GEOTRACES
Atlantic Workshop

September 10 – 13th 2007,
St. Annes College,
Oxford.

GEOTRACES Atlantic Basin Workshop
September 2007, Oxford, UK

Workshop Report

Written by the workshop participants

Draft
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GENERAL INTRODUCTION

GEOTRACES is an international research programme focused on understanding the cycling of trace elements and isotopes in the oceans. The GEOTRACES science plan was published in 2006 and can be downloaded, together with additional information about the programme, at http://www.geotraces.org. Additional information about the scientific rationale for the programme, and its overarching goals, can be found in the Science Plan and are not reiterated here.

The first GEOTRACES Scientific Steering Committee (SSC) meeting was held in December 2006 in San Francisco. At that meeting, the SSC decided to run four workshops during 2007 to advance the planning of implementation of the programme. One of these, held in Germany in September 2006, brought together modelers and observationalists with interests in ocean chemistry to discuss the role of ocean modeling within GEOTRACES. The other three workshops were designed to plan the ship tracks and justification for the ocean sections that will form the back-bone of GEOTRACES. One meeting was planned for each of the major ocean basins - Pacific, Atlantic, Indian (planning for GEOTRACES research in the Arctic and Southern Ocean was initiated as part of the International Polar Year). This document reports discussion and recommendations arising at the Atlantic Basin Workshop.

The meeting was divided into four sections. The first of these, on Day 1, presented an overview of the justification for GEOTRACES, of present planning for the programme, and of related research in other programmes. The second section of the meeting was an open microphone section (on Day 2) during which all those present at the meeting were able to briefly present their views about regions, cruises, or measurements that GEOTRACES should encompass in the Atlantic Basin. The third section of the meeting, initiated on Day 2 and finishing on Day 3, featured two sets of four breakout groups to discuss specific ocean regions in more detail. The final section of the meeting included plenary discussion of the Atlantic section map developed by the breakout groups, and writing up of breakout group reports. These breakout group reports form the basis of this workshop report.

This report presents the opinions of participants at the workshop regarding the important processes for trace-element cycling in the Atlantic Basin, the regions in which these processes should be studied, and suggestions for appropriate ocean sections to sample these regions in an efficient manner. This report will be considered by the GEOTRACES SSC in November 2007 along with those from the Pacific and Indian workshops in order to draw up a global map of proposed GEOTRACES ocean sections. It is also expected that material in this report will provide useful justification information to those seeking funding for the planned research in the coming years.

Gideon Henderson
October 2007

ACKNOWLEDGEMENTS

The GEOTRACES Atlantic workshop was made possible by funding from SCOR, US-GEOTRACES, and Oxford University. Significant help in the organization of the meeting was provided by Caroline Hutchings, with additional support from Jingjing Yang and Ben Hickey. Logisitical details and help with financial processing was also provided by those at SCOR – Ed Urban and Liz Gross. We thank all those that made this meeting possible.

BREAKOUT GROUP 1
1.1 Northern Atlantic Zonal Section(s)

Participants: Bob Anderson (Chair); Matt Charette (Rapporteur); Per Andersson; Ed Boyle; Hein de Baar; Angelos Hannides; Cecelia Hannides; Catherine Jeandel; Chris Measures; Kuria Ndungu; Jackie Pates; Dominik Weiss.

Executive Summary

This breakout group was charged with recommending zonal sections in the Atlantic Ocean north of 30°N. A number of key oceanographic features relevant to GEOTRACES were identified within this zone. They include: deep-water formation to the north, shelf-slope exchange of materials to the west, hydrothermal venting in the south, a number of mid- and deep water transport processes in on either side of the mid Atlantic ridge, and outflow of Mediterranean water in the east. With these characteristics in mind, two transects were identified (Fig. 1), including nations that would take the lead on implementing each. An Overflow Transect (OT) section would intercept the locations of deep-water formation/overflow, characterizing the end-member TEI composition of North Atlantic Deep Water (NADW) near its source, while also determining the extent to which NADW composition is modified by exchange with continental margin sediments, and other processes, during its initial transit toward the south. To accomplish this goal, the OT would depart from a European Port (e.g.Vigo) travel northwest to Cape Farewell, Greenland continuing on to St. John's, Newfoundland (or the reverse). A Northern Gyre (NG) section would begin in Woods Hole and follow the existing Line W transect to Bermuda, before turning east and eventually concluding at a port in Spain or Portugal. This section would address the impact of shelf-basin exchange processes, hydrothermal venting, and the Mediterranean outflow on TEIs distributions in the North Atlantic Ocean. It would also establish the contrasting TEI distributions in deep waters of the western and eastern basins. It is anticipated that the OT Line will be led by France, while the U.S. will lead the NG section.

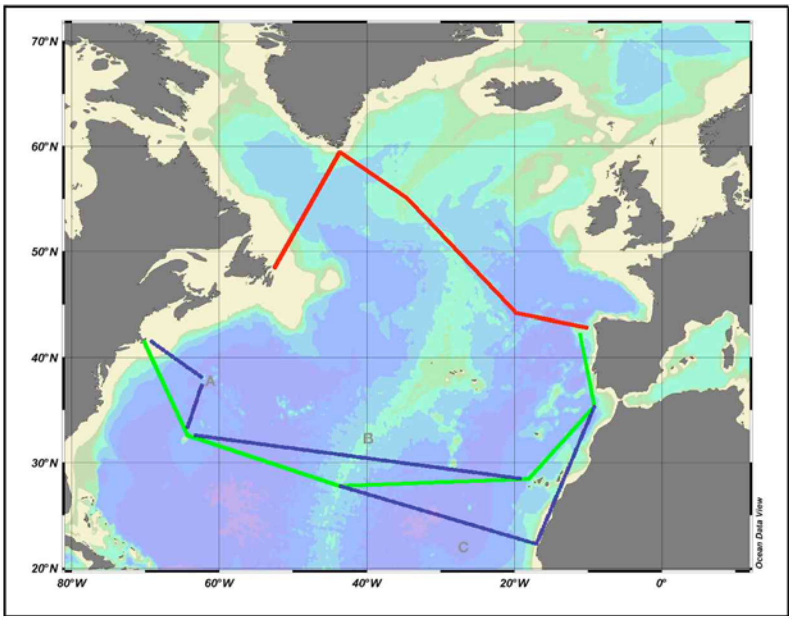


Figure 1. Map of the North Atlantic basin including two proposed GEOTRACES transects: (1) Northern Gyre (green) and (2) Overflow Transect (red). The blue lines depict alternative tracks for the Northern Gyre section that would intercept the area of mode water formation (A), the Rainbow hydrothermal field (B), and the high productivity eastern boundary current off NW Africa (C).

Processes of Interest

This working group discussed a broad spectrum of objectives related to TEI distributions within the North Atlantic Ocean. Relevant processes and related objectives (not necessarily in order of priority) include:

- characterizing the TEI composition of North Atlantic Deep Water at its point of origin (preformed TEI concentrations), within and just downstream of its overflow from the Greenland and Norwegian Seas, as well as within the region of Labrador Sea Water formation (Fig. 2);
- input of TEIs, traced by a nonradiogenic Nd signal, derived from weathering of Greenland and northern North America;
- exchange of dissolved and particulate TEIs from broad continental shelves (Fig. 3);
- high dust/high productivity eastern boundary region south of the Canary Islands (though it was later determined that this would be covered by the tropical working group);
- impact of mode water formation on midwater TEI distribution (mode water formation occurs north of about 40°N);
- hydrothermal sources and sinks, to be explored by having the section pass through either the TAG, 27° N 45° W or Rainbow (36° N) vent region;
- lateral transport of particles from the broad shelf west of the English Channel;
- scavenging of dissolved TEIs by particles, and its sensitivity to gradients in particle flux and particle composition, including lithogenic particles near continents and biogenic particles near coastal and northern regions of high productivity (e.g. diatom-coccolithophorid gradient in the eastern Atlantic), with specific benefits for calibrating $^{231}Pa/^{230}Th$ ratios as a paleo proxy for NADW ventilation; and,
- sources of TEIs carried by Mediterranean Outflow water.

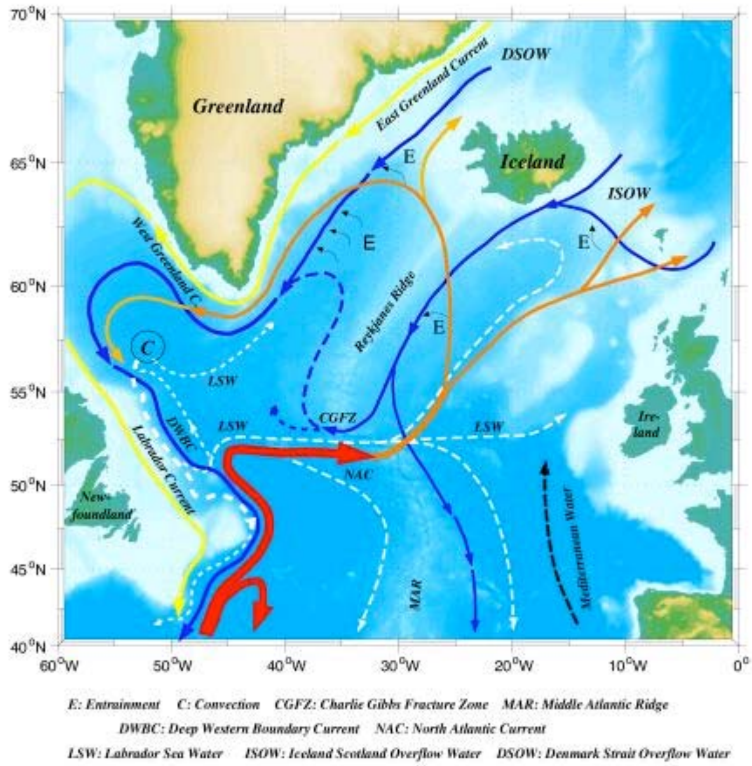


Figure 2. Circulation in the North Atlantic subpolar gyre area studied by the OVIDE program: Parameters measured include TCO2, LADCP, nutrients, pH, Alk., CFCs (28 depths). Figure provided by Catherine Jeandel, courtesy of Herle Mercier.

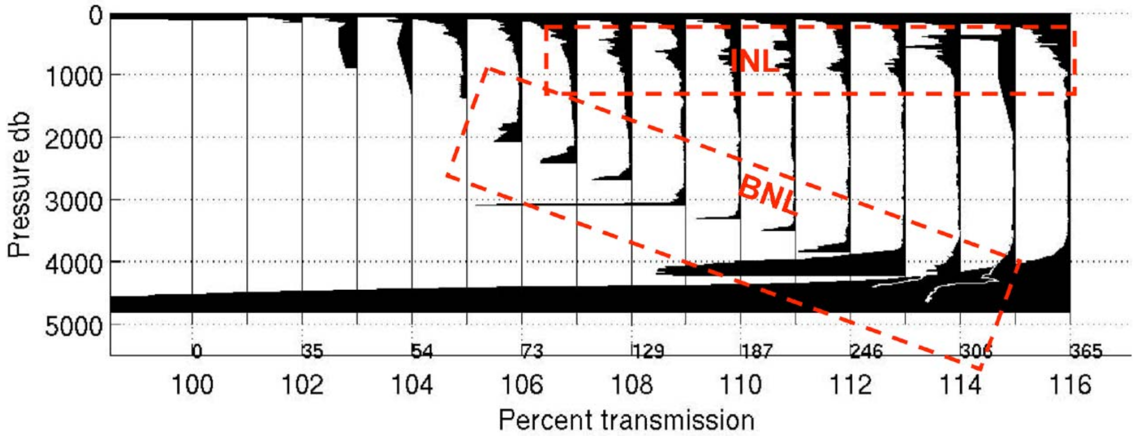


Figure 3. Transmissometry profiles along Line W, a repeat transect from Woods Hole towards Bermuda, depicting both intermediate (INL) and benthic (BNL) nephloid layers extending a large distance away from the shelf. Small numbers just above the x-axis labels are distance in kilometers from the first station just landward of the shelf break. Shelf-basin exchange of TEIs, both in dissolved form and carried by suspended particles, as illustrated here, will be evaluated by GEOTRACES. In addition to evaluating net TEI fluxes associated with shelf-basin exchange, the TEI composition of suspended particles is diagnostic of its source. Figure courtesy of John Toole.

Transect Strategies

Prior to drawing actual lines, the location of possible transects was discussed in the context of ongoing programs, historical studies, and specific targets for sampling:

Overflow Transect (French Lead)

- Recent French cruises have started to explore the exchange of Nd between NADW and margin sediments in the vicinity of Greenland.
- The French OVIDE program, a contribution to CLIVAR, runs biennial sections between Portugal and Greenland (Fig. 4). The possibility of combining GEOTRACES and OVIDE sampling was discussed, and ruled out, because the general CLIVAR strategy requires short, closely spaced stations, which is incompatible with GEOTRACES sampling needs. An alternative strategy that should be explored is to run OVIDE and GEOTRACES sections back to back, making efficient use of the ship by leaving shared facilities (e.g., nutrients and hydrography) set up between cruises.
- Transit time for a St. John's to Greenland (Cape Farwell) to Vigo cruise is estimated to be about 11 days.
- The IOC 93 cruise established historical data for concentrations of several TEIs of interest. Reoccupying some of those stations would provide information about decadal changes in TEI concentrations.
- The Dickson current meter array off the east coast of Greenland provides a valuable time series of NADW flow near its source. It is recommended that the GEOTRACES OT section pass by the Dickson array to place GEOTRACES data in a broader context of interannual to decadal variability in NADW flow. The main flow of NADW will be sampled by several GEOTRACES sections down the length of the western Atlantic Ocean, so it is valuable to characterize the flow, where possible, to put the geochemical results into a context of mean and variability of NADW flow (to quantify fluxes).

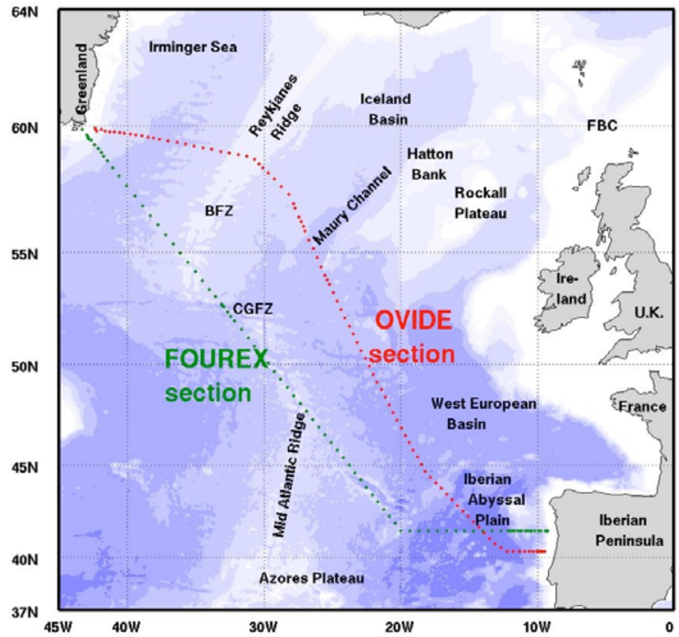


Figure 4. The French OVIDE program was considered as a model for the Overflow Transect. OVIDE contributes to the monitoring and the understanding of ocean variability in the northern North Atlantic ocean (transports, water mass properties). A hydrographic section with direct velocity measurements is repeated every 2 years in summer, between Greenland and Portugal. Figure provided by Catherine Jeandel courtesy of Herle Mercier.

Northern Gyre Transect (US Lead)

- The Line W transect between Woods Hole and Bermuda is heavily instrumented and regularly sampled (Fig. 5) to study the mean and variability of the southward transport of deep water. In addition, this line crosses a broad, high productivity shelf, where the effect of high productivity on TEI distributions can be investigated. Resuspension of sediments along the dynamic western boundary region injects suspended particles into the water column (Figure 2). This GEOTRACES section will examine the impact of these nepheloid layers on TEI cycling
- The Northern Gyre section will pass by Bermuda to sample at the Baseline Station established during the Intercalibration Program.
- The zonal section will cross the Mid Atlantic Ridge at a previously studied location of hydrothermal vents, either the TAG area (27°N) or the Rainbow area (36°N), to examine sources and sinks of TEIs associated with hydrothermal circulation.
- Depending on the time of year of the section, taking a more northerly route would allow sampling within the region of mode water formation at the time of its formation to characterize preformed TEI concentrations.
- An option that should be considered when designing the final section is to pass by the ESTOC time series station (currently not operational) near the Canary Islands. This would be desirable if the ESTOC station were to be restarted, or if a baseline station were to be established near the Canary Islands.
- Sampling near the eastern end of the section would characterize the end member composition of Mediterranean Outflow Water (MOW). Results from the CLIVAR repeat survey indicate that the MOW has high concentrations of dissolved Al (Measures, unpublished, but see GEOTRACES Science Plan), reflecting the high loading of dust in the Mediterranean Sea. End member concentrations of Al and

other TEIs should be established, along with estimates of the fluxes of TEIs into the North Atlantic Ocean via the MOW.

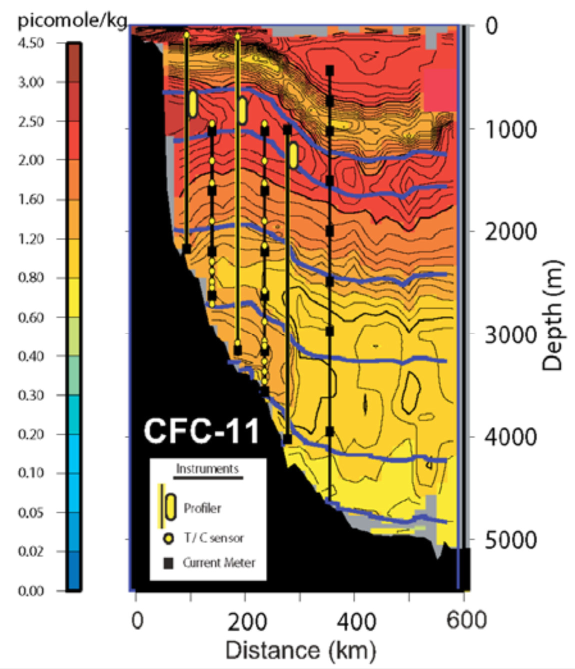
- The eastern end of the section offers two opportunities for crossover/intercalibration with other sections: one outside the Straits of Gibraltar will be occupied by the Med section, and one offshore of Vigo will be occupied by the OT section.
- Steaming time for the longest possible section (WHOI-BDA-TAG-Canary Islands-Gibraltar-Vigo) is about 20 days.

Other Considerations

1) Meridional sections, considered by another working group, and the zonal sections considered here should each measure the full suite of TEIs and related parameters at crossover stations for intercalibration;

2) Canadian scientists are likely to wish to contribute to GEOTRACES research in the northern North Atlantic Ocean. Unfortunately, Canadian representatives were unable to attend the workshop due to schedule conflicts. Canadian input should be sought before final plans for the field program are established; and

3) Exchange of TEIs between the Arctic and North Atlantic Oceans is of interest to GEOTRACES. However, it was felt that it would be best to wait until after the results of the GEOTRACES IPY cruises have been synthesized before planning any new initiatives within the boundary regions between the Atlantic and Arctic Oceans.



Moorings:

Fixed instruments (moorings 2,4,6)
-T/C sensors
- Vector averaging current meters (VACMs)

Moored Profilers (MMPs, moorings 1,3,5)
- CTD
- ADCP
- Optical backscatter
- Transmissometry (proposed)

Hydrographic survey cruises:

- CTD
- Nutrients
- Dissolved O2
- I-129
- CFCs/SF_6
- Optical backscatter + transmissometry

Figure 5. On-going and planned physical oceanographic measurements along Line W. The section plot includes contoured concentrations of CFC-11, an anthropogenic contaminant introduced mainly during the latter half of the 20th century and incorporated into deepwater via gas exchange within regions of deepwater formation. The section plot also depicts the locations of moored instruments, which are listed on the right hand side of the figure. The wealth of physical oceanographic information available along this array will aid in estimating sources, sinks and transport of TEIs within this margin region. Figure courtesy of John Toole.

BREAKOUT GROUPS 1
1.2 Atlantic Ocean Tropical-Sub Tropical Region

Participants: Bill Landing (Chair); Eric Achterberg (Rapporteur); Tom Church; Peter Croot; Jana Friedrich; Walter Geibert; Bill Jenkins; Pere Masque; Armando Ramirez; Peter Sedwick; Simon Ussher.

The working group agreed that several very important biogeochemical aspects of TEI cycling could be studied in the tropical/subtropical Atlantic Ocean:

1. effects of Saharan dust input to the oceans on TEI cycles, phytoplankton productivity, and cyanobacterial activity, and the influences of these processes on climate.
2. effects of sedimentary suboxic redox cycling on TEI cycles.
3. effects of hydrothermal activity from a slow spreading ridge on TEI cycles
4. effects of turbulence-generated sediment resuspension from mid-ocean ridges and seamounts.
5. effect of the Amazon River plume (and the offshore muds) on TEI cycles.
6. spatial and temporal variations in the TEI signatures of deep water masses of the deep western boundary current system.
7. distributions and fluxes of TEIs, and paleoproxy calibration in the Cariaco basin.

We propose to undertake 2 transects in the tropical/subtropical Atlantic.

Transect 1 (Fig. 6) will be a TEI/microbial/dust/Fe plume study cruise, hopefully championed by Eric Achterberg (with a UK/NERC proposal) and Bill Landing (with a complimentary NSF proposal).

A primary motivation is to investigate the mechanisms for the maintenance of the intermediate-depth tropical Fe and Co (Fig. 7), nitrate (Fig. 8), and phosphate plumes, and TEI transport into and out of these plumes. Is in-situ generation from remineralization of biogenic debris or is lateral mixing /advection along the intermediate-depth redox plume the most important process? The dissolved Mn section from the A16N CLIVAR cruise in 2003 (Fig. 7) strongly supports the hypothesis that the dominant process is vertical settling of biogenic debris followed by in-situ remineralization.

Another strong motivation is to quantify the relationships between atmospheric dust concentrations and the imprint of this dust on TEI concentrations in the surface ocean. Fig. 9 (from the CLIVAR A16N 2003 cruise) shows that high levels of aerosol Fe are expressed as elevated particulate and dissolved Fe in the water column.

The cruise is designed to address the following important aspects of TEI cycling:

1. Investigate control of ocean productivity by TEIs
2. Establish natural microbial community structure
3. Determine ammonium and nitrate uptake rates
4. Determine nitrogen fixation rates
5. Link atmospheric TEI concentrations to dissolved and particulate TEI concentrations in the region under the Saharan dust plume.
6. Determine atmospheric inputs of bioactive trace metals through aerosol and rainfall collections. We envisage the deployments of LIDAR and Cloud-Condensation Nuclei

(CCN) counter on the cruise for ship-board aerosol observations (to be used to ground-truth satellite observations over the region).

7. Quantify aerosol TEI solubility using variety of leaching treatments.
8. Collect unfiltered and filtered rainfall to quantify solubilization of TEIs in dust during rain events.
9. Determine intermediate and deep water TEI supply to the photic zone from diapycnal mixing and upwelling (modeling using high resolution data set).
10. Use turbulence measurements (Microstructure Profiler (MSS90L; Sea and Sun Technology GmbH) in the upper ocean (with ADCP) to apply physical mixing rates to TEI cycling models.
11. Identify sources of TEIs to the region through tracer measurements (Ra isotopes, T/He-3, C-14, O2 balance, in addition to Fe, Al, Ti, Mn). The transect is designed to characterize TEI cycling in the shallow O2 minimum off western Africa, and deeper O2 minimum plume extending across the North Atlantic.
12. Establish trace elements and nutrient fluxes through modeling.
13. Stations over seamounts and the Mid-Atlantic Ridge will be included in the cruise track to study the impact of the nepheloid layer on water column TEI concentrations and undertake proxy studies.
14. Stations over hydrothermal vents on the mid-Atlantic ridge will be included to investigate dissolved and particulate TEI signatures. Sampling in the rift valley would include He-3 as a tracer for hydrothermal input.

This cruise should take place in a period of year with enhanced atmospheric dust concentrations over the tropical North Atlantic. The cruise could start in Cape Verde, and run southeasterly towards the west African coast to characterize TEI cycling in the shallow O2 minimum (Fig. 10). We would also occupy the TENATSO Ocean Time Series station located 50 km northeast off Sao Vicente (Cape Verde). The next leg would run southwesterly across the southern side of the atmospheric dust and deep redox plumes to at least 5ºS, and would include sampling in the Romanche Fracture zone to characterize the TEI chemistry of the mixture between NADW/AABW exchanging through to the Angola Basin. The next leg would head northwesterly to 22ºN to traverse the dust/redox plumes and characterize the horizontal TEI gradients along the northern edge of the dust/redox plumes. The final leg would head almost due south to once again traverse the dust/redox plume and quantify horizontal and vertical TEI gradients, and end in Natal or Fortaleza.

By crossing the dust/redox plumes multiple times, we create a “virtual” offshore transect along the axis of the redox plume. The zigzag pattern of crossings will define the horizontal and vertical extent of the redox plume and the volume of water impacted by remineralization/redox cycling processes.

Stations are proposed at 2 degrees intervals. Not all stations will be full depth. “Shallow” stations would nominally extend below the depth of the redox plume (1800 m, with at least 24 depths to define the vertical gradients above and below the redox plume). Superstations (full depth, high resolution, all TEIs) will be occupied at frequent intervals along the cruise track and will also be positioned at cross-over points among the various Atlantic transects. Stations will overlap with other GEOTRACES stations when lines intersect, and also with GEOSECS, TTO, and CLIVAR stations whenever possible.

Transect 2 (Fig. 6) will be a western boundary current/Amazon/Cariaco Basin cruise. There are three primary motivations for this transect.

1. GEOTRACES sections throughout the Atlantic Ocean will quantify the TEI "signature" of the many deep and intermediate water masses that ventilate the Atlantic. The NADW complex and AABW are found as relatively intense deep western boundary currents, and will be sampled via short sections crossing the boundaries and by along-path transects from Iceland to Argentina. Transect 2 in the tropical/subtropical Atlantic would include 5-6 short transects from the coast into deep water in order to sample these water masses as they pass through the region.

2. From the AMANDES I Project Description (Jeandel and Hamelin, 2007):
The Amazon River provides the largest fresh water input as well as enormous dissolved and particulate loads to the Atlantic Ocean, but little or none influenced by human activity. This very extensive input of sediments and the intense physical reworking of shelf sediments dramatically enhances the upward diffusion of TEIs from the sediment to the water column, particularly the redox-sensitive ones. For these reasons, the Amazon appears to be one of the largest sources of dissolved elements to the Atlantic Ocean. In addition, the Amazon river supplies a large amount of nutrients. When the river outflow mixes with oceanic waters, the turbidity decreases and large diatom blooms are observed. This creates a strong CO_2 drawdown leading to a significant sink of atmospheric CO_2.

In addition, tidal flushing (up to 7 meters) along the northeastern Brazilian coast interacts with the permeable sediments and wide-spread mangrove marshes, delivering massive quantities of terrestrial organic matter and diagenetically-remobilized TEIs to the coastal ocean.

3. Taken from: http://www.imars.usf.edu/CAR/index.html
The CARIACO (CArbon Retention In A Colored Ocean) Program has studied the relationship between surface primary production, physical forcing variables like the wind, and the settling flux of particulate carbon in the Cariaco Basin. This depression, located on the continental shelf of Venezuela, shows marked seasonal and interannual variation in hydrographic properties and primary production.

This peculiar basin is anoxic below ~250 m, due to its restricted circulation and high primary production. CARIACO observations show annual primary production rates exceed 500 gC/m^2y, of which over 15-20% can be accounted for by events lasting one month or less.

The Cariaco Basin has long been the center of attention of scientists trying to explain paleoclimate. Due to its high rates of sedimentation (30 to >100 cm/ky) and excellent preservation, the varved sediments of the Cariaco Basin offer the opportunity to study high resolution paleoclimate and better understand the role of the tropics in global climate change.

The CARIACO program also provides a link between the sediment record and processes near the surface of the ocean. Sediment traps maintained by the CARIACO program show that over 5% of autochthonous material reaches 275 m depth, and that nearly 2% reaches 1,400 m. The significance of this flux is that it represents a sink for carbon and that it helps explain the record of ancient climate stored at the bottom of the Cariaco Basin.

Specific goals for Transect 2 are thus:

1. To characterize the TEI chemistry of the NADW deep water mass complex and AABW as it passes through the tropical/subtropical Atlantic.

2. To constrain the nature, transformation and dispersion into the ocean of the fluxes of TEIs weathered from the Andes Mountains and transported by the Amazon river and estuarine systems to the northeastern Brazilian shelf and ultimately into the western Atlantic.
3. To quantify the fluxes of TEIs in the Cariaco basin.
4. To enable paleoproxy calibration efforts associated with the established sediment records from the Cariaco basin.

Closely spaced stations will be required to characterize the shallow jets coming off the northeastern coast of South America that carry coastal and Amazon-influenced water into the interior. We will undertake high resolution shallow casts and lower resolution deep casts to characterize deep water masses. Stations in the Cariaco basin should be coordinated with the monthly visits to the Cariaco time-series station where basic hydrographic and biological measurements are made. Superstations (full depth, high resolution, all TEIs) will be positioned at cross-over points among the various Atlantic transects. Stations will overlap with other GEOTRACES stations when lines intersect, and also with GEOSECS, TTO, and CLIVAR stations whenever possible.

Links to other Transect

-Germans run north-south oxygen cruises on 23ºW. Peter Croot is the liaison person.

-Our proposed two transects would cross the proposed DeBaar North Atlantic lines at 15N and 2N.

-Ed Boyle plans to run a TEI line from Cape Verde to Barbados in 2009 to study atmospheric dust concentrations and the upper ocean response.

-Balzer (Bremen) is leading a TEI cruise in 2009 to occupy an "L" line from Barbados to Natal and over to Cape Verde

-There may be German TEI cruises in this region in 2012-2014, some of which may be full GEOTRACES cruises (contact person: Martin Frank).

-Peter Croot is part of a 3-year program conducting aerosol and water column sampling in Cape Verde (the TENATSO atmospheric observatory and TENATSO ocean observatory: shallow for now; 1000m hoped). Additional funding will be needed to continue the program after 2010.

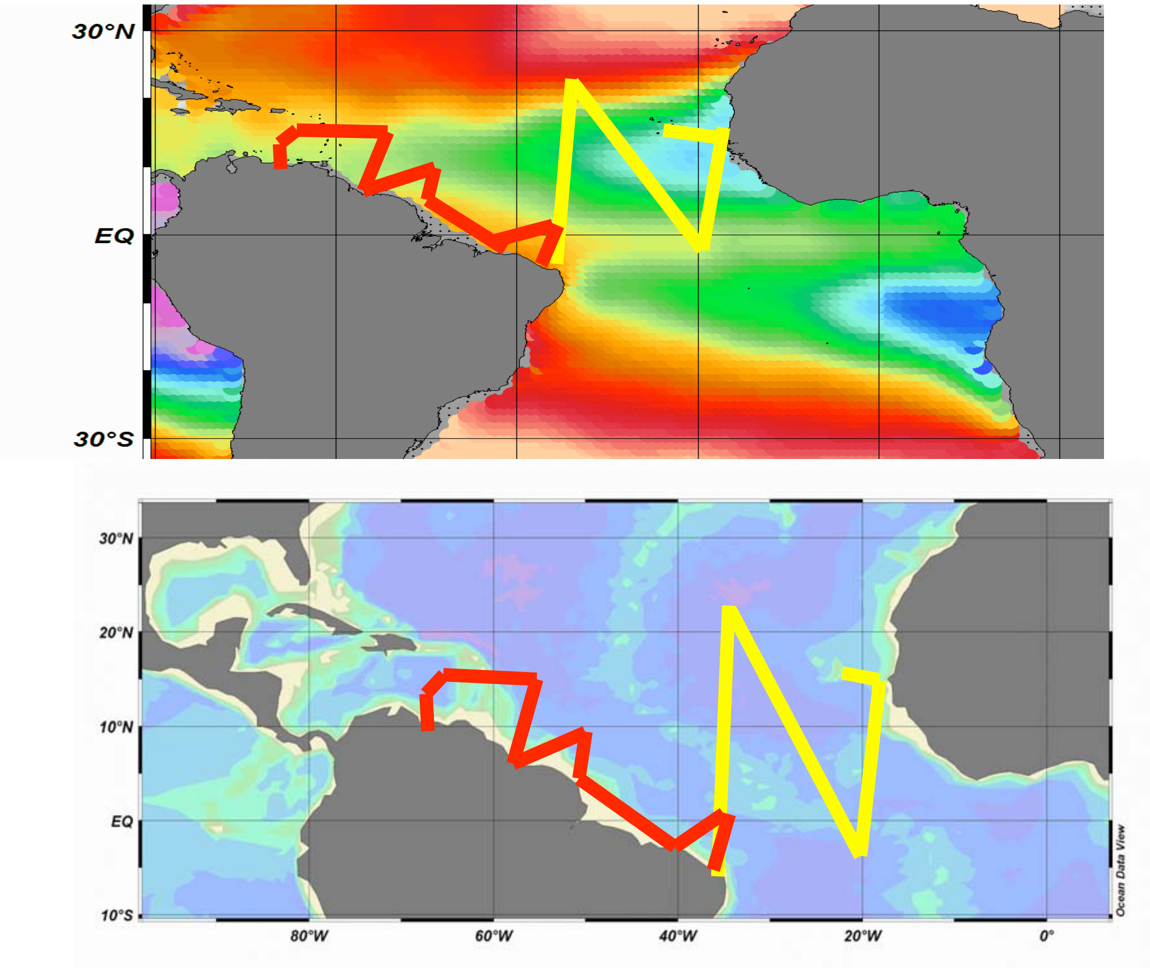


Figure 6. Preliminary cruise tracks for the tropical/subtropical Atlantic. Transect 1 is in yellow, Transect 2 is in red. The top panel shows the cruise tracks superimposed on the dissolved oxygen distribution on the 27.1 sigma-0 density surface (approx. 500 m). The lower panel shows the cruise tracks superimposed on the bathymetry.

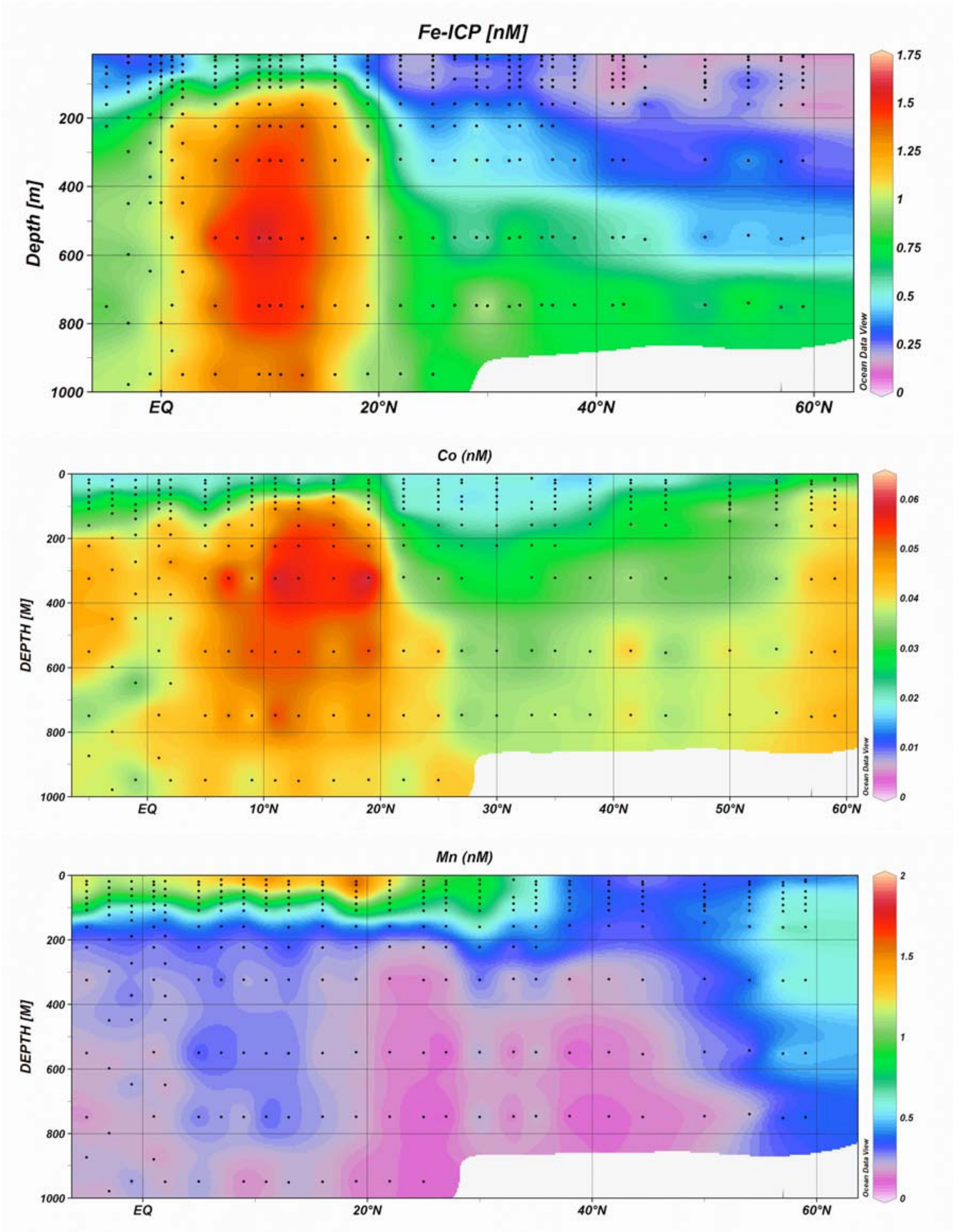


Figure 7. Dissolved Fe, Co, and Mn sections from the CLIVAR A16N cruise in 2003. This is the northern portion of the A16 cruise track shown in Fig. 8. Fe and Co show maxima in nitrate-rich, low oxygen intermediate waters from 0-20ºN, while Mn shows low values. (unpublished data from Bill Landing).

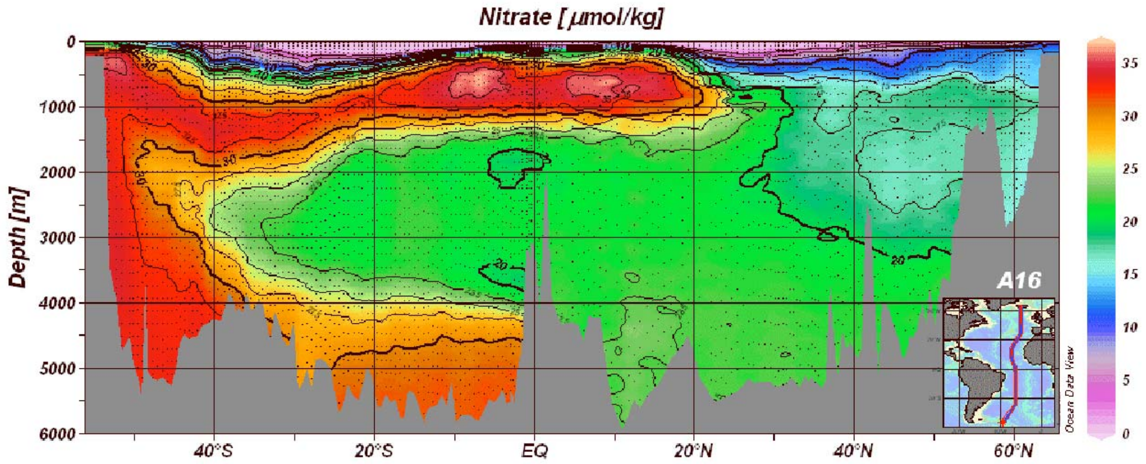


Figure 8. Nitrate section from the A16 WOCE line showing the elevated nitrate values in the intermediate depth oxygen-minimum redox plume from 0-20ºN. eWOCE figure; Schlitzer, R., Electronic Atlas of WOCE Hydrographic and Tracer Data Now Available, Eos Trans. AGU, 81(5), 45, 2000; Schlitzer, R., Electronic Atlas of WOCE Data, http://www.ewoce.org/, 2008.

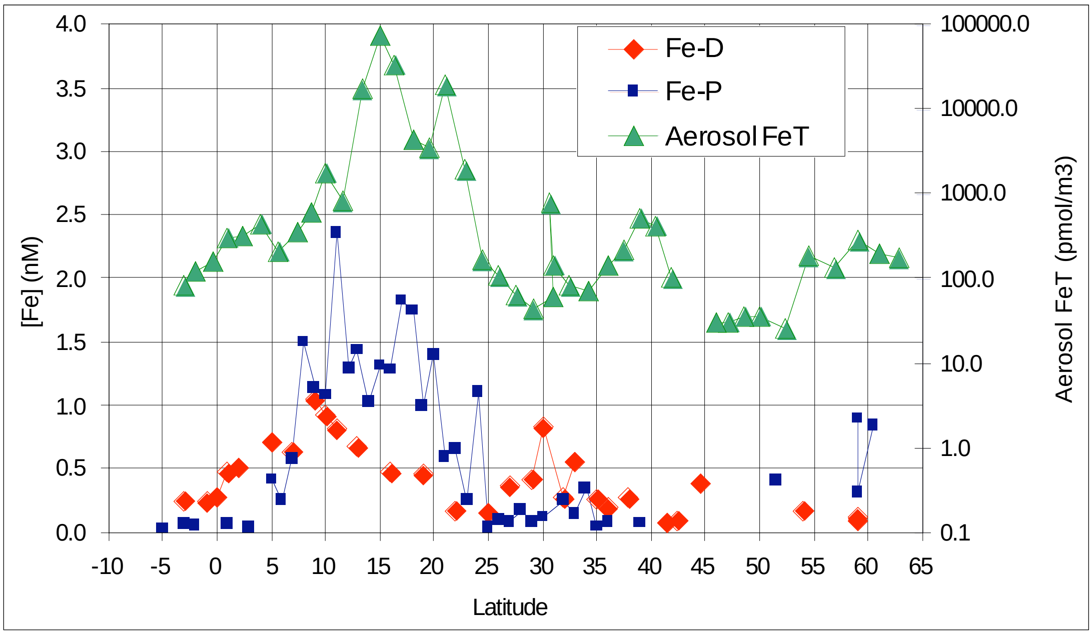


Figure 9. Concentrations of aerosol Fe (green triangles, log-scale, right axis), particulate Fe (blue squares, linear left axis), and dissolved Fe (red diamonds, linear left axis) along the A16N cruise track. Unpublished Data provided by W.M. Landing and C.S. Buck

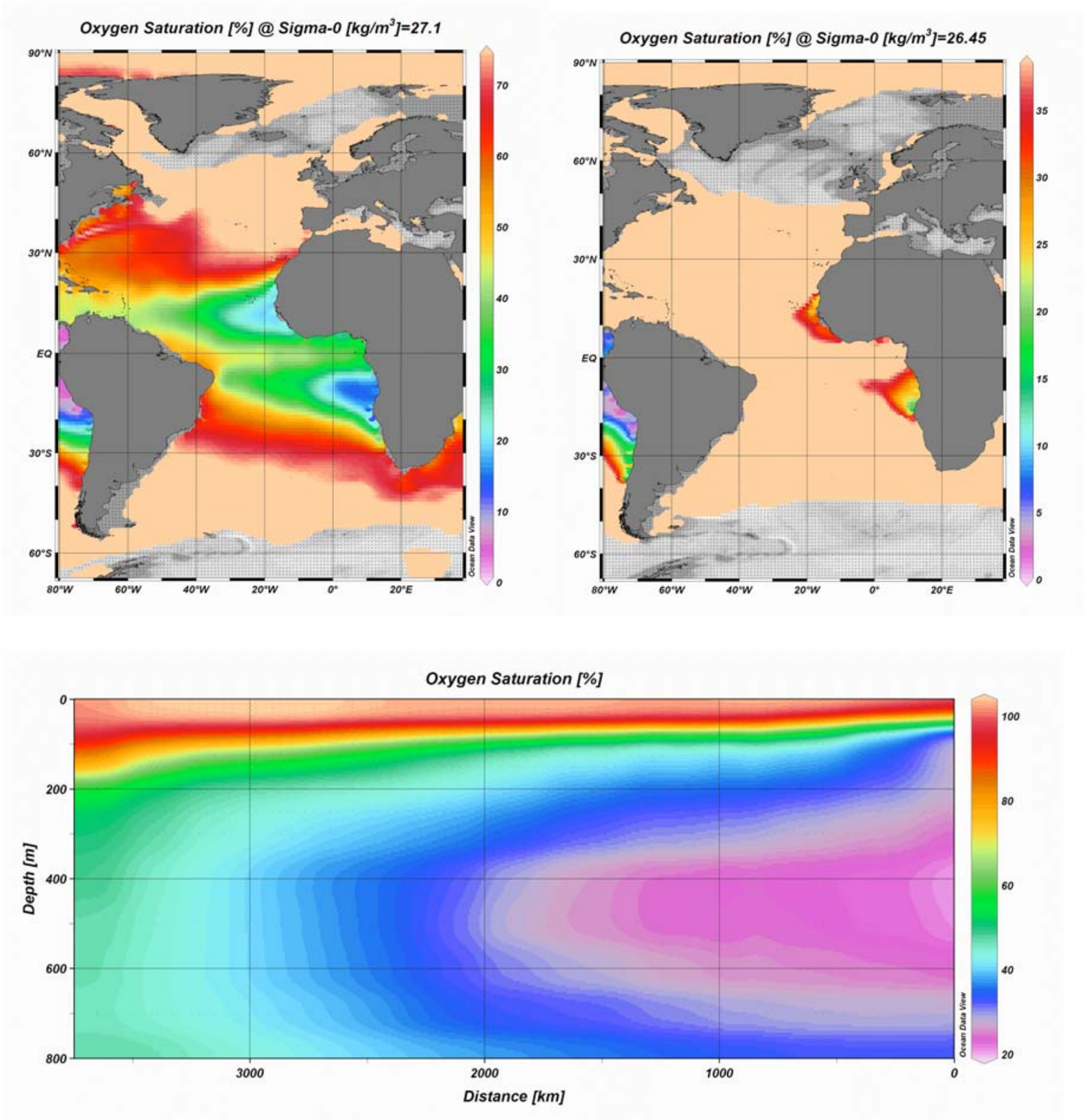


Figure 10. Dissolved oxygen distributions in the tropical/subtropical Atlantic showing the shallow oxygen minimum on the 26.45 sigma-0 surface (<100m), the intermediate-depth redox plume on the 27.1 sigma-0 surface (400-500m), and a depth section from western Africa into the basin. eWOCE figure; Schlitzer, R., Electronic Atlas of WOCE Hydrographic and Tracer Data Now Available, Eos Trans. AGU, 81(5), 45, 2000; Schlitzer, R., Electronic Atlas of WOCE Data, http://www.ewoce.org/, 2008.

BREAKOUT GROUPS 1

1.3 South East Atlantic Basin

Participants: Mak Saito (Chair); Rachel Mills (Rapporteur); Greg Cutter; Martin Frank; Ben Reynolds; Jan Scholten; Bronwen Wake.

Executive Summary

The southeastern Atlantic basin is a region of considerable geochemical interest with significant TEI inputs along the West African margin. We discussed potential cruises tracks and the numerous processes in the region that should be considered. These include: high productivity of the Benguela upwelling region, redox processes associated with the strong oxygen minimum zone, deepwater water mass movement and evolution, Namibian dust inputs, and Congo river output. In addition, there are the seasonal features of the Angola Dome and high upwelling productivity that could constrain the timing of a cruise (January to May).

Three cruise tracks were proposed: a meridional section, and two major zonal tracks across the Southern Atlantic basin. Discussions with the Southwest Atlantic Working group led to connecting the most southern zonal lines of each group. The cruise tracks are described in detail below.

Southeastern basin meridional transect

The proposed cruise track (Fig. 11) is a modified version of WOCE line A13 primarily along 5E. The strong OMZ is sampled along the northern part of the transect to 23^{o}S. The deepwater of the Angolan basin, and the Cape Basin are sampled along this transect. The Walvis Ridge is believed to significantly impede exchange of waters between NADW and AABW (Fig. 12); the Guinea Ridge has a smaller but potentially significant impact on the deep water properties. Additional short/intermediate length zonal transects were included on this transect to capture the productivity filaments associated with the Benguela upwelling region, and the Angola Dome (Fig. 13), the interaction of the OMZ with the shelf sea sediments, and Congo River outputs. The southern end of the transect was extended south to ~33-35^{o}S rather than following the A13 WOCE line eastwards. This is an important change in order to capture deepwater features of the Cape Basin.

Given significant previous German involvement in this area, this was considered a potential German GEOTRACES line. This meridional track is also synergistic with an upcoming R/V Knorr cruise aiming to be GEOTRACES-compliant from Natal, Brazil to Walvis Bay, Namibia (Saito Chief Scientist – light blue line on Fig. 11), which will cross the basin zonally following the southern component of the oxygen minimum zone and Benguela current.

Southern Zonal Transect at 40S

The A10 Clivar/WOCE line is at 30S but we have chosen a more southern track at 40S to allow sampling of the deepwater basins more effectively. In particular, the Cape and Argentine basins are effectively sampled along this transect, while 30S crosses shallow bathymetry including the Walvis Ridge and thus misses much of the Cape Basin. The 40S transect crosses the mid-Atlantic ridge where significant primordial ^{3}He effluxes have been observed at all Southern Atlantic WOCE sections indicating that hydrothermal inputs may be dispersed widely in the Southern Atlantic. The 40S region is also an area of enhanced biomass (significant nanoplankton activity) and sharp productivity gradients. The section offers an ideal section for sediment core-top proxy calibration against known water column parameters. The eastern jog into Capetown contributes to studying surface water retroflection in the Agulhas current which is important rapid western boundary process. This particular feature is synergistic with the French BONUS-GOODHOPE project, which is particularly focused on water mass circulation processes in the area south of South Africa. This transect could be underpinned by a UK proposal to calibrate proxies.

Northern Zonal Transect from the Congo River to Amazon River

A transect investigating river influences on the central Atlantic basin through a zonal cruise connecting the output of the Congo basin with the Amazon output. While this cruise was the least discussed due to overlap with the equatorial group, this track would cover the southern reach of Saharan dust inputs, Amazon and Congo riverine inputs, equatorial and intertropical convergence zone processes, and reaching the shadow zone near the Guinea Dome and the south Atlantic subtropical gyre. This cruise could be an extension of US equatorial Atlantic cruise(s).

Additional information:

Links to German sampling information in the Benguela region.
http://www-odp.tamu.edu/publications/citations/cite175.html

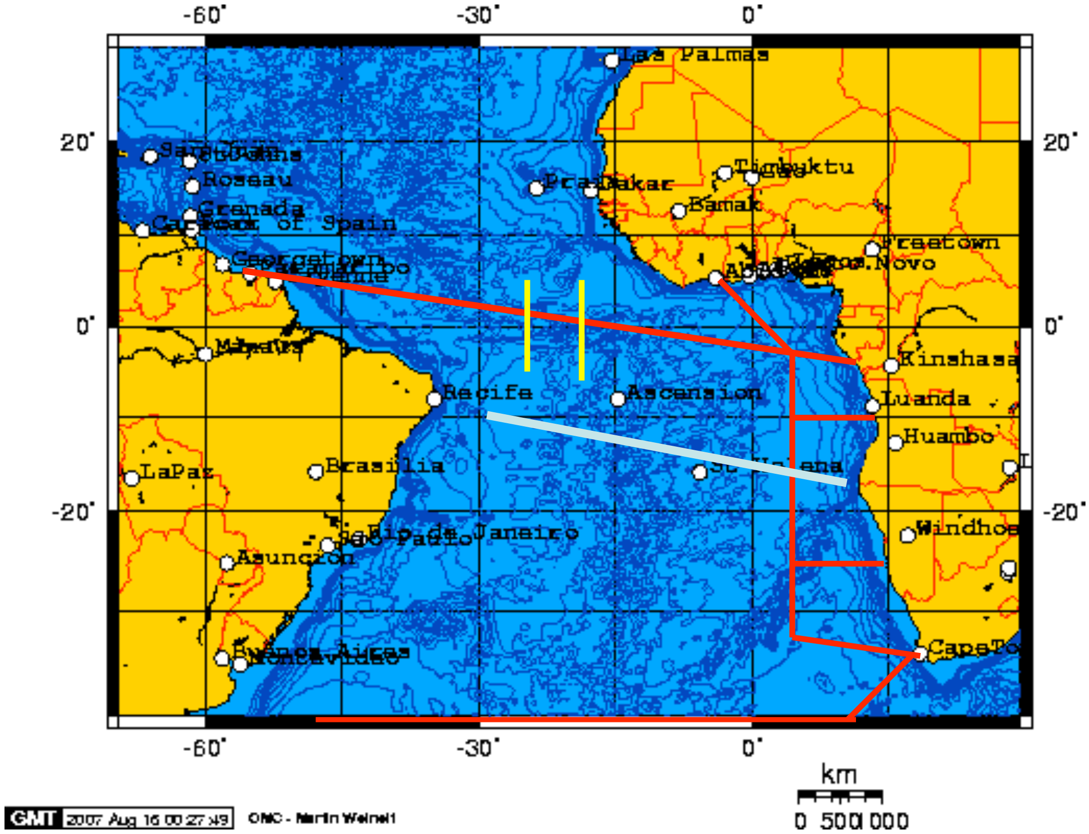


Figure 11. Three proposed cruise tracks from Southeastern Atlantic Working group. 1) Meridional transect from Capetown to Ghana intersects the oxygen minimum zone and several deep basins including the Guinea Abyssal Basin, Angola Abyssal Basin, and Cape Abyssal Basin. Intermediate length zonal transects are included that correspond to Angola Dome, Benguela upwelling, and access to the Cape Abyssal Basin, respectively from north to south. 2) 40S zonal transect connects to the west south Atlantic group's line, and should covers all major water masses in the Southern Atlantic. 3) Congo Basin to Amazon Basin: a zonal transect intended to capture riverine inputs, southern edge of Saharan dust inputs, and equatorial processes. In addition yellow lines indicate either suggested longitude of AMT/Antarctica resupply GEOTRACES lines (or short meridional transects) in order to capture deepwater TEI fluxes through the Romanche Fracture Zone. The light blue line indicates putative GEOTRACES-compliant cruise (Saito chief scientist, Nov-Dec 2007). In addition, there is a major EU/French program south of South Africa BONUS-GOODHOPE that may also be GEOTRACES-compliant.

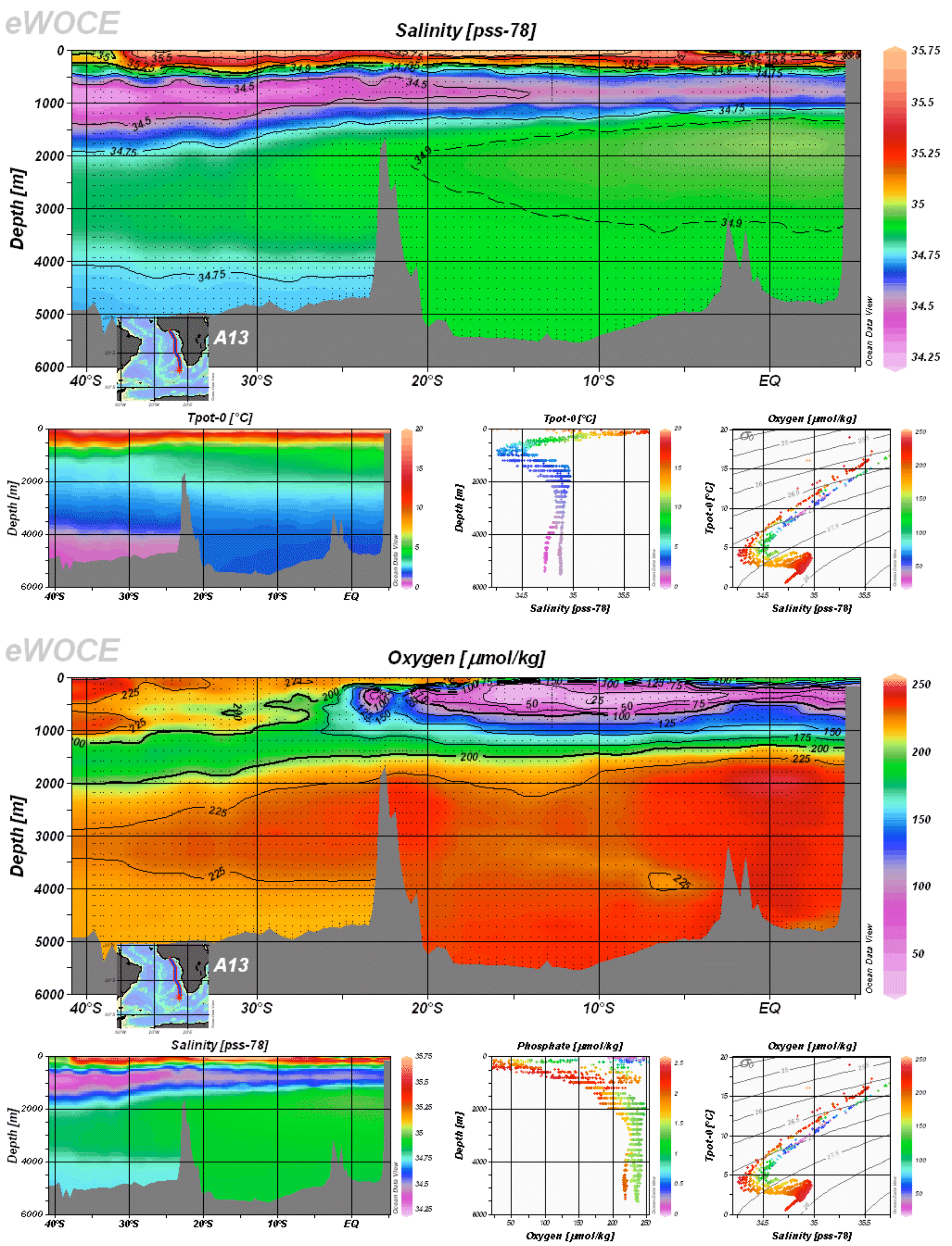


Figure 12. WOCE salinity and oxygen data from A13, similar to the location of our first proposed transect. Note the influence of Walvis Ridge on deepwater salinity, and the presence of a strong oxygen minimum zone north of ~23S. (Schlitzer, R., Electronic Atlas of WOCE Hydrographic and Tracer Data Now Available, Eos Trans. AGU, 81(5), 45, 2000; Schlitzer, R., Electronic Atlas of WOCE Data, http://www.ewoce.org/, 2008).

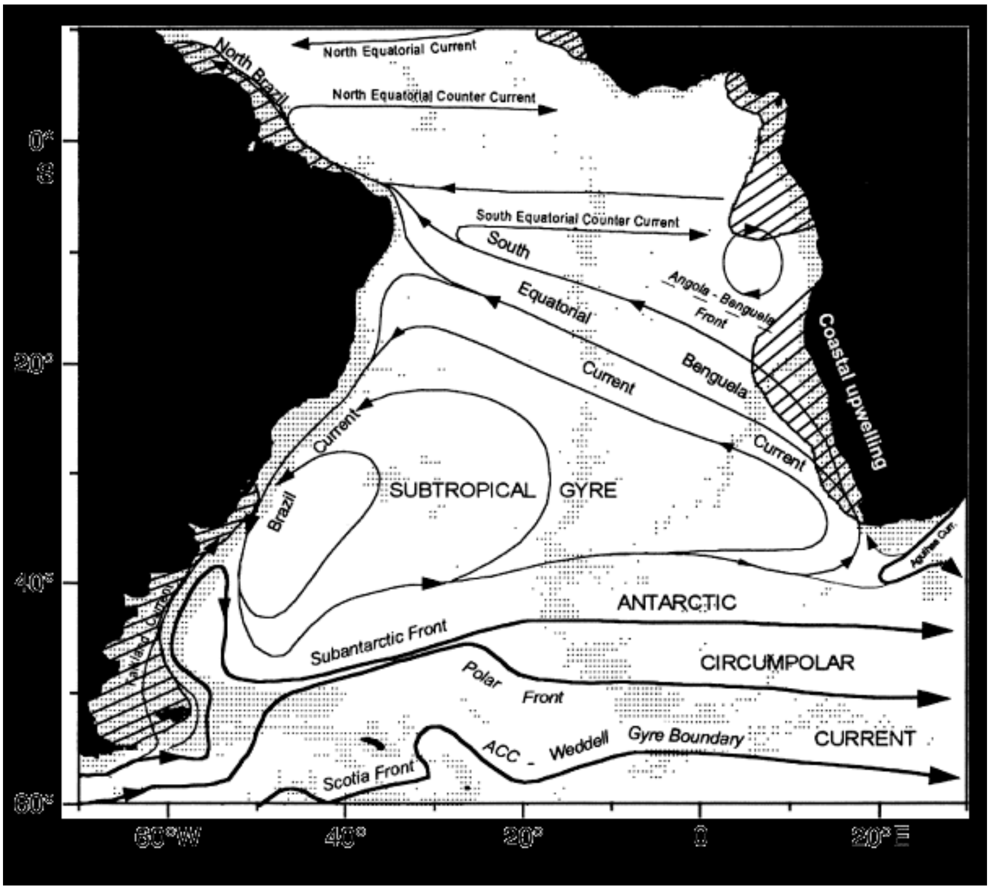


Figure 13. Major circulation patterns and location of the Angola Dome in the South Atlantic. Reprinted from Progress in Oceanography, Vol. 26 / Issue No. 1, Ray G. Peterson and Lothar Stramma,Upper-level in circulation in the South Atlantic Ocean, Pages Nos.1 - 73, Copyright (1991), with permission from Elsevier; http://www.sciencedirect.com/science/journal/00796611.

BREAKOUT GROUPS 1
1.4 Southwest Atlantic Ocean

Participants: Billy Moore (Chair); Tina van de Flierdt (Rapporteur); Jana Friedrich; Steven Goldstein; Gideon Henderson; Felipe Niencheski; Peter Statham

Executive Summary

The southwest Atlantic Ocean is recognized as one of the primary CO_2 sinks of the world ocean and one of the most biologically productive. This is apparent from satellite imagery of the chlorophyll field. However, little is known about the sources, sinks and cycling of many TEIs in this region. Almost no information is available concerning interactions of TEIs and productivity in this region.

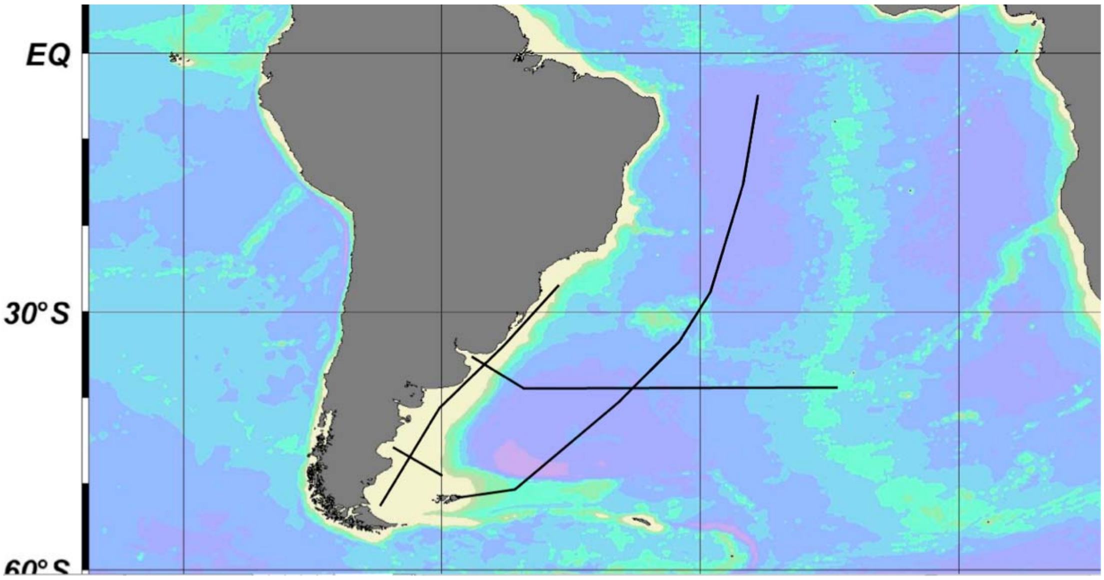


Figure 14: Proposed GEOTRACES cruise tracks for the southwest Atlantic Ocean.

High productivity transect on shelf

This area is controlled by the northward flowing Malvinas Current, and the southward flowing Brazil Current. The convergence zone of these two major ocean currents is recognized as a zone of high productivity. The highest productivity occurs during the austral spring/summer (October through January) (Fig. 15). During the austral winter the productivity is constrained to the near coastal area (Fig. 16). The high productivity in the region is the reason this is one of the richest fishery areas of the world, illustrated by the night lights from fishing vessels shown in Fig. 17. The source of controlling macro- and micronutrients are not resolved. The Malvinas Current transports macronutrients from the Southern Ocean and is augmented during its course by upwelling of fresh nutrients. Additional nutrient sources may include rivers (Rio de la Plata; Patos Lagoon complex) and submarine groundwater discharge. The source of micronutrients is largely unknown. Primary candidates include dust transport from Patagonia, upwelling of deep waters, river flow, and submarine groundwater discharge. Each of these sources has not only the potential to supply large quantities of micronutrients, but also represent potential major sources of other TEIs. One of the challenges will be to separate source terms in this area and identify controlling processes. The transect will likely be a zig-zag path to cover near-shore and shelf-break processes. We recommend repeating the section in November/December and July/August to cover the seasonality of the productivity feature.

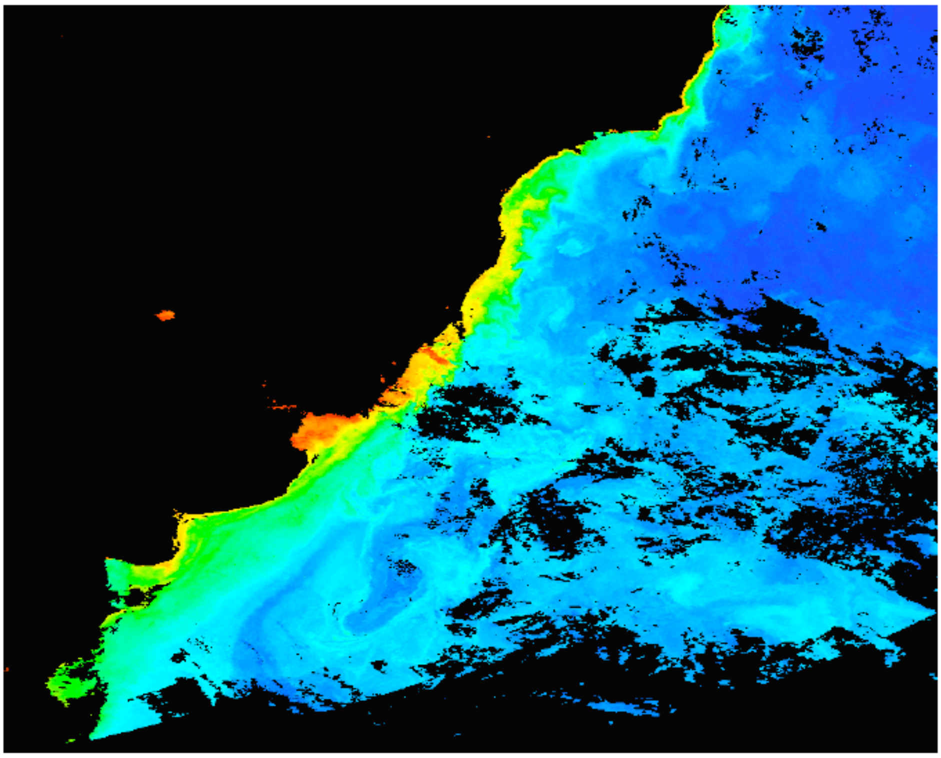


Figure 15: Chlorophyll a concentrations in SW Atlantic, 1-8 November 2003, (Courtesy of NASA at http://visibleearth.nasa.gov).

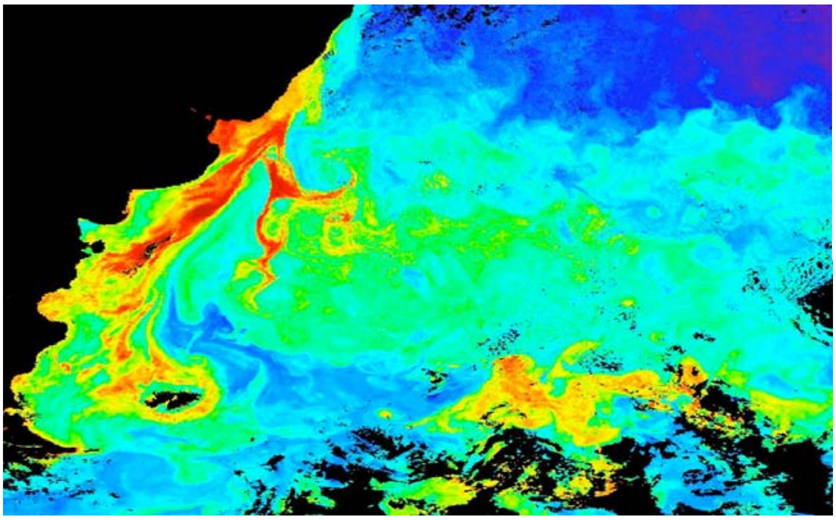


Figure 16: Chlorophyll a concentrations in SW Atlantic, 20-27 July 2003, (Courtesy of NASA at http://visibleearth.nasa.gov)..

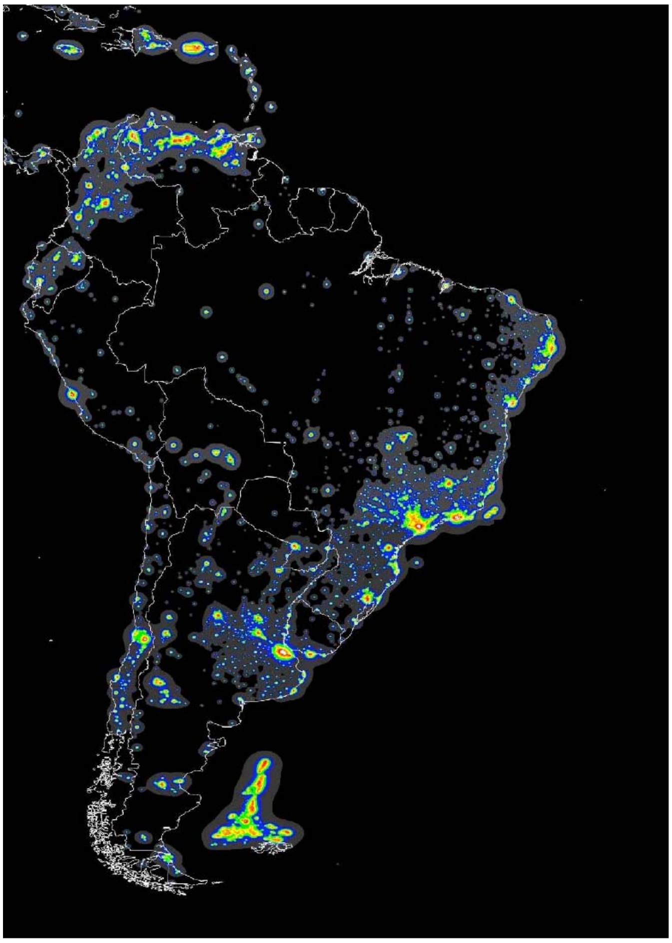


Figure 17: A view of the artificial night sky. Note the very bright patches in the ocean off Argentina due to fishing vessels. From The first World Atlas of the artificial night sky brightness, P. Cinzano, F. Falchi, and C.D. Elvidge, Mon. Not. R. Astron. Soc. 328, 689-702, 2001. Reproduced with permission from Blackwell Publishing Ltd.

Southwest Zonal Section

This section will capture the main water masses of the Atlantic Ocean (NADW, AAIW, AABW) in a E-W transect at ~ 40°S (Fig. 18). It also allows characterizing riverine inputs from South America to the Argentine Basin, and to study far field effect of these inputs. A major scientific objective will be proxy calibration, and sediment cores should be taken from the South American shelf/slope and flank of the mid ocean ridge. This approach will cover two vastly different sedimentary regimes, with high terrigenous inputs in the W, and carbonate sedimentation in the E. For the deep Argentine basin, grab samples may be sufficient.

Additionally, the eastern part of the section captures a potential ^{3}He plume coming off the mid Atlantic ridge. From a paper by Ruth et al. (2000) it looks like this plume may increase in strength from N to S, but their data only reach about 30°S (Fig. 19). The zonal transect at 40°S would therefore be a major opportunity to study a hydrothermal plume in the South Atlantic and its effect on TEIs.

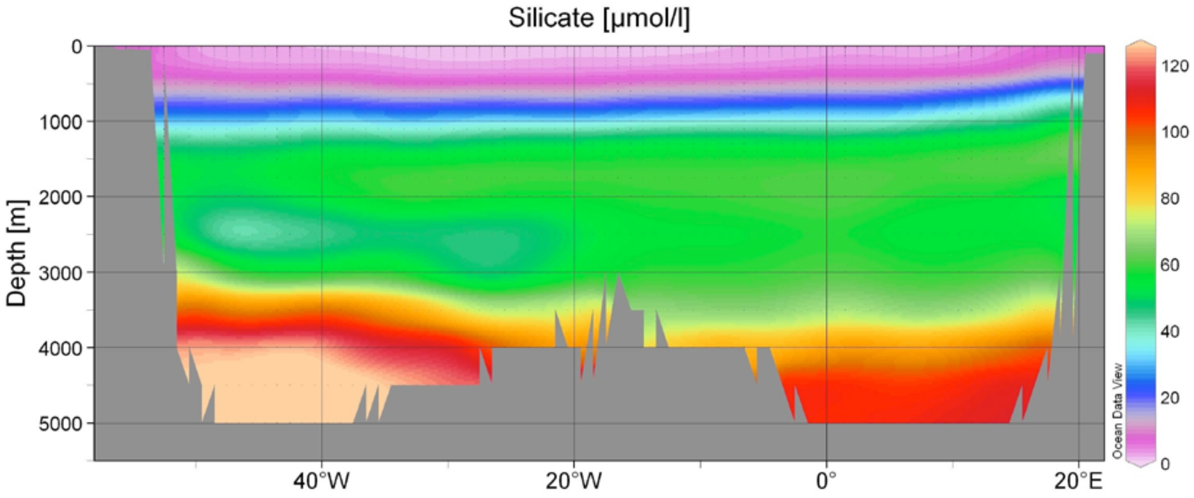


Figure 18: Transect across the Atlantic Ocean showing the silicate content of the different water masses. (Schlitzer, R., Electronic Atlas of WOCE Hydrographic and Tracer Data Now Available, Eos Trans. AGU, 81(5), 45, 2000; Schlitzer, R., Electronic Atlas of WOCE Data, http://www.ewoce.org/, 2008).

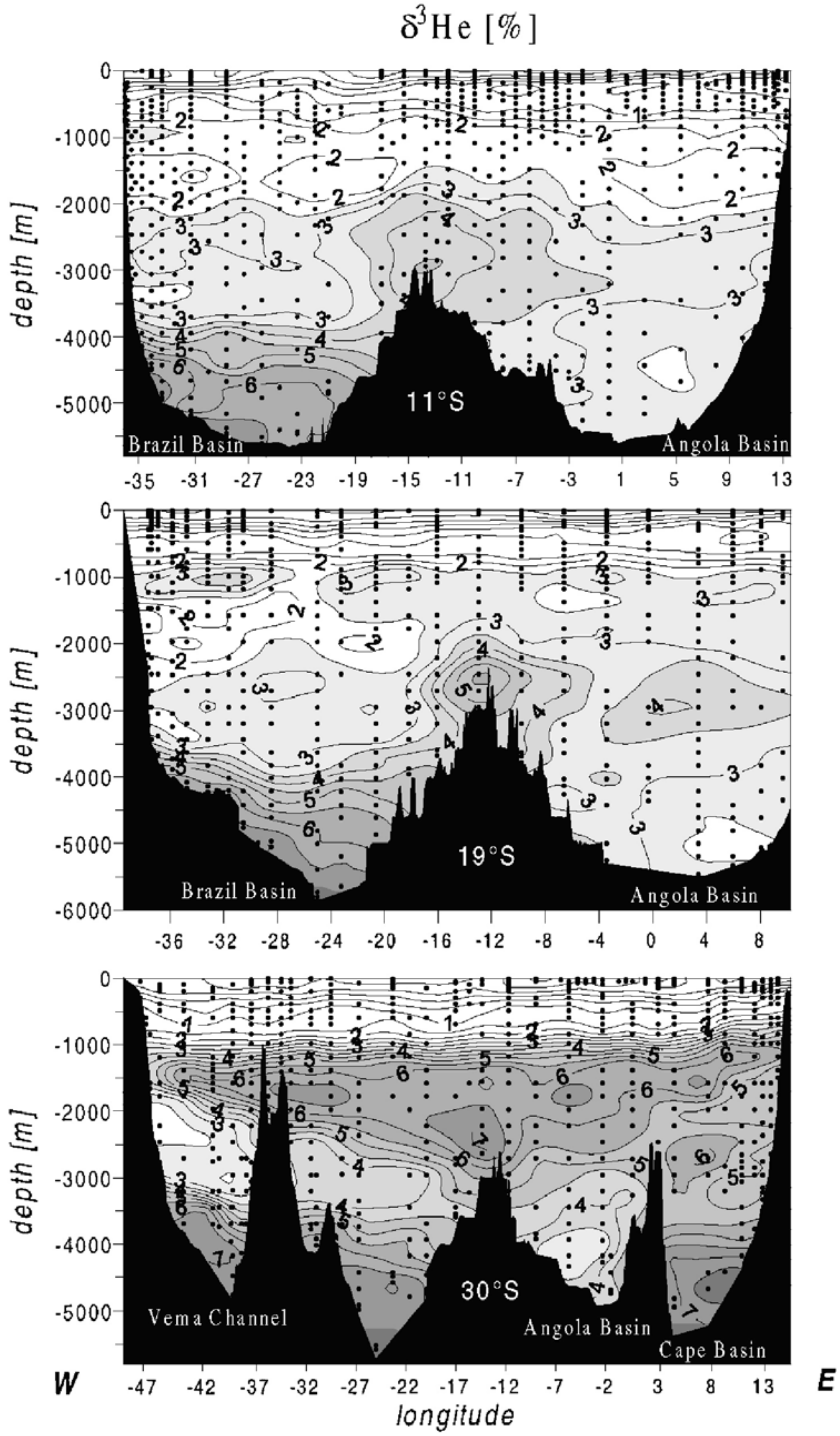


Figure 19: ^{3}He isolines (%) along the sections in 11°S, 19°S and 30°S. Data points are indicated by dots (Reprinted from Deep Sea Research Part I: Oceanographic Research Papers, Vol. 47, No. 6, Christine Rüth, Roland Well and Wolfgang Roether, Primordial ^{3}He in South Atlantic deep waters from sources on the Mid-Atlantic Ridge,pp. 1059-1075, 2000, with permission from Elsevier) http://www.sciencedirect.com/science/journal/01980149.

Meridional Transect

The main scientific rationale for this transect is to capture all the main Atlantic water masses along the meridional flow path (NADW, AAIW, AABW; Fig. 20). The line will complete a N-S transect along the entire western Atlantic basin. Additionally, the southern meridional transect will be ideally suited to investigate the far field effects of dust input from Patagonia into the Atlantic Ocean and its effect on TEIs. According to models, the dust plume reaching eastwards from Patagonia into the Atlantic Ocean is one of the few robust features (Fig. 21).

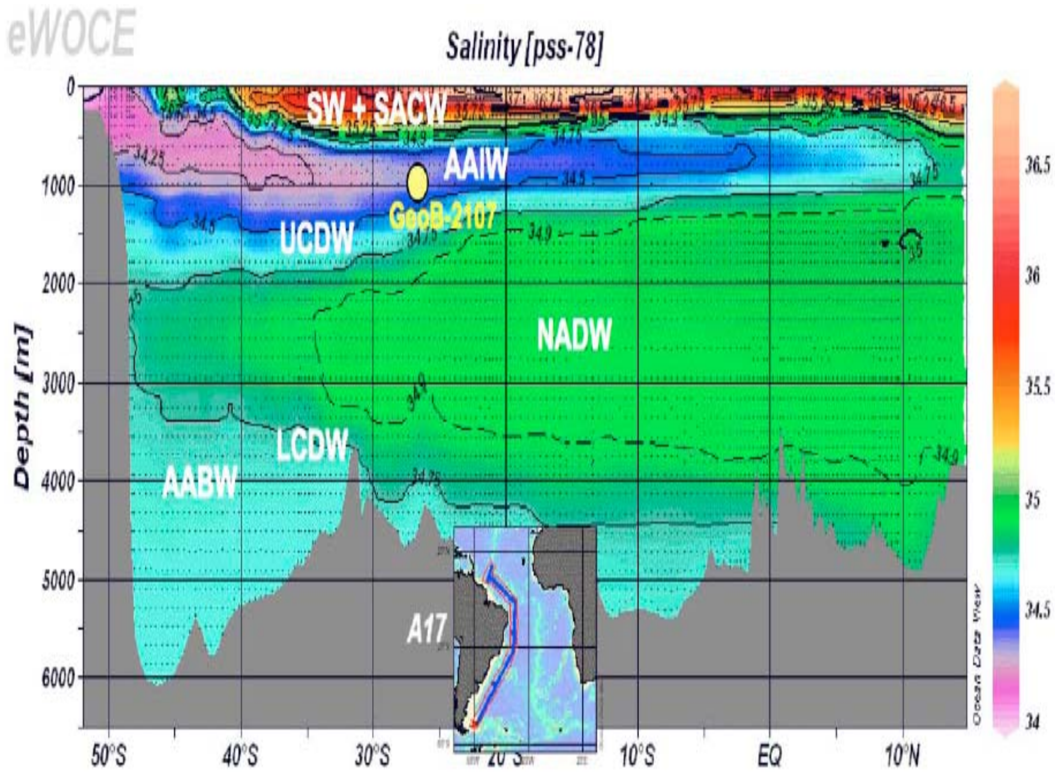


Figure 20. Meridional salinity section in the western South Atlantic Ocean along WOCE line A17 illustrating the principal water masses. Tongue of green color: North Atlantic Deep Water (NADW) moving southward. Tongues of light blue and blue colors: Southern Ocean-derived water masses moving northward (AABW: Antarctic Bottom Water; LCDW: Lower Circumpolar Deep Water; UCDW: Upper Circumpolar Deep Water; AAIW: Antarctic Intermediate Water). SACW: South Atlantic Central water; SW: Shelf Water. (Schlitzer, R., Electronic Atlas of WOCE Hydrographic and Tracer Data Now Available, Eos Trans. AGU, 81(5), 45, 2000; Schlitzer, R., Electronic Atlas of WOCE Data, http://www.ewoce.org/, 2008).

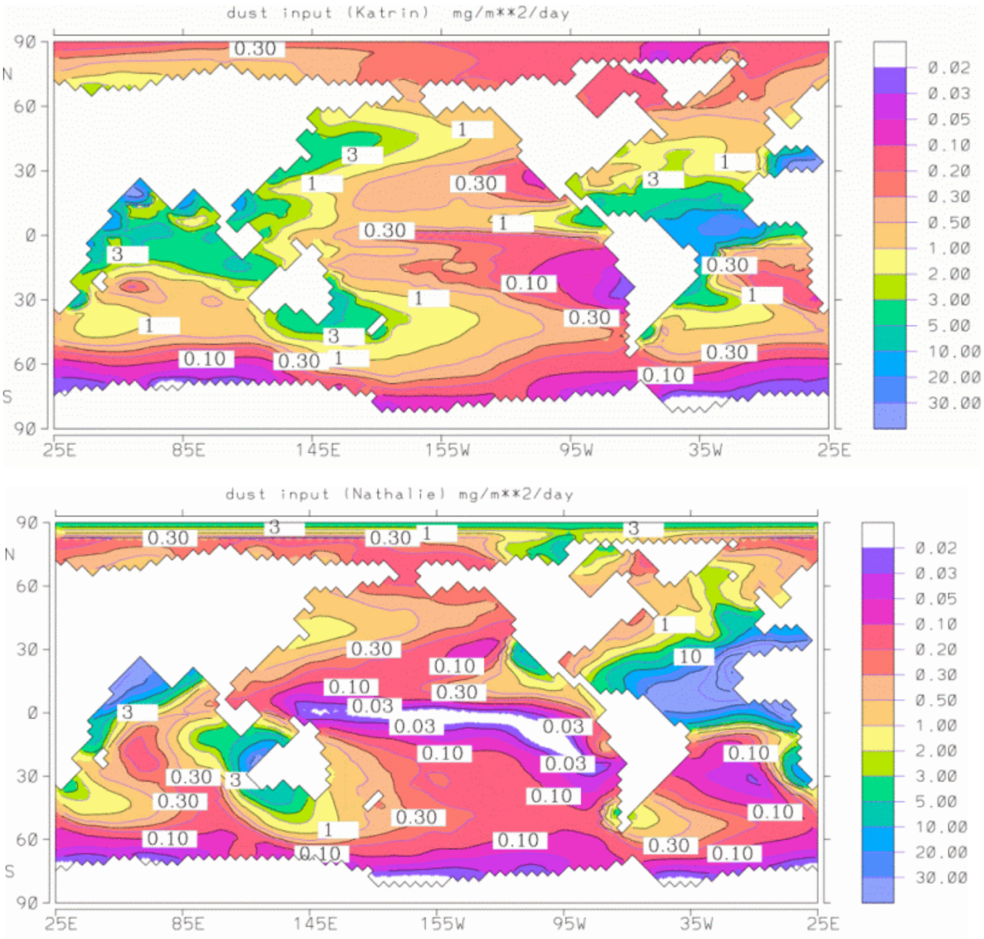


Figure 21. Two different model simulations for dust input to the surface ocean (in mg/m^2/day). Figures supplied by Ernst Maier-Reimer following Mahowold et al. (1999, lower panel) and Andersen (pers com., upper panel). N. Mahowald, K. Kohfeld, M. Hansson, Y. Balkanski, S.P. Harrison, I.C. Prentice, M. Schulz, H. Rodhe, Dust sources and deposition during the last glacial maximum and current climate: A comparison of model results with paleodata from ice cores and marine sediments, Journal of Geophysical Research-Atmospheres 104(1999) 15895-15916.

BREAKOUT GROUPS 2

2.1 Mediterranean Basin

Participants: Angelos Hannides (rapporteur); Cecelia Hannides; Catherine Jeandel; Pere Masqué; Chris Measures; Felipe Nienchenski; Jackie Pates; Mak Saito; Jan Scholten; Peter Statham.

The Mediterranean Working Group met in the afternoon of day 3 of the Atlantic Ocean Workshop (11th September 2007). We drafted potential GEOTRACES section tracks (see figure) that were motivated by (and cover) the following features and important processes:

- Atlantic Ocean water entering and traversing the Mediterranean and changes in its chemical signal during this process;
- Sites of formation of intermediate/deep waters in both basins and the evolution of their chemical signal;
- Sites of shelf-basin exchange, e.g., riverine input;
- Regions of dust deposition and geochemical processes associated with such events;
- Diverse topographic features, e.g., shelves, sills, abyssal plains, seamounts;
- An inter-calibration site on the Atlantic Ocean side of the Straits of Gibraltar.

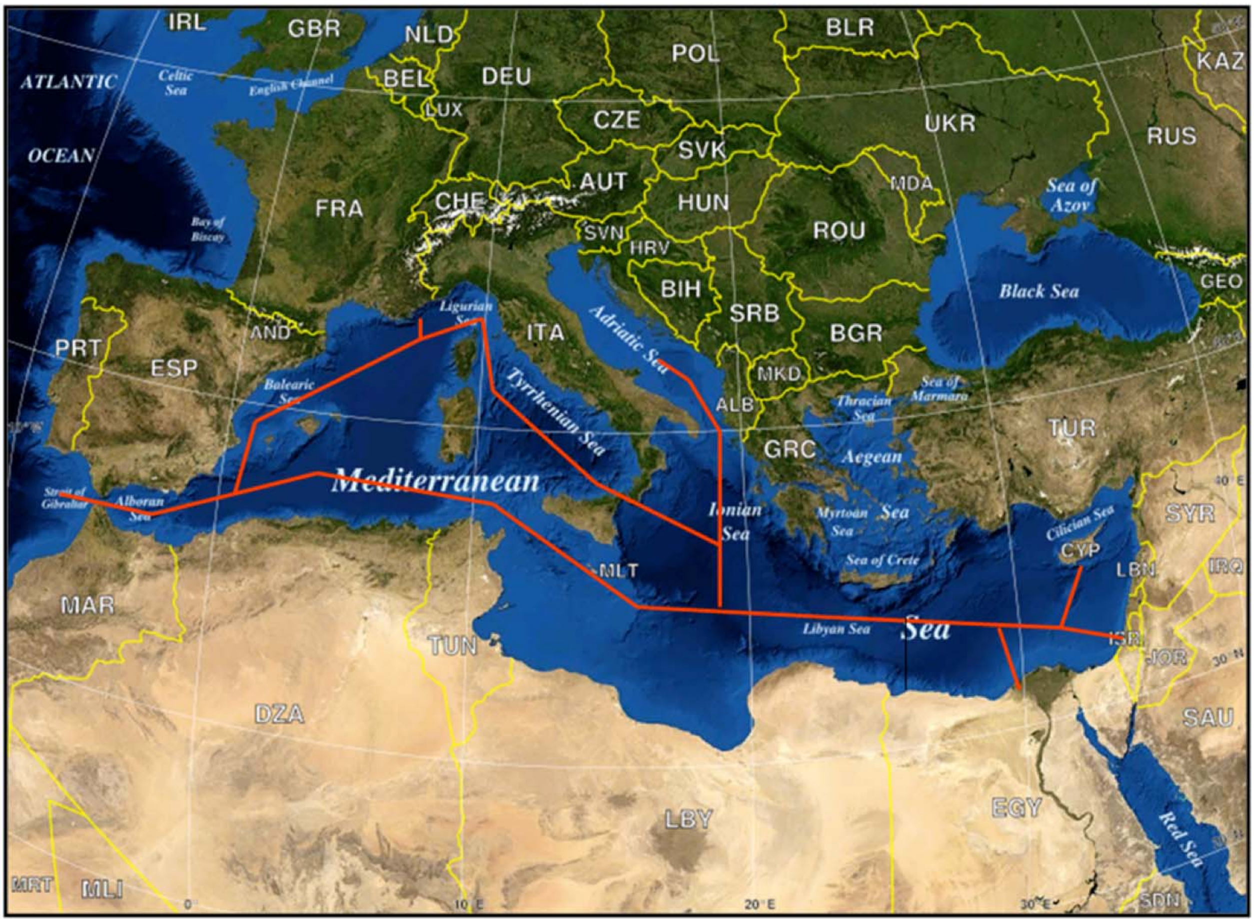


Figure 22: Proposed GEOTRACES section(s) covering the Mediterranean basin. The steaming time needed to cover these tracks was estimated at 17 days.

We were informed that France is planning to actively pursue broader Mediterranean oceanographic operations in the coming years. This may well translate into ship time opportunities for GEOTRACES sections. It was also recognized that France, Spain, and Italy are the only Mediterranean countries which currently have vessels with the capability to conduct GEOTRACES cruises. Based on what we knew about the commitments of such vessels for the next few years, we estimated that realistically we should anticipate actual oceanographic operations (specifically from French vessels) from 2013 on-wards.

BREAKOUT GROUPS 2
2.2 Caribbean

Participants: Billy Moore (Chair); Martin Frank (Rapporteur); Bill Landing; Armando Ramirez

Scientific Goals

There are essentially five scientific goals that can be covered by the proposed Caribbean Cruise track. The amount of TEI work that has been carried out in the Caribbean in the past is very scarce, which, according to the opinion of the breakout group should be an essential contribution of GEOTRACES given the importance of the Caribbean for the formation of the Gulf Stream and its large submarine groundwater discharges (SGDs).

Major currents and water masses

The central goal which is of immediate interest in connection with the Atlantic and global circulation is the characterization, the endmember composition and potential alterations of the TEI distribution of the major water masses of the Caribbean, which ultimately form the Gulf Stream exiting through Florida Strait. The Caribbean only has a limited exchange with the western Atlantic Ocean which is for example reflected by its low oxygen content. Major features to be covered by a Caribbean section are the inflowing waters from the Atlantic Ocean in the southeastern part of the Caribbean Basin through the Lesser Antilles, which will be coordinated with the envisaged UK cruise track along the northern margin of South America. Within the Caribbean detailed data on the TEI composition of the water masses going through Yucatan Strait, the Loop Current in the Gulf of Mexico, and Florida Strait will be of particular interest (Fig. 23).

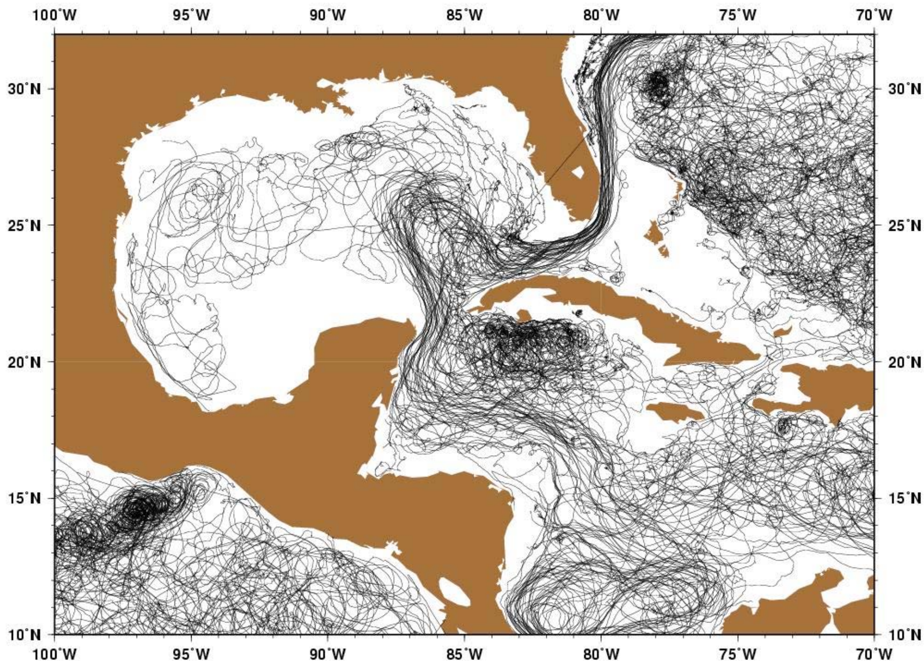


Figure 23. Caribbean surface water hydrography as indicated by tracks of drifters. Drifter image kindly supplied by Arthur J. Mariano and Edward H. Ryan, 2008. Ocean Surface Currents. http://oceancurrents.rsmas.miami.edu/.
See also; http://oceancurrents.rsmas.miami.edu/caribbean/spaghetti-bw.html.

Dissolved and particulate riverine inputs

Two major rivers have an impact on the Caribbean surface water hydrography and TEI distribution. The Orinoco river mainly drains an area covered by tropical rain forest, which is thus dominated by intense chemical weathering. The Orinoco plume (main discharge in July/August) which contains some contributions from the Amazon river plume flows directly into the Caribbean Basin and influences the salinity in the entire Caribbean Sea (e.g. Chérubin and Richardson, 2007). In the Gulf of Mexico the Mississippi with its high particulate load is expected to strongly affect the TEI distribution. The impact of these rivers with respect to the TEI distributions and budgets is largely unconstrained.

Submarine Groundwater Discharge

All along the coast of the Gulf of Mexico and most likely also at the Nicaragua Rise there are well known and extensive SGD contributions. It is known that the different discharge regions have largely differing compositions and their impact as a major source of TEIs to the Caribbean and the Gulf of Mexico will be the main goal of investigation.

Anthropogenic Pollutants

The distribution of anthropogenic pollutant TEIs such as mercury will be a specific goal. In addition, the relationship between anthropogenically caused eutrophication, as well as harmful algal blooms and the TEI distribution will be a focus of interest.

Accretionary wedges as a source of TEIs

The influence of fluid expulsion from accretionary wedges in the Puerto Rico and Caiman Trenches on the TEI distribution will be a goal of investigation, which will be tackled by two along trench sections of the cruise track. It is not envisaged to actively search for fluid seepages but the idea is rather to use existing information on existing seepages and make an attempt to monitor potential far field effects during on the along trench sections.

Proposed cruise track:

The proposed cruise track (Fig. 24) covers about 20 days of steaming time. The cruise is proposed to start in Puerto Rico, from where it will go north into the Puerto Rico Trench, which it will follow westward for some time and then will head south into the Caribbean Sea for the CATS time series station (south of Puerto Rico). It was discussed to also cover the Cariaco time series station (dashed line) but this will be a long travel time and this section will be covered by the Achterberg U.K. cruise. The cruise will then continue to the northwest to cover the sampling of the deep Caribbean Sea including the Atlantic inflow and the influence of the Orinoco plume until the Caiman Trench will be reached, which it then will follow for some distance. Next focus of interest will be the Yucatan Strait and then three sections aiming to cover different SGD sources in the Gulf of Mexico, which will also be sampled to full depth. It will be attempted to also sample the Loop Current depending on its position during the cruise. Finally the cruise will collect samples on a profile across the Florida Strait and will exit through the Florida Strait to end at a location such as Jacksonville.

Logistics:

It will be possible to go to port at various locations along the track to potentially exchange crew and scientists, if required. Although the highest discharge of the Orinoco occurs in July/August this is probably not the best time of the year for the cruise because this is also the main Hurricane Season.

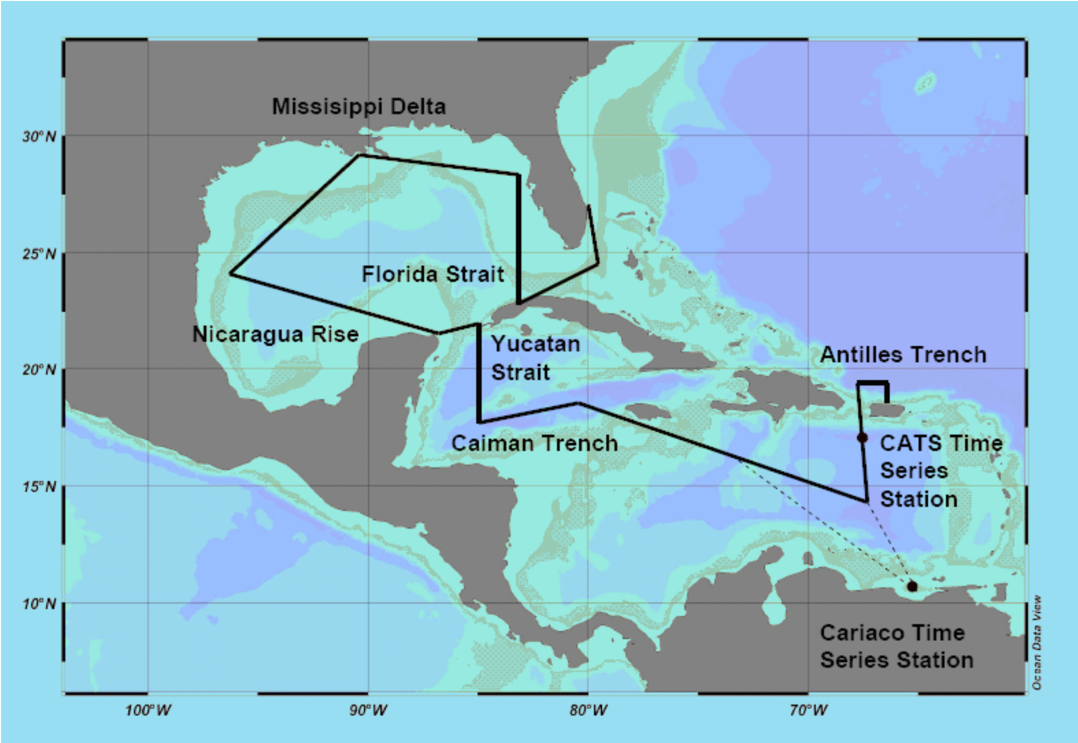


Figure 24. Proposed cruise track. Dotted line represents a possible diversion to the CARIACO time series station.

References:

Chérubin, L.M., and Richardson, P.L. (2007): Caribbean current variability and the influence of the Amazon and Orinoco freshwater plumes. Deep-Sea Research I 54, 1451-1473.

BREAKOUT GROUPS 2
2.3 Polar Oceans

Participants: Per Andersson (Chair); Kuria Ndungu (Raportteur); Bob Anderson; Greg Cutter; Russ Flegal; Jana Friedrich; Chris Measures; Ben Reynolds

Task:
Identify specific GEOTRACES scientific issues to be studied in the Polar Regions and coordination with current and planned IPY cruises.

Arctic features:
Multiple Inputs: riverine, atmospheric – direct and via sea ice, and groundwater.
Shelf-ocean exchange, including ice rafting.
Pollutant transport via atmospheric deposition
Pacific water inflow and outflow through Fram Strait.
Micronutrient limitation of primary production in certain regions (e.g., southeastern Bering Sea).

Rationales for including the Arctic in GEOTRACES:
Impact of the Arctic Ocean outflow on TEI contribution to the North Atlantic and its deep water formation.
Arctic Ocean crucial for global change studies:
Arctic rivers contribute 10% of global river runoff
Arctic shelves represent 25% of global shelf area
Arctic ecosystem contain 33% of the world's soil carbon
TEIs may be important indicators of paleo ventilation processes in the Arctic

Current and future IPY work in the Arctic more or less related to GEOTRACES. Identified cruises and projects:

- **AGAVE, Arctic Gakkel Vents**. *I/B Oden*, 1 July - 10 Aug., 2007 ; PI H. Edmonds, Univ. of Texas (hydrothermal vents).

- **SPACE, Synoptic Pan-Arctic Climate and Environment Study**, *R/V Polarstern*, 28 July – 10 October, 2007; PI M. Rutgers van der Loeff, P. Masque, H. de Baar, B. Moran. GEOTRACES; Fe, Mn, Al, Fe speciation, Cu, Cd, Ni, Zn, Ag, Ra isotopes, Th isotopes, ^{231}Pa, ^{227}Ac, ^{210}Po/^{210}Pb,^{129}I, ^{13}7Cs, ^{237}Np, ^{99}Tc, ^{240}Pu/^{239}Pu, nutrients, Ba, Be, REE, ε_{Nd} δ^{18}O, DIC-δ^{13}C.

- **LOMROG, Lomonossov Ridge off Greenland**. *I/B Oden*, Aug. 12 – 17 Sept., 2007. M Jakobsson and C. Marcussen. (ε_{Nd}, P. Andersson).

- **ATOS, Atmospheric inputs of organic carbon and pollutants to the polar ocean**. *R/V Hespérides*, 27 June – 27 July, 2007. C. Duarte, A. Tovar-Sánchez. Ag, Cd, Co, Cu, Fe, Ni, Mo, Pb, Zn, and V.

- **Sea of Okhotsk, Japan IPY/GEOTRACES**, Aug. – Sept., 2007. Jun Nishioka.

- **Nordic LSBI**, *R/V Ivan Kireev*, Aug. – Sept. 2008, Igor Semiletov, P. Andersson, Ö. Gustafsson. Fe and Fe isotopes (particles) (*Zn, Ni, Cd, Cu, Co, Mn?)*, Si isotopes, Ba, REE, (ε_{Nd}, Ra isotopes, ^{234}Th, ^{230}Th/^{232}Th, Ra isotopes, DOC, TOC, POC -δ^{13}C -POC, δ^{18}O -wat, TerrOC biomarkers, ^{14}C-TerrOC biomarkers, Org. pollutants. Surface sediments.

- **Nordic LSBI,** *I/B Yamal?*, Aug – Sept. 2008, Igor Semiletov, L. Anderson.

- **DAMOCLES, Developing Arctic Modelling and Observing Capabilities for Long-term Environmental Studies**. *R/V Polarstern*, July-Aug. 2008. Exchanges between the Arctic Ocean and the Nordic Seas through Fram Strait. Contact Ursula Schauer, AWI.

- **Bering Sea Ecosystem Study (BEST).** *R/V Healy*, 2008, 2009, 2010. Primary production, phytoplankton community structure, and gross/net O_2 production. B. Moran.

- **Sea of Okhotsk and discharges of Amur River** June-July 2008. Jun Nishioka.

- **"GEOTRACES Canada".** Multi-tracer investigation of the effect of climate change on nutrient and carbon cycles in the Arctic Ocean. Beaufort Sea; September 2009; ca 3 weeks (exact dates and duration still to be established) PIs: Roger Francois, K. Orians, M. Maldonado, P. Tortell, K. Orians, J. Cullen, D. Varela. CO_2, CH_4, N_2O, DMS in the atmosphere. Key trace micoronutrient elements (Fe, Cu, Zn, Cd) or tracers of sources or processes (Al, Ba, Ga, Mn, Cr, Th, Pa). ^{230}Th, ^{231}Pa, Si isotope.

Letter of intent for a combined RV Oden/RV Polarstern activity in 2011/2012 to be sent in during late 2007 early 2008 for requesting ship time in the Arctic.

Group Recommendations for GEOTRACES in the Arctic:

After IPY cruises are finished we propose an evaluation of the IPY work (e.g., workshop) for detailed planning. Based on this we would propose a full GEOTRACES cruise(s) across the major basins and geochemical gradients in the Arctic Ocean. Revisiting of some stations for time series purposes is likely. Details on the cruise tracks are to be worked out at a meeting in connection to the IPY evaluation.

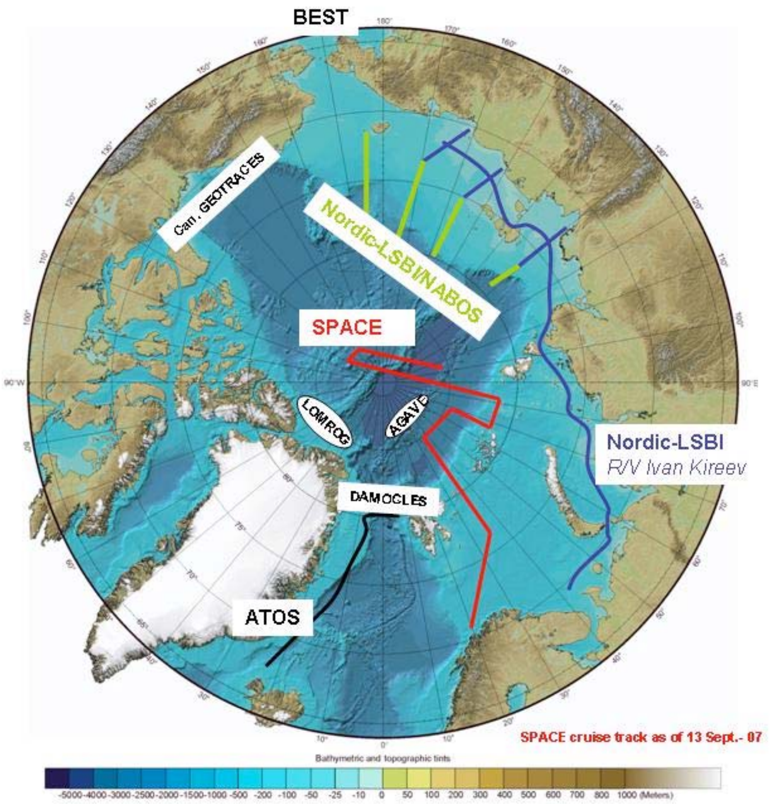


Figure 25. Cruise tracks for ongoing and proposed Arctic Ocean expeditions during IPY. Figure courtesy of Hein de Baar.

Antarctic

Major issues:

Input of ice from continental glaciers to the Southern Ocean varies around Antarctica; what is the influence on the TEI distribution? What is the fate of TEI's across the Polar Front? What is the effect of subantarctic islands/Antarctica on iron input; What fuels high productivity areas close to the Antarctic coast?

Areas of particular interest: Amundsen Sea, Ross Sea.

Variation in Nd isotopic signature of Antarctic waters due to different ages of bedrock around Antarctica and available supply of TEIs into the water column.

Circumpolar calibration of paleoproxies in sediments complementary to studies in the Argentina Basin and Scotia Sea. Surface sediment samples needed for paleo-proxy calibrations, e.g. silicon isotope studies.

Upcoming cruises:

- ***Zero and Drake**, *R/V Polarstern*, February-April 2008 (PI's M. Rutgers van der Loeff, Hein de Baar, E. Fahrbach)
- ***Bonus & Good Hope** February-March 2008 (PI Marie Boye)
- **"Australian line",** January 2008 (PI Steve Rintoul)
- **ATOS,** Jan. – Feb. 2008, (PI. C. Duarte)

*Science on cruises will aim to conform to GEOTRACES protocols.

Proposed cruises:

- US 170 W (PI Bob Anderson)
- Japan GEOTRACES Indian Ocean?
  - *I/B Oden*. 5 year contract NSF-Sweden. There will be possibilities for science during transit between Punta Arenas and Ross Sea about 20 days/cruise. Potential for a "pure GEOTRACES cruise" during one of the years, with upto 20 days of scientific sampling within the Admundsen Sea, Track Punta Arenas and Ross Sea
  - There may be the potential for a cruise using the Polarstern, and collaboration with South Africa and South African icebreaker.

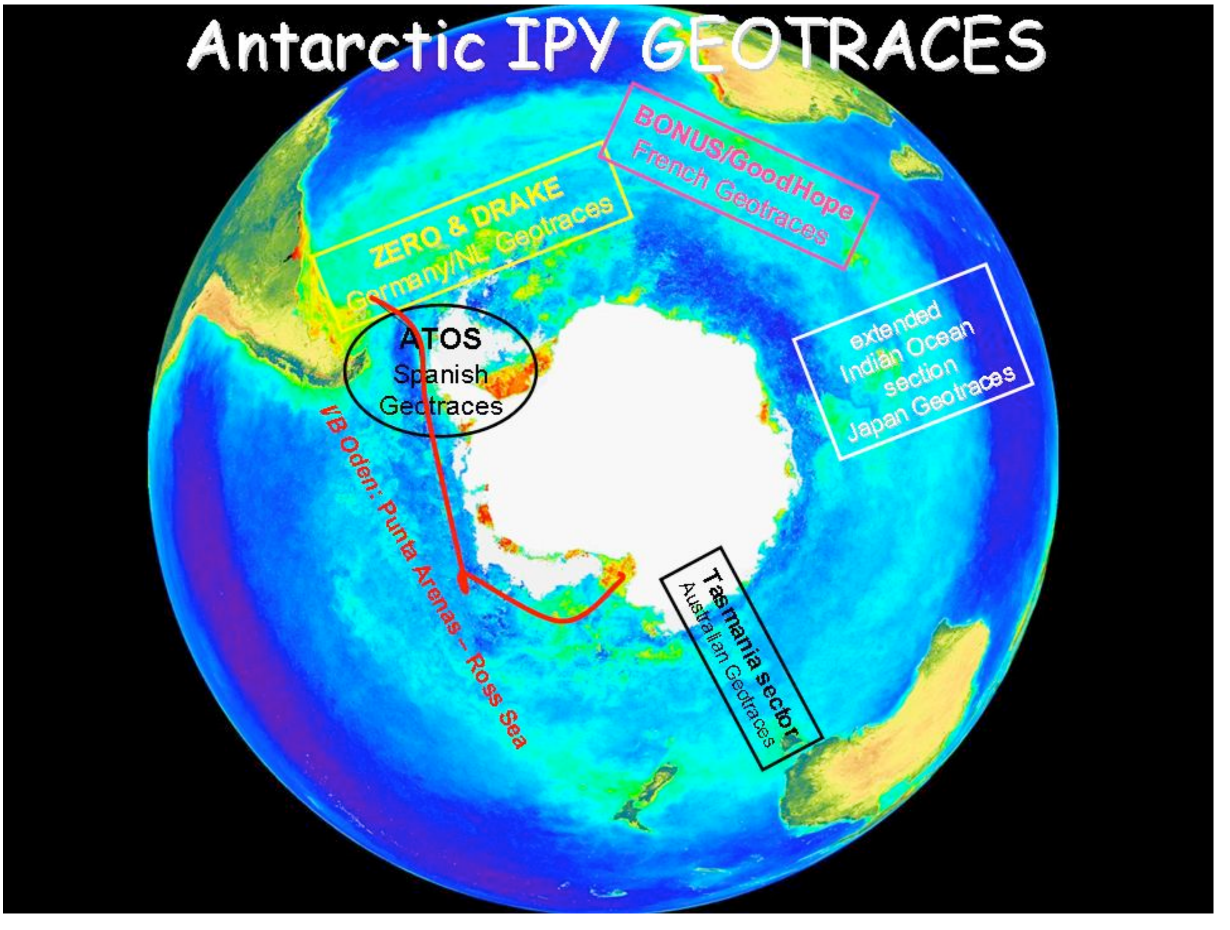


Figure 26. Southern Ocean IPY cruises. Figure courtesy of Hein de Baar.

Group Recommendations for GEOTRACES in the Antarctic

Like the Arctic, we recommend convening a workshop to synthesize data from the upcoming cruises in order to plan GEOTRACES-specific expeditions to address issues not attended to by the upcoming cruises. Such issues may include: quantifying the continental inputs of TEIs to the Southern Ocean, or cycling of TEI's during phytoplankton growth in the Subantarctic and Polar Frontal Zones.

BREAKOUT GROUPS 2
2.4 Meridional Atlantic Sections

Participants: Steve Goldstein (Chair); Simon Ussher (Raportteur); Hein de Baar and others

Meridional circulation in the Atlantic basin plays a central role in the present-day global meridional circulation (MOC) system. The formation of North Atlantic Deep Water (NADW) and its southward flow is the driving force of the MOC system in the present day, and it can be followed as a deep water mass southward into the Circum-Antarctic and Indian Oceans. Surface currents that counterbalance NADW include the meridional flowing Gulf Stream in the North Atlantic, which is the major oceanic means of transporting heat from the tropics to the northern latitudes, and the Agulhas-Benguela combination that leaks additional heat and salt into the Atlantic system brings it to the northern hemisphere. The deep and intermediate water masses that counterbalance NADW, Antarctic Bottom and Intermediate Water (AABW and AAIW) are the primary water masses formed in the Antarctic, and both can be detected far into the Northern Hemisphere. Understanding of the processes affecting the major Atlantic water masses is crucial to understanding the present-day circulation system, and by extension, past modes of ocean circulation.

The strength of the MOC is tied directly to the flux of NADW, and the effects of temporal variability of NADW on meridional heat transport in the North Atlantic region makes it a major potential factor for parameterizing global climate change. As a result, the variability of NADW formation and export, and the associated behavior of the return flow water masses has been a major focus of paleocirculation studies. Such studies rely on the use of proxies (d13C, Cd/Ca, Pa/Th, epsNd), all of which clearly show climate driven variability in the marine sedimentary record, and all of which appear to yield different interpretations of conveyor history. One of the purposes of the Geotraces Program is to better address the processes that affect these mass water proxies in order to generate a better understanding of their strengths and limitations.

The overriding goals of the Geotraces Program include determination of "ocean distributions of selected trace elements and isotopes – including their concentration, chemical speciation and physical form – and to evaluate the sources, sinks, and internal cycling of these species to characterise more completely the physical, chemical and biological processes regulating their distributions" and understanding of "the processes that control the concentrations of geochemical species used for proxies of the past environment …". In order to successfully achieve these goals, it is necessary to accurately characterize the major water masses when they form, and the changes that occur as they evolve.

Therefore it is necessary to include meridional transects of the Atlantic basin, following the primary transport pathways of the major water masses with the purpose of tracing their compositions with distance traveled from the source areas. Meridional transects are the means to generate the fundamental data on what happens to the TEIs along the flow paths of the major water masses that drive the conveyor (e.g. Western Boundary Current, North Atlantic Deep Water, AAIW, AABW). Moreover, they provide a means to evaluate far field effects compared to near shore process studies along the coasts.

Primary Questions to be addressed

Since Atlantic circulation is governed by water masses that form in the polar regions and flow meridionally, the primary question to be addressed is: to what extent do TEIs in Atlantic water masses Atlantic TEIs reflect mixing of the north and southern source waters, to what extent are they changed in transit.

This approach will test the following hypothesis. (1a) For some tracers with long seawater residence times (e.g. centuries) compared to timescale of meridional flow (decades), such as Nd isotopes, deep waters primarily reflect simple mixing of Northern and Southern source components. That is, overall these are not strongly affected by new inputs during transit. (1b) Tracers with short residence times (e.g. 228Ra, 210Pb), compared to timescale of meridional flow are strongly affected by inputs along transit path. Thus (1c) in the eastern basin, which is less well ventilated than the western basin and water residence times are longer, the effects of inputs are stronger.

The example of Nd isotopes is given because deep waters appear to generally follow simple binary mixing behavior of northern (NADW) and southern (AABW and AAIW) source components. However, the concentrations of REE in Atlantic deep seawater is low (15-35 pmol/kg in the source waters) many processes can be expected to affect this tracer over its travel path.

Possible TEI delivery mechanisms include atmospheric fallout such as dissolution from dust combined with falling particles from surface waters; margin additions from rivers, seepage from groundwaters, margin particulate exchange, shelf erosion, turbidity currents, ocean islands, bottom sediment suspension, hydrothermal vents.

Potential TEI sources in the Atlantic basin that could affect NADW along its transport path include, include, in the western basin, the St. Lawrence input, the North American shelf, ocean islands or seamounts such as the New England seamounts or Bermuda), the Saharan dust plume, leakage from the Caribbean and Gulf of Mexico, input from the Orinoco, Amazon. Sao Francisco, Plata Rivers, the Brazil Margin, the Rio Grande Rise, inputs from Patagonian dust or Argentine Shelf and slope, bottom sediments. In the eastern basin these include the northeast Atlantic overflows, Iceland, the European continental shelf, Mediterranean outflow, the Saharan Dust Plume, Niger and Congo Rivers, the Walvis Ridge, Kalahari dust plume, and various islands. In addition there are a number of geological age boundaries in the contiguous continental that are crossed by the water masses, which may affect some tracers. High resolution sampling along the transport path, taking these potential inputs into account, is the only way to determine which of these processes and sources are significance, and to evaluate the magnitude of the effects.

Recommendations

A meridional transect of the western basins should follow primary southward flowpath of NADW and northward flowpath of AABW and AAIW along western margin, following the Western Boundary Currents. Although NADW tends to hug the 4000 m contour, the sampling route should make sure that it also includes AABW.

A NIOS cruise is planned from Greenland overflows to N Atl. Basin, following major transport along the western boundary current, be sure to hit all water masses including AABW. Refuel in Bermuda and interact with BATS Station. Continue to tropical Atl. To NE coast of S America, make sure goals complement US and French Geotraces cruises in that region continue south to Rio Grande Rise through Vema Channel? Where main N-S transit occurs. Plans on 1 degree resolution for “normal” ctd deployments, and super stations every 3 degrees. From the Rio Grande Rise southward, the British Antarctic supply ship will be used to continue to Port Stanley. This will also use opportunity to fill in gaps farther north in the S Atlantic subtropical gyre..

In the northeast Atlantic we do not propose special meridional cruises, but recommend construction of a “virtual meridional section” by combining appropriate stations from zonal and cruises.

In the southeast Atlantic no additional cruises are recommended, beyond the meridional section that is recommended by the Southeast Atlantic Working Group, which is strongly endorsed.

CONCLUDING DISCUSSION AND SYNOPSIS

Following the Break Out Groups, the workshop reconvened in plenary session to discuss the overall coverage of the Atlantic basin, the balance between research proposed in each region, and to finalize a set of proposed GEOTRACES Sections for the Atlantic.

Final routing of sections

In some Break-Out-Group reports, more than one option was suggested for a proposed section (e.g. the North Atlantic Gyre Zonal Section, Fig 1). In others, proposed sections are complex and arguments not yet fully developed about the best exact track to follow (e.g. the Mediterranean Section, Fig 22). In still others, the exact track was discussed in plenary and subtle changes suggested relative to those in the Break-Out-Group report (e.g. the Equatorial Zig-Zag Section, Fig 6). All such cases were discussed in plenary and, where appropriate, small changes made to proposed tracks before they were drawn on the final summary map of Atlantic sections. It was recognized in this process, that the cruise tracks on this map are representative only. The precise final track to be followed must be set by those scientists and nations who propose, fund, and carry out the cruise. Final cruise tracks should be fully informed by discussion in the Break-Out Group reports, but will have to also reflect the national priorities of those who conduct them.

Strengths and weaknesses of "zig-zag" sections

Plenary discussion also addressed whether cruises with multiple legs in different directions were true GEOTRACES sections, or were instead process studies. It was recognized that there is a grey area here but that it was certainly possible for such zig-zag legs to be considered sections. The GEOTRACES Science Plan laid out the guiding principle that sections should pass through regions were important geochemical processes were occurring, and should cross expected gradients in trace element and isotope concentrations. Changing direction within a section can be a highly effective way to achieve these goals. As long as a significant zonal or meridional distance is covered, and the goal is to measure the full suite of GEOTRACES parameters, such tracks are well suited as GEOTRACES sections.

Justification for Sections close to one another

The plenary group also considered situations where two sections were proposed close to one another, and discussed whether it was appropriate to plan both such sections. One example was the Equatorial Zig-Zag Section (proposed by the Equatorial Break-Out Group; Fig 6), and the Congo-Amazon Section (proposed by the SE Atlantic Break-Out Group; Fig 11). These two sections shared many of the same goals. It was decided that it was not merited to plan both of these cruises, and that only the Equatorial Zig-Zag Section should be included in the proposed summary map of sections. Planning for that section should, of course, consider discussion related to the Congo-Amazon section to maximize the scope of the research conducted.

Other situations where two proposed sections are close to one another are those where the Western Meridional section is close to coastal sections offshore NE and SE South American. Plenary discussion considered both of these situations to be broadly appropriate. The Meridional Sections has the goal of assessing conditions in the deep basins and tracing deep-water masses along their flow paths. The coastal sections have very different goals of identifying and quantifying the trace-metal inputs from rivers, ground-water discharge, and margin exchange. It is not easy to see how the goals of these two cruise types could be merged, and plenary discussion considered it appropriate to leave all these sections in the proposed plans for Atlantic GEOTRACES sections.

It was also noted, more generally, that funding for each section must be secured on a stand-alone basis. Each proposed section must therefore be justified on its own scientific merits, as well as on its contribution to the overall program.

Atlantic Meridional sections

The justification for meridional basin sections was made clear in the GEOTRACES science plan and it was agreed in plenary discussion that such sections are critical to characterize the large scale features of trace-element and isotope distribution within a basin. Significant plenary discussion focused on suitable tracks for meridional sections in the Atlantic. Dutch workers, led by Hein deBaar, are already planning a meridional section in the Western Atlantic which follows the path of the West Atlantic GEOSECS section. The rationale for this approach was discussed, including the positive facts that it samples deep basins, and follows evolving deep-water masses, as well as the fact that it allows comparison of some measurements with those made in the 1970s during the GEOSECS programme. It was agreed that this was a highly suitable approach for a GEOTRACES meridional section, and that Dutch plans should be extended into the far South Atlantic to achieve a full transect of the Basin, and ideally to link to Southern Ocean work conducted during IPY.

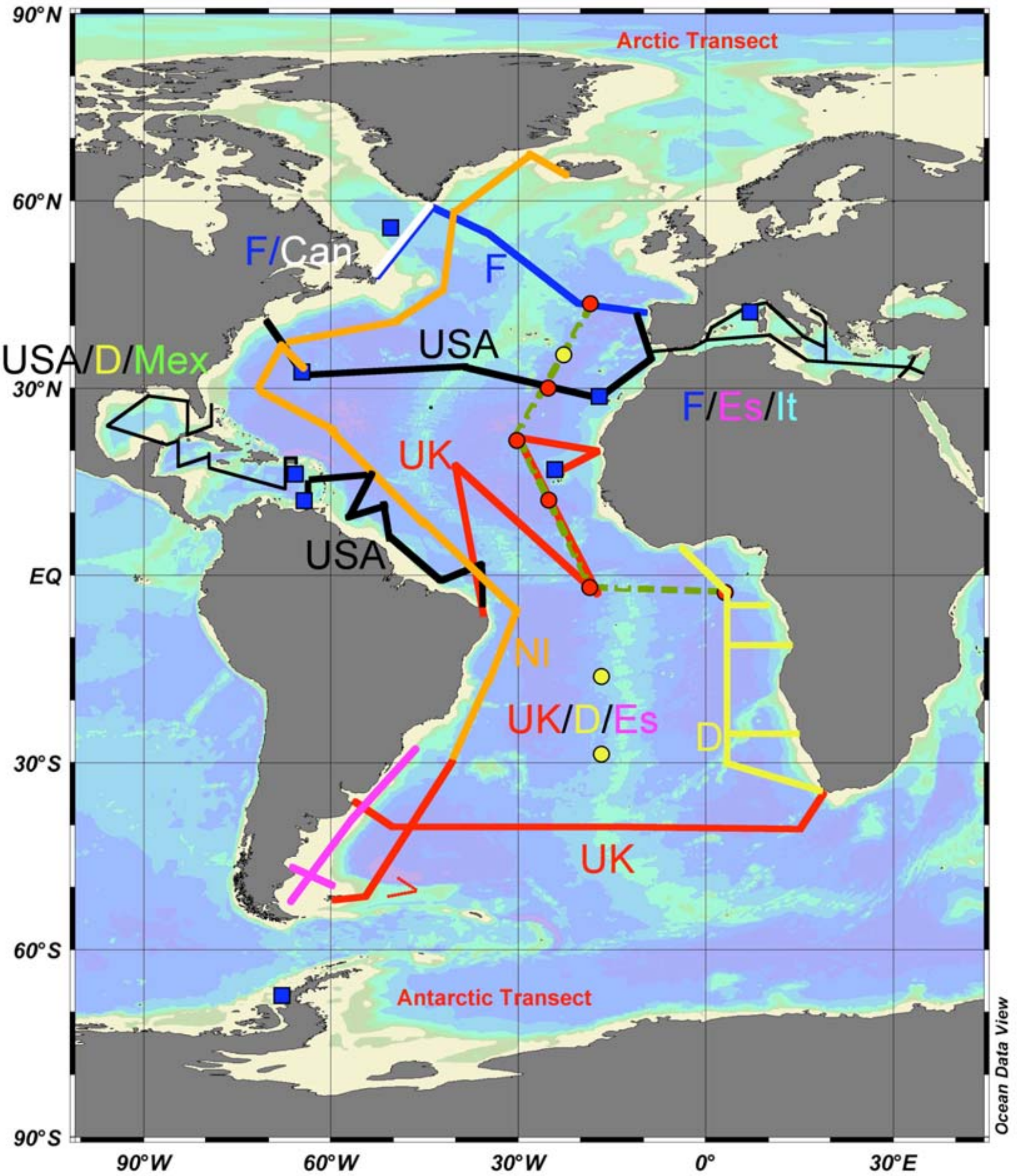
There was also significant discussion as to whether an Eastern Atlantic meridional section was justified. Although there are arguments in favour of such a section, no one spoke of it as essential and, given the resources required to realize the other proposed sections, it was considered difficult to fund such a large additional effort. Instead, a plan was developed during plenary discussion to have a “virtual” Eastern Atlantic meridional section composed of stations from other cruises. This would not be a high-resolution section, but the consensus was that sufficient information would be achieved with such an approach. It would also be desirable to add a small number of additional stations to such a section, and this might be achieved using a small amount of ship time on one of the regular Antarctic supply cruises conducted by the UK or Germany.

A summary of proposed Atlantic cruises

Following appraisal of issues raised in the Break-Out Groups, plenary discussion finalized a list and map of proposed Atlantic GEOTRACES sections, and tentatively agreed nations (and in some cases individual scientists) to lead efforts to fund each section. The resulting list contains 12 sections (including the “virtual” Eastern Atlantic Meridional section):

1. North Atlantic Overflows (France; Catherine Jeandal)
2. Labrador Sea Entrance (Canada)
3. North Atlantic Gyre (USA; Ed Boyle and Matt Charette)
4. Western Atlantic Meridional (The Netherlands; Hein deBaar. With most southerly section tentatively to be completed by UK)
5. Mediterranean (consortium of countries with Mediterranean seaboard)
6. Caribbean (USA, with possible German and/or Mexican involvement))
7. Equatorial Zig-Zag (UK, Eric Achterberg)
8. Amazon Basin (USA; Bill Landing and Greg Cutter)
9. South East Atlantic Basins (Germany; Martin Frank)
10. South West Atlantic Shelf (Spain)
11. 40^{o}S Atlantic Zonal (UK; Gideon Henderson)
12. Virtual Eastern Atlantic Meridional (various, with extra stations by UK or Germany)

SUMMARY MAP OF SECTIONS PROPOSED FOR THE ATLANTIC



Cruises coded by anticipated lead country:

- White: Canada
- Black: USA
- Dark Blue: France
- Orange: Netherlands
- Red: UK
- Pink: Spain
- Yellow: Germany

Blue squares represent known time-series stations of interest

Dashed green line represents the "virtual" East Atlantic Meridional section consisting of stations on other sections (identified by red circles)

Yellow circles represent possible additional stations to be sampled during transit to other Southern Ocean legs if possible

For these additional stations, as well as the Mediterranean and Caribbean cruises, no single country was identified as taking the lead at this stage, but several possible countries were identified (as noted on the figure)

APPENDIX 1: WORKSHOP PROGRAMME

Monday 10th September:

09.45: Registration opens

10.00: Coffee

10.30: "*Introduction to the GEOTRACES programme and the goals of the workshop"*
Gideon Henderson (Oxford, UK)

11.10: Keynote 1: *"Observations and modelling the ocean Fe cycle: Role in the carbon cycle and state of understanding"*
Ed Boyle (MIT, USA)

11.50: Keynote 2: *"The importance of bioactive trace metals in the marine environment"*
Mak Saito (WHOI, USA)

12.30: Buffet Lunch at St. Annes

13.40: Keynote 3: *"Trace element and isotope proxies: constraints on the carbon cycle"*
Ros Rickaby (Oxford, UK)

14.20: Programme Logistics 1: *"Intercalibration of measurements for GEOTRACES"*
Gregg Cutter (Old Dominion, USA)

15.00: Programme Logistics 2: *"Data management during GEOTRACES"*
Chris Measures (Hawaii, USA)

15.20: Coffee

15:50: Planned Activities 1: *"The BONUS-GOODHOPE IPY Cruise"*
Marie Boye (LEMAR, Plouzane, France)

16.05: Planned Activities 2: *"Zero and Drake IPY Cruise"*
Hein de Baar (Royal Netherlands Institute for Sea Research, Netherlands)

16.20: Planned Activities 3: *"Arctic IPY activities"*
Per Anderson (Swedish Museum of Natural History, Sweden)

16.35: Planned Activities 4: *"Mauretania to the Brazil Basin cruise*
Martin Frank (Kiel, Germany)

16.50: Planned Activities 5: *"UK SOLAS work with relevance to GEOTRACES"*
Eric Achterberg (National Oceanography Centre, UK)

17.05: Planned Activities 6: *"German SOLAS work with relevance to GEOTRACES"*
Peter Croot (Kiel, Germany)

17.20: Drinks reception at St. Annes

19.00: Dinner at St. Annes

Tuesday 11th September:

09.00: Keynote 4: *"A GEOTRACER's perspective of the hydrography and circulation of the Atlantic"*
Bill Jenkins (WHOI, US)

09.45: Advocacy talks (1-6):
(ten minutes per talk, maximum three slides and five minutes per presentation, with five minutes of discussion)

10.45: Coffee

11.15: Advocacy talks (7-15)

12.45: Lunch

14.00: Advocacy talks (16-18)

14.30: Plenary discussion to form and task break out groups

14.40: First set of break out groups
(each group discuss the justification and path of a particular section (or more than one related section. These sections to be chosen based on advocacy talks earlier in the day)

15.30: Coffee

16.00: Breakout groups continue

17.00: End for day. Rapporteurs to prepare presentation for following morning

19.00: Group dinner at Al Shami Lebanese Restaurant

Wednesday 12th September:

09.00: Plenary Discussion
Reports from the first set of working groups and discussion)

10.20: Discussion of next working groups: Other sections - what's missing

10.30: Coffee

11.00: Second working groups

12.45: Lunch

14.00: Working groups continue, and rapporteurs prepare presentations

15.00: Plenary discussion
Reports from the four working groups and discussion. Allocate 20 minutes for each

16.20: Coffee

16.40: The proposed map:
Open discussion of unresolved issues and balance of the first map of proposed sections in the Atlantic.

17.30: End of schedule

18.00: Drinks party. No group dinner – delegates are free to gather in smaller groups

Thursday 14th September

09.00: Plenary discussion
Continued discussion of final map and preparation of written report

10.30: Coffee

12.45: Lunch

TBC: End of meeting

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