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# From pole to pole: 33 years of physical oceanography on board of R/V POLARSTERN

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**Abstract.** Measuring temperature and salinity profiles in the world's oceans is crucial to understand ocean dynamics and its influence on the heat budget, the water cycle, the marine environment and on our climate. Since 1983 the German research vessel and icebreaker POLARSTERN has been the platform of numerous CTD deployments in the Arctic and the Antarctic. We report on a unique data collection spanning 33 years of polar CTD (conductivity, temperature, depth) data. In total 131 datasets (one dataset per cruise leg) containing data from 10063 CTD casts are now freely available at doi:10.1594/PANGAEA.860066. During this long period five CTD types with different characteristics and accuracies have been used. Therefore the instruments and processing procedures (sensor calibration, data validation etc.) are described in detail. This compilation is special not only with regard to the quantity, but also the quality of the data - the latter one being indicated for each dataset using defined quality codes. The complete data collection includes a number of repeated sections for which the quality code can be used to

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investigate and evaluate long-term changes. Beginning with 2010, the salinity measurements presented here are of the highest quality possible in this field owing to the introduction of the Optimare Precision Salinometer.

## 1 Introduction

Our oceans are always in motion - huge water masses are circulated not only by winds, but also by global seawater density gradients. These gradients result from differences in water temperatures and salinities and the water movement transports heat, oxygen, $CO_2$ and nutrients among latitudes (Stewart, 2009). Measuring the ocean's temperature and salinity is therefore essential not only to understand the ecology of the world oceans but also the influence of the oceans on our climate.

According to Stewart (2009) the first water samples from depths down to around 1600 m were taken in the tropical Atlantic from the ship "Earl of Hallifax" in 1750/51 with a special bucket and a thermometer (Hales, 1751). The results (a stable cold water layer beneath the warm surface) already hinted to an inflow of deep water from the Polar Regions (Stewart, 2009). Until the 1970s, measurements of ocean temperatures and salinities were conducted primarily using reversing mercury thermometers and Nansen water bottles (Warren, 2008). Due to the usually limited number of Nansen bottles and thermometers on board, the number of depth levels which could be sampled were also limited, which resulted in a rather coarse vertical resolution of temperature and salinity. With the development of submersible electrical instruments for temperature and salinity (conductivity) measurements in the 1950s, high-resolution measurements of temperature and salinity profiles became possible (Brown, 1991; Stewart, 2009). During the 1970s and 80s, the use of CTDs (conductivity, temperature, depth) replaced the formerly used method almost completely. Numerous manufacturers produced a variety of sensors and instruments. In 1974 e.g. Neil Brown formed Neil Brown Instrument Systems, Inc. and manufactured the Mark III CTD[1] (Brown, 1991).

R/V POLARSTERN is a research icebreaker operated by the Alfred Wegener Institute (AWI) in Bremerhaven (Germany), navigating since 1982 in Antarctica (austral summer) and the Arctic (northern summer)[2]. The first CTD used on POLARSTERN was the aforementioned Neil Brown, Mark IIIB CTD. It was deployed for the first time on cruise leg ANT-II/3, during the ships second trip to Antarctica in November/December 1983. This giant step for AWI oceanographers, which was supervised by Gerd Rohardt (Rohardt, 2010a), ended abruptly when that same probe accidentally 'flew' over board a month later during ANT-II/4. Despite many efforts to regain it, the probe was lost, which is why the respective dataset of this leg (Rohardt, 2010b) contains CTD as well as Nansen-bottle derived data. The latter was only possible due to the fact that guest researcher Dr. Manfred Stein (Institut für Seefischerei, Hamburg) had brought Nansen bottles and reversing thermometers as a backup for his ME-OTS-CTD on board during leg ANT-II/2 (no data). This little anecdote clearly demonstrates that 1983 was still a transition period for hydrographic observations to electronic devices.

Despite this rather unfortunate start, a Neil Brown, Mark IIIB CTD was successfully deployed on POLARSTERN until 1996. Already in 1992, a SEA-BIRD SBE 911plus CTD was used by Kees Veth (Royal Netherlands Institute for Sea Research, data included here). A year later, Gereon Budéus was the first AWI researcher using the SBE 911plus on POLARSTERN,

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[1] Later it was manufactured by EG&G Ocean Instruments and after that by General Oceanics

[2] See also the description in Driemel et al. (2016) about POLARSTERN history and cruise characteristics

testing in particular the behaviour of the probe at cold conditions. The instrument was used routinely on POLARSTERN since then, in parallel with Neil Brown equipment. On four cruise legs (1995-1999) POLARSTERN was equipped with the direct successor of the Mark IIIB, called the ICTD and manufactured by Falmouth Scientific. Additionally, two legs (1986/87) have been archived where guest researchers deployed a ME-OTS-CTD. Nowadays the SEA-BIRD SBE 911plus probably is the most widely used CTD type, and since around 1999 is the only type used on POLARSTERN (see also Figure 1).

In the following, we describe a data compilation of 33 years (1983-2016) of CTD measurements from R/V POLARSTERN. In the 'Methods' section we provide details on the CTD types used, on the parameters measured, and on the data processing. A focus is set on the improvement of the salinity measurements over time and the reasons hereof. In the 'Resulting datasets' section we describe the datasets in respect to composition, extent, access and again quality.

## 2 Methods

A CTD directly measures conductivity, temperature and pressure of water during its down- and upcast, resulting in a profile from the water surface to the bottom and back. Derived variables are salinity, density and water depth. The CTDs on board of POLARSTERN were typically deployed in combination with a water sampler construction, holding 12, 24 or 36 bottles (named Rosette or Carousel, depending on the manufacturer, see Figure 2). The CTD is mounted inside the frame of the water sampler in a way that the sensors measure the undisturbed waters during the downcast. The downcast CTD profile is displayed on board in real-time to allow the CTD operator to choose the water layers from which water samples for subsequent chemical and biological analyses are to be taken during the up-cast.

Due to the way of mounting, the measurements during the upcast are not measurements from undisturbed waters but are influenced by water parcels from deeper layers which are dragged upwards by the CTD/Rosette. Therefore, mostly only the downcast CTD profile is used and archived (details see chapter 'Data processing').

### 2.1 Instruments and specifications

Five different CTD types have been used on board of POLARSTERN from 1983 until today. As the instruments changed, so did the range, accuracy, stability, resolution and response of the sensors. Table 1 shows in detail the manufacturers' specifications of the instruments; the respective period of use is illustrated in Figure 1 (SeaBird probes combined). The table also indicates the accuracy limits officially adopted for the World Ocean Circulation Experiment (WOCE). Since the use of the Optimare Precision Salinometer OPS the achieved accuracies are even better than those required by WOCE (see chapter 2.6). However, we would like to stress here that a regular service and calibration is mandatory to keep the instrument at least within the accuracy given by the manufacturer.

### 2.2 Laboratory calibration of instruments

In order to obtain precise hydrographic data, frequent calibrations of the sensors and careful inspection and preparation of the instruments (CTD, water sampler and bottles) is mandatory. From 1983 until 1986 Neil Brown Mark IIIB CTDs were calibrated by the manufacturer. Each sensor had its own electronic board with the calibration stored on it. Changing a sensor thus required installing the corresponding electronic board, too. When Dr. Ray Weiss from Scripps Institution of Oceanography (SIO) participated on POLARSTERN cruise ANT-V/3 in 1986, he suggested including the AWI-CTDs into the SIO calibration process. Since that time, the AWI-CTDs were calibrated by SIO before and after each campaign. The first calibration revealed, that the AWI Mark IIIB showed the same behavior as the SIO Mark IIIB which was: (a) the pressure sensor had a strong hysteresis depending on the maximum pressure and (b) the temperature readout showed a step-like discontinuity near 0°C which further depended on the direction of the temperature change, i.e. whether the temperature increased or decreased (Robert Williams, SIO, personal communication in 1986). Because a temperature correction of such a behavior is fairly complicated, a few years later SIO modified the electronic boards shifting the discontinuity from about 0°C to +3°C.

The Falmouth Triton ICTDs from AWI were also shipped to SIO for calibration. This continued support made the change from Mark IIIB to ICTD much easier, and underlined the advantages of the new instrument: The SIO calibration confirmed that the pressure had a neglectably low hysteresis and that the temperature correction was only small, with no stepwise behavior from -2°C to 30°C.

The long lasting cooperation between AWI and the calibration laboratory of SIO ended after completely switching over to Seabirds SBE911plus because Sea-Bird Electronics themselves performed a high level calibration of their instruments. In general, ever since the SBE 911plus was introduced, the CTD operators' job on board became much easier. The SBE 911plus featured dual sensors (2x temperature and 2x conductivity) and software, which displayed the sensor differences. This allowed identifying and changing sensors which became faulty. Replacing faulty sensors early prevents losing valuable data. With the introduction of dual sensors and the usage of special software, in-situ calibrations were still executed (see chapter 2.4), but the number of samples could be reduced.

### 2.3 Water samplers

With the exception of the self-contained probe SBE19, all CTDs were used in combination with a water sampler. The Neil Brown Mark IIIB was combined with a General Oceanics (GO) Rosette. The GO Rosette required taking numerous samples for the check of the conductivity measurements and also to use reversing thermometers to verify that bottles were closed at the desired depth. The reason is that GO used a non robust mechanical release to close the water samplers. Often the mechanics got stuck, which resulted in the closure of two or more samplers during one release command. This problem was solved with the introduction of the ICTD because Falmouth Scientific (FSI) supplied a new release module which confirmed successful or non-successful release commands. Later the complete GO-hardware was replaced by a release unit from FSI, which used a release system similar to the one used in the SBE32 Carousel Water Sampler, confirming the release command and thus making water sampling more reliable. This positive development (1992 onwards) affected the in-situ calibration, rendering the usage of reversing thermometers obsolete.

### 2.4 In situ calibration

Laboratory calibration of instruments (see chapter 2.2) is crucial to maintain the sensors and obtain comparable results. It is not sufficient, however to anticipate how a sensor behaves at sea under tough environmental conditions, especially during deep casts. Also a sensor drift may not be a continuous process. For this purpose in-situ calibrations are essential.

Temperature: The Mark IIIB CTD was equipped with one temperature (and one conductivity) sensor only. Therefore reversing thermometers attached to the bottles of the water sampler had to be used to verify the quality of the temperature data. The Triton ICTD was equipped with a redundant temperature sensor which allowed for a much better control of temperature data than the reversing thermometers. Lastly, the SBE911plus features double sensors both for temperature and conductivity measurements, allowing to plot the difference between both sensors versus depth which eases identification of individual sensor problems and pressure effects. Additionally, a SBE 35 Deep Ocean Standards Thermometer was attached to the water sampler, recording the temperature every time a water sample was taken. However, to compare the SBE35 temperature with the temperature from the CTD respectively the SBE3plus temperature sensors, the temperature variation has to be extremely low.

Conductivity: For the in-situ calibration of the conductivity sensor (Mark IIIB and Triton ICTD) or the conductivity double sensors (SBE911plus) water samples were taken and measured on board with the laboratory salinometer Guildline Autosal 8400a/b and, since 2010, with the Optimare Precision Salinometer (OPS, see chapter 2.6). The samples were taken from deep (> 3000 m) and shallow depths (ca. 500 - 1000 m) regularly during the CTD deployments in order to reveal pressure effects of the conductivity sensor and its temporal shift.

### 2.5 Data processing

The data processing procedures were substantially dependent on the development of the CTD and the computer generation. In 1983, CTD data were recorded on 9 track magnetic tape. The station data (location, water depth, date and time) were noted on a sheet of paper. An HP 9825B computer was used to visualize the temperature and salinity profile on a connected plotter. The data processing was performed in the institute. Due to the fact that, for safety reasons, the magnetic tapes always came back to Bremerhaven with POLARSTERN, the data processing often only started several months after the end of the cruise leg. Later (around 1986), EG&G - who took over the production of the Mark IIIB in 1984 - transferred the FORTRAN code of the data acquisition and processing routines of the Woods Hole Oceanographic Institution (WHOI) (Millard, 1993) for usage on a PC. A similar software package was also provided for the ICTD from Falmouth Scientific. This made the data acquisition and visualization as well as the transfer of raw data to AWI much easier. The substructure of the software for applying the SIO-calibration came from R. Williams and F. Delahoyde in 1990 (personal comm.).

Seabird Electronics provided the data acquisition software SEASAVE and developed a package especially for their pumped CTD SBE911plus, SBE DataProcessing. This software became the primary tool for CTD data processing at the AWI. Also, the raw data were routinely stored on the onboard computer and transferred to the AWI in an automatic workflow.

The data processing workflow can be divided into four parts:

### 2.5.1 Data cropping and handling

Data recording started before the actual profile began (starting point: lowering of the CTD/Rosette to the water surface) thus one of the first tasks was the truncation of the unused beginning (the depth of the first 'used' datapoint depends e.g. on the wave height). Converting the raw file in readable engineering units was the next step as well as the separation between the down- and up-cast, if both had been saved in one file. Afterwards, the station information was added to the data file. In the past this information was manually edited from handwritten station protocols. With the inauguration of the DSHIP electronic station book (http://www.werum.de/en/platforms/DSHIP.jsp) station details were directly merged with the CTD data.

### 2.5.2 Correction of measurement errors

Physical properties of the sensors and environmental influences on them, as well as disturbances of the data transmission between sensors and recording units on deck, can create measurement errors. These were reduced using suitable software in the following ways:

- Spikes: Spikes in the pressure measurements, resulting e.g. from winch cable or slip ring problems were removed. The procedure is called “par” in Seabirds SBEDataProcessing software package.
- Response time/time lag correction: Salinity was computed from conductivity, temperature and pressure. The response time of a temperature sensor, however, is higher than the response time of the pressure and conductivity sensors. If left uncorrected, this would result in salinity spikes in layers with strong gradients. A precise correction for this time lag would require a constant lowering speed of the CTD, which is not possible on a moving ship. Seabird solved this problem by pumping water with a constant speed through the temperature and conductivity sensors. For Mark IIIB and ICTD the time lag was adjusted/corrected by minimizing the salinity spikes and evaluated visually based on profile plots.
- Pressure hysteresis: Mark IIIB strain gauge pressure sensors did not respond linearly to increasing pressure and additionally exhibited a lagged response during decreasing pressure. This behavior also depended on the maximum pressure. A laboratory calibration (see chapter 2.2) revealed this behavior and provided the coefficients for the software to apply the correction. However, the software was rather tricky because it only used hysteresis correction for the maximum pressure (6500 dbar) to calculate the correction for all profile depths (R. Williams and F. Delahoyde, personal communication in 1990). A second calibration up to 1500 dbars was recorded to verify the algorithm of the software. ICTDs did not show this behavior and only a minor offset had to be applied. A Digiquatz® pressure sensor from Paroscientific was used in the SBE911plus. This sensor was stable, operating without hysteresis, so no frequent calibration was necessary.

- Compression and thermal effect: The ICTD with its inductive conductivity sensor had a known pressure dependency (compression of the cell ceramics) which was corrected by SBE-software. In addition a thermal mass correction[3] was applied for the ICTD and the SBE911plus conductivity cell.

### 2.5.3 Creation of a uniform profile

- Monotonic increasing pressure: As a ship is always pitching and rolling, the constant lowering speed of the winch is superimposed by the ships motion. Rejecting all records with pressure reversals is thus one of the standard procedures in CTD data processing, and was also applied on POLARSTERN data.

- Averaging: The SBE911plus CTD e.g. sampled with a frequency of 24 Hz. A typical lowering speed of 0.8 m/s resulted in a vertical resolution of around 3 cm. The sample rate was needed to apply the time lag correction reliably and also to guarantee that, although lots of records were rejected, a monotonic increasing pressure record could be created. In the end, the profile was smoothed by averaging on 1 dbar levels (i.e. P, T and C were averaged for instance between >=1.5 and <2.5; between >=2.5 and <3.5 dbar, and so on). As this will not necessarily result in an averaged pressure record for 2.0, 3.0, . . . dbar (more probable e.g. in 1.97, 3.05,..dbar) a linear interpolation was applied for temperature and conductivity, so that the values could be centered on exactly 2.0, 3.0, . . . dbar. Only after this procedure the salinity was calculated.

### 2.5.4 Final correction and validation

- Drift, stability and pressure dependency: The physical characteristics of sensors change continuously through time. This behavior becomes visible as a slight change of their sensitivity. The order of this change is given by the manufacturer ("stability", see Table 1). But the stability depends on the environmental conditions, too. By conducting many deep casts e.g. an additional sensor drift could be induced due to an a priori unknown pressure dependency. Also marine growth inside the conductivity cell will change the drift. On top of it all, POLARSTERN CTDs were deployed even in rough weather conditions meaning that the instruments could bump against the ship's hull or had to experience a hard drop back on deck. These events could result in a visible step-like change. The station log sheets (notes with special occurrences), the pre- and post-calibration and the in-situ calibration helped to reconstruct the history of a sensor during a cruise and to identify which T-C sensor pair should be used. General plotting software can be used to visualize the in-situ calibrations versus pressure or versus time to investigate the dependency (drift), and to then apply and verify the corrections.

- Validation: All profiles were imported into Ocean Data View (Schlitzer, 2015) which provides various plots (profiles, scatter, and sections) for a visual inspection. When a suspicious profile was found, the processing steps mentioned above were repeated from the necessary level onwards. Additionally, these profiles were compared to profiles from previous

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[3] A cell which is lowered e.g. from a warm into a cold layer needs some time to reach the same temperature as the water. That means that heat from the cell is transferred into the water and the water becomes slightly warmer resulting in a higher conductivity

cruises. The working database included a number of regularly repeated transects, which allowed consistency checks and quality confirmation.

### 2.6 Optimare Precision Salinometer

Since 1985, laboratory measurements of salinity were conducted on water samples taken with a Rosette/Carousel multi-bottle sampler to cross-validate the in-situ CTD measurements. These laboratory salinity measurements were made employing salinometers. Salinometer measurements have several advantages compared to in-situ measurements. For one, the salinometer measurements are controlled directly with the primary standard IAPSO Standard Seawater, which means that the salinometer is closer to the primary standard. Furthermore, the calibration of the SBE911plus salinity sensor (SBE4) is done using a bath of nearly constant salinity and varying temperatures, leading to different conductivities. The calibration of the salinometer, however, is done by using different salt concentrations, which makes the salinometer measurements more accurate for salinities varying around the typical open-ocean value of 35.

Until 2010 a salinometer type Guildline Autosal 8400a/b was in use. From then onward it was replaced by a new laboratory salinometer, developed by AWI scientists and engineers and manufactured by Optimare[4]. It is called Optimare Precision Salinometer, OPS (Budéus, 2011, 2015). The highly accurate OPS lab measurements were used [illegible] June 2010 to cross-calibrate in-situ salinity data measured by the CTD. As a result, beginning with campaign ANT-XXV/1 (2010-06) the accuracy of the salinity measurements improved tremendously and the resulting datasets are of the highest quality possible for these kinds of measurements.

## 3 Resulting datasets

In total 131 datasets (one dataset per cruise leg) containing data from 10063 CTD casts have been produced on POLARSTERN in the course of 33 years (1983-11-22 to 2016-02-14, Figure 3) and are archived in the database PANGAEA (Data Publisher for Earth and Environmental Science, www.pangaea.de). The datasets can be accessed using the link: http://doi.pangaea.de/10.1594/PANGAEA.860066 (Rohardt et al., 2016). This link leads to the central "parent"-page which contains all meta-information of the respective cruise legs (name of leg, start/end, area, link to cruise report), the number of CTD-casts, the CTD type used, the overall quality of the data, the link to a map displaying all CTD-stations, as well as the link to the dataset of the specific leg.

When clicking on the link to a dataset of one cruise leg (see e.g. Rohardt, 2010a, doi:10.1594/PANGAEA.733664) the dataset page opens containing metadata, a google map of all sample sites, and on the bottom the actual data. On the top of the page the citation of the dataset is given, followed by the citation of the respective cruise report (if available). The CTD type used is given under "Method". The data table opens by clicking on "View dataset as html". Here, the position, date/time (at maximum depth) of sampling and the water depth precedes the actual data. The 'Elevation' is the bathymetric depth relative to sea level and is therefore negative. It can be used e.g. to extract information on how close to the seafloor the CTD measurements

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[4] Optimare Sensorsysteme GmbH & Co. KG

ended (compare water depth of the last measurement with the elevation). The “Number of observations” is the number of measurements included in one averaging step (see chapter 2.5.3). With programs like Ocean Data View (Schlitzer, 2015) and Pan2Applic (Sieger and Grobe, 2005) the data can be visualized easily, for more information see https://wiki.pangaea.de/wiki/ODV. With respect to CTD type, the 131 datasets are composed of 27 legs with Mark IIIB CTD data, 4 legs with ICTD data, 2 legs with ME-OTS data, 5 legs with data from a SeaBird self-recording CTD and 93 legs with the SBE911plus. Most of the datasets (1992 onwards) contain additional measurements on oxygen concentration, light transmission/attenuation or chlorophyll fluorescence.

### 3.1 Four remarks for the best usage of POLARSTERN CTD data

- If available, the respective cruise report is linked to the dataset. It contains valuable information on the cruise itinerary, the scientific purpose, and also on the quality of the CTD data or the calibration applied
- We defined a column on the overall quality of the data of each leg in Rohardt et al. (2016) called Quality code. Here we use flags ’A’ to ’C’ to classify the data with ’A’ being high quality data, see Table 2 for details.
- In general, the number of decimals in the datasets is at least n+1, with n being the last significant decimal. This was done deliberately, as we experienced that for calculations (e.g. in models), the actual (unrounded) number of the last significant decimal can be essential
- You can search for specific parameters, regions etc. in the datasets described here using the www.pangaea.de search engine and adding ’PSctd’. Try e.g. ’PSctd +parameter:oxygen’ to get all datasets with oxygen measurements. We also added an overview in xls format on additional measurements at http://doi.pangaea.de/10.1594/PANGAEA.860066 ("Further details").

## 4 Conclusions

Even small changes in sea-water density might affect vertical layering of water masses in the ocean (Olbers et al., 2012). Especially at low temperatures small salinity changes affect the density much more than temperature changes of the same order (Schott et al., 1993). Therefore especially in Polar Regions precise salinity measurements are needed. Based on repeated measurements long-term changes of water mass properties can be studied, see e.g. Fahrbach et al. (2011). Figure 4 shows the mean potential temperature and mean salinity of the Weddell Sea Bottom Water from nine repeated CTD sections at the tip of the Antarctic Peninsula. While the temperature shows similar errors of the mean, the errors of the mean salinity became much smaller since 2005, which coincides with the usage of the SBE911plus CTD on POLARSTERN. This illustrates clearly, that when analyzing long-term trends from CTD data, the CTD type has to be taken into account. Additionally, the in-situ calibration on board, a regular service and laboratory calibration, the data processing procedure and experienced operators are all together a criteria for precise data. CTD data therefore is of the highest value only if it comes with a proper documentation.

One ambitious project analyzing and describing the complete set of available Arctic CTD data in respect to quality is currently taking place and will hopefully be published soon (Behrendt et al., in preparation).

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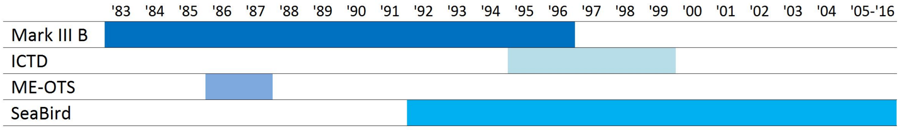

**Figure 1.** Overview of the period of deployment of different CTD types on board of POLARSTERN, first line denotes the years. SeaBird CTD-sondes were here combined into one single bar line

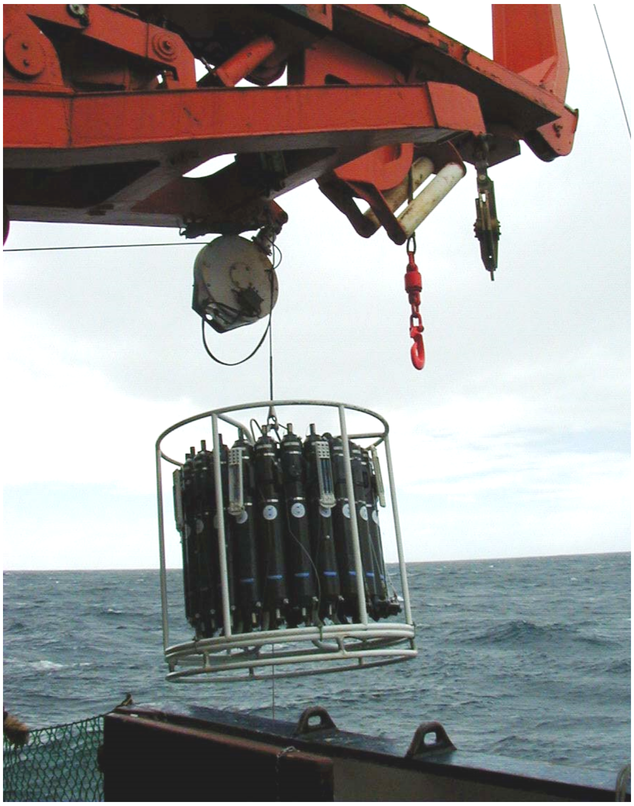

**Figure 2.** Picture of a typical CTD/Rosette system used by the Alfred-Wegener-Institut, picture by Gerd Rohardt

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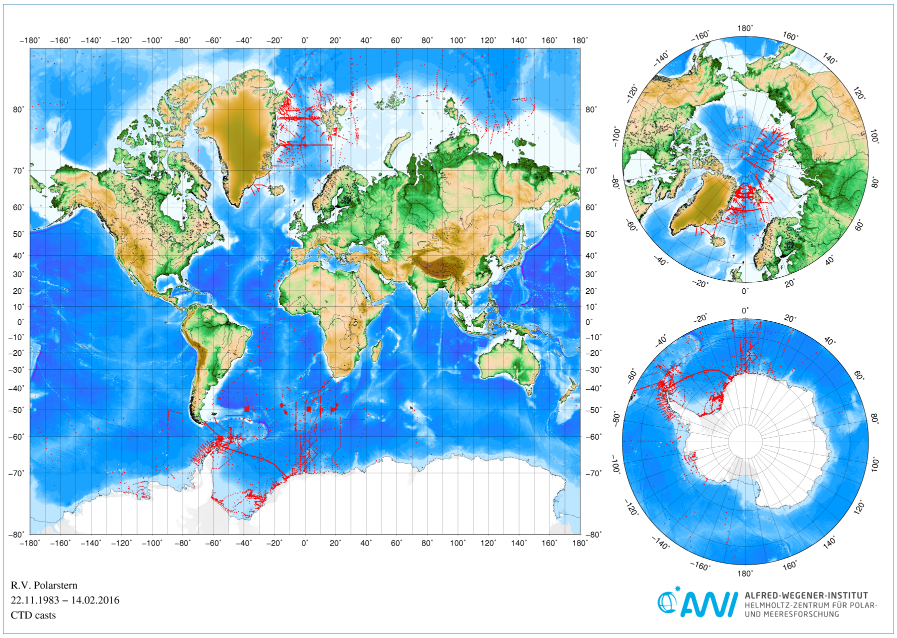

**Figure 3.** Map showing all sites where CTD data have been collected with POLARSTERN from 1983-2016

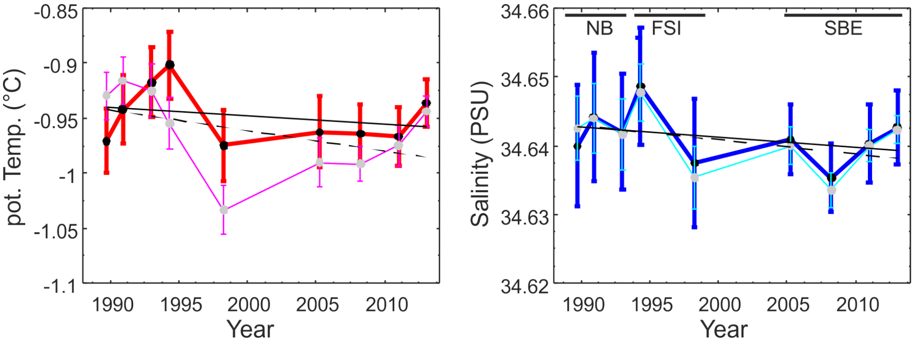

**Figure 4.** Mean potential temperature (left) and mean salinity (right) of the Weddell Sea Bottom Water calculated from nine repeated CTD sections at the tip of the Antarctic Peninsula (Kanzow et al., in preparation). The thin curve - magenta respectively cyan - includes the seasonal effect. In the thick red respectively blue curves the seasonal influence is eliminated. Linear regression lines are shown in black; dashed with seasonality included and solid with seasonality removed. The used CTD type is indicated with NB: Neil Brown, FSI: Triton ICTD, and SBE: SBE911plus

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**Table 1.** Sensor types and the manufacturers' specifications of CTDs used on board POLARSTERN (* = operated by guest institutes; f.s. = full scale; – = no data)

| Instrument and Manufacturer | Period of use | Specifications | Pressure | Temperature | Conductivity |
|---|---|---|---|---|---|
| | | WOCE Accuracy limits | ± 3 dbar | ± 0.001 °C | ± 0.003 mS/cm |
| Multisonde*<br>ME-OTS-CTD<br>Meerestechnik Elektronik, Trappenkamp | 1986/87 | Sensor: | Strain gauge bridge | Platinum resistance | Symetric electrode cell |
| | | Range: | 0 to 6000 dbar | -2 to 35 °C | 5 to 55 mS/cm |
| | | Accuracy: | 0.35 % f.s. | ±0.005 °C | ±0.005 mS/cm |
| | | Stability: | – | ±0.001°C/month | 0.002 mS/cm/month |
| | | Resolution: | 0.2 dbar | 0.001 °C | 0.001 mS/cm |
| | | Response: | – | 60 ms | – |
| Mark IIIB Neil Brown Instruments<br>Later: EG&G Marine Instruments / General Oceanics | 1983 to 1996 | Sensor: | Strain gauge bridge | Platinum Thermistor | 4 electrode cell |
| | | Range: | 0 to 6500 dbar | -3 to 32 °C | 1 to 65 mS/cm |
| | | Accuracy: | ±6.5 dbar | ±0.005 °C | ±0.005 mS/cm |
| | | Stability: | 0.1 %/month | 0.001 °C/month | 0.003 mS/cm/month |
| | | Resolution: | 0.1 dbar | 0.0005 °C | 0.001 mS/cm |
| | | Response: | – | – | – |
| Triton ICTD<br>Falmouth Scientific<br>Product line continued by Teledyne RD Instruments | 1995 to 1999 | Sensor: | Precision-machined Si | Platinum Thermistor | Inductive cell |
| | | Range: | 0 to 7000 dbar | -2 to 35 °C | 1 to 70 mS/cm |
| | | Accuracy: | ±0.01 % f.s. | ±0.002 °C | ±0.002 mS/cm |
| | | Stability: | ±0.002 % f.s./month | ±0.0002 °C/month | ±0.0005 mS/cm/month |
| | | Resolution: | 0.0004 % f.s. | 0.00005 °C | 0.0001 mS/cm |
| | | Response: | 25 ms | 150 ms | 5 cm at 1m/s |
| SBE911plus<br>Seabird Electronics | 1992 to today | Sensor: | Paroscientific Digiquartz | Thermistor | 3 electrode cell |
| | | Range: | 0 to 6800 dbar | -5 to 35 °C | 1 to 70 mS/cm |
| | | Accuracy: | ±0.015 % f.s. | ±0.001 °C | ±0.003 mS/cm |
| | | Stability: | ±0.0015 % f.s./month | ±0.0002 °C/month | ±0.003 mS/cm/month |
| | | Resolution: | 0.001 % f.s. | 0.0002 °C | 0.00001 mS/cm |
| | | Response: | 15 ms | 65 ms | 65 ms |
| SBE19<br>self-recording<br>Seabird Electronics | 1997 to 2003 | Sensor: | Strain gauge | Thermistor | 3 electrode cell |
| | | Range: | 0 to 10000 psi | -5 to 35 °C | 0 to 70 mS/cm |
| | | Accuracy: | 0.15 % f.s. | ±0.01 °C | ±0.01 mS/cm |
| | | Stability: | – | – | – |
| | | Resolution: | 0.015% f.s. | 0.001 °C | 0.001 mS/cm |
| | | Response: | – | – | – |

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**Table 2.** Quality code details for POLARSTERN CTD datasets in PANGAEA

| Quality code | Description | Comment | Possible use (example) |
|---|---|---|---|
| A | Highest accuracy and quality possible | SBE911plus with double sensors; pre- and post-calibration applied, salinity samples measured during the cruise | Investigate long-term changes of temperature and salinity |
| B | Within WOCE accuracy and quality limits | SBE911plus without double sensors, Mark IIIB or ICTD; pre- and post-calibration applied, salinity samples measured during the cruise | Investigate long-term changes of temperature |
| C | Accuracy and quality of the data is rather low or unknown | Without pre- and post-calibration, no salinity samples, or no detailed documentation of data processing | Hydrography for the specific cruise only |