctic Bottom Water (AABW) (SPEER & ZENK, 1993). Its properties will be discussed in more details in the next paragraph on observations in the Vema Channel.

Our presentation of the water mass structure in the  $\theta/S$  diagram (Fig.X10) is paralleled by figures of vertical sections of potential temperature ( $\theta$ ) and salinity (S) from the adjunct sections on  $9^\circ\text{W}$  and  $24^\circ\text{S}$  (Fig.X13, X14). The low saline tongue of Intermediate Water at 750 m remains unchanged at  $S_{\min} 34.40$  on the zonal section (Fig.X14) while we recognize a well expressed meridional gradient with equatorward increasing salinities on the meridional section (Fig.X13).

The thick tongue of North Atlantic Deep Water ( $S > 34.90$ ) appears to be blocked by the topography of the Middle Atlantic Ridge (Fig.X14). However, at the northern side

of the 9° W section we cut through a salty tongue of Deep Water ( $S > 34.90$ ) which we interpret as being deflected eastwards across the Ridge into the Angola Basin by the change of its potential vorticity in the presence of the zonal Vitoria Trindade Ridge a 19°S (ZANGENBERG & SIEDLER, 1998) and being one source of the Namib Col current (SPEER et al., 1995).

Farther South we have traversed the deep Rio de Janeiro Fracture Zone at 23.7° S. It allows lower Circumpolar Deep Water with  $2.0^{\circ}$  C to be exchanged across the Ridge. Its role in the deep circulation of the Angola Basin remains unclear and deserves further efforts. As expected in the Angola Basin, we nowhere found a distinct near-bottom temperature step in vertical profiles as they were seen so clearly in the Brazil Basin. This observation agrees with the known absence of Antarctic Bottom Water in the Angola Basin (SIEDLER et al., 1996).

### **Flow of Antarctic Bottom Water through the Vema Channel**

The Vema Channel represents the deepest conduit for bottom water of the Rio Grande Rise (HOGG et al., 1982). According to our newest bathymetric survey (Fig. X9b) its depth varies between 4620 and 4640 m. Its northern extension can easily be followed by tracking the 4000 m isobath on the digital topographic map by SMITH & SANDWELL (1997) displayed in Fig.X15.

We have included positions of the two hydrographic sections: 'Vema Channel' (VC) across the Vema Sill and the section 'Vema Extension' (VE) at the northeastern corner. Both sections are shown on different horizontal scales (section VC in Fig.X16, section VE in Fig.X17). Mooring V389 that was deployed 21 May 1998 (Fig.X8; Tab.X2) lies 4 km upstream between CTD Sta 210 and 211 (Fig.X16). Its projection can be seen in the temperature sections of Fig.X16. Results from the self-recording instruments are not expected before the year 2000.

Water masses found in the Vema Channel (SPEER & ZENK, 1993) resemble those described in the last paragraph for the central South Atlantic. They are stacked in the well known fashion from the top to the bottom: Tropical surface Water and South Atlantic Central Water of the main thermocline, low saline Antarctic Intermediate Water at 900 m, upper and lower Circumpolar Deep Water penetrated by more saline North Atlantic Deep Water (1500 - 3500 m) and closest to the ground Antarctic Bottom Water with  $< 2^{\circ}$  C including its coldest compound Weddell Sea Deep Water ( $< 0.2^{\circ}$  C, see Fig.X16, X17 for pressures larger 2500 dbar).

Water properties of the Vema Channel and in the Vema Extension below approximately 4100 m can be studied in more detail in the blown-up  $\sigma_t/S$  diagram of the deepest stations (stat. no. 212 and 215) in Fig.X18. The form of the vertical profile (Fig.X19) demonstrates the well mixed bottom boundary layer in the channel. Its thickness is of O(140 - 180) m.

Thick bottom boundary layers are a unique feature of narrow oceanic passages with bottom water flow (HOGG et al., 1982; JUNGCLAUS & VANICEK, 1998).

Frictionally driven secondary circulation drive relatively warm waters down the (here western) channel wall leading to hydrostatic unstable conditions and intense vertical mixing. On the eastern side of the Vema Sill relatively cold water is transported upslope enhancing the stratification there. Thus, the coldest waters are trapped and shielded on the eastern side of the channel (Fig.X16) both by a pronounced thermocline and the channel wall (Fig.X9).

## Summary and concluding remarks

We summarize our preliminary results as follows:

- Earlier observations (Fig.X20; ZENK & HOGG, 1996; HOGG & ZENK, 1997) showing increasing bottom temperatures and salinities in the Vema Channel were confirmed. Compared with 1996, the lowest potential temperature in the Vema Sill rose again by 20 mK (Tab.X3). A pertinent salinity increase of 0.007 was directly observed from salinity samples taken by the rosette sampler closest to the bottom from two METEOR expeditions (M36 in 1996 and M41). No change in the density stratification appears to be associated with this change in  $\rho/\sigma$  properties. However, final salinity calibration of the CTD records remains subject of the post-cruise calibration.
- Between the Vema Sill and the Vema Extension (  $27^\circ$  S,  $34^\circ$  W, see Fig.X15) Weddell Sea Bottom Water with  $0.2^\circ$  C is guided and isolated from mixing with warmer Lower Circumpolar Deep Water for over 700 km by the cañon-dominated topography. Its temperature rises from  $-0.136$  to  $-0.098$ , i.e. by only 38 mK, salinity increases by barely 0.005 practical salinity units (34.670 to 34.675). In how far these temperature and salinity increases are caused by turbulent diffusion and/or by advected modulations of the source waters must remain open, since they both can be of the same order.
- Further mixing takes place northeast of the funnel-shaped end of the Vema Extension in the deep Brazil Basin with depths  $> 4800$  m (upper right hand corner in Fig.X15). Some additional 1300 km downstream at Sta 218 (see Fig.X1) the tongue of Weddell Sea Deep Water, the coldest subtype of Antarctic Bottom Water, has been totally eroded. There we found bottom values of  $T = 0.440^\circ$  C and  $S = 34.716$ . Hence, the horizontal bottom temperature and salinity gradients between the exit of the Vema Extension and the inner Brazil Basin increase significantly due to turbulent mixing in the absence of a shielding cañon. They are one order of magnitude larger,  $\{550 \text{ mK}, 0.04\}/1300 \text{ km}$  in  $\{T, S\}$  then in the Vema Channel itself.
- A long-term mooring carrying current meters (Fig.X8; Tab.X2), thermistor chains and a CTD recorder for the observation of property fluctuations was deployed without any problems.

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Tab. X1: Inventory of CTD stations

Station No/ Profile No	GeoB No	Date 1998	Time UTC	Lat °S	Long °W	z(m) Bridge Log	near surface T(°C)	at depth (m) T(°C) p <sub>max</sub> (dbar)	IADCP y/n	Remarks
208 / 01	5101-1	20/04	16:44	28 26.25	40 54.59	4388	23.94	0.36 4421	y	Test station Vema Channel
210 / 02	5103-1	21/04	17:42	31 11.84	39 23.86	4614	21.04	0.22 4666	y	
211 / 03	5104-1	21/04	21:59	31 12.04	39 21.02	4574	21.15	0.22 4630	y	
212 / 04	5105-1	22/04	01:42	31 12.02	39 18.90	4475	21.16	0.20 4510	y	
213 / 05	5106-1	22/04	05:56	31 12.03	39 16.02	4066	21.44	1.20 4098	y	
214 / 06	5107-1	23/04	19:16	26 53.99	33 54.96	3798	23.59	1.60 3812	y	Vema Extension
215 / 07	5108-1	23/04	23:53	26 41.97	34 14.02	4783	23.65	0.28 4862	y	
216 / 08	5109-1	24/04	07:06	26 17.99	34 56.16	4341	24.35	0.30 4388	y	
217 / 09	5110-1	24/04	16:45	25 53.88	35 38.89	4215	25.03	0.41 4241	y	
218 / 10	5111-1	28/04	10:14	23 48.81	20 00.03	5215	25.71	0.90 5284	y	24°S
219 / 11	5112-1	29/04	10:07	23 49.59	16 16.34	3874	25.19	1.50 3901	y	
220 / 12	5113-1	30/04	02:58	23 40.12	15 00.02	3853	25.01	2.14 3885	y	
221 / 13	5114-1	30/04	11:46	24 09.95	13 59.86	3171	24.75	2.61 3204	y	
225 / 14	5118-1	01/05	08:17	24 10.81	13 23.07	2741	24.61	2.71 2778	y	
226 / 15	5119-1	01/05	15:57	24 10.08	12 18.11	3910	24.46	2.49 4008	y	
229 / 16	5122-1	02/05	10:56	24 10.25	11 07.95	3737	24.31	2.41 3760	y	
231 / 17	5124-1	02/05	23:35	24 09.96	09 53.92	4322	23.91	2.43 4375	n	
232 / 18	5125-1	03/05	06:55	24 09.91	09 00.19	4462	23.68	2.44 4523	n	9°W
233 / 19	5126-1	03/05	19:00	22 23.96	08 59.96	4192	24.04	2.40 4231	n	
234 / 20	5127-1	04/05	03:51	21 12.10	09 00.15	3941	24.34	2.38 3878	n	
235 / 21	5128-1	04/05	13:03	20 00.03	09 00.09	3959	23.93	2.40 3951	n	
236 / 22	5129-1	04/05	21:48	18 59.98	09 46.23	3838	24.46	2.43 3857	n	19°S
236 / 23	5129-2	05/05	00:57	18 59.98	09 46.20	3840	24.45	13.14 250	n	
243 / 24	5136-3	07/05	22:22	19 22.00	12 42.67	4536	24.69	3.48 1500	n	
248 / 25	5141-1	09/05	18:30	19 05.75	17 15.12	3453	25.62	3.65 1502	n	

**Tab. X2: Mooring activities**

Sta. No	IfM VNo	CTD Sta/Prof	Date 1998	Latitude S	Longitude W	Depth (m)	Ref	Instr. No	Instr. Type	S/N	Remarks
209	389	{210/2-212/4}	21APR	31°14.30'	39°20.00'	4580	-		WD	2266	ARGOS, no receipt. d. deploym.
								389101	ThCh	1295/1960	nom recorder depth 4090 m i.e. 490 m above ground 11 sensors, 20 m apart
								389102	AVTP	11442	nominal depth 4310 m i.e. 270 m above ground
								389103	ThCh	1296/1961	nom recorder depth 4312 m i.e. 268 m above ground 11 sensors, 20 m apart
								389104	AVTP	11348	nominal depth 4528 m i.e. 52 m above ground
								389105	MiCat	206	nominal depth 4529 m i.e. 51 m above ground
								-	AR	428	48 m above ground

Abbreviations: AVTP Anderaa Current Meter incl. pressure sensor  
 ThCh Aanderaa Thermistor Chain, recorder / chain  
 MiCat MicroCat moored CTD by SeaBird, Inc.  
 WD WatchDog bouy built at IfM Kiel  
 AR Acoustic Release by MORS

**Tab X3: Near-bottom CTD and salinometer values from the Vema Sill, 1972 - 1998**

(acc. to ZENK &amp; HOGG, 1996; HOGG &amp; ZENK, 1997).

Expedition mm/yy	Sta. No	Pro. No	$\theta$ °C	Acc.T mK	S <sub>CTD</sub> raw	S <sub>CTD</sub> corr	S <sub>Sali</sub> No 1	2	Acc.S 3
Cato									
11/72	14		<b>-0.175</b>						
Geosecs									
11/72	59		<b>-0.180</b>						
CHAIN									
4/74	4		<b>-0.188</b>						
ATLANTIS II									
10/79	76		<b>-0.192</b>						
ATLANTIS II									
5/80	112		<b>-0.181</b>						
METEOR 15									
1/91	49	47	<b>-0.185</b>	±2					
METEOR 22									
12/92	43		<b>-0.155</b>						
COROAS I §									
3/93	24		<b>-0.140</b>						
COROAS II §									
3/94			<b>-0.134</b>						
POLAR STERN									
10/94	128	31	<b>-0.158</b>	±2	34.655		34.683 34.683	./.	
METEOR 34									
3/96	49	5	<b>-0.156</b>	±2	34.657	<b>34.665</b>	34.664 <sub>9</sub> 34.665 <sub>1</sub>	34.663 <sub>7</sub>	±0.003
METEOR 41									
4/98	212	4	<b>-0.136</b>	±2	34.670	<b>34.671<sub>8</sub></b>	34.673 <sub>0</sub> 34.672 <sub>4</sub>	./.	±0.003

§ Kindly provided by Y. Ikeda, University of Sao Paulo.

Tab X4a: LADCP Log

Pr. No.	Stat No.	LADCP Start (UTC)	Tiefe (m)	Date (Start, End) yyyy,mm,dd yyyy,mm,dd	Time, down 10m. (CTD Prot) hh,mm,ss (UTC)	Posi., down 10m (CTD Prot) gg,mm.mm gg,mm.mm	Posi., down 10m (DVS Stream) gg,mm.mmm gg,mm.mmm	Time, up 10m. Start hh,mm,ss	Posi, up 10m (CTD Prot) gg,mm.mm gg,mm.mm	Posi, up 10m (DVS Stream) gg,mm.mmm S gg,mm.mmm	Time, up 10m End (DVS) hh,mm,ss	Posi, up 10m (DVS,End) gg,mm.mmm S gg,mm.mmm
1	208	15,37	4387	1998,04,20	16,46,35	28,26.34 S 40,54.60 W	Wrong time in protocol	19,43,35	28,26.48 S 40,54.69 W			
2	210	17,24,48	4611	1998,04,21	17,45,05	31,11.99 S 39,23.93 W	31,11.987 S 39,23.928 W	20,38,40	31,12.11 S 39,23.79 W	31,12.108 S 39,23.784 W	20,41,40	31,12.152 S 39,23.812 W
3	211	21,36,54	4574	1998,04,21 1998,04,22	22,02,13	31,12.04 S 39,21.01 W	31,12.003 S 39,21.055 W	00,43,45	31,12.27 S 39,21.02 W (End)	31,12.258 S 39,20.989 W	00,47,45	31,12.263 S 39,21.019
4	212	"-"	4475	1998,04,22	01,47,12	31,12.06 S 39,18.88 W	31,12.057 S 39,18.872 W	04,40,54	31,12.05 S 39,19.13 W (End)	31,12.027 S 39,19.121 W	04,43,45	31,12.046 S 39,19.132 W
5	213	"-"	4065	1998,04,22	05,58,37	31,12.02 S 39,16.00 W	31,12.019 S 39,16.008 W	08,20,00	31,11.98 S 39,15.98 W (Start)	31,11.985 S 39,15.978 W	08,23,15	31,12.000 39,15.968
6	214	19,09,19	3784	1998,04,23	19,21,38	26,53.99 S 33,54.96 W	26,53.943 S 33,54.934 W	21,48,03	26,53.97 S (S) 33,55.00 W 26,53.95 S (E) 33,54.99 W	26,53.972 S 33,55.007 W	21,51,07	26,53.949 S 33,54.994 W
7	215	?	4785	1998,04,23 1998,04,24	23,56,07	26,41.96 S 34,14.01 W	26,41.956 S 34,14.005 W	02,59,19	26,41.98 S (S) 34,14.00 W 26,42.00 S (E) 34,14.02 W	26,41.978 S 34,14.001 W	03,02,21	26,41.996 S 33,14.019 W

Tab X4b: LADCP Log (continued)

Pr. No.	Stat No.	LADCP Start (UTC)	Tiefe (m)	Date (Start, End) yyyy,mm,dd yyyy,mm,dd	Time, down 10m. (CTD Prot) hh,mm,ss (UTC)	Posi., down 10m (CTD Prot) gg,mm.mm gg,mm.mm	Posi., down 10m (DVS Stream) gg,mm.mmm gg,mm.mmm	Time, up 10m. Start hh,mm,ss	Posi, up 10m (CTD Prot) gg,mm.mm gg,mm.mm	Posi, up 10m (DVS Stream) gg,mm.mmm S gg,mm.mmm	Time, up 10m End (DVS) hh,mm,ss	Posi, up 10m (DVS,End) gg,mm.mmm S gg,mm.mmm
8	216	06,55,41	4350	1998,04,24	07,09,27	26,18.00 S 34,56.17 W	26,17.995 S 34,56.165 W	09,50,40	26,18.00 S (A) 34,55.99 W 26,18.03 S (E) 34,55.95	26,18.001 S 34,55.988 W	09,53,41	26,18.030 S 34,55.950 W
9	217	?	4190	1998,04,24	16,47,49	25,53.97 S 35,38.88 W	25,53.965 S 35,38.881 W	19,26,15	25,54.00 S (A) 35,39.01 W 25,53.99 S (E) 35,39.01 W	25,53.996 S 35,39.005 W	19,29,15	25,53.986 S 35,39.014 W
10	218	09,58,05	5215	1998,04,28	10,17,19	23,48.93S 20,00.01W	23,48.904 S 20,00.009 W	13,31,27	23,48.95 S 19,59.78W(A) 23,48.96S 19,59.75W(E)	23,48.950 S 19,59.774 W	13,34,29	23,48,962 19,59.756
11	219	09,57,43	3860	1998,04,29	10,09,49	23,49.57 S 16,16.34 W	23,49.570 S 16,16.333 W	12,38,38	23,49.57 S 16,16.34 W(A) 23,49.57 S 16,16.33 W (E)	23,49.571 S 16,16,339 W	12,41,42	23,49.580S 16,16.320W
12	220	02,43,28	3850	1998,04,30	03,01,14	23,40.18 S 15,00.09 W	23,40.180 S 15,00.090 W	05,20,38	23,40.21 S 14,59.94 W(A) 23,40.21 14.59.94W (E)	kein DVS!	05,30,55	kein DVS
13	221	11,23,09	3130	1998,04,30	11,49,45	24,09.97 S 13,59.81 W	24,09.972 S 13,59.817 W	13,54,48	24,09,88 S 13,59.56 W 24,09,88 S 13,59,55 W	24,09,876 S 13,59.559 W	13,57,56	24,09.881 S 13,59.546 W
14	225	08,05,08	2740	1998,05,01	08,19,59	24,10.83 S 13,23.07 W	24,10.827 S 13,23.074 W	10,13,18	24,10.77 S 13,23.01 W 24,10.78 S 13,23,07 W	24,10.767 S 13,23.005 W	10,16,27	24,10.777 S 13,23.036 W
15	226	15,25,02	3865	1998,05,01	16,02,21	24,10,05 S 12,18.01 W	24,10.045 S 12,18.014 W	18,30,38	24,10.05 S 12,17.86 W 24,10.04 S 12,17.85 W	24,10.767 S 13,23.005 W	18,33,38	24,10.041 S 12,17.852 W

## List of Figure Captures

- Figure X1: Location of all CTD station (\*). Hydrographic work was equally split between Vema Channel, Vema Extension, and sections on 24° S and 9° W. For details see Tab X1.
- Figure X2: CTD station (\*) distribution in the area of the Vema Sill. Location (0) denotes the position of IfM mooring V-289. For details see Tab X1 and X2.
- Figure X3: Comparison of displayed CTD data and their bottle check values as a function of station number or time. The upper curve (\*) contains all cases from the mixed layer at 10 m depth. The lower curve (o) denote check values from the deepest level, i.e. 20 m above the sea bed. No drift or calibration shifts are visible.
- Figure X4: Comparison of displayed CTD data and their bottle check values as a function of salinity. For symbols see Fig X3.
- Figure X5: Comparison of the two sea surface thermometers of the meteorological station METEOR. Data were recorded by the DVS system. Sensors show a bias of O(0.15° C).
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- Figure X7: Sample plots of the lowered Acoustic Doppler Current Profiler (IADCP) from CTD Sta 212 in the Vema Channel. Note the bottom intensified current profiles (d and e) which indicate the northward transport of Antarctic Bottom Water (AABW) across the Vema Sill. For further details see text.
- Figure X8: Design of IfM mooring V-389 which was moored in the Vema Channel. For details see Tab.X2.
- Figure X9: Topographic charts from the eastern side of the Vema Sill taken in January 1991 during METEOR cruise M15 (a) and during METEOR cruise M41 (b) in April 1998.
- Figure X10: Diagram of all pairs of salinity (S) and potential temperature (  $\theta$  ) from Sections at 24° S and 9° W. Data were interpolated in 2 dbar steps prior to plotting. Abbreviations: TW - Tropical Surface Water, SACW - South Atlantic Central Water, AAIW - Antarctic Intermediate Water, NADW - North Atlantic Deep Water, CDW - Circumpolar Deep Water (u - upper, l - lower), AABW - Antarctic Bottom Water. Diagonal lines of equal densities are referenced to the surface (  $\sigma_t$  / kg m<sup>-3</sup> ).

- Figure X11: DVS plots of surface temperatures and salinities on various track lines (see top of graphs). In (a) we have included 10 m CTD temperature values. They appear to lie systematically above the two ship's own surface thermometer readings. See also Fig X5.
- Figure X12: Diagram of all pairs of salinity and temperature from the surface of Sections at 24° S (+ and \*) and 9° W (+ with o) recorded by the DVS system. Values \* and + differ by their location East or West of 18° W. Note that data feature two clusters.  $\sigma_t$  lines ( $\text{kg m}^{-3}$ ) are overlaid.
- Figure X13: Salinity (a) and potential temperature (b) sections along 9° W in the deep Angola Basin east of the Middle Atlantic Ridge. The distribution of water masses is discussed in the text. Note that no water with  $T < 2.0^\circ \text{C}$  reaches the Angola Basin, i.e. Antarctic Bottom Water is absent.
- Figure X14: Salinity (a) and potential temperature (b) sections along 24° S. The center of the Middle Atlantic Ridge (MAR) is situated at 13.5° W. Note the drastic differences between the stratification on the eastern side, i.e. in the Angola Basin and in the Brazil Basin on the western side of the MAR. North Atlantic Deep Water features a deep front preventing this water mass from penetrating into the Angola Basin. The western abyssal is filled with Antarctic Bottom Water ( $T < 2^\circ \text{C}$ ). No such water is present in the eastern abyssal.
- Figure X15: Topographic map of the Vema Channel and its northeastern extension. The 4000 m isobath is an optimal indicator for the channelized spreading of Antarctic Bottom Water ( $T < 2^\circ \text{C}$ ) while filling the deep Brazil Basin.
- Figure X16: Salinity (a) and potential temperature (b) sections from the Vema Sill below 2500 m. In the right subfigure we have included the position and length of IfM mooring V-389 (see Tab X2). Note the asymmetric horizontal property distribution in the range below 3800 m. For details see text..
- Figure X17: Sections as in Fig.X14, however from the Vema Extension. Note the isolated deep channel that prevents Antarctic Bottom Water to be mixed more rapidly with its surrounding water masses than farther north in the inner Brazil Basin.
- Figure X18: Diagram of potential temperature vs. salinity ( $T/S$ ) from Sta 212 (+) and 215 (o) from the Vema Sill (see Figs.X1 and X2) and from the Vema Extension (see Fig.X1).
- Figure X19: Bottom oriented profiles of potential temperature from section (a) at the Vema Channel and (b) the Vema Extension. Note the homogenized temperature on the sill also see in Fig.X17.

Figure X20: Long-term CTD temperature time series from the Vema Channel. The newest data point from M41 shows again increased temperatures. In fact, the latest value of  $\theta_{\min} = -0.136^{\circ} \text{C}$  measured on Sta 212 (see Figs.X2 and X9) is among the highest in the total time series from the sill region in the Vema Channel.

## ANNEX X1

Distribution of hydrographic parameters on standard pressure levels from all CTD stations taken during cruise M41/3. Columns represent pressure (p), *in situ* temperature (T), potential temperature (θ) and salinity (S) for each station. Considerations on data accuracies are given in the text.

**Station 208      Profil    01**  
**40° 54.59 W    28° 26.25 S**  
**20.04.1998    UTC 16:44    4388 m**

**Station 210      Profil    02**  
**39° 23.86 W    31° 11.84 S**  
**21.04.1998    UTC 17:42    4614 m**

p dbar	T °C	θ °C	S
2.0	23.911	23.911	36.554
10.0	23.912	23.910	36.551
20.0	23.908	23.904	36.551
50.0	22.920	22.910	36.393
75.0	19.622	19.608	36.159
100.0	18.548	18.531	36.083
150.0	16.836	16.811	35.830
200.0	15.487	15.456	35.569
250.0	14.667	14.630	35.467
300.0	14.590	14.545	35.534
350.0	13.504	13.454	35.337
400.0	12.769	12.714	35.222
450.0	11.689	11.631	35.051
500.0	10.307	10.247	34.855
600.0	8.122	8.060	34.598
700.0	6.434	6.370	34.426
800.0	5.302	5.235	34.349
900.0	4.436	4.366	34.329
1000.0	3.830	3.756	34.338
1500.0	3.014	2.906	34.628
2000.0	3.528	3.368	34.922
2500.0	3.202	2.998	34.944
3000.0	2.878	2.630	34.928
3500.0	1.186	0.927	34.769
4000.0	0.504	0.214	34.698
4430.0	0.364	0.032	34.682

p dbar	T °C	θ °C	S
4.0	21.070	21.070	35.754
10.0	21.027	21.025	35.760
20.0	20.983	20.979	35.767
50.0	20.628	20.619	36.008
75.0	17.265	17.252	35.763
100.0	16.030	16.014	35.669
150.0	15.043	15.020	35.589
200.0	14.338	14.309	35.490
250.0	13.936	13.900	35.427
300.0	13.551	13.508	35.386
350.0	12.725	12.678	35.228
400.0	11.484	11.433	35.024
450.0	10.298	10.244	34.868
500.0	9.136	9.080	34.714
600.0	6.501	6.452	34.397
700.0	5.154	5.097	34.281
800.0	4.579	4.516	34.279
900.0	4.005	3.938	34.281
1000.0	3.701	3.628	34.325
1500.0	2.859	2.753	34.626
2000.0	3.240	3.084	34.886
2500.0	3.112	2.910	34.936
3000.0	2.751	2.506	34.922
3500.0	2.140	1.856	34.869
4000.0	0.950	0.646	34.727
4500.0	0.207	-0.128	34.675
4666.0	0.220	-0.133	34.673

**Station 211 Profil 03**  
**39° 21.02 W 31° 12.04 S**  
**21.04.1998 UTC 21:59 4574 m**

**Station 212 Profil 04**  
**39° 18.90 W 31° 12.02 S**  
**22.04.1998 UTC 01:42 4475 m**

p dbar	T °C	$\theta$ °C	S
2.0	21.183	21.183	35.768
10.0	21.177	21.175	35.764
20.0	21.056	21.052	35.757
50.0	20.703	20.694	36.009
75.0	17.446	17.433	35.753
100.0	16.247	16.231	35.708
150.0	15.126	15.103	35.597
200.0	14.533	14.503	35.521
250.0	13.975	13.939	35.441
300.0	13.476	13.433	35.370
350.0	12.539	12.492	35.198
400.0	11.342	11.292	35.010
450.0	10.324	10.270	34.867
500.0	9.292	9.235	34.720
600.0	6.939	6.882	34.459
700.0	5.461	5.402	34.314
800.0	4.550	4.487	34.262
900.0	4.086	4.018	34.292
1000.0	3.712	3.639	34.330
1500.0	2.877	2.770	34.616
2000.0	3.211	3.055	34.879
2500.0	3.096	2.895	34.938
3000.0	2.776	2.530	34.923
3500.0	2.188	1.903	34.874
4000.0	1.275	0.962	34.772
4500.0	0.205	-0.129	34.674
4630.0	0.217	-0.132	34.674

p dbar	T °C	$\theta$ °C	S
2.0	21.129	21.128	35.780
10.0	21.143	21.141	35.773
20.0	21.069	21.066	35.762
50.0	20.679	20.670	35.985
75.0	17.478	17.466	35.833
100.0	15.957	15.941	35.673
150.0	15.117	15.094	35.597
200.0	14.572	14.542	35.541
250.0	14.141	14.105	35.476
300.0	13.504	13.462	35.376
350.0	12.560	12.513	35.203
400.0	11.507	11.455	35.039
450.0	10.421	10.367	34.879
500.0	8.749	8.695	34.640
600.0	6.665	6.609	34.408
700.0	5.354	5.295	34.322
800.0	4.477	4.415	34.269
900.0	4.118	4.050	34.298
1000.0	3.673	3.600	34.322
1500.0	2.877	2.771	34.613
2000.0	3.165	3.010	34.862
2500.0	3.098	2.896	34.936
3000.0	2.777	2.531	34.919
3500.0	2.223	1.938	34.873
4000.0	1.378	1.062	34.781
4500.0	0.198	-0.137	34.672
4528.0	0.201	-0.136	34.674

**Station 213      Profil    05**  
**39° 16.02 W      31° 12.03 S**  
**22.04.1998    UTC 05:56    4066 m**

**Station 214      Profil    06**  
**33° 54.96 W      26° 53.99 S**  
**23.04.1998    UTC 19:16    3798 m**

<b>p</b> <b>dbar</b>	<b>T</b> <b>°C</b>	<b>Θ</b> <b>°C</b>	<b>S</b>
2.0	21.412	21.412	35.772
10.0	21.419	21.417	35.764
20.0	21.233	21.229	35.754
50.0	20.857	20.848	35.957
75.0	17.798	17.785	35.786
100.0	16.425	16.409	35.754
150.0	15.241	15.218	35.623
200.0	14.635	14.605	35.548
250.0	14.030	13.993	35.437
300.0	13.494	13.451	35.367
350.0	12.650	12.602	35.212
400.0	11.802	11.750	35.083
450.0	10.464	10.410	34.889
500.0	9.098	9.042	34.703
600.0	6.836	6.779	34.449
700.0	5.380	5.322	34.326
800.0	4.577	4.515	34.288
900.0	4.169	4.101	34.316
1000.0	3.643	3.571	34.330
1500.0	3.109	3.000	34.664
2000.0	3.176	3.021	34.870
2500.0	3.093	2.892	34.934
3000.0	2.786	2.540	34.924
3500.0	2.288	2.001	34.882
4000.0	1.378	1.062	34.786
4096.0	1.247	0.925	34.771

<b>p</b> <b>dbar</b>	<b>T</b> <b>°C</b>	<b>Θ</b> <b>°C</b>	<b>S</b>
2.0	23.566	23.565	36.051
10.0	23.569	23.567	36.046
20.0	23.565	23.560	36.040
50.0	22.402	22.392	36.006
75.0	20.422	20.407	36.249
100.0	18.757	18.739	36.061
150.0	16.584	16.559	35.784
200.0	15.157	15.126	35.553
250.0	14.602	14.564	35.556
300.0	14.257	14.213	35.515
350.0	13.643	13.593	35.406
400.0	12.363	12.310	35.172
450.0	11.192	11.136	34.979
500.0	10.308	10.248	34.865
600.0	7.704	7.643	34.560
700.0	6.150	6.088	34.409
800.0	4.847	4.782	34.324
900.0	4.099	4.031	34.325
1000.0	3.601	3.529	34.364
1500.0	2.872	2.765	34.687
2000.0	2.834	2.684	34.852
2500.0	2.903	2.705	34.927
3000.0	2.673	2.430	34.922
3500.0	2.262	1.976	34.886
3820.0	1.605	1.302	34.815

**Station 215 Profil 07**  
**34° 14.02 W 26° 41.97 S**  
**23.04.1998 UTC 23:53 4783 m**

<b>p</b> <b>dbar</b>	<b>T</b> <b>°C</b>	<b>θ</b> <b>°C</b>	<b>S</b>
2.0	23.629	23.629	36.075
10.0	23.632	23.630	36.076
20.0	23.633	23.628	36.075
50.0	22.641	22.631	36.237
75.0	20.524	20.510	36.221
100.0	19.303	19.285	36.155
150.0	17.544	17.518	35.864
200.0	16.135	16.103	35.663
250.0	14.920	14.882	35.490
300.0	14.927	14.881	35.588
350.0	13.621	13.571	35.327
400.0	12.716	12.661	35.199
450.0	11.631	11.573	35.038
500.0	10.656	10.594	34.914
600.0	8.254	8.191	34.615
700.0	6.374	6.310	34.430
800.0	5.005	4.940	34.326
900.0	4.210	4.141	34.329
1000.0	3.601	3.529	34.359
1500.0	2.910	2.803	34.685
2000.0	3.277	3.120	34.929
2500.0	3.002	2.802	34.939
3000.0	2.755	2.509	34.927
3500.0	2.362	2.073	34.892
4000.0	1.351	1.036	34.785
4500.0	0.505	0.161	34.694
4862.0	0.278	-0.098	34.676

**Station 216 Profil 08**  
**34° 56.16 W 26° 17.99 S**  
**24.04.1998 UTC 07:06 4341 m**

<b>p</b> <b>dbar</b>	<b>T</b> <b>°C</b>	<b>θ</b> <b>°C</b>	<b>S</b>
2.0	24.313	24.312	36.004
10.0	24.327	24.325	36.016
20.0	24.323	24.319	36.013
50.0	22.340	22.330	36.384
75.0	20.277	20.263	36.264
100.0	19.045	19.027	36.091
150.0	17.066	17.041	35.784
200.0	16.044	16.012	35.632
250.0	14.994	14.956	35.493
300.0	14.322	14.277	35.428
350.0	13.415	13.366	35.280
400.0	12.337	12.283	35.118
450.0	11.551	11.493	35.013
500.0	10.404	10.344	34.862
600.0	7.900	7.838	34.570
700.0	5.961	5.899	34.387
800.0	4.701	4.638	34.319
900.0	4.169	4.100	34.337
1000.0	3.740	3.667	34.378
1500.0	3.192	3.082	34.727
2000.0	3.380	3.222	34.938
2500.0	3.051	2.850	34.941
3000.0	2.754	2.509	34.924
3500.0	2.291	2.004	34.885
4000.0	1.114	0.806	34.759
4388.0	0.303	-0.023	34.680

**Station 217    Profil    09**  
**35° 38.89 W    25° 53.88 S**  
**24.04.1998    UTC 16:45 4215 m**

<b>p</b> <b>dbar</b>	<b>T</b> <b>°C</b>	<b>θ</b> <b>°C</b>	<b>S</b>
2.0	25.065	25.065	36.244
10.0	24.988	24.986	36.273
20.0	24.951	24.947	36.352
50.0	24.597	24.586	36.525
75.0	21.502	21.487	36.470
100.0	20.511	20.493	36.332
150.0	18.227	18.201	35.978
200.0	16.792	16.759	35.747
250.0	15.415	15.376	35.529
300.0	14.396	14.351	35.379
350.0	13.369	13.320	35.269
400.0	12.432	12.378	35.125
450.0	11.223	11.166	34.963
500.0	10.217	10.157	34.834
600.0	8.166	8.103	34.609
700.0	6.361	6.297	34.441
800.0	5.083	5.017	34.364
900.0	4.157	4.089	34.350
1000.0	3.811	3.737	34.401
1500.0	3.699	3.583	34.727
2000.0	3.950	3.783	34.952
2500.0	2.950	2.751	34.937
3000.0	2.286	2.051	34.892
3500.0	1.636	1.366	34.820
4000.0	0.794	0.494	34.728
4240.0	0.415	0.102	34.689

**Station 218    Profil    10**  
**20° 00.03 W    23° 48.81 S**  
**28.04.1998    UTC 10:14 5215 m**

<b>p</b> <b>dbar</b>	<b>T</b> <b>°C</b>	<b>θ</b> <b>°C</b>	<b>S</b>
4.0	25.685	25.684	36.793
10.0	25.685	25.683	36.799
20.0	25.696	25.691	36.806
50.0	25.701	25.689	36.807
75.0	23.416	23.400	36.404
100.0	21.480	21.461	36.303
150.0	18.158	18.132	35.920
200.0	15.772	15.741	35.546
250.0	14.493	14.456	35.349
300.0	13.376	13.333	35.203
350.0	12.332	12.285	35.080
400.0	11.110	11.060	34.937
450.0	10.240	10.187	34.831
500.0	9.068	9.013	34.698
600.0	7.181	7.123	34.519
700.0	5.495	5.436	34.402
800.0	4.515	4.452	34.388
900.0	3.965	3.898	34.410
1000.0	3.628	3.555	34.470
1500.0	3.129	3.019	34.758
2000.0	3.138	2.984	34.916
2500.0	2.929	2.730	34.934
3000.0	2.700	2.455	34.920
3500.0	2.305	2.017	34.883
4000.0	1.634	1.310	34.811
4500.0	1.227	0.860	34.767
5000.0	0.927	0.512	34.734
5282.0	0.893	0.445	34.726

**Station 219**    **Profil 11**  
**16° 16.34 W**    **23° 49.59 S**  
**29.4.1998**    **UTC 10:07**    **3874 m**

**Station 220**    **Profil 12**  
**15° 00.02 W**    **23° 40.12 S**  
**30.04.1998**    **UTC 02:58**    **3853 m**

<b>p</b> <b>dbar</b>	<b>T</b> <b>°C</b>	<b>θ</b> <b>°C</b>	<b>S</b>
2.0	25.167	25.167	36.679
10.0	25.170	25.168	36.722
20.0	25.175	25.170	36.734
50.0	25.156	25.145	36.728
75.0	20.837	20.822	36.219
100.0	19.614	19.596	36.169
150.0	18.363	18.337	35.985
200.0	16.071	16.039	35.610
250.0	14.656	14.619	35.375
300.0	13.465	13.423	35.214
350.0	12.245	12.198	35.072
400.0	10.778	10.729	34.899
450.0	9.532	9.481	34.760
500.0	8.831	8.777	34.685
600.0	7.020	6.962	34.519
700.0	5.493	5.433	34.413
800.0	4.563	4.500	34.386
900.0	3.938	3.871	34.414
1000.0	3.527	3.455	34.459
1500.0	3.240	3.129	34.806
2000.0	3.217	3.061	34.938
2500.0	2.888	2.690	34.930
3000.0	2.604	2.362	34.907
3500.0	2.231	1.945	34.867
3900.0	1.937	1.616	34.838

<b>p</b> <b>dbar</b>	<b>T</b> <b>°C</b>	<b>θ</b> <b>°C</b>	<b>S</b>
4.0	24.989	24.988	36.728
10.0	24.992	24.990	36.739
20.0	24.993	24.989	36.757
50.0	24.989	24.978	36.756
75.0	21.944	21.929	36.318
100.0	21.158	21.139	36.302
150.0	19.166	19.139	36.128
200.0	17.149	17.116	35.780
250.0	15.009	14.971	35.427
300.0	13.424	13.382	35.205
350.0	12.463	12.416	35.093
400.0	11.484	11.433	34.976
450.0	10.188	10.135	34.830
500.0	8.732	8.677	34.675
600.0	7.171	7.113	34.541
700.0	5.778	5.717	34.420
800.0	4.571	4.508	34.370
900.0	4.014	3.947	34.393
1000.0	3.603	3.530	34.453
1500.0	3.088	2.979	34.759
2000.0	3.197	3.042	34.933
2500.0	2.766	2.571	34.906
3000.0	2.654	2.411	34.908
3500.0	2.446	2.155	34.887
3888.0	2.136	1.811	34.857

**Station 221    Profil    13**  
**13° 59.86 W    24° 09.95 S**  
**30.04.1998    UTC 11:46    3171 m**

<b>p</b> <b>dbar</b>	<b>T</b> <b>°C</b>	<b>Θ</b> <b>°C</b>	<b>S</b>
4.0	24.725	24.724	36.740
10.0	24.728	24.725	36.740
20.0	24.730	24.726	36.739
50.0	24.723	24.712	36.736
75.0	22.406	22.391	36.307
100.0	20.866	20.847	36.233
150.0	19.339	19.312	36.153
200.0	16.756	16.724	35.719
250.0	14.673	14.636	35.377
300.0	13.215	13.173	35.180
350.0	11.684	11.638	34.997
400.0	10.849	10.800	34.899
450.0	9.994	9.941	34.805
500.0	8.744	8.690	34.671
600.0	6.995	6.938	34.506
700.0	5.632	5.572	34.411
800.0	4.790	4.726	34.398
900.0	4.191	4.122	34.424
1000.0	3.877	3.803	34.471
1500.0	3.178	3.067	34.741
2000.0	2.864	2.713	34.871
2500.0	2.739	2.544	34.897
3000.0	2.616	2.374	34.891
3200.0	2.608	2.345	34.892

**Station 225    Profil    14**  
**13° 23.07 W    24° 10.81 S**  
**01.05.1998    UTC 08:17    2741 m**

<b>p</b> <b>dbar</b>	<b>T</b> <b>°C</b>	<b>Θ</b> <b>°C</b>	<b>S</b>
4.0	24.584	24.583	36.668
10.0	24.594	24.592	36.668
20.0	24.598	24.593	36.670
50.0	24.608	24.597	36.670
75.0	23.072	23.057	36.485
100.0	20.861	20.842	36.281
150.0	18.768	18.742	36.061
200.0	16.094	16.062	35.611
250.0	14.747	14.709	35.391
300.0	13.659	13.616	35.240
350.0	12.359	12.312	35.082
400.0	11.038	10.988	34.924
450.0	10.100	10.046	34.819
500.0	9.021	8.966	34.687
600.0	7.093	7.035	34.525
700.0	5.474	5.415	34.415
800.0	4.709	4.646	34.411
900.0	4.242	4.173	34.430
1000.0	3.909	3.834	34.463
1500.0	3.170	3.060	34.741
2000.0	2.870	2.720	34.889
2500.0	2.761	2.565	34.894
2774.0	2.713	2.491	34.895

**Station 226 Profil 15**  
**12° 18.11 W 24° 10.08 S**  
**01.05.1998 UTC 15:57 3910 m**

<b>p</b> <b>dbar</b>	<b>T</b> <b>°C</b>	<b>θ</b> <b>°C</b>	<b>S</b>
4.0	24.432	24.431	36.637
10.0	24.432	24.430	36.637
20.0	24.429	24.425	36.640
50.0	24.403	24.392	36.644
75.0	21.050	21.036	36.194
100.0	19.853	19.834	36.189
150.0	17.491	17.465	35.810
200.0	15.543	15.512	35.511
250.0	14.514	14.476	35.350
300.0	13.638	13.595	35.231
350.0	12.554	12.507	35.099
400.0	11.287	11.236	34.952
450.0	10.094	10.041	34.815
500.0	8.905	8.851	34.688
600.0	7.077	7.019	34.517
700.0	5.416	5.357	34.407
800.0	4.728	4.665	34.403
900.0	4.127	4.058	34.434
1000.0	3.818	3.744	34.478
1500.0	3.144	3.034	34.738
2000.0	2.665	2.518	34.832
2500.0	2.511	2.321	34.874
3000.0	2.478	2.239	34.881
3500.0	2.489	2.197	34.880
4000.0	2.487	2.139	34.879
4006.0	2.487	2.139	34.880

**Station 229 Profil 16**  
**11° 07.95 W 24° 10.25 S**  
**02.05.1998 UTC 10:56 3737 m**

<b>p</b> <b>dbar</b>	<b>T</b> <b>°C</b>	<b>θ</b> <b>°C</b>	<b>S</b>
2.0	24.273	24.273	36.540
10.0	24.288	24.286	36.538
20.0	24.293	24.288	36.537
50.0	24.270	24.260	36.534
75.0	23.752	23.737	36.372
100.0	19.784	19.766	35.925
150.0	16.207	16.183	35.570
200.0	14.233	14.203	35.299
250.0	13.320	13.285	35.183
300.0	12.411	12.371	35.082
350.0	11.293	11.249	34.952
400.0	10.116	10.068	34.813
450.0	9.446	9.395	34.739
500.0	8.616	8.563	34.652
600.0	6.754	6.698	34.483
700.0	5.162	5.105	34.372
800.0	4.331	4.270	34.403
900.0	3.893	3.826	34.437
1000.0	3.604	3.531	34.475
1500.0	3.168	3.058	34.758
2000.0	2.661	2.514	34.838
2500.0	2.511	2.321	34.874
3000.0	2.434	2.195	34.880
3500.0	2.400	2.110	34.880
3764.0	2.410	2.091	34.881

**Station 231 Profil 17**  
**09° 53.92 W 24° 09.96 S**  
**02.05.1998 UTC 23:35 4322 m**

<b>p</b> <b>dbar</b>	<b>T</b> <b>°C</b>	<b>θ</b> <b>°C</b>	<b>S</b>
4.0	23.874	23.873	36.566
10.0	23.873	23.871	36.570
20.0	23.871	23.867	36.574
50.0	23.876	23.865	36.573
75.0	22.069	22.054	36.189
100.0	19.430	19.412	36.037
150.0	17.559	17.534	35.791
200.0	15.069	15.038	35.436
250.0	13.735	13.699	35.242
300.0	12.954	12.913	35.145
350.0	11.884	11.838	35.025
400.0	11.118	11.068	34.935
450.0	9.964	9.912	34.801
500.0	8.367	8.315	34.633
600.0	6.375	6.320	34.455
700.0	5.312	5.254	34.391
800.0	4.365	4.304	34.380
900.0	3.894	3.827	34.420
1000.0	3.701	3.628	34.483
1500.0	3.332	3.220	34.755
2000.0	2.750	2.601	34.848
2500.0	2.541	2.350	34.873
3000.0	2.429	2.191	34.880
3500.0	2.384	2.094	34.880
4000.0	2.395	2.050	34.885
4374.0	2.428	2.038	34.886

**Station 232 Profil 18**  
**09° 00.19 W 24° 09.91 S**  
**03.05.1998 UTC 06:55 4462 m**

<b>p</b> <b>dbar</b>	<b>T</b> <b>°C</b>	<b>θ</b> <b>°C</b>	<b>S</b>
2.0	23.715	23.715	36.423
10.0	23.726	23.724	36.424
20.0	23.735	23.731	36.427
50.0	23.662	23.652	36.425
75.0	20.946	20.932	35.978
100.0	19.052	19.034	35.929
150.0	17.125	17.100	35.733
200.0	15.455	15.424	35.488
250.0	14.211	14.174	35.309
300.0	12.922	12.881	35.138
350.0	11.959	11.913	35.031
400.0	10.862	10.813	34.902
450.0	9.573	9.522	34.758
500.0	8.912	8.857	34.676
600.0	7.260	7.201	34.544
700.0	5.364	5.306	34.392
800.0	4.445	4.383	34.373
900.0	4.127	4.058	34.427
1000.0	3.786	3.712	34.474
1500.0	3.470	3.356	34.765
2000.0	2.737	2.589	34.835
2500.0	2.510	2.319	34.873
3000.0	2.399	2.161	34.878
3500.0	2.361	2.072	34.884
4000.0	2.393	2.047	34.887
4500.0	2.438	2.033	34.887
4522.0	2.441	2.033	34.887

**Station 233 Profil 19**  
**08° 59.96 W 22° 23.96 S**  
**03.05.1998 UTC 19:00 4192 m**

<b>p</b> <b>dbar</b>	<b>T</b> <b>°C</b>	<b>θ</b> <b>°C</b>	<b>S</b>
2.0	24.105	24.105	36.497
10.0	24.031	24.029	36.552
20.0	24.018	24.013	36.580
50.0	24.002	23.992	36.612
75.0	23.018	23.003	36.397
100.0	20.287	20.268	36.003
150.0	17.878	17.853	35.818
200.0	15.852	15.820	35.536
250.0	14.185	14.148	35.302
300.0	12.934	12.893	35.140
350.0	11.835	11.790	35.018
400.0	10.389	10.341	34.830
450.0	9.211	9.161	34.721
500.0	8.096	8.044	34.603
600.0	6.102	6.048	34.446
700.0	4.872	4.816	34.395
800.0	4.184	4.124	34.414
900.0	3.867	3.801	34.450
1000.0	3.646	3.573	34.512
1500.0	3.473	3.359	34.810
2000.0	3.058	2.905	34.890
2500.0	2.589	2.397	34.878
3000.0	2.441	2.203	34.878
3500.0	2.364	2.075	34.883
4000.0	2.382	2.037	34.888
4236.0	2.401	2.028	34.889

**Station 234 Profil 20**  
**09° 00.15 W 21° 12.10 S**  
**04.05.1998 UTC 03:51 3941 m**

<b>p</b> <b>dbar</b>	<b>T</b> <b>°C</b>	<b>θ</b> <b>°C</b>	<b>S</b>
4.0	24.325	24.324	36.693
10.0	24.328	24.326	36.693
20.0	24.333	24.328	36.693
50.0	24.336	24.326	36.691
75.0	21.873	21.858	36.273
100.0	20.422	20.403	36.141
150.0	17.202	17.177	35.765
200.0	15.492	15.461	35.504
250.0	14.056	14.020	35.286
300.0	13.295	13.253	35.187
350.0	11.710	11.665	34.996
400.0	10.229	10.182	34.829
450.0	9.126	9.076	34.716
500.0	8.037	7.986	34.611
600.0	6.378	6.323	34.501
700.0	5.088	5.030	34.424
800.0	4.329	4.268	34.434
900.0	3.947	3.880	34.468
1000.0	3.736	3.663	34.519
1500.0	3.439	3.326	34.816
2000.0	3.036	2.883	34.898
2500.0	2.654	2.461	34.894
3000.0	2.441	2.203	34.882
3500.0	2.368	2.079	34.881
3876.0	2.381	2.050	34.882

**Station 235 Profil 21**  
**09° 00.09 W 20° 00.03 S**  
**04.05.1998 UTC 13:03 3959 m**

<b>p</b> <b>dbar</b>	<b>T</b> <b>°C</b>	<b>Θ</b> <b>°C</b>	<b>S</b>
2.0	23.967	23.967	36.466
10.0	23.943	23.941	36.461
20.0	23.890	23.886	36.459
50.0	23.846	23.836	36.455
75.0	21.581	21.566	36.252
100.0	20.324	20.305	36.206
150.0	18.076	18.050	35.881
200.0	15.206	15.176	35.431
250.0	13.364	13.329	35.196
300.0	11.904	11.865	35.028
350.0	10.750	10.707	34.906
400.0	9.552	9.506	34.775
450.0	8.259	8.212	34.644
500.0	7.205	7.157	34.552
600.0	5.883	5.830	34.486
700.0	5.030	4.973	34.450
800.0	4.329	4.268	34.458
900.0	4.001	3.934	34.494
1000.0	3.840	3.765	34.541
1500.0	3.642	3.527	34.824
2000.0	3.092	2.938	34.903
2500.0	2.643	2.450	34.891
3000.0	2.454	2.216	34.884
3500.0	2.388	2.099	34.883
3962.0	2.396	2.055	34.889

**Station 236 Profil 22**  
**09° 46.23 W 18° 59.98 S**  
**04.05.1998 UTC 21:48 3838 m**

<b>p</b> <b>dbar</b>	<b>T</b> <b>°C</b>	<b>Θ</b> <b>°C</b>	<b>S</b>
4.0	24.448	24.448	36.733
10.0	24.452	24.450	36.732
20.0	24.458	24.454	36.733
50.0	24.412	24.401	36.720
75.0	21.409	21.394	36.228
100.0	19.608	19.590	36.066
150.0	17.286	17.261	35.756
200.0	14.320	14.291	35.323
250.0	12.773	12.739	35.124
300.0	11.544	11.506	34.986
350.0	10.058	10.017	34.821
400.0	9.351	9.306	34.753
450.0	8.538	8.490	34.676
500.0	7.379	7.330	34.567
600.0	5.785	5.734	34.484
700.0	4.723	4.668	34.452
800.0	4.236	4.175	34.464
900.0	3.936	3.869	34.499
1000.0	3.824	3.750	34.567
1500.0	3.668	3.551	34.836
2000.0	3.172	3.017	34.904
2500.0	2.706	2.512	34.896
3000.0	2.466	2.227	34.886
3500.0	2.404	2.114	34.883
3856.0	2.428	2.098	34.884

**Station 236 Profil 23**  
**09° 46.20 W 18° 59.98 S**  
**05.05.1998 UTC 00:57 3840 m**

p dbar	T °C	$\theta$ °C	S
2.0	24.431	24.430	36.740
10.0	24.447	24.445	36.738
20.0	24.434	24.430	36.738
50.0	24.434	24.423	36.735
75.0	22.587	22.572	36.388
100.0	19.317	19.299	36.047
150.0	17.077	17.052	35.730
200.0	14.577	14.547	35.365
248.0	13.174	13.140	35.178

**Station 243 Profil 24**  
**12° 42.67 W 19° 22.00 S**  
**07.05.1998 UTC 22:22 4536 m**

p dbar	T °C	$\theta$ °C	S
4.0	24.677	24.676	36.697
10.0	24.673	24.671	36.715
20.0	24.674	24.670	36.730
50.0	24.630	24.619	36.739
75.0	22.372	22.357	36.394
100.0	20.598	20.579	36.252
150.0	18.568	18.542	36.046
200.0	16.025	15.993	35.612
250.0	14.194	14.158	35.316
300.0	12.601	12.560	35.108
350.0	11.131	11.087	34.959
400.0	9.763	9.717	34.798
450.0	8.568	8.520	34.671
500.0	7.347	7.298	34.567
600.0	5.764	5.712	34.472
700.0	4.829	4.773	34.446
800.0	4.267	4.206	34.457
900.0	3.825	3.759	34.500
1000.0	3.700	3.626	34.548
1498.0	3.482	3.368	34.849

**Station 248 Profil 25**  
**17° 15.12 W 19° 05.75 S**  
**09.05.1998 UTC 18:30 3453 m**

p dbar	T °C	$\theta$ °C	S
2.0	25.829	25.829	36.947
10.0	25.567	25.564	36.971
20.0	25.541	25.536	36.993
50.0	25.523	25.512	37.005
75.0	23.108	23.093	36.537
100.0	21.152	21.132	36.413
150.0	19.127	19.100	36.152
200.0	16.246	16.214	35.637
250.0	14.339	14.302	35.352
300.0	12.869	12.828	35.167

p dbar	T °C	$\theta$ °C	S
350.0	11.445	11.401	35.000
400.0	10.030	9.983	34.841
450.0	8.928	8.879	34.728
500.0	7.941	7.890	34.636
600.0	6.127	6.073	34.497
700.0	4.823	4.767	34.431
800.0	4.213	4.153	34.437
900.0	3.847	3.781	34.467
1000.0	3.713	3.640	34.508
1500.0	3.651	3.535	34.847