METEOR-Berichte 02-2

North Atlantic 2001

Part 1

Cruise No. 50, Leg 1

7 May – 31 May 2001, Halifax – St. John's

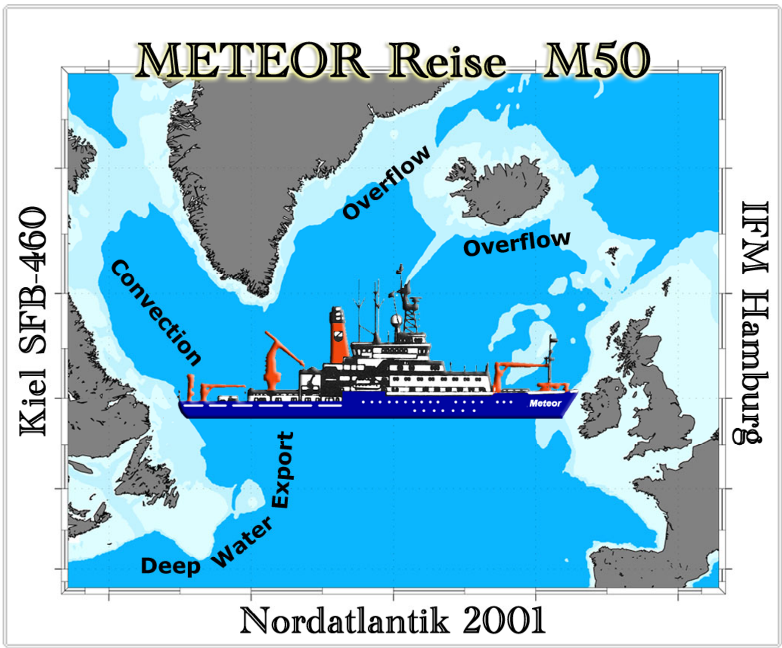

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Table of Contents (M 50/1)

1.1 Participants M 50/1

1	Fischer, Jürgen, Dr.	Chief Scientist	IfMK
2	Begler, Christian	Moorings	IfMK
3	Brandt, Peter, Dr.	CTD/ADCP-Watch	IfMK
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8	Jancke, Kai	Moorings/ADCP	BSH
9	Johannsen, Hergen	Oxygen / Nutrients	IfMK
10	Kahl, Gerhard	Meteorology	DWD
11	Kieke, Dagmar	CFC's, CCL_4	UBU
12	Lübs, Holger	Moorings/CTD	BSH
13	Lüger, Heike	CO_2-System	IfMK
14	Müller, Mario	Moorings/ADCP	IfMK
15	Ochsenhirt, Wolf-Thilo	Meteorology	DWD
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1.2 Research Program

Leg M50/1 from Halifax to St. Johns, Canada, is embedded in the "Sonderforschungsbereich 460" (SFB-460) of the "Institut für Meereskunde, Kiel" (IFMK). The central research object of the SFB-460 is the thermohaline circulation and its variability in the northern North Atlantic. Central to the work performed during this leg are the SFB subprograms A4 and A5.

The aims of subprogram A4 are the quantification of the deep water circulation and its variability in response to the annually and longer term varying forcing fields in the western subpolar North Atlantic. Mass transports and water mass variability are at the focus of these investigations. A variety of observational methods are applied to reach these goals. Moored current meter stations at key locations of the deep circulation are installed for several years, and had to be serviced during this leg. The first current meter array is located at the Tail of the Grand Banks to measure the deep water export from the subpolar to the subtropical North Atlantic. The second array of moorings is located at the exit of the Labrador Sea to measure the deep water (especially the Labrador Sea Water) export out of the source region into the open subpolar North Atlantic. While the Grand Banks array has been recovered and redeployed the second array was only recovered and instruments are prepared to be redeployed during leg M50/2. The mooring work is summarized in Figure 1.1 and table 1.4 in chapter 1.6.

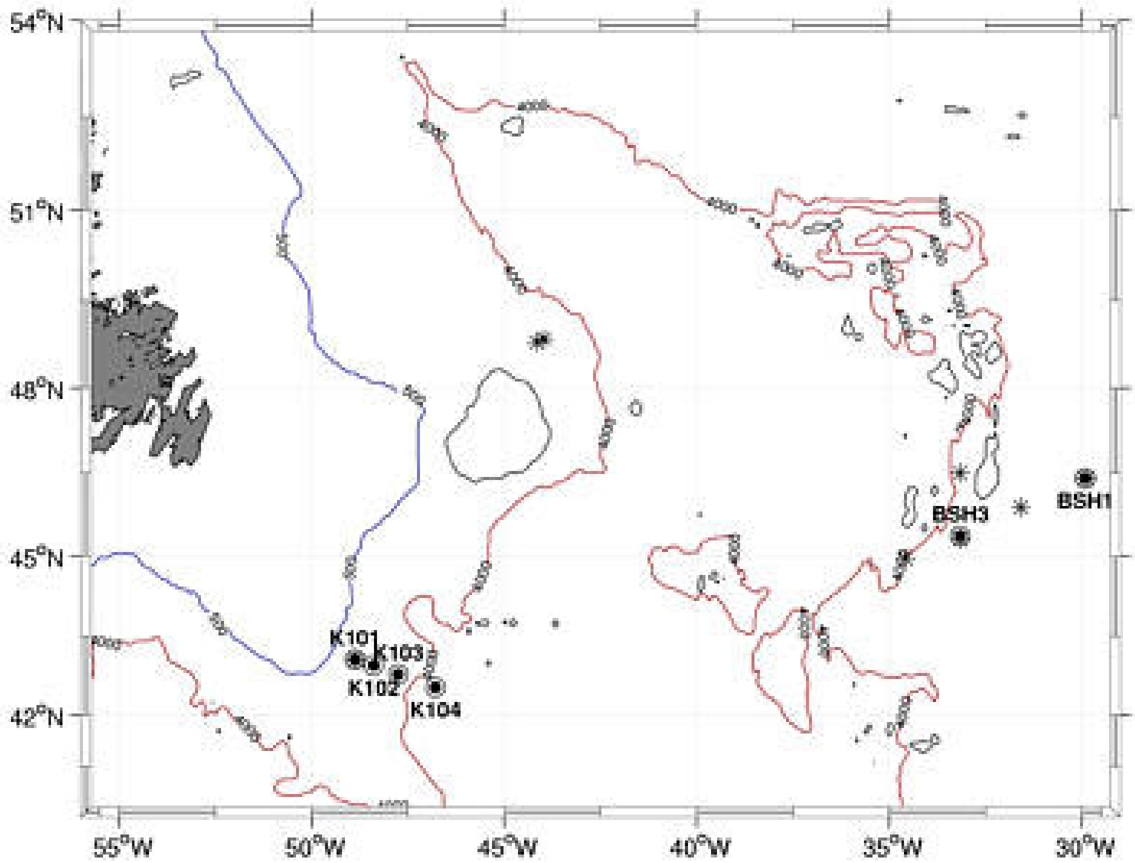

Fig. 1.1: Locations of deployed current meter moorings at the tail of the Grand Banks (IfM-Kiel) and at the Mid-Atlantic Ridge (BSH-Hamburg). Deployment positions of profiling floats (APEX) of IfM Kiel and BSH marked by *).

CTD/LADCP station work concentrated on three boundary current sections, see station map Figure 1.2, with one section replating the former WOCE section A2 from the Grand Banks extending to the Midatlantic Ridge, one section a repetition of the M45/3 – section north of Flemish Cap, and the third section at the exit of the Labrador Sea along the 53° N moored array.

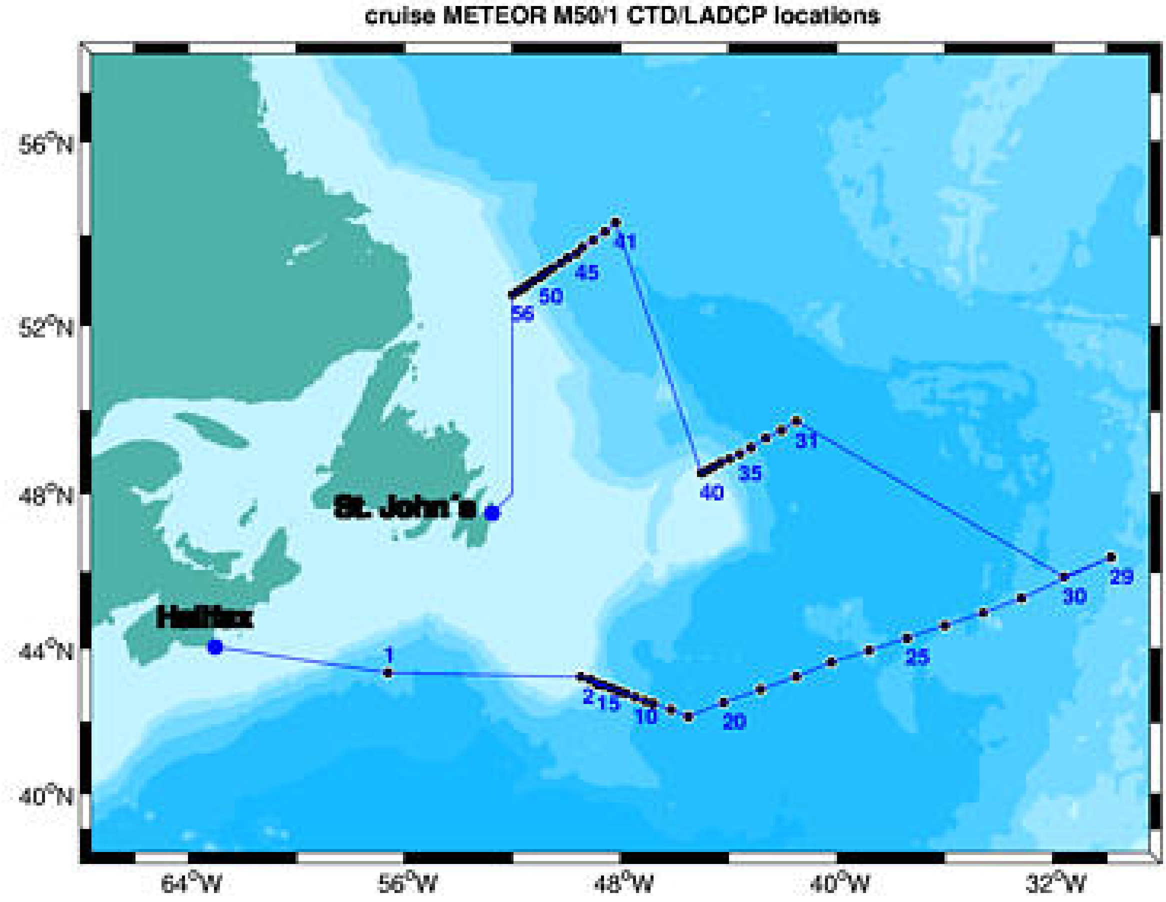

Fig. 1.2: Station list of CTD and LADCP locations of cruise M50/1.

An ADCP attached to the CTD rosette and lowered with it on each station enabled us to directly measure full ocean depth current profiles which are very important in a region of predominantly barotropic currents and in the absence of a reference level with no motion. Several additional parameters were measured from water samples taken at the CTD stations, the main focus being on CFC's (Freon 11 and Freon 12), CCL4 and nutrients taken at all stations. The third component consisted of underway measurements of currents by METEOR's new shipboard ADCP and sea surface parameters measured by the ship's thermosalinograph. These observations were supplemented by autonomous profiling floats (Figure 1.1), drifting with the deep currents and profiling the upper 1500 m of the water column; eight of these floats were launched during this leg (3 IFMK, 5 BSH).

The SFB subprogram A5 investigates the anthropogenic CO_2 increase of the subpolar North Atlantic. Four independent detection strategies were employed; (1) A backcalculation technique which is based on measurements of at least two of the four classical marine CO_2-parameters (total dissolved inorganic carbon, *p*H, total alkalinity, partial pressure of CO_2) together with nutrients and oxygen in surface-to-deepwater profiles; (2) Determination of the carbon isotope ratio $^{12}C/^{13}C$ and phosphate in the water column; (3) Measurement of the ^{14}C-signal in the water column in context with historical data sets; (4) Continuous CO_2 fugacity measurements in the sea surface water and the overlying atmosphere. For the CO_2 working group the transatlantic WOCE A2 section has been repeated the fourth time since 1994 (M30). Therefore, an anthropogenic CO_2 increase should be detectable with respect to the sensitivity of the independent strategies (1)-(4). An additional aspect that can improve the sensitivity of all detection stategies is an improved understanding of the biological impact on the carbon cycle; therefore, samples for total organic carbon (TOC) and chlorophyll were taken.

The two moorings west of the Mid Atlantic Ridge are serviced by BSH since summer 1996. This mooring array covers the deep eastern boundary in the western basin. It was implemented as part of the WOCE activities along the A2/AR19 section. The velocity, temperature and salinity data will describe the long-term changes of this current system that appears to play an important role in the exchange of newly formed water masses such as the LSW within the ocean basin and across the ridge. The moorings have been redeployed for another year, to be recovered in summer 2002 by RV "GAUSS".

Floats have been increasingly used in the past decade to provide profiles of temperature and salinity of the top 1500 m of the ocean throughout the year and for using the Lagrangian displacement between ascents to estimate the current velocity at the parking level. Five APEX floats manufactured by Webb Corp., USA were reseeded at sites where in previous years similar floats had already been launched.

1.3 Narrative of the Cruise

Heavy loading activities took place on Monday, May 7, 2001, including the transport of tested instruments from Bedford Institute (BIO) to the METEOR. Departure from Halifax was as scheduled on Tuesday, May 8, a nice and sunny day. Winds were weak and METEOR sailed at 12 kn towards the edge of the Grand Banks. Most of the scientific party were still tying down their equipment.

In the afternoon of May 9, we had a boat manœuver where some of us had the opportunity to make some photographs from METEOR at sea during her 50ties cruise. This manœuver was followed by the first test station with the CTD/LADCP package lowered to 2000 m depth (table 1.3 in chapter 1.6). The ADCP used was inside the damaged container, but worked well during that first station. Most of the test-measurements were successful. Some of the scientific party and the staff of the electronics department worked hard to get METEOR's new ADCP, a 75kHz phased array called Ocean Surveyor, running.

By May 10, we were still steaming towards the edge of the Grand Banks, where we arrived at about 23:00. We now had two shipboard ADCP's running, a 150 kHz narrow band sytem built into the ship's hull and the new Ocean Surveyor in the sea chest. Both instruments showed surprisingly large ranges (400 m and 700 m). Overnight CTD stations in shallow water were carried out until the scheduled mooring recovery time at 6:00 (9:00 UTC) (Table 1.4 in chapter 1.6). Due to low visibility (foggy) the mooring work was shifted by 1.5h. At 7:35 we began to interrogate the releases of mooring K101 using first the shipboard transducer stem with no success. When lowering the hydrophon over the side of the ship both releases responded. At 8:15

the mooring was released and 10 min later the mooring radio indicated the surfacing of the mooring. The mooring top was found by using the radio bearings of the ships receiver and at 9:50 all components were safely recovered. Before the next mooring CTD stations were performed underway to mooring K102. This mooring was released at 14:20 (17:20 UTC); visibility was much better after crossing the NAC front a few miles west of the mooring position.

In between the mooring work, CTD stations were made towards mooring K103 which we recovered in the early morning of May 12. In the afternoon the last mooring off the Grand Banks (K104) was recovered.

On Sunday, May 13, we started to redeploy the moored array beginning with mooring K103 (2. deployment). On May 14, we deployed moorings K101 (2. depl.) and K102 (2. depl.). It was quite easy to launch K101 on the target position as winds and currents were low. As instruments had touched the deck during deployment (not severe) we decided to use a toggle release hook for the following deployments. As an additional activity the first IfM Kiel float was launched at 13:38 UTC.

Our arrival at the position of mooring K104_2 on 15.05.2001 was somewhat delayed due to head winds that slowed the ship down to 9 kn. Mooring work began with the first element launched at 11:58. At 13:32 UTC the stainless steel wire beneath the last Aanderaa broke on deck, but the instrument (and the rest of the mooring) was still save in the toggle release. Unfortunetely one of the seaman was hurt at his leg. This led to some unplanned maneuvers during which the mooring driftet northward, such that the target position could not be held. The water depth at this slightly different place was still ok: 4280m uncorrected (Correction about 8m), for final position see table 1.5 in chapter 1.6.

This was the last mooring activity at the Grand Banks and we headed towards the Midatlantic Ridge performing a CTD program along the former WOCE section A2. Station distance was only affordable at a little more than 60 nm in order to arrive at the western BSH mooring (3) during the morning of May 19. However, the weather became unfavourable with winds blowing at 6 to 7 Bft. from easterly directions.

At somewhat more rough weather we arrived at the BSH mooring in time. Southeasterly winds at 7-8 Bft., low visibility and rain showers made working on deck rather unpleasant. At 6:20 the mooring was released and it was sighted a little south of the expected position. The radio beacon worked but was difficult to hear. It took some time to recover the thermistor strings, but at 10:30 the releasers were savely recovered. Mooring recovery was followed by a CTD station and float (302) deployment. The weather became much better meanwhile and at 15:03 the deployment began at 45°26.87'N, 33°08.97'W. The thermistor strings went out much faster than expected. The anchor was dropped at 17:34 at 45°21.34'N, 33°09.28'W . Steaming to the top buoys we were able to observe the top element descending for final position of the mooring see table 1.5 in chapter 1.6.

Unfortunately some of us were not present during the M50 celebration (due to some delay in the mooring work), but had the nice dinner and some fresh beers thereafter. Kapt. Kull said a few words and thanked the Leitstelle and RF. T-shirts and Jubiläumsteller are a nice reminder for participating the 50th METEOR cruise.

On our way to the eastern BSH mooring (1) a BSH float was launched (table 1.6 in chapter 1.6) halfway between the moorings. The recovery of BSH-1 began at 08:04 (local). The visibility was good and it was no problem to spot the ADCP buoy without the radio beacon operating on that mooring. At 11:15 the releasers were on deck.

As one of the immediate operations we tried to service the ADCP of that mooring, but were not able to establish good communication with the instrument. Therefore we decided not to redeploy that ADCP and altered the mooring top accordingly (replacing the Foam Float by 10 Benthos glass spheres). Deployment start was at 18:02 UTC and all instruments except the releasers were launched until 20:30 UTC, much faster than expected for the three thermistor strings. As we were 2 nm away from the target position the mooring was towed into position for about one hour. After the deployment the fourth BSH float was launched near the mooring position. Thereafter we steamed back to a position half way between the moorings for the last CTD station at that section (former WOCE A2 section).

After the last CTD station METEOR headed northwestward towards the Flemish Cap (FC) section. On our way to that section we dropped the last BSH Float about 75 nm from the beginning of the transit section. Wheather reports were unfavourable, prognosing a heavy storm lying between us and our destination. Winds and swell increased considerably during the day and the night to May 22. We had a stormy day and night with the ship heading into the wind at low (5-6 kn) speeds. A considerable delay had to be taken into account. On May 23, we reached the FC section and the first station began at 16:00 local (19 UTC). The station coverage had to be reduced from 12 to 10 stations in order to finish that section in time for the rest of the program. Station work went smooth and we were a little ahead of the schedule. Winds of May 24 are decreasing further. Two floats were released (Float 288 on CTD station 36, and Float 289 about midway between station 36 and 37 at 2000 m water depth).

Station work at the Flemish Cap section ended early morning of May 25, and we are heading northwestward to the 53°N - section where we expect some more CTD stations and the recovery of three moorings.

However, the transect to the 53°N section was faster than expected, as northerly winds were weaker than expected. Station work along that section went smoothly and we arrived at mooring K27 a little ahead of time. Recovery was scheduled for 12.30, after lunch. The recovery went very well and two hours later everything was on deck. Overnight station work kept us busy until the next morning. Two moorings should be recovered on May 28. The first, K28, was released after breakfast and was recovered safely at 10:45 (local). Then we steamed to the position of the last mooring, K29. We began to interrogate the two releases with both, the built-in hydrophone and one deployed over the side without success. During the next three hours we tried to release the mooring. Visibility was exellent, winds about 5 Bft from southerly directions. There were no signs of the mooring. We made a nearby CTD cast (about one mile away), which took about 2 hours. After that we surveyed the area with several observers on the bridge but without any success. As there was no immediate dredging possible, we decided to leave that operation for the second leg (M50/2). A little north of the mooring position we performed a Microcat calibration station with 6 Microcats mounted to the Rosette. The last stations along this section were performed during the moorning of May 29 at rather shallow water; somewhat shallower than in the sea charts, but approximately right in the TOPEX_TOPO bathymetry (2 nm resolution). After the last station we headed southward to St Johns and on the evening we had a nice little Glühwein Abschlussparty in the Geolab, and we reached St. John's as scheduled in the morning of May 31, 2001.

1.4 Preliminary Results

1.4.1 Mooring Activities

(J. Fischer)

Heavy mooring work dominated the working plans during the first week of the cruise. Four moorings located at the shelf edge at the southern tip of the Grand Banks had to be exchanged within 5 days. All mooring work had to be carried out during daylight hours, and between recovery and redeployment some time was needed to service the instruments as most of them were re-used in the new deployment. The mooring work is summarized in table 1.4 and 1.5 in chapter 1.6. Mooring recovery was done over the side using the Geological Boom without any problems. Deployments were carried out over the stern and using the A-frame for secure instrument deployment. Deployments went well and fast.

A first inspection of all instruments recovered showed that most of them had full, 22 months long records. One Aanderaa current meter lost the current speed record after about a year and one acoustic current meter had no data. Unfortunately the Aanderaa was redeployed before the detection of the problem with the speed sensor.

The 2 BSH moorings were exchanged on May 19 and 20, 2001; for final mooring positions see table 1.5 in chapter 1.6. In each of the recovered moorings one ring made of titanium was broken at the welding point, but due to the strength of the material it had opened only about a few mm. One shackle in an bouancy element was found without the bolt, but with signs of heavy corrosion at the position where the non-titanium splint must have been.

All Aanderaa current meter records stopped before the recovery date due to battery problems. The typical length of record is 4500 hrs, about six months. The Thermistor Chain Recorders showed no problems. The seacats and microcats manufactured by SBE showed no problems, except that 2 out of 4 microcats were giving read errors, when reading the data. A Broadband ADCP used in BSH 1 mooring could not be read and hence it was decided to take it back home for service and repair. The moorings head bouy had to be replaced by 10 Benthos elements. Further a pair of bouyancy elements was added at 2500 m depth, as calculation showed these elements being to small dimensioned. The deployment technique over the stern was new to BSH staff and it was noted that this technique is very safe and even faster than deployment over the side.

Preliminary Evaluation of the Mooring Data

Currents were rather weak, but at greater depths in the offshore moorings K103 and K104 the deep records show the deep western boundary current that is associated with the Denmark Strait Overflow Water. Currents in the Labrador Sea Water range were weak.

1.4.2 Direct Current Measurements with VMADCP/LADCP

(P. Brandt, J. Fischer, M. Dengler)

a) Technical Aspects

I) VMADCP

On the first leg of M 50, two vessel mounted acoustic Doppler current profiler (VMADCP), were used for data acquisition: a 153 kHz VMADCP mounted on METEOR'S bottom and a new 75 kHz phased array ADCP called Ocean Surveyor (OS) mounted in METEOR'S sea chest. Both ADCPs worked well throughout the cruise. While good data were obtained by the 153 kHz VMADCP to a depth of 400 m, the 75 kHz OS has a deeper measurement range. In most of the surveyed area, good data (50%-good criterion) were obtained by the OS to a depth of 600 m and even to a depth of 650 m during day time. The range especially of the OS decreased during heavy weather when METEOR headed against strong swell and wind waves. In particular, a heavy storm with wind speeds above 25 m/s led almost to a total loss of reliable data. Altogether, during 7% of the M50/1 cruise period, the depth down to which good data were acquired by the OS reduces to less than 300 m due to heavy weather.

The 75 kHz OS collected single ping data using a vertical resolution of 16 m with the first reliable depth cell located 24 m below the ship (8 m blanking range and first depth cell omitted). The first depth cell appeared to be contaminated in almost all profiles; it might be that the potential flow around the ships hull is responsible for this behavior. The ping interval was set to 2 s, which force the OS to ping as fast as possible leading to an effective time between pings of about 2.2 s. The processing mode was set to low resolution (long range). The chassis of the OS as well as the chassis of the VMADCP obtain heading information from the Fiber Optical Gyro (FOG) via an analog synchro interface. Ashtech headings, GPS data as well as digital Fiber Optical Gyro (FOG) headings were stored together with the velocity data by the RD-Instruments VmDas software package used with Windows NT.

The data of the 153 kHz VMADCP were collected using a bin length of 8 m, but sending 16m acoustic pulses for longer range. Further acquisition parameters were an ensemble interval of 5 min in which about 250 individual profiles are averaged, and a blank distance of 8 m. Together with the raw data, navigation information originating from the ships GPS receiver and the mean difference (for 5 min intervals) between the FOG- and Ashtech headings were stored by the user exit program ue4.exe in the ADCP raw data files. It is this mean heading difference that is used to correct individual 5 min ensembles for errors in the FOG synchro heading; thus basically Ashtech heading were used. The user exit program ue4.exe also aligned the PC clock to satellite time. For post-processing and calibration, the CODAS software package was used.

In the cruise report of our last cruise with METEOR, M47/1, we concluded that the new FOG should lead to an improvement of the acquired velocity data when using directly heading information from the FOG's digital interface. The electronic chassis of the VMADCP is only able to use a analog synchro signal to obtain heading information. It was shown that this analog heading signal shows an heading dependence, which is not present in the digital heading signal. However, the new OS has the capability to use also digital heading information. One aim of the calibration of the OS data was thus to investigate the data quality improvement due to METEOR'S new FOG compass when using directly its digital heading information.

By intercomparing heading values from the FOG, the Ashtech, and from the conventional Gyro, we found out that during M50/1 the FOG heading appears to fluctuate strongly with time (low frequency variability). While the differences between Ashtech and Gyro heading show the typical errors of the Gyro due to the ship's meridional velocity and acceleration (e.g., the Schuler oscillation), the differences between Ashtech- and FOG heading as well as between FOG- and Gyro heading show strong temporal fluctuation of up to 4 degrees on timescales of days. Such an behavior of the FOG was not observed on an earlier cruise, where the FOG heading was reliable. At the beginning of the next METEOR leg, M50/2, the FOG was rebooted and a speed correction was included in the setup. It turned out that the exclusion of the speed correction during M50/1 was responsible for the strong temporal fluctuations of the FOG heading signal. However, during M50/1 the Ashtech heading was, due to the implementation of a new firmware package, almost continuously available with only occasional short gaps. The FOG heading was therefore replaced by the Ashtech heading on a ping to ping basis for the OS and for five minute ensembles for the 150 kHz shipboard ADCP.

The shipboard ADCP data (OS and VMADCP) had to be calibrated for possible misalignments between the ADCP axis (usually the line between acoustic beams 3 and 4) and the ships axis (which of course is aligned with the ships compass). For calibration the usual acceleration / deceleration procedure for watertrack determination of misalignment angles was used. The assumption thereby is, that within a small region and a short time interval the currents are constant and any changes in absolute currents arise from nonperfect elimination of the ships speed over ground. This error is large at high ship speeds and small during station work. Thus, the aim of the calibration is to determine a misalignment angle for which the differences between on-station and underway measurements close to the station location are smallest in a least square sense for all calibration points. Basically this gives two independent calibration points per station, one when approaching the station and a second after the station has been finished. Approximately 100 independent estimates contributed to the calibration of the M50/1 data.

The standard deviation of the misalignment angle for the individual calibrations was obtained to be about 0.5° resulting in an error of the mean calibration angle of about 0.05° for M50/1. The error is calculated as the standard deviation divided by the square root of the number of independent contributions. No significant time dependence of the misalignment angle was found. For the VMADCP the standard deviation of the misalignment angle for the individual estimates was obtained to be about 0.5°, very similar to what was achieved for the OS data. At this point, we would like to acknowledge the support by the electronic engineers of the METEOR.

II) LADCP

On M50/1 all CTD-stations were accompanied by an ADCP attached to the CTD-rosette. The system in use was a narrow-band ADCP (NBADCP S/N 301). The NBADCP worked well throughout the whole cruise. Altogether 56 profiles were obtained. On all stations a ping rate of 12 pings/8s and a bin length of 16 m was used. While the data acquired above 2000 m water depth were of good quality, the data acquired at larger depths sometimes showed large spikes in the resulting currents which is possibly due to an interference with earlier pings.

b) Results

The near-surface current field of the western subpolar North Atlantic is characterized by the along-shore flowing Labrador Current carrying cold water from the north to the south and by the NAC carrying warm water from the south to the north. Figure 1.3 shows the current vectors averaged between 54 to 630 m as measured by the OS during M50/1. The current field is dominated by a pronounced eddy field that is superimposed to the main current system. the vertically averaged velocities within the Labrador Current reach maximum values around Flemish Cap of about 20 cm/s and slightly smaller values near the Grand Banks. The NAC flows near the Grand Banks in a narrow current branch east of the Labrador Current northward reaching the region northeast of Flemish Cap, where typically the Northwest Corner of the NAC can be found. In this region strong northeastward velocities of nearly 1 m/s were observed. A pronounced feature within this current map is the anticyclonic Mann Eddy, which is situated east of narrow current branch of the NAC near the Grand Banks. This eddy has an diameter of about 300 km and maximum velocities of more than 80 cm/s.

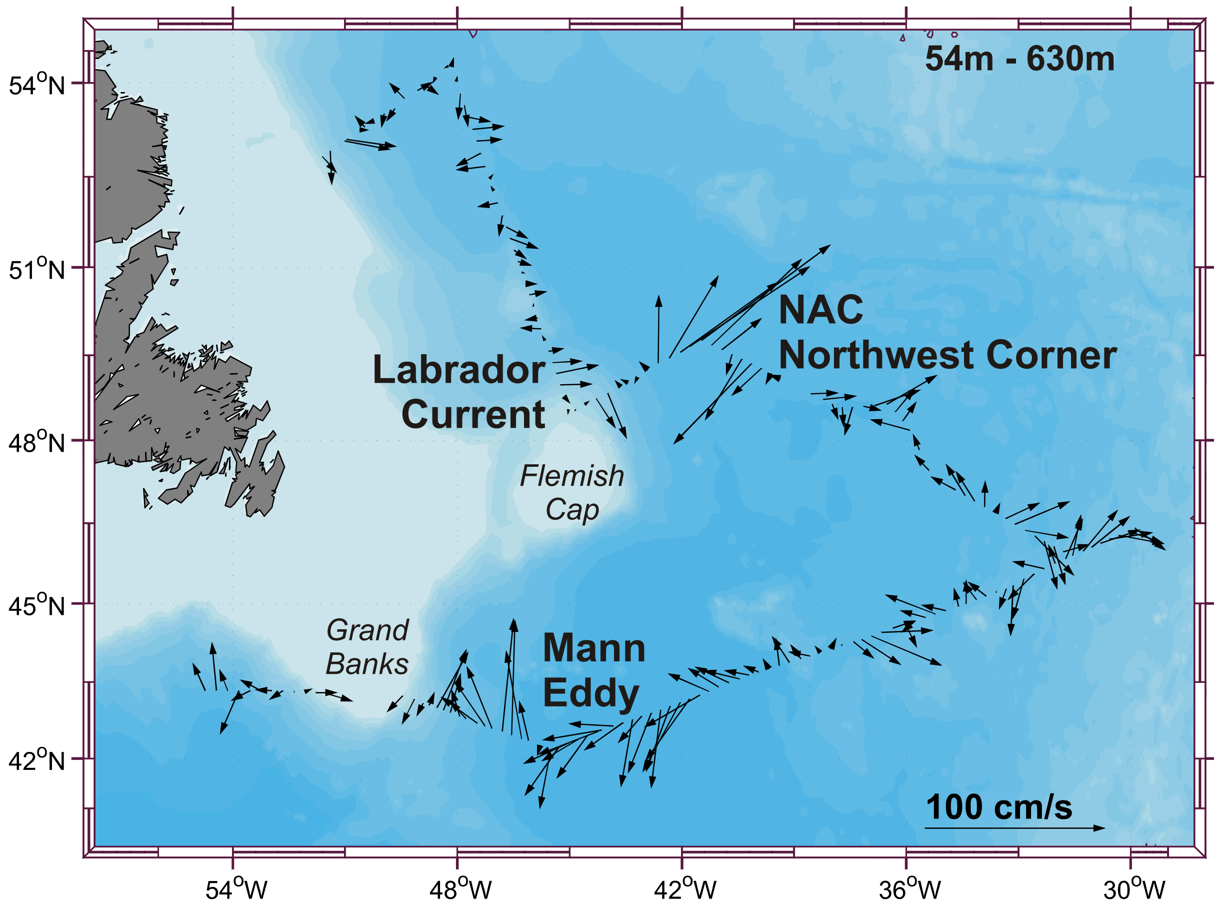

Fig. 1.3: Bottom topography of the western subpolar North Atlantic Ocean with current vectors from the OS. The arrows represent strength and direction of the velocity averaged between 54 and 630 m.

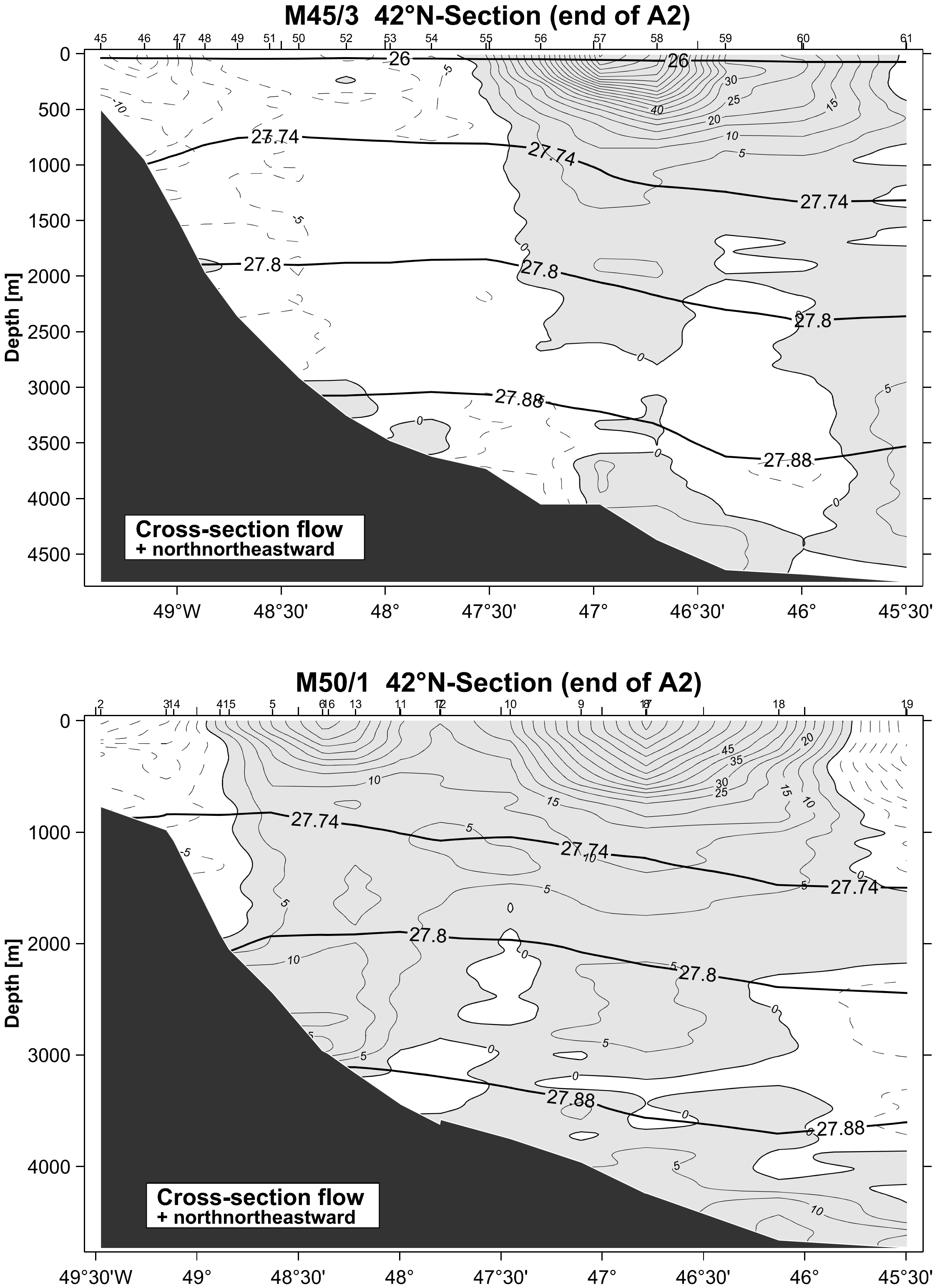

Fig. 1.4: LADCP section near 42°N (A2 section west of Grand Banks) for METEOR cruises M45/3 (July 1999) (upper panel) and M50/1 (lower panel) showing the cross-section current component in cm/s; positive flow is shaded. Also included are the isopycnals σ_θ=27.74, 27.8 and 27.88 (thick solid lines).

Figure 1.4 shows the cross-section current component for the 42°N sections for METEOR cruises M45/3 (July 1999) and M50/1 as measured by the NBADCP. While during July 1999 a large fraction of the flow confined to the shelf edge was in southward direction the northward flowing NAC (in May 2001) was found much closer to shelf. There was only a small gap through which Labrador Sea Water flows southward.

1.4.3 CTD - O_2 Station Work and Analysis

(L. Stramma)

a) Technical Aspects

The CTD-system used during the entire cruise M50/1 was a Seabird 9 plus. The CTD worked very well including the dissolved oxygen sensor. A Seabird bottle release unit was used with the rosette and except for some problems caused by too short bottle wires or wire problems with the thermometer frames, the release unit worked properly. In total 56 CTD stations were made during the leg M50/1. On all stations the LADCP was lowered with the CTD to the bottom.

For calibration purpose water samples were taken at 54 stations from the rosette bottles. Bottle salinities were determined with an Autosal salinometer (Kiel AS3). This salinometer showed drifts between measuring sessions as well as during the measurements, hence drift corrections had to be applied for all measurements. The salinometer used first, the Kiel AS7 showed heavy drift after a few bottles and then wide jumps during standby as well as measurements and could not be repaired and hence not be used. Oxygen from the bottle samples was determined by the Winkler titration method by hand. The CTD values for calibration were chosen from the downcast profiles to avoid hysteresis problems. Erroneous data were rejected when exceeding 2.8 times the standard deviation of the conductivity difference. Calibration of the SBE 9 CTD conductivity was done with on the basis of 173 sample pairs lying within the 2.8 times standard deviation criteria. After correcting the conductivity with respect to temperature, pressure, conductivity itself and time, the rms differences between the bottle and CTD conductivity samples were 0.0017 mS/cm corresponding to 0.00198 in salinity, despite the problems with the salinometer.

CTD pressure and temperature were compared to reversing electronic thermometers and barometers attached to some of the water bottles. The mean difference in pressure of 1 dbar was lower than the rms difference of 3.1 dbar and the mean difference in temperature 0.0019°C was lower than the rms difference of 0.0033°C, hence no corrections for pressure and temperature were done.

The calibration of dissolved oxygen with almost 900 water samples was quite accurate. After correction with respect to pressure, temperature and oxygen itself and temporal drift, the rms difference was 0.045 ml/l.

b) Water Mass Changes

The major aim of the hydrographic measurements is to investigate temporal changes of the water mass distribution, especially of the deep water masses, which are exported southward with the Deep Western Boundary Current. The upper range of the deep water is occupied by Labrador Sea Water (LSW), located in about 1500 m depth and revealing a salinity minimum and an oxygen maximum. Below the LSW a salinity maximum occurs that is connected to an oxygen minimum. This water mass is called Charlie Gibbs Fracture Zone Water (CGFZW) or also named Iceland-Scotland Overflow Water (ISOW). Near the bottom, below about 2500 m in the Labrador Sea (at 52°N) and below about 3500 m in the New Foundland Basin (at 44°N) the water becomes less saline and colder then the CGFZW and is called Denmark Strait Overflow Water (DSOW).

LSW is formed in the Labrador Sea by winter convection, however, during the last years the LSW formation was weaker then normal and the LSW temperature and salinity increased. A first inspection of the M50/1-data showed that the LSW temperature and salinity further increased, hence no new LSW was formed, which reached the Deep Western Boundary Current. This increase in temperature and salinity compared to earlier cruises was observed at the western boundary in all three hydrographic sections. The strongest signal was observed at about 53°N shown in Figure 1.5. The thickness of the LSW-layer decreased compared to earlier observations in 1996, 1997, 1998 and 1999, while the temperature and salinity increased over the entire western boundary current region from 49°W to 51°30'W.

In contrast to the LSW the DSOW-signal was stronger at all three hydrographic sections. The increase of DSOW characteristics is presented as an example of the potential temperature distribution of the sections in May 2001 and July 1999 (Figure 1.6). Bottom temperatures in July 1999 had been about 1.5°C, but decreased to 1.2°C in May 2001. Related to the potential temperature changes the salinity at the bottom decreased from 34.885 in July 1999 to less than 34.870 in May 2001. This decrease in temperature and salinity shows the arrival of a strong pulse of DSOW, which can be traced at all three sections of M50.

The CGFZW located in-between the LSW and the DSOW shows no strong changes. A first glance at the data at 53°N indicates that the salinity maximum in May 2001 is weaker than that of July 1999 near the shelf break but of similar strength farther offshore. The same is true for the oxygen minimum. This might be an indication of a farther offshore location of the CGFZW, but a closer look into the data is necessary to investigate the changes in the CGFZW.

The results presented here are also confirmed by the tracer measurements presented in the next paragraph. It would be most useful to combine the observations from the CTD, the tracer measurements and the oxygen and nutrient measurement to present the combined view of the water masses. However, due to different calibration procedures the results are presented in separate paragraphs.

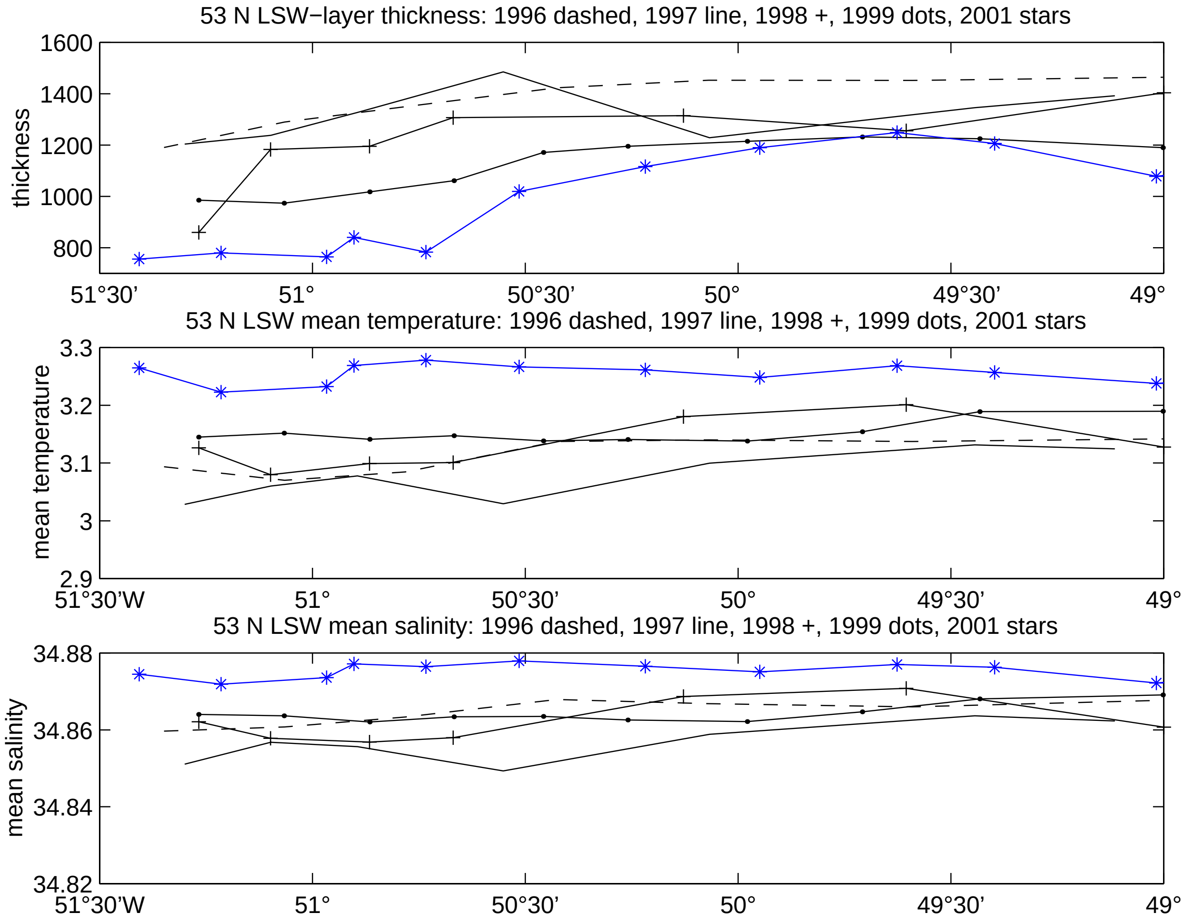

Fig.1.5: Layer thickness of the LSW at about 53°N (upper frame), mean temperature (middle frame) and salinity (lower frame) for cruises in 1996 (dashed line), 1997 (solid line), 1998 (+-line) 1999 (dot-line) and 2001 (star-line). The LSW is defined as the layer between the isopycnal sigma-theta 27.74 and 27.8.

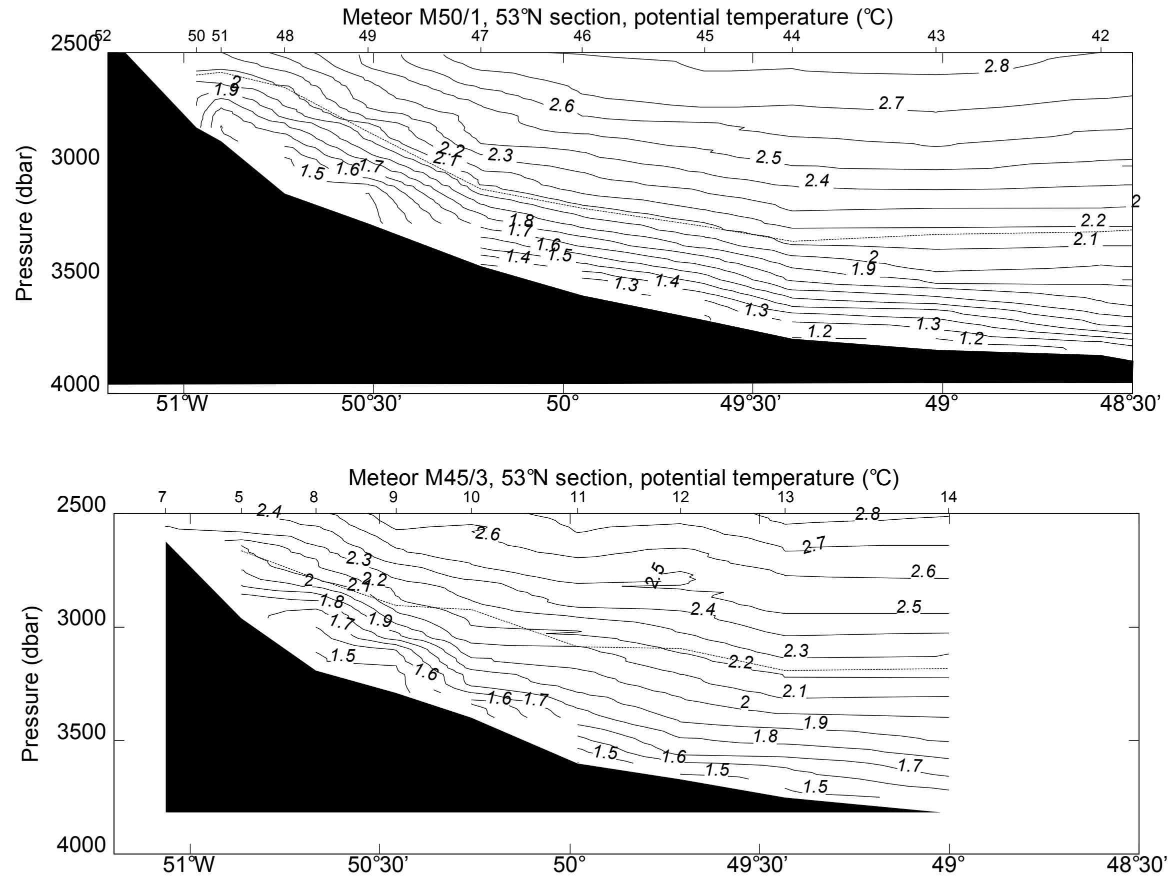

Fig.1.6: Potential temperature distribution near the shelf break at 53°N for a) May 2001 and b) July 1999. The broken line indicates the isopycnal sigma-theta = 27.88, indicating the upper boundary of the DSOW.

1.4.4 CFC's Station Work and Analysis

(D. Kieke, M. Schütt, K. Getzlaff)

a) Aims

Measurements of chlorofluorocarbon (CFC) and carbontetrachloride (CCl4) performed during cruise M50/1 serve to study the water mass characteristics and circulation of different deep water masses. A special focus is on investigating pathways and time scales of recently modes of Labrador Sea Water (LSW) as well as tracking the very cold and dense Denmark Strait Overflow Water (DSOW) upstream.

b) Technical Aspects

During M50/1, two gaseous chlorofluorocarbon (CFC) components, namely CFC-12 and CFC-11, have been analyzed. Water samples, sampled by precleaned 10 L Niskin bottles attached to a rosette/CTD system, are transferred in amounts of 20 ml to a purge and trap gas-chromatographic unit. Separation of the dissolved gases is performed using an gas-chromatoraphic packed column, detection is done using an Electron Capture Detector (ECD). ECD-signals are calibrated and converted into CFC concentration by means of standard gas.

Temporal variations of the ECD were about 6 % for both CFC components, thus being very stable in time. The temporal drift of the ECD is corrected by applying a calibration curve using six different gas volumes. These curves are taken before and after each station, assuming temporal changes between two calibrations being linear in time. All but one profiles were successfully analyzed, leading to 847 water samples in total. Reproducibility was checked by analyzing at least 10 % of the samples twice and standard deviation was found to be 0.8 % for CFC-12 and 0.6 % for CFC-11.

The analysis procedure of carbontetrachloride is similar to the one for CFCs. Both measurement units differ in using a capillary column instead of a packed one, as well as different carrier gas fluxes and purge and trap materials. At the beginning of the cruise, the CCl4 system suffered from a malfunctioned ventilator, which forced us to open the oven of the gas-chromatographic system and fix it. Afterwards, the system took more than a week to become fairly stable again. Thus, CCl4 measurements have only been performed from profile 29 onwards. In total, 318 water samples were analyzed. Reproducibility was found to be 1.4 %.

c) Pathways and Water Mass Characteristics

The program of cruise M50/1 aimed at repeating sections, performed in the framework of "SFB 460" during earlier years and, thus, investigating temporal variability of water mass properties and currents.

Labrador Sea Water (LSW) represents the upper layer of the Deep Western Boundary Current (DWBC). It is formed by winter time convection presumably in the central and southern Labrador Sea and carries low temperatures and salinities, but high oxygen and CFC concentrations. Bounding isopycnals used in this study are σ_θ=27.74 and σ_θ=27.80.

The first and southermost section from the Grand Banks to the Middle Atlantic Ridge (WOCE-A2-line) showed LSW focussing on the DWBC region with CFC-11 concentrations greater 2.6 pmol/kg, reaching down to a depth of 2400 m. Additionally, CFC- and oxygen rich LSW could be found at the western side of the Middle Atlantic Ridge (MAR) at about 43.5°W to 41.5°W. These increased concentrations (~3.2 pmol/kg) fall together with southward velocities measured by lADCP at this location, suggesting LSW being transported southward also far off-shore the continental shelf. Figure 1.7 shows LSW CFC concentrations for all sections performed during M50/1 in comparison to previous years.

The middle layer of the DWBC, bounded by the isopycnals σ_θ=27.80 and σ_θ=27.88 and namely Gibbs Fracture Zone Water (GFZW), is identified by low CFC-11 concentrations. Two cores show up west of 40°W. The first lies close to the shelf at 48°W at about 2400-2600m depth with CFC-11 concentrations less than 1.8 pmol/kg. The second covers the deep Newfoundland basin with concentrations less than 1.2 pmol/kg, but higher silicate concentrations (see figure 1.8, bottom). This core rather seems to be influenced by the presence of Antarctic Bottom Water (AABW).

The deepest and densest layer of the DWBC, the Denmark Strait Overflow Water (DSOW), showed the strongest signals during M50/1. Whereas previous Meteor cruises from 1997 and 1999 (M39/4, M45/3) revealed single DSOW cores in depths at about 3600m to 4200m, M50/1 showed a CFC- and oxygen enriched layer at the bottom of the section. Oxygen and CFC concentrations intensified from the southern to the northern sections. Antarctic Bottom Water (AABW) which spreads northward into the Newfoundland Basin and can be identified by its high silicate content is displaced by DSOW during 2001. Comparisons with cruise data from 1994 and 1999 showed silicate concentrations being much smaller in 2001 than in previous years. 1994 and 1999 data showed bottom intensified silicate cores at around 30 micro mol/kg and more, whereas the silicate maximum during M50/1 only gave 26 micro mol/kg. The presence of a strongly developed DSOW seems to shift the AABW upwards in the water column by a few hundred meters.

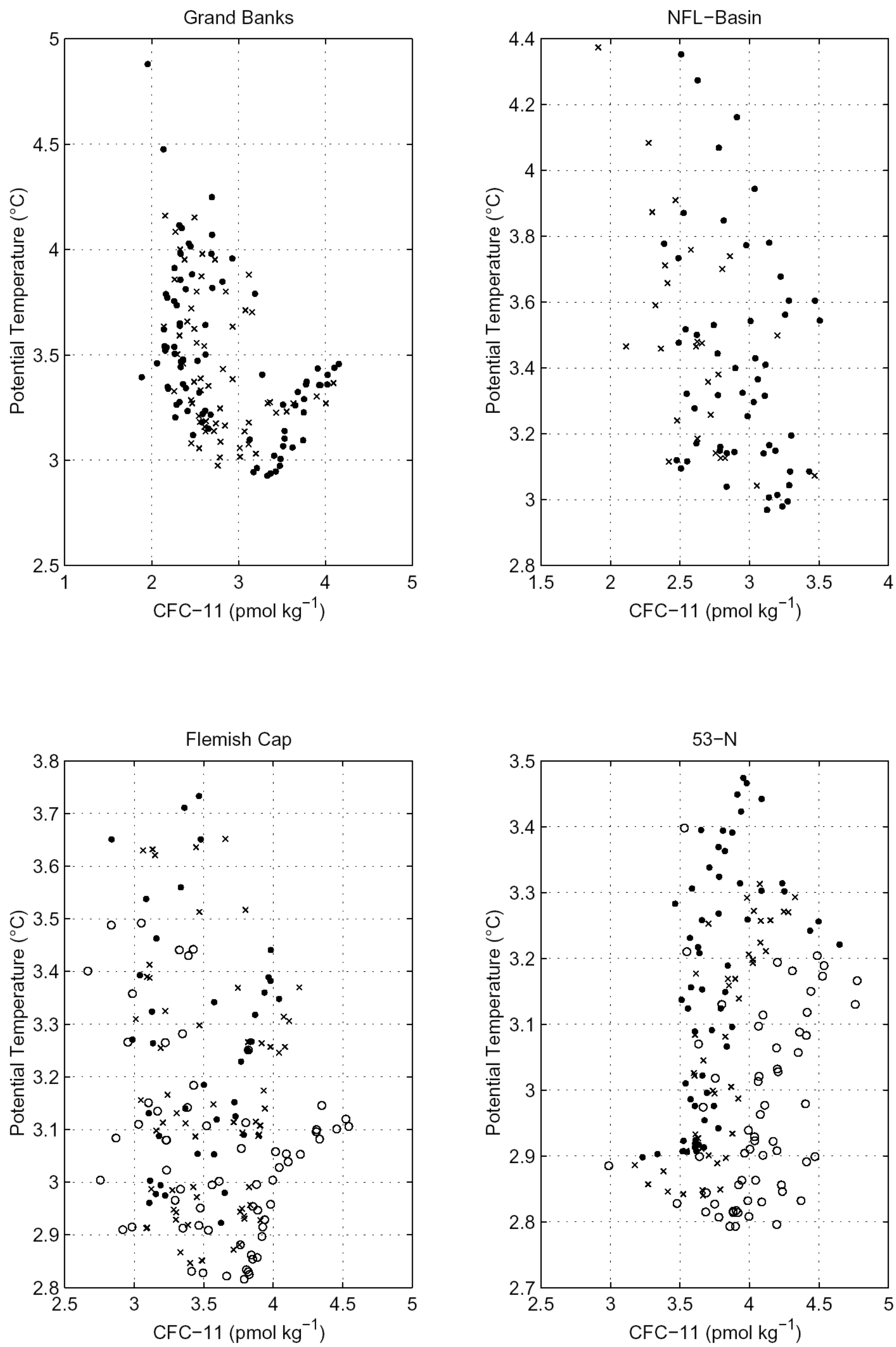

Fig. 1.7: CFC-11 concentration [pmol/kg] for LSW at all performed sections. Dots: M50/1, 2001; crosses: M45/3 1999; open circles M39/4, 1997.

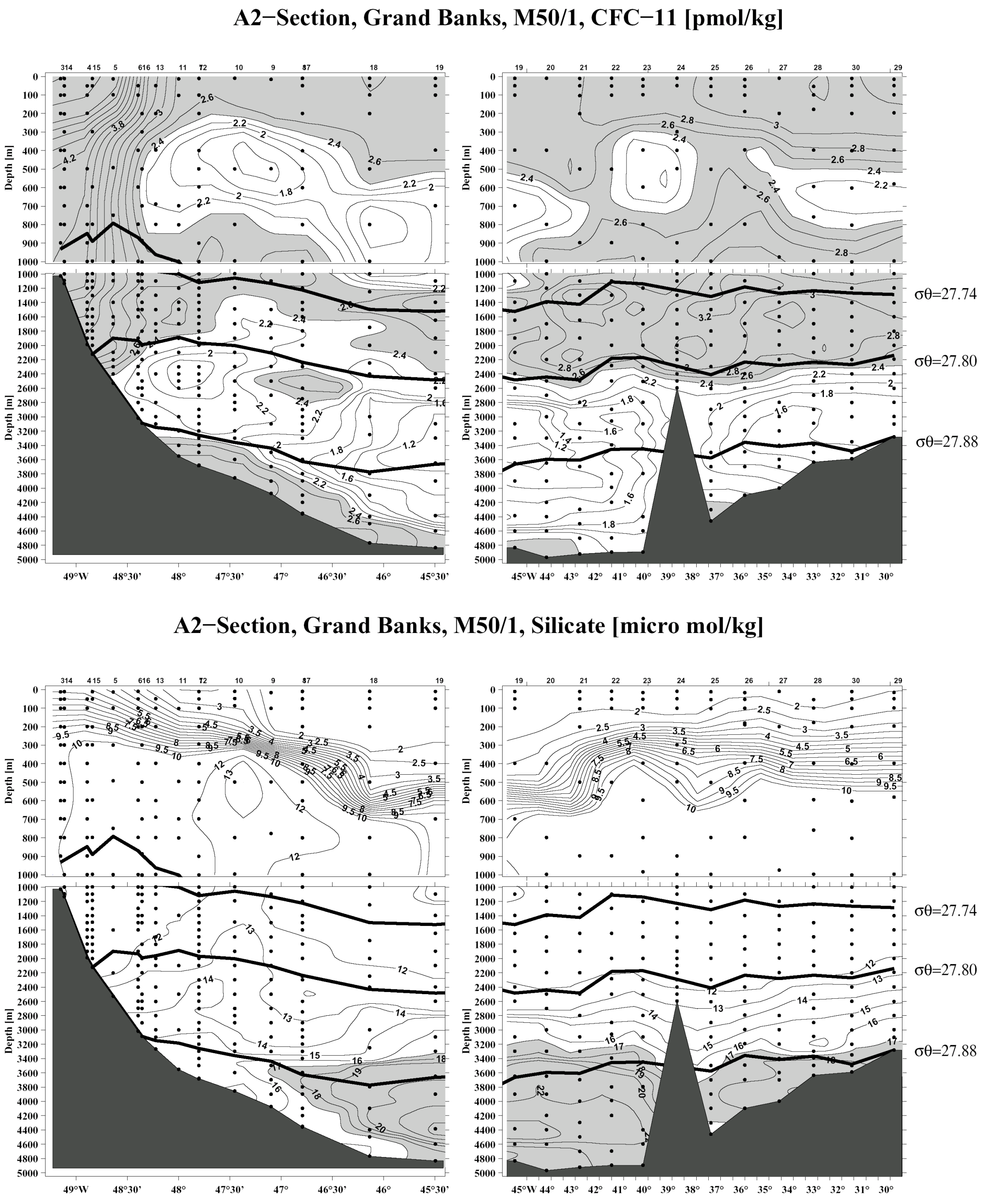

Fig. 1.8: CFC-11 [pmol/kg] (top) and silicate [μmol/kg] (bottom) along the A2 section. Thick lines denote isopycnals σ_θ=27.74, 27.80, and 27.88. CFC-11 concentrations greater 2.4 pmol/kg and silicate concentrations greater 17 micro mol/kg are shaded grey.

1.4.5 CO_2 Work and Preliminary Results

(K. Friis, H. Lüger, T. Steinhoff, P. Streu)

Methods

On the METEOR cruise M50/1 three of the possible four characteristic properties of the carbonate system were determined: total dissolved inorganic carbon (C_T, DIC), total alkalinity (A_T) and *p*H. The fourth parameter, partial pressure of carbon dioxide (pCO_2), was continuously measured in the sea surface (~5 m).

Sample Collection and Storage of CO_2 Samples

Two samples for each depth were collected in 500 ml glass bottles with ground glass stoppers. Using such large sample bottles enables two analyses to be performed on a single sample (*p*H first followed by A_T) and the second bottle was used to measure the C_T. A short drawing tube extending from the Niskin bottle to the bottom of the sample bottle was used to fill sample bottles. The stoppers were held down firmly with a large rubber band which secures to a clamp on the neck of the bottle. All samples were analyzed within 24 hours of being collected.

Sample Collection and Storage of ^{13}C and ^{14}C Samples

On leg M50/1, 444 samples for ^{13}C mass spectrometer analysis were collected. Each 100 mL bottle was carefully taken, poisoned with 50 µL $HgCl_2$ and afterwards crimp-sealed for storage and analysis onshore. Based on the ^{13}C data we will make a priority list for about 75 samples for ^{14}C mass spectrometer analysis, that can be done from the ^{13}C sample extract.

Sample Collection and Storage of TOC and Chlorophyll Samples

TOC samples were filled in glass tubes, that were combusted beforehand, frozen at –20°C and will be analysed onshore. This accounts for the chlorophyll samples, too, where one liter for each sample was collected, filtered and frozen at -20°C. 242 TOC samples and 69 chlorophyll samples were stored.

Total Dissolved Carbon Dioxide

The C_T analyses were made by a coulometric titration method using the SOMMA (single operator multi-parameter metabolic analyzer) system (Johnson et al., 1993). The SOMMA collects and dispenses an accurately known volume of seawater to a stripping chamber, acidifies it, sparges the CO_2 from the solution, dries the gas, and delivers it to a coulometer cell. The coulometer cell is filled with a partially aqueous solution containing monoethanolamine and a colorimetric indicator. A platinum cathode and a silver anode are positioned in the cell and the assembly is positioned between a light source and a photodetector in the coulometer. When the gas stream from the SOMMA stripping chamber passes through the solution, CO_2 is quantitatively absorbed, reacting with the ethanolamine to form a titratable acid. This acid causes the color indicator to fade. When the photodetector measures a color fade, the coulometer activates a titration current to neutralize the acid until the solution reaches its original color. The titration current is integrated over the time of the analysis, which provides a determination of CO_2 in the sample. Each sample is sparged and titrated until the amount of CO_2 coming from the stripping chamber is at blank level for four minutes - this is usually between 10 and 16 minutes per sample. An integral part of the SOMMA is a gas calibration system that is used to calibrate the coulometer. In the gas calibration procedure, each of two gas sample loops is filled with pure CO_2 gas, the temperature of the loop and the atmospheric pressure are automatically measured so that the mass of CO_2 in the loop can be calculated. The contents of the loop are then injected into the SOMMA gas stream - following the same path through the stripping chamber and to the coulometer cell that is used by water sample sparge gas. The percent recovery of the CO_2 is calculated (typically about 99.96 - 99.98%) and a „calfactor" is entered into the software in order to determine the sample C_T following the equation:

$$C_T = \text{Calfactor} * \mu\text{mol} * (1000 / V_t * \rho)$$

Here, µmol is the result of the sample coulometric titration, V_t the sample volume at the sample temperature and salinity (T = 20°C), and ρ the density of sea water at the sample temperature and salinity.

After the instrument is calibrated, as additional reference, a bottle of certified reference material (CRM) and two duplicate samples per station are analyzed. The CRM bottles are prepared by Dr. Andrew Dickson's laboratory at the Scripps Institute of Oceanography. Normally the CO_2 content measured by the SOMMA should be within two micro moles/kg (about 0.1%) of the certified value.

Alkalinity Determination

Total Alkalinity (A_T) is determined by titration of seawater with a strong acid, following the electric motoric force with a proton sensitive electrode. The titration curve shows two inflection points, characterizing the protonation of carbonate and bicarbonate, respectively. The acid consumption up to the second point is equal to the titration alkalinity.

Alkalinity was determined by a semi-automatic analysator, the VINDTA instrument (Versatile Instrument for the Determination of Titration Alkalinity). It consists of two parts, the titration cell with its manifold for filling, draining and acid delivery and the data acquisition and system control unit (Mintrop et al., 2000).

Alkalinity is determined by titrating a seawater sample with hydrochloric acid (0.1 µM) and then measuring the *p*H using a reference and a glass electrode. The difference in *p*H potential is measured by a *p*H-Meter which delivers the data to the computer for calculation of the alkalinity. The program allows complete titration with preset volume increments of the acid.

A precisely known volume of the sample is filled into a glass pipette (volume 100 ml) and filled into the open cell. Then the sample is titrated with the acid. A stir bar inside the cell mixes acid and sample. The total volume of the acid added to the sample is 3.9 ml. The analysis is performed at 25 °C, which is maintained by a water bath.

The standardization is done the same way as the C_T samples, running a CRM (see above) in the beginning and two duplicats per station and finishing with a CRM. The alkalinity results should be within a range of 2-3 µmoles of the CRM values.

*p*H *determination*

The *p*H is determined by a spectrophotometric method that is based on the absorbance spectrum of a *p*H-indicator dye. All measurements are made with an automated system described in Friis (2001) and using meta-cresol purple as indicator dye. The indicator was calibrated for *p*H on the total seawater scale (pH_T) by Clayton and Byrne (1993). For the *p*H calculation procedure we followed the description in Doe (1994).

Six samples can be analyzed per hour, which is one complete hydrocast within 4 to 5 hours. The indicator dye is dissolved in seawater and for analysis the mixing ratio (sample:indicator) is about 650:1. The analysis is performed at 21°C ± 1°C. During the spectrophotometric detection the exact temperature is measured by a calibrated Platinum resistence thermometer [± 0.05°C]. Afterwards all *p*H data are fitted to 21°C. This is done with the computer program ‚CO2SYS' by Lewis and Wallace (1998) using the dissociation constants after Mehrbach et al. (Millero and Dickson, 1987) constants and the corresponding A_T or C_T value. The standardization is done the same way as the C_T ans A_T samples, running a CRM in the beginning and two duplicats per station and finishing with a CRM. The pH results should be within a range of ± 0.005 pH units according to the accuracies in C_T and A_T of 2-3 µmoles of the CRM values.

CO_2 Partial Pressure Determination

The fourth analytical strategy involved the continous determination of the partial pressure of CO_2 (pCO_2) in surface water and in the overlying atmosphere. For this purpose an automated underway pCO_2 system (Körtzinger et al., 1996) with a non-dispersive infrared gas detector for CO_2 was continuously operated along the cruise track. A continous flow of seawater was drawn at 5 m depth from the ship's "moon pool" which was equipped with a CTD. Every 2 minutes a pCO_2 data point together with temperature and salinity from the CTD were logged along with the position data from an independent GPS system. Previous work (Körtzinger et al. 1996) has shown that the system is accurate and precise to ± 2 µatm. The instrument was calibrated using three standard gases with a known CO_2 concentration. These gases were measured approximately every 12 hours.

C_T, A_T and pH Quality Control

The quality control of the various parameters of the carbonate system was performed with the help of certified reference materials (CRM) and analysis of duplicates that were taken approximately every tenth sample. The CRMs were provided by Dr. Andrew Dickson and analyzed by Dr. D.C. Keeling by vacuum extraction with manometric detection at the SCRIPPS Institution of Oceanography in La Jolla, California. The CRMs are certified for C_T and A_T only, but have to have a constant *p*H. These standards are used to determine the accuracy and performance of the systems. The duplicates show the precision of the analytical instrument. For the *p*H quality control the CRM measurements allow assessment of the long term precision during the cruise, if a specific CRM batch is used fro the whole cruise. An overview of the quality controls is shown in Tab. 1.4.5.1. and in Fig. 1.9. The control samples show a very good agreement with the achievable accuracy and precision estimates according to Millero et al. (1993), that can be seen in Tab. 1.4.5.1 and Tab. 1.4.5.2.

Fig. 1.9 A and B show constant analytical C_T performance during the whole cruise. This is true for the A_T analyses, too (Fig. 1.9 C and D), with the exception of a significant underestimation of 0.89 µmol/kg from CRM measurements, that is obvious from the mean in Fig. 1.9 D. Based on the CRM quality control 0.9 µmol/kg were added on every sample A_T. Although the pH of the CRM measurements in Fig. 1.9 F show a significant deviation between the control of stations 54-84 and stations 87-126 this is within the accuracy range of Millero et al. (1993) in Tab. 1.4.5.1 An uncertainty of ± 0.002 pH units corresponds with a C_T and A_T uncertainty of ± 1 µmol/kg and therefore seems to be acceptable. Nevertheless, the *p*H trend of the CRM measurements from Station 54 to 87 could be explained by aging of the Pt-100 temperature probe. This will be proved onshore, so that all *p*H data can be corrected, if it is neccessary. A temperature correction 0.1 °C leads to a *p*H correction of – 0.0015 pH units.

Tab. 1.1: Key data of the discrete C_T, A_T, pH analyses. The CRM measurements give an accuracy estimate, the duplicate measurements a precision estimate.

	C_T	A_T	$pH_T^{21\,°C}$
CRM: Analyzed bottles	26	52	40
Batches used	(52, 47, 41)	(52, 47, 41)	(52)
Mean deviation from certified CRM value	0.20 µmol/kg	- 0.89 µmol/kg	not certified for pH
(standard deviation)	(± 1.28 µmol/kg)	(± 1.58 µmol/kg)	(± 0.0017)
Duplicates: Analyzed pairs	38	58	66
Mean deviation from duplicate value	1.3 µmol/kg	2.1 µmol/kg	0.0016
(standard deviation)	(± 1.4 µmol/kg)	(± 1.45 µmol/kg)	(± 0.0016)

Tab. 1.2: State of the art of achievable accuracy and precision for C_T, A_T and pH measurements (Millero et al., 1993) in comparison to the M50/1 estimate.

Parameter	**Accuracy**	**M50/01 estimate**	**Precision**	**M50/01 estimate**
$\mathbf{C_T}$	± 2 µmol/kg	± 1.28 µmol/kg	± 1 µmol/kg	± 1.4 µmol/kg
$\mathbf{A_T}$	± 4 µmol/kg	± 1.58 µmol/kg	± 2 µmol/kg	± 1.45 µmol/kg
***P*H**	± 0.002	± 0.0017 µmol/kg	± 0.0004	± 0.0016 µmol/kg

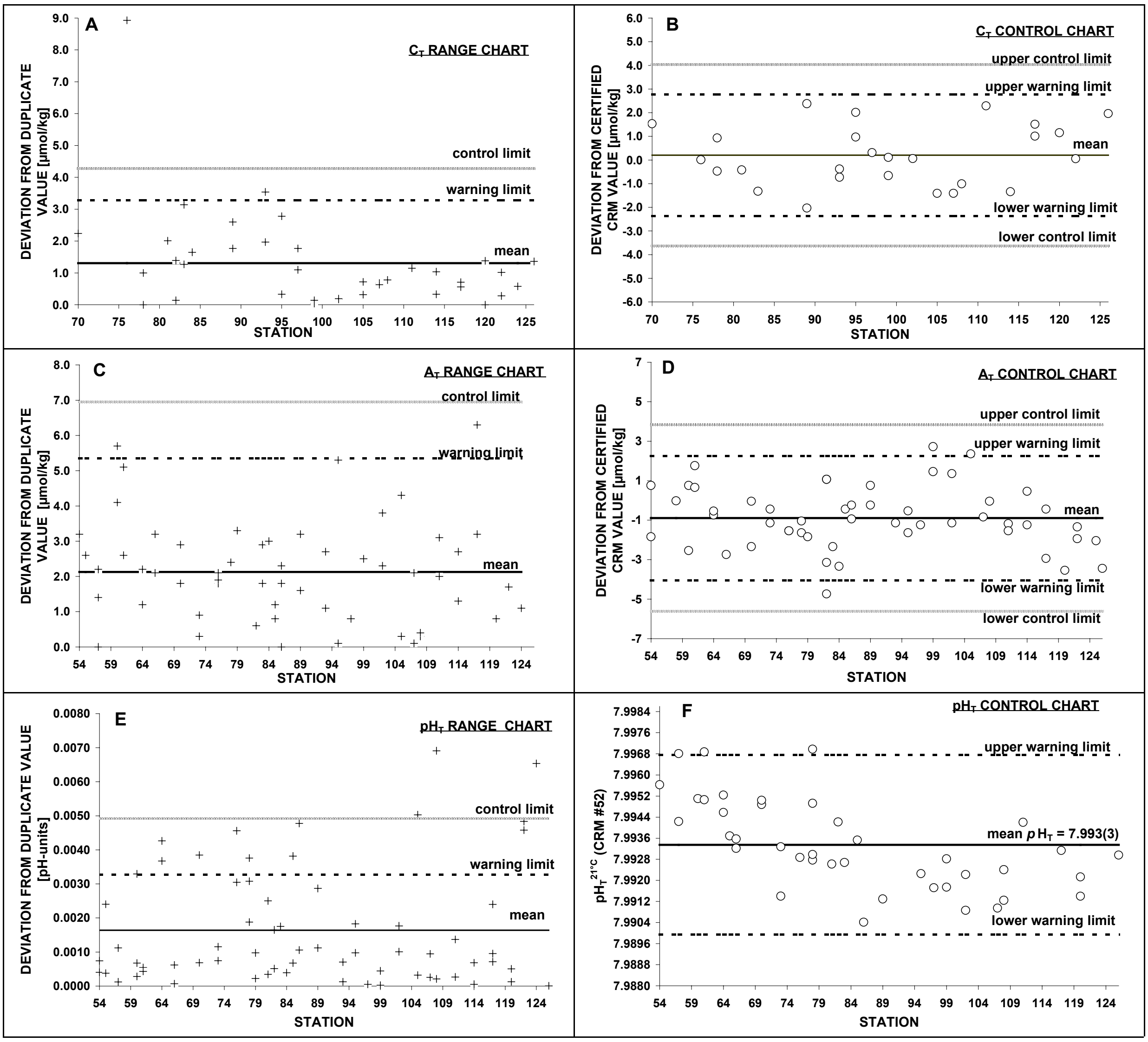

Fig. 1.9: Quality charts for C_T, A_T and pH_T analysis The range charts on the left-hand side are based on duplicate analysis of usually two niskin bottles per hydrocast. The control chart on the right-hand side are based on measurements of certified reference materials (CRM), that was at minimum one control measurement per hydrocast and parameter. Also shown are ‚warning' and ‚control limits', these are included according to a standard procedure for marine CO_2 parameter analysis in DOE (1994). The ‚warning limits' result in muliplying the standard deviation by two and the ‚control limits' by three. About 95 % of the plotted points should be within the warning limits.

Preliminary Results of the pCO₂

- The preliminary pCO_2 shipboard results (Fig. 1.10) illustrate typical aspects of pCO_2 in the central North Atlantic during the summer months:
- CO_2 sea surface conditions with pCO_2 undersaturation up to differences from 100 µatm are not rare.
- Plankton blooms and high photosynthesis activity are clearly seen in a decrease of sea surface pCO_2.

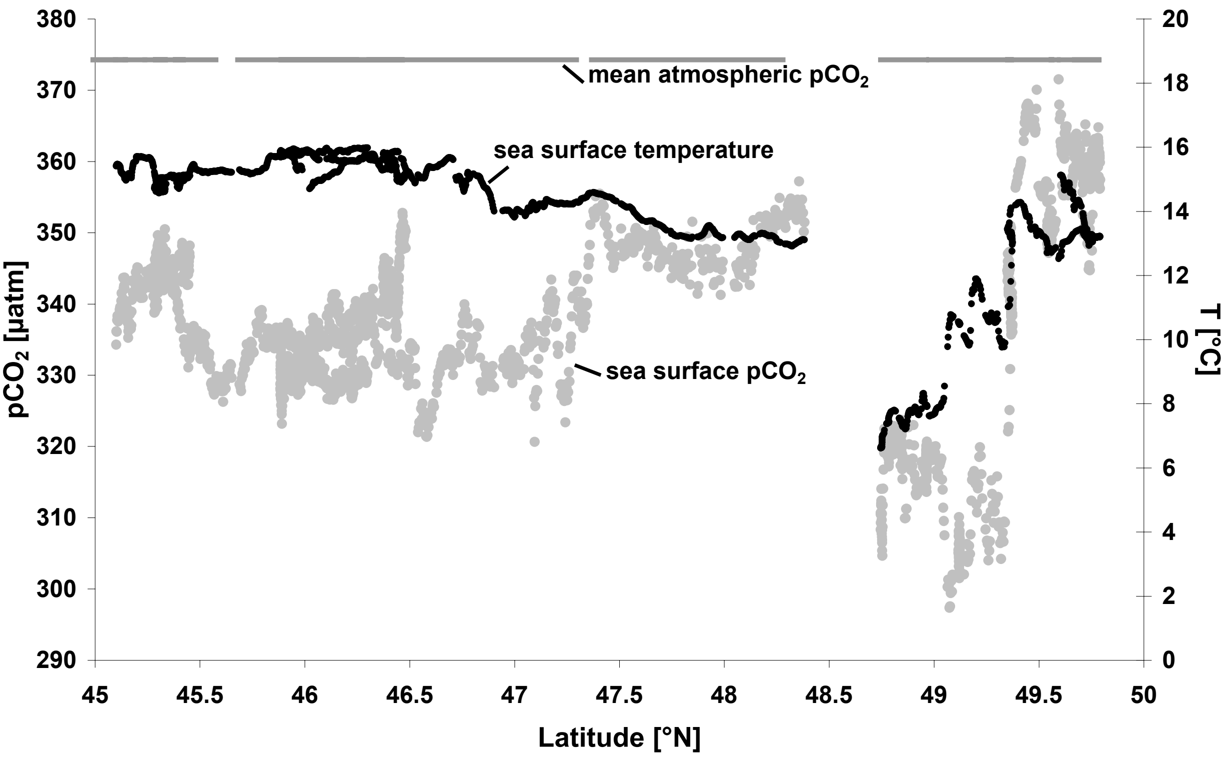

Fig. 1.10: Preliminary results of the pCO_2 measurements along the cruise track from 19 to 24 May, 2001.

- Sea surface temperature increase should lead to (from the thermodynamic point of view) an increase in pCO_2, but this effect can be masked by the biological processes.
- Sea surface temperature decrease should lead to a pCO_2 decrease through increased gas solubility, but this maybe compensated by a net CO_2 flux from the atmosphere into the ocean.
- Mixing of cold and warm water surface regimes can produce pCO_2 distribution patterns that can not easily interpreted with thermodynamic considerations.

Preliminary Results of the C_T, A_T and pH Analysis

A total number of 459 (416 individual samples) C_T samples, 663 (601 individual samples) A_T samples, and 688 (622 individual samples) pH samples were anlayzed. An overview of all data is given in Fig. 1.11 as surface-to-deepwater profiles. The carbonate parameters range from 2050 to 2185 µmol/kg for C_T, 2205 to 2440 µmol/kg for A_T and 7.76 to 8.13 for pH_T at 21 °C. All three parameters show highest variabilities from the surface to about 1000 m depth, which is mainly caused by biological activity from photosynthesis, calcification and respiration. Between the surface and 500 m one can also see two C_T and A_T branches, which matches the higher salinity and temperature data for higher values, and vice versa for lower values. The slight separation of two pH branches below 2500 m in Fig. 1.11 C indicates different source regions for the deeper water masses. Property-property-plots of pH_T vs. C_T and A_T vs. C_T (Fig. 1.12 A and B) show three different CO_2 patterns for the near surface waters, with high pH and variable A_T values. These CO_2 patterns come together with increasing C_T values, i.e. with less varaible C_T values in intermediate and deep water masses.

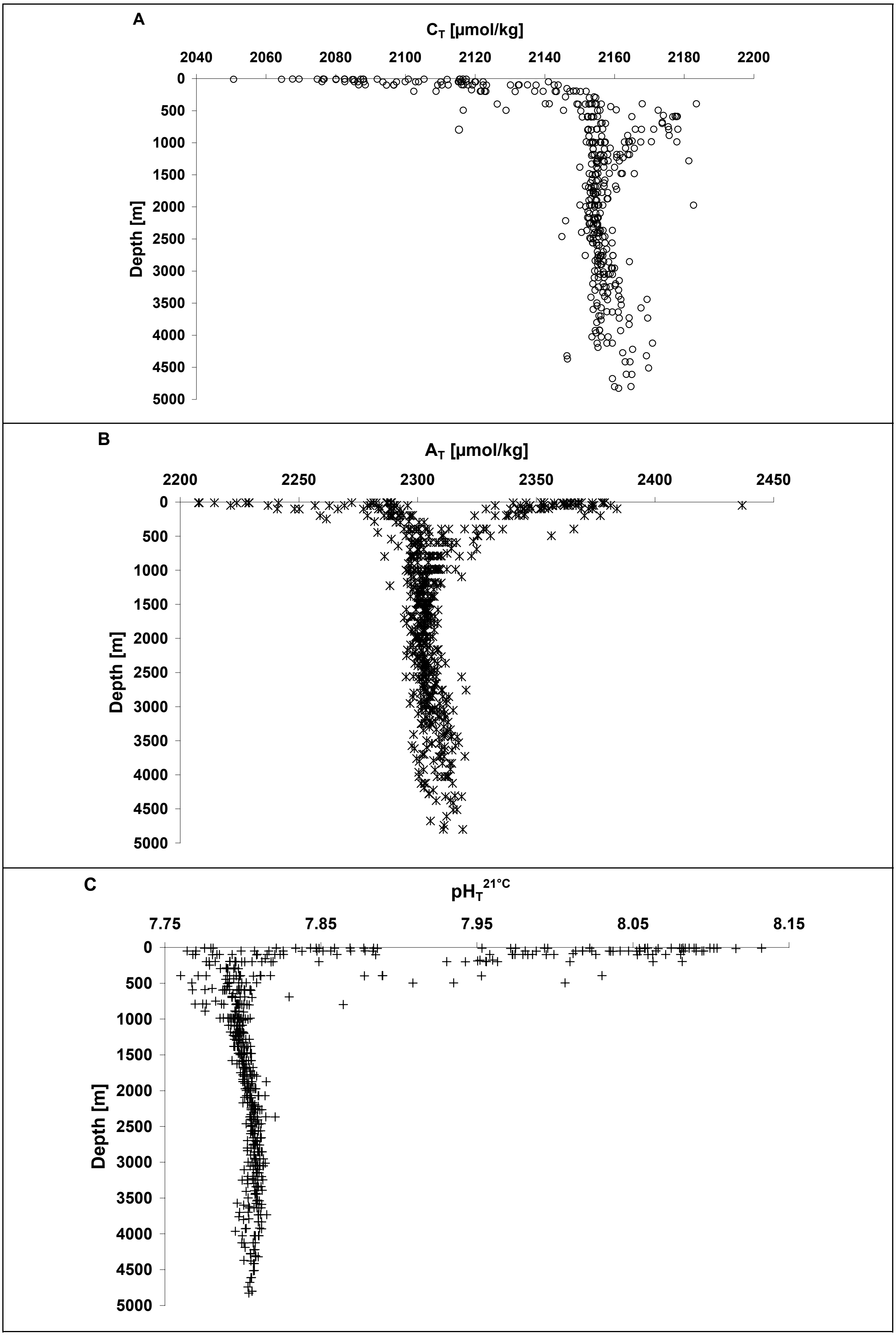

Fig. 1.11: Surface-to-deep water profiles of all C_T, A_T and pH_T measurements.

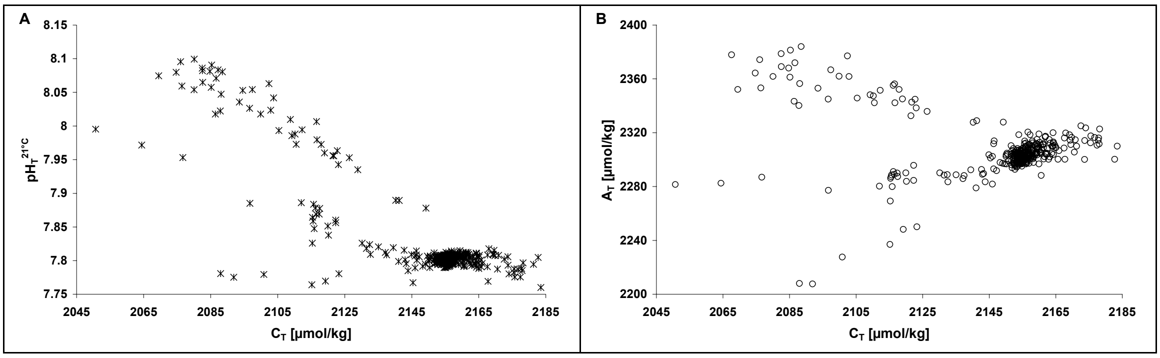

Fig. 1.12: Property-property-plots for C_T, A_T, pH_T. Both plots indicate three different CO_2 patterns near surface waters, with high pH and variable A_T values. These patterns come together with increasing C_T values, i.e. with less variable C_T values in intermediate and deep water masses.

1.4.6 Underway Measurements of Sea Surface Parameters

(H. Schmidt)

During METEOR cruise M50/1 the ships on-track observational system DVS was used to collect quasicontinuous near surface temperature and salinity (conductivity) from the ships thermosalinograph, depth data by the PARASOUND and HYDROSWEEP echosounders as well as wind speed and wind direction data.

a) Thermosalinograph

After despiking (mainly salinity data) the thermosaliniogrph data was calibrated versus CTD data from 5 meter depth.

While the temperatures were in close agreement with those from the CTD, only a least square linear fit was necessary to consider the temperatur dependency of the devitations. We found the following calibration equation:

$$T_{corr} = A \times T_{thermosal} + B \quad (1)$$

with A = - 0.021 and B = 0.2817.

The salinity measurements showed larged differences initially. After calibration thermosalinograph- and CTD salinity agreed within a standard deviation of 0.145 and a mean offset of 0.169. Salinity- and SST- maps have been constructed with the calibrated data.

b) Wind speed and direction

Wind speed and wind direction were measured on port and on starboard of the ship. For the graphic only luv data were used. Figure 1.13 shows the recorded wind vectors during M50/1.

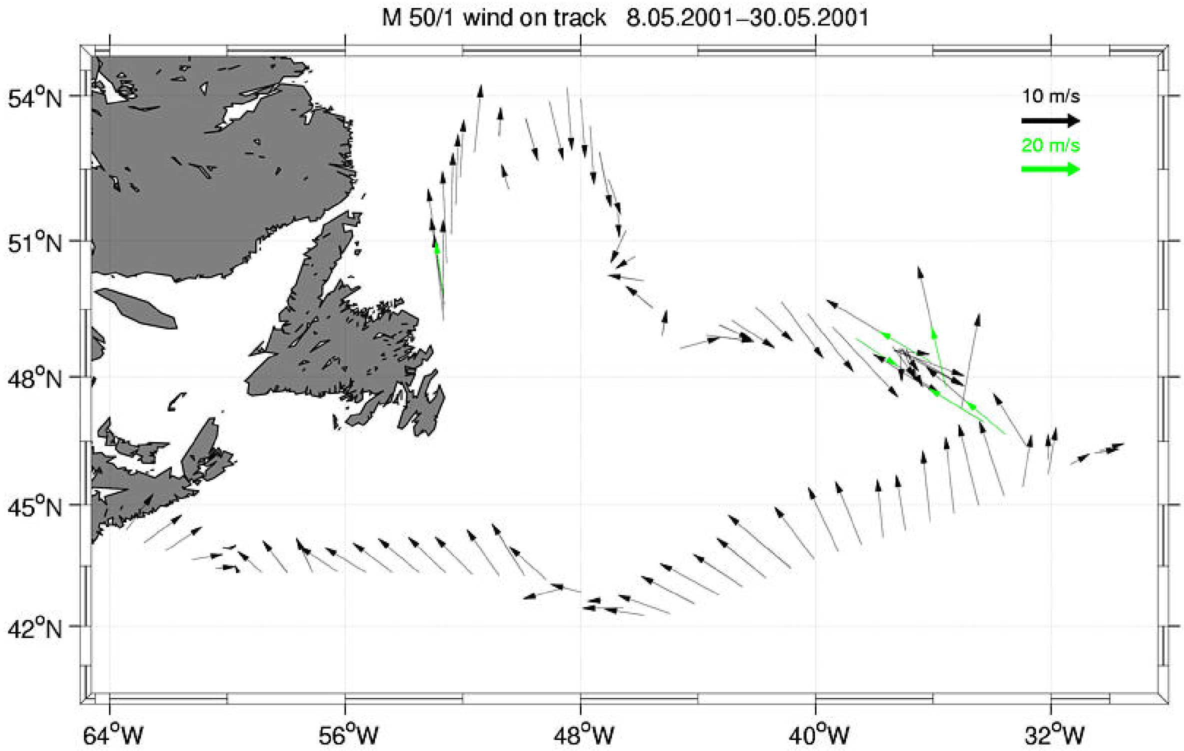

Fig. 1.13: Wind speed and direction on M50/1.The black arrows are scaled with 10 m/s and gray arrows are scaled with 20 m/s.

1.4.7 Deployment of Profiling Floats

Three profiling floats of type APEX were deployed in the Deep Western Boundary Current regime; one off the Grand Banks and two off Flemish Cap. For positions and launch times see table 1.6 in chapter 1.6. These three were IFMK floats, and were programmed to drift at 1500 m and rising to the surface every ten days. The other bunch of 5 floats were from the BSH and were deployed near the Midatlantic Ridge in the vicinity of the BSH moorings. These floats also drift at 1500 m depth at a 14-day schedule. All floats were started several hours before launch, such that the initial surface time remained short (a few hours only).

1.5 Weather Conditions during M50/1

When the METEOR left Halifax, NS, on May 08, 2001, she had a sunny day with light westerly winds under the influence of an elongated high that extended south of Newfoundland to south of New York. However, a gale center of 1005 was situated south of Bermuda, moving northeast so that winds backed southeast on May 09. The gale center intensified to 1000 on May 11, lying south of Cape Breton Island, and winds were up to 6 Bft on our position. Then, the gale center changed ist course to move southeast, passing south of the research vessel on May 14 when we observed northeasterly winds 6 Bft abating to 5 Bft 5 but slowly. However, a low is never alone in creating winds. The high over Greenland had been strengthened to 1040 by a low that had moved from New England to the eastern entrance of Hudson Strait, and it had developed a wedge of 1030 south of Greenland. The gale center reached the Azores on May 15 and moved further east during the next days, thereby filling. Meanwhile, another gale center 1000 had developed near 40 North 57 West, intensifying to 995 the next day at 55 West. Prior to passage of a cold front on May 18, southeasterly gales of 7 Bft were observed at the METEOR, and during passage of the front, there were southerly gales force 8 Bft. The high south of Greenland had meanwhile migrated east to the Bay of Biscay. The gale center turned northeast, moving quicker than before and intensifying to 990 on May 19 at 48 North 40 West while winds at our position veered southwest and abated somewhat. During the next days, this gale center moved northwest, then turned southwest, filling thereby until its vestiges merged with the next storm center. A secondary low went up past Iceland to the Norwegian Sea where it found favourable conditions for development into a gale center. When METEOR reached her easternmost position on May 20, winds had veered further to the northwest, force being 5 Bft.

On May 19, south of Cape Hatteras a new low 1010 had formed, central presure being down to 1005 during May 20 when the low passed far south of Newfoundland. Conditions being favourable for further development into a storm center, it followed its predecessor as far as its path was concerned. A central pressure of 995 was reached at 06 UTC on May 21 at 42 North 42 West and 980 by 18 UTC at 46 North 38 West. Our research ship, in the meantime, was under way on a northwesterly course to 49'45 North 41'30 West, the starting point for another series of probing positions. Winds were already up to southeast 9 Bft, and at 06 UTC on May 22, even a storm of southeast 10 Bft was recorded for a few hours. Central pressure of the storm center was 965, and at the ship lowest recorded pressure was 968,6. It can be concluded that the storm center was passed within a few miles. Thereafter, the storm center began to fill, central pressure reaching 970 by 18 UTC on May 22 and 980 by 06 UTC on May 23 while we experienced westerly to northwesterly gales of 8 Bft. By 18 UTC on that day, central presure was further up to 985 at 52 North 36 West, and the northwesterly winds had abated to 6 Bft.

During the next few days, filling went on up to a central pressure of 1000, and the low moved up to 52 Nord 38 West, then turned southwest to south, passing again within a short distance of the ship, its passage being nearly unnoticed (that is, except on the weather map) and then swinging southeast to east.

Meanwhile, a high of up to 1035 had established itself over the northern part of Hudson Bay on May 25, and this migrated southeast to Labrador during May 26, weakening to 1025. Still, it was responsible for northerly winds of 6 Bft on METEOR's probing position by then.

Movement of the high did not stop there, the high reaching 40 North 50 west by May 28. By that time it became stationary, but ist central pressure did not stop strengthening. When it had passed Newfoundland, it had created favourable conditions for the development of a low over northern Quebec in its wake. This low formed in due course on May 27 and intensified to 995 until May 29. At the same time, a low of 1007 developed near Cape Cod, moving northeast. On the eastern flank of both these lows, strong southerly winds developed. Dealing with those, the METEOR headed for St. John's and called there on May 31, 2001.

The meteorological instruments proved to be of no concern during this cruise. The same can be said, fortunately, of the METCO computer processing and storing the data.

As far as the global radiation data measured during the cruise are concerned, there is an additional clue to the data being reliable: they are sent for immediate inspection weekly to the German Weather Service's facilities in Hamburg, and they have not been declared faulty there. So, it can be concluded that all data made available to the scientific crew by the ship's weather station are reliable.

1.6 Station List M 50/1

Table 1.3: CTD/ADCP List

Meteor M50/1 CTD Stations

Profile	Station	Date	Time	Latitude	Longitude	Water Depth	Profile Depth	Comment
1	53	09.05.01	19:56	43° 21.41' N	56° 36.45' W	3458	2008	
2	54	11.05.01	01:37	43° 14.63' N	49° 28.53' W	903	807	
3	55	11.05.01	04:15	43° 10.00' N	49° 9.01' W	1062	1028	
4	56	11.05.01	08:50	43° 4.58' N	48° 53.43' W	2015	1989	
5	58	11.05.01	14:05	43° 0.81' N	48° 38.22' W	2548	2530	
6	60	11.05.01	20:14	42° 57.20' N	48° 23.61' W	3030	3018	
7	61	12.05.01	06:09	42° 47.53' N	47° 48.00' W	3662	3682	
8	64	12.05.01	19:21	42° 31.16' N	46° 47.49' W	4326	4360	
9	65	13.05.01	01:07	42° 35.26' N	47° 5.79' W	4044	4074	
10	66	13.05.01	05:33	42° 41.05' N	47° 27.07' W	3833	3857	
11	67	13.05.01	10:28	42° 50.53' N	47° 59.86' W	3535	3553	
12	69	13.05.01	19:25	42° 47.67' N	47° 48.10' W	3667	3687	
13	70	13.05.01	23:33	42° 54.19' N	48° 13.27' W	3258	3267	
14	71	14.05.01	06:38	43° 10.64' N	49° 6.83' W	1170	1135	
15	73	14.05.01	11:45	43° 2.31' N	48° 50.41' W	2153	2124	
16	75	14.05.01	20:15	42° 55.48' N	48° 21.34' W	3069	3090	
17	76	15.05.01	07:28	42° 31.17' N	46° 47.44' W	4303	4353	
18	78	15.05.01	18:07	42° 21.06' N	46° 8.12' W	4679	4769	
19	79	16.05.01	00:14	42° 9.73' N	45° 29.61' W	4750	4834	
20	80	16.05.01	09:35	42° 32.99' N	44° 11.10' W	4877	4969	
21	81	16.05.01	19:17	42° 54.25' N	42° 48.66' W	4841	4923	
22	82	17.05.01	04:33	43° 14.95' N	41° 30.00' W	4825	4896	
23	83	17.05.01	13:43	43° 37.98' N	40° 12.15' W	4816	4895	
24	84	17.05.01	22:41	43° 57.04' N	38° 47.95' W	2615	2597	
25	85	18.05.01	06:26	44° 17.11' N	37° 23.87' W	4408	4461	
26	86	18.05.01	14:28	44° 36.98' N	36° 0.00' W	4052	4097	
27	87	18.05.01	22:51	44° 57.06' N	34° 35.01' W	3958	3998	
28	89	19.05.01	14:15	45° 20.10' N	33° 9.53' W	3615	3635	
29	93	20.05.01	14:22	46° 23.52' N	29° 50.56' W	3240	3283	
30	95	21.05.01	06:10	45° 53.07' N	31° 34.98' W	3590	3591	
31	97	23.05.01	18:56	49° 45.30' N	41° 29.31' W	4403	4456	
32	98	24.05.01	01:00	49° 32.40' N	42° 2.75' W	4448	4472	
33	99	24.05.01	06:43	49° 21.15' N	42° 37.61' W	4228	4270	
34	100	24.05.01	11:43	49° 7.36' N	43° 10.69' W	3941	3957	
35	101	24.05.01	15:58	48° 57.95' N	43° 35.54' W	3467	3469	
36	102	24.05.01	19:56	48° 50.93' N	43° 57.89' W	2418	2367	
37	104	24.05.01	23:26	48° 45.12' N	44° 18.47' W	1809	1788	
38	105	25.05.01	02:05	48° 38.43' N	44° 35.07' W	1395	1368	
39	106	25.05.01	04:33	48° 33.98' N	44° 47.86' W	1036	1003	
40	107	25.05.01	06:45	48° 30.02' N	45° 0.04' W	815	785	
41	108	26.05.01	18:22	54° 16.97' N	48° 10.97' W	3949	3965	
42	109	26.05.01	22:41	54° 4.94' N	48° 35.06' W	3818	3837	
43	110	27.05.01	03:20	53° 53.90' N	49° 1.04' W	3793	3810	
44	111	27.05.01	07:46	53° 44.96' N	49° 23.83' W	3747	3763	
45	112	27.05.01	11:35	53° 36.78' N	49° 37.58' W	3676	3688	
46	114	27.05.01	18:56	53° 30.96' N	49° 56.96' W	3570	3574	
47	115	27.05.01	22:44	53° 23.99' N	50° 13.08' W	3450	3449	
48	116	28.05.01	03:08	53° 12.45' N	50° 44.01' W	3126	3127	
49	117	28.05.01	06:16	53° 17.53' N	50° 30.88' W	3255	3251	
50	120	28.05.01	19:56	53° 5.30' N	50° 58.02' W	2857	2839	
51	121	28.05.01	23:32	53° 8.07' N	50° 54.15' W	2904	2895	
52	122	29.05.01	03:45	53° 0.52' N	51° 12.88' W	2410	2410	
53	123	29.05.01	06:35	52° 55.47' N	51° 24.43' W	2069	2041	
54	124	29.05.01	09:13	52° 50.96' N	51° 34.84' W	1364	1323	
55	125	29.05.01	11:31	52° 46.56' N	51° 47.15' W	446	450	
56	126	29.05.01	13:41	52° 41.62' N	52° 0.60' W	310	288	

Table 1.4: M50/1 Mooring recovery

MOORING	DATE OF RECOVERY	START (UTC)	END (UTC)	COMMENTS
K101_1	May 11. 2001	11:46	12:46	low visibility
K102_1	May 11. 2001	17:20	19:24	
K103_1	May 12. 2001	10:09	11:53	
K104_1	May 12. 2001	16:45	18:41	
BSH K3	May 19. 2001	09:20	13:30	
BSH K1	May 20. 2001	11:04	14:15	radio defect
K27	May 27. 2001	15:39	17:50	
K28	May 28. 2001	08:46	10:36	radio defect
K29				not found

Table 1.5: M50/1 Mooring deployments

MOORING	DEPLOYMENT	UTC	LATITUDE	LONGITUDE	WATER DEPTH
K101_2	May 14. 2001	11:05	43° 04.0' N	48° 52.5' W	2016 m (corr.)
K102_2	May 14. 2001	19:21	42° 57.0' N	48° 23.5' W	3001 m (corr.)
K103_2	May 13. 2001	18:51	42° 46.8' N	47° 45.2' W	3600 m (corr.)
K104_2	May 15. 2001	14:20	42° 31.8' N	46° 47.35' W	4310 m (corr.)
BSH 3 2001	May 19. 2001	20:34	45° 21.67' N	33° 09.40' W	3640 m (uncorr.)
BSH 1 2001	May 20. 2001	21:32	46° 24.26' N	29° 54.60' W	3220 m (corr.)

Table 1.6: Float Deployments

S/N	Dec-Argos-ID	Hex-Argos-ID	Start time UTC	Launched UTC	Position	Remarks
IFM						
283	03836	3BF23	14.05.01 / 12:07	14.05.01 / 13:38	43°N3,44 / 48°W50,63	touched the ship during launch
288	13811	D7CD1	24.05.01 / 17:16	24.05.01 / 21:45	48°N49,85 / 43°W58,16	WD 2300m
289	13812	D7D3B	24.05.01 / 19:10	24.05.01 / 22:40	48°N47,06 / 44°W08,92	WD 2000 m
BSH						
298	21612	51B29	18.05.01 / 22:15	19.05.01 / 01:15	44°N56,92 / 34°W34,51	
299	22005	57D64	20.05.01 / 02:16	20.05.01 / 03:38	45°N53,09 / 31°W34,95	

300	22335	5CFF7	20.05.01 / 17:55	20.05.01 / 22:00	46°N24,28 / 29°W53,62	
301	15396	F0933	21.05.01 / 10:02	21.05.01 / 15:21	46°N30,19 / 33°W09,90	
302	15398	F0995	19.05.01 / 13:40	19.05.01 / 16:30	45°N18,78 / 33°W09,00	

Tabel 1.7: Marine chemistry measurements

Station/Profil	**C_T/Dup.**	**PH/Dup.**	**A_T/Dup.**	**^{13}C**	**TOC**	**Chlorophyll**
53/01	-	-	-	-	-	-
54/02	-	12/2	12/2	10	-	-
55/03	-	14/2	14/2	12	12	4
57/04	-	22/2	22/2	20	-	2
58/05	-	1	1	-	1	-
60/06	-	22/2	22/2	20	6	3
61/07	-	21/2	21/2	19	7	4
64/08	-	22/2	22/2	20	6	3
65/09	-	1	1	-	-	1
66/10	-	22/2	22/2	20	13	3
67/11	-	1	1	-	-	1
69/12	-	-	-	-	-	-
70/13	22/2	23/2	23/2	21	8	2
71/14	-	1	1	-	-	1
73/15	-	21/2	21/2	-	-	-
76/17	24/2	24/2	24/2	22	-	-
78/18	22/2	22/2	22/2	20	7	3
79/19	-	22/2	22/2	20	5	3
80/20	1	1	1	-	-	1
81/21	23/2	23/2	-	21	6	3
82/22	23/2	23/2	23/3	21	6	3
83/23	22/2	22/2	22	20	7	3
84/24	9/1	9/2	9/3	-	-	1
85/25	-	22/2	22/2	20	20	3
86/26	-	23/2	23/2	21	21	3
87/27	1	1	1	-	-	1
89/28	22/2	22/2	22/2	20	20	2
93/29	23/2	23/2	23/2	21	21	4
95/30	24/2	24/2	24/2	22	22	3
97/31	24/2	24/2	24/2	22	22	3
99/33	24/2	24/2	24/2	22	7	3
102/36	19/2	19/2	19/4	-	-	3

Station/Profil	C_T/Dup.	PH/Dup.	A_T/Dup.	^{13}C	TOC	Chlorophyll
105/38	12/2	12/2	10	8	8	2
107/40	11/2	11/2	11/2	-	-	-
108/41	24/2	24/2	24/2	22	22	3
111/44	24/2	24/2	24/2	22	-	-
114/46	23/2	23/2	23/2	-	-	-
117/49	24/2	24/2	24/2	-	-	-
120/50	23/2	23/2	23/2	-	-	-
122/52	13/1	13/1	13/1	-	-	-
124/54	12/1	12/1	12/1	-	-	-
125/55	5	5	5	-	-	-
126/56	4/1	4/1	4/1	-	-	-
Total:	459/43	688/66	663/62	444	242	69

1.7 Concluding Remarks

It is our particular pleasure to thank captain M. Kull and his crew for the friendly, professional and helpful attitude, that made this cruise pleasant and very successful. We also thank our colleagues at the Bedford Institute of Oceanography, Allyn Clarke and Murray Scotney, for their generous help when we were faced by the problem with our damaged container and all the instruments inside.

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1.8 References

Clayton, T.D. and Byrne, R.H., 1993. Spectrophotometric seawater pH measurements: Total hydrogen ion concentration scale calibration of m-cresol purple and at-sea results. Deep Sea Res., 40(1): 2115-2129.

Doe, 1994. Handbook of methods for the analysis of various parameters of the carbon dioxide system in sea water. ORNL/CDIAC-74, U. S. Dep. of Energy, Oak Ridge Natl. Lab., Oak Ridge, Tenn., USA.

Friis, K., 2001. Separation von anthropogenem CO_2 im Nordatlantik – Methodische Entwicklungen und Messungen. Dissertation. Christian-Albrechts-Universität zu Kiel, Kiel, 137 pp.

Johnson, K.M., Wills, K.D., Butler, D.B., Johnson, W.K. und Wong, C.S., 1993. Coulometric total carbon dioxide analysis for marine studies: Maximizing the performance of an automated gas extraction system and coulometric detector. Mar. Chem., 44(2-4): 167-188.

Körtzinger, A., Thomas, H., Schneider, B., Gronau, N., Mintrop, L. und Duinker, J.C., 1996. At-sea intercomparison of two newly designed underway pCO2 systems - encouraging results. Mar. Chem., 52(2): 133-145.

Lewis, E. und Wallace, D.W.R., 1998. CO2SYS - Program developed for the CO2 system calculations. Carbon Dioxide Inf. Anal. Center; Report ORNL/CDIAC-105, Oak Ridge, Tenn., U.S.A.

Millero, F.J. and Dickson, A.G., 1987. A comparison of the equilibrium constants for the dissociation of carbonic acid in seawater media. Deep Sea Res., 34A(10): 1733-1743.

Millero, F.J., Byrne, R.H., Wanninkhof, R., Feely, R., Clayton, T., Murphy, P. und Lamb, M.F., 1993. The internal consistency of CO2 measurements in the Equatorial Pacific. Mar. Chem., 44(2-4): 269-280.

Mintrop, L., Perez, F.F., Gonzalez-Davila, M., Santana-Casiano, J.M. und Körtzinger, A., 2000. Alkalinity determination by potentiometry: intercalibration using three different methods. Ciencias Marinas, 26(1): 23-37.