

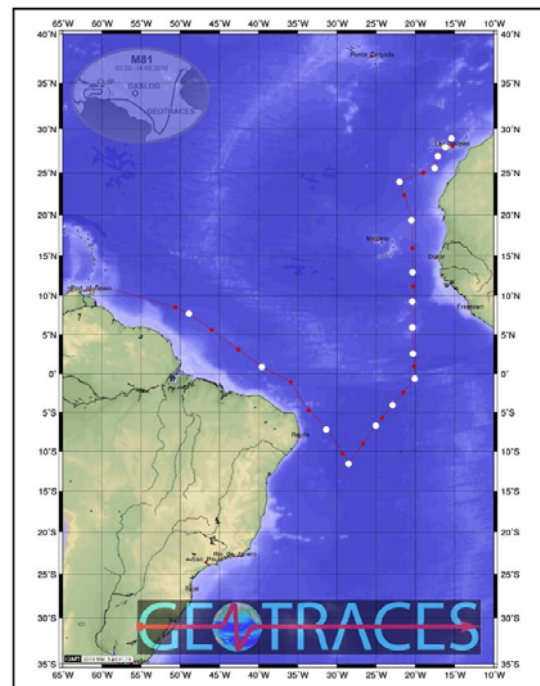
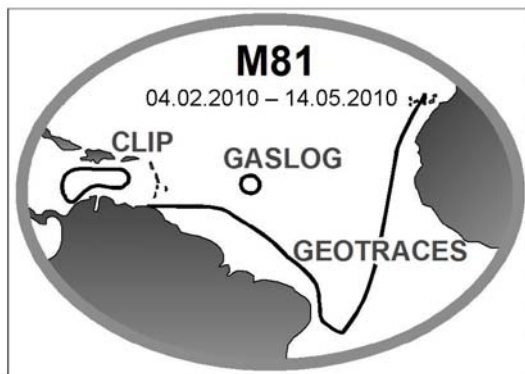
METEOR-Berichte

## Trace Metals and Their Isotopes in the Tropical Atlantic Ocean

Cruise No. M81/1

February 04 – March 08, 2010

Las Palmas (Canary Islands, Spain) – Port of Spain (Trinidad & Tobago)



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## 1 Summary

Meteor Cruise M81/1 was dedicated to the investigation of the distribution of dissolved and particulate trace metals and their isotopic compositions (TEIs) in the full water column of the tropical Atlantic Ocean and their driving factors including main external inputs and internal cycling and ocean circulation. The research program is embedded in the international GEOTRACES program (e.g. Henderson et al., 2007), which this cruise was an official part of and thus corresponds to GEOTRACES cruise GA11. This cruise was completely dedicated to the trace metal clean and contamination-free sampling of waters and particulates for subsequent analyses of the TEIs in the home laboratories of the national and international participants. Besides a standard rosette for the less contaminant prone metals, trace metal clean sampling was realized by using a dedicated and coated trace metal clean rosette equipped with Teflon-coated GO-FLO bottles operated via a polyester coated cable from a mobile winch that was thankfully made available by the U.S. partners of the GEOTRACES program for this cruise. The particulate samples were also collected under trace metal clean conditions using established in-situ pump systems. The cruise track led the cruise southward from the Canary Islands to 11°S and then continued northwestward along the northern margin of South America until it reached Port of Spain, Trinidad & Tobago. The track crossed areas of major external inputs including exchange with the volcanic Canary Islands, the Saharan dust plume, as well as the plume of the Amazon outflow. In terms of internal cycling the equatorial high biological productivity band, as well as increased productivity associated with the Amazon Plume were covered. All major water masses contributing the Atlantic Meridional Overturning Circulation, as well as the distinct narrow equatorial surface and subsurface east-west current bands were sampled. A total of 17 deep stations were sampled for the different dissolved TEIs, which were in most cases accompanied by particulate sampling. In addition, surface waters were continuously sampled under trace metal clean conditions using a towed fish.

## Zusammenfassung

Die Forschungsreise Meteor 81/1 hatte die Untersuchung der Verteilung der Konzentrationen gelöster und partikulärer Spurementalle sowie deren Isotopie in der gesamten Wassersäule des tropischen Atlantiks zum Ziel. Insbesondere sollten die steuernden Faktoren wie die externe Einträge, die internen Kreisläufe und die Ozeanzirkulation erfasst werden. Dieses Forschungsprogramm ist in das internationale GEOTRACES-Programm eingebettet, von dem diese Ausfahrt ein offizieller Bestandteil ist und als GEOTRACES-Fahrt GA11 geführt wird. Die Fahrt war vollständig der spurenmetallsauberen, kontaminationsfreien Beprobung des Wassers und der Partikel zur nachfolgenden Messung in den landbasierten Laboren der nationalen und internationalen Partner gewidmet. Neben einem Standard-Kranzwasserschöpfer für die weniger kontaminationsanfälligen Metalle wurde die spurenmetallsaubere Beprobung mittels eines speziell entwickelten und beschichteten Kranzwasserschöpfers umgesetzt, der mit teflonbeschichteten GO-FLO-Flaschen bestückt war und mittels eines Polyester-Kabels und einer mobilen Winde betrieben wurde. Diese Geräte wurden dankenswerter Weise von Partnern des GEOTRACES-Programms der Vereinigten Staaten zur Verfügung gestellt. Die partikulären Proben wurden ebenfalls unter spurenmetallsauberen Bedingungen mittels etablierter In-Situ-Pumpensysteme entnommen. Die Fahrtroute führte von den Kanarischen Inseln südwärts bis auf

eine Breite von 11°S und von dort in nordwestlicher Richtung entlang des Kontinentalrands von Südamerika bis nach Port of Spain, Trinidad & Tobago. Die Route überquerte Gebiete erhöhten externen Eintrags inklusive des Austauschs mit den vulkanischen Kanarischen Inseln, der Staubfahne der Sahara und dem Amazonaseinstrom. Zur Untersuchung der internen Kreisläufe wurde die äquatoriale biologische Hochproduktivitätszone, sowie die erhöhte Produktivität im Zusammenhang mit dem Amazonaseinstrom abgedeckt. Alle Hauptwassermassen die Teil der Umwälzzirkulation im Atlantik sind, wurden genauso wie die schmalen West-Ost verlaufenden Strömungsbänder in der oberen Wassersäule nahe des Äquators beprobt. Insgesamt wurden 17 tiefe Stationen für die gelösten Spurenmetalle beprobt, an denen in den meisten Fällen auch partikuläre Proben entnommen wurden. Zusätzlich wurde das Oberflächenwasser kontinuierlich ebenfalls unter spurenmetallsauberen Bedingungen mittels eines Schleppfischs beprobt.

## 2 Participants

Name	Discipline	Institution
01. Frank, Martin, Prof.	<i>Chief Scientist</i>	IFM-GEOMAR
02. Alexander, Brian, Dr.	<i>Trace metals/speciation</i>	Jacobs University
03. Merschel, Gila	<i>Trace metals/speciation</i>	Jacobs University
04. Fischer, Maitri	<i>Trace metals/speciation</i>	Jacobs University
05. Pöhle, Sandra	<i>Trace metals</i>	IOW
06. Staubwasser, Michael, Prof.	<i>Fe isotopes</i>	Cologne University
07. Fichtner, Vanessa	<i>Fe isotopes</i>	Cologne University
08. Tang, Xiaoliang, Dr.	<i>Particulates</i>	MCB
09. Ostendorf, Michael	<i>Particulates</i>	MCB
10. Vogt, Martin	<i>CTD/ADCP</i>	IFM-GEOMAR
11. Roth, Christina	<i>CTD/ADCP-Watch</i>	IFM-GEOMAR
12. Haynert, Kristin	<i>Salinity</i>	IFM-GEOMAR
13. Hagenow, Alexander	<i>CTD/ADCP-Watch</i>	IFM-GEOMAR
14. Barnes, Curtis	<i>Trace-metal clean rosette</i>	ODU
15. Lorenzen, Janne	<i>Natural radionuclides</i>	IFM-GEOMAR
16. Camara-Mor, Patricia	<i>Natural radionuclides</i>	UAB
17. Teschner, Claudia	<i>Natural radionuclides</i>	IFM-GEOMAR
18. Zieringer, Moritz	<i>Radiogenic isotopes</i>	IFM-GEOMAR
19. Ehlert, Claudia	<i>Stable Cd/Pb isotopes</i>	IFM-GEOMAR
20. Stumpf, Roland	<i>Radiogenic isotopes</i>	IFM-GEOMAR
21. Kraft, Steffanie	<i><math>\delta^{13}\text{C-DIC}</math></i>	IFM-GEOMAR
22. Heinze, Jutta	<i>Stable Cd/Pb isotopes</i>	IFM-GEOMAR
23. Kretschmer, Kerstin	<i>CTD/ADCP-Watch</i>	IFM-GEOMAR
24. Goldstein, Fabian	<i>Trace metal sampling</i>	Munich University
25. Truscheit, Torsten, Dr.	<i>Meteorologist</i>	DWD

IFM-GEOMAR	Leibniz-Institute for Marine Sciences at the University of Kiel
MCB	FB2 Marine Chemistry, University of Bremen
Jacobs University	Jacobs University, Bremen
ODU	Old Dominion University, Norfolk, U.S.A.
UAB	Universitat Autònoma de Barcelona, Bellaterra, Spain
IOW	Institute for Baltic Sea Research Warnemünde at the University of Rostock
Cologne University	Institute for Geology and Mineralogy at the University of Cologne
DWD	Deutscher Wetterdienst, Geschäftsfeld Seeschifffahrt
Munich University	Department for Geological and Environmental Sciences at the University of Munich

### **3 Research Program**

The core of the research program of Meteor cruise M81/1 (GEOTRACES cruise GA11; Fig. 3.1) was a detailed sampling of the water column for trace metals and their isotopes (TEIs) along a NNE-SSW section in the tropical Atlantic Ocean as part of the international GEOTRACES program (e.g. Henderson et al., 2007). The scientific goal of the cruise was an improved understanding of the sources, sinks, speciation, and biogeochemical cycling of TEIs, which on the one hand control biogeochemical processes as essential micronutrients, as is the case for Fe, Cd, or Zn. On the other hand, the distributions of TEIs are also influenced by biogeochemical and physical processes, which is the reason why many of these metals are used as proxy indicators of past seawater variations. The goal of the GEOTRACES program which has been officially launched in February 2010 and which is planned to last for more than 10 years, is to better understand the processes that govern the distribution of TEIs in the ocean and to establish the sensitivity of these distributions to changing environmental conditions. This will mainly be achieved by a coordinated international effort to carry out ocean sections across the main ocean basins, along which the dissolved and particulate distributions of the TEIs will be measured at high resolution in full depth water column profiles. Internationally established sampling protocols that guarantee the full comparability of data acquired during different cruises carried out by different nations are applied. Combining the results from the about 50 planned sections will ultimately result in a three-dimensional picture of the distribution of TEIs in the global ocean which will allow to better constrain sources, such as dust, rivers, exchange with the continental landmasses and shelves, or hydrothermal activity, as well as the biogeochemical cycling of the TEIs including their distribution within the global circulation system. The dissolved data are complemented by collection of TEI compositions of the particulate fraction.

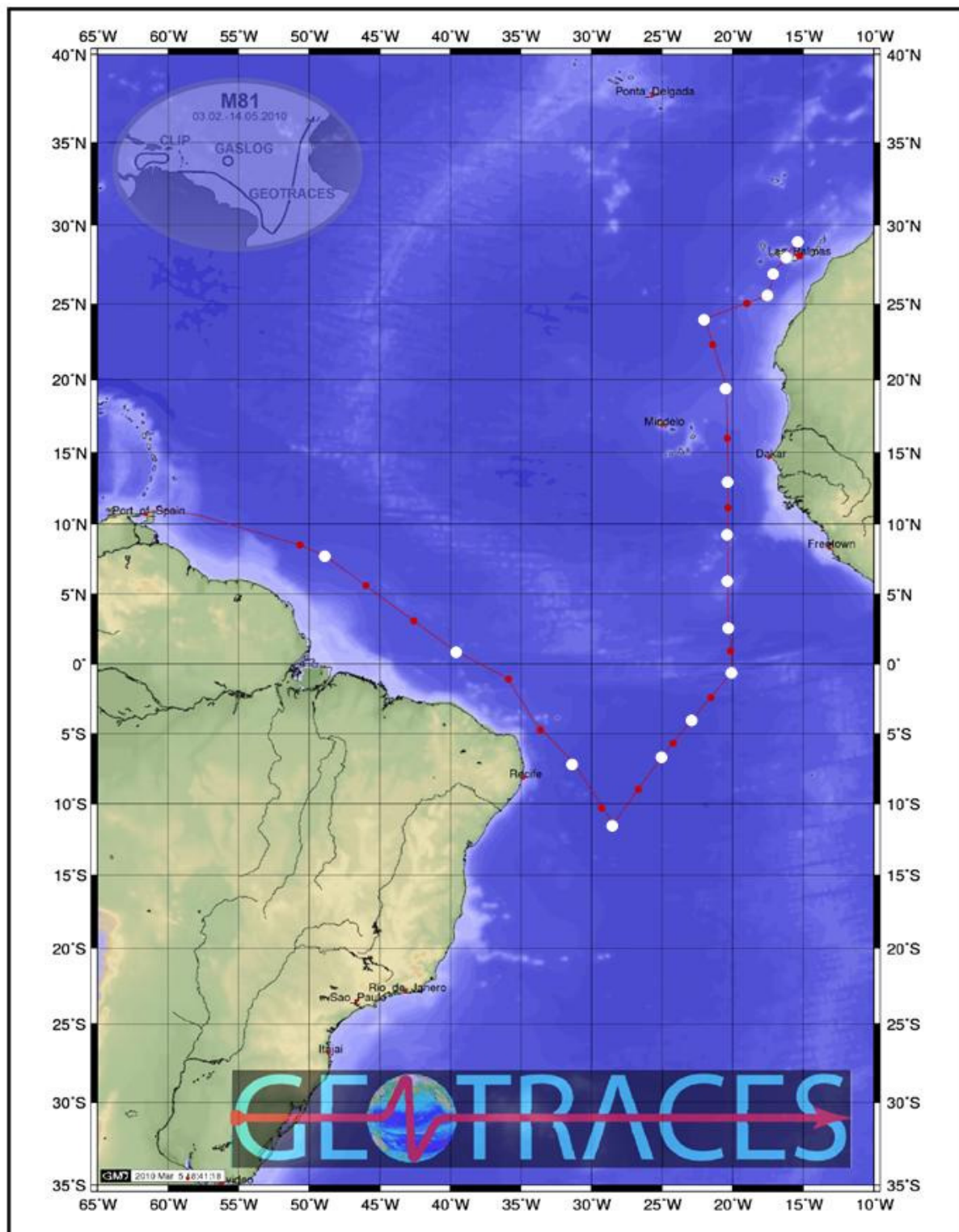
During M81/1 one of the scientific questions that were tackled specifically was the importance of the release of TEIs from external sources, such as from Saharan dust, as well as through exchange with volcanic islands and through the inputs of the dissolved and particulate load of the world's largest river, the Amazon, for which particularly surface waters were sampled along the entire cruise track. How, where, when and in which quantities are TEIs supplied to the surface waters and in which way are they recycled? These questions were tackled by a combined sampling for dissolved and particulate trace metals. The samples for dissolved trace metals were obtained by using for the first time a specific trace metal clean rosette and CTD system operated with a polyester coated cable from a mobile winch that was designed and constructed for the U.S. partners of the GEOTRACES program to collect surface and deep water samples under reliable and contamination-free, trace metal clean conditions. This system was thankfully made available by the U.S. GEOTRACES program. For sampling of the corresponding particulate concentrations and distributions, the well-established in situ pumping systems of the Marine Chemistry Department of the University of Bremen were used. In order to be able to handle, to filter, and to acidify the dissolved water samples and particulates under contamination free conditions on board, two mobile clean laboratory containers were installed on the ship and used during the cruise.

The chemical oceanographic working groups were interested to use certain TEIs to track ocean currents in the eastern and western North Atlantic basins as part of the global thermohaline circulation system. Additional interest was focussed on the detailed investigation of the near

surface and subsurface water mass exchange between the eastern and western tropical Atlantic along the equatorial system of narrow east and west directed currents and countercurrents. This was achieved by a detailed sampling of the cores of distinct subsurface, intermediate and deep water masses either determined by their hydrographic parameters or by the current speeds and directions located via the shipboard ADCP system.

Finally, the nutrient cycling in the oceans was subject to investigation by utilizing innovative stable isotope compositions, such as those of iron, cadmium, silicon or nitrogen, for which also the trace metal clean rosette system was used.

Essentially all of the trace metal parameters can and will only be measured in the home laboratories on land, which is the reason why the major focus of cruise M81/1 was contamination-free sampling of sea water and particulate samples. The only exceptions were preliminary determinations of the dissolved Al distributions carried out by the Marine Chemistry group, University of Bremen, which will be discussed and shown in section 5.2. It is therefore not possible to show significant amounts of preliminary results but we will rather use section 5 to describe the scientific goals and applications of the different trace metals and isotopes to be analysed.



**Fig. 3.1.** Track chart of R/V METEOR Cruise M81/1. The white dots are major sampling stations, the red dots only represent way points

#### **4 Narrative of the Cruise**

Cruise M81/1 started in Las Palmas, Canary Islands, Spain. A first group of scientists from IFM-GEOMAR, Kiel and from the Old Dominion University (ODU), Norfolk, U.S.A., arrived in Las Palmas on the 1<sup>st</sup> February 2010 and boarded Meteor in the morning of the 2<sup>nd</sup> February. All containers from Germany and the U.S.A. had already arrived and thus the installation of the trace metal clean CTD-rosette equipped with 24 x 12 litre GO-FLO water samplers and mobile winch with an 8 km conductive, polyester coated cable of the U.S. GEOTRACES program started immediately. These devices were essential for contamination-free sampling of seawater. Two clean room laboratory containers, one from the U.S. GEOTRACES program and one from the Marine Chemistry group of the University of Bremen were installed to guarantee clean laboratory handling of contamination-prone TEIs. The remaining scientists from IFM-GEOMAR, the Autonomous University of Barcelona (UAB), the Universities of Bremen and Cologne, the Jacobs University, Bremen, and the Institute for Baltic Sea Research, Warnemünde (IOW) arrived on board of Meteor in the afternoon of the 3<sup>rd</sup> February. Unpacking of the equipment from the containers was finished in the same evening, which allowed some visits to German research vessel “RV Poseidon”, which was scheduled to leave for an expedition to a big submarine landslide off northwest Africa on the next morning. After two scientists from ODU and IOW had finished their installation work and had left, “RV Meteor” started cruise M81/1 at 10:30 a.m., one hour after “RV Poseidon” had started.

The ship then steamed for twelve hours to the first planned full water depth station north of Gran Canaria, Canary Islands at 29°N, 15°20'W. On the way to this station Meteor stopped for 30 minutes to carry out a successful test station for the trace metal clean rosette and winch that were operated over a block fixed to the A-Frame of Meteor in order to maintain stable conditions for deployment and recovery. Having reached the first deep water station, the trace metal clean rosette was operated twice alternating with the conventional CTD-rosette equipped with 24 Niskin bottles for sampling of less contaminant prone metals and natural radionuclides. The in-situ pumps for sampling of the particulate fraction were also deployed alternating with the water sampling devices, which saved station time and allowed enough time for emptying the sampling bottles and for processing the water and particulate samples. In those cases where samples were taken for all core parameters of the GEOTRACES program and various additional parameters, the entire station time amounted to between 20 and 25 hours. The second main station followed at a location between Gran Canaria and Tenerife at a water depth of about 2000 m, the main purpose of which was to compare open ocean stations with a location influenced by weathering inputs from the volcanic islands on the dissolved TEI distribution. A further station still close to the Canary Islands was occupied south of Tenerife to compare the TEI distribution upstream and downstream of the Canary Islands. Between the three deep water stations, continuous surface water sampling was carried out in order to determine the influence of Saharan dust inputs. For this purpose a towed fish was applied, a device for pumping water under trace metal-clean conditions, which is towed by the vessel while it is steaming. Surface water sampling was continued between all subsequent stations of M81/1.

The following station at 25°32,7'N, 17°31,2'W completed the work in Spanish waters on the 8<sup>th</sup> February and the choice of the location was mainly aimed at evaluating the influence of TEIs supplied through exchange with the partly suboxic or anoxic shelf sediments close to the African

coast. At this station only water sampling was performed and no particulate samples were taken.

The location of the next full water depth open ocean station at 24°N, 22°W sampled on the 9<sup>th</sup>/10<sup>th</sup> February was chosen in order to occupy a crossover station with U.S. GEOTRACES cruise GA03, which crossed the North Atlantic in east-west direction on board “RV Knorr” in autumn 2010. This is in fulfillment of the guidelines of the GEOTRACES program and will provide an additional means to guarantee compatibility of the deep water TEI data acquired on different cruises and will also serve as a monitor for TEI variability in the surface waters at this location over time.

The cruise was then continued southward with six more stations outside national EEZs along 20°20'W until the deepest point of the cruise close to 7000 m water depth was reached above the Romanche Fracture Zone (0°37'S, 20°1.8'W) on 19<sup>th</sup> February. This location was sampled down to the maximum depth permitted by the instrumentation of the CTD systems at 5800 m water depth. The Romanche Fracture Zone is a gap in the Mid-Atlantic Ridge and represents the deepest exchange pathway between the eastern and western Atlantic basins, which is essentially the only location where Antarctic Bottom Water can flow across the Mid Atlantic Ridge and which is mainly responsible for the ventilation of the deep eastern Atlantic Basins. At this location the relationship between TEI signatures and mixing of major water masses was of particular interest. At the same time the cruise track crossed the pronounced east-west directed current bands in the upper 1000 m water depth in the tropical Atlantic between 10°N and 10°S, the cores of which, as identified by the ship's 38 kHz ADCP system, were sampled during the deep stations, wherever possible.

The next four deep water stations were sampled in the Brasil Basin outside the Brazilian EEZ until 26<sup>th</sup> February and served to complete the NNE-SSW tropical Atlantic section and to acquire data on the TEI signatures of the main water masses of the Atlantic Meridional Overturning Circulation (AMOC) west of the Mid Atlantic Ridge. Surface waters were continuously sampled to determine TEI signatures outside the Saharan dust plume south of the Intertropical Convergence Zone (ITCZ).

The cruise track then continued northwestward along the South American continent to monitor the influence of exchange processes with land on the distribution of TEIs. During this part of the cruise which mainly consisted of the transit towards Port of Spain two more deep water profiles were sampled on 1<sup>st</sup> March at 0°55'N, 39°37'W and on 4<sup>th</sup> March at 7°46'N, 48°53'W, the second of which was another crossover station with the Dutch GEOTRACES cruise GA02 on “RV Pelagia” in summer 2010 that followed the main pathway of the southward deep water flow of the AMOC in the western North Atlantic Ocean. Surface water sampling continued outside South American national EEZs with the towed fish with the goal to sample the plume of the Amazon River. The plume was met in the evening of 5<sup>th</sup> March and surface water samples were taken at salinities as low as 27 psu until sampling operations were finalized near the EEZ of Trinidad and Tobago at 22:00 on 5<sup>th</sup> March. During the remaining transit the treatment of the samples in the laboratories was finalized and the equipment was packed.

The ship reached Port of Spain, Trinidad and Tobago in the morning of 8<sup>th</sup> March and the cruise ended after 5396 nautical miles with the disembarking of the scientists in the late afternoon after the equipment had been packed into three containers and the two clean laboratory containers on the pier in the harbour of Port of Spain.

## **5 Preliminary and Expected Results**

### **5.1 Hydrographic Observations**

(M. Zieringer, M. Frank, IFM-GEOMAR)

The Atlantic Ocean extends from the Arctic to the Antarctic regions and its abyssal basin is divided into two sub-basins almost equal in size by the north-south trending Mid-Atlantic Ridge. The ridge reaches the 2000 m depth contour line nearly everywhere and consequently has a strong impact on deep water circulation. The thermohaline deep water circulation of the Atlantic Ocean (AMOC) is driven by subduction of cold and dense waters in the northern North Atlantic as well as at several locations in the Southern Ocean. North Atlantic Deep Water (NADW) is produced from saline surface waters originating from the Caribbean warm-pool, which are transported by the Gulf Stream and the North Atlantic Current to high latitudes, where they are cooled and thereby increase their density. After sinking, NADW flows to the South Atlantic as part of the deep Western Boundary Current and ultimately joins the Antarctic Circumpolar Current (ACC), from where it spreads into the Indian and Pacific Ocean. This export is compensated by the inflow of surface and intermediate waters from the Indian and the Pacific Ocean into the South Atlantic. These waters are transported by northward flowing currents of the subtropical gyre until they reach the equator, where parts of the intermediate waters are upwelled and finally enter the Caribbean, from where they flow into the Gulf Stream after passing the Florida Strait (Schmitz and McCartney, 1993).

The circulation of the upper layers of the ocean is wind-driven. The most dominant feature in the Atlantic Ocean is the subtropical gyre in the northern hemisphere that spans the entire ocean width and roughly extends from 10°N to 40°N. The clockwise circulation of the upper water masses includes the Gulf Stream, the North Atlantic Current, the Canary Current and the North Equatorial Current (NEC) as main current systems. Compared to the subtropical gyres the tropical circulation shows several zonal current and countercurrent bands of smaller meridional and vertical extent (Stramma and Schott, 1999), of which the major current systems are the North Equatorial Countercurrent (NECC), the South Equatorial Current (SEC), the Equatorial Undercurrent (EUC) and the South Equatorial Undercurrent (SEUC).

Water mass exchange in the tropical Atlantic Ocean including net northward meridional heat transport across the equator is accomplished by warm Tropical Surface Water (TSW), Atlantic Central Water, Antarctic Intermediate Water (AAIW) and upper Circumpolar Deep Water (uCDW) moving northward in the upper 1200 m compensated by cold North Atlantic Deep Water (NADW) moving southward between 1200 and 4000 m. At the bottom, the northward flow of Antarctic Bottom Water (AABW) also carries a small amount of cold water into the northern hemisphere (Stramma and Schott, 1999).

Sampling intervals and depths below 200 m at all stations were mostly chosen based on the locations of the cores of the major water masses, where possible, because one of the main goals of the GEOTRACES program is the investigation of the distribution of the TEIs in relation to major water mass circulation and mixing.

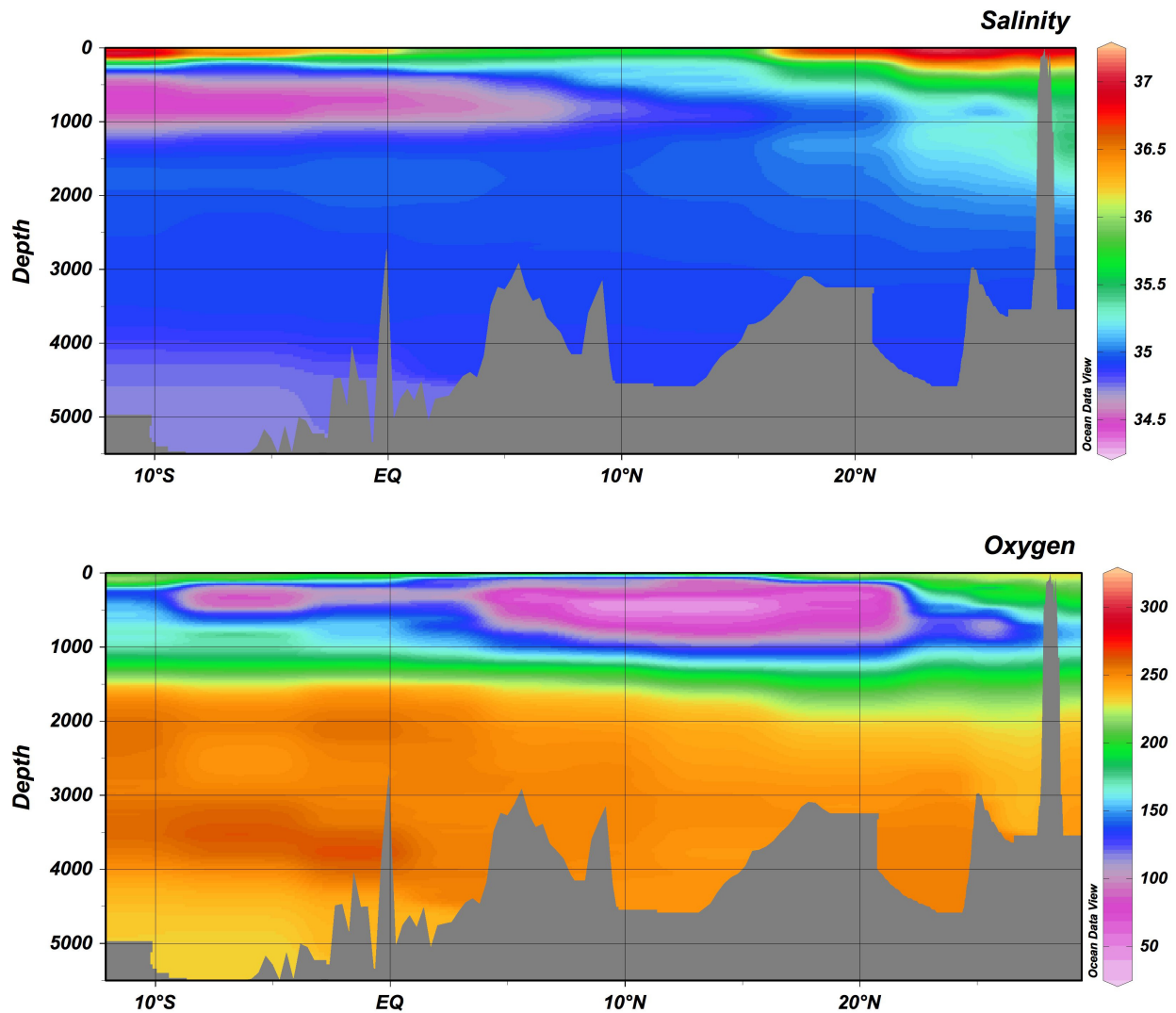
#### **Antarctic Bottom Water**

AABW is formed in the Southern Ocean and can be separated into two components. The densest type of AABW is formed in the Weddell Sea and is therefore called Weddell Sea Bottom Water

(WSBW). The upper part, known as lower Circumpolar Deep Water (ICDW), is formed in the Antarctic Circumpolar Current and consists of old deep water masses (Stramma and England, 1999). Tsuchiya et al. (1994) suggested that bottom water south of 41°S is WSBW and bottom water north of that latitude mainly consists of ICDW. In the eastern basin the direct northward flow of AABW is inhibited by the Walvis Ridge acting as a topographic barrier. In the western basin AABW flows into the Argentine Basin and transits through the Vema and Hunter channels into the Brazil Basin. AABW exits the Brazil Basin at its northern boundary via two routes: one part is diverted to the eastern Atlantic basin through the Romanche Fracture Zone at the equator, while the remainder crosses the equator into the Guiana Basin and further into the western North Atlantic basin.

During M81/1, AABW was encountered and sampled at a total of eight stations (in the following the station numbers of the standard rosettes are used as a reference for the corresponding locations, which can be identified from the station list in section 7). Three sites are located in the western basin, four in the eastern basin, and one station was located above the Romanche Fracture Zone. According to Stramma and England (1999) the density represented by the isopycnal at  $\sigma_4 = 45.90$  marks the upper boundary of AABW in the western tropical Atlantic Ocean. For stations 179-1, 188-1 and 197-1 in the western Atlantic basin this boundary was identified at a depth near 3800 m and a potential temperature near 1.74°C. Below this boundary, salinity, temperature and oxygen concentrations decrease steadily until the bottom (see Fig. 5.1 for a section of salinity and oxygen concentrations from 29°N to 11°30'S obtained during M81/1). Station 167-1, which is located above the Romanche Fracture Zone, showed hydrographic characteristics for AABW similar to the above stations in the western basin.

Due to the topographic constraints mentioned above, the hydrographic characteristics of AABW in the eastern basin of the Atlantic Ocean are different from the western basin given that it is only possible for a relatively small amount of the densest type of AABW to flow into the eastern basin via the Romanche Fracture Zone, whereby it also mixes with overlying NADW. Thus Tsuchiya et al. (1992) used the isotherm  $\theta = 2^\circ \text{C}$  to define the upper boundary for AABW in the eastern basin. At Station 161-1, the southernmost station in the eastern basin, the boundary is located at 3925 m depth and the isotherm  $\theta = 2^\circ \text{C}$  deepens to 4055 m at station 128-1, the northernmost station where AABW was encountered and which is located in the Canary Basin. Bottom water characteristics of station 161-1 at 4425 m are  $\theta = 1.87^\circ \text{C}$ ,  $S = 34.88$ ,  $\sigma_4 = 45.89$ ,  $\text{O}_2 = 251.81 \mu\text{mol l}^{-1}$ . According to Tsuchiya et al. (1992) AABW found at station 140-1, located in the Cape Verde Basin, mainly originates from the Guiana Basin and reaches this position through the Vema Fracture Zone of the Mid-Atlantic Ridge. There the bottom water characteristics are  $\theta = 1.88^\circ \text{C}$ ,  $S = 34.88$ ,  $\sigma_4 = 45.89$ ,  $\text{O}_2 = 246.17 \mu\text{mol l}^{-1}$ . A part of these densest waters entering the eastern basin turns north and flows into the Canary Basin. Due to vertical mixing with the overlying NADW its characteristics are altered to  $\theta = 1.97^\circ \text{C}$ ,  $S = 34.89$ ,  $\sigma_4 = 45.88$ ,  $\text{O}_2 = 252.90 \mu\text{mol l}^{-1}$  by the time it reached station 128-1 at 24°N. In summary, AABW is colder, fresher, and poorer in oxygen than the overlying NADW, but vertical gradients are more strongly developed in the western basin because AABW is less diluted with admixed NADW.



**Fig. 5.1.** Distribution of salinity (upper diagram) and oxygen concentration (lower diagram) during cruise M81/1 between 29°N and 11°30'S. The northward flowing tongue of fresher AAIW with its core around 750 m depth is clearly visible on the salinity plot. Its influence can be clearly traced until 25° N.

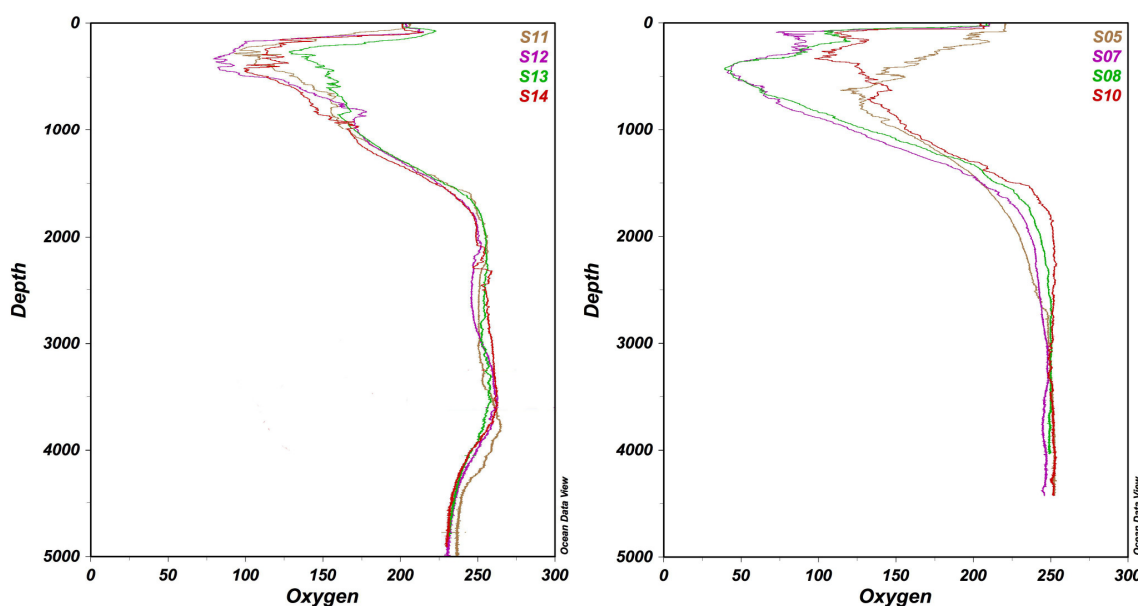
### North Atlantic Deep Water

NADW flows southward as a tongue of saline, oxygen-rich and nutrient-poor water. NADW covers a wide density range because it is composed of deep waters originating from various regions with different boundary conditions in the northern North Atlantic (Tsuchiya et al., 1994). Wüst (1935) divided NADW into three components on the basis of distinct maxima of salinity and oxygen. The Upper North Atlantic Deep Water (UNADW) is characterized by a salinity maximum of Mediterranean origin, while the Middle (MNADW) and Lower North Atlantic Deep Water (LNADW) are defined by two oxygen maxima, originating from the Labrador Sea and the Greenland-Norwegian Sea, respectively (Arhan et al., 1998).

Stramma and England (1999) use the  $\sigma_1 = 32.15$  isopycnal as the upper boundary for NADW in the tropical Atlantic Ocean, which results in NADW occupying the water depths between 1200 m and 3800 m in the area covered by cruise M81/1. It is noted that at this density surface, temperature and salinity in the Canary Basin are significantly higher than further south and in the western Atlantic basin. The salinity maximum defining the core of the UNADW is present at a depth of 1600 m at the last deep station 204-1 of the cruise at 7°46' N in the western basin and

deepens to 1800 m at station 188-1, located at 11°30'S in the Brazil Basin. At the southernmost stations of the eastern basin (stations 148-1, 155-1 and 161-1) and at the Romanche Fracture Zone station (167-1) the high salinity core of the Upper North Atlantic Deep Water occurred near 1700 m. Characteristics of the core of UNADW are  $\theta = 3.27^{\circ}\text{C}$ ,  $S = 34.97$ ,  $\sigma_1 = 32.44$ ,  $\text{O}_2 = 258.45 \mu\text{mol l}^{-1}$ . North of 10°N a pronounced increase of salinity and potential temperature is observed at this depth range. While the core of UNADW in the Cape Verde Basin is characterized by  $\theta = 3.57^{\circ}\text{C}$ ,  $S = 35.00$ ,  $\sigma_1 = 32.44$ ,  $\text{O}_2 = 229.25 \mu\text{mol l}^{-1}$ , these properties change to  $\theta = 4.44^{\circ}\text{C}$ ,  $S = 35.16$ ,  $\sigma_1 = 32.45$ ,  $\text{O}_2 = 231.19 \mu\text{mol l}^{-1}$  near the Canary Islands (Fig 5.2). The main cause for this increase in salinity and temperature is the admixture of southward flowing Mediterranean Outflow Water (MOW).

The unambiguous identification of middle and the lower NADW by the two oxygen maxima described above was only possible at the stations in the western Atlantic basin. There, the upper oxygen maximum was found between 2100 and 2400 m water depth, while the lower oxygen maximum occurred between 3600 and 3800 m (Figs. 5.1, 5.2). Both maxima show values near  $\text{O}_2$  concentrations of  $260 \mu\text{mol l}^{-1}$ . Characteristics for the core of MNADW are  $\theta = 2.77^{\circ}\text{C}$ ,  $S = 34.92$ ,  $\sigma_1 = 32.47$ ,  $\text{O}_2 = 257.09 \mu\text{mol l}^{-1}$ . The core of LNADW is characterized by  $\theta = 2.12^{\circ}\text{C}$ ,  $S = 34.91$ ,  $\sigma_1 = 32.53$ ,  $\text{O}_2 = 263.30 \mu\text{mol l}^{-1}$ . In the eastern north Atlantic basin efficient vertical mixing above the equatorial fracture zones causes the signatures of MNADW and LNADW to become indistinguishable by their oxygen concentrations (Fig. 5.2).



**Fig. 5.2.** Oxygen concentrations in  $\mu\text{mol l}^{-1}$  against depth for western Atlantic basin (left) and eastern Atlantic basin stations (right) during M81/1.

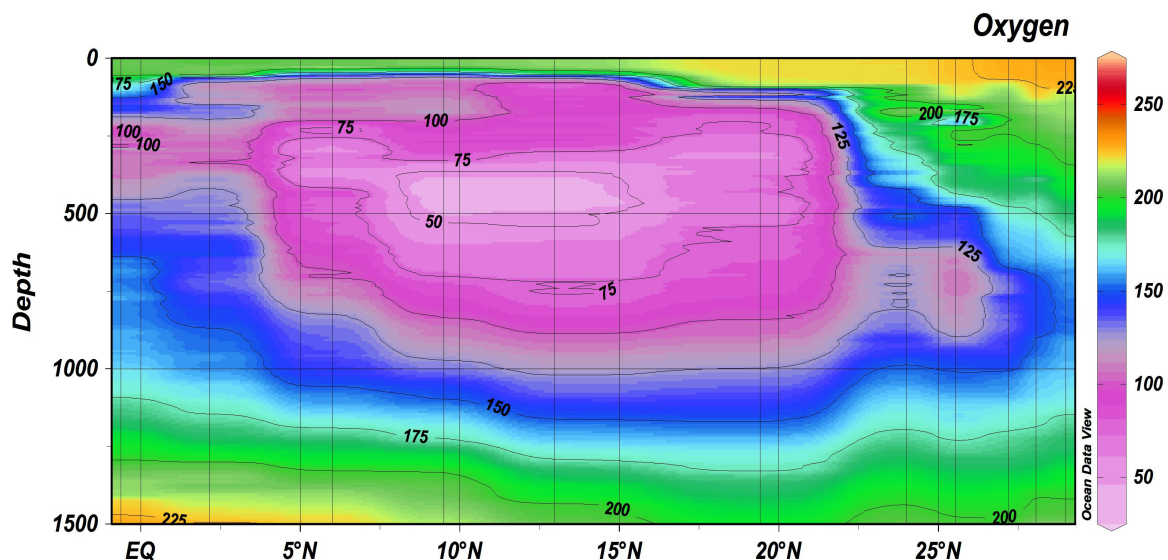
### Antarctic Intermediate Water

Above the body of UNADW, AAIW flows northward in the entire Atlantic basin. AAIW originates from subduction processes in the frontal system of the Antarctic Circumpolar Current and is characterized by high oxygen concentrations and low salinities that can be tracked until about 20°N in the North Atlantic at all stations of M81/1 (Fig. 5.1). It occupies the depth range between 500 and 1200 m with the core of its salinity minimum located near 700 m water depth. Its signature is most pronounced in the western basin reaching salinity values below 34.55. The

accompanying high oxygen concentrations (e.g. Arhan et al., 1998, Stramma and England, 1999) were only encountered in the western Atlantic basin during M81/1 but were not found in the eastern basin due to the processes consuming oxygen and producing the pronounced Oxygen Minimum Zone (OMZ) discussed below. AAIW is clearly identifiable by its low salinity core ( $S < 34.75$ ), which is fully developed until  $7^{\circ}\text{N}$ . From there salinity increases northwards to the northern end of the section of M81/1. This is due to admixing of more saline waters flowing southwards such as MOW but AAIW can still be identified near  $20^{\circ}\text{N}$  (station 136-1), where, however the characteristics of its core have been altered to  $\theta = 7.90^{\circ}\text{C}$ ,  $S = 35.04$ ,  $\sigma_1 = 27.31$ ,  $\text{O}_2 = 85.22 \mu\text{mol l}^{-1}$ .

### The Oxygen Minimum Zone off NW Africa

The section of M81/1 along  $20^{\circ}\text{W}$  crossed the OMZ extending between  $20^{\circ}\text{N}$  and  $5^{\circ}\text{N}$  reaching oxygen concentrations of less than  $50 \mu\text{mol l}^{-1}$  (Fig. 5.3). A pronounced oxycline in water depths of less than 100 m depth separates the oxygen rich surface waters from the oxygen poor Central Water. The OMZ is expressed until a depth of 900 m and thus comprises the Central Water and parts of the AAIW. The lowest oxygen values of less than  $50 \mu\text{mol l}^{-1}$  were located between  $8^{\circ}\text{N}$  and  $15^{\circ}\text{N}$  near 400 m water depth, which is a consequence of high biological productivity in the surface waters above but also of advection of oxygen depleted waters from the West African margin upwelling areas, which are characterized by extremely high biological productivity. The oxygen depletion is counteracted by ventilation from other areas, the interplay of which determines the distribution and extent of the OMZ. The OMZ southeast and east of the Cap Verde islands results from exactly this interplay (Karstensen et al., 2008). A second less pronounced OMZ is found south of the equator (Fig. 5.1.) which most likely represents the southward continuation of the northern part, which is interrupted by the oxygen transport along the equatorial current bands (see below).

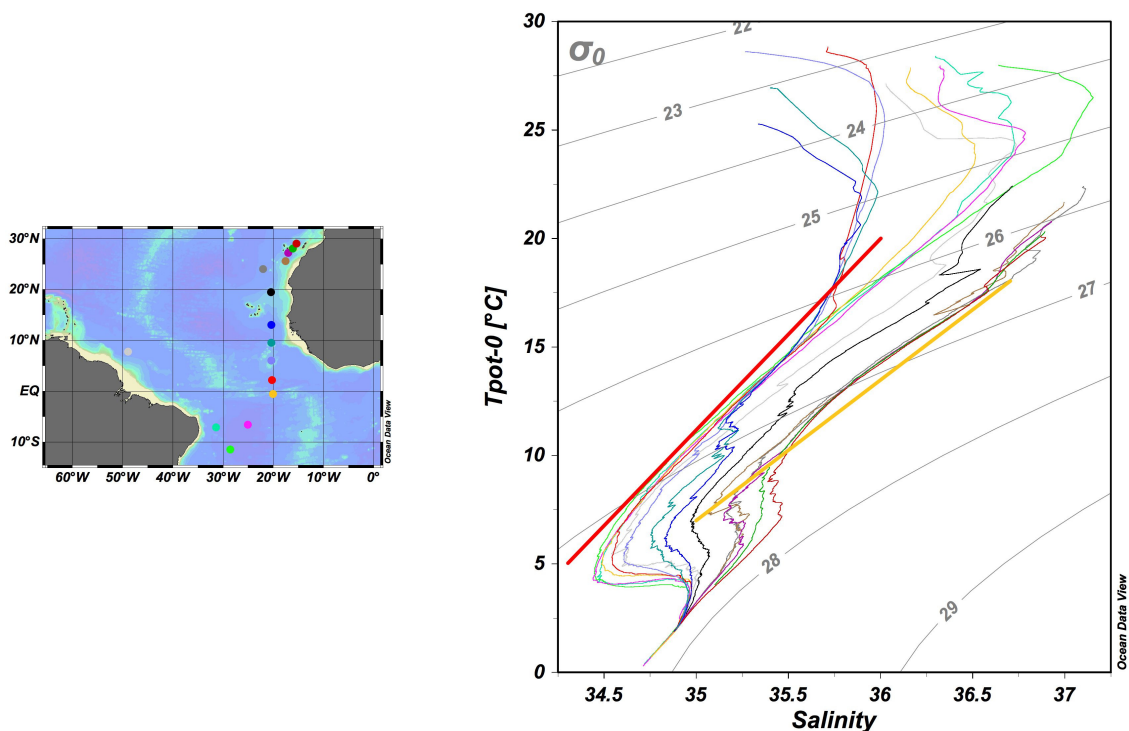


**Fig. 5.3.** Oxygen distribution in  $\mu\text{mol l}^{-1}$  in the upper 1500 m between  $29^{\circ}\text{N}$  and  $1^{\circ}\text{S}$ . Lowest values ( $< 50 \mu\text{mol l}^{-1}$ ) occurred between 400 to 500 m depth between  $9^{\circ}\text{N}$  and  $15^{\circ}\text{N}$ .

### North Atlantic Central Water and South Atlantic Central Water

The upper ocean of the tropical and subtropical Atlantic is occupied by North Atlantic Central Water (NACW) and South Atlantic Central Water (SACW). The boundary between SACW and NACW is located at about 15°N. SACW is formed near the subtropical front in the southwestern South Atlantic, but according to *Tomczak and Godfrey* (1994) a large fraction of SACW found in the tropical regions originates from Indian Central Water brought into the Atlantic by the Agulhas Current.

Both SACW and NACW are characterized by a nearly linear T-S relationship. The T-S pattern of SACW is described by a near straight line between T-S of 5°C, 34.3 and 20°C, 36.0, while the characteristic T-S curve of NACW is located between T-S of 7°C, 35.0 and 18°C, 36.7. Compared to SACW, NACW is saltier, warmer and contains less dissolved oxygen (Stramma and Schott, 1999) (Fig. 5.4). The T-S relationships of the M81/1 stations close to or south of the equator are closest to the SACW endmember given by Tomczak and Godfrey (1994), but show higher salinities for a given temperature, in particular at depths shallower than 200 m. Stations 140-1, 148-1 and 155-1 located on the 20°W meridian show an increase in salinity from south to north at depths between 250 and 500 m. Above 250 m water depth temperature and salinity were indistinguishable at these stations. Station 136-1, near 20°N northeast of the Cap Verde Islands, shows T-S characteristics that are intermediate between the SACW and NACW endmembers, suggesting that mixing between the two water masses occurs near this latitude. Given that station 204-1 near 8°N in the western basin shows similar T-S properties, it may be suggested that the water mass boundary between SACW and NACW was shifted to the south in the western Atlantic. In contrast, all stations in the Canary Basin are close to the signature of NACW in the corresponding depth window. Applying the isopycnals  $\sigma_\theta = 25.8 \text{ kg/m}^3$  as upper boundary and  $\sigma_\theta = 27.1 \text{ kg/m}^3$  as lower boundary, the Atlantic Central Waters occupy the depth range between 100 and 500 m in the western basin and between 70 and 500 m in the eastern basin.



**Fig. 5.4.** Potential temperature versus salinity for all deep stations sampled during M81/1. All Central Waters plot between the two endmembers given for NACW (solid yellow line) and SACW (solid red line).

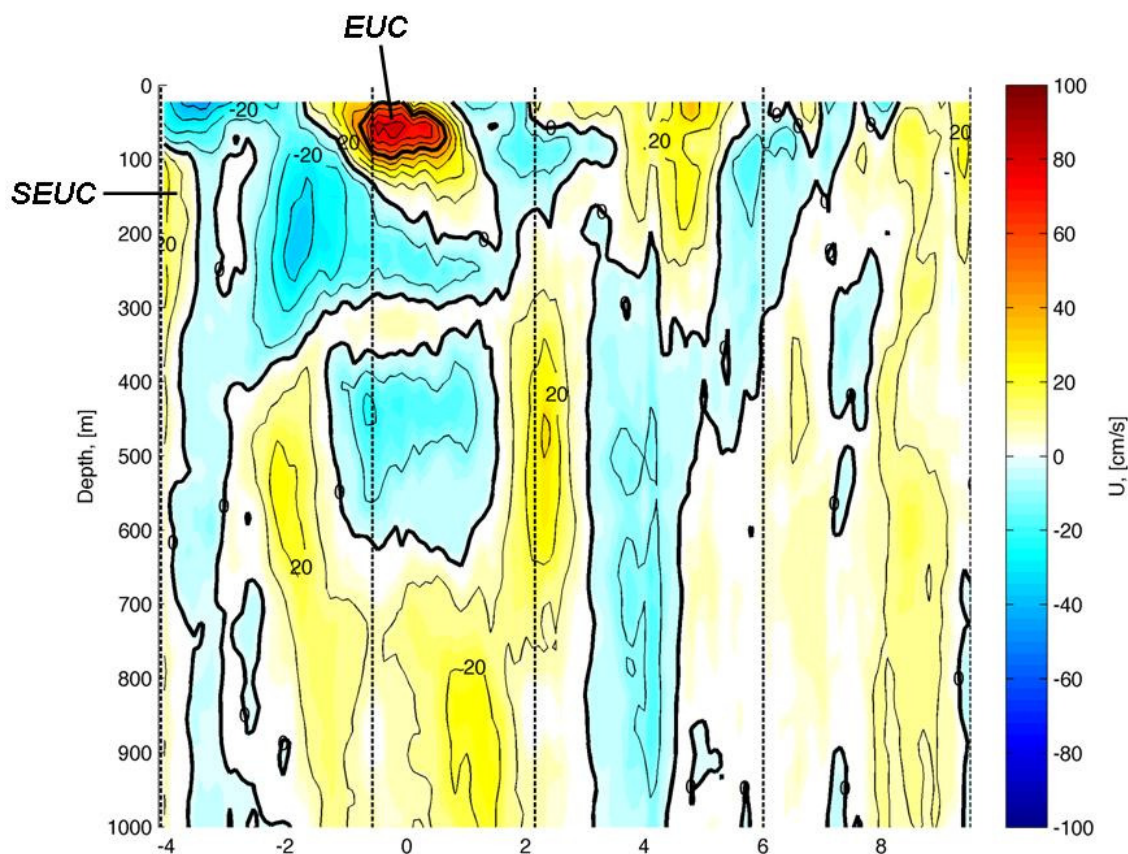
## **Tropical Surface Water**

The surface mixed layer in the research area of M81/1 is usually termed Tropical Surface Water (TSW). Highest sea surface salinities are found in the Canary Basin (37.10 at station 128-1), while the lowest values occur around 5° N (35.27 at station 155-1). This is caused by the position of the Inter-Tropical Convergence Zone (ITCZ) and its connected high precipitation rates. Highest sea surface temperatures occur around the equator, the lowest ones were encountered between the Canary Islands. In the Canary Basin the surface layer is well mixed and salinity and temperature values are homogeneous throughout the complete surface layer. Stations close to the Sierra Leone Rise show a shallow salinity maximum at depths around 40 m. According to Stramma et al. (2005) this water can be termed Salinity Maximum Water and originated in the central subtropical gyre. This salinity maximum is accompanied by a rapid drop in temperature at the sharp thermocline underneath the TSW from more than 25° C to 15° C within about 70 m. The surface layer in the western basin also shows a salinity maximum near 70 m, which, similar to the thermocline, is not as pronounced as in the eastern basin.

### **5.1.1 Current Bands of the Upper 1000 m of the Equatorial Atlantic**

(M. Vogt, M. Frank, IFM-GEOMAR)

The equatorial tropical and subtropical Atlantic is an area of vigorous east-west exchange of surface and subsurface/thermocline waters, which are focused into narrow bands of high current velocity. These current bands and their branches are largely responsible for water mass exchange between the western and eastern tropical Atlantic and largely control the ventilation and nutrient supply into the OMZ of the eastern tropical Atlantic (Brandt et al., 2010). It is clear that these bands are also responsible for trace metal and micronutrient exchange between the eastern and western basins. Some of the TEIs (e.g. radiogenic isotopes) may either allow tracing of the distinct sources of these narrow currents or may indicate export from the OMZ, such as manganese (Mn). Thus the velocity, depth and direction of these currents was continuously recorded during cruise M81/1 using the ship's own ADCP system. Based on a previous study of these current bands, in which the mean position of these currents was compiled (Brandt et al., 2010), the positions of a total of 5 stations covering the upper 1000 m between 10°N and 4°S were chosen, which are shown together with the actual ADCP data obtained during cruise M81/1 itself (Fig. 5.5). The figure shows that the main features of the current bands were covered by the CTD stations, which will allow a detailed investigation of the TEI contents and origins in the distinct current bands.



**Fig. 5.5.** ADCP data covering the east-west current bands of the uppermost 1000 m between 10°N and 4°S. Positive values mark the speed of eastward flowing currents, negative values mark westward flowing currents. The Equatorial Undercurrent (EUC) represents the strongest current reaching speeds of up to 1 m/s in the uppermost 100 m water depth at the equator. The position of the South Equatorial Undercurrent is also marked. The dashed lines mark the positions of the sampled stations.

## 5.2 Dissolved Trace Metals and Water Sampling with the Trace Metal Clean Rosette and Towed Fish

(S. Pöhle, A. Koschinsky, Jacobs University/IOW; W. Balzer, X. Tang, University of Bremen)

Trace metals play an important role for the growth and distribution of marine organisms in the world ocean. Within the GEOTRACES program the distribution of the following trace elements in surface waters are of special interest in the frame of ongoing research projects at Leibniz-Institute for Baltic Sea Research, IOW, the “Marine Chemistry” working group at the University of Bremen, and the Jacobs University Bremen: cadmium (Cd), copper (Cu), zinc (Zn), nickel (Ni), iron (Fe), manganese (Mn), cobalt (Co), lead (Pb), mercury (Hg), uranium (U), molybdenum (Mo), titanium (Ti), rubidium (Rb), strontium (Sr), and barium (Ba), for which samples were taken under trace metal clean conditions during M81/1 in order to gain more detailed insights into their biogeochemical cycling and their sources.

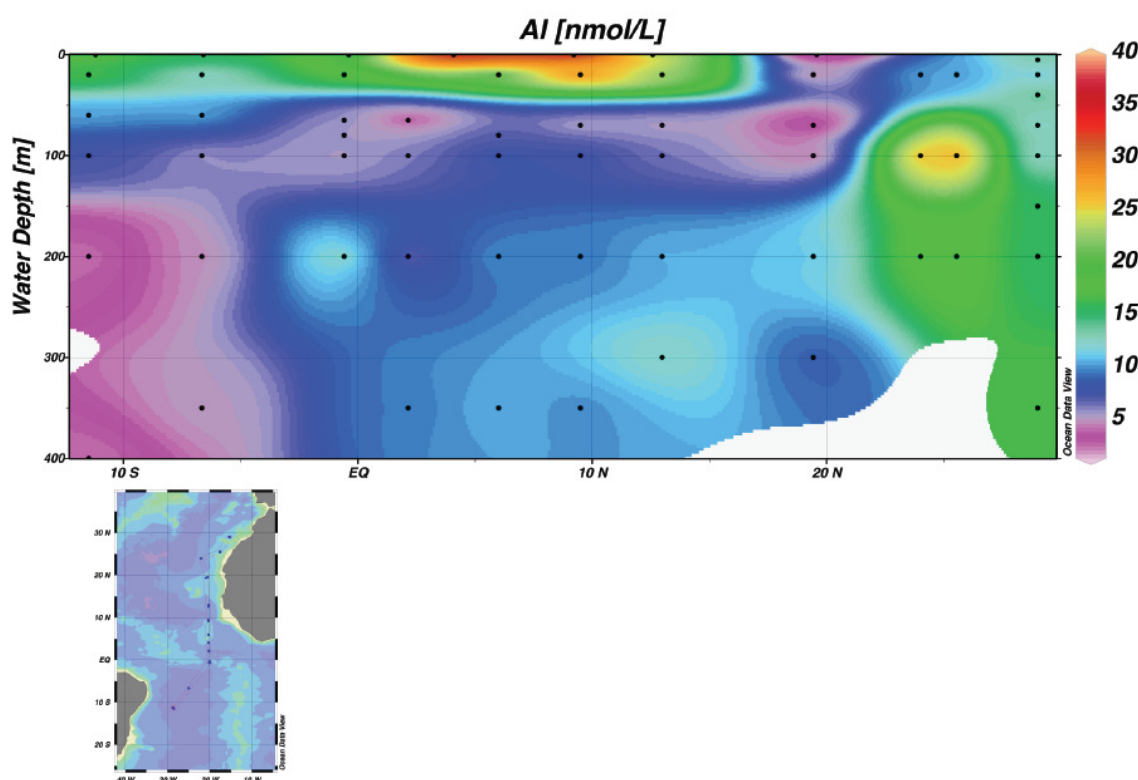
Riverine input as well as wet and dry atmospheric deposition represent the main source of TEI's to the oceanic water masses. Entering through surface waters the transport of TEI's is closely linked to seasonal variations of the biological production and the composition of suspended particulate matter (SPM) (Pohl et al., 2004). Recent studies show that Zn, Ni, Cu, Co and Cd display a behavior similar to macronutrients, such as nitrate and phosphate indicating their involvement in biogeochemical cycles. Moreover, Co, Ni, Zn and Ni are essential for the growth of marine phytoplankton populations (Morel and Price, 2003), while Mn and in particular Ba serve as a tracer of fluvial input to the ocean. For many key trace elements, eg. Fe, aluminium (Al), Mn or titanium (Ti), aerosol dust is the major source and represents an important transport pathway to oceanic surface waters, which will also be covered by investigations of the particulate material at the department of Marine Chemistry in Bremen. Furthermore, the concentration of Hg provides important information about the distribution in the different hydrographic and meteorological regimes, for which the influence of the Amazon was also of special interest.

During the Atlantic transect of Meteor M81/1 input to surface waters from Saharan dust as the main atmospheric source, as well as riverine input from the Amazon were investigated. In total, 58 samples (0.7-1.5 litre per sample) have been collected for the analysis of Cd, Cu, Zn, Fe, Mn, Co, Pb and Hg from the tropical and subtropical Atlantic. Further on, 18 samples were taken following the plume of the Amazon. In order to avoid contamination by the ship the towed fish was used for sampling the surface waters and was deployed at a distance of 3-4 m besides the ship to continuously pump surface waters from a depth of 2-3 m via a membrane pump directly into one of the clean laboratory containers, where the samples were exclusively handled in a laminar flow hood. Furthermore, samples for the IOW have been collected under trace metal clean conditions from the trace metal clean rosette at 7 deep stations resulting in a total 176 samples for trace metal analysis. All these samples were not filtered and after acidification using one ml of suprapure nitric acid per liter of seawater, they were wrapped in polyethylene bags and stored in boxes at room temperature until analysis in the home laboratory at IOW.

The same metals, many of which are key metals of the GEOTRACES program, complemented by a number of others are also subject of interest in terms of their vertical depth distribution. For this purpose 2 litre samples were also taken under trace metal, clean conditions with the trace metal clean rosette system at a resolution between 14 and 17 depths per cast. After the rosette was back on deck the closed GO-FLO bottles were transferred from the rosette into the clean laboratory container, where the waters were directly filtered through Sartobran® filter capsules (0.45 and 0.22 µm) in order to avoid any contamination. The samples were subsequently directly acidified in the clean laboratory with suprapure acids to avoid adsorption of the metals to the walls of the bottles. The focus of investigation will be on particle scavenging and desorption processes together with large scale water mass circulation. In addition, detailed studies on the speciation of some of the metals will be carried out. For redox-sensitive metals their vertical distribution is expected to be influenced by the oxygen levels.

As an example for the results to be expected, the preliminary distribution of Al concentrations (these samples were filtered using the Sartobran® filter capsules) along the main north south transect of the cruise (a total of 104 samples) determined onboard by X. Tang, University of Bremen, are shown (Abb. 5.6). A pronounced surface water maximum between 15°N and the equator coincides with the area of the largest dust fluxes, which clearly shows that

Al is readily released from the dust particles. Below 20 m the concentrations rapidly decrease, which is typical for a particle reactive element that is not biologically utilized. After introduction into surface waters Al subsequently has a long enough oceanic residence time to follow quasi-conservative mixing of subsurface waters. This is documented by the pronounced subsurface maximum below 100 m north of 20°N which is not accompanied by high concentrations at the surface. This is most likely a consequence of the presence of former surface waters that have been loaded with dissolved Al somewhere else and then were subducted as a consequence of winter convection to reach the depths of the observed Al maximum, which is consistent with previous observations (Measures et al., 2008). In addition, weathering contributions from the Canaries may have played a role for this pattern.



**Fig. 5.6.** Preliminary distribution of the dissolved aluminium concentration [nmol/L] within the upper 350 m water depth along the cruise track between 30°N and 11°30'S (the inset shows the stations included in the plot).

Measurements by X. Tang, W. Balzer, University of Bremen.

A further example for the planned work is the distribution of the redox speciation of chromium (Cr) in the water column of the tropical Atlantic Ocean with respect to the extent and strength of the tropical Atlantic OMZ. Trivalent Cr is characterized by its strong tendency to sorb on particles and its low solubility. It is therefore less bioavailable compared to Cr(VI). Moreover, Cr(III) is known to serve as a micronutrient in contrast to Cr(VI), which acts as a microtoxin crossing cell membranes and working as an oxidizing agent (Gianguzza et al., 2000). Given that the toxicity, bioavailability, and mobility of Cr depend on its oxidation state knowledge about the redox behavior is of high importance in order to gain more insights in the interaction with biota and resulting environmental effects. Besides weathering of rocks, dry and wet precipitation, as well as riverine run-off represent the main contribution of Cr to seawater

while hydrothermalism serves as a natural source for Cr(III). Samples from three detailed vertical profiles (149-1, 180-1, 198-1) for this study representative of the main chemical and environmental differences have been taken (in this case without filtration). Applying a cathodic adsorptive stripping voltammetry (Sander and Koschinsky, 2000) total Cr concentration, as well as Cr(VI) and reactive Cr will be determined. Using these data, the concentrations of reactive Cr(III), unreactive Cr(III), as well as total Cr(III) will be calculated.

The third example for the planned studies at Jacobs University Bremen intends to gain insights into the factors controlling the distribution of heavy particle-reactive elements, e.g. zirconium (Zr), hafnium (Hf), niobium (Nb), tantalum (Ta) and Ti in the Atlantic water column. The concentrations of Zr, Hf, Nb and Ta in seawater are very low (partly below 1 pmol/litre). As these elements are characterized as particle-reactive a decrease in concentration with depth is expected. However, the opposite behaviour has been observed in some areas in the case of Zr and Hf (Firdaus et al., 2008) or even a relationship with water mass distribution has been observed for dissolved Zr/Hf (Firdaus et al., 2011). This latter study even suggests a distinct fractionation between Zr and Hf, which is unexpected due the fact that they are chemical twin elements and for which the reason is enigmatic. In the case of Nb and Ta only few data are published concerning their distribution in the water column (Sohrin et al., 1998; Firdaus et al., 2011). During M81/1, 17 stations have been sampled under trace metal clean conditions providing 185 samples for this particular study. Only very few data on their dissolved distribution in the water column have so far been published and this study intends to shed some light on their cycling. A total of 342 samples for the studies to be carried out at Jacobs University Bremen and by the "Marine Chemistry" working group at the University of Bremen were collected.

### 5.3 Particulate Trace Metals and Sampling with In-Situ Pumps

(W. Balzer, X. Tang, University of Bremen)

During the cruise the "Marine Chemistry" working group at the University of Bremen collected samples primarily to evaluate the composition and the distribution of the Suspended Particulate Matter (SPM). The results of the concentrations of the dissolved phase samples taken at the same locations as the SPM samples (as described in the previous section) will serve to study solution-particle interaction processes. Since mineral dust and aerosol deposition are the most important sources of trace elements (TE) in the open subtropical Atlantic and given that the cruise track of M81/1 followed an (approximated) gradient from high to low dust inputs, the focus was on the fate of dust in the water column of mesotrophic and oligotrophic regions. The evaluations at the University of Bremen will serve the following goals: (i) contribute "key parameters" from the subtropical Atlantic to the GEOTRACES data set, (ii) evaluate the distribution of particulate and dissolved TE in the surface ocean with respect to estimated dust deposition rates, and (iii) evaluate the distribution of dissolved and particulate TE in the sub-surface water column to extend our knowledge of particle-solution interaction of the TE with differing chemical properties and to better understand the joint vertical transport of aggregates between the dust derived particulate TE (e.g. Fe, Al, Mn) and organic materials.

By using in-situ pumps a total of 117 samples of suspended particulate metals were obtained from the stations 108-1/111-1, 120-1/122-1, 131-1/134-1, 139-1, 143-1/146-1, 151-1,

157-1/159-1, 164-1, 168-1/172-1, 182-1/184-1, 191-1/193-1, and 208-1. Except for 4 stations with 5-6 depths only, 12 depths per location were sampled in most cases. The focus was on the upper 1500 m but a few samples from greater depths were also collected. In the home clean laboratory of the Univ. Bremen the filters will be subjected to a well-established total dissolution procedure in a microwave unit. The TE concentrations will be determined with high resolution ICP-MS to obtain results in moles per volume to evaluate the interaction with the dissolved phase and in moles per mass to derive changes in the particle composition. For the latter purpose the used (small weight) polycarbonate filters (142 mm Nuclepore) were weighed before and after use.

By using information on the average dust composition from various sources, the first evaluation step will be the quantification of the element-dependent non-crustal fraction of the SPM. For the more refractory elements (e.g. Al, Fe, Ti) this fraction resulting from scavenging, dissolution and aggregation/disaggregation processes is a minor component but nevertheless it may hold clues about the link to the biogeochemical cycles when evaluated in relation to depth and productivity regime. Eventually, the data on the distribution of TE in the SPM will be used to refine an existing 3-D-model of aggregation/disaggregation and joint sedimentation of mineral and organic particles in the subtropical Atlantic (1-D-model: Barkmann et al. 2010).

#### **5.4 Radiogenic Isotopes (Nd/Hf) and Large Volume Water sampling with the Conventional Rosette and the Towed Fish**

(M. Zieringer, M. Frank, IFM-GEOMAR)

Radiogenic Nd and Hf isotopes are a set of tracers that provide information about water mass mixing and erosional input into seawater. The isotopic signatures in continental rocks vary as a function of type and age of the rocks, which release these signatures during weathering and transfer them to seawater via riverine and dust inputs, but also via exchange with shelf sediments (e.g. Frank 2002). The residence times of both metals are on the order of the global mixing time of the ocean which means that water masses in the Atlantic basin are labeled with distinct isotopic signatures that only change by mixing with other water masses in the absence of external inputs and at a distance from the coast (e.g. Rickli et al., 2009).

The cruise track of M81/1 provided the opportunity for a detailed investigation of the influence of water mass mixing on the distributions of Nd and Hf isotopes and concentrations as part of the AMOC and thus their applicability as water mass tracers in the present and past ocean. Possible external sources of both isotopes covered through sampling along the cruise track of M81/1 were input through leaching and exchange with volcanic shelf sediments near and between the Canary Islands, partial dissolution of airborne dust particles from the Sahara desert, interaction with shelf sediments along the continental margin of South America, as well as the effects of the Amazon inflow. In addition, the influence of the east-west directed equatorial current bands of the uppermost 1000 m in the equatorial Atlantic on the distribution of Nd isotopes and their potential to provide information on the distinct sources of these waters was subject of detailed sampling. A further focus of the sampling activity was the deep water mass exchange pathways between the western and the eastern basin through the equatorial fracture zones of the Mid-Atlantic Ridge.

Large volume water samples were taken from the 10-L Niskin bottles attached to the standard rosette and CTD. 20 litre samples from 8-10 depths were taken for Nd isotopes from all deep water sampling stations (a total of 140 samples), which allowed sampling of all major water masses in the tropical and subtropical Atlantic along the track of M81/1. A total of 26 surface water samples were taken for Nd isotope investigation of external inputs.

In addition, distinct 60 litre samples for Hf isotope analyses (larger sample volumes were required due to the very low concentration of Hf in Atlantic seawater between 0.1 and 1 pmol/kg) were taken from station 113-1 to specifically investigate the influence of shelf exchange with the Canary Islands. In the western Atlantic basin there are to date no Hf isotope data available and thus five 60 litre samples from distinct depths at the locations covered by stations 188-1/190-1/192-1/195-1 from 11°30'S and five samples at stations 204-1/206-1/207-1/209-1/210-1 covering the northernmost profile of cruise M81/1 at 7°46'N in the western basin were sampled.

## 5.5 Stable Cd Isotopes and radiogenic Pb Isotopes

(S. Galer, W. Abouchami, Max Planck Institute for Chemistry, Mainz)

High-precision Cd isotope data on seawater samples collected during Meteor 81 cruise will be obtained to investigate the use of Cd isotopes as proxy for water mass mixing and nutrient utilization. Recent results on seawater samples from the Southern Ocean (ANTXXIV-III cruise Polarstern, IPY 2008) demonstrated convincingly that Cd isotopic variations track the gradient of biological productivity across the main Antarctic fronts and trace water mass distribution along the Greenwich Meridian (Abouchami et al., 2011). No Cd isotope data are yet available for the Equatorial Atlantic and the samples from Meteor cruise M81/1 offer a unique opportunity to delimitate the effects of water mass mixing vs. biological uptake on the distribution of dissolved Cd isotopes. The Romanche Fracture Zone is, in this respect, a particularly ideal location since it is known to be a region of intense vertical mixing. Seawater volumes varying between 20 L for surface waters, 4 L for intermediate depth and 1 L for deep waters were sampled using the trace metal clean rosette, and were filtered through Sartobran filter capsules and acidified to a pH of 1, using ultra-clean Seastar® HCl (low level Cd blank). Six vertical profiles distributed along the section of M81/1 (stations 114-1, 129-1, 141-1, 162-1, 189-1, 205-1), each consisting of 8 to 11 depths were sampled and will be analysed for their stable Cd isotope compositions by Thermal-Ionization Mass Spectrometry in the laboratories of the Max-Planck Institute for Chemistry in Mainz (Germany).

On a selection of 9 of the above trace metal clean samples from the vertical stations, as well as on 7 surface samples obtained with the towed fish, and further 4 near surface samples obtained with the trace metal clean rosette, radiogenic Pb isotope compositions using a  $^{202}\text{Pb}$ - $^{205}\text{Pb}$  double spike will be measured. The double spike will allow simultaneous determination of Pb concentration by isotope dilution and instrumental mass fractionation correction. Chemical separations and isotope measurements by Thermal-Ionization Mass Spectrometry will be performed at the Max-Planck Institute (Mainz). The objective of investigations of the distribution of Pb and its isotopes is to study the impact of anthropogenic inputs (mainly gasoline Pb) on ocean biogeochemistry by documenting the distribution and the various natural sources of

Pb to the ocean, the vertical cycling of Pb in the water column, and assessing ventilation rates and mixing in surface waters of the central gyres.

## **5.6 Stable Fe Isotopes**

(M. Staubwasser, University of Cologne)

The tropical Atlantic is one of the open ocean regions where Fe is not the limiting nutrient for phytoplankton growth. Dust deposition from the Sahara – the world's largest desert – and discharge of suspended matter from the Amazon – the world's largest river – are known large sources of Fe. In addition, upwelling and high productivity along the West Africa and volcanic Islands, such as the Canaries, are also sources of Fe to the ocean. There are hopes that Fe isotopes will allow to discriminate between these sources because the endmembers are reasonably well constrained and distinct in their Fe isotope signatures. The objective of sampling large volume seawater samples from depth transects along cruise M81/1 was to map out the spatial and depth distribution of the dissolved and suspended Fe isotope composition and to test whether Fe isotopes can be used to trace the various Fe sources. For this purpose a total of 96 samples (8 litres each) and 12 larger volume samples (20 litres) of seawater were taken with the GO-FLO bottles of the trace metal clean rosette system and were filtered on board at 5µm and 0.45 µm in a laminar flow hood inside the GEOTRACES clean laboratory container. The samples were then acidified and stored for later on-shore analysis. Profiles were taken from at a total of 12 depth profiles from off the Canaries, along the West African upwelling system, across the major dust plume in the equatorial North Atlantic, as well as south of the Amazonas delta above the Brazilian continental slope. One profile above the Romanche Fracture Zone reached 5800 meters water depth. Surface samples corresponding to all depth profiles were taken from the towed fish, pumped directly into the clean laboratory container and filtered on-line. An additional surface profile of 10 samples was taken near the end of the cruise across the distal Amazon plume, where the salinities dropped from ~ 36 psu to a minimum of near 27 psu. Dissolved and suspended Fe from these samples will be analyzed for their Fe isotope composition in the laboratories of the University of Cologne. Complementary continental samples, such as a unique profile of soil samples taken during a recent expedition across the Chad – the largest source of Saharan dust – will be used for comparison. The expected outcome is to answer to the question if and to what extent the dissolved and particulate Fe isotope compositions in the tropical Atlantic reflect the various Fe sources.

## **5.7 Natural Radionuclides ( $^{231}\text{Pa}$ , $^{230}\text{Th}$ , $^{234}\text{Th}$ , $^{227}\text{Ac}$ , Ra isotopes)**

(M.M. Rutgers van der Loeff, S. Kretschmer, Alfred-Wegener-Institute for Polar and Marine Research Bremerhaven (AWI); P. Camara-Mor, P. Masque, V. Puigcorb , UAB; W. Geibert, University of Edinburgh)

Two natural and radioactive isotopes of protactinium ( $^{231}\text{Pa}$ ) and thorium ( $^{230}\text{Th}$ ) are produced in seawater by decay of their parent U nuclides  $^{235}\text{U}$  and  $^{234}\text{U}$ , respectively, at a constant and well-known rate. Both elements are highly particle reactive, and are consequently scavenged by the particle rain and transported to the sea floor. Because  $^{230}\text{Th}$  has a residence time of only about 30

years, most of  $^{230}\text{Th}$  is deposited in the respective ocean basin sediments close to where it was actually produced.  $^{231}\text{Pa}$  is somewhat less reactive and has an average residence time of about 150 years, which allows this nuclide to be transported by ocean currents much farther away from the region where it was produced. This is the background for the idea that  $^{231}\text{Pa}/^{230}\text{Th}$  ratios in marine sediments may record the intensity of deep water ventilation, an approach that is particularly promising in the Atlantic Ocean due to the time scales of ventilation of the deep Atlantic by North Atlantic Deep Water, which at present occurs at about the time scales as the average residence time of Pa. Thus, this pair of tracers has been studied intensively for its suitability in reconstructing the strength of the Meridional Atlantic Ocean Circulation, thought to be a major factor in controlling the Glacial to Holocene climate transition. Whereas several attempts have been made already to model the  $^{231}\text{Pa}$  and  $^{230}\text{Th}$  distribution in the Atlantic Ocean (e.g. Luo et al., 2010) and to interpret  $^{231}\text{Pa}/^{230}\text{Th}$  ratios in the Atlantic sediments (e.g. McManus et al., 2004; Negre et al., 2010), we do not yet know in sufficient detail the distribution of the isotopes in the Atlantic, and consequently the quantitative suitability of the  $^{231}\text{Pa}/^{230}\text{Th}$  tracer to track NADW intensity cannot even be judged for the present day Atlantic ocean. It is thus very important to measure the distribution of  $^{230}\text{Th}$  and  $^{231}\text{Pa}$  in the water column along the pathway of NADW and to compare these data with the less ventilated deep waters in the eastern North Atlantic basin. Complementary data will be collected on samples obtained during several other GEOTRACES expeditions in the Atlantic Ocean including GEOTRACES cruises GA02 and GA03 mentioned before, and cruise GA10 in the Southern Atlantic Ocean, as well as cruises in the Southern Ocean that were carried out in the frame of the International Polar Year (IPY) in 2008.

The analysis of the isotopes by ICP-MS requires approximately 20L of seawater. A total set of 80 samples were collected from 8 locations sampled for full water depth, which were sampled during a composite of several CTD casts (stations 128-1/130-1/133-1, 148-1/150-1/152-1/153-1, 161-1/163-1/165-1, 167-1/169-1/171-1/173-1/175-1, 177-1, 179-1/181-1/183-1/185-1/186-1, 188-1/190-1/192-1/194-1/195-1, 197-1/199-1/200-1, 204-1/206-1/207-1/209-1). All samples were filtered over 0.4 $\mu\text{m}$  Supor® filters and were subsequently acidified on board and stored for further treatment in the home laboratory at AWI, Bremenhaven. Ultraclean sampling using the trace metal clean rosette was not required for these isotopes, which is why these samples were taken from the standard rosette equipped with 12 liter Niskin bottles.

A disequilibrium between  $^{238}\text{U}$  and  $^{234}\text{Th}$  activities in the upper water column of the ocean is produced by the scavenging of highly particle reactive  $^{234}\text{Th}$  by sinking particles while the parent isotope  $^{238}\text{U}$  is highly soluble and essentially is a conservative element in seawater. Using models based on the short half-life of  $^{234}\text{Th}$  (24 days), the deficit of  $^{234}\text{Th}$  can be converted into export fluxes from the photic zone or the mixed layer (e.g. Cochran and Masqué, 2003). Together with information on the  $\text{C}/^{234}\text{Th}$  ratios in sinking particles (i.e. by measuring this ratio in the particulate matter collected by the in situ pumps), it is possible to estimate the export fluxes of C (or any other parameter for which its ratio to  $^{234}\text{Th}$  in particles can be determined). For C (or particulate organic carbon, POC), these estimates can be compared to data on primary production and be used to evaluate the efficiency of the biological pump. Also, these data can be used to estimate remineralisation rates below the photic zone. Water samples (4 litres each) were collected from all deep stations of the cruise resulting in a total of ~200 samples. High resolution sampling was performed on the upper 200 m, where most of the biological

productivity and remineralisation processes occur that lead to  $^{238}\text{U}/^{234}\text{Th}$  disequilibria, but also several additional depths down to 1500 m were sampled. The nuclides contained in these samples were coprecipitated with  $\text{MnO}_2$  and filtered onboard and only the precipitates were taken to the UAB laboratories for analyses of the  $^{238}\text{U}$  and  $^{234}\text{Th}$  activities.

Water mass circulation, deep upwelling and mixing rates can be assessed by using highly soluble natural radionuclide tracers such as Ra isotopes and  $^{227}\text{Ac}$  (e.g. Sarmiento et al., 1982; Geibert et al, 2002).  $^{228}\text{Ra}$  activities provide insight in tracing shelf water input into the open ocean. The radium quartet ( $^{223}\text{Ra}$ ,  $^{224}\text{Ra}$ ,  $^{226}\text{Ra}$ ,  $^{228}\text{Ra}$ ) is useful for estimating the importance of submarine groundwater discharge (SGD) in coastal areas, and in particular the  $^{228}\text{Ra}/^{226}\text{Ra}$  ratio allows estimating SGD on a basin scale. Combining  $^{227}\text{Ac}$  and  $^{228}\text{Ra}$  data will allow discriminating between lateral and vertical advection processes. In particular, excess  $^{227}\text{Ac}$  activities can be used to constrain vertical mixing coefficients in the deep ocean, which is a crucial parameter for coupled atmosphere/ocean models. In fact, global coupled models have been shown to respond strongly to different parameterization of vertical mixing, which is still poorly constrained so far. Another important application is the release of this nuclide from the bottom sediments to the deep water column of the ocean, which can then be used as a tracer for deep upwelling (Geibert et al., 2002).

Between 60 and 120 l samples have been collected at three locations for  $^{227}\text{Ac}$  (140-1/142-1/144-1/145-1, 167-1/169-1/171-1/173-1/175-1, 179-1/181-1/183-1/185-1) complemented by some surface samples. For measurements of the  $^{228}\text{Ra}$  activities, the same stations as above and for the anthropogenic nuclides (see section 5.8) have been sampled. On board the Ra and Ac was extracted from the samples using Mn-coated fibres, which were taken to the home laboratories for analysis.

## 5.8 Artificial/Anthropogenic Radionuclides ( $^{137}\text{Cs}$ , $^{239}\text{Pu}$ , $^{240}\text{Pu}$ , $^{237}\text{Np}$ )

(T. Kenna, Lamont Doherty Earth Observatory (LDEO), New York; P. Masque, P. Camara- Mor, UAB)

By comparing radionuclide distributions, isotopic composition, inventories, and inventory ratios of particle reactive plutonium (Pu) to conservative cesium and neptunium (Cs and Np) it will be possible to gain first order information about rates of scavenging and transport of these nuclides that is complimentary to that gained through study of other TEIs within GEOTRACES. This collaborative project of LDEO and UAB is focused on determining the total concentrations of the anthropogenic radionuclides (ARNs)  $^{239}\text{Pu}$ ,  $^{240}\text{Pu}$ ,  $^{237}\text{Np}$ , and  $^{137}\text{Cs}$  in full depth profiles, which will be compared with data collected on several other Atlantic GEOTRACES cruises that took place in 2010 with the goal of a broad brush characterization of the ARNs in the Atlantic Ocean some 37 years after their first systematic investigation as part of the GEOSECS program. These isotopes also exhibit a range of  $K_d$  values (sediment water distribution coefficients,  $\text{Pu} > \text{Np}, \text{Cs}$ ) and geochemical behaviours, as well as provide a means to resolve different sources of radioactive contamination. Processes such as advection (new water mass tracers), sources and sinks (characteristic isotopic signatures), as well as scavenging and particle dynamics across a range of contrasting regions in terms of total particle fluxes and types of particles will be addressed. The specific objectives of the project are as follows:

- 1) Determine the vertical distributions of  $^{239}\text{Pu}$ ,  $^{240}\text{Pu}$ ,  $^{237}\text{Np}$ , and  $^{137}\text{Cs}$  and compute water column inventories for each nuclide.
- 2) Determine the horizontal distributions of the radionuclides of interest; combined stations from the different cruises will allow the compilation of zonal and meridional sections.
- 3) Characterize the isotopic composition of the different water masses where they intersect the different cruise tracks and in areas where important processes are occurring.

Sampling for the anthropogenic radionuclides during M81/1 took place at 6 locations. Unfiltered seawater samples of between 20 and 60 litres were collected from full depth profiles using the standard rosette and in addition 5 surface samples (100 litres each) were taken using the towed fish. Sampling resolution for full depth varied between 7-13 depths for each profile. Samples were acidified to pH 2 at sea using trace metal grade hydrochloric acid and no further treatment was carried out on board. For the anthropogenic nuclide measurements, 20 litre samples were collected from a total of 4 locations at full water depth, which were sampled during several CTD casts at the same location (stations 148-1/150-1/152-1/153-1, 167-1/169-1/171-1/173-1/175-1, 188-1/190-1/192-1/194-1/195-1, 204-1/206-1/207-1/209-1). Large volume samples (60 litres) were also collected during several casts for the full water depth at a total of 3 locations (140-1/142-1/144-1/145-1, 167-1/169-1/171-1/173-1/175-1, 179-1/181-1/183-1/185-1), which will also serve for the measurements of the activities of some of the natural radionuclides (see section 5.7).

## 5.9 Stable nutrient isotopes ( $\delta^{15}\text{NO}_3^-$ , $\delta^{13}\text{C}_{\text{DIC}}$ )

(E. Ryabenko, IFM-GEOMAR, P. Quay, University of Washington)

The GEOTRACES program has identified the dissolved  $\delta^{15}\text{NO}_3^-$  and  $\delta^{13}\text{C}_{\text{DIC}}$  signatures as ancillary parameters. The  $\delta^{15}\text{NO}_3^-$  signatures of dissolved nitrate vary in seawater due to stable isotope fractionation processes of nitrogen as part of the complex biogeochemical nitrogen cycle, which in many parts of the ocean is not well constrained and not well represented by data. The  $\delta^{13}\text{C}_{\text{DIC}}$  signatures serve to better constrain the controlling factors of the nutrient content of seawater and also in many cases can be used to characterize deep water masses and their mixing. This parameter was also part of the GEOSECS program in the 1970s and the GEOTRACES program aims at completing and reevaluating its global distribution. In addition and very importantly, both parameters are used extensively as paleo proxies for the nitrogen cycle and for ocean circulation.

On Meteor M81/1 between 10 and 15 samples were collected at all deep stations for the  $\delta^{15}\text{NO}_3^-$  measurements and at most deep stations for the  $\delta^{13}\text{C}_{\text{DIC}}$  measurements using water from the Niskin bottles of the standard rosette. For the  $\delta^{15}\text{NO}_3^-$  measurements 125 ml of unfiltered seawater were taken in pre-cleaned plastic bottles directly from the standard rosette to analysed at IFM-GEOMAR. For  $\delta^{13}\text{C}_{\text{DIC}}$  one litre of unfiltered seawater was sampled in glass bottles following established procedures by the group of Paul Quay, University of Washington, U.S.A.

## **6 Ship's Meteorological Station**

(T. Truscheit, DWD)

When RV Meteor left the port of Las Palmas/Gran Canaria on February 4<sup>th</sup> 2010 weak north easterly trade winds of 4 Beaufort dominated the weather conditions. The Canary Islands were under influence of an extended zone of high pressure at 1023 hPa westward of these islands, which was slowly moving east-north-eastward. Only on Monday, February 6<sup>th</sup>, a cold frontal system belonging to an extensive storm front was approaching but had little effect in the working area. Only some cloudbanks were moving eastward and the wind force increased to 5 Beaufort for a very short period of time. Actually, only the following field of swell influenced the working area and the route of RV Meteor.

As during the previous days, the area between the Canary Islands and the Cape Verde Islands were still under influence of extended high pressure zones located westward of the Canary Islands. The weak north easterly trade winds of 4 to a maximum of 5 Beaufort prevailed and dominated the conditions. At a position east of Cape Verde Islands a development of storm fronts in the North Atlantic Ocean occurred but did not influence the southward course of RV Meteor. The ITC with its cloudbanks was reached near 9°N on February 17<sup>th</sup> but was only weakly expressed and at the most some light showers of rain occurred in the morning of this day. Still the north easterly trade winds of 4 Beaufort prevailed.

Already on the following day the ITC was passed and RV Meteor entered the influence of the south easterly trade winds, which were only weakly expressed as well. These conditions were stable until February 24<sup>th</sup>. On the northward course of RV Meteor (from a position at 11,5°S, 23,5°W onwards) the weather conditions did not change significantly. By then R/V Meteor reached an area of weak differences of air pressure between the high pressure zones of the northern and southern hemispheres. Still weak south easterly trade winds of 4 Beaufort dominated. On its now north-westerly course RV Meteor reached the ITC once again on March 1<sup>st</sup>. In these days the ITC extended from Liberia (Africa) to the Amazon mouth. On this day, as well as on the following day some heavy showers of rain and gusts up to 6 Beaufort occurred. However, thunderstorms failed to appear.

On March 3<sup>rd</sup> the ITC was left behind again and RV Meteor was within the zone of influence of the north easterly trade winds again. The trade wind increased to 6 Beaufort with gusts to 7 Beaufort and a swell of up to 3 meters until March 5<sup>th</sup>. Only in the afternoon of this day, the north easterly wind decreased to 5 Beaufort and the swell was again rather only 2 meters.

North easterly winds of 4 to 5 Beaufort prevailed for the last 3 days of the expedition.

## 7 Station List M81/1

Station	Gear No.	Date	Station Start				Station End			
			Time	Position Lat	Position Lon	Depth [m]	Time	Position Lat	Position Lon	Depth [m]
104-1	CTD/TM-1	04.02.10	18:30	28° 30.02' N	15° 20.05' W	3452	19:00	28° 30.09' N	15° 20.10' W	3450
105-1	IFISH-1	04.02.10	19:15	28° 30.28' N	15° 20.10' W	3462	22:10	28° 58.35' N	15° 20.01' W	3595
106-1	CTD/TM-2	04.02.10	22:44	28° 59.72' N	15° 20.14' W	3595	03:00	28° 59.64' N	15° 20.53' W	3597
107-1	CTD/NISK-1	05.02.10	03:23	28° 59.64' N	15° 20.53' W	3598	05:56	28° 59.64' N	15° 20.53' W	3599
108-1	ISP-1	05.02.10	07:12	29° 0.03' N	15° 20.08' W	3598	12:25	29° 0.01' N	15° 20.13' W	3594
109-1	CTD/TM-3	05.02.10	13:00	29° 0.01' N	15° 20.13' W	3594	16:41	29° 0.01' N	15° 20.34' W	3570
110-1	CTD/NISK-2	05.02.10	16:54	29° 0.01' N	15° 20.35' W	3577	17:07	29° 0.01' N	15° 20.35' W	3580
111-1	ISP-2	05.02.10	17:21	29° 0.01' N	15° 20.35' W	3577	20:23	28° 59.63' N	15° 21.12' W	3582
112-1	IFISH-2	05.02.10	20:37	28° 59.38' N	15° 21.58' W	3576	02:15	28° 11.25' N	16° 9.64' W	2205
113-1	CTD/NISK-3	06.02.10	03:40	28° 3.77' N	16° 3.10' W	2001	05:09	28° 3.93' N	16° 3.35' W	2047
114-1	CTD/TM-4	06.02.10	06:26	28° 3.97' N	16° 3.36' W	1910	08:31	28° 4.03' N	16° 3.49' W	1903
115-1	CTD/NISK-4	06.02.10	08:41	28° 4.03' N	16° 3.49' W	2007	09:21	28° 4.03' N	16° 3.49' W	2217
116-1	ISP-3	06.02.10	09:50	28° 4.03' N	16° 3.49' W	2247	11:13	28° 4.07' N	16° 3.61' W	2261
117-1	IFISH-3	06.02.10	11:30	28° 3.84' N	16° 3.63' W	2073	17:58	27° 12.45' N	16° 59.70' W	3618
118-1	CTD/TM-5	06.02.10	18:13	27° 12.00' N	17° 0.00' W	3622	21:29	27° 12.03' N	17° 0.03' W	3621
119-1	CTD/NISK-5	06.02.10	22:23	27° 12.04' N	17° 0.03' W	3619	00:55	27° 12.04' N	17° 0.03' W	3618
120-1	ISP-4	07.02.10	01:36	27° 12.04' N	17° 0.03' W	3618	06:17	27° 12.04' N	17° 0.03' W	3621
121-1	CTD/NISK-6	07.02.10	06:34	27° 12.04' N	17° 0.03' W	3620	06:48	27° 12.04' N	17° 0.03' W	3621
122-1	ISP-5	07.02.10	07:00	27° 12.04' N	17° 0.03' W	3621	09:49	27° 12.04' N	17° 0.03' W	3618
123-1	IFISH-4	07.02.10	10:00	27° 11.64' N	17° 0.03' W	3620	20:53	25° 33.45' N	17° 30.41' W	3204
124-1	CTD/TM-6	07.02.10	21:18	25° 32.71' N	17° 31.20' W	3203	00:06	25° 32.73' N	17° 31.21' W	3201
125-1	CTD/NISK-7	08.02.10	00:20	25° 32.73' N	17° 31.20' W	3204	02:32	25° 32.73' N	17° 31.20' W	3205
126-1	CTD/NISK-8	08.02.10	03:14	25° 32.73' N	17° 31.20' W	3211	03:30	25° 32.73' N	17° 31.21' W	3209
127-1	IFISH-5	08.02.10	15:12	24° 50.74' N	19° 33.35' W	3453	05:44	23° 59.70' N	21° 59.78' W	4613
128-1	CTD/NISK-9	09.02.10	05:55	24° 0.00' N	22° 0.06' W	4611	09:00	23° 59.21' N	22° 1.27' W	4616
129-1	CTD/TM-7	09.02.10	09:48	23° 59.91' N	22° 0.18' W	4614	11:31	23° 59.87' N	22° 0.29' W	4615
130-1	CTD/NISK-10	09.02.10	13:50	23° 59.78' N	22° 0.44' W	4612	14:04	23° 59.77' N	22° 0.47' W	4616
131-1	ISP-6	09.02.10	15:00	23° 59.76' N	22° 0.53' W	4618	20:51	23° 59.13' N	22° 0.09' W	4615
132-1	CTD/TM-8	09.02.10	20:59	23° 59.11' N	22° 0.07' W	4613	21:37	23° 58.96' N	22° 0.26' W	4614
133-1	CTD/NISK-11	09.02.10	21:49	23° 58.90' N	22° 0.35' W	4619	22:29	23° 58.79' N	22° 0.54' W	4619
134-1	ISP-7	09.02.10	22:59	23° 59.99' N	21° 59.99' W	4612	01:53	23° 59.33' N	22° 1.11' W	4618

Station	Gear No.	Date	Station Start				Station End			
			Time	Position Lat	Position Lon	Depth [m]	Time	Position Lat	Position Lon	Depth [m]
135-1	IFISH-6	10.02.10	02:06	23° 59.49' N	22° 1.35' W	4620	06:48	19° 24.72' N	20° 26.54' W	3416
136-1	CTD/NISK-12	11.02.10	07:00	19° 25.25' N	20° 26.53' W	3424	09:20	19° 25.25' N	20° 26.52' W	3424
137-1	CTD/TM-9	11.02.10	09:28	19° 25.25' N	20° 26.53' W	3428	12:24	19° 25.28' N	20° 26.54' W	3423
138-1	CTD/NISK-13	11.02.10	12:30	19° 25.28' N	20° 26.55' W	3423	12:44	19° 25.28' N	20° 26.54' W	3421
139-1	ISP-8	11.02.10	13:12	19° 25.28' N	20° 26.54' W	3422	15:50	19° 25.29' N	20° 26.55' W	3422
140-1	CTD/NISK-14	13.02.10	06:52	12° 58.61' N	20° 19.99' W	4678	09:51	12° 58.60' N	20° 20.00' W	4679
141-1	CTD/TM-10	13.02.10	09:57	12° 58.60' N	20° 20.00' W	4676	12:34	12° 58.64' N	20° 19.99' W	4683
142-1	CTD/NISK-15	13.02.10	12:40	12° 58.65' N	20° 19.99' W	4677	15:04	12° 58.64' N	20° 19.99' W	4679
143-1	ISP-9	13.02.10	15:54	12° 58.67' N	20° 19.99' W	4677	21:49	12° 59.38' N	20° 19.95' W	4673
144-1	CTD/TM-11	13.02.10	21:54	12° 59.38' N	20° 19.95' W	4675	22:07	12° 59.47' N	20° 19.93' W	4674
145-1	CTD/NISK-16	13.02.10	22:10	12° 59.47' N	20° 19.93' W	4677	22:41	12° 59.47' N	20° 19.93' W	4674
146-1	ISP-10	13.02.10	22:50	12° 59.47' N	20° 19.93' W	4673	01:25	13° 0.18' N	20° 19.93' W	4671
147-1	IFISH-7	14.02.10	01:42	12° 59.66' N	20° 19.81' W	4676	20:38	9° 30.18' N	20° 20.20' W	4290
148-1	CTD/NISK-17	14.02.10	20:47	9° 30.00' N	20° 19.99' W	4301	22:11	9° 30.00' N	20° 19.99' W	4302
149-1	CTD/TM-12	14.02.10	23:44	9° 29.99' N	20° 19.99' W	4296	03:30	9° 30.00' N	20° 20.00' W	4249
150-1	CTD/NISK-18	15.02.10	03:39	9° 30.00' N	20° 20.00' W	4276	05:08	9° 30.00' N	20° 20.00' W	4299
151-1	ISP-11	15.02.10	05:59	9° 30.00' N	20° 20.00' W	4298	08:19	9° 30.00' N	20° 20.00' W	4286
152-1	CTD/NISK-19	15.02.10	08:28	9° 30.00' N	20° 20.00' W	4279	08:58	9° 30.00' N	20° 20.00' W	4274
153-1	CTD/NISK-20	15.02.10	09:32	9° 30.00' N	20° 20.00' W	4279	09:39	9° 30.00' N	20° 20.00' W	4275
154-1	IFISH-8	15.02.10	09:49	9° 29.87' N	20° 19.93' W	4273	04:20	6° 4.21' N	20° 19.96' W	2768
155-1	CTD/NISK-21	16.02.10	05:00	5° 59.99' N	20° 20.00' W	2754	06:59	5° 59.99' N	20° 20.00' W	2742
156-1	CTD/TM-13	16.02.10	07:12	5° 59.99' N	20° 20.00' W	2733	09:40	6° 0.00' N	20° 20.00' W	2763
157-1	ISP-12	16.02.10	10:20	5° 59.98' N	20° 20.02' W	2791	14:50	5° 59.98' N	20° 20.02' W	2697
158-1	CTD/NISK-22	16.02.10	15:00	5° 59.98' N	20° 20.02' W	2696	15:10	5° 59.98' N	20° 20.02' W	2670
159-1	ISP-13	16.02.10	15:18	5° 59.98' N	20° 20.02' W	2665	17:50	5° 59.98' N	20° 20.02' W	2451
160-1	IFISH-9	16.02.10	18:00	6° 0.14' N	20° 20.04' W	2438	15:24	2° 11.85' N	20° 20.01' W	4520
161-1	CTD/NISK-23	17.02.10	16:48	2° 8.98' N	20° 12.40' W	4594	19:57	2° 8.98' N	20° 12.40' W	4595
162-1	CTD/TM-14	17.02.10	20:10	2° 9.04' N	20° 12.44' W	4598	00:02	2° 9.07' N	20° 12.49' W	4446
163-1	CTD/NISK-24	18.02.10	00:10	2° 9.06' N	20° 12.51' W	4584	01:10	2° 9.06' N	20° 12.52' W	4601
164-1	ISP-14	18.02.10	01:48	2° 9.09' N	20° 12.52' W	4598	04:08	2° 9.09' N	20° 12.53' W	4580
165-1	CTD/NISK-25	18.02.10	04:18	2° 9.09' N	20° 12.53' W	4588	04:32	2° 9.08' N	20° 12.61' W	4674
166-1	IFISH-10	18.02.10	04:44	2° 8.96' N	20° 12.87' W	4515	20:54	0° 36.80' S	20° 2.66' W	6614

Station	Gear No.	Date	Station Start				Station End			
			Time	Position Lat	Position Lon	Depth [m]	Time	Position Lat	Position Lon	Depth [m]
167-1	CTD/NISK-26	18.02.10	21:03	0° 36.91' S	20° 2.55' W	6642	00:38	0° 36.90' S	20° 2.54' W	6737
168-1	ISP-15	19.02.10	00:54	0° 36.90' S	20° 2.54' W	6744	08:02	0° 37.20' S	20° 1.79' W	6682
169-1	CTD/NISK-27	19.02.10	09:03	0° 37.19' S	20° 1.78' W	6682	11:31	0° 37.19' S	20° 1.80' W	6695
170-1	CTD/TM-15	19.02.10	11:40	0° 37.19' S	20° 1.80' W	6705	16:16	0° 37.07' S	20° 1.93' W	6653
171-1	CTD/NISK-28	19.02.10	16:25	0° 37.06' S	20° 1.93' W	6682	17:50	0° 37.03' S	20° 1.86' W	6694
172-1	ISP-16	19.02.10	18:32	0° 36.97' S	20° 1.92' W	6690	20:54	0° 36.98' S	20° 1.67' W	6675
173-1	CTD/NISK-29	19.02.10	21:01	0° 36.98' S	20° 1.67' W	6683	21:25	0° 36.97' S	20° 1.66' W	6626
174-1	CTD/TM-16	19.02.10	21:33	0° 36.92' S	20° 1.68' W	6696	21:46	0° 36.86' S	20° 1.70' W	6706
175-1	CTD/NISK-30	19.02.10	22:17	0° 36.77' S	20° 1.75' W	6668	22:30	0° 36.74' S	20° 1.71' W	6681
176-1	IFISH-11	19.02.10	22:38	0° 36.80' S	20° 1.76' W	6669	22:54	3° 56.79' S	22° 49.16' W	5657
177-1	CTD/TM-17	20.02.10	23:27	4° 0.02' S	22° 51.74' W	5653	00:26	4° 0.19' S	22° 52.41' W	5577
178-1	IFISH-12	21.02.10	00:32	4° 0.31' S	22° 52.67' W	5534	18:50	6° 38.51' S	24° 59.87' W	5199
179-1	CTD/NISK-31	21.02.10	19:00	6° 38.99' S	25° 0.01' W	5265	22:42	6° 39.00' S	25° 0.01' W	5780
180-1	CTD/TM-18	21.02.10	22:52	6° 39.02' S	25° 0.01' W	5504	03:00	6° 39.06' S	25° 0.04' W	5538
181-1	CTD/NISK-32	22.02.10	03:06	6° 39.06' S	25° 0.04' W	5523	05:33	6° 39.07' S	25° 0.02' W	5515
182-1	ISP-17	22.02.10	06:27	6° 39.05' S	25° 0.04' W	5516	13:07	6° 39.06' S	25° 0.02' W	5521
183-1	CTD/NISK-33	22.02.10	13:20	6° 39.06' S	25° 0.02' W	5522	14:26	6° 39.06' S	25° 0.02' W	5544
184-1	ISP-18	22.02.10	14:36	6° 39.06' S	25° 0.02' W	5527	17:00	6° 39.06' S	25° 0.02' W	5541
185-1	CTD/NISK-34	22.02.10	18:04	6° 39.05' S	25° 0.02' W	5530	18:24	6° 39.05' S	25° 0.02' W	5524
186-1	CTD/NISK-35	22.02.10	18:47	6° 39.05' S	25° 0.02' W	5521	18:55	6° 39.05' S	25° 0.02' W	5520
187-1	IFISH-13	22.02.10	19:06	6° 39.23' S	24° 59.84' W	5511	05:03	11° 28.34' S	28° 28.80' W	5463
188-1	CTD/NISK-36	24.02.10	05:26	11° 30.03' S	28° 30.02' W	5482	08:39	11° 30.03' S	28° 30.02' W	5523
189-1	CTD/TM-19	24.02.10	08:44	11° 30.03' S	28° 30.02' W	5521	13:06	11° 30.06' S	28° 30.05' W	5516
190-1	CTD/NISK-37	24.02.10	13:13	11° 30.12' S	28° 30.10' W	5521	15:42	11° 30.12' S	28° 30.10' W	5499
191-1	ISP-19	24.02.10	16:24	11° 30.07' S	28° 30.06' W	5499	22:36	11° 30.07' S	28° 30.06' W	5485
192-1	CTD/NISK-38	24.02.10	22:42	11° 30.07' S	28° 30.06' W	5480	23:59	11° 30.07' S	28° 30.06' W	5492
193-1	ISP-20	25.02.10	00:36	11° 30.06' S	28° 29.98' W	5497	02:46	11° 30.06' S	28° 29.98' W	5496
194-1	CTD/NISK-39	25.02.10	03:00	11° 30.06' S	28° 29.97' W	5490	03:14	11° 30.06' S	28° 29.97' W	5487
195-1	CTD/NISK-40	25.02.10	03:43	11° 30.06' S	28° 29.97' W	5482	04:10	11° 30.06' S	28° 29.97' W	5488
196-1	IFISH-14	25.02.10	04:20	11° 29.92' S	28° 29.98' W	5487	08:22	7° 10.37' S	31° 19.75' W	5190
197-1	CTD/NISK-41	26.02.10	08:34	7° 10.01' S	31° 20.00' W	5163	11:58	7° 10.01' S	31° 20.00' W	5192
198-1	CTD/TM-20	26.02.10	12:06	7° 10.01' S	31° 20.00' W	5178	15:54	7° 10.12' S	31° 20.07' W	5149

Station	Gear No.	Date	Station Start				Station End			
			Time	Position Lat	Position Lon	Depth [m]	Time	Position Lat	Position Lon	Depth [m]
199-1	CTD/NISK-42	26.02.10	16:00	7° 10.12' S	31° 20.06' W	5142	16:12	7° 10.12' S	31° 20.06' W	5154
200-1	CTD/NISK-43	26.02.10	16:40	7° 10.12' S	31° 20.06' W	5123	17:33	7° 10.12' S	31° 20.06' W	4898
201-1	IFISH-15	28.02.10	12:21	1° 2.65' S	35° 53.88' W	4220	11:44	0° 52.75' N	39° 32.21' W	4369
202-1	CTD/TM-21	01.03.10	13:05	0° 54.74' N	39° 36.09' W	4367	14:24	0° 54.72' N	39° 35.81' W	4394
203-1	IFISH-16	01.03.10	15:30	0° 56.95' N	39° 40.16' W	4366	10:45	7° 45.31' N	48° 52.06' W	4340
204-1	CTD/NISK-44	04.03.10	11:12	7° 45.99' N	48° 53.01' W	4308	13:16	7° 45.99' N	48° 53.00' W	4278
205-1	CTD/TM-22	04.03.10	13:21	7° 46.00' N	48° 53.00' W	4272	15:51	7° 46.02' N	48° 53.00' W	4281
206-1	CTD/NISK-45	04.03.10	15:54	7° 46.01' N	48° 53.00' W	4301	17:12	7° 46.01' N	48° 53.00' W	4305
207-1	CTD/NISK-46	04.03.10	17:30	7° 46.01' N	48° 53.00' W	4302	18:15	7° 46.01' N	48° 53.00' W	4298
208-1	ISP-21	04.03.10	18:50	7° 46.00' N	48° 53.03' W	4302	21:40	7° 45.99' N	48° 53.03' W	4313
209-1	CTD/NISK-47	04.03.10	21:46	7° 45.99' N	48° 53.03' W	4303	22:04	7° 45.99' N	48° 53.03' W	4313
210-1	CTD/NISK-48	04.03.10	22:30	7° 45.99' N	48° 53.03' W	4292	23:42	7° 45.99' N	48° 53.03' W	4269
211-1	IFISH-17	04.03.10	23:56	7° 46.05' N	48° 53.37' W	4296	02:56	7° 57.67' N	49° 20.14' W	4372
212-1	IFISH-18	05.03.10	11:15	8° 28.75' N	50° 32.47' W	4511	12:08	8° 31.21' N	50° 39.70' W	4555
213-1	IFISH-19	05.03.10	21:10	8° 58.54' N	52° 12.22' W	4681	22:00	10° 15.86' N	56° 34.29' W	3757

### Gear acronyms in the Station list:

CTD/NISK

CTD-Rosette water sampler with Niskin bottles

CTD/TM

Trace metal clean CTD-Rosette water sampler with GO-FLO bottles

IFISH

Towed Fish surface water sampler

ISP

In-situ pumping system

## 8 Data and Sample Storage and Availability

A cruise summary report (CSR) was compiled and submitted to DOD (Deutsches Ozeanographisches Datenzentrum), BSH, Hamburg, immediately after the cruise. The initial part of the cruise was performed in waters of Spanish (Canary Islands) jurisdiction. As requested, the CTD data and this cruise report have been transferred to the Spanish authorities.

All hydrographic data acquired during the cruise have been stored at the GEOTRACES data base at BODC, Liverpool, U.K., and will also be made available at the PANGAEA data base, AWI, Bremerhaven. All trace metal and isotope data to be acquired will also be fed into these data bases and will be made publicly available within 2 years after production. All water and particulate samples are stored at the respective laboratories, where the measurements will be carried out. The Kiel Data Management Team (KDMT) provides an information and data archival system where metadata of the onboard DSHIP-System are collected and are publicly

available. This Ocean Science Information System (OSIS-Kiel) is accessible for all project participants and can be used to share and edit field information. Table 8.1 lists the target data bases, tentative availability times and responsible scientists.

**Hydrography** - CTD and ADCP data are held at the GEOMAR Helmholtz Institute for Ocean Research Kiel and will be made publicly available at the end of 2014 after the GEOTRACES Intermediate Data Product has been published.

**Dissolved trace metals** - samples and data are held at the Jacobs University, Bremen (responsible: Prof. A. Koschinsky) and are subject of the PhD study of S. Pöhle under supervision of Prof. A. Koschinsky.

**Particulate trace metals** - samples and data are held at the University of Bremen (responsible: Prof. W. Balzer).

**Radiogenic isotopes (Hf/Nd)** - samples and data are held at the GEOMAR Helmholtz Institute for Ocean Research Kiel (responsible: Prof. M. Frank) and are subject of the PhD study of M. Zieringer under supervision of Prof. M. Frank.

**Stable Cd isotopes and radiogenic Pb isotopes** - samples and data are held at the Max Planck Institute for Chemistry, Mainz (responsible: Dr. W. Abouchami, Dr. S. Galer).

**Stable Fe isotopes** - samples and data are held at the Institute for Geology and Mineralogy at the University of Cologne (responsible Prof. M. Staubwasser).

**Natural radionuclides** - samples and data are held at the Alfred-Wegener-Institute for Polar and Marine Research, Bremerhaven (responsible Dr. M. Rutgers van der Loeff) and at the UAB Barcelona (responsible Dr. P. Masque) and are analysed by S. Kretschmer ( $^{230}\text{Th}/^{231}\text{Pa}$ ) in the laboratory of Dr. M. Rutgers van der Loeff.

**Artificial/Anthropogenic radionuclides** - samples and data are held at the Lamont Doherty Earth Observatory (LDEO), New York (responsible Dr. T. Kenna).

**Stable nutrient isotopes ( $\delta^{15}\text{NO}_3^-$ ,  $\delta^{13}\text{C}_{\text{DIC}}$ )** - samples and data are held at the GEOMAR Helmholtz Institute for Ocean Research Kiel (responsible Prof. M. Frank) and at the University of Washington (responsible Dr. P. Quay).

**Table 8.1: Data storage and tentative availability**

Type	database	free access	contact
Hydrography	BODC/PANGAEA	Dec. 2014	mfrank@geomar.de
Dissolved trace metals	BODC/PANGAEA	Dec. 2016	a.koschinsky@jacobs-university.de
Particulate trace metals	BODC/PANGAEA	Dec. 2016	balzer@mch.uni-bremen.de
Radiogenic Nd/Hf isotopes	BODC/PANGAEA	Dec. 2014	mfrank@geomar.de
Stable Cd-isotopes and radiogenic Pb isotopes	BODC/PANGAEA	Dec. 2016	wafa.abouchami@mpic.de
Stable Fe isotopes	BODC/PANGAEA	Dec. 2016	m.staubwasser@uni-koeln.de
Natural radionuclides	BODC/PANGAEA	Dec. 2016	mloeff@awi.de, Pere.Masque@uab.cat
Artificial/Anthropogenic radionuclides	BODC/PANGAEA	Dec. 2016	tkenna@ldeo.columbia.edu, Pere.Masque@uab.cat
Stable nutrient isotopes	BODC/PANGAEA	Dec. 2016	mfrank@geomar.de, pdquay@u.washington.edu

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