AR9−WHP work during POLARSTERN ANT−XIV, Leg 4

Status: 26 November 1998
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0. Preliminary Remark

This report summarizes and updates hydrographic work that has been conducted during POLARSTERN cruise ANT−XIV−4 as part of the World Circulation Experiment (WOCE). It first has been described in the cruise report by D.K. Futterer and co−workers (1998).
The present summary is designated as accompanying document to the WOCE hydrographic programme.
It describes CTD data processing and calibration of the CTD sensors.

1. Cruise Narrative

Expedition designation:

WOCE−Südatlantik 1997
Kap der Guten Hoffnung Experiment (KAPEX), see also Boebel et al (1998) and http://triton.sea.uct.ac.za

Chief Scientist

Dieter K. Futterer, AWI, Bremerhaven, Germany

Ship

FS POLARSTERN, Bremerhaven, Germany

Leg

ANT−XIV/4: Cape Town − Bremerhaven
21 March − 25 April 1997

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For further details see cruise report by Futterer et al (1998).

2. Measurement Techniques, Calibration and Processing

2.1 CTD/Rosette

Station numbers are not only related to CTD work; thus they are gappy. CTD profiles are counted consecutively, with gaps occuring only if profiles have been omitted.

The only CTD in use was a Neil Brown MKIIIB instrument (IFMK internal identification NB2). This instrument carried a Pt100 Rosemount temperature sensor, a (fast) NTC temperature sensor for analogue time constant compensation, a strain gauge pressure sensor made by Paine Instruments, a standard NBIS 4−electrode conductivity sensor, and a polarographic type Beckman oxygen sensor. The outputs of both temperature sensors are combined in an analogue circuit to a single signal. Pre− and post cruise lab calibration are available for the combined temperature signal and for the pressure sensor. The calibration of conductivity depends on in−situ samples. No oxygen samples are available to calibrate the oxygen sensor.

In−situ samples to measure salinity, were drawn from 10 l Niskin bottles mounted on a 24 x 10 l General Oceanics rosette sampler. Bottles were closed on the way up. Samples were drawn immediately after the profile. Salinity samples solely served for CTD calibration.

No samples were drawn from bottles that failed to close properly or showed other problems like apparent leaking. These bottles therefore are not included in the bottle file. This also means that all bottles in the file were flagged as ’no problem’ (QF2).

2.2 Bottle Salinity

Samples to be analyzed for salinity usually were drawn from:

- The deepest point of the profile or 20 m above the bottom, for the1500 m and the bottom stations respectively
- The Antarctic Intermediate Water level
- The mixed layer where vertical gradients are small

All samples were filled to German beer bottles ’Flensburger Pils’,a cheap and social method that has been recommended in pre−WOCE daysby Grasshoff et al. (1983) and that keeps samples stable over the typical length of a cruise (4 weeks) better than 0.001 psu.

Batch No P122 of IAPSO standard seawater was used to standardize the salinometer. No double samples were considered. The overall accuray of bottle salinities for calibration purposes of the CTD
is estimated by the precision of the overall calibration (0.005 psu) and the accuracy standard seawater (better 0.001 psu) to 0.002 psu.

Bottle salinities that differ more than 2.8 and 3.5 times the standard deviation in salinity calibration from the calibrated CTD salinity (see below) were flagged as suspicious (QF3) and bad (QF4), respectively. The bottles may have closed at wrong positions here. However, since no other samples were taken, no corrections for wrong bottle depths have been made.

2.3 Bottle Oxygen

No samples drawn, therefore the oxygen values in the data fileshave to be regarded as uncalibrated.

2.4 CTD: Data Processing

The CTD used throughout the cruise was a Neil Brown MKIIIB (IFMK identifier NB2). It was mounted below a 24 x 10 l bottle rosette made by General Oceanics and lowered at almost constant speed (about 1 m/s) from 200 m depth on. Data processing is similiar to that described by Millard and Yang (1993). The steps were:

- Visually inspect each profile, especially to identify ’strange’ effects in the pressure record.
- Create a time relative to the start of the profile for each record to well resolve the record interval 1/32 s.
- Check that pressure, temperature and conductivity are in reasonable ranges.
- Remove spikes in pressure, temperature and conductivity values.
- Identify the first ’in water’ record and associated pressure offset from the first reasonable conductivity measuremnet.
- Remove cycles that were taken at a lowering speed less 0.2 m/s.Monotonize with respect to increasing pressure. For a lowering speed of 1 m/s, the number of remaining cycles then corresponds to the resolution of the pressure sensor.
- Correct for different response times of the (combined) temperature and conductivity measurements. Visual inspections in large gradients suggested a 60 ms time constant for a recursive filter to slow down the conductivity response.
- Apply a moving average over 29 cyles (corresponding to 3 dbar)
- Apply calibrations to pressure, temperature and conductivity (see below).
- Interpolate Lagrangian to 2 dbar.
- Recalculate salinity and potential temperature.

- Identify records as statically unstable if the vertical gradient of potential density (reference level increasing at500 dbar intervals) over a 2 dbar interval is less −0.001 Kg/m^3. Set salinity flag of such cycles to 3.

For a 2 dbar output interval after removing spikes etc, the number of basic measurements is 13 on the average. This was transferred as constant to the output files.

A special problem showed up in two profiles: At constant lowering rate of the CTD, one expects smooth sensor outputs as a function of time at large depths, say from 1400 m on. However, a problem
showed up with the conductivity signal on station 543/profile 3 and on station 579/profile 35. When plotted, temperature is smoothly decreasing and pressure is linearly increasing as expected but conductivity jumps at 1750 dbar at station 543. This jump could not be removed, and therefore the deeper part of this profile was cut off. At station 579, bad conductivity values occurred between 1198 dbar and 1226 dbar. These were interpolated using polynomial of 3rd. order and flagged as such.

2.5 CTD: Sensor Calibration

2.5.1 Temperature

Pre− and post− cruise laboratory calibrations are available from July 1992 and April 1993, respectively. They were performed over the whole range at 2 K intervals between −1 C and 28 C. As a
secondary standard served a Rosemount Pt25 resistance in a bridge made by SIS, Kiel. The Pt25 was calibrated according to the ITS90. Prior to the CTD calibrations, bias and linear coefficient of the Pt25 basic calibration were adjusted to meet the triple point of water (2 cells independently) and the melting point of Gallium. The adjustments were small (less 1 mK). The quadratic term is believed not to change.

A polynomial regression for the CTD's correction to T90 in pre− and post−cruise calibrations (Tables A1 and A2) shows standard deviation of less than 1 mK with about 10 degrees of freedom. The drift of the sensor output was small (1.5 mK/a at 0 C). High order polynomials are needed to correct for the MKIIIB typical nonlinearity close to 0 C (see Mueller et al., 1995). From these results, temperature outputs TCTD were corrected for both
laboratory calibrations and then interpolated in time to the mean cruise date (Tables A1, A2). Figure 2 shows the corrections applied to the CTD temperatures in the bottle file.

2.5.2 Pressure

Two aspects are important with the calibration of the Paine strain gauge pressure sensor: (i) nonlinear and temperature dependent static responses to pressure changes (including a hysteresis during up−profiles) and (ii) dynamic response to fast temperature changes. Corrections from, both, the static (PRC) and the dynamic responses (PDYN) are superposed linearly to the sensor output PCTD. The procedure has been described in more detail by Mueller et al. (1994, 1995).

PRES = PCTD + PRC + PDYN

Static laboratory calibration is performed on a Budenberg dead−weight tester in loading mode up to 6000 dbar in 500 dbar intervals with the pressure sensor being immersed in a water bath of different temperatures, i.e 13 calibration points at fixed temperatures. At the same temperatures, unloading

calibrations are achieved in 500 dbar intervals starting at maximum pressures of 2000 dbar, 4000 dbar and 6000 dbar. All calibration points are arranged in a single table. For the loading mode, for each
temperature polynomial correction coefficients are calculated (PRC=POLY(PCTD,TEMP). Typical standard deviations in a 3rd to 5th order polynomial regression are less than 1 dbar.

The dynamic response model used is written:

PDYN = k * (T1l − T2l)

where T1l and T2l are lagged from the CTD temperature sensor at
record time t(j):

Tl1(j)=TCTD(j) + (Tl1(j−1)−TCTD(j))*exp(−(t(j)−t(j−1))/tau1)
Tl2(j)=Tl1(j) + (Tl2(j−1)−Tl1(j)) *exp(−(t(j)−t(j−1))/tau2)

The three coefficients tau1, tau2 and k are the two time constants representing the temperature response time at the outer (tau1) and the inner (tau2) part of the pressure sensor, respectively, and an amplitude that typically amounts to 0.2 dbar/K. These coefficients are calculated from a laboratory dunck
test with the pressure sensor being duncked from a warm (20 C) water pool into a cold (0.5 C) water pool. The sensor is kept there until full response is achieved and duncked back to the warm water pool again. With the dynamic correction applied, the error in the pressure sensor output can be reduced to less than 30% of its amplitude.

To process the pressure record in CTD profiles of M28/2, it was assumed that the CTD was in temperature equilibrium before the profile started. Then, for the lowering part pressure measurements were corrected with the polynomial regressions that are valid for the two temperatures that bracket the in−situ temperature with the bias being replaced by the ’in water’ offset. The two resulting corrections are linearly interpolated with respect to temperature. If the in−situ temperature was outside a calibration interval the correction was constantly set forth. Finally, the dynamic correction was added.

On the way up, hysteresis plays a role, and simple regressions are not possible. Therefore, CTD pressure measurements in the rosette file were corrected by linear interpolation within the calibration table with the offset being replaced by the ’in water’ offset. Dynamic correction started with the assumption that the CTD was lowered at a mean speed of 1 m/s to its maximum pressure.

For M28/2, laboratory calibrations are available for static effects from July 1992 (pre−cruise, Table A3), for static effects at from April 1993 (post− cruise, Table A4) and for the dynamic response to temperature changes from July 1992 (Table A5). They were applied as described above. The accuracy of corrected pressure values is estimated to be better than 3 dbar at full range (6000 dbar). Figure 3 shows the corrections as applied to the CTD pressure sensor records in the bottle file.

2.5.3 Conductivity and Salinity

In the bottle file, bottle salinity and calibrated CTD temperature and pressure are used to calculate in−situ reference conductivity. Then, the CTD cell’s output is corrected for a nonlinearity for values CCTD<=32.768 (Mueller et al., 1995)

CN = CCTD −0.002 mS/cm.

Next, the cell’s output CCTD is compensated to temperature and pressure effects (Millard and Yang, 1993).

CC = CN*(1+ alpha*(TEMP−T0) + beta*(PRES−P0))
where alpha=−6.5e−06, T0=2.8
beta=1.5e−08, P0=3000

In−situ calibration coefficients are then estimated for the compensated conductivity measurements applying a linear least square method for a five coefficient correction CRC that includes a drift correction by profile number PROF, i.e. time (Tables A6).

COND = CC+CRC where
CRC = a1 + (a2+a3*CC)*CC + (a4+a5*PROF)*PROF

It was found that the calibration could be done over the whole data set (Table A6, fig. 4).

Let a conservative estimate of the number of degrees of freedom in the calibration be either the number of profiles from which samples are used or half of all individual samples (2 samples maximum for each profile), whatever is the minimum. From the statistics below, the precision in CTD salinity then is estimated to 0.001 psu. For stations where bottle salinities were measured, accuracy is the maximum of CTD salinity precision and bottle salinity accuracy, i.e. 0.002 psu.

2.5.4 Oxygen

As no oxygen samples were drawn, the CTD oxygen sensor has not been calibrated. The oxygen sensor’s current and temperature output are kept as raw data.

References

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Table A1: ANTXIV/4 pre−cruise temperature calibration of MKIIIB CTD, IFMK NB2, NOV 1993.
TCTD and T90 are the CTD's temperature signal and the reference temperature (secondary standard),
respectively. Polynomial correction of TCTD with coefficients c (values below) gives

TEMP.TDIF=T90−TLAB is the residuum.
TEMP = c(0) + (1 + c(1))*TCTD + c(2)*TCTD^2 + c(3)*TCTD^3 + ...

Temperature calibration in ITS90 with CALTRC.M.

IFMK NB2 FEB96

TCTD	T90	TLAB	TDIF
62181.0000	30.9871	30.9871	−0.0000
62182.0000	30.9876	30.9877	−0.0001
56430.0000	27.9313	27.9312	0.0001
50753.0000	24.9159	24.9159	0.0000
41471.0000	19.9888	19.9884	0.0004
32035.0000	14.9815	14.9822	−0.0007
22628.0000	9.9942	9.9942	−0.0000
13210.0000	5.0032	5.0031	0.0001
11294.0000	3.9881	3.9880	0.0001
9422.0000	2.9968	2.9963	0.0005
7534.0000	1.9960	1.9962	−0.0002
5651.0000	0.9990	0.9989	0.0001
4716.0000	0.5036	0.5037	−0.0001
3753.0000	−0.0069	−0.0063	−0.0006
3761.0000	−0.0021	−0.0021	0.0000
2799.0000	−0.5116	−0.5116	−0.0000
1864.0000	−1.0068	−1.0067	−0.0001
720.0000	−1.6123	−1.6125	0.0002
714.0000	−1.6155	−1.6156	0.0001

```
 Polynomial degree    is M=3
 Number of data pairs is N=19

 Coefficients, starting at lowest order:

 co(0)= −1.993698e+00
 co(1)=  5.294941e−04
 co(2)=  1.168238e−11
 co(3)=  4.656400e−17

Statistics:
Range: minimum         is  −1.615500e+00
       maximum         is   3.098760e+01
Number of data points is             19
Degree of fit          is              3
Degree of freedoms     is             15
Test sigq=rms/(N−M)    is   1.740346e−05
Mean error             is   1.940402e−15
66 perc error, rms     is   2.784554e−04
95 perc error, 2*rms   is   5.569108e−04
99 perc error, 3*rms   is   8.353661e−04
Minimum of error       is  −6.637854e−04
Maximum of error       is   5.292969e−04
```

Table A2: ANTXIV/4 post−cruise laboratory pressure sensor calibration of MKIIIB CTD, IFMK NB2, NOV 1993. Calibration with the sensor immersed into a bath at two temperatures (1 C and 10 C). Unloading modes starting at different maximum pressures.

Pressure calibration with CALPRC.M.

IFMK NB2 MAY96

Input data with PCTD at reference pressure and temperatures:

N O T E : If spikes were removed do not use the last table in the output. Repeat calculation then with spikes removed from start on:

TEMP PRES	0.2	0.5	0.7	0.3	10.9	11.2	11.3	11.0	24.9	24.8	24.8	24.9
0.0	1.5	2.6	2.5	2.9	2.5	2.6	2.6	3.3	1.9	2.7	2.9	3.2
500.0	500.3	505.6	505.1	505.4	501.0	506.1	505.7	506.3	500.4	505.9	505.5	505.8
1000.0	1002.1	1008.4	1007.1	1008.2	1002.7	1008.7	1007.7	1008.7	1002.1	1008.4	1007.3	1008.2
1500.0	1503.9	1509.2	1506.9	1509.1	1504.3	1509.7	1507.4	1509.7	1503.6	1509.2	1506.9	1508.9
2000.0	2005.0	2009.0	2004.9	2009.0	2005.3	2009.3	2005.3	2009.3	2004.5	2008.6	2004.8	2008.5
2500.0	2505.3	2507.9	−9999.0	2507.8	2505.5	2508.1	−9999.0	2508.2	2504.4	2507.2	−9999.0	2507.2
3000.0	3005.0	3006.4	−9999.0	3006.7	3005.0	3006.6	−9999.0	3006.8	3003.9	3005.6	−9999.0	3005.8
3500.0	3504.4	3504.9	−9999.0	3505.4	3504.5	3505.1	−9999.0	3505.7	3503.1	3504.0	−9999.0	3504.3
4000.0	4003.9	4003.6	−9999.0	4004.6	4003.7	4003.9	−9999.0	4004.5	4002.4	4002.5	−9999.0	4003.3
4500.0	4503.5	−9999.0	−9999.0	4504.0	4497.1	−9999.0	−9999.0	4500.9	4501.9	−9999.0	−9999.0	4502.4
5000.0	5003.5	−9999.0	−9999.0	5003.7	5003.4	−9999.0	−9999.0	5003.6	5001.8	−9999.0	−9999.0	5001.8
5500.0	5503.7	−9999.0	−9999.0	5503.9	5503.4	−9999.0	−9999.0	5503.9	5501.6	−9999.0	−9999.0	5502.0
6000.0	6004.3	−9999.0	−9999.0	6004.6	6004.3	−9999.0	−9999.0	6004.4	6002.4	−9999.0	−9999.0	6002.2

Loading curve at temperature T0= 0.5

PCTD	PREF	PPOL	PDIF
1.5	0.0	1.5	−1.5
500.3	500.0	499.5	0.5
1002.1	1000.0	999.8	0.2
1503.9	1500.0	1500.1	−0.1
2005.0	2000.0	2000.2	−0.2
2505.3	2500.0	2500.1	−0.1
3005.0	3000.0	2999.9	0.1
3504.4	3500.0	3499.9	0.1
4003.9	4000.0	4000.0	0.0
4503.5	4500.0	4500.0	−0.0
5003.5	5000.0	5000.1	−0.1
5503.7	5500.0	5499.9	0.1
6004.3	6000.0	6000.0	−0.0

Coefficients for static correction at temperature T0=0.5 C

PRES(T0)=PCTD(T0)+Pol(PCTD(T0))

Polynomial degree   is M=5
Number of data pairs is N=13

Coefficients, starting at lowest order:

```
co(0)=  0.000000e+00
co(1)=  0.000000e+00
co(2)= −3.963898e−06
co(3)=  1.985301e−09
co(4)= −3.434035e−13
co(5)=  1.988652e−17
```

Statistics:

```
Range: minimum         is   0.000000e+00
       maximum         is   6.000000e+03
Number of data points  is             13
Degree of fit          is              5
Degree of freedoms     is              7
Test sigq=rms/(N−M)    is   5.699552e−02
Mean error             is  −7.872762e−02
66 perc error, rms     is   4.559641e−01
95 perc error, 2*rms   is   9.119283e−01
99 perc error, 3*rms   is   1.367892e+00
Minimum of error       is  −1.499991e+00
Maximum of error       is   4.644453e−01
```

CTD pressure output first order corrected with respect
to loading at T0= 0.5

TEMP PRES	0.2	0.5	0.7	0.3	10.9	11.2	11.3	11.0	24.9	24.8	24.8	24.9
0.0	1.5	2.6	2.5	2.9	2.5	2.6	2.6	3.3	1.9	2.7	2.9	3.2
500.0	499.5	504.8	504.3	504.6	500.2	505.3	504.9	505.5	499.6	505.1	504.7	505.0
1000.0	999.8	1006.1	1004.8	1005.9	1000.4	1006.4	1005.4	1006.4	999.8	1006.1	1005.0	1005.9
1500.0	1500.1	1505.4	1503.1	1505.3	1500.5	1505.9	1503.6	1505.9	1499.8	1505.4	1503.1	1505.1
2000.0	2000.2	2004.2	2000.1	2004.2	2000.5	2004.5	2000.5	2004.5	1999.7	2003.8	2000.0	2003.7
2500.0	2500.1	2502.7	−9999.0	2502.6	2500.3	2502.9	−9999.0	2503.0	2499.2	2502.0	−9999.0	2502.0
3000.0	2999.9	3001.3	−9999.0	3001.7	2999.9	3001.6	−9999.0	3001.8	2998.8	3000.5	−9999.0	3000.7
3500.0	3499.9	3500.4	−9999.0	3500.9	3500.0	3500.6	−9999.0	3501.2	3498.6	3499.5	−9999.0	3499.8
4000.0	4000.0	3999.7	−9999.0	4000.7	3999.8	4000.0	−9999.0	4000.6	3998.5	3998.6	−9999.0	3999.4
4500.0	4500.0	−9999.0	−9999.0	4500.5	4493.6	−9999.0	−9999.0	4497.4	4498.4	−9999.0	−9999.0	4498.9
5000.0	5000.1	−9999.0	−9999.0	5000.3	5000.0	−9999.0	−9999.0	5000.2	4998.4	−9999.0	−9999.0	4998.4
5500.0	5499.9	−9999.0	−9999.0	5500.1	5499.6	−9999.0	−9999.0	5500.1	5497.8	−9999.0	−9999.0	5498.2
6000.0	6000.0	−9999.0	−9999.0	6000.3	6000.0	−9999.0	−9999.0	6000.1	5998.1	−9999.0	−9999.0	5997.9

Table A3: ANTXIV/4, MKIIIB CTD, IFMK NB2, APR 1993, pressure senor’s dynamic response to temperature changes. Coefficients are outerand inner sensor time constants tau1 and tau2 and the amplitude k (Mueller et al., 1995; see text).

Coefficients for dynamic pressure correction

```
tau1/s   tau2/s      ishift/s     k/(dbar/K)
52.0518  1530.1525   345.7106     0.1193
```

Table A6: ANTXIV/4, MKIIIB CTD, IFMK NB2: Calibration of conductivity cell.

Model CRC=a1 + (a2+a3*C)*C + (a4+a5*PROF)*PROF

Vector of coefficients:

1	−0.0015
2	3.4870e−04
3	0
4	1.0001e−04
5	−1.2447e−06

Final statistics of residuals:

Number of cycles N=60

	Cond. mS/cm	Salinity psu
Min	−0.0026	−0.0031
Max	0.0028	0.0032
Mean	0.0001	0.0000
Median	−0.0000	−0.0000
Std.	0.0014	0.0016