Upper Ocean Climate

Ship-of-Opportunity Programme of BSH

- A Status Report -

BUNDESAMT FÜR
SEESCHIFFFAHRT
UND
HYDROGRAPHIE

Alexander Sy, Jürgen Ulrich and Hans-Joachim Weichert

Bundesamt für Seeschifffahrt und Hydrographie
Bernhard-Nocht-Str. 78
D-20359 Hamburg,
Germany

Contents

1. Overview of upper ocean climate monitoring activities

The ship-of-opportunity programme (SOOP) managed by "Bundesamt für Seeschifffahrt und Hydrographie" (BSH) focuses on the North Atlantic Ocean, and on the North and Baltic Seas. Its main contribution, the Atlantic XBT programme along the TOGA-WOCE-IGOSS (TWI) lines AX-3 and AX-11, which was originally planned in the late 80s as a contribution to WOCE (World Ocean Circulation Experiment) and IGOSS (Integrated Global Ocean Services System, now JCOMM) (Sy and Ulrich, 1989; Sy 1993a), has been continued and developed. Almost 15,000 temperature profiles from expendable bathythermographs (XBT) have been obtained so far covering the Atlantic Ocean from the North Pole to the Equator. Within the framework of BSH's SOOP, research and merchant vessels equipped with thermosalinographs or contact thermometers participate in near-surface temperature and salinity measurements.

The thermohaline circulation (THC) of the North Atlantic is subject to strong natural variability on time scales ranging from years to decades which are correlated somehow with the atmospheric North Atlantic Oscillation (NAO) (e.g. Dickson et al., 1996; Sy et al., 1997a; Koltermann et al., 1999; Curry and McCartney, 2001) and thus influence European climate. In particular occurrences of rapid and sustained THC changes severely affect the European climate, as has been shown by palaeo-climate records and model studies (e.g. Dansgaard et al., 1993; Rahmsdorf, 1994; 1995; Manabe and Stouffer, 1994; 1995; IPCC, 2001). Therefore, and because all observations indicate that global warming is continuing (IPCC, 2001), the risk of such changes must be better assessed. However, this is hampered by lack of observation data. For that reason, BSH's plans to upgrade its commercial vessel-based upper ocean thermal programme to an enlarged upper ocean climate programme (in particular TWI line AX-3) by using more sophisticated measurements were translated into action in 1998. As a contribution to GOOS (Global Ocean Observing System) and CLIVAR (Climate Variability and Predictability), BSH combined the AX-3 XBT programme with occasional XCTD measurements and with repeats of research vessel-based full-depth hydrographic sections in order to operate a well designed and cost-effective climate related monitoring programme in the GOOS A2-corridor of the North Atlantic (BSH, 1999), a key region for both ocean climate and European climate change investigation.

As BSH acts as the German input and output GTS hub for real-time oceanographic data, all SOOP data are inserted as BATHY, TESAC or TRACKOB coded bulletins onto GTS (Global Telecommunication System of WMO) with a delay of about 1 day to 1 week. Real-time data from various Atlantic ocean areas have been contributed by the German Navy which accounted for some 20 % of a total of more than 15,000 German BATHY data circulating on the GTS in 2000 and 2001, respectively. Since 2001, however, the Navy's data contribution has decreased almost to zero due to changes in its declassifying policy. Further BATHY data are contributed in real-time by BSH's stationary "Marine Environmental Monitoring Network in the North and Baltic Seas" (MARNET).

The scientific rationale, current technical and organizational status, and some preliminary results of the operational programme and other related operational data activities are described briefly in this report.

2. XBT network

A summarized regional overview of BSH's XBT SOOP activities from 1988 to 2002 is presented in Fig. 1 which shows the areas of main emphasis, i.e. lines AX-3 (GOOS A-2 corridor) and AX-11.

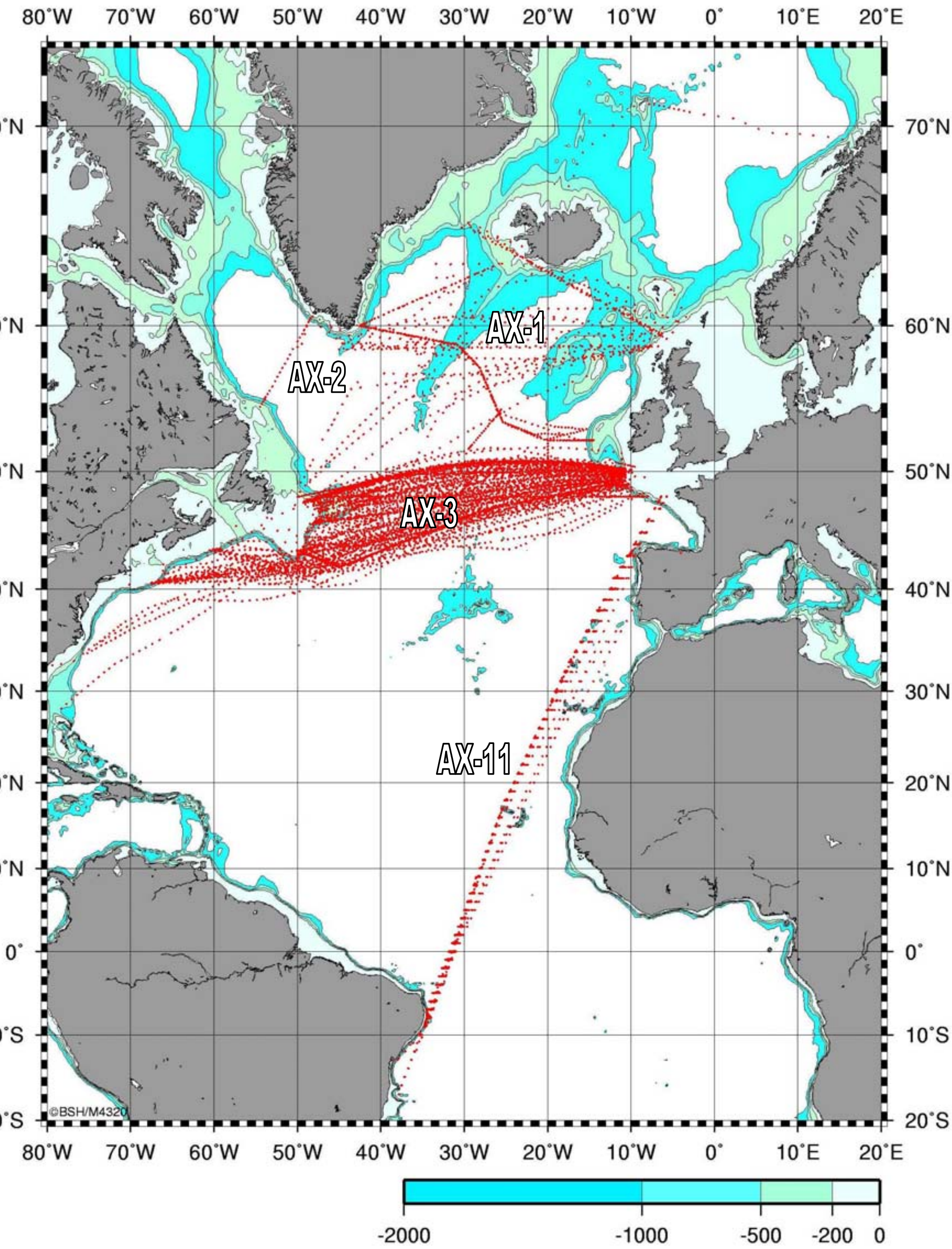


Fig. 1: Regional distribution of XBT drop locations from SOOs 1988 – 2002.

An enlarged regional overview of XBT measurements carried out in the recent past along lines AX-3 and AX-11 is given in Figs. 2 a, b, and the corresponding line status in Table 1 below. With this activity, BSH has continued its long-term contribution to the international SOOP (Fig. 3). Concerning the role of our XBT sampling strategy for upper ocean thermal monitoring, we met the recommendations for an advanced strategy proposed by Smith et al. (2000) from the very beginning of the programme and thus exceeded the requirements of WOCE (WOCE, 1988). In our practical field work, we followed the requirements and recommendations of WOCE (Sy, 1991) and the guidelines for SOOP managers as given by IOC (1999) and Cook and Sy (2001).

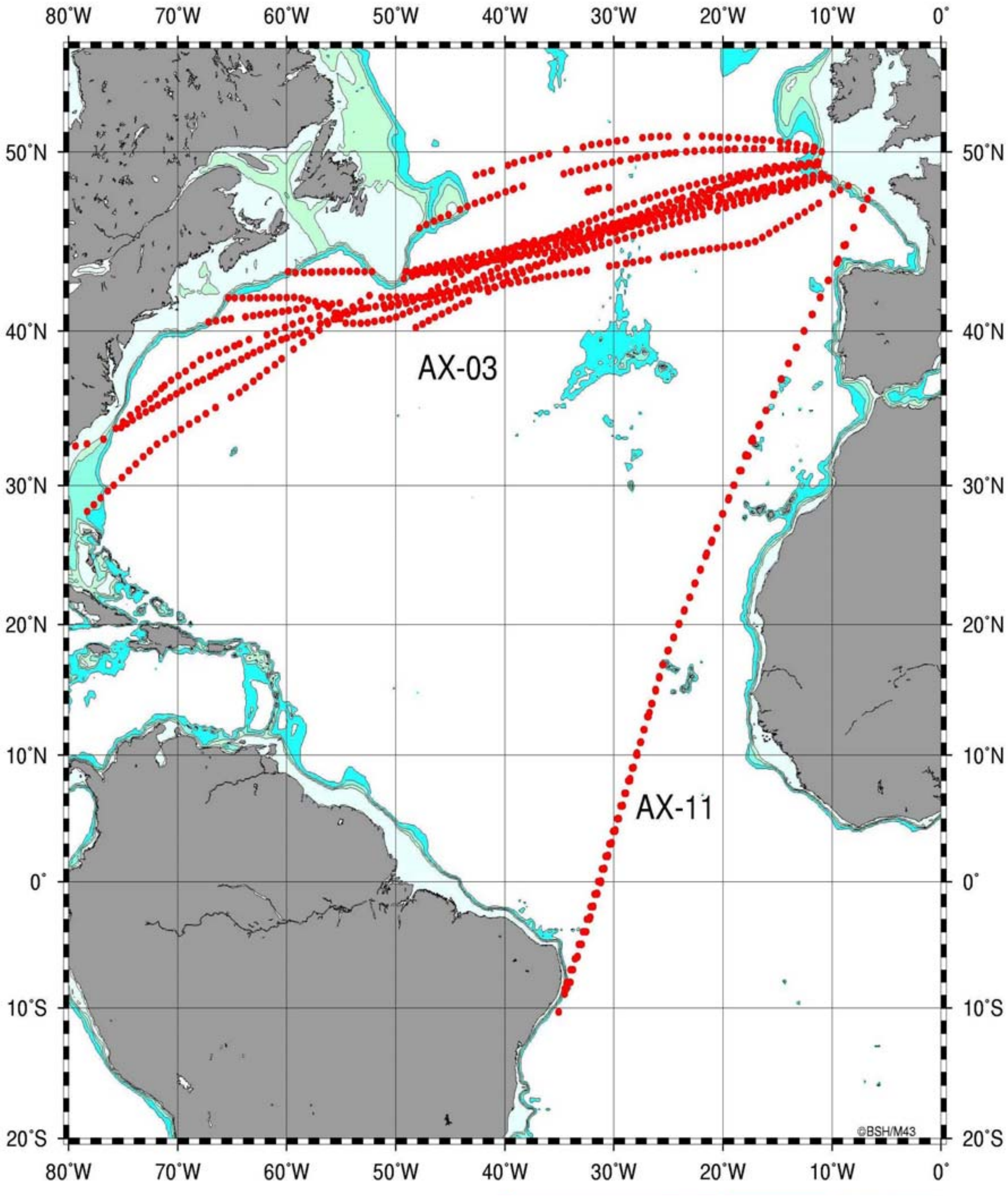


Fig. 2a: Positions of XBT measurements carried out in 2001 by BSH operated ships of opportunity.
AX-3: „Bonn Express“ (11 sections, 737 profiles, 1200 m depth range).
AX-11: „Cap Finisterre“ (7 sections, 395 profiles, 800 m depth range).

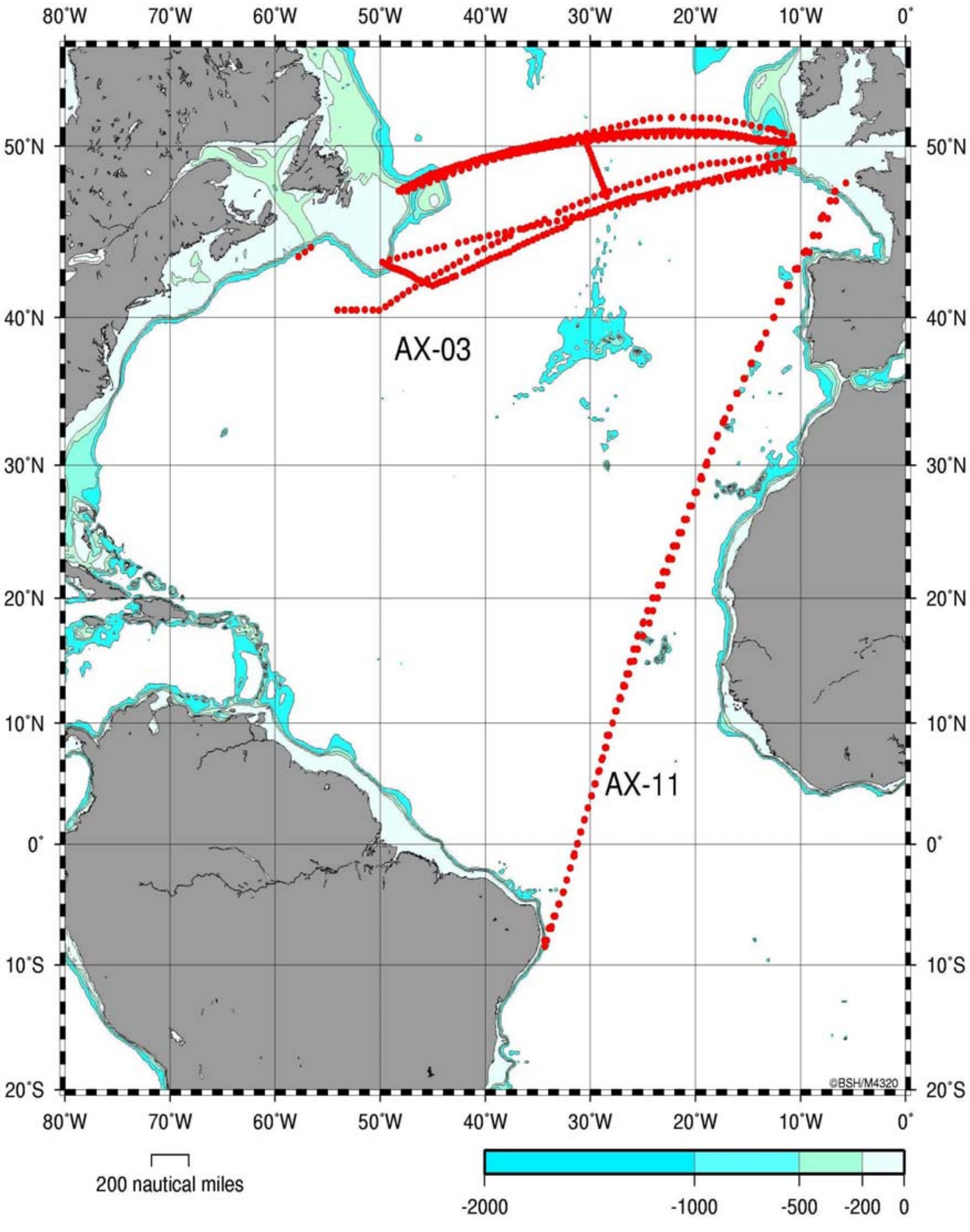


Fig. 2b: Positions of XBT measurements carried out in 2002 by BSH operated ships of opportunity.
AX-3: “Bonn Express” (5 sections, 265 profiles, 1200 m depth range).
“Gauss” (2 sections, 245 profiles, 2000 m depth range).
AX-11: “Cap Finisterre” (9 sections, 510 profiles, 800 m depth range).

Table. 1: Status of existing SOOP lines operated continuously by BSH

TWI #	**AX-3**	**AX-11**
Start of operation	May 88	1981/June 90
Co-operating vessels	Köln Express/Bonn Express/Gauss	Cap Finisterre
Call sign	9VBL/DGNB/DBBX	DACF
Mode	high density (HDX)	frequently repeated (FRX)
Frequency (sections)	8/year	7/year
Density (drops)	12/day	6/day
Probe type	Sippican Fast Deep/T-5	Sippican Deep Blue
Equipment	SEAS IV, MK-12	SEAS IV, MK-12
Real-time data transmission	METEOSAT	METEOSAT
Agency	BSH, Hamburg	BSH, Hamburg
Programme	GOOS/CLIVAR	GOOS
QC of delayed mode data	yes	yes
Sections 2000/2001/2002	8 11 7	6 7 9
Profiles 2000/2001/2002	595 737 510	309 395 510
GTS Input 2000/2001/2002	435 717 505	301 378 508
Sections planned in 2003	8	6
Problems 2000/2001/2002	none	10.99 – 04.2000: bad probe quality
Remarks	1 XCTD section in 2000 2 CTD sections (hydr. box) each in 1998, 2000, 2002 by RV Gauss	

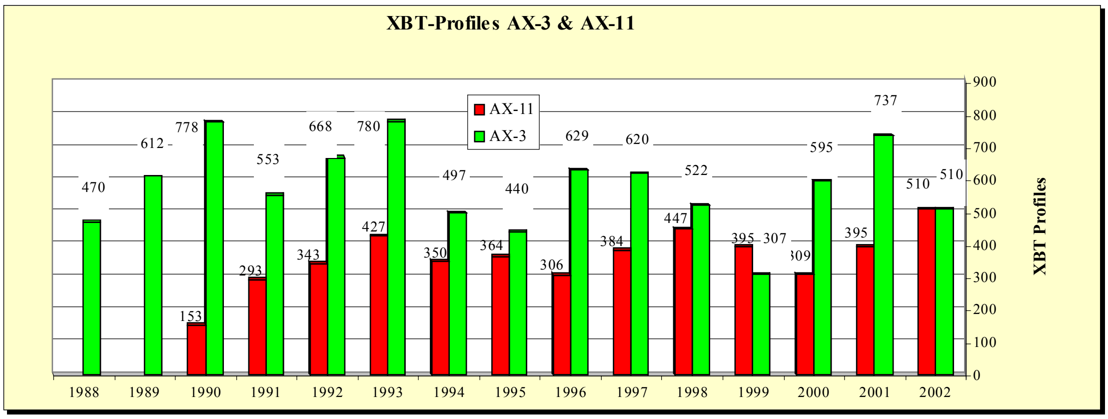


Fig. 3: Number of XBT profiles obtained along AX-3 and AX-11 from 1988 until 2002. The decrease for AX-3 in 1999 and AX-11 in 2000 is caused by wire related probe failures.

2.1 North Atlantic line AX-3

Line AX-3 from the English Channel to the Grand Banks (Halifax/New York) has been operated by BSH as a high density line almost without any serious problems since 1988 (Fig. 3). The WOCE related programme was funded by the German Ministry of Education and Research (BMBF) until the end of 1997. After that period, funding from different sources has allowed, and hopefully will continue to allow, these measurements to be carried out as part of BSH's contribution to the GOOS climate module (see section 3).

Fig. 4: CMS "Bonn Express" operated by Hapag-Lloyd, Hamburg, Germany

From the start of the programme in 1988, measurements have been carried out regularly until now. In 2000, after 12 years of continuous SOOP activity (5730 XBT profiles), the German container vessel "Köln Express" (DAKE, 9VBL) changed service and was replaced by "Bonn Express" (DGNB, Fig. 4). XBT measurements along this line were supplemented in 1998, 2000 and 2002 each by two deep and very closely spaced XBT sections (resolution 15 nm or better, 2000 m depth range) carried out by BSH's RV "Gauss" (DBBX).

A Sippican MK-12 unit and NOAA's SEAS IV (rev. 4.54) software are used for data acquisition and transmission. Most transects have a resolution of better than 40 nautical miles (Fig. 5). We replaced Sippican's Deep Blue probes (800 m depth range) in 1995 by the new Fast Deep type as a standard because these modified T-5 probes are capable of covering the upper 1200 m at a ship's speed of 20 knots. In this way, systematic monitoring of the thermal field in the upper kilometre has become possible (WCRP-11, 1988), which allows the Mode Water temperature to be measured in the seasonally deep mixed upper layer of the subpolar North Atlantic Ocean as far down as the underlying thermocline, providing information on the baroclinicity of this layer.

To estimate heat transports, measurements using expendable CTD probes (XCTD) have been carried out occasionally since 1992.

So far, the line has been kept operational almost without interruptions. However, data quality problems appeared in late 1998 which impeded the programme seriously due to an increased probe failure rate exceeding 30 % (see data decrease in Fig. 3). Fast Deep probe failures were wire related and occurred as wire stretching, constant signals and premature wire breaks (see also section 2.2). After probe replacements (warranty) had been made in October 1999, the probe failure rate again dropped to the previous level of about 5 %. No unusual quality problems with this probe type have been observed since then.

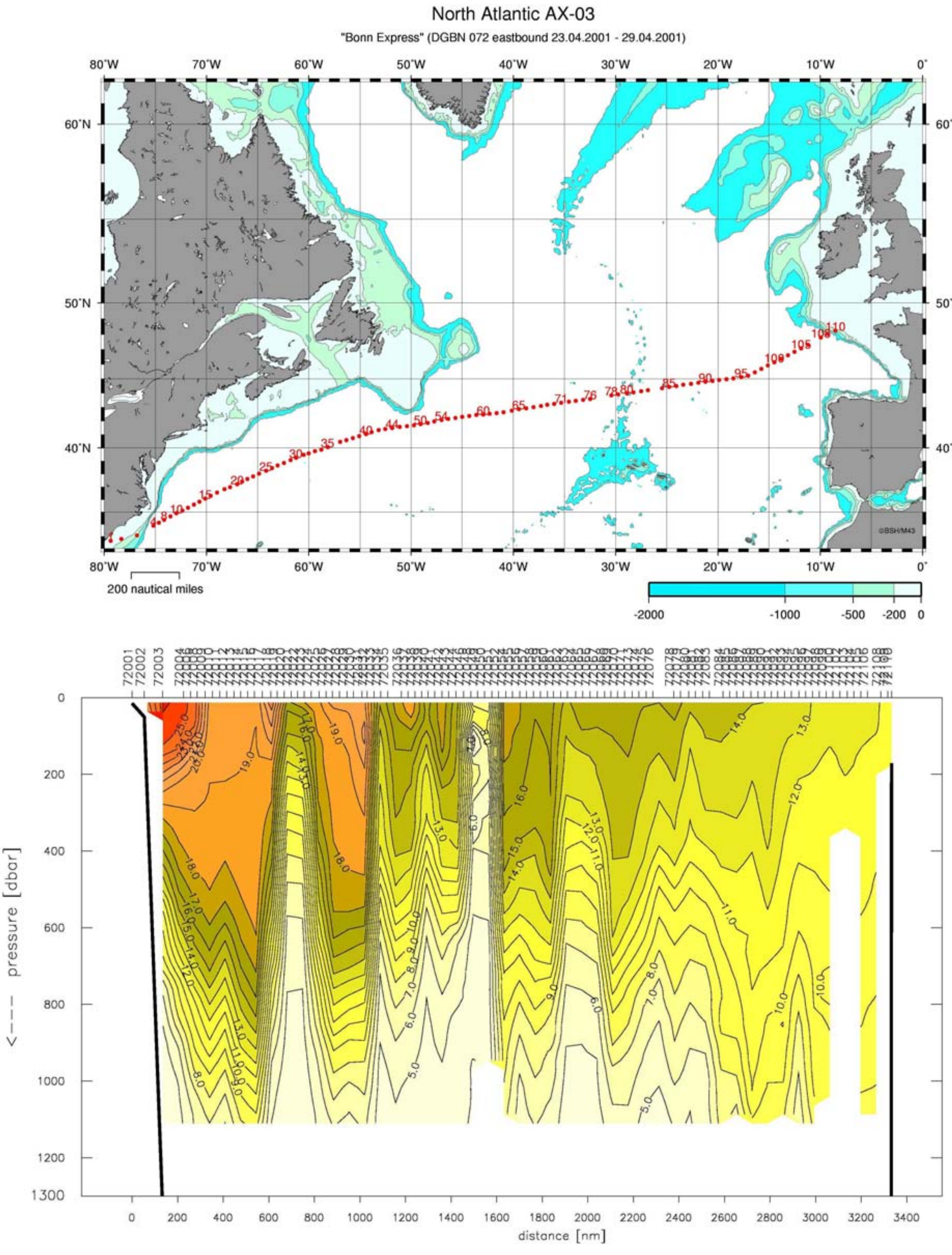


Fig. 5: Example of a high density Fast Deep XBT temperature section across the North Atlantic (AX-3) carried out by CMS „Bonn Express“ in April 2001. Note the extremely high variability caused by meanders, branches and rings of the Gulf Stream and North Atlantic Current and by distinctive eddy activity.

2.2 Europe - Brazil line AX-11

Fig. 6: CMS “Cap Finisterre” operated by Hamburg-Süd, Hamburg, Germany

The Europe-Brazil line was established in 1981 by former DHI (now BSH) as the first German contribution to the IGOSS SOOP line system, and has been kept operational until today without major interruptions. The introduction of SEAS equipment allowed an improved sampling strategy in 1990 because the analysis of Emery et al. (1987) had shown that the original low density modus of this line was of limited scientific value only. Since the summer of 1996 the measurements have been carried out by the German container vessel "Cap Finisterre" (DACF, Fig. 6) on her way due north. The transects have a resolution of 60 nm because XBTs are dropped at each degree latitude.

Both the data acquisition and data management systems are the same as those used for line AX-3, except for the use of Sippican’s Deep Blue XBT (800 m depth range) as standard probe type due to the shallower mixed layer of the tropics and subtropics. Since October 1999, the operation of this line has been seriously affected by the same probe wire related quality problems as described above (see section 2.1). Because of the tremendous increase in the failure rate from less than 5 % to over 50 %, the programme was interrupted several times in 2000 and 2001 until the probes were finally replaced (warranty) (see data decrease in Fig. 3). Since then the failure rate has dropped to the previous low level (Fig. 7).

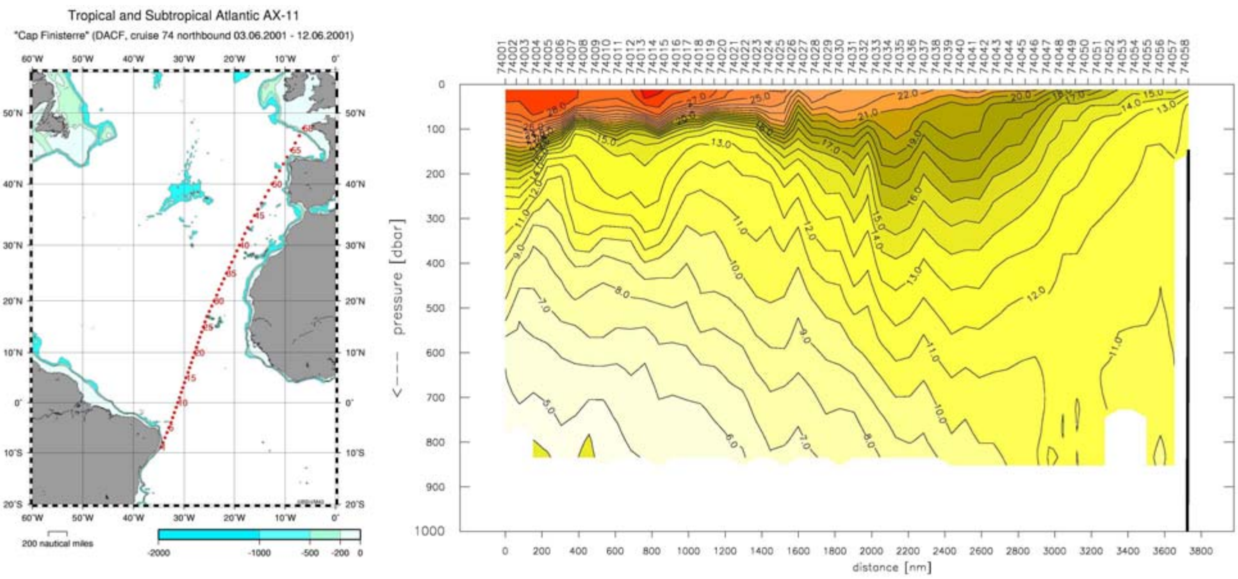


Fig. 7: Example of a regular Deep Blue XBT temperature section from Brazil to Europe (AX-11) carried out by CMS „Cap Finisterre“ in June 2001. The line intersects the eastern margin of the subtropical gyre.

Line AX-11 intersects the eastern margin of the subtropical gyre. The mean temperature field (Fig. 8 top) represents the main water masses such as the Tropical Surface Water (Θ > 20 °C), the Central Water, and the northward spreading Antarctic Intermediate Water (AAIW). The dominant feature is the bowl of warm water of the subtropical gyre which limits the northward spreading of AAIW north of 24°N. RMS values (Fig. 8 bottom) are highest in the surface layer down to 150 m, especially in the equatorial region from 5°S to 15°N. This high variability of the temperature field is associated with seasonal changes in the wind field and migration of the intertropical convergence zone from its southernmost position in north spring to its northernmost position in north fall. These atmospheric variations induce changes in the currents, like the weakening or even reversal of the North Equatorial Countercurrent from north spring to north fall.

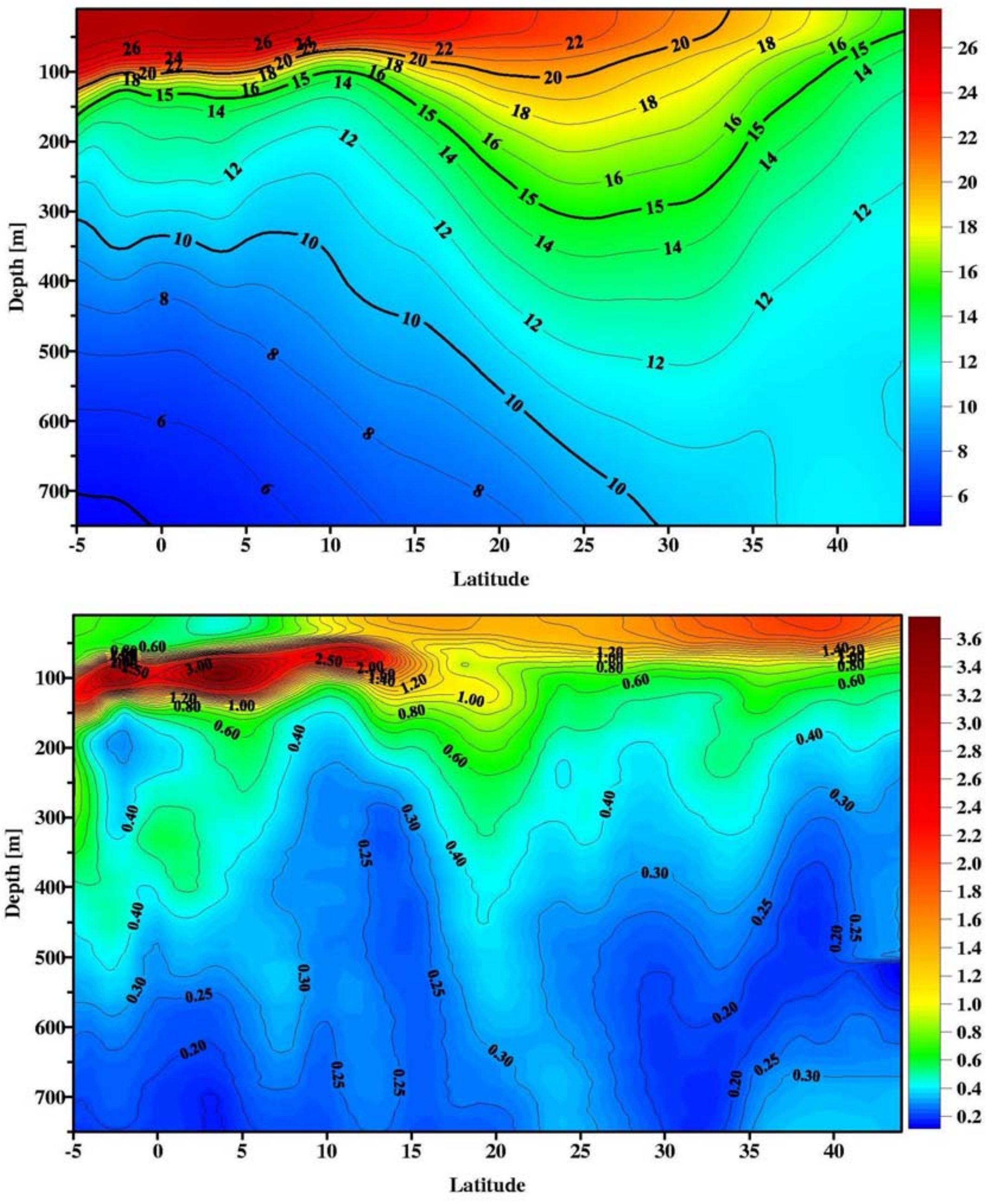


Fig. 8: Mean temperature field (top) and RMS values (bottom) along line AX-11

2.3 Further activities

During August 1990, the Soviet nuclear icebreaker "Rossiya" (UPIG) carried a party of tourists from Murmansk to the North Pole, cutting across the Eurasian Basin at longitudes 60°E and 95°E. As the vessel was not fully booked, we took the opportunity to join them and carry out some research in co-operation with Hamburg University, Germany. The Arctic region is virtually inaccessible to normal ocean-going vessels and, therefore, available ocean data is extremely sparse. On the other hand, it is a region vulnerable to climatic changes. Closely spaced temperature profile measurements in the upper 500 m of the water column were made using T-7 (depth range up to 800 m) and T-5 (depth range up to 2000 m) XBTs dropped in leads or small polynyas. Our assumption that XBT drops in ice-covered areas would be challenging was confirmed, and only half of the 170 probes launched in the ice regime reached a depth of more than 350 m. Nevertheless, the results obtained were well worth the effort. The data were reported by Sy and Ulrich (1994), and the scientific results were published by Quadfasel et al. (1991, 1993).

Additional XBT measurements have been carried out occasionally by different German and Russian research vessels in order to improve the data density of lines AX-1, AX-2 and AX-3. An overview of all vessels which participated in the BSH SOOP from 1988 until 2002 is given in Table 2 below.

	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	Total
CMS Koeln Express /AX-03	470	612	778	553	546	491	384	440	321	415	260	307	150			5727
CMS Monte Rosa /AX-11			153	293	343	427	350	364	259							2189
RV Walther Herwig /AX-01		26			55	54	83	60	112	62	56	30				538
RV Gauss /AX-03						128			308		262		266		245	1209
RV Meteor /AX-1/2/3							259			275						534
CMS Bonn Express /AX-03													179	737	265	1181
RV Prof. Multanovsky /AX-03					122	161										283
RV Valdivia /AX-01					110											110
NS Rossiya /Arctic			156													156
CMS Cap Finisterre /AX-11									47	384	447	395	309	395	510	2487
RV Prof. Shtokman /AX-03										75						75
SS Dagmar Aaen / Ice Sail						53										53
Total	470	638	1987	846	1176	1314	1076	864	1047	1211	1025	732	904	1132	1020	14542

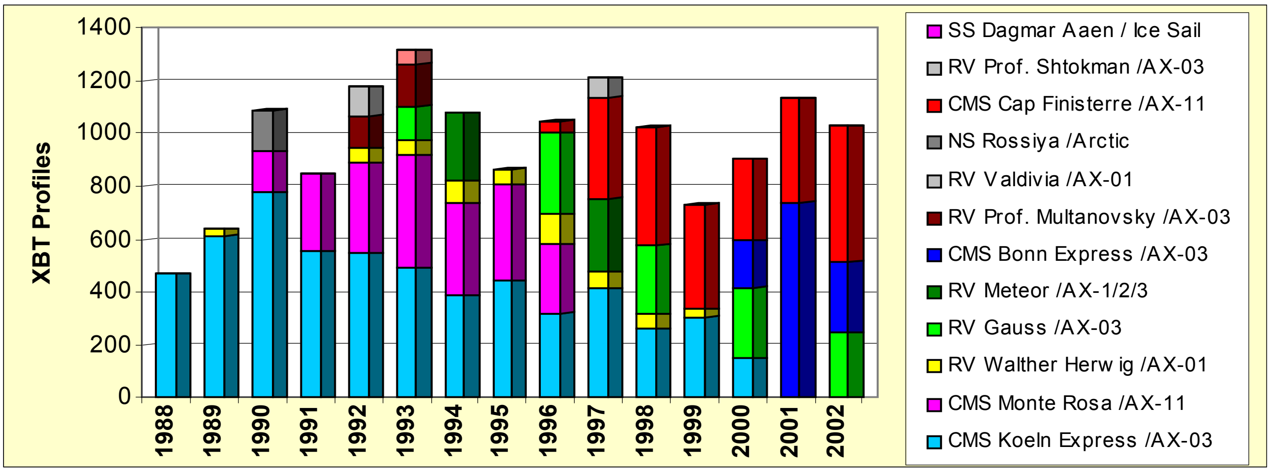
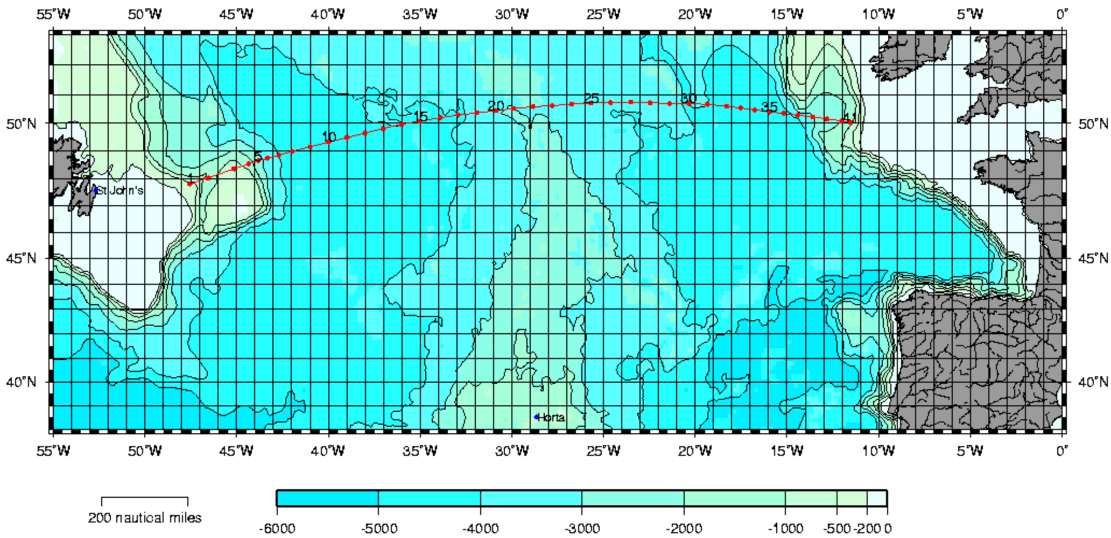


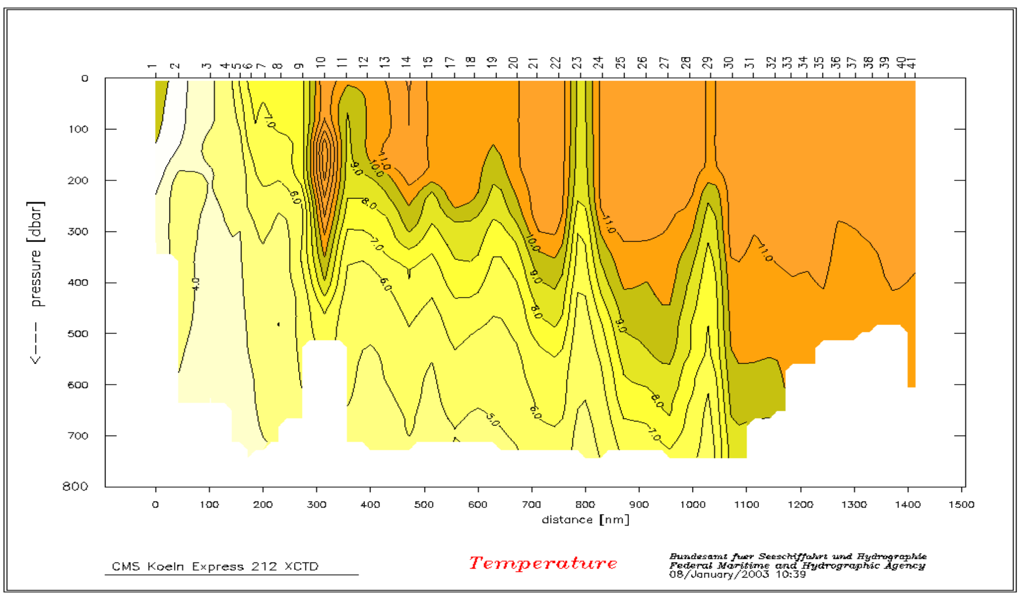
Table 2: Vessels participated in BSH's SOOP and number of XBT profiles acquired from 1988 to 2002.

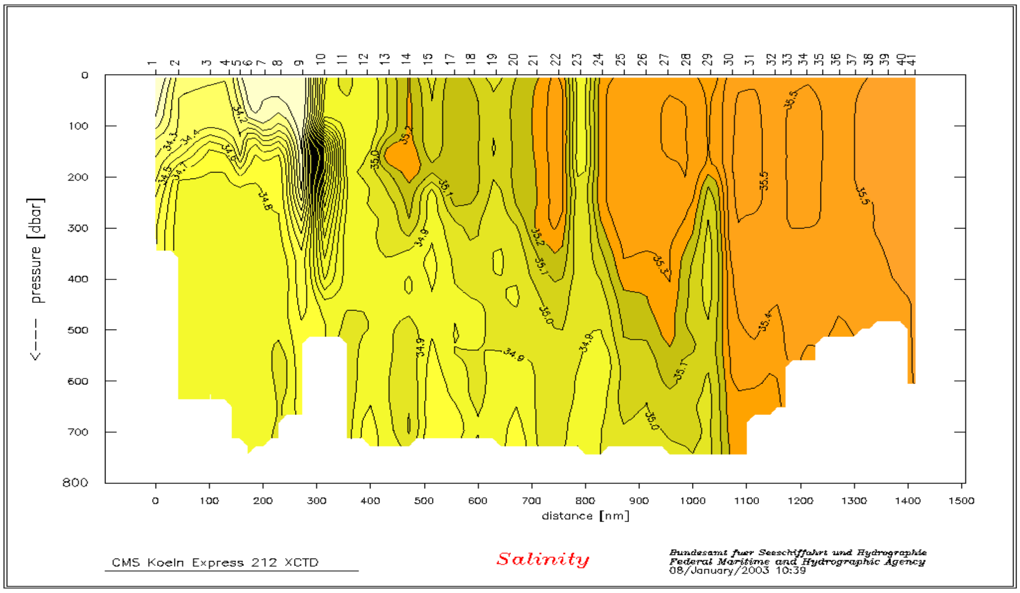
Measurements of temperature profiles alone, even if they are supplemented by occasional CTD sections, do not satisfactorily meet the requirements for monitoring heat transport variability or other important processes of highly variable upper ocean or thermocline T/S relations. Therefore, we started to carry out occasional XCTD measurements as soon as possible, initially using prototype expendable CTDs developed by Sippican Inc., Marion, USA (Sy, 1992). Although XCTD probes with the required performance are now available for operational use to close this gap (Sy, 1998a, b; Watanabe et al., 1998; Gilson et al., 2000) BSH meanwhile has reduced its XCTD programme because of an unsatisfactory cost-benefit relation. The last North Atlantic XCTD transect was carried out with good success in January 2000 (Fig. 9) using the probes and an acquisition system designed by Tsurumi-Seiki Co. (TSK), Yokohama, Japan.

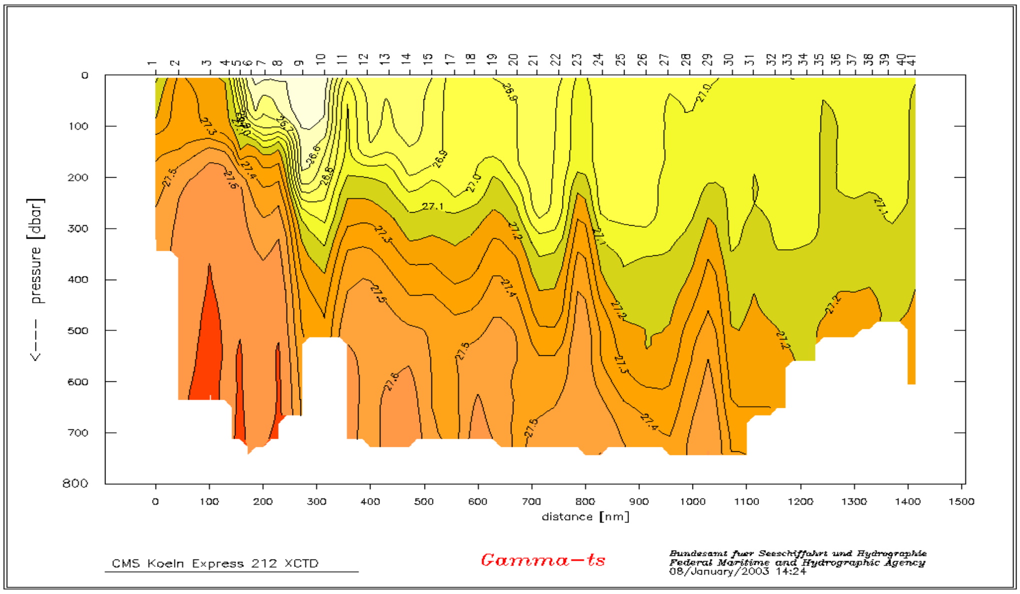


CMS Koeln Express Cruise 212 E

(11.01. - 14.01.2000)







<u>Fig. 9:</u> AX-3 XCTD section of temperature (previous page), salinity (top) and density bottom) carried out with CMS „Köln Express“ in January 2000.

3. BSH contribution to the climate module of GOOS in the North Atlantic Ocean (GOOS A-2 corridor)

3.1 Scientific background

As a contribution to CLIVAR and GOOS, BSH combined the AX-3 XBT programme with occasional XCTD sections and with repeats of research vessel based full-depth CTD measurements along the extended WOCE hydrographic section A-2/AR19 between English Channel and Grand Banks (Fig. 10). The scientific rationale of this BSH funded programme is to monitor ocean climate variability and change in this North Atlantic key region (BSH, 1999). This ocean area is characterized by extremely high variability of the North Atlantic Current (NAC) (e.g. Krauss, 1986; Sy, 1988; Sy et al., 1992; Lozier et al., 1995; Schmitz, 1996) (Figs. 5, 11 and 15). Changes in its path and intensity, and hence the space-time variability of its heat transport, have an obvious impact on European climate. Furthermore, this corridor represents the division line of subpolar-subtropical exchange, and anomaly patterns suggest a north-south heat storage anomaly dipole across this latitude. Long-term observations in such a priority region thus are indispensable contributions to European climate prediction efforts.

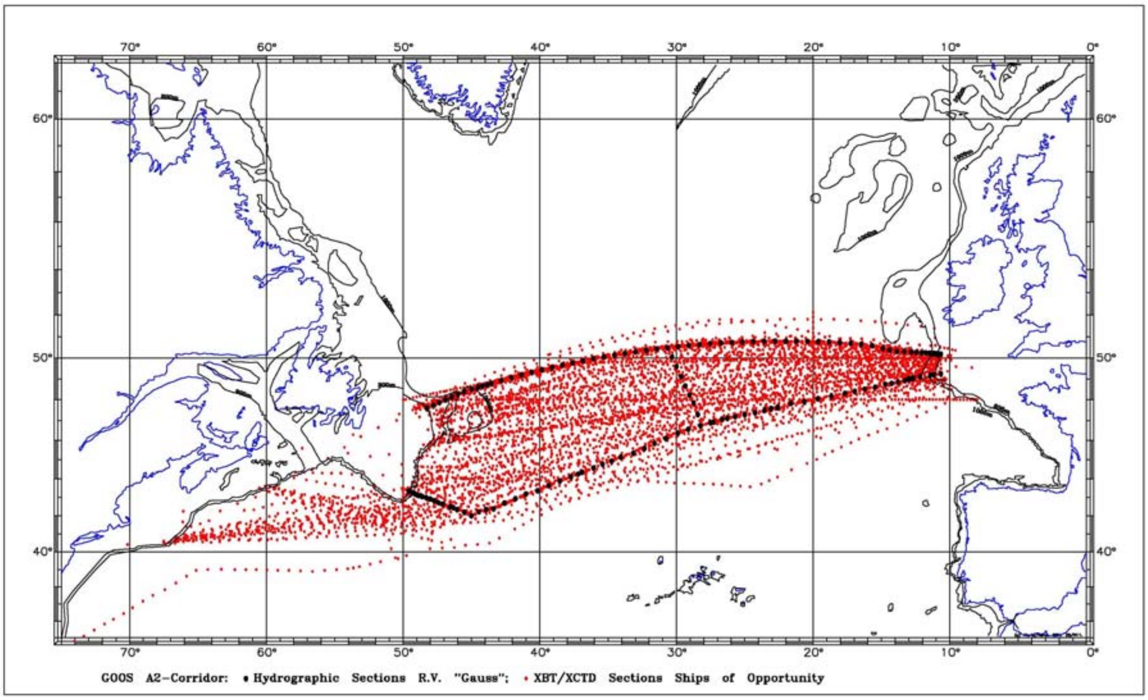


Fig. 10: The BSH network of ocean climate investigation in the central North Atlantic (GOOS A-2 corridor). It consists of bi-monthly XBT sections (red) supplemented by CTD sections every 2 – 3 years (black dots). The locations of hydrographic stations have been designed to form closed boxes in order to improve geostrophic current estimates by application of the box inverse theory (Wunsch, 1978; Sy, 1988).

It is believed that the THC of the North Atlantic underlies a natural and recurrent mode of variability of the atmosphere known as the North Atlantic Oscillation (NAO), i.e. the northern North Atlantic responds by significant adjustments of its stratification to changes in the strength and location of the sea level pressure dipole between the Icelandic low and Azores high on interannual to interdecadal time scales (Dickson et al.,1996; Sy et al.,1997a; Bersch et al., 1999; Koltermann et al., 1999; Curry and McCartney, 2001). Since Rogers (1984), the NAO pattern has been described by an index of that pressure difference between Portugal/Azores and Iceland (Koslowski and Löwe, 1994; Hurrel, 1995; 1996; Löwe and Koslowski, 1998). A high NAO index, characterized by an intense Iceland low and a strong Azores high, indicates strong westerly winds, while in a low NAO index case the signs of this dipole are reversed. The NAO seesaw-like mode of variability is particularly dominant in winter months, and time-series have shown that the NAO index has undergone major low-frequency variations during the last century (Koslowski and Löwe, 1994; Hurrell, 1995). However, the role of this complex dynamic ocean-atmosphere-land system of the North Atlantic and the mechanisms of its interaction are not yet fully understood and are, therefore, investigated intensively. (CLIVAR, 1998; DFG, 2000). A central question is whether the ocean is a passive participant in climate change merely responding to atmospheric conditions, or a more active component of the climate (McCartney, 1997)

Different explanations have been proposed to explain the low-frequency NAO variability, e.g. as a response to changes in the ocean or to changes of external forcings such as solar radiation, or internal generation in the atmosphere. However, the lack of long-term observation records makes it difficult to confirm one of the different hypothesis.

On the other hand, low-frequency variability of the ocean is poorly understood and, as is to be expected, the strong seesaw-like atmospheric changes have been held responsible for a wide range of phenomena observed in all layers of the ocean. Some selected examples are briefly described below.

The largest known dislocation of the freshwater balance in the surface layer of the subpolar gyre, the so-called Great Salinity Anomaly which circulated this gyre for a 14-year period from 1968 to 1982 (Dickson et al., 1988), was explained by the NAO minimum in the 60s due to an extreme amplification of the Icelandic low.

Observations from WOCE reveal surprisingly large and rapid changes in the water mass distribution of the intermediate and upper layers of the North Atlantic. In the Subpolar Mode Water layer, significant changes in the baroclinic structure along the eastern margin of the sub-polar gyre were observed in the mid 90s coinciding with the strong decrease of the NAO Index (Bersch et al., 1999; Flatau et al., 2002).

The layer below the main thermocline, where Labrador Sea Water (LSW) dominates the intermediate depth level and which had been assumed to have a nearly constant temperature and salinity, is undergoing major changes at present. It was the most important oceanic occurrence of the 90s in the North Atlantic, associated with the evolution of the NAO from its extreme negative state recorded in winter 1960 to its extreme positive state in the early 1990s. This event was characterized by marked cooling of intermediate waters which proceeded at annual intervals (cascades), and the newly formed so-called “1988 LSW cascade” (Sy et al., 1997a, b) was fresher, colder, and denser than at any other time in the history of deep measurements in that area. Its signal spread from its source area towards the European shelf with a mean speed of about 1.5 to 2 cm/s (Sy et al., 1997a). That is three to four times faster than previously estimated by Read and Gould (1992). With a delay of 6 years the signal appeared in the deep water of the subtropical basins near Bermuda (Curry et al., 1998). The Labrador Sea is one of the two convective cells of the North Atlantic Deep Water production.

There is evidence that the NAO-induced substantial changes in the formation of North Atlantic Deep Water affect the Meridional Overturning Circulation (MOC), which is the driving power engine at the northern terminus of the THC, and thus the key element of global THC (Dickson et al., 2002). Data from the last 40 years indicate that the MOC is subject to strong and natural variability on time scales of 10 to 30 years which is correlated with the NAO (Koltermann et al., 1999; Lorbacher, 2000). However, the question as to cause and effect still remains.

Paleo-climate records and model results show that climate changes have occurred in the geological past and have been associated with sometimes sudden changes of the MOC, i.e. within a few decades (Duplessy at al., 1988; Fichefet et al., 1994; Manabe and Stouffer, 1995). In extreme cases a more or less complete collapse of the MOC occurred which led to dramatic changes of the European climate.

3.2 Some preliminary results

As has been stated above, the northward transport of heat in the Atlantic Ocean is a key process governing the climate in Europe. Systematic measurements of temperature and current velocity are necessary to determine oceanic heat transport. Because basin wide direct current measurements are not available, the geostrophic method of calculating the relative velocities is appropriate to estimate currents and its transport rates from hydrographic data. To obtain the required information on the density field, derived from the measured distribution of temperature and salinity versus depth, BSH has carried out 10 transatlantic full depth CTD sections between the English Channel and the Grand Banks since 1992, supplemented by 6 XCTD sections (Table 3). For our upper ocean climate SOOP the XCTD depth range of only 600 m is just sufficient. Finally, XBT data are used to obtain a better statistical data base in time and space providing good access to the seasonal and long-term variability of the upper ocean thermal structure within the GOOS A-2 corridor.

Table 3: Hydrographic sections carried out in the GOOS A2 corridor 1992 - 2002

Cruise (vessel, cruise no.)	Date (first/last profile)	Year	Instrument (type)	depth (range (m))	Position (in corridor)	
Köln Express 172	22.-26. 2.	1992	XCTD	600	south	
Köln Express 177	23.-26. 7.	1992	XCTD	600	south	
Gauss 226/1	16.-26.6.	1993	XCTD	1000	south	
Gauss 226/2	6.-26.7.	1993	CTD	bottom	south	
Meteor 30/3	15.10.-10.11.	1994	CTD	bottom	south	
Köln Express 195	29.9.-2.10.	1995	XCTD	600	(north)	
Gauss 276/2	13.5.-2.6.	1996	CTD	bottom	south	
Gauss 276/3	16.-27.6.	1996	XCTD	1000	north	
Meteor 39/3	13.-30.6.	1997	CTD	bottom	south	
Gauss 316/1	1.-20.5.	1998	CTD	bottom	south	box
Gauss 316/2	30.5.-14.6.	1998	CTD	bottom	north	-“-
Köln Express 212	11.-14.-1.	2000	XCTD	600	north	
Gauss 350/1	10.5.-4.6.	2000	CTD	bottom	south	box
Gauss 350/2	10.-29.6.	2000	CTD	bottom	north	-“-
Gauss 384/1	21.5.-9.6.	2002	CTD	bottom	south	box
Gauss 384/2	20.6.-7.7.	2002	CTD	bottom	north	-“-

A first impression of the mean and fluctuating fields of the GOOS A-2 corridor can be obtained from Fig. 11 which shows the main features of the dynamical system of the North Atlantic Current regime in the transition zone between subtropical and subpolar gyres of the upper 750 m. The frontal system of the so-called ”Cold Wall”, which separates the southward flow of cold Labrador Current water and the northward flow of warm NAC water, is clearly visible by the region of greatest horizontal gradients off the Grand Banks. Estimates of the locations of the front for every XBT section show lateral displacements of about +/- 30 nm, a zone of variability only half as wide as that found by Horne and Petrie (1988) from SST measurements. The corresponding field of standard deviation of heat content shows the intensified temporal fluctuations in this frontal zone area and along the path of the NAC (Fig. 11 bottom).

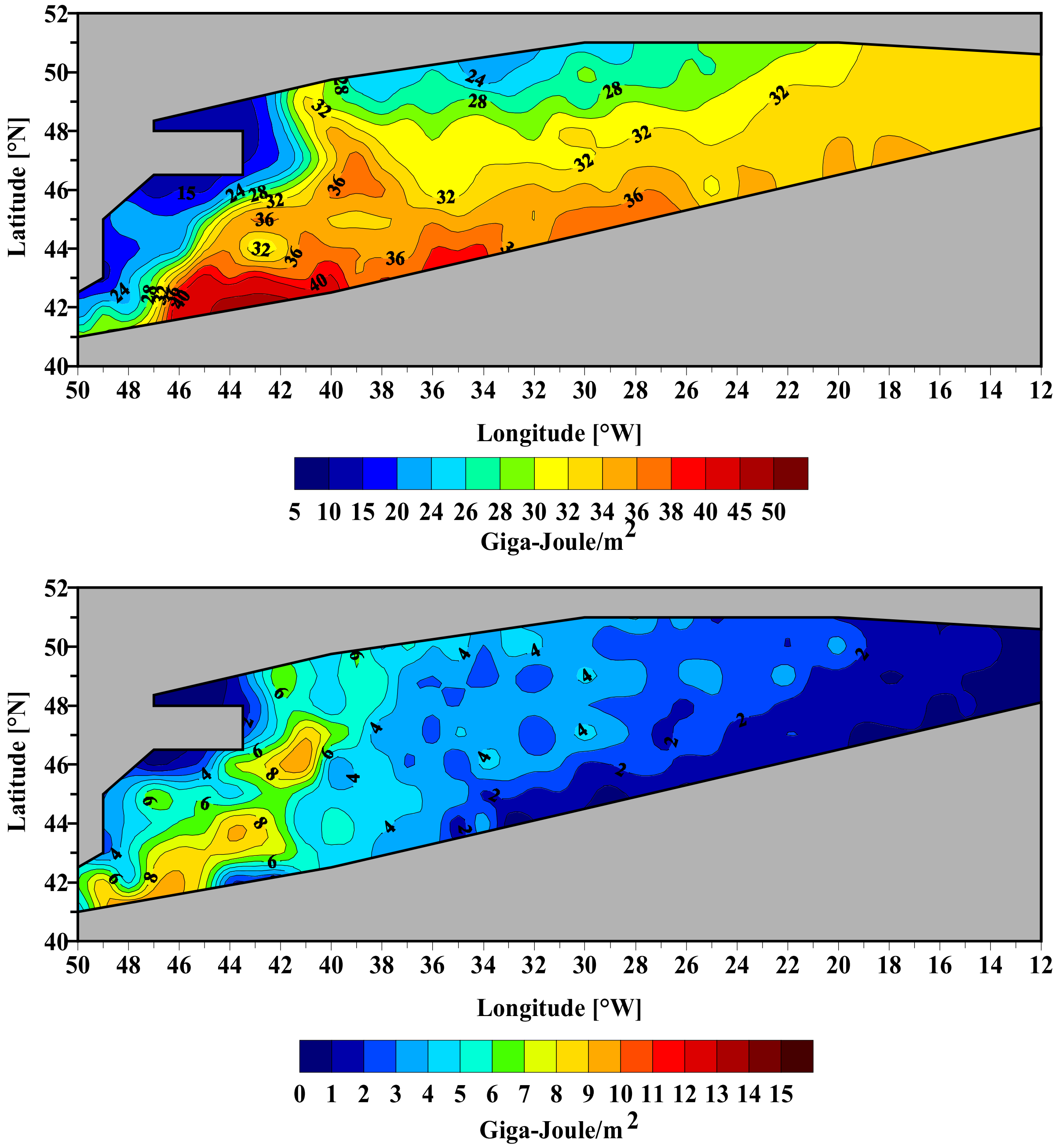


Fig. 11: Long-term average (top) and standard deviation (bottom) of heat content of upper 750 m calculated from XBT data 1988 – 2000.

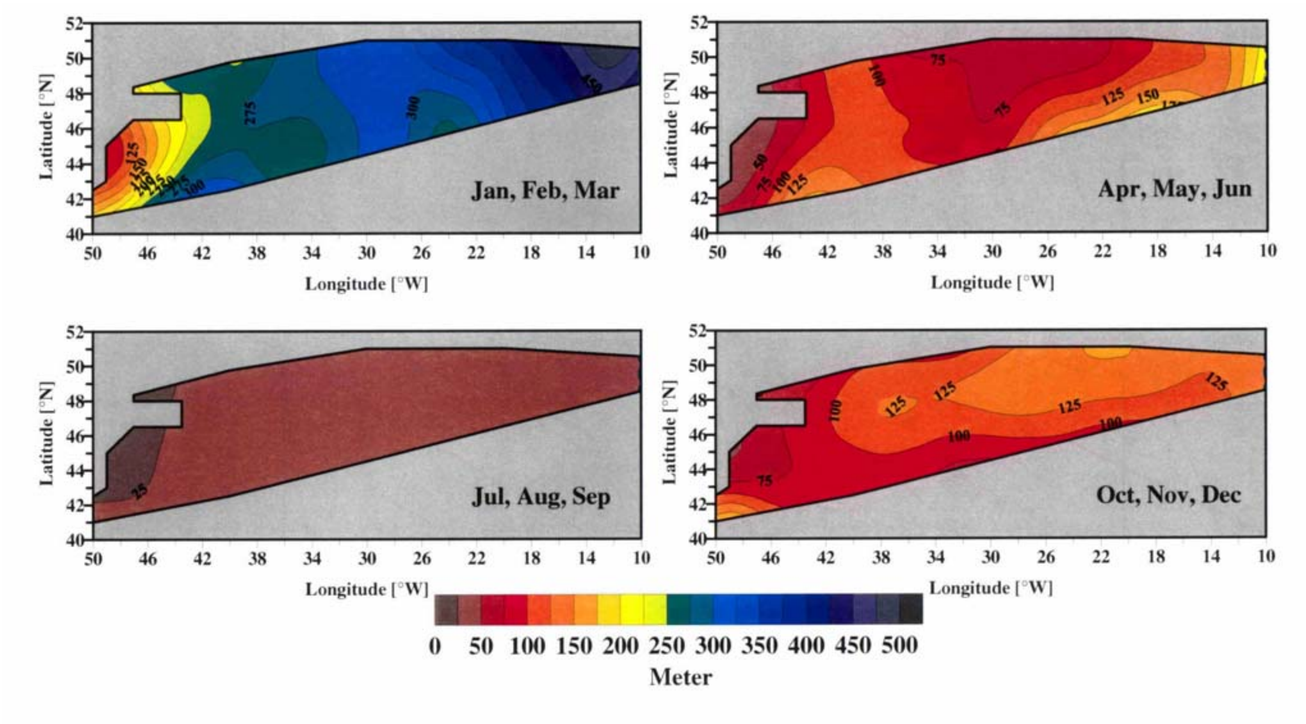


Fig. 12: Seasonal mixed layer depth z_Θ (estimated from XBT data with $\Theta = \Theta_{z=0} - 0.75$ °C).

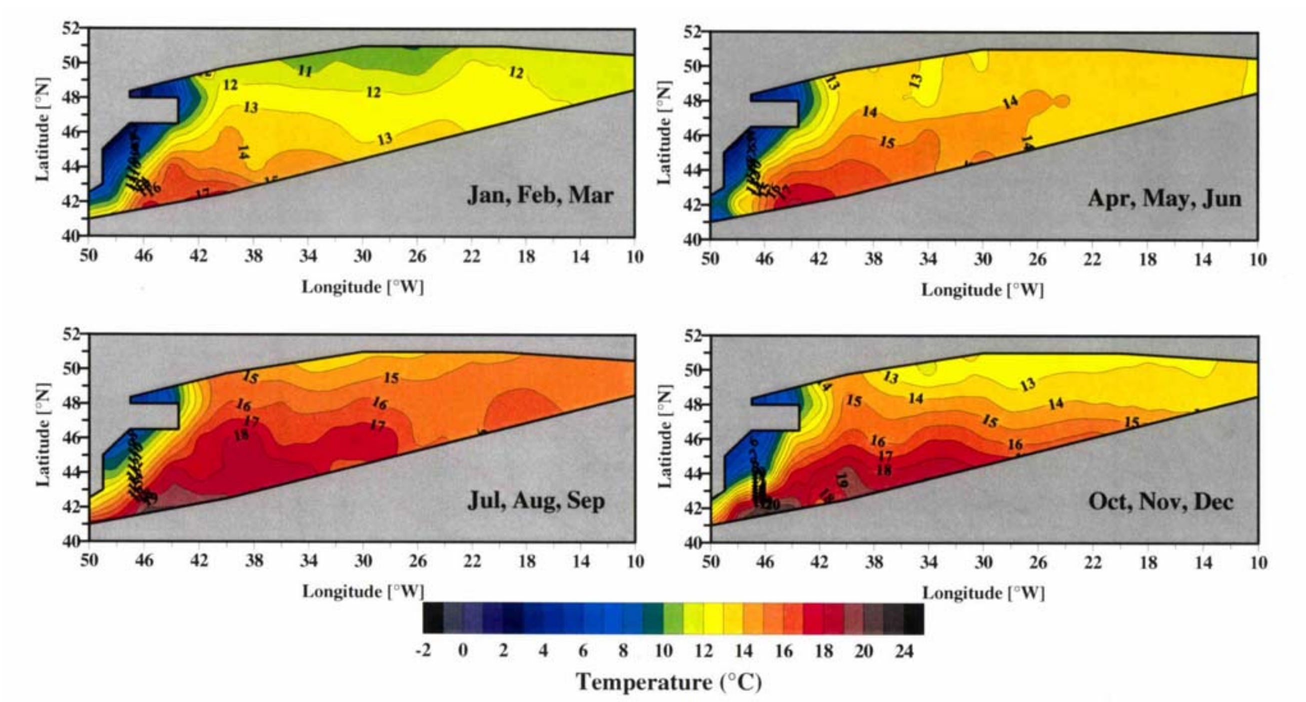


Fig. 13: Seasonal mixed layer temperature (depth of mixed layer defined as in Fig. 12).

The depth range of the seasonally mixed layer in the GOOS A-2 corridor covers the upper 40 – 50 m in summer (Fig. 12), deepening to 200 – 300 m west of the Mid-Atlantic Ridge and up to 500 m in areas east of the ridge during fall and winter due to cooling and mixing, in good agreement with Robinson et al. (1979) and McCartney and Talley (1982). The largest mixed-layer depth of 650 m was found close to the European shelf.

Of course, the temperature of the mixed layer (Fig. 13) shows the same seasonal development as its depth. The warming phase lasts from March to September, followed by cooling (and deepening of the mixed layer) until February. The variability of the monthly mean temperature, however, does not exceed 4.5 °C between the warmest month of September (15.5 °C) and the coldest month of February (11 °C).

Time series of the annual mean heat content anomalies from 1988 to 2000 (Fig. 14) show as a clear signal a period of relatively low heat content until 1991 followed by a period of relatively high values in 1992 and 1993. The next cold period in 1994 and 1995 and the warm period since 1996 are not developed as clearly as the preceding periods. The annual mean heat content values of the coldest year 1990 (28.7 GJ/m^2) and of the warmest year 1993 (33,5 GJ/m^2) give a range of variability of only about 15 %.

Since 1998, CTD full-depth sections carried out in the framework of GOOS and CLIVAR have been designed to form so-called inverse boxes, i.e. volume transport conserving closed areas, in order to improve geostrophic current estimates by application of the simple concept of continuity or the more sophisticated inverse method (Wunsch, 1978; Sy, 1988). A first result is presented in Fig. 15 which compares the main branches of the NAC as observed during the three box cruises 1998, 2000 and 2002. The optimum reference level for the geostrophic calculation was chosen at a depth where the baroclinic box transport imbalance vanished. The ocean above the reference level may be interpreted as an advection path of the NAC, and thus represents the upper branch of the MOC in the North Atlantic with its advection of warm water of subtropical origin flowing in northeastern direction into the Nordic Seas. The current branches through the box boundaries were identified and determined as NAC branches by the same continuity principle and by water mass (T/S) analysis.

A comparison of the three realizations in Fig. 15 gives a good overall impression of the extreme variability of the NAC regime. In the southwest, the huge inflow of the NAC as the north-eastward extension of the Gulfstream, and its recirculation eddy are typical. However, the net inflow into the western box decreased from 20 Sv ($10^6 m^3/s$) (1998) and 24 Sv (2000) to 12 Sv (2002). The transport calculation for the northern boundary of the western box confirms this result. After following the 4000 m depth contour east of the Grand Banks, the NAC leaves the western box due north and again the transport is dramatically reduced from 17 Sv (1998) and 18 Sv (2000) to 10 Sv (2002).

Along its course the NAC often divides into several branches and meanders (Sy, 1988). The main branch, the subpolar front, separates the cold subpolar gyre from the warm subtropical gyre. East of the Mid-Atlantic Ridge the NAC finally turns north. In 1998 this change of direction took place significantly closer to the ridge than in 2000 and 2002, indicative of the eastward expansion of the Subpolar Mode Water of the subpolar gyre (Bersch, 1999).

Although the volume transport of the NAC appears to be highly variable in Fig. 15, we found only small changes in the total volume transport figures through the GOOS A-2 corridor transect, despite the decrease of the main NAC branch between 2000 and 2002. The necessary compensation comes from a unique branch observed only in 2002 which enters the eastern box from the south.

Annual Mean Heat Content Anomalies 0 - 750 Meter

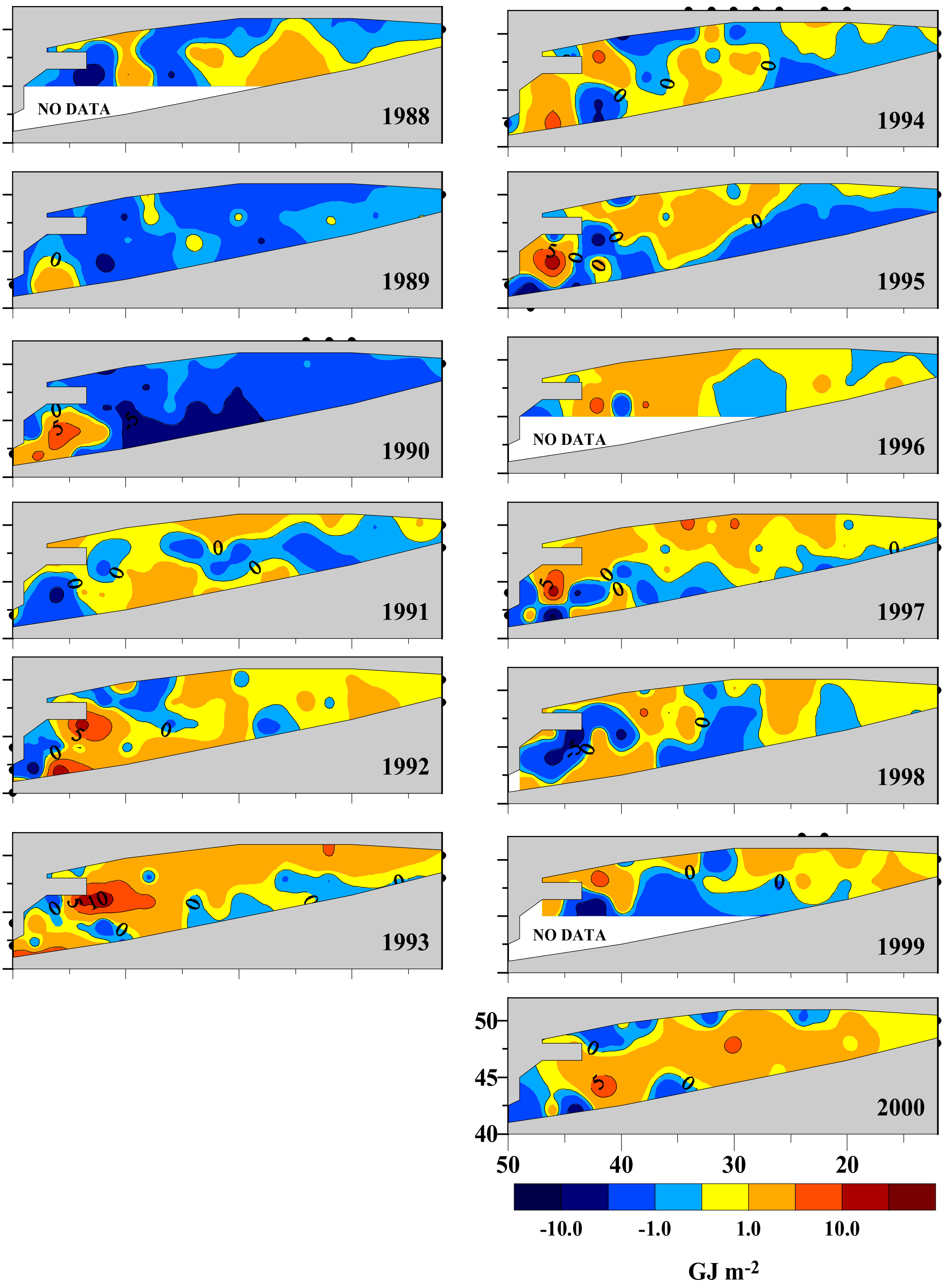


Fig. 14: Annual mean heat content anomalies of upper 750 m.

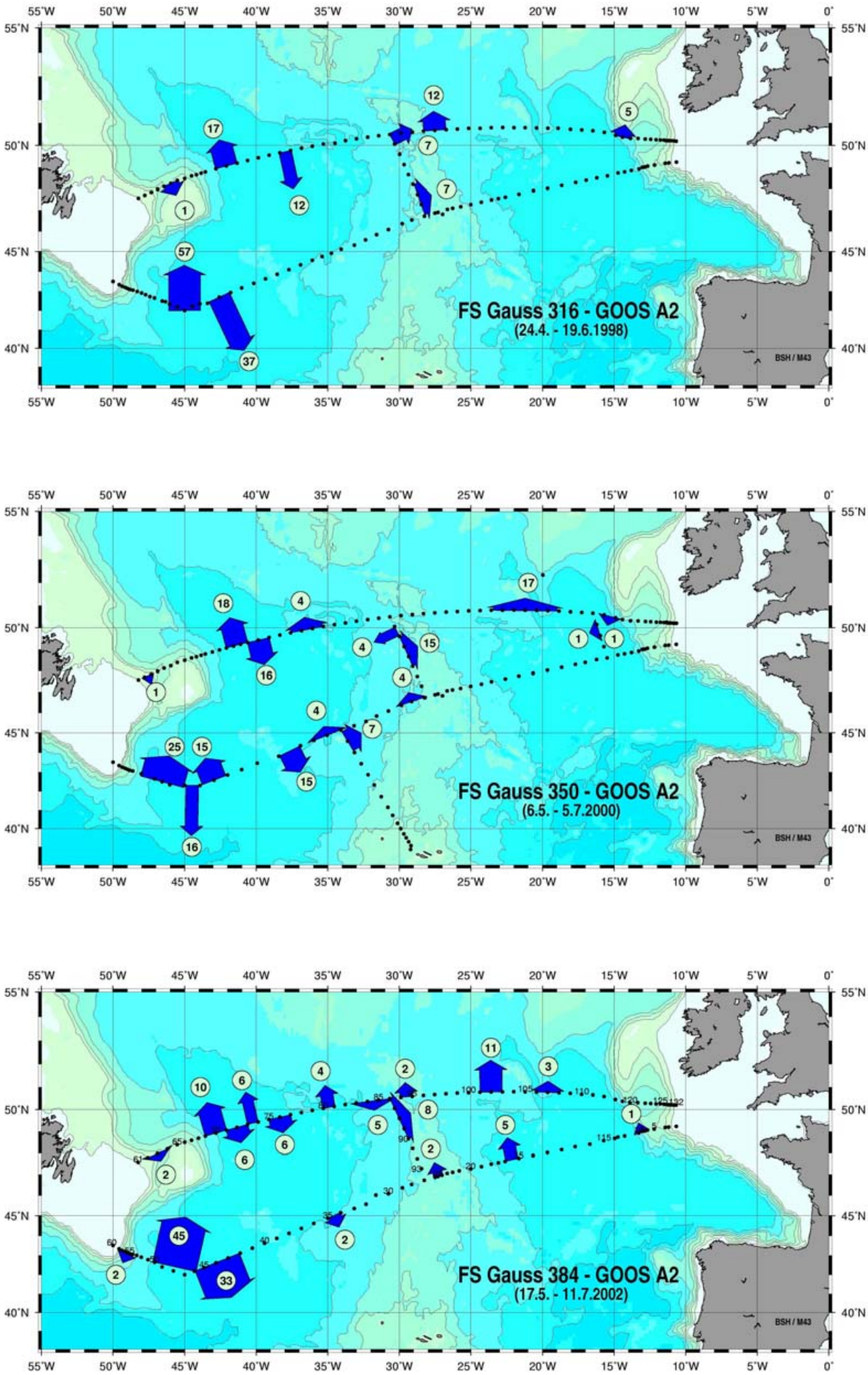


Fig.15: Branches of the North Atlantic Current in 1998 (top), 2000 (middle) and 2002 (bottom). Blue arrows with numbers in circles denote the calculated geostrophic transports in Sv ($10^6 m^3/s$).

Research into the variability of the North Atlantic current system and its steering mechanisms has been carried on for several years now. Some kind of ocean-atmosphere interaction has been considered as a possible explanation and, since WOCE, interest has focused increasingly on the North Atlantic Oscillation (NAO).

Owing to the long-term character of the BSH's upper ocean climate monitoring programme it has provided a unique data set of 16 hydrographic sections (CTD and XCTD, Table 3) covering at least the upper 600 m of the ocean. That is the layer of strongest current activities. The time series of the estimated upper layer volume transports together with the NAO winter (DJF) index after Löwe and Koslowski (1998) is displayed in Fig. 16 (top). For the volume transport estimates systematic differences apparently do not exist between CTD and XCTD sections and between sections located close to the northern or southern boundaries of the GOOS A-2 corridor. Consequently, all sections can be treated in the same way for this purpose.

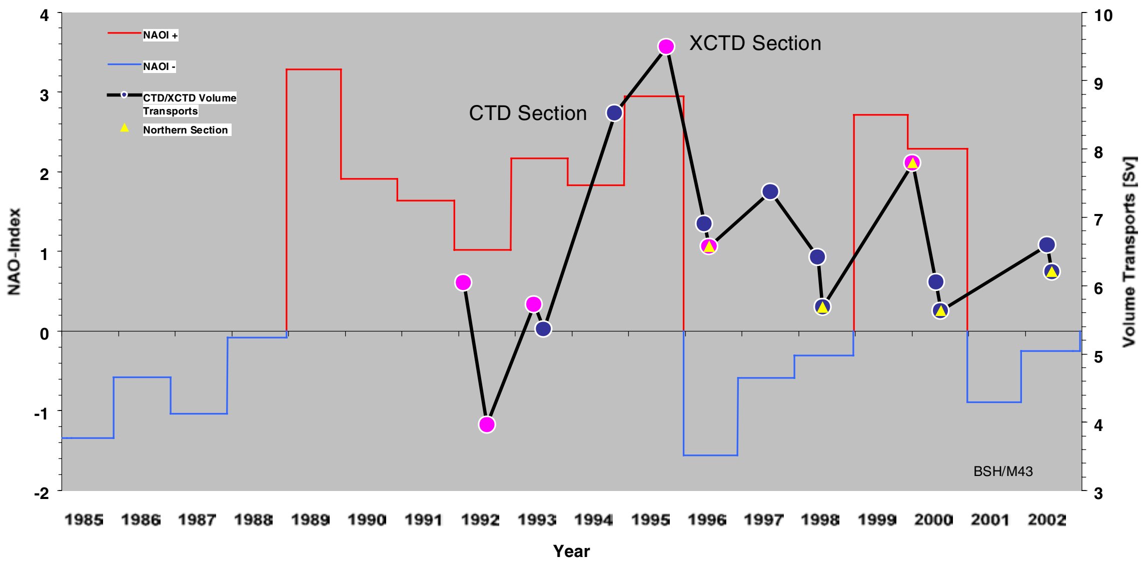
No correlation of any kind can be detected in Fig. 16 (top). However, after a 5-year backward phase shift of transports (- 5 years) a functional relationship can be identified. We received the best results (explained variance of 62 %) with a second-order polynomial fit (Fig. 17). This shows that the ocean and atmosphere interact with a time lag of 5 years. Our results from AX-3 XBT data, where we found an upper ocean heat content periodicity of about 5 years (Fig. 18), supports this result.

Correlation attempts with the corresponding heat transport time series (Fig. 16 bottom), however, provided less clear results. The cause is that the heat content and hence the heat transport of the upper ocean is prone to both seasonal and regional heat flux variability. The volume transport difference between the northern and southern transects determined for the four Gauss cruises 276, 316, 350 and 384 is small and varies between 4 % and 11 %, whereas the corresponding differences of heat content and heat transport were found to be up to three times larger. This shows that the northern and southern transects cannot be treated in the same way as in the case of volume transports, even if the seasonal signal of the surface layer has been removed.

However, after deduction of the 5 northern sections, the correlation of NAO with the heat transport time series of the remaining 11 southern sections again provided the best results with a second-order polynomial fit and after a time shift of – 5 years (explained variance of 44 %). The reduced significance is due to the principle of propagation of errors.

Our finding does not confirm Lorbacher’s (2000) result of a linear correlation between NAO and MOC with a phase lag of only one year, which she interpreted as the effect of a short-term change in atmospheric forcing on the overturning. However, her data base differed in some significant points from that used here. Including two historical cruises made in 1957 and 1982, she used only 5 WOCE hydrographic sections A2/AR19 from 1993, 1994, 1996, 1997 and 1998 for her analysis. Her data cover a time period of 40 years but have an extremely inhomogeneous distribution in time.

Because a positive time shift cannot be made with the presently existing data, it is not yet possible to distinguish between cause and effect, i.e. between active forcing and passive reaction of this coupled ocean-atmosphere system. The question who is at the helm, the ocean or the atmosphere, as brought to the point by McCartney (1997), must remain open, at least until a positive phase shift is applicable to the data. Finally, in the present phase of the discussion, the assumption that the NAO dominates oceanic variability leads to another question, independent of questions regarding statistical significance: Is an extremely rapid and linear response in large-scale circulation reasonable or is a slower, non-linear response more plausible? Further results might be available at www.bsh.de.



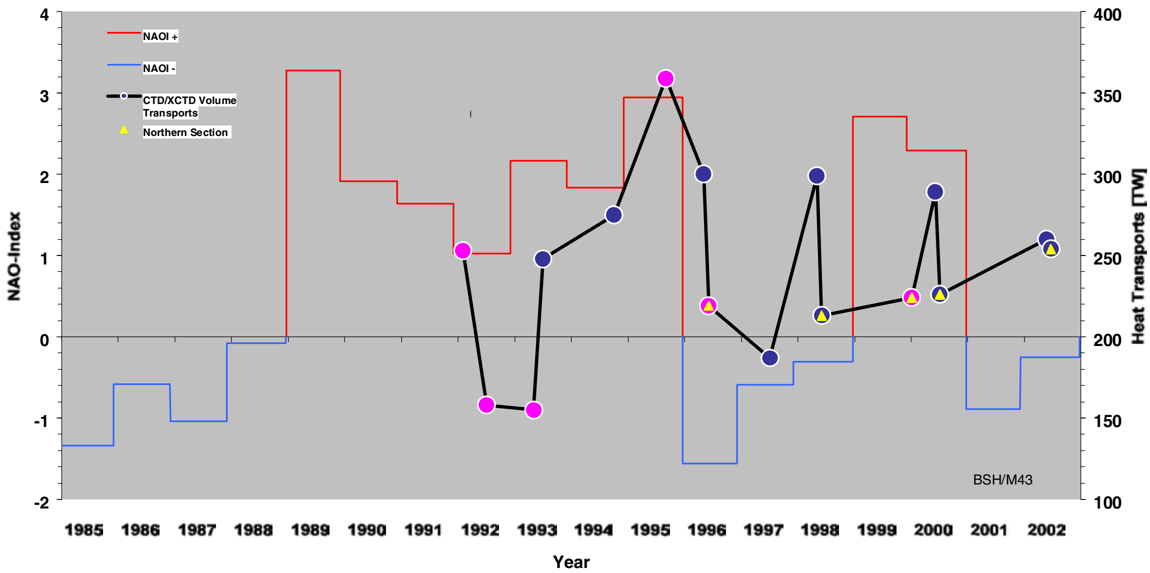
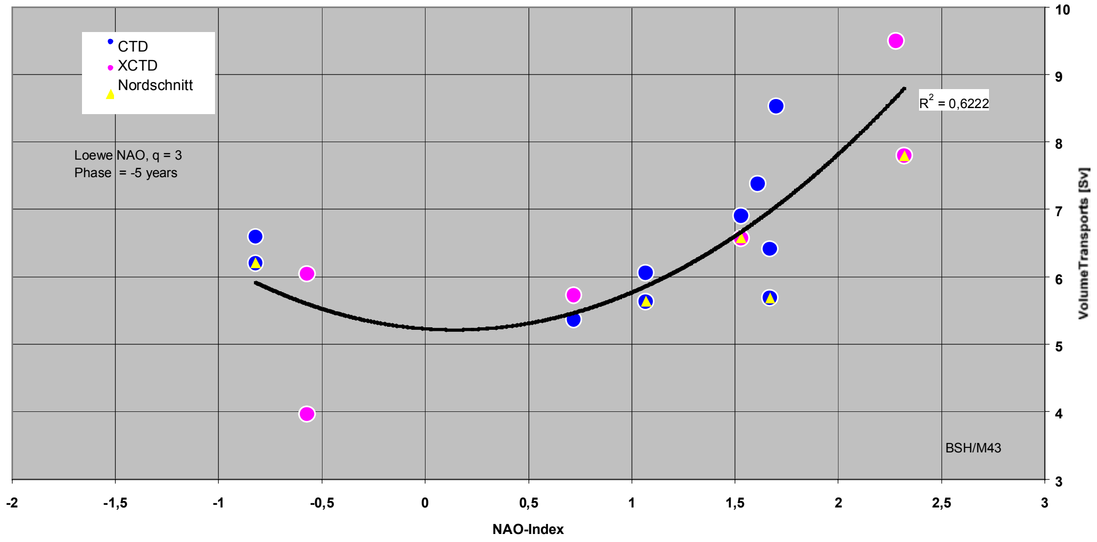


Fig. 16: Time series of NAO index and upper layer (0 – 600 m) volume transports (top) and heat transports (bottom). Seasonal temperature signal of surface layer is removed, NAOi numbers are from Löwe and Koslowski (1998).



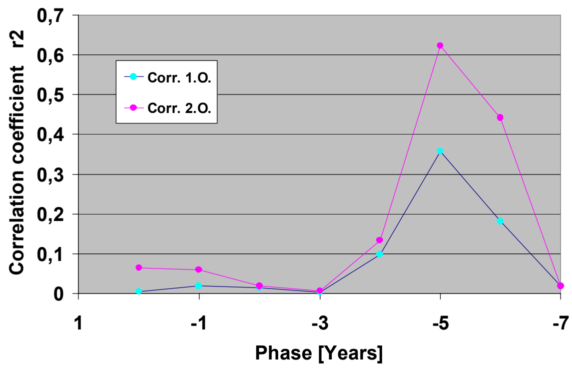
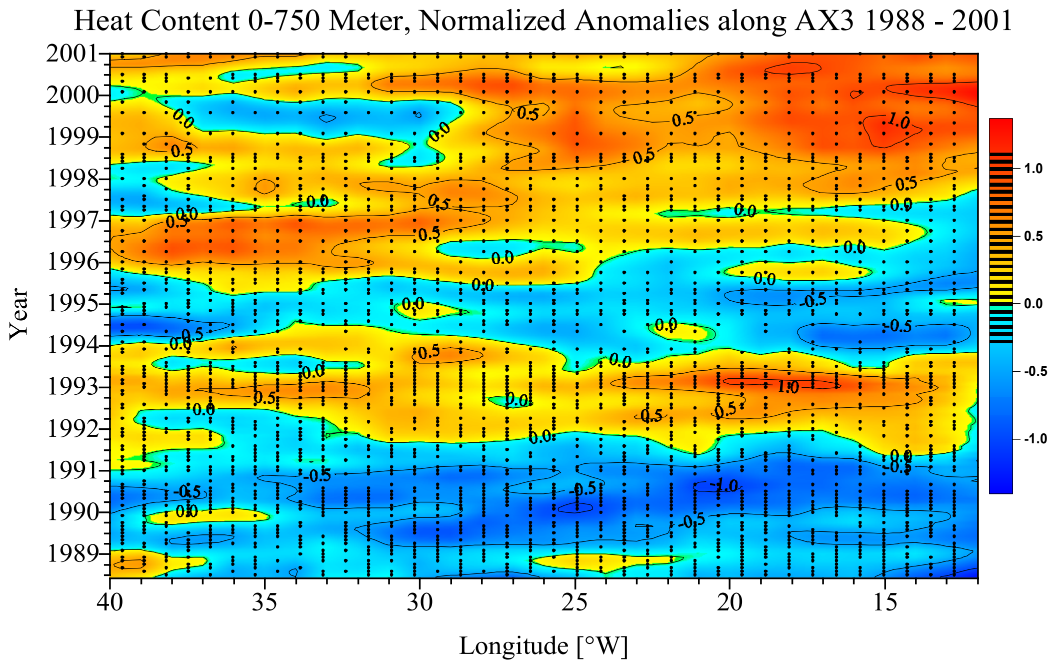
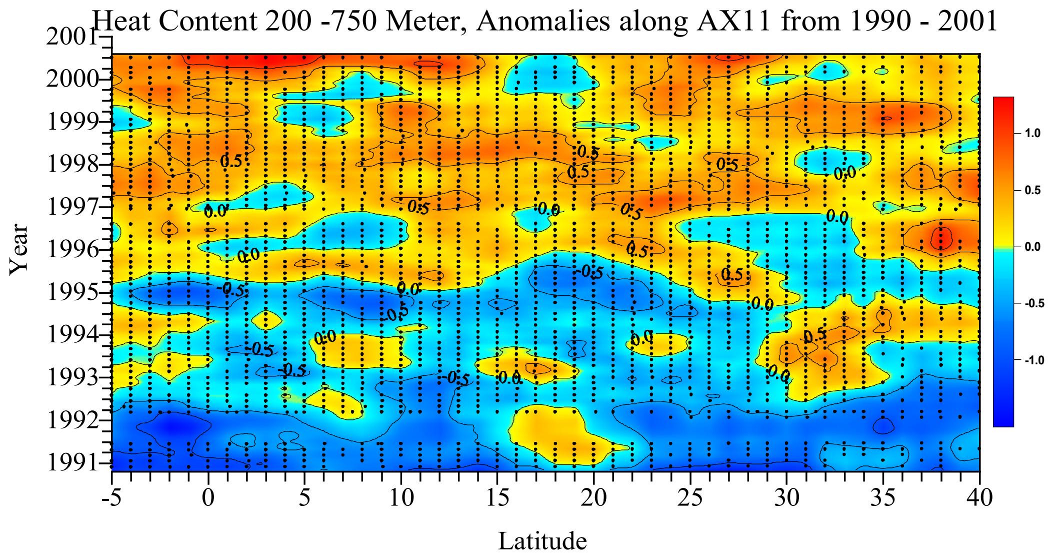


Fig. 17: Relationship between NAO-index and volume transports from Fig. 16 (top) after transport time series has been time shifted by – 5 years and use of second order polynomial least squares fitting. NAOi time series smoothed by running mean filter q = 3. Although the ocean volume transports can be linked with time lag of 5 years to the atmosphere winter NAO (DJF) at an explained variance of 62 % the assigned cause and effect cannot yet be decided.
Left: Comparison of correlation results of linear and second order fitting for different phase lags.

Various observations have shown a pronounced surface and subsurface temperature variability on a multi-year time scale in the subtropical and mid-latitude North Atlantic (e.g. Hansen and Bezdek, 1996; Sutton and Allen, 1997; Molinari et al., 1997; Yang, 1999; Krahmann et al., 2001). Our analysis of XBT data shows similar results of temporal and spatial variability for the entire main thermocline (Figs. 14, 18, 19, 21).

As one of the most striking features, the 13-year time series of upper ocean heat content anomalies along AX-3 shows fluctuations on inter-annual time scales with periods of about 5 years (Fig. 18 top, 19). The observed periodicity coincides with results of earlier investigations of the subtropical Atlantic Ocean (Molinari et al., 1997). Again, the question as to the controlling mechanism is still open. We found no evidence of a direct relation with the warming of the Subpolar Mode Water as observed by Bersch et al. (1999) or of a slow anomalous SST pattern propagation as suggested by Sutten and Allen (1997).





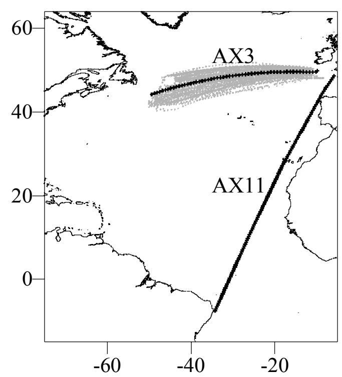


Fig. 18: Normalized monthly heat content anomalies (reference time: period of observation) of the upper 750 m along the lines AX-3 (1988 – 2001) and AX-11 (1990 – 2001).
The seasonal signals are removed. In order to calculate the heat content anomalies along a centred line the AX-3 data are projected on a 'mean orthodrome' by means of a regression function. This method works well in areas east of 40 °W where the mean fields of temperature and heat content show a zonal structure.

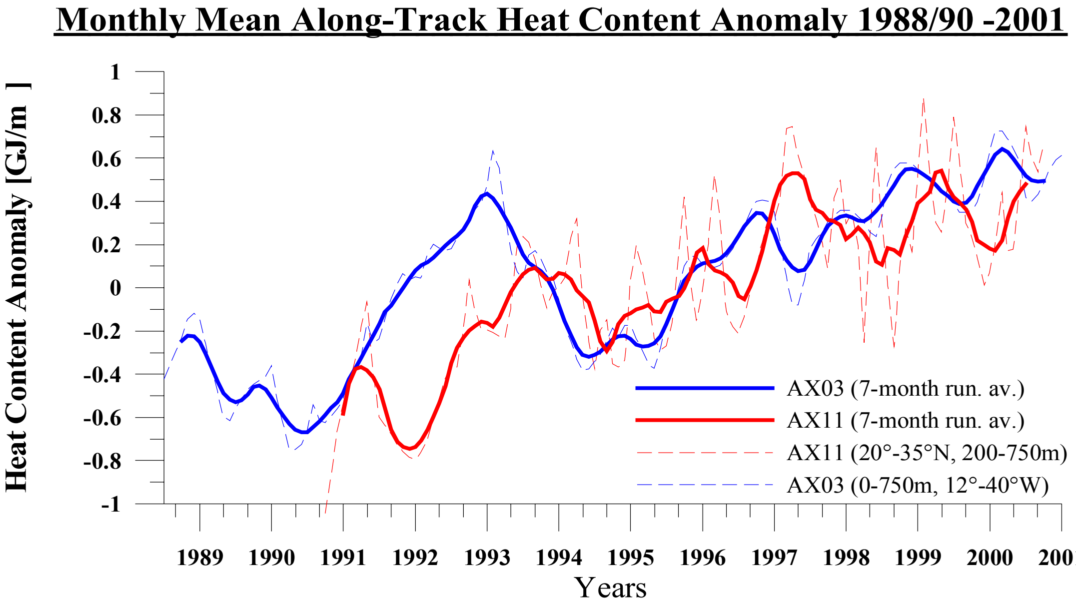


Fig. 19: Time series of integrated normalized heat content anomalies of upper 750 m along TWI lines AX-3 (mean orthodrome) and AX-11 (20 °N – 35 °N only).

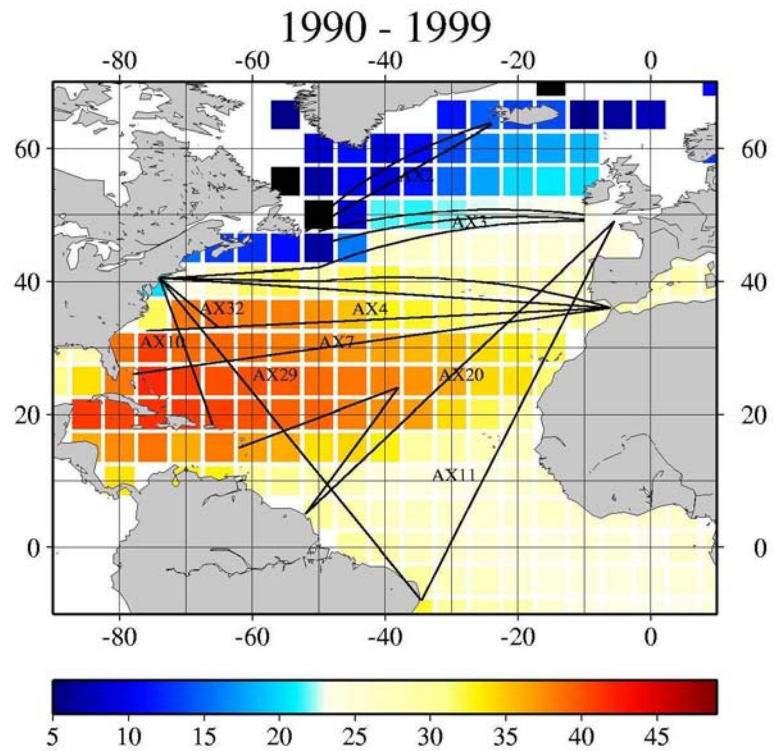
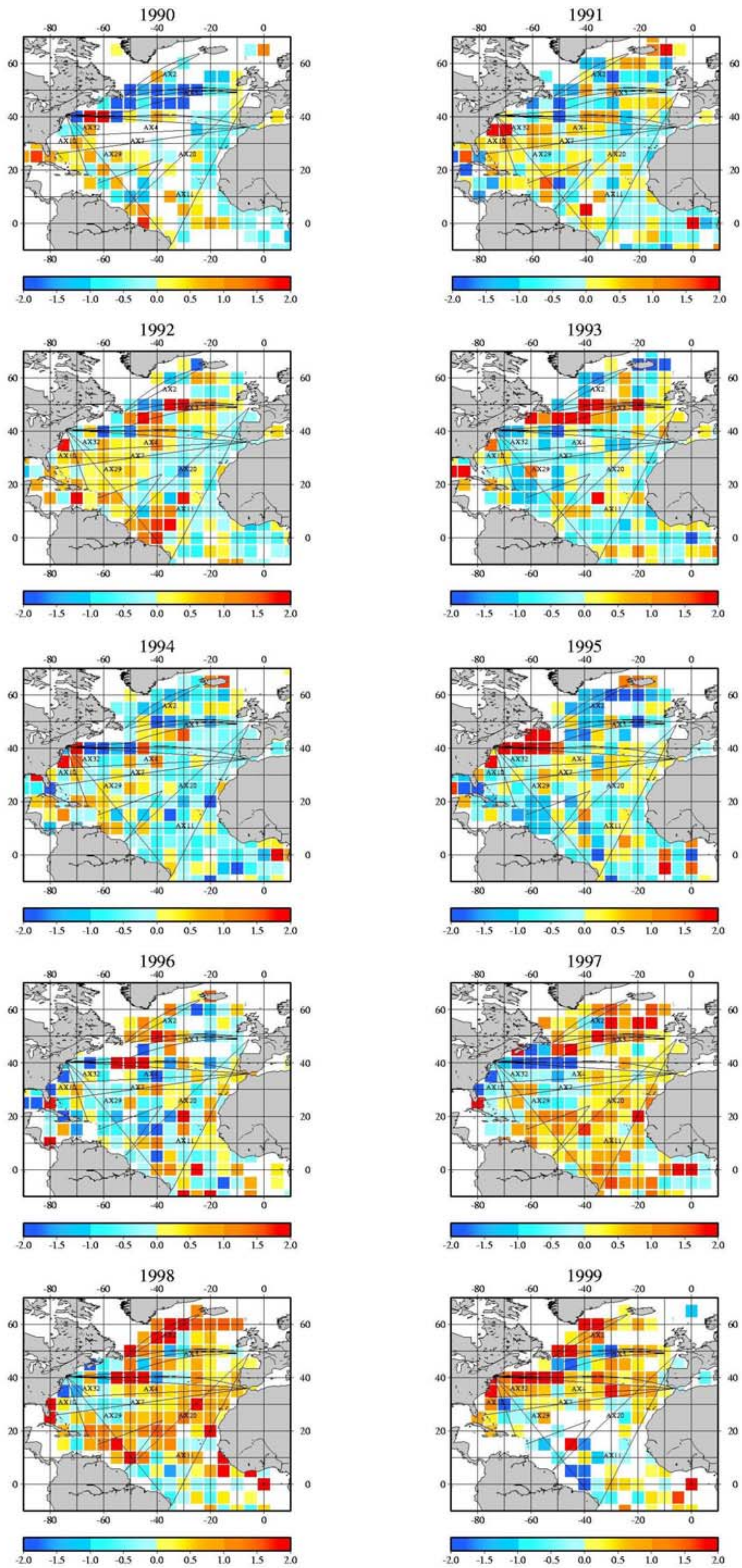


Fig. 20: Mean distribution of heat content (GJ/m^2) of the upper 750 m for 5° x 5° fields.

Fig. 21 (next page): Time series of heat content anomalies (GJ/m^2) of the upper 750 m for 5° x 5° fields from 1990 until 1999.


1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
-80 -60 -40 -20 0
0 20 40 60
-2.0 -1.5 -1.0 -0.5 0.0 0.5 1.0 1.5 2.0
AX2
AX3
AX4
AX7
AX10
AX11
AX20
AX29
AX32

The AX-11 time series from the upper 750 m of the subtropical and tropical Atlantic indicate a gradual warming from 1991 to 2000 (Figs. 18 bottom, 19). This coincides with conclusions by Yang (1999) who found a significant correlation between observed LSW thickness and the equatorial SST dipole, with a time lag of 5 years, and suggested a dynamic linkage between these two features. The long period of gradual warming which matches the lagged last period of intensified LSW formation (Sy et al., 1997) gives rise to the speculative question whether, and how, changes in LSW production affect the northward flow in the upper ocean.

In order to take a step forward and overcome the limited analysis of our single SOOP lines AX-3 and AX-11 towards a reconstruction of the North Atlantic circulation, we extended the data base by including additional XBT data from lines AX-2, AX-4, AX-7, AX-10, AX-20, AX-29 and AX-32 which are to be combined with a dynamical model developed in the framework of CLIVAR at AWI, Bremerhaven, Germany. Model and measurements will be combined by applying a variational assimilation technique, also known as the adjoint method. For further information see www.awi-bremerhaven.de.

The locations of these lines together with the 10-year mean field of heat content of the upper 750 m is shown in Fig. 20. In Fig. 21 the corresponding annual time series of mean heat content anomalies are displayed. Compared to the mean, the upper North Atlantic Ocean was significantly colder from 1993 to 1995 and warmer from 1997 to 1999. No clear correlations between patterns can be found which could be indicative of the existence of propagation paths of anomalies of the upper ocean temperature field.

3.3 Future plans

Although the SOOP has been extremely cost-effective in scientific use and operational applications, it has been argued that it is time for a change of direction and a new focus. A plan for a new world wide network of some 3,000 autonomous profiling floats was developed in the late 90s (ARGO, 1998), which may affect the classical XBT network (Smith et al., 2000). This Array for Real-time Geostrophic Oceanography (ARGO) is now being implemented. Autonomous profiling float technology is a novel and very effective tool in sampling of the upper ocean climate variability, especially when combined with an appropriate XBT/XCTD SOOP network. Therefore, an ARGO proposal for the A-2 corridor has been drafted by BSH in conjunction with proposals by Institut für Meereskunde, Kiel, and Alfred Wegener Institute for Polar and Marine Research, Bremerhaven, and submitted to the German Ministry of Education and Research (BMBF) in October 2002.

The main objectives of BSH's ARGO proposal are

- the investigation of baroclinic variability in time and space in the transition zone between subtropical and subpolar gyres,
- improvement of a T/S climatology,
- evaluation of this ARGO contribution as a tool for ocean climate monitoring and, in this context,
- evaluation and optimisation of the AX-3 SOOP.

4. Real-time data distribution

- In order to meet the requirement for more real-time T/S profiles, it has been common practice at BSH since the early 90s to convert the CTD bottle readings to TESAC coded bulletins which are e-mailed from the ship to BSH where they are inserted immediately onto GTS.

- Since 1992, temperature data from stations of the BSH's automated stationary "Marine Environmental Monitoring Network in the North and Baltic Seas" (Holzkamm, 1988) have been inserted increasingly onto GTS as BATHY coded messages. This network is under development. A new station ("Nordseeboje III") will be launched in 2003. Sea water parameters presently measured at 2 – 5 depth levels are temperature, salinity, oxygen, radioactivity, and nutrients. A complete overview of all MARNET stations is listed below and shown in Fig. 22. Further details are available under www.bsh.de.

MARNET Station	WMO-ID	Position	Remarks
"Ems"	10004	54° 10.0' N, 6° 20.8' E	unmanned lightvessel
"Nordseeboje II"	62086	55° 00.0' N, 6° 20.0' E	buoy
"Nordseeboje III"	62087	54° 41.0' N, 6° 45.0' E	buoy, deployment in 2003
"Deutsche Bucht"	10007	54° 10.0' N, 7° 26.0' E	unmanned lightvessel
"Kiel"	10044	54° 30.0' N, 10° 16.0' E	lighthouse
"Fehmarn Belt"	62088	54° 36.0' N, 11° 09.0' E	buoy
"Darsser Schwelle"	62089	54° 41.8' N, 12° 42.4' E	mast
"Arkona Becken"	66021	54° 55.5' N, 13° 30.0' E	buoy, deployed in 2002
"Oder Bank"	66022	54° 04.6' N, 14° 09.6' E	buoy

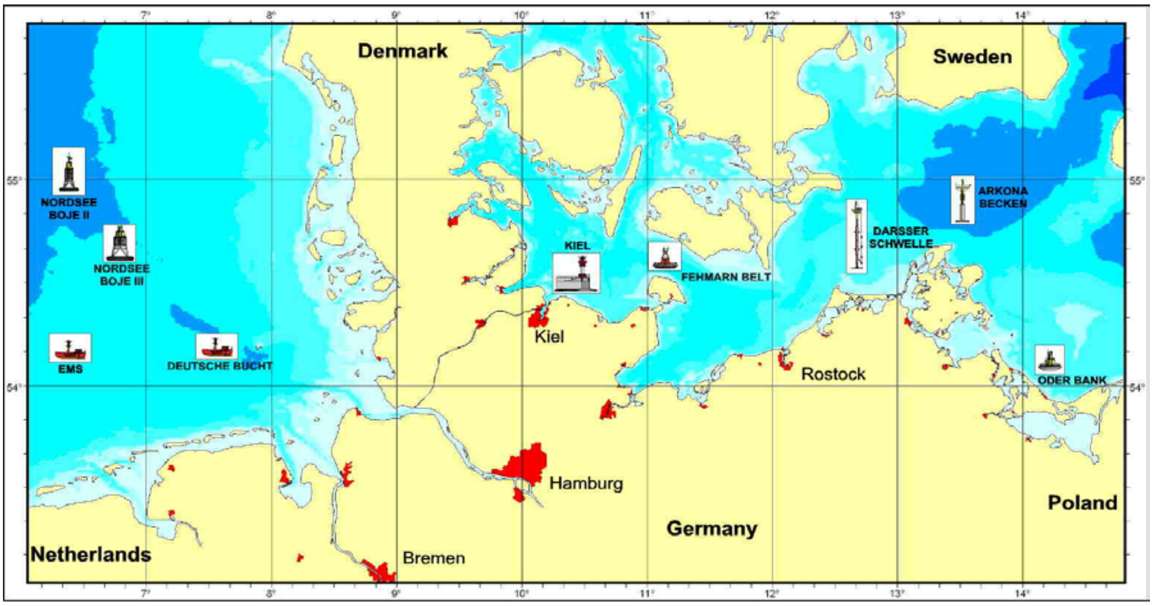


Fig. 22: Locations of stations of Marine Monitoring Network in the North Sea and Baltic Sea.

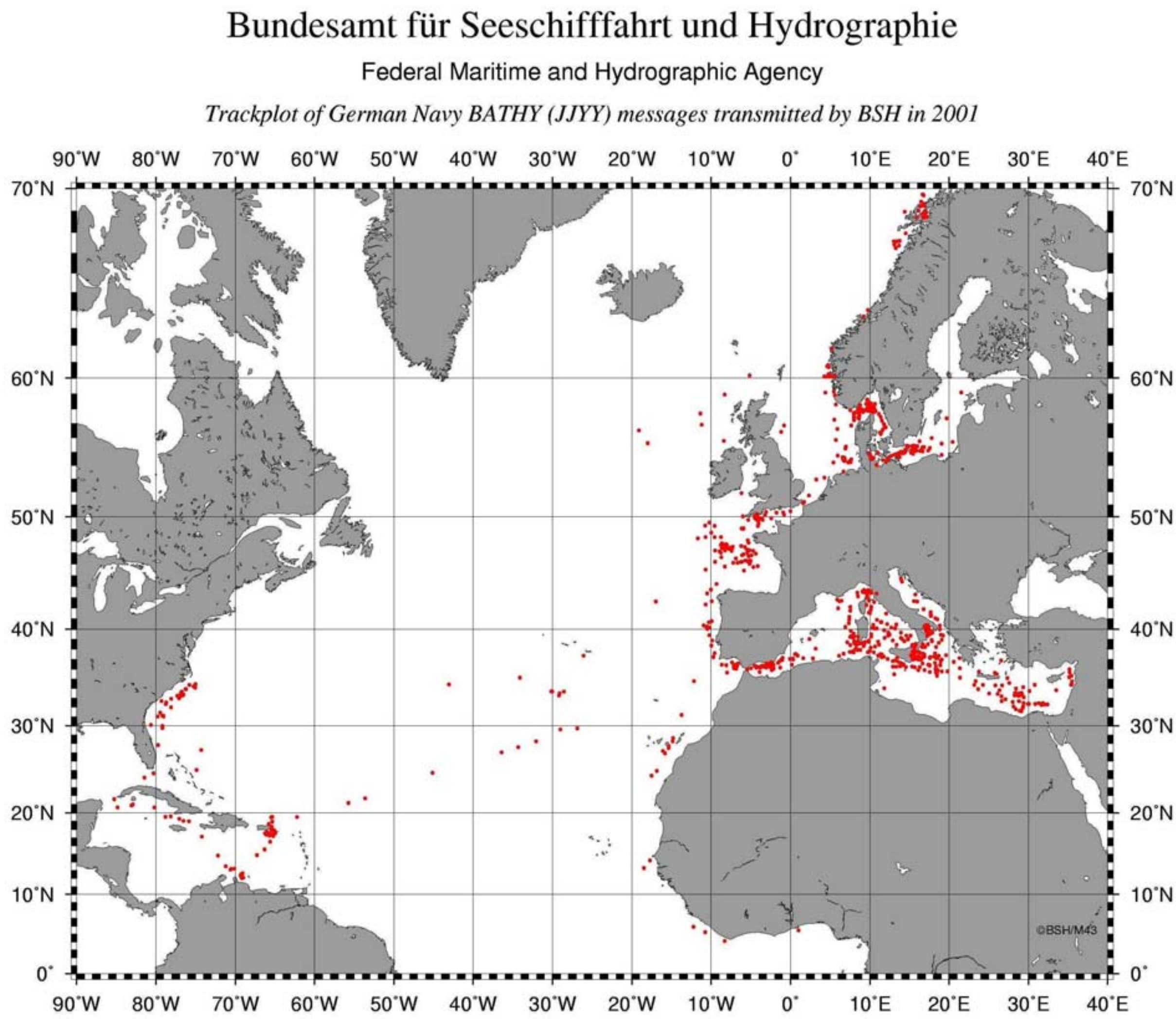


Fig. 23: Contribution of BATHYs from the German Navy in 2001 (real-time input only).

- Since 1993, and as a result of German unification, an additional and significant contribution of real-time temperature data has come from the German Navy (Fig. 23). However, this real-time data source dried up completely in 2002 due to the Navy's decision to declassify their data not earlier than 1 month after collection. This decision was made for safety reasons. Therefore, and to avoid data losses, the non-real-time BATHY messages are submitted to MEDS (Canada) for archiving.

- The SST programme of BSH, which was established in 1987, has been supplemented by SSS measurements since 1996. Data are collected by both governmental and commercial vessels using Pt100 hull contact thermometers (Sy and Ulrich, 1990) or SBE-21 thermosalinographs. All SST and SSS data received at BSH in time are inserted onto GTS as TRACKOB coded reports. This programme is restricted to the North and Baltic Seas with special focus on the German EEZ (Fig. 24) and does not follow the TWI line system.

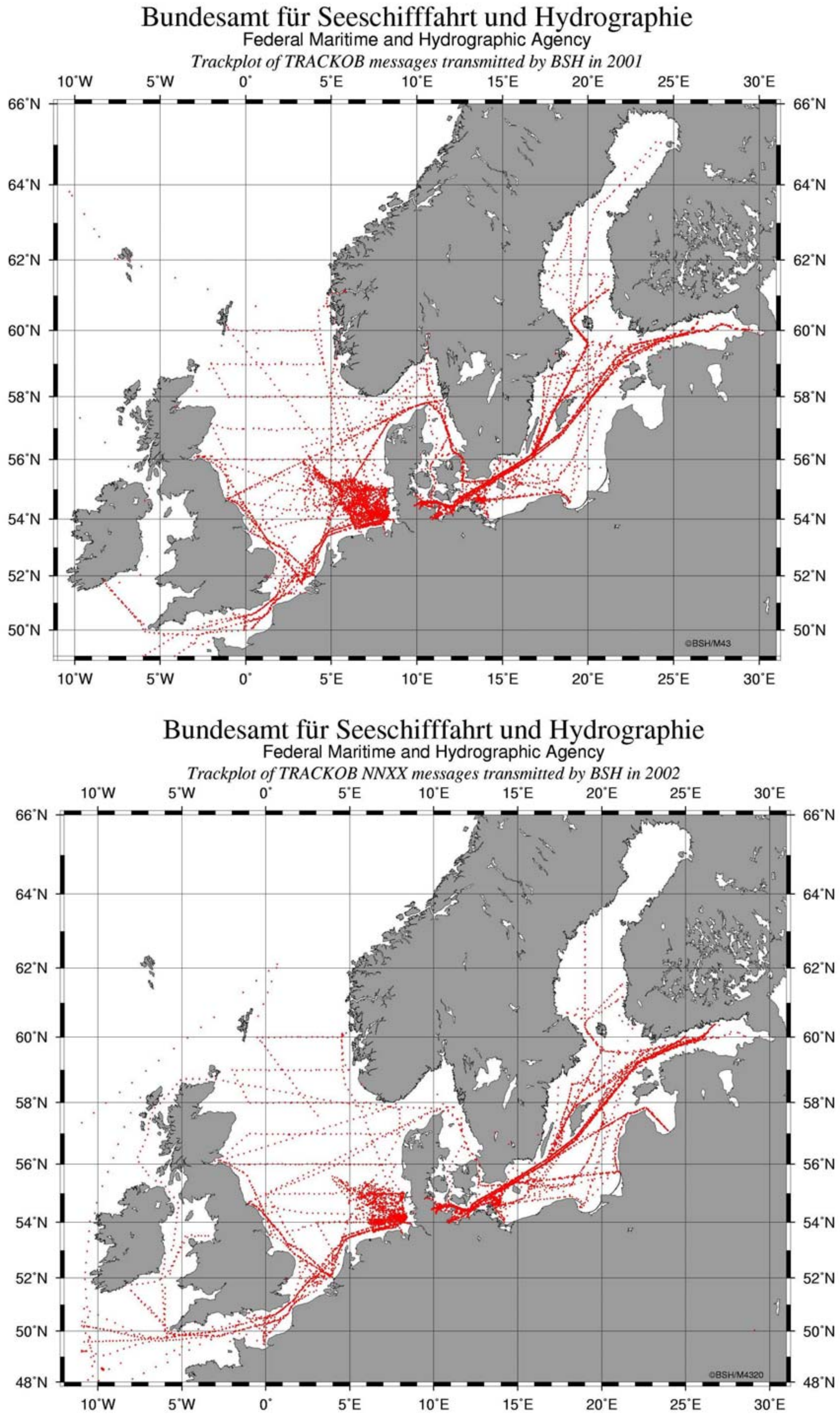


Fig. 24: Trackplot of TRACKOB messages of the BSH SST/SSS programme in 2001 (top) and 2002 (bottom).

- Institut für Meereskunde, Kiel (IfM Kiel), recently started the European Union (EU) funded pCO_2-SSS programme CAVASSOO (Carbon Variability Studies by Ships Of Opportunity) on the southern fringe of the GOOS A2 corridor. The equipment is installed on the Swedish car carrier "Falstaff" operated by Wallenius Wilhelmsen Line. The first Transatlantic run was carried out successfully in February 2002.

  The measurement system consisting of an SBE-21 thermosalinograph (TSG), CO_2 analysis system and fluorescene sensor is installed on the lowest deck of the engine compartment, close to the main diesel engine, and uses the ship's seawater intake. Further details are available at www.ifm.uni-kiel.de. Because of the close relationship of this programme to BSH's North Atlantic GOOS activities, co-operation was an obvious choice. BSH provided the TSG and uses the SST and SSS data in return. Fig. 25 shows the transects with TSG measurements which we received in 2002.

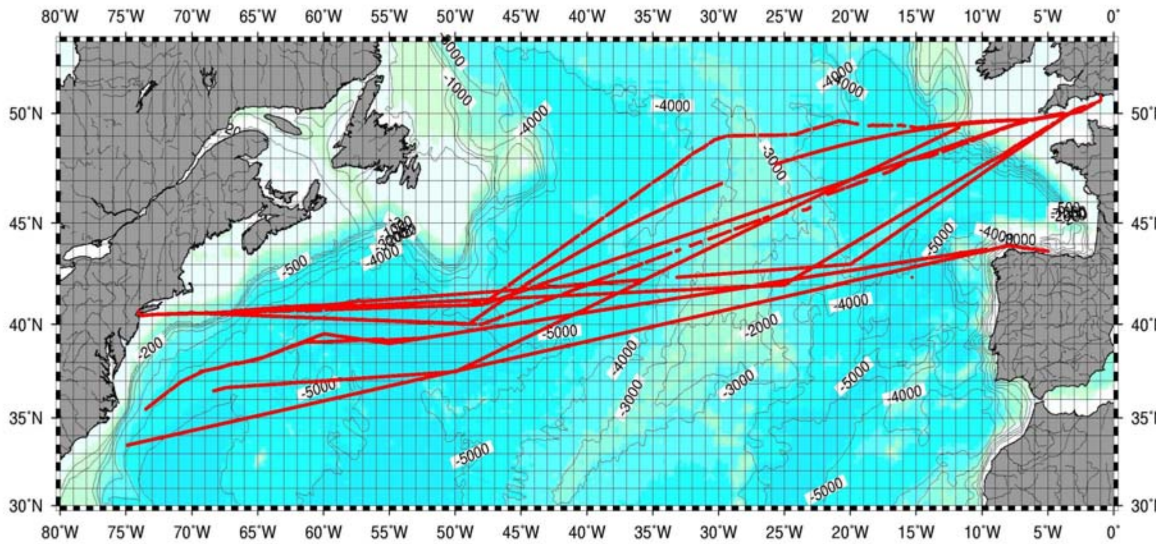
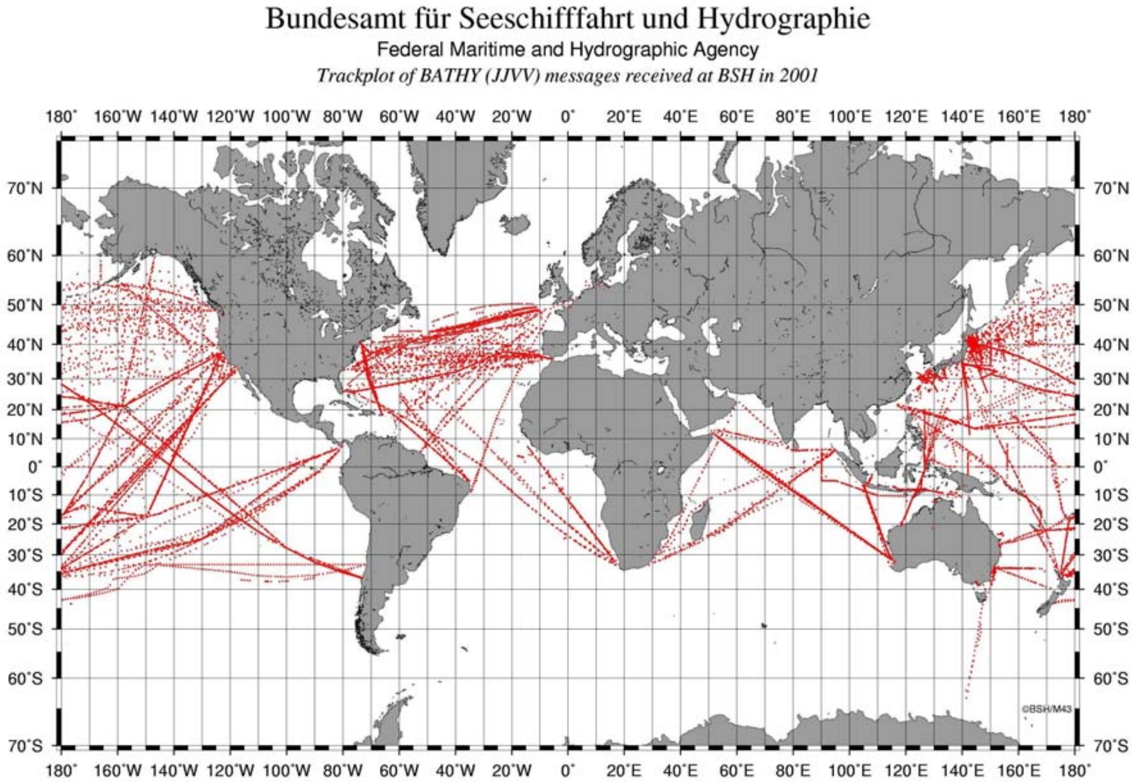


Fig. 25: Trackplot of TSG measurements carried out by CC "Falstaff" in 2002.

- Since 1972, BSH has participated actively in IGOSS (now JCOMM) and acts as the German input and output GTS hub for real-time oceanographic bulletins (IOC, 1999) in close co-operation with the German Weather Service (DWD (Station EDZW)). All German BATHY, TESAC and TRACKOB bulletins circulating on the GTS have been submitted by BSH. We hope to be able to contribute in the same way in the future. Trackplots of the output for BATHY and TESAC messages in 2001 and 2002 are presented in Figs. 26 and 27.



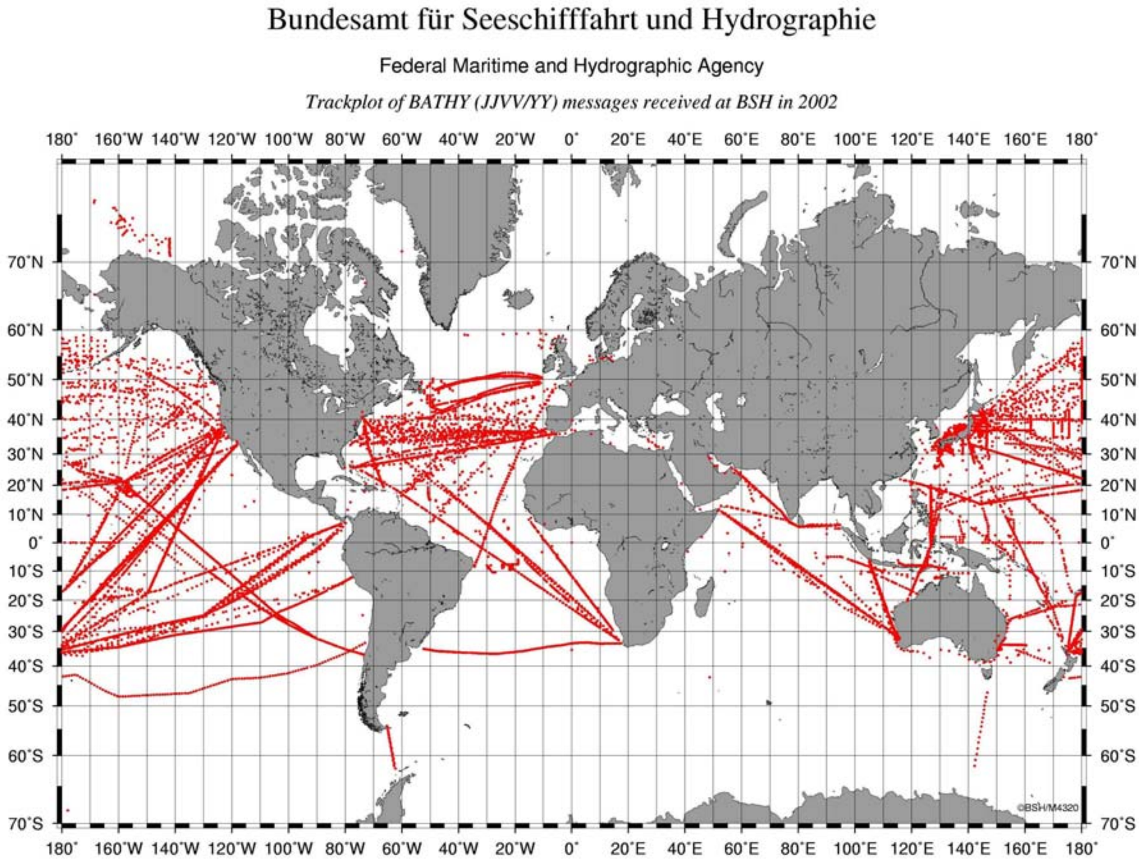
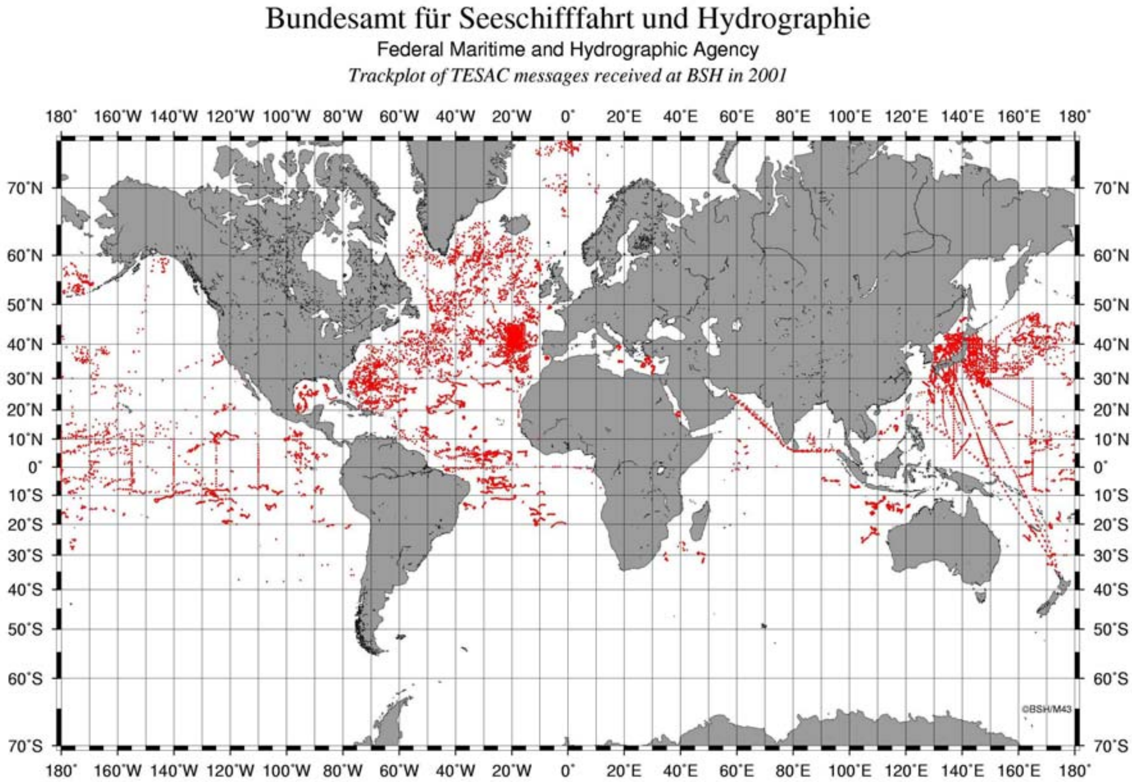


Fig. 26: Trackplot of BATHY messages received at BSH in 2001 (top) and 2002 (bottom).



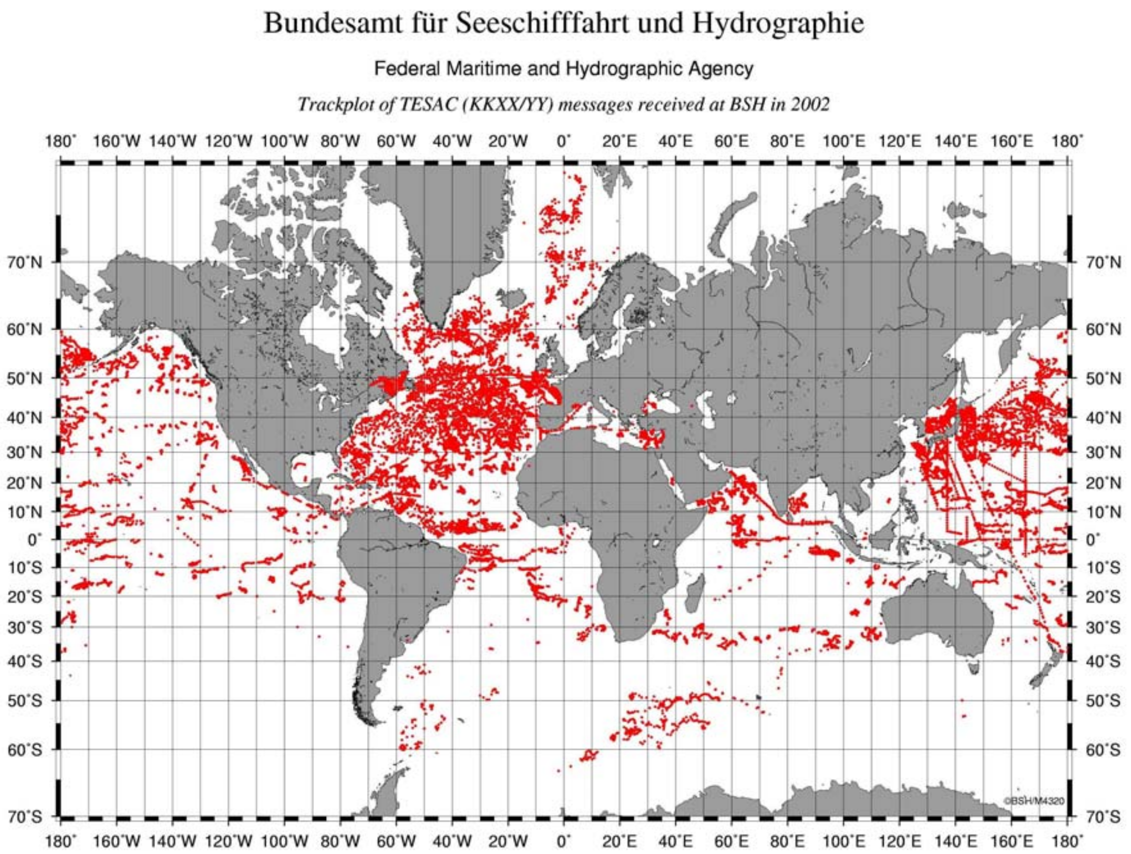


Fig. 27: Trackplot of TESAC messages received at BSH in 2001 (top) and 2002 (bottom).

- Fig. 28 and Table 4 show that BSH initiated total real-time data flow has been relatively continuous. Quality control (QC) of real-time data prior to insertion onto GTS is carried out for most SOOP data but not for Navy data. Delayed mode data, if processed and quality controlled by BSH, have been submitted on a yearly basis to the responsible data centre (NOAA/NODC in Silver Springs, USA and DOD of BSH, Germany). Delayed real-time data, as e.g. German Navy BATHYs, have been submitted to MEDS in Ottawa, Canada to avoid losses.

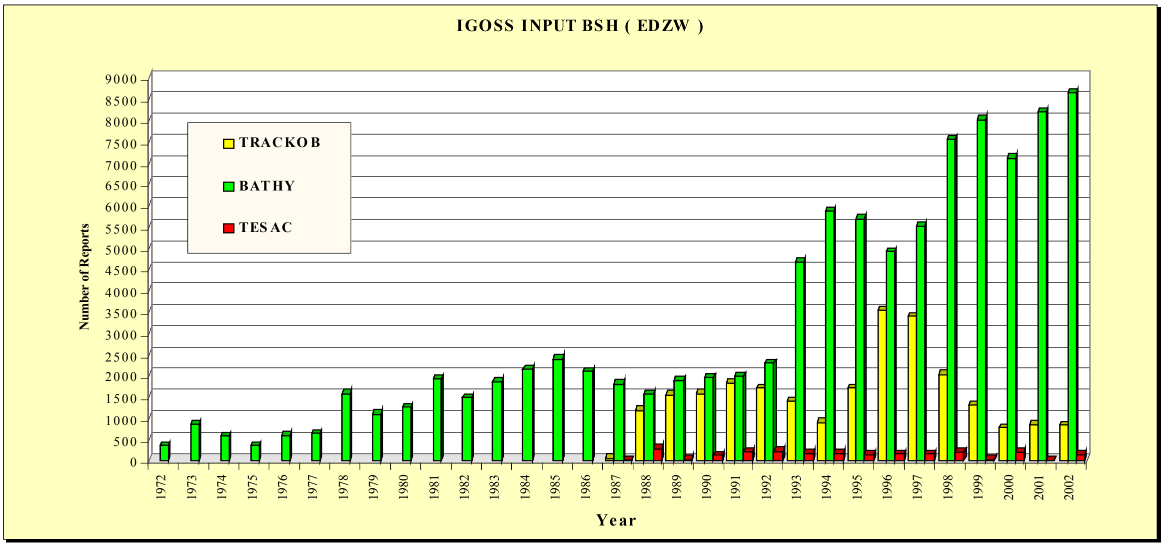


Fig. 28: Time series of total real-time data input by BSH since 1972.

Table 4: Real-time data distribution by ship (EDZW input 2000 - 2002).

	BATHY			TESAC			TRACKOB		
Ship/Call Sign	**2000**	**2001**	**2002**	**2000**	**2001**	**2002**	**2000**	**2001**	**2002**
Köln Express, 9VBL	105								
Bonn Express, DGNB	95	717	289						
Cap Finisterre, DACF	301	378	508						
Gauss, DBBK	235		216	148		134	158	188	197
Meteor, DBBH							24		
A.v.Humboldt, Y3CW				33					17
Penck, Y3CH				24					
Ebro, CSEP							256	225	114
Komet, DBBF							17	77	96
Seefalke, DBFO							150	184	124
Barbara, DJOK							196	144	229
Falstaff , SLCO									56
German Navy, SHIP	2069	964	92						
Ems, 10004	996	1053	1204						
Nordseeboje II, 62086		353	1069						
Deutsche Bucht, 10007	936	1127	1385						
Kiel, 10044	1293	1150	935						
Fehmarnbelt, 62088		431	1036						
Darsser Schwelle, 62089	64	981	1304						
Oder Bank, 66022	1029	1025	408						
Arkona Becken, 66021			164						

5. Data processing of delayed mode XBT data, quality control and hardware testing

XBT data processing is carried out within the framework of our standard CTD data processing. It is part of the BSH quality system which has been certified according to the international standard ISO 9001. An overview of the main processing steps is given in Fig. 29. In this context, the filter coefficients for the moving average and median applications are only meant as guideline values. The processing of individual profiles of particularly poor quality may differ under certain circumstances. For instance, in the case of profiles disturbed by heavy noise, stronger median filtering (Sy, 1985) was carried out using q > 15 filter weights. Such doubtful profiles are indicated in the station lists. The final depth-averaging at 1 m intervals does not take into account the reduced statistical independence caused by previous filtering. Compaction on 1 m steps should guarantee a uniform standard for archived data. Whatever the requirements of scientific analysis may be, the relatively high nominal vertical resolution of the final data allows investigators to adjust data according to their own needs. The final data are archived in the Deutsches Ozeanographisches Datenzentrum (DOD) which is operated by BSH.

Quality assessment of the XBTs and XCTDs currently in use and of any new expendable probe that may enter the market is a very important part of assuring a high-quality data base. Provided that the system is working correctly, there are three main error sources which may seriously affect the data quality. They are

- digitizer errors which are responsible for inaccuracies in the conversion of the electronic signal into temperature and/or conductivity units.
- Sensor errors due to various causes, e.g. wrong thermistor response, air bubbles in the conductivity cell (bubble adhesion) or calibration failure.
- Depth fall rate errors, e.g. due to an inaccurate depth time equation or production changes.

A well designed quality test strategy should be aimed at keeping all three main error sources under control.

Systematic field tests of expendable probes, which had been initiated at the 3rd SOOP meeting held in Hamburg in 1989 (IGOSS, 1989; Sy and Ulrich, 1990) and were aimed at checking the manufacturer's specification independently, i.e. from the customer's point of view (TT/QCAS, 1992), have been carried out in the past by members of the Task Team of Quality Control of Automated Systems (TT/QCAS). They resulted in significant equipment improvements by the manufacturer and also helped to improve data quality through internationally co-ordinated and controlled XBT depth fall rate experiments (Hanawa et al., 1994; 1995; Rual et al., 1996). As Sippican Inc., Marion, USA, monopolizes the market of XBT probes, the importance of this type of co-ordinated quality tests cannot be overemphasized.

Since the early days of WOCE, there have been demands for an improvement of the quality of industrially produced expendable CTDs (XCTD) in order to ensure the accuracy and precision needed for large-scale measurements of heat and salt storage of the upper ocean in the WOCE voluntary observing ship programme. Comparative data from research vessels were to be used to check the accuracy of XCTDs (WOCE, 1988). Therefore, during WOCE cruises, independent scientists took the opportunity to test this new expendable device against a controlled and accurate CTD reference (Sy, 1992; 1993b; 1995; 1996; 1998a; 1998b; Johnson, 1995; TT/QCAS, 1997; Watanabe et al., 1998; Gilson et al., 2000), which helped to improve the system's performance so that it eventually met the claimed specifications and became a valuable tool for upper ocean thermal and salinity investigation meeting the requirements of the oceanographic community.

- Return from greeting of SOOP vessel with data disk, XBT drop log, ship visit report

Raw data transfer on Workstation

Header information check and completion according XBT log and ship visit report

Conversion of raw data in physical units,
re-formatting in SDAF*),
addition of comments

*) SDAF = BSH internal Scientific Data Analysis Format

- First visual inspection of profiles

median filtering (standard: 2 x q = 15),
clipping of upper 3 cycles

- Visual quality control

Interactive screen editing and quality control:
a) running mean filtering
b) interpolation
c) clipping of profile ends

Depth interval compaction
(standard: Δz = 1 m)

- Final products: profile plots
  section plots
  maps
  commented drop listings

- Final quality control

- Transfer of processed data to final archive in German Oceanographic Data Centre (DOD) at BSH

Fig. 29: Flow diagram for processing of delayed mode XBT data.

6. References

ARGO (1998): On the design and implementation of ARGO. An initial plan for a Global array of profiling floats. GODAE Report No. 5, BoM, Melbourne, Australia.

Bersch, M., J. Meincke and A. Sy (1999): Interannual thermohaline changes in the northern North Atlantic 1991-1996. Deep-Sea Res., Part II, **46**, 55-75.

BSH (1999): German programme contribution to the Global Ocean Observing System (GOOS). Berichte des BSH, **19**, 74 pp.

CLIVAR (1998): CLIVAR Initial Implementation Plan, WMO/TD No. 869

Cook, A. and A. Sy (2000): Best Guide and Principles Manual for the Ships-of-Opportunity (SOOP) and Expendable Bathythermogrpah (XBT) Operations. JCOMM SOOP Implementation Panel III (SOOPIP), 28-31 March, La Jolla, 25 pp., http://www.fr/ird/soopip/.

Curry, R.G., M.S. McCartney and T.M. Joyce (1998): Oceanic transport of subpolar climate signals to mid-depth subtropical waters. Nature, **391**, 575 – 577.

Curry, R.G. and M.S. McCartney (2001): Ocean gyre circulation changes associated with the North Atlantic Oscillation. J. Phys. Oceanogr., **31**, 3374 – 3400.

Dansgaard, W. et al. (1993): Evidence for general instability of past climate from a 250-kyr ice-core record. Nature, **364**, 218 – 220.

DFG (2000): Meeresforschung im nächsten Jahrzehnt – Denkschrift. DFG, Bonn, 203 pp.

Dickson, R., J. Meincke, S.-A. Malmberg and A.J. Lee (1988): The „Great Salinity Anomaly“ in the northern North Atlantic 1968 – 1982. Prog. Oceanogr., **20**, 103 – 151.

Dickson, R., J.R.N. Lazier, J. Meincke, P. Rhines and J. Swift (1996): Long-term co-ordinated changes in the convective activity of the North Atlantic. Prog. Oceanogr., **38**, 241 – 295.

Dickson, R., J. Yashayev, J. Meincke, B. Turrell, S. Dye and J. Holfort (2002): Rapid freshening of the deep North Atlantic Ocean over the past four decades. Nature, **416**, 832 – 836.

Duplessy, J.C. et al. (1988): Deep water source variations during the last climatic cycle and their impact on the global deep water circulation. Palaeoceanography, **3**, 343 – 360.

Emery, J.W., W. Zenk, K. Huber, P. Rual and P. Nowlan (1987): Trends in the Atlantic Equatorial Current variability. Dt. Hydrogr. Z., **40**, 261 – 276.

Fichefet, T., S. Hovine and J.C. Duplessy (1994): A model study of the Atlantic circulation during the last glacial maximum. Nature, **372**, 252 – 255.

Flatau, M.K., L.D. Talley and P.P. Niiler (2002): The North Atlantic Oscillation, surface current velocities and SST changes in the subpolar North Atlantic. Subm. to J. of Climate.

Gilson, J., G. Pezzoli and D. Roemmich (2000): Shipboard XCTD’s – Performance, problems and prospects. UCSD, La Jolla, USA (unpublished ms.), 5 pp.

Hanawa, K., P. Rual, R. Bailey, A. Sy and M. Szabados (1994): Calculation of new depth equations for expendable bathythermographs using a temperature-error-free method. UNESCO technical papers in marine science, **67**, 46 pp. and IOC Techn. Ser., **42**, 46 pp.

Hanawa, K., P. Rual, R.Bailey, A. Sy and M. Szabados (1995): A new depth-time equation for Sippican or TSK T-7, T-6 and T-4 Expendable Bathythermographs (XBT). Deep-Sea Res., **42**, 1423-1451.

Hansen, D.V. and H.F. Bezdek (1996): On the nature of decadal anomalies in North Atlantic sea surface temperature. J. Geophys. Res., **101**, 8749-8758.

Holzkamm, F. (1988): Das automatische ozeanographische Meßnetz des DHI in Nord- und Ostsee (Stand 1988). Wiss-Techn. Berichte aus dem DHI, 1988-3, 13 pp.

Horne E. and B. Petrie (1988): Mean position and variability of the sea surface temperature front east of the Grand Banks. Atmosphere-Ocean, **26**, 321 – 328.

Hurrell, J.W. (1995): Decadal trends in the North Atlantic Oscillation regional temperatures and precipitation. Science, **269**, 676 – 679.

Hurrell, J.W. (1996): Influence of variations in extratropical wintertime teleconnections on Northern Hermisphere temperature. Geophys. Res. Lett., **23**, 665 – 668.

IGOSS (1989): Summary of ship-of-opportunity programmes and technical reports. 3rd Session of the Joint IOC-WMO Meeting for the Implementation of IGOSS XBT SOOP, Hamburg, Germany, 16 – 20 Oct. 1989. IOC/INF-804, 192 pp.

IOC (1999): Guide to operational procedures for the collection and exchange of JCOMM oceanographic data. Manuals and Guides No. 3. 38 pp

IPCC (2001): IPCC Third Assessment Report – Climate Change 2001: The scientific basis (eds. Houghton, T.J. et al.), www.wmo.ch.

Johnson, G. (1995): Revised XCTD fall-rate equation coefficients from CTD data. J. Atmos. Oceanic Technol., **12**, 1367 – 1373.

Koltermann, K.P., A.V. Sokov, V.B. Tereschenkov, S.A. Dobroliubov, K. Lorbacher and A. Sy (1999): Decadal changes in the thermohaline circulation of the North Atlantic. Deep-Sea Res., II, **46**, 109-138.

Koslowski, G. and P. Löwe (1994): The western Baltic sea ice season in terms of a mass-related severity index: 1879 – 1992. Part I: Temporal variability and association with the north Atlantic oscillation. Tellus, **46A**, 66 - 74

Krahmann, G., M. Visbeck and G. Riverdin (2001): Formation and propagation of temperature anomalies along the North Atlantic Current. J. Phys. Oc., **31**, 1287-1303

Krauss, W. (1986): The North Atlantic Current. J. Geophys. Res., **91**, 5061 – 5074.

Lorbacher, K. (2000): Niederfrequente Variabilität meridionaler Transporte in der Divergenzzone des nordatlantischen Subtropen- und Subpolarwirbels – Der WOCE-Schnitt A2. Ber. BSH, **22**, 156 pp.

Löwe, P and G. Koslowski (1998): The Western Baltic sea ice season in terms of a mass-related severity index 1979 – 1992. Part II: Spectral characteristics and associations with the NAO, QBO and solar cycle. Tellus, **50A**, 219 – 241.

Lozier, M.S., W.B. Owens and R.G. Curry (1995): The climatology of the North Atlantic. Prog. Oceanogr., **36**, 1 – 44.

McCartney, M.S. and L.D. Talley (1982): Warm-to-cold water conversion in the northern North Atlantic Ocean. J. Phys. Oc., **14**, 922 – 935.

McCartney, M. (1997): Is the ocean at the helm? Nature, **388**, 521 – 522.

Manabe, S. and R.J. Stouffer (1994): Multiple-century response of a coupled ocean-atmosphere model to an increase of atmosphere carbon dioxide. J. Climate, **7**, 5 – 23.

Manabe, S. and R.J. Stouffer (1995): Simulation of abrupt climate change induced by freshwater input to the North Atlantic Ocean. Nature, **378**, 165 – 167.

Molinari, R.L., A.M. Dennis, J.F. Fiesta and H.F. Bezdek (1997): Multiyear variability in the near-surface temperature structure of the mid-latitude western North Atlantic Ocean. J. Geophys. Res., **102**, 3267-3278.

Quadfasel, D., A. Sy, D. Wells and A. Tunik (1991): Warming in the Arctic. Nature, **350**, p. 385.

Quadfasel, D., A. Sy and B. Rudels (1993): A ship of opportunity section to the North Pole: upper ocean temperature observations. Deep-Sea Research, **40**, 777-789.

Rahmsdorf, S. (1994): Rapid climate transitions in a coupled ocean-atmosphere model. Nature, **372**, 82 –85.

Rahmsdorf, S. (1995): Bifurcations of the Atlantic thermohaline circulation in response to changes in the hydrological cycle. Nature, **378**, 145 – 149.

Read, J.F. and W.J. Gould (1992): Cooling and freshening of the subpolar North Atlantic Ocean since the 1960s. Nature, **360**, 55-57.

Reverdin, G., N. Verbrugge and H. Valdimarsson (1999): Upper ocean variability between Iceland and Newfoundland, 1993 – 1998. J. Geophys. Res., **104**, 29599 – 29611.

Robinson, M.K., R.A. Bauer and E.H. Schroeder (1979): Atlas of North Atlantic – Indian Ocean mean temperatures and mean salinities of the surface layer. U.S. Naval Oceanographic Office, pub. 18.

Rogers (1984): The association between North Atlantic Oscillation and the Southern Oscillation in the Northern hemisphere. Mon. Wea. Rev., **112**, 1999 – 2015.

Rual, R., A. Dessier, J.P. Rebert, A. Sy and K. Hanawa (1996): New Depth Equation for Sparton XBT-7 Expendable Bathythermographs. Intern. WOCE Newsletter, **24**, 39-40.

Schmitz, W.J. (1996): On the World Ocean Circulation: Volume 1. WHOI, Technical Report, WHOI-96-03, 141 pp.

Smith, N.R. et al. (2000): The role of XBT sampling on the ocean thermal network. JCOMM SOOP Implementation Panel, 3rd session, La Jolla, Ca., USA, 28-31 March 2000. SOOP Status Reports. WMO/TD-No. 1005, 130-151.

Sutton, R.T. and M.R. Allen (1997): Decadal predictability of North Atlantic sea surface temperature and climate. Nature, **388**, 563-567.

Sy. A. (1985): An alternative editing technique for oceanographic data. Deep-Sea Res., **32**, 1591-1599.

Sy, A. (1988): Investigation of large-scale circulation patterns in the central North Atlantic: the North Atlantic Current, the Azores Current, and the Mediterranean Water plume in the area of the Mid-Atlantic Ridge. Deep-Sea Research, **35**, 383 - 413.

Sy, A. and J. Ulrich (1989): North Atlantic Ship of Opportunity XBT Programme 1988 - Data Report. DHI, Wissensch.-Techn. Berichte, 1989-2, 79 pp.

Sy, A. and J. Ulrich (1990): North Atlantic Ship of Opportunity XBT Programme 1989 - Data Report. DHI, Wissensch.-Techn. Berichte, 1990-2, 88 pp.

Sy, A. (1991): XBT Measurements. In: WOCE Operations Manual, Part 3.1.3: WHP Operations and Methods (Ed.: T. Joyce), WOCE Report No. 68/91, Woods Hole, 19 pp.

Sy, A. (1992): XCTD measurements in the North Atlantic: Report on XCTD data. IOC/INF-932 (1993), Addendum to the Summary Report of a Meeting of the IGOSS Task Team on Quality Control for Automated Systems, Genf, 19-21 October 1992, Annex V, 22 pp.

Sy, A., U. Schauer and J. Meincke (1992): The North Atlantic Current and its hydrographic structure above and eastwards of the Mid-Atlantic Ridge. Deep-Sea Res. **39**, 825-853.

Sy, A. (1993a): Handelsschiffe in der modernen Meeresforschung. In: Schiffahrt und Meer (Eds.: P. Ehlers, G. Duensing, G. Heise). Verlag E. S. Mittler & Sohn, Herford, 229-237.

Sy, A. (1993b): Field evaluation of XCTD performance. International WOCE Newsletter, **14**, 33-37.

Sy, A. and J. Ulrich (1994) : North Atlantic Ship-of-Opportunity XBT Programme 1990 - Data Report. Ber. BSH, **1**, 134 pp.

Sy, A. (1995): Improved MK-12/XCTD System tested in the Field. Summary Report of the Third Meeting of the IGOSS Task Team on Quality Control for Automated Systems, Ottawa, Canada, 23-25 Oct 1995, 20 pp.

Sy, A. (1996): Summary of Field Tests of improved XCTD/MK-12 System. Intern. WOCE Newsl., **22**, 11-13.

Sy, A., M. Rhein, J.R.N. Lazier, K.P. Koltermann, J. Meincke, A. Putzka and M. Bersch (1997a): Surprisingly rapid spreading of newly formed intermediate waters across the North Atlantic Ocean. Nature, **386**, 675-679.

Sy, A., K.P. Koltermann and U. Paul (1997b): Observing opposing temperature changes in the upper and intermediate layers of the North Atlantic Ocean. Intern. WOCE Newsl., **26**, 30 – 33.

Sy, A. (1998a): At-sea test of a new XCTD system. Intern. WOCE Newsl., **31** 45-47.

Sy, A. (1998b): Field Evaluation of Tsurumi-Seiki's (TSK) Expendable CTD System. Second Meeting of the SOOPIP, Noumea 26-30 October 1998, Final Report, Annex XVIII, p. 16-29.

TT/QCAS (1992): Report on field tests in 1990 on the evaluation of the XBT depth fall rate equation. IOC/INF-888 (1992), Summary Report and Addendum of the Ad Hoc Meeting of the IGOSS Task Team on Quality Control for Autom. Systems, Marion, USA, 3 - 6 June 1991, 144 pp.

TT/QCAS (1997): Summaries of XCTD representations by BSH, CSIRO, TSK and Sippican. IOC/INF-1074 (1997), Summary Report of the fourth meeting of the SOOPIP Ad Hoc Task Team on Quality Control for Automated Systems, Cape Town, South Africa, 14 – 15 April 1997, 37 pp.

Watanabe, T., K. Mizuno, M. Okazaki and H. Yoritaka (1998): Performance of TSK XCTD. Final Report of IGOSS Ship-of-Opportunity Programme Implementation Panel (SOOPIP), 2nd Session, Noumea, New Caledonia, 26-30 Oct 1998.

WMO/IOC (2000): JCOMM Ship-of-Opportunity Programme Implementation Panel (SOOPIP), third session , La Jolla, USA, 28-31 March 2000, SOOP Status Report, WMO/TD-No 1005, 173 pp.

WOCE (1988): World Ocean Circulation Experiment Implementation Plan, Vol. 1 – Detailed Requirements. WCRP-11, WMO/TD No. 242.

Woods, J.D. et al. (1996):The strategy for EuroGOOS. EuroGOOS Publ. No. 1. Southampton Oceanography Centre, Southampton, England.

Wunsch, C. (1978): The North Atlantic general circulation west of 50 °N determined by inverse methods. Rev. Geophys. and Space Physics, **16**, 583 – 620.

Yang, J. (1999): A linkage between decadal climate variations in the Labrador Sea and the Tropical Atlantic Ocean. Geophys. Res. Letters, **26**, 1023-1026.

7. Acronyms

ARGO	Array for Real-time Geostrophic Oceanography
BATHY	WMO Code for reporting bathythermal observations
BSH	Bundesamt für Seeschifffahrt und Hydrographie (Germany)
CAVASSOO	Carbon Variability Studies by Ships of Opportunity
CLIVAR	Climate Variability and Predictability (WCRP component)
CTD	Conductivity-Temperature-Depth instrument
DFG	Deutsche Forschungsgemeinschaft (Germany)
DHI	Deutsches Hydrographisches Institut (Germany)
EU	European Union
GOOS	Global Ocean Observing System
GTS	Global Telecommunication System of WMO
IGOSS	Integrated Global Ocean Services System of IOC-WMO
IOC	Intergovernmental Oceanographic Commission (UNESCO)
JCOMM	Joint Commission for Ocean and Marine Measurements of IOC-WMO
LSW	Labrador Sea Water
MARNET	Marine Monitoring Network in the North Sea and Baltic Sea (Germany)
MEDS	Marine Environmental Data Services (Canada)
MOC	Meridional Overturning Circulation
NAC	North Atlantic Current
NAO	North Atlantic Oscillation
NOAA	National Oceanic and Atmospheric Administration (USA)
NODC	National Oceanographic Data Centre of IODE
SEAS	Shipboard Environmental Data Acquisition System of NOAA
SOOP	Ship of Opportunity Programme
SOOPIP	Ship of Opportunity Programme Implementation Panel of IOC
SSS	Sea Surface Salinity

SST	Sea Surface Temperature
TESAC	Code for reporting of temperature, salinity and current observations
THC	Thermohaline circulation
TOGA	Tropical Ocean Global Atmosphere (WCRP component)
TRACKOB	Code for reporting of surface observations taken along a ship's track
TSG	Thermosalinograph
TT/QCAS	Task Team of Quality Control of Automated Systems
TWI	TOGA-WOCE-IGOSS line system
WCRP	World Climate Research Programme
WMO	World Meteorological Organization
WOCE	World Ocean Circulation Experiment (WCRP component)
XBT	Expendable Bathythermograph
XCTD	Expendable Conductivity-Temperature-Depth instrument

Authors:	Dr. Alexander Sy	+49 40 3190 3430	sy@bsh.de
	Jürgen Ulrich	+49 40 3190 3432	ulrich@bsh.de
	Hans-Joachim Weichert	+49 40 3190 3431	weichert@bsh.de

Bundesamt für Seeschiffahrt und Hydrographie
Bernhard-Nocht-Str. 78
20359 Hamburg
Germany

Berichte des Bundesamtes für Seeschiffahrt und Hydrographie

Verzeichnis der veröffentlichten Arbeiten

1	(1994)	Sy, A., Ulrich, J.	North Atlantic Ship-of-Opportunity XBT Programme 1990 - Data Report, 134 pp.
2	(1994)	Hagen, E., Mittelstaedt, E., Feistel, R., Klein, H.	Hydrographische Untersuchungen im Ostrandstromsystem vor Portugal und Marokko 1991 - 1992, 49 pp.
3	(1994)	Oliczewski, J., Schmidt, D.	Entwicklung einer Bestrahlungsapparatur zum photochemischen Aufschluß von Meerwasserproben zur Bestimmung von Schwermetallen, 70 pp.
4	(1994)	BSH [Hrsg.]	Das UN-Seerechtsübereinkommen tritt in Kraft: Inhalte und Konsequenzen für die Bundesrepublik Deutschland, 71 pp.
5	(1995)	BSH [Hrsg.]	Nationale Folgerungen aus dem Inkrafttreten des UN-Seerechtsübereinkommens, 103 pp
6	(1995)	Haffer, E., Schmidt, D.	Entwicklung eines Probenvorbereitungsverfahrens zur Bestimmung von Arsen im Meerwasser mit der Totalreflexions-Röntgenfluoreszenzanalyse, 109 pp.
7	(1995)	BSH [Hrsg.]	Global Ocean Observing System - Statusbericht, 100 pp.
8	(1996)	Mittelstaedt, E., Meincke, J., Klein, H.	WOCE-Current measurements: The ACM8 array – Data Report, 150 pp.
9	(1996)	BSH [Hrsg]	GOOS Workshop - Anforderungen an ein wissenschaftliches Konzept für den deutschen Beitrag, 60 pp.
10	(1997)	Sterzenbach, D.	Entwicklung eines Analyseverfahrens zur Bestimmung von chlorierten Kohlenwasserstoffen in marinen Sedimenten und Schwebstoffen unter besonderer Berücksichtigung der überkritischen Fluidextraktion, 233 pp.
11	(1997)	Jonas, M., Richter, R.	Stand und Entwicklungstendenzen nautischer Systeme, Anlagen und Geräte an Bord von Seeschiffen, 37 pp.
12	(1997)	Wedekind, C., Gabriel, H., Goroncy, I., Främke, G., Kautsky, H.	"Meteor"-Reise Nr. 71/1985, Norwegen-Grönlandsee – Datenbericht. 44 pp.
13	(1998)	BSH [Hrsg]	HELCOM Scientific Workshop - The Effects of the 1997 Flood of the Odra and Vistula Rivers. 46 pp.
14	(1998)	Berger, R., Klein, H., Mittelstaedt, E., Ricklefs, K., Ross, J.	Der Wasseraustausch im Tidebecken Hörnum-Tief – Datenreport. 260 pp.
15	(1998)	Röske, F.	Wasserstandsvorhersage mittels neuronaler Netze. 212 pp.
16	(1998)	Ross, J., Mittelstaedt, E. Klein, H., Berger, R., Ricklefs, K.	Der Wasseraustausch im Tidebecken Hörnum-Tief – Abschlußbericht. 98 pp.
17	(1998)	Klein, H.	OPUS-Current Measurements: Mecklenburg Bight and Fehmarnbelt - Data Report, 150 pp
18	(1999)	BSH [Hrsg]	Deutscher Programmbeitrag zum Globalen Ozeanbeobachtungssystem (GOOS), 67 pp.
19	(1999)	BSH [Hrsg]	German Programme Contribution to the Global Ocean Observing System (GOOS), 71pp.
20	(1999)	Sztobryn, M., Stanislawczyk, I., Schmelzer, N.	Ice Conditions in the Szczecin and Pomeranian Bay During the Normal Period from 1961-1990, 36 pp.
21	(1999)	Nies, H., Karcher, M., Bahe, C., Backhaus, J., Harms, I.	Transportmechanismen radioaktiver Substanzen im Arktischen Ozean - Numerische und experimentelle Studien am Beispiel der Barents- und Karasee, 134 pp.
22	(2000)	Lorbacher, K.	Niederfrequente Variabilität meridionaler Transporte in der Divergenzzone des nordatlantischen Subtropen- und Subpolarwirbels – Der WOCE-Schnitt A2, 156 pp.
23	(2000)	Klein, H.	The Subsurface Eastern Boundary Current of the North Atlantic between 32°N and 53°N – Data Report, 240 pp.

24	(2000)	Klein, H.	Strömungen und Seegangsverhältnisse westlich der Insel Hiddensee - Datenreport, 59 pp.
25	(2001)	Goedecke, E.	Der hydrographische Aufbau in der Deutschen Bucht vornehmlich dargestellt auf Grund der vorliegenden Unterlagen über Temperatur, Salzgehalt und Dichte, 202 pp.
26	(2001)	Klein, H., Mittelstaedt, E.	Strömungen und Seegangsverhältnisse vor Graal-Müritz und in der Tromper Wiek - Datenreport, 162 pp.
27	(2001)	Klein, H., Mittelstaedt, E.	Gezeitenströme und Tidekurven im Nahfeld von Helgoland, 24 pp. und Anhang.
28	(2001)	Behnke, J., Berking, B., Herberg, J., Jonas, M., Mathes, S.	Functional Scope and Model of Integrated Navigation Systems - A Toolbox for Identification and Testing. 181 pp.
29	(2001)	Dick, S., Kleine, E., Müller-Navarra, S., Klein, H., Komo, H.	The Operational Circulation Model of BSH (BSHcmod) – Model description and validation. 49 pp.
30	(2002)	Sy, A. , Ulrich, J., Weichert, H.-J.	Upper Ocean Climate Ship-of-Opportunity Programme of BSH – A Status Report. 45 pp.