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Report of the TACE Implementation Workshop

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1. Introduction

The ocean has a major influence on tropical Atlantic variability mainly through the influence of tropical Atlantic SST on variations of the Atlantic marine ITCZ complex. The most notable climate impacts involve the variability of rainfall over northeast Brazil and the coastal regions surrounding the Gulf of Guinea, and the fluctuations in rainfall and dustiness in sub-Saharan Africa (Sahel). Many studies indicate a high degree of potential predictability for climate variations in the tropical Atlantic region. However, progress in tropical Atlantic climate prediction has been slow to come due to insufficient understanding of ocean-atmosphere processes that determine climate variability, lack of adequate data to initialise forecasts, and systematic errors in the models used for prediction.

Understanding tropical Atlantic climate variability and predictability, with the goal of improving its prediction and identifying and quantifying its relationship to various societal impacts, are important research goals recognized by CLIVAR. Concerted international effort is needed to improve the understanding of the region's climate variability and the mechanisms that underlie its observed behaviour. A "Tropical Atlantic Climate Experiment" (TACE) has been proposed to address these issues. TACE is envisioned as a program of enhanced observations and process studies in the tropical Atlantic spanning a period of approximately 6 years (2006-2011). Its goal is to provide a focused observational and modelling effort to advance climate predictability in the surrounding region and to provide a basis for assessment and improvement of coupled models. The results of TACE are expected to contribute to the final design of a sustained observing system for the tropical Atlantic.

A TACE "White Paper" (http://www.clivar.org/science/atlantic.htm) provides an overview of the physical processes affecting climate variability in the tropical Atlantic and priorities for further study. An abbreviated synopsis of TACE (http://www.clivar.org/science/atlantic.htm#NEWS) outlines its major scientific thrusts and provides recommendations for new and/or continuing observations and modelling studies that are thought to be essential for TACE. These recommendations represent the culmination of planning efforts that have been carried out between 1999-2004 at several workshops, including the recent Tropical Atlantic Workshop in de Bilt, Netherlands (June 2004). Details of implementation were discussed at these meetings and represent the current consensus on the required observational and modelling components of the program.

To further the development of TACE and to bring together scientists who are interested in participating in its implementation, a one-day "TACE Implementation Workshop" was held in Miami, Florida on February 3, 2005. The workshop immediately followed the U.S. CLIVAR Atlantic Science Meeting in Miami (Jan.31-Feb.2, 2005) to maximize attendance and minimize travel costs of participants. This report provides a brief summary of the workshop proceedings and its recommendations.
A list of workshop participants is included in Appendix 1. The meeting was attended by over 50 observationalists, modellers, and representatives from operational groups. (Unfortunately not all participants are listed in Appendix 1 due to incomplete distribution of the sign-up list). Several representatives from CLIVAR's Working Group on Ocean Model Development (WGOMD), Working Group on Seasonal to Interannual Prediction (WGSIP) and Atlantic Implementation Panel (AIP) were present.

2. Workshop Format

A copy of the Workshop Agenda is included in Appendix 2. The workshop began with introductory presentations on the present status of TACE planning (W. Johns, M. Visbeck), opportunities for modelling and synthesis (W. Hazeleger), and the current state of predictability and prediction studies in the tropical Atlantic (T. Stockdale, P. Chang).

This was followed by a morning session on TACE observations in which a large number of short presentations were given by workshop participants on current observational plans relevant to TACE. The afternoon session covered modelling plans, with the central topic being "How can TACE observations be used to improve models and predictive systems?". One-page abstracts of observational and modelling plans were requested of workshop participants and are included in Appendix 3.

The workshop concluded with a discussion on data archiving and distribution within TACE, and an open discussion on possible observational and modelling gaps. The focus of this discussion was on what additional elements might be required for a successful program. Views were solicited in particular from representatives of the operational centres to assess what may be crucial missing elements for climate prediction.

3. Workshop Findings and Recommendations

The present observational plan for TACE is shown schematically in Figure 1. Owing to the short duration of the meeting there was a limited time for formal recommendations to be produced, however a consensus was reached on the following:

1. The workshop participants endorsed the TACE initiative as timely and relevant to CLIVAR objectives.
2. A critical mass of people and resources are focused on the problem. It was apparent from the presentations that much of the observational plan is already subscribed.
3. The overall observational plan is suitable but needs enhancements. Recommended enhancements include:
    - More focus on the western equatorial region to improve equatorial SST predictions (*recommended*: additional moorings across the equatorial waveguide at ~35ºW)
    - Addressing the data void in the southwestern tropical Atlantic (*recommended*: extend the 23ºW array to at least 10ºS)
    - Better observational coverage of the eastern Gulf of Guinea, including the area south of the equator (*recommended*: enhance profiling float coverage; this is probably the best alternative due to vandalism problems with PIRATA moorings in the region)
4. A more focused effort on model development and intercomparison for the tropical Atlantic (and Pacific) is needed. The CLIVAR WGOMD charter is focused on mid-to-high latitudes and low-frequency variability; therefore the WGSIP may be the logical group to coordinate this activity. An initial step would be to organize a comparison experiment of currently available high-resolution models of the region (MERCATOR, HYCOM/GODAE, etc.)
5. A TACE data archive needs to be created to facilitate and encourage full use of TACE observations in synthesis experiments. A "distributed mode" archive was felt to be the best and most workable model.
6. Two TACE Working Groups should be established:
    - A TACE "Observations Working Group" (to coordinate observational logistics, evaluate effectiveness of the observational network, and develop needed enhancements)
    - A TACE "Modeling and Synthesis Working Group" (to work with WGOMD and WGSIP to coordinate modeling efforts, encourage collaboration between research modelers and operational centers, and provide "transitions" to operational centers)

4. Action Items and Next Steps

The items were agreed upon:

- Terms of Reference for these working groups will be drafted in the coming months and forwarded to the Atlantic Implementation Panel. Members will be appointed.
- Final revisions will be made to the TACE Synopsis document (incorporating the Workshop discussions) for circulation to WGSIP and submission to the Atlantic Implementation Panel and the Scientific Steering Group of CLIVAR for endorsement.
- Follow-up discussions will be held at the Tropical Atlantic Workshop planned for October 2005 (Venice, Italy; contact: P. Rizzoli). TACE activities will be a focus of the meeting.

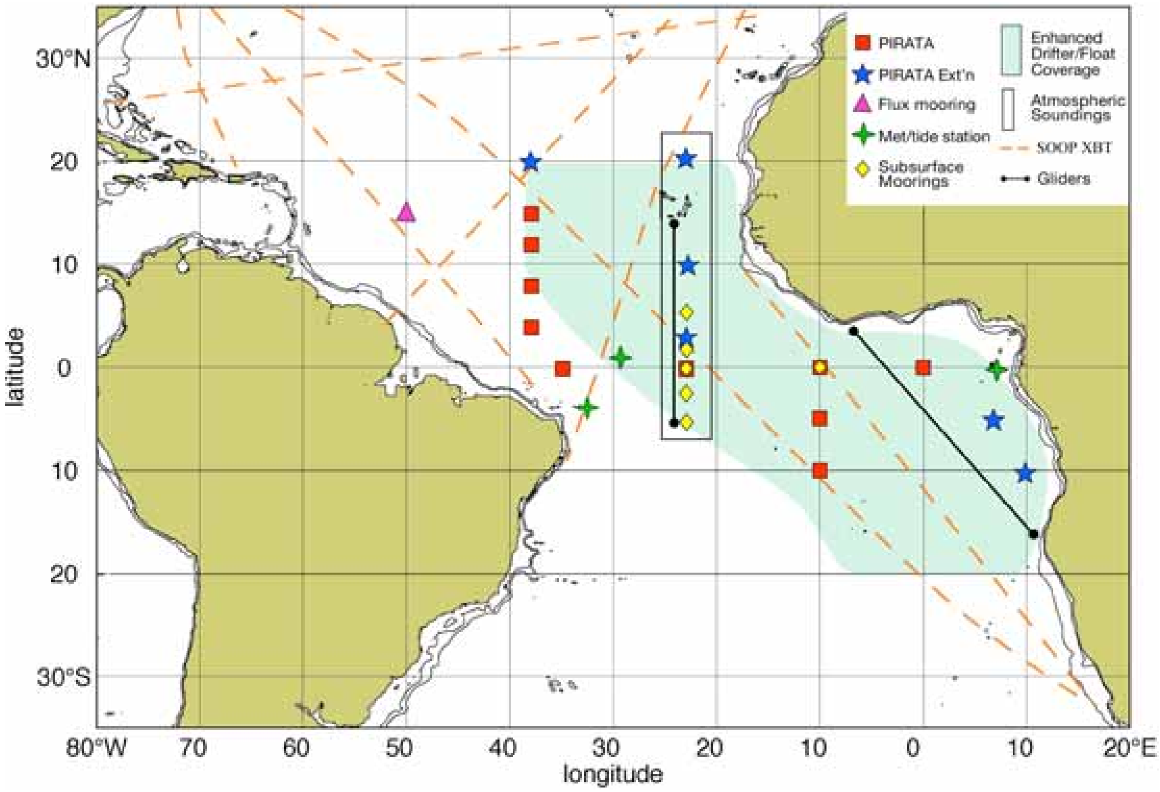

Figure 1. TACE Observational Strategy. The proposed observing system components include (see legend): Continuation of PIRATA moorings, PIRATA extensions along 23 º W and 5-10º E, equatorial subsurface (non-realtime) moorings along 23 ºE and at 10º W, island meteorological and tide gauge stations, enhanced float/drifter coverage in the eastern TA, repeated atmospheric soundings along 23 º W, ship-of-opportunity XBT lines, and selected glider transects (see the "TACE Synopsis" for more details).

5. Acknowledgements

The workshop organizers and the Atlantic Implementation Panel would like to thank the many participants who attended the meeting to contribute their expertise, especially the international participants who travelled long hours to join us and to attend the preceding U.S. CLIVAR Atlantic Science Meeting. Limited support for travel of international participants was provided by the U.S. CLIVAR Office.

Appendix 1. List of Participants

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Appendix 2. Agenda

09:00 Welcome (B. Johns and M. Visbeck)
09:10 TACE Introduction (B. Johns)
09:25 Opportunities for Modelling and Synthesis in TACE (W. Hazeleger)
09:40 Predictability in the Tropical Atlantic (T. Stockdale and P. Chang)

10:15 Coffee Break

10:45 TACE Implementation: Observational Plans

- PIRATA Backbone (B. Bourles)
- PIRATA Extensions (P. Nobre, R. Lumpkin, C. Reason)
- Equatorial Moorings (P. Brandt)
- Island Stations (B. Bourles, P. Nobre)
- Floats and Drifters (R. Lumpkin, C. Schmid, P. Brandt)
- Ship Surveys, Hydrography and Tracers (B. Bourles, B. Molinari, R. Fine)
- VOS XBT lines (G. Goni, S. Garzoli)
- Satellite Measurements: Altimetry (G. Goni)
- Atmospheric Observations and Profiling (C. Fairall)
- Upwelling and Diapycnal mixing processes (M. Dengler)
- New German SFB (M. Visbeck)

12:30 Lunch

14:00 TACE Implementation: Modelling Plans - How can TACE observations be used to improve models and predictive systems?

- Data Assimilation (E. Chassignet)
- Ocean dynamics and processes (C. Boening, R. Murtugudde, G. Halliwell)
- Coupled processes studies (W. Hazeleger, S. Xie, P. Chang)
- Atmospheric issues (C. Zhang)
- Coupled Predictive systems (T. Stockdale, A. Robertson)

15:30 Coffee break

16:00 Wrapup Discussion

- Data archiving and distribution (lead: R. Boscolo)
    - Tropical and South Atlantic Data and Data Products (B. Molinari)
    - The CLIVAR/Carbon Hydrography Data Office (S. Diggs)
- Whats missing? Observational and Modelling gaps (lead: B. Johns, W. Hazeleger)

17:30 Adjourn

Appendix 3. Short Presentations

Study of the upper layers and of the air-sea exchanges in the Gulf of Guinea

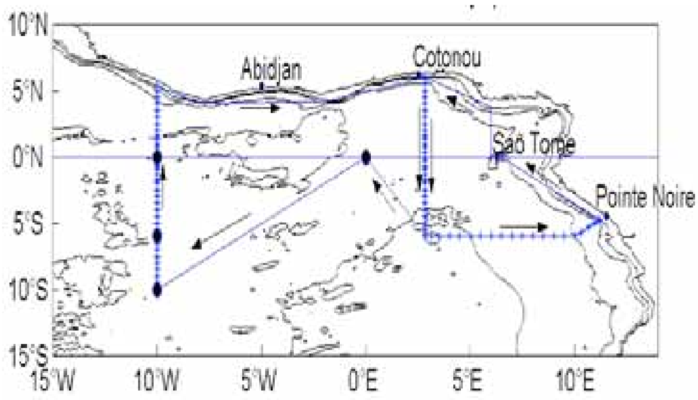
Bernard Bourlès, Institut de Recherche pour le Développement (IRD), Laboratoire d'Etudes en Géophysique et Océanographie Spatiales (LEGOS), Centre IRD de Brest, France. bourles@ird.fr

Objectives :

Mostly due to the presence of equatorial and coastal upwellings and of the "cold tongue" in boreal summer, the Gulf of Guinea (GG) is an area of prior interest for climatic studies in the Tropical Atlantic and for the West African Monsoon (WAM). The prior goal of the program EGEE, French oceanic component of AMMA (African Monsoon Multidisciplinary Analysis) and contribution to TACE, lies in the comprehension of the oceanic processes that control key parameters such as the Sea Surface Temperature -SST- and salinity -SSS-, the mixed layer depth -MLD- and heat content, and thus that control the energy exchanges at the ocean-atmosphere interface in the GG, and their variability mainly from seasonal to interannual time scales. Through the use of numerical models and experiments, of in situ and satellite measurements or products analysis, of process studies etc, this program aims to improve the knowledge and the simulation of the boundary oceanic and atmospheric layers that control the air-sea exchanges in this particular area.

Measurements program:

The measurements program is principally dedicated to the GG area, and mostly consists in research cruises during the whole Extended Observation Period (EOP) of AMMA, i.e. from 2005 to 2007, at the rate of two cruises per year that will be carried out in May-June and September-October of each year, i.e. during the onset and late phases of the WAM (roughly corresponding to the ones of the equatorial upwelling and cold tongue).
During these six cruises, the measurement of classical hydrological parameters (through CTD-O_2, XBT and XCTD profiles, TSgraph, sea water samplings and analysis…) and currents (S&L-ADCP will be achieved. The maintenance of the ATLAS buoys of the PIRATA program will also be ensured in the GG. SVP drifters equipped with barometric pressure and wind sensors (resp. GDP/AOML/NOAA) and ARGO profilers will be deployed. pCO_2 will also be measured all along the tracklines from 2006 (resp. IRD/LODYC).



Additional microstructure measurements will be carried out (resp. IFM-GEOMAR; see 1-pager by M.Dengler) and Helium measurements in the upper layer (resp. Univ. Bremen; see 1-pager by M.Rhein) during five of the cruises, for mixing and upwelling rates studies respectively.

During the June-July 2006 cruise, corresponding to the AMMA SOP-1 observation period, turbulent flux measurement will also be carried out thanks to a turbulent flux measurement system of INSU/Météo-France, similar to the instrumented mast used during EQUALANT 1999 (see picture A). The meridional section south of Cotonou (Benin), at 2°50'E, will be occupied twice at

3 week interval, and this section will also be simultaneously covered from aircraft in order to sample both atmospheric and oceanic boundary layers.

The measurements program also consists in a) the installation and maintenance of a meteorological station at São Tomé island, located at 6°E-Equator in the far east of the GG (see picture B); b) the contribution for maintenance of coastal stations along the GG coasts, c) short specific cruises between Dakar and Cape-Vert Island during the 2006 SOP for the ocean surface layer survey, in collaboration with the Senegal-AMMA program, and d) the validation (XBT, ARGO profiler deployments…) of research or merchant vessels transits in the area.

Transport variability in the equatorial Atlantic

As part of the proposal "Role of the equatorial Atlantic for climate variability in Atlantic region" by P. Brandt, C. Boening, M. Latif, L. Stramma, F. Schott, Leibniz-Institut fur Meereswissenschaften (IFM-GEOMAR) an der Universitat Kiel, Germany

Objectives

Main goal is the understanding of upper ocean circulation variability and its role in the heat balance of the eastern tropical Atlantic Ocean. Main issues of this part of the proposal are:

- Quantification of the zonal equatorial circulation and its intraseasonal to interannual variability as part of the subtropical cell and the meridional overturning
- Role of temperature and velocity anomalies for upwelling and sea surface temperature in the eastern equatorial Atlantic Equatorial wave dynamics and its role for Atlantic and Benguela Nino's

Measurement program

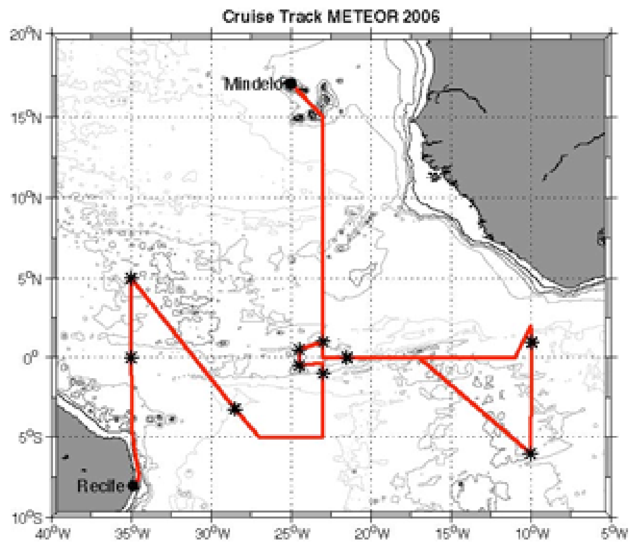


Figure.: Cruise track of METEOR M68/2 in June 2006. Stars represent mooring positions. Mooring at 35W, 0N and 5 moorings near 23W, 0N are current meter moorings, other moorings are sound source moorings for a RAFOS float project that will be completed in 2006.

The measurement program will consist of an array of 5 moorings at 23W on the equator between 1S and 1N, repeated ship sections along 23W, and a glider section along 23W. It is planned to deploy the mooring array during the funded METEOR cruise M68/2 in June 2006. The moorings will consist of ADCPs for the upper layer flow and point velocity and CTD measurements at different depths down to about 1500m. An equatorial mooring at 23W was already successfully deployed during 2002 (Provost et al. 2004) and redeployed in February 2004 (cooperation between LODYC, IFREMER, IFM-GEOMAR). Additionally, an equatorial mooring with similar instrumentation as the 23W mooring was deployed by IFMGEOMAR during August 2004 at 35W. This mooring will be finally recovered in June 2006. It is not planned to redeploy this mooring. The mooring/glider proposal will be submitted to the German Bundesministerium fur Bildung, Wissenschaft und Forschung (BMBF) in February 2005.

Circulation within the subtropical cell of the Atlantic Ocean

F. Schott and P. Brandt, Leibniz-Institut fur Meereswissenschaften (IFM-GEOMAR) an der Universitat Kiel, Germany

Objectives

- Study of the circulation of the western and central tropical Atlantic using isopycnic RAFOS floats. Main issues are:
  - Pathways within the subtropical cell for the supply of eastern upwelling regions
  - Role of intraseasonal to seasonal variability for the mean subtropical cell

Measurement program

The measurement program consists of the deployment of about 50 isopycnic RAFOS floats at 35W, 28W and 23W near the equator during METEOR cruise M62/2 in August 2004 and during SUROIT cruise in May 2005. The floats drift for about one year on isopycnic surfaces __=25.7 kg/m^3 and__=26.8 kg/m^3. Five sound source moorings were deployed and will be recovered during METEOR cruise M68/2 in June 2006.

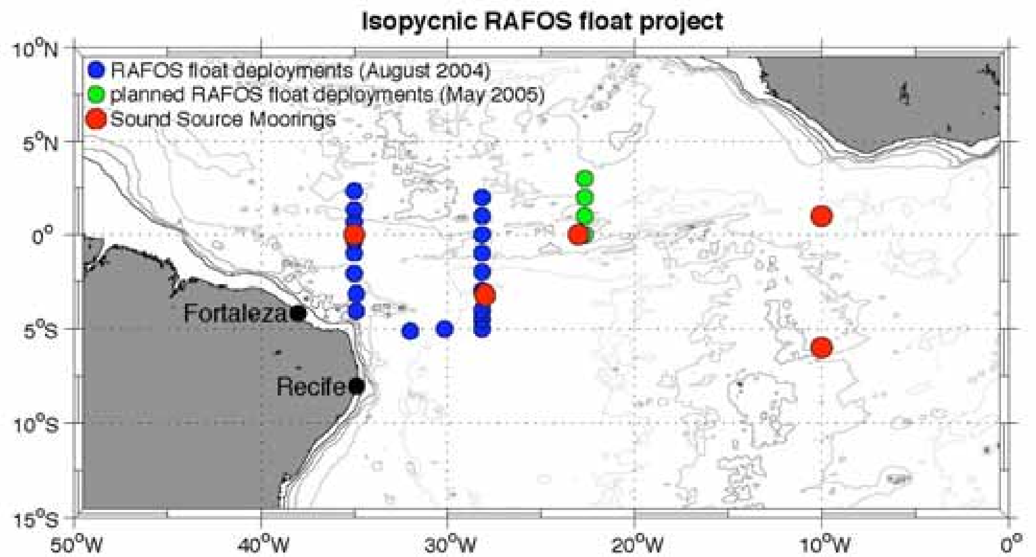


Figure: Deployment positions of isopycnic RAFOS floats and positions of sound source moorings.

Surface fluxes in the eastern tropical Atlantic

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Based on observations from the 15N, 51W NTAS flux mooring, it is expected that the available gridded flux products for the TACE region will have substantial errors (Fig. 1). As a result, validation of flux products for the region using in-situ observations will be important for the estimation of mixed layer heat budgets during TACE

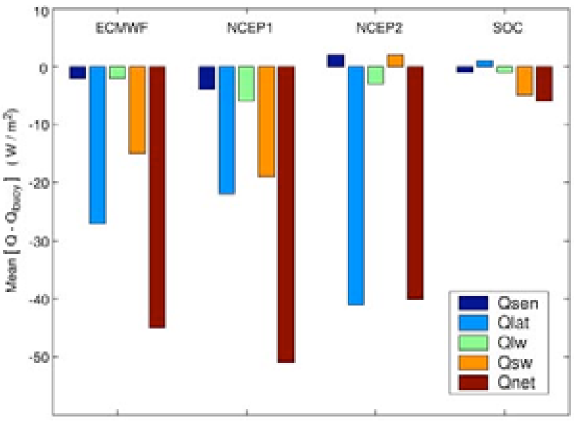


Figure 1. Differences between in-situ and modeled net heat flux at the NTAS site (15N, 51W) are large (4-5 times larger than the expected NTAS error of about 10 W/m^2). The two-year mean netheat flux is significantly underestimated by the three models: All three models indicate a negativtwo-year mean net heat flux, whereas the observed value is +40 W/m^2. The SOC climatology

Objectives

Evaluate the accuracy of gridded flux products for the TACE region and provide alternative fluxes derived from in-situ observations.

Approach

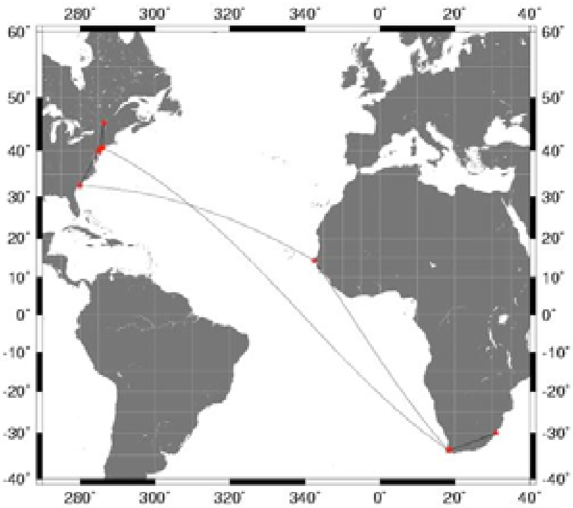


Figure 2. The route of the SeaLand Express. The VOS AUTO-IMET system was installed in March2004. The ship is on a cross-equatorial route between the U.S. east coast and South Africa takes about 7 weeks to complete. It includes a

As a part of the NOAA VOS program, we presently operate a bulk flux package on the SeaLand Express, operating between the U.S. East Coast and Africa, along a route that includes a high density XBT run (AX-8) from Cape Town to New York (Fig. 2). As part of TACE, we would propose to compute and analyze fluxes from the SeaLand Express as a means to tie together the PIRATA and PIRATA-extension mooring data in the eastern tropical Atlantic, to provide information on spatial correlation scales for the fluxes, to provide flux estimates for the TACE region based on in-situ data, and to allow determination of the accuracy of gridded flux products in the region.

Quasi-synoptic collection of oceanographic and meteorological observations from a Research Vessel.

PIs B. Molinari, C. Schmid and R. Lumpkin, AOML/NOAA Miami, USA.

Objectives:

The objective is to collect atmospheric and oceanic data to improve the understanding of the ocean-atmosphere interaction in the Eastern Tropical Atlantic. The primary regions of interest are the African Monsoon (in support of AMMA), the structure of the Saharan Aerosol Layer and the stratocumulus cloud layer in the equatorial cold tongue region. The cruise will take place during the onset phase of the African Monsoon, which is also the time when equatorial cold tongue starts to develop. It is thought that the Monsoon, the stratocumulus cloud and the equatorial cold tongue

build a system of positive feedback that has a large impact on seasonal cycle of the sea surface temperature and rainfall over the land and the ocean.
The Saharan Aerosol Layer is of major interest because of its impact on tropical storm formation and because of its contamination of satellite sea surface temperature observations.
The cruise will also be used to deploy Atlas moorings in coordination with PIRATA (northeast extension) surface drifters and Argo floats.

Measurement program:
The proposed cruise track is shown in Figure 1 (note that the start and end ports may change). Atmospheric measurements collected during the cruise will be: radiosonde, wind profiler and Doppler observations. Measurements important for deriving the surface fluxes will be collected (e.g. humidity). The oceanic data set will consist of CTD/O2, XBT, ADCP, LADCP and microstructure measurements. It can be used for the tracing of water masses, to study changes of the ocean characteristics through comparison with earlier surveys in the same area, and to derive the heat budget terms along the cruise track.

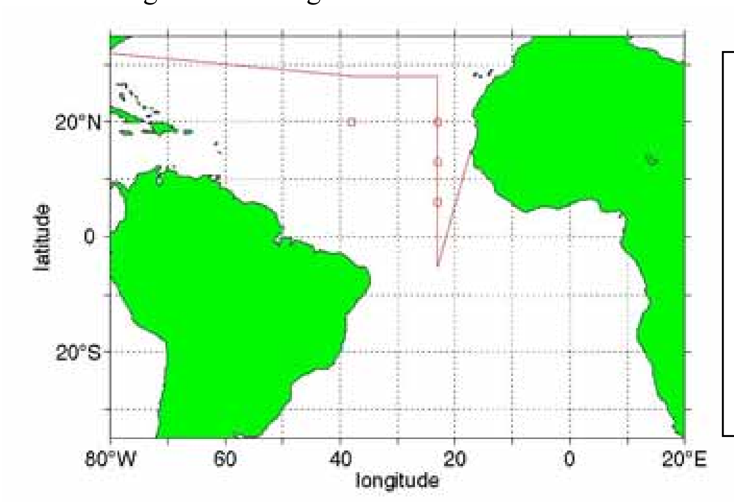


Figure 1. Plan for R/V Ronald H. Brown cruise for May/June 2006. Proposed locations for the Atlas moorings are shown as circles. Two of them will be deployed in 2006. The other two are scheduled for deployment in 2007.

Expansion of the Argo array of profiling floats in the Tropical Atlantic
S. Garzoli and C. Schmid, AOML/NOAA Miami, USA

Objectives:
The objective of Argo is to deploy and maintain an array of profiling floats that measures the upper ocean temperature and salinity on 3 x 3 deg. grid globally in real time. The resulting data set is used by modellers for data assimilation and model validation. It is also used for analysis of the temporal variability in the ocean and the ocean-atmosphere interactions (e.g. the heat budget). In addition the quasi-Lagrangioan data from the floats are used to study the subsurface flow.

Measurements program:
The deployment of Argo floats is planned to fill in the gaps in existing array of profiling floats. Most deployments are done from Voluntary Observing Ships and Research Vessels. The US Argo Data Center at AOML receives the deployment information and processes the float data received from satellites. After an automatic quality control the collected profiles are distributed to users via GTS and the Argo Global Data Centres.
The USA plans to deploy 98 floats in the Atlantic in 2005, about one third of these will be deployed in the tropical Atlantic (within 20N of the equator, figure 1). Additional deployments will be undertaken by other Argo partners (e.g. France, UK)

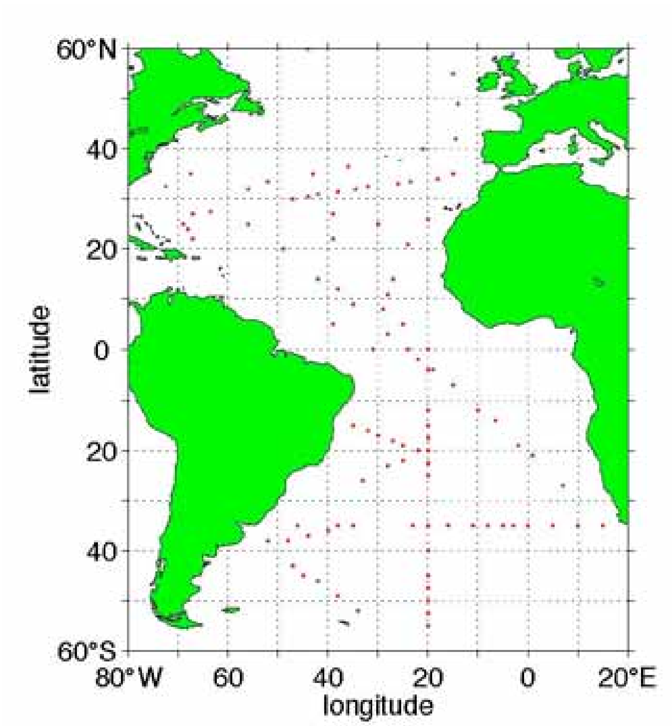


Figure 1. Planned deployment positions for US Argo Floats for 2005

Diapycnal mixing processes in the upwelling regions of the tropical Atlantic.

Marcus Dengler, Leibniz-Institut fur Meereswissenschaften (IFM-GEOMAR) an der Universitat Kiel, Germany.

Objectives

There are severe gaps in our understanding of mixing processes and diapycnal transport in the upper tropical Atlantic, although these mechanisms are known to be important for the mean state and variability of SST and thus strongly contribute to the variability of the tropical Atlantic climate system. The overarching goal of this project is to quantify the impact of diapycnal mixing processes on the variability of sea surface temperature from observations that will be collected during a microstructure measurement programme in the central and eastern tropical Atlantic between 2005 and 2008. Primary objectives are:

- to observe and understand the spatial and temporal variability of mixing processes within the upwelling regions.
- to improve mixing parameterizations through analysis of oceanic and meteorological conditions for mixing mechanisms.
- to improve estimates of diapycnal fluxes of heat, salt and biogeochemical tracers across the base of the oceanic mixed layer.

Measurement program

The measurement program is designed to capture the temporal and spatial variability of mixing processes associated with the variability of ocean circulation and meteorological forcing. Observations will focus on the region of the Gulf of Guinea during the seasons of strongest temporal SST variability, but will also include measurements in the areas of the upwelling regions in the Guinea and Angola domes. To resolve the different background conditions during the dominant annual cycle in the Gulf of Guinea, microstructure surveys will be carried out on 5 French (coordinator B. Bourles) and 3 German research cruises. Two cruises each are scheduled for boreal spring and for boreal fall. In boreal summer, surveys will be carried out on 3 cruises to analyze diapycnal processes acting to maintain the cold tongue and to study the modulation of mixing due to the presence of instability waves. Additionally, one summer survey is planned in the region of the Guinea Dome. Enhanced microstructure observations will be performed at the locations of the PIRATA moorings in the Gulf of Guinea that will be surveyed during 7 of the 8 cruises. At these locations continuous time series of several days will be collected to resolve the diurnal cycle.

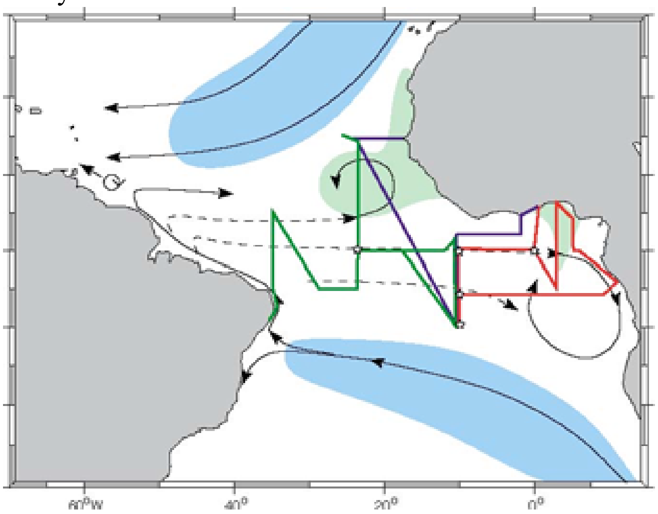


Figure: Approximate cruise tracks of six cruises of the measurement program (green, blue and red lines). Stars indicate positions of PIRATA moorings.

The project was proposed to Deutsche Forschungsgemeinschaft (DFG) in December 2004

Satellite altimetry observations
Gustavo Goni (NOAA/AOML, USA) and Joaquin Trinanes (University of Miami/CIMAS, USA)

Several satellite altimetry missions have been continuously providing sea height anomaly (SHA) fields for more than ten years. Although their individual spatial and temporal coverage varies, they provide global observations that comprise sufficient accuracy and precision to study the oceanic variability on a wide range of space and time scales. Most of the oceanic heat content in the tropical Atlantic (and the rest of the tropical oceans for that matter) is found in the upper layer, for which variations in the depth of the thermocline are directly linked to sea level height. Superimposed on this larger steric signal, mesoscale processes also produce clear deviations of the sea height. In the tropical Atlantic (TA), these processes include the North Brazil Current, its retroflection and rings, westward propagating Rossby and eastward propagating Kelvin waves, tropical instability waves, and westward flowing surface currents and eastward flowing countercurrents and undercurrents. The importance of altimetric observations is that when they are blended with hydrographic data or assimilated in computer models, they have shown to improve estimates of the variability of mass and heat transport.

Current Work:
Our efforts are oriented towards estimating and monitoring:

- Upper ocean heat content. When altimetry observations are blended with hydrographic data, their 2D SHA fields may be used to make estimates of the upper ocean (<1000m) vertical temperature and density structure. The fairly good correlation between the altimetry and hydrographic estimates allows the extension back in time of the PIRATA array time series (Figure 1).
- Surface currents, by investigating the sea surface signal that characterizes each of the zonal current and undercurrent in the region.

Future work will include investigating the hypothesis that instabilities in the tropical currents produce eddy fluxes of heat that significantly impact heat content and sea surface temperature (SST) anomalies. Results will aid the modeling community by assessing the role of the upper ocean heat content in driving SST in coupled atmosphere-ocean dynamics.

Data Distribution:
We are currently monitoring the upper ocean heat content relative to the depth of the 20^{o}C and 26^{o}C isotherms, which have been shown to be critical for hurricanes studies. Daily fields in real-time are posted daily on the web at http://www.aoml.noaa.gov/phod/cyclone/data/. Geostrophic currents derived from satellite altimetry are also estimated and posted daily in near-real time at
http://www.aoml.noaa.gov/phod/dataphod/work/trinanes/INTERFACE/index.html
Regional indexes for the TA region were also created using altimeter-derived parameters and will start being distributed soon through our web pages.
It is crucial that altimetric observations continue as they provide the best tool available at this moment to monitor in real-time mass and heat transport on the global scale.

Acknowledgments: parts of this work are done in collaboration with William Johns and Carlos Fonseca (University of Miami).

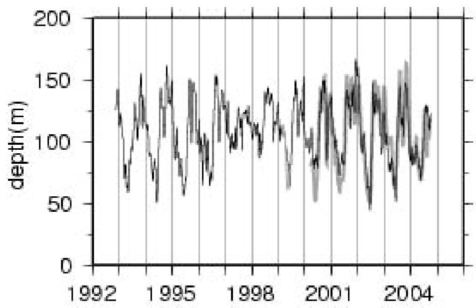


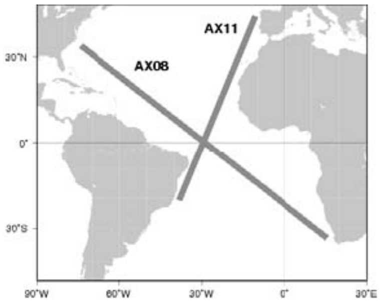
Figure 1. Time series of the depth of the 20ºC isotherm obtained from the PIRATA mooring located at 38W,4N(black) and the atitmetry derived estimate (gray).

High density XBT/XCTD lines in the tropical Atlantic
Gustavo Goni (NOAA/AOML), Molly Baringer (NOAA/AOML) and Sabine Arnault (LODYC)

The upper ocean dynamics in the equatorial Atlantic is dominated by the presence of westward surface currents, eastward countercurrents and undercurrents. In support of the CLIVAR Program and with focus on the ocean-atmospheric interactions in the tropical Atlantic, two high density lines designated as AX08 (XBT) and AX11 (XBT+XCTD) have been implemented in order to improve the current observing system by measuring the long term spatial-temporal variability of mesoscale oceanic features, including vertical temperature structure. Given the importance of the tropical Atlantic in climate variability, and the scarcity of observations in this region, data obtained from the measurements along these lines are key to improving climate forecasts by increasing the subsurface coverage. The objective of these high density XBT/XCTD lines is to characterize both the mean and the time-dependent upper ocean properties of the tropical portion of the Meridional Overturning Circulation and of the shallow Subtropical Cell in the Tropical Atlantic, with particular emphasis in sampling between 30_N and 30_S (AX08) and 20_S and 35_N (AX11) and improve our understanding of the role of the oceans in climate. The goals of these projects include implementing a methodology derived from altimetry to monitor the zonal currents to investigate the role of heat advection in SST fields, and determining subsurface climate signals.

Implementation:
NOAA's Office of Global Programs sponsors line AX08. Line AX08 has been operating since December 2000. Since 2002 there are four transects scheduled per year and there have been 14 transects completed as of December 2005. Profiling floats are deployed in selected transects. Additional information and data on AX08 can be found at
http://www.aoml.noaa.gov/phod/hdenxbt/ax8_home.html

The Institut de Recherche pour le Developpement (IRD) and the Centre National d'Etudes Spatiales (CNES) sponsor the French Altimetrie sur un Rail Atlantique et Mesures In Situ (ARAMIS) Project that maintains AX11. A total of 5 transects have been carried since his line was implemented in 2002, with 2 transects done every year during spring and fall. XBT and XCTD are deployed, together with thermosalinograph acquisition and chemical measurements. More information can be found at http://www.lodyc.jussieu.fr/arnault/ARAMIS



Methodology:
These lines are being used to compute the mass transport of the zonal surface current and subsurface undercurrent system in the region and to determine near surface temperature variability. The dynamic heights are estimated using the XCTD temperature-salinity profiles or T-S profiles from adjacent XCTD stations (AX11) or the XBT temperature profiles with salinity derived from historical T-S relationships (AX08). The errors introduced by using this approximation are being investigated in both lines using actual salinity profiles derived from profiling float observations. The dynamic height fields are used to investigate the surface signature of surface and subsurface currents. Dynamic height estimates using altimetric fields are also obtained and compared against those derived from XCTD/XBTs.

Future Work:
AX08: Four transects are expected to be carried every year with approximately 1200 XBTs deployed.
AX11: Two transects will be done during 2005, the next one will be in April 2005.

Enhancing the northeastern Tropical Atlantic Ocean Observing System
Project Title: Improved forecasts of rainfall in the eastern United States on time-scales from synoptic to decadal (a joint AOML/PMEL proposal to NOAA/OGP) PIs: R. L. Molinari, R. Lumpkin and C. Schmid (NOAA/AOML)

Objectives: augment the ocean observing system in the northeastern tropical Atlantic Ocean with the primary objective of improving rainfall predictions for the Eastern United States on timescales ranging from synoptic to decadal.

Plans: the absence of PIRATA Atlas moorings in the northeastern Atlantic introduces a data gap in the main development region (MDR) where easterly waves translate from the African continent to the Atlantic and (sometimes) develop into closed-circulation tropical cyclones. Our plans are to deploy three Atlas buoys along 23W (6, 13 & 20N) to complement the existing equatorial mooring array and provide real-time data for NWP model initialization. Another mooring will be deployed at 20N, 38W to extend the PIRATA array on this longitude into the MDR. Satellite tracked surface drifters instrumented with sea-level pressure, SST and surface wind sensors will provide data in the gap between 23W and 38W in the MDR. A two-degree of latitude by two degree of longitude grid of 54 surface drifters will be deployed in this region during the hurricane season. Both the moorings and drifters will provide real-time data for use by the operational weather forecast community. Servicing the moorings and deploying the drifter and float arrays will simultaneously provide the opportunity to conduct periodic synoptic surveys of lower atmosphere and upper ocean conditions throughout the MDR. When combined with the existing in situ networks, data to study climatic signals will become available (i.e., we assume that the moorings will be in place for at least 5 years to explore/demonstrate their utility to the operational weather and climate research communities). Moored and drifting buoys will be deployed during a proposed 40-day hydrographic cruise in May-June 2006.

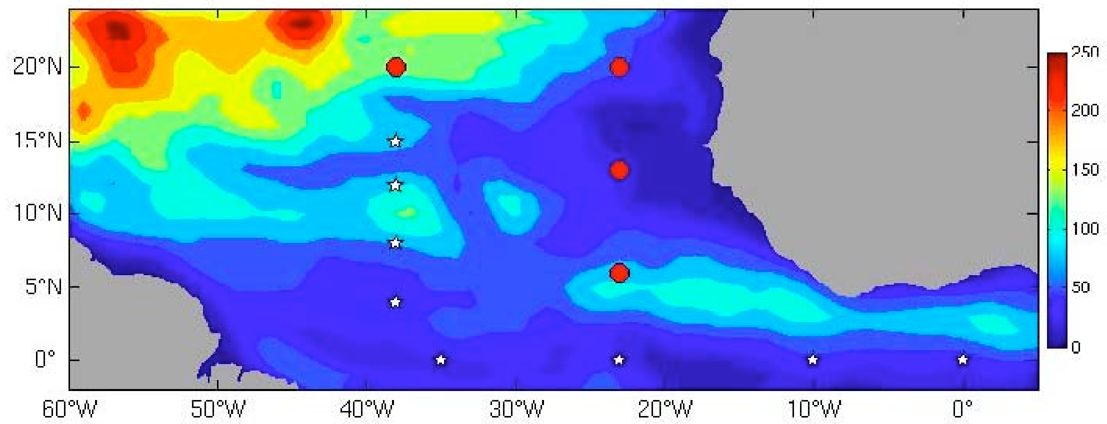


Fig.1: location of proposed Atlas moorings (red dots) and existing PIRATA Atlas buoys (white stars), superimposed on the density of surface drifter observations (drifter-days per square degree) for the period October 1990 through November 2004.

Proposed Study of Circulation and Heat Storage Variability in the Atlantic ITCZ Triangle
Kevin D. Leaman and William E. Johns

The eastern tropical Atlantic Ocean plays a crucial role in climate variability over Africa and the Americas that is of importance to humans, including impacts on human diseases, droughts over Africa and northeastern Brazil, and the generation and intensification of tropical storms in the North Atlantic. The dominant atmospheric structure that influences this region is the Inter-Tropical Convergence Zone (ITCZ), which in turn is strongly influenced by the ocean below.
North of the equator in the eastern Atlantic the wind flowing off the African coast and the Ekman divergence produce both coastal and open-ocean upwelling in a triangular zone extending from the African coast to about 30 W, and from somewhat north of the equator to 15 -20 N. In addition to increased biological productivity, this process leads to thin surface mixed layers, lifting of deeper, colder water, and consequent impacts on heat storage. Recent numerical models have shown that this "ITCZ triangle" is also in roughly the same area as the subtropical shadow zone, where subsurface flow from subduction sites farther north tends to circulate around a plateau in potential vorticity off northwest Africa. Water that takes this route as part of the lower limb of the so-called "Subtropical Cell" finally arrives to be upwelled in the tropics on decadal time scales.
Our proposed work focuses on heat storage and circulation in this region. The proposed work will include: 1) deployment of profiling floats to augment the regional ARGO coverage (poor in much of the area in question); 2) deployment of isobaric and isopycnal RAFOS floats at a number of shallow levels; 3) quantification of the annual cycle and anomalies of heat storage in the area from the augmented ARGO array; 4) description of the circulation into this "ITCZ triangle" as well as around it at deeper levels from a combination of tracked profiling floats, ARGO floats and RAFOS floats; 5) estimation of heat advection from combined thermal (profile) data along with geostrophically computed and directly measured velocities (by floats). The resources needed for the float observations (i.e. sound sources) are strongly leveraged by ongoing projects in the region by French and German investigators. These measurements will be important in developing numerical models of the area that can adequately represent the variability in heat storage produced by changes in surface layer thickness, advection, and the characteristics of the water upwelled from below, something that current coupled models do not do well and which may limit predictability of SST in the region.

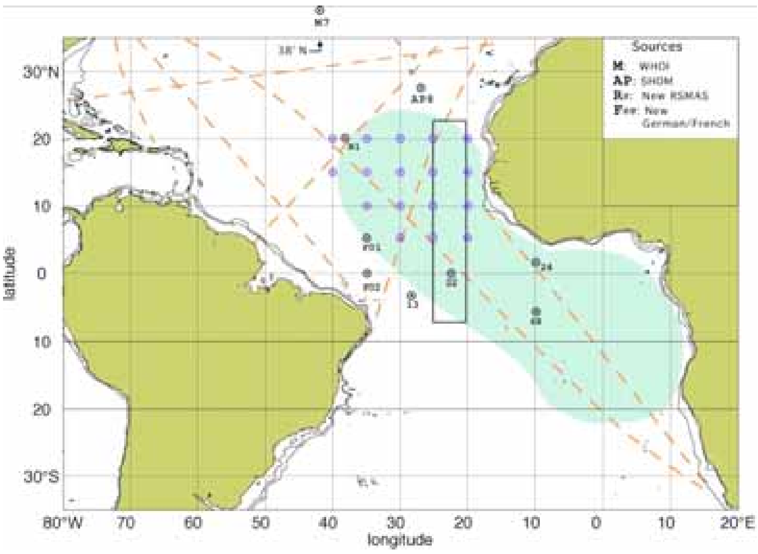


Figure. Proposed RAFOS deployments

Meridional Heat transport in the South Atlantic Ocean

S. L. Garzoli, M. Baringer and G. Goni (NOAA/AOML, US), A. Piola, A. Troisi and F. Vetere (SHN, Argentina)

Data from the existing NOAA/AOML high density (HD) XBT line AX18 are currently being used to obtain estimates of the heat transport (HT) across the nominal latitude of 35S in the South Atlantic, until a more comprehensive plan is formulated.

In collaboration with the Argentine National Hydrographic Service, AOML has been maintaining this line between Cape Town (South Africa) and Buenos Aires (Argentina) since 2002. Through December 2004, a total of eight transects have been completed. Four transects are being planned for each year.

A methodology similar to that used in the North Atlantic with data obtained from AX07 has been developed to estimate the HT across AX18. Salinity profile data obtained from ARGO profiling floats launched along this transect are used in combination with historical T/S relationships, to compute the mass transport in the region. The first estimates of the HT range between 0.5 and 1.0 ± 0.3 PW.

This HD line has the ideal location to capture the heat and mass exchanges between the Indian Ocean and the South Atlantic. However, its western end crosses the highly variable and energetic region of the Brazil/Malvinas Confluence, making it difficult to estimate the barotropic component of the mass transport. Although this problem could potentially be avoided by choosing an alternate western port near 20S, far from the Confluence region, there are several logistical problems that would need to be resolved.

Additionally, sea heights derived from altimetry fields are being used to aid in identifying the ocean features, such as fronts, eddies and rings, crossed by each transect. These fields will be also used to investigate the surface signature produced by the variability of the HT.

Proposed plans:

A. Improve the estimates by measuring the Malvinas Current at the end of the line.

1. Deploy two bottom current meters, one on the continental shelf and the other on the continental slope. Advantage: time series of the current. Disadvantages: time delay between availability of XBT and current data.
2. Launch expandable current profilers on the west end of the XBT line.

B. Change the route of the line from Cape Town to the more northern city of Santos, instead of Buenos Aires. Advantage: the west end of the transect does not cross the highly variable Confluence region, as the Brazil Current is less variable and could be monitored more easily. In collaboration with AOML, Mauricio Matta (FURG, Brazil) is running an XBT line between Rio and the island of Trindade to monitor the Brazil Current. These observations could be used to improve the mass transports on the west end of the alternate HD XBT line. Disadvantage: It could be difficult to find container ship line that follows this route.

Changes in Thermocline Ventilation Rates
Rana A. Fine, Rosenstiel School USA

Objectives are to**:**

- Monitor changes in ventilation rates of waters feeding the equatorial thermocline,
- Document variations in water mass pathways between the subtropics and tropics,
- Assess the larger scale impacts of these changes-how they relate to variations in atmospheric indices and oceanic circulation and fluxes.

Methods:

Tracer, oxygen, and hydrographic data collected along 23W annually during the R/V Ron Brown cruises will be used to calculate subduction rates. Oceanic trends will be correlated with variations in atmosphere and large scale ocean circulation. Oxygen sensors on several 23W Pirata and 35W moorings in the thermocline will be used to bridge the temporal gap between hydrographic cruises. The relative dynamical contributions to subduction rate variations will be examined in a model context.

Two decades (1982-2004) of tracer and hydrographic data from the subtropical/tropical North Atlantic show that these data can be used to monitor decadal variability of ocean circulation. Subduction rates of Salinity Maximum Water (SMW) can be quantified using the tracer ages. Thermocline ventilation, and specifically subduction rates of SMW vary by an order of magnitude over the two decades. Subduction rates correlate with other properties: inversely with age, positive correlations with salinity and oxygen. Some of the interest in SMW comes from their equatorward subduction in subtropical circulation cells, and from their secular trends.

The North Atlantic Oscillation (NAO) is one of the dominant modes of atmospheric variability in the North Atlantic sector. Variations in the NAO index and associated wind fields imply strong changes in the surface air-sea flux fields of heat, momentum, and water. These changes impact both the local thermodynamic response of the mixed layer and the large scale circulation field. Correlation of SMW subduction rates with NAO is highest at lags of 2 and 7 years, there are correlations with AO, and to a lesser degree with tropical indices. Part of the ocean response to atmospheric forcing is local and rapid (changing wind stress curl), and part of the response seems to be longer time (waves). In addition, there probably are other influences on the two decades of subduction rates beyond the NAO, etc. including longer term secular trends like the increasing salinity and temperature. Variations in subduction rates and thus the ventilation pattern will affect the uptake of other gases, e.g., CO_2

Larger Scale Issues to address with TACE observations:

Does the whole STC speed up/slow down with changes in the NAO?

How do subtropical/tropical pathways change?

Does some fraction of the decreasing subduction rate fit a longer-term pattern than the NAO index, that of global warming?

On what time scales do anomalies of T'v dominate, and on what time scales do Tv' dominate?

What will happen in 30 years, if STCs slow, will upwelling also slow/stop, and what about affects on fisheries?

If upwelling changes-how will this affect the base level of the thermocline?

Equatorial Upwelling Rates inferred from Helium Isotope Data

Monika Rhein, Oceanography Dep. University Bremen, Germany,
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Upwelling is one of the key processes to maintain the Tropical Atlantic cold tongue. Direct measurements of the upwelling have been hampered by the small speeds involved. Instead, vertical motion has to be estimated by indirect methods. Klein and Rhein (2004) propose a novel approach to infer equatorial upwelling velocities by exploiting the helium isotope disequilibrium between atmosphere and equatorial oceanic mixed layer. Although the vertical and horizontal resolution of the existing helium data in the upper tropical oceans was too poor to support a detailed study, it was sufficient to show the potential of the method.
The advantage of the helium isotope method is that the equatorial helium disequilibrium between mixed layer and atmosphere can only be maintained by vertical motions (w), since horizontal advection in the mixed layer would import equilibrated water and thus erode the signal. Assuming moderate levels of turbulence at the base of the mixed layer the vertical diffusion turned out to be much smaller than the air-sea gas exchange, which has then to be balanced by upwelling from below.
For an accurate determination of the helium balance in the mixed layer it would be advisable to perform concurrent turbulence measurements during future experiments. Temporal as well as zonal gradients were ignored by Klein and Rhein (2004) due to lack of sufficient tracer data. The time scale of the gas transfer (order of 10 days) determines the validity of a helium-derived estimate of w. To detect small changes in $_^{3}$He, repeated measurements will be necessary to decrease the error margins of the individual measurements. At present, the major uncertainty of w is caused by the insufficient number of helium data in space and time.

Objectives:

- to estimate upwelling rates from the distribution of Helium isotopes in the equatorial Atlantic
- to infer the temporal variability of the upwelling in the eastern tropical Atlantic by a time series of Helium distribution and the spatial variability by sampling along cross-equatorial sections at different longitudes (23W, 10W, 10E)

Methods and field work:

- analyse Helium samples from zonal sections crossing the equator in spring 2006 (RV METEOR cruise)
- in order to obtain a time series, analyse Helium samples from three French cruises in the eastern tropical Atlantic in fall 2005, spring 2006 and fall 2006 (IFREMER, coordinator B. Bourles), and on the RV Ron Brown (NOAA, coordinator Bob Molinari).
- the Helium distribution will be combined with the profiles of vertical turbulence (P. Brandt, IFM-Geomar) and with meteorological data (winds, buoyancy fluxes) to optimize the estimate of the upwelling rate, using a dedicated mixed layer model.

Literature:

Klein, B., und M. Rhein, Equatorial Upwelling Rates inferred from helium isotope data: a novel approach. Geophys. Res. Lett. 31, L23308, doi: 10.1029/2004GL021262, 2004

Changes in tropical Atlantic climate variability and its teleconnections.

W. Hazeleger, R. Haarsma, and W.P. Breugem
KNMI, Climate Research and Seismology, De Bilt, The Netherlands

The tropical Atlantic variability is characterized by a cold tongue mode and a meridional gradient mode. Also, remote patterns of variability such as ENSO and the NAO impact the tropical Atlantic climate. Recent studies indicate that the cold tongue mode can affect the NAO, with a lead time of 4 months.

We investigate tropical Atlantic variability with the coupled *SPEEDO* model. This model consists of an atmospheric primitive equation model with simplified parameterizations (Speedy) and a suite of ocean models ranging from a simple slab mixed layer, a slab mixed layer with Ekman dynamics and wind mixing, to the MICOM isopycnic primitive equation model. Speedy is a global atmosphere model, but MICOM can be set up for any basin at any resolution.
The mean state and natural variability is simulated realistically. Future work includes: a) Study mechanisms of natural variability in the tropical Atlantic b) Determination of teleconnections from tropical Atlantic to Western Europe c) Characterization of modulation of the tropical Atlantic climate (mean state, annual cycle, and low-frequency variability) due to CO_2 rise in the atmosphere d) Determination of changes in impact of tropical Atlantic on remote regions (with emphasis on the NAO) due to CO2 rise in the atmosphere.

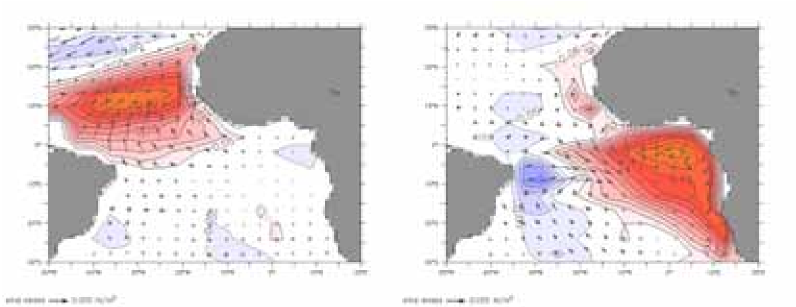

Figure: First and second rotated EOF of SST in the fully coupled SPEEDO model (Speedy T30 atmosphere coupled to 1-degree MICOM) and associated wind stresses. In accordance with observations, the first REOF dominates in spring, the second in late summer.

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Modelling Tropical Atlantic mesoscale field

Paola Malanotte-Rizzoli, MIT (work with M. Jochum, NCAR; R. Murtugudde and J. Ballabrera, UMD)

CLIVAR Questions:

- What explains the annual cycle of the AMI?
- How is the interannual variability of the AMI connected to the interannual variability of the tropical SST?

Overall Hypothesis:

Nonlinear ocean dynamics, frontal processes and the details of coastal upwelling along the African coast are essential features of TAV and need to be resolved to reproduce and realistically simulate the variability of the AMI from seasonal to decadal time-scales.
Previous studies by Jochum and Malanotte-Rizzoli show that resolving the mesoscale field is crucial to correctly reproduce the SST seasonal cycle.

Approach:

Numerical simulations with coupled ocean-atmospheric models.

- **Complex OGCM in eddy-resolving configuration** (Reduced gravity, primitive equation, sigma-coordinate model of Gent and Cane with oceanic mixed layer coupled to atmospheric boundary layer model for interactive heat flux computations.)

- **Simple atmospheric model of Lindzen and Nigam** (Shallow water model evaluating surface winds based on SST distribution, radiative heating and friction)

Strategy:
1 Control run: coupled models with 1/4^o resolution.
2 Coarse resolution ocean forced by climatological winds
3 High resolution ocean forced by climatological winds
4 High resolution ocean coupled to coarse resolution atmosphere

Improvement and Analysis of Tropical Ocean Climate Hindcasts Using a Global Ocean Data Assimilation System (HYCOM)
PIs: George Halliwell (RSMAS/UM) and Chunzai Wang (AOML/NOAA)

A global ocean data assimilation system based on the HYbrid Coordinate Ocean Model (HYCOM) will be used in conjunction with satellite-derived SST and altimetry fields, along with other satellite and *in-situ* observations, to study tropical ocean climate variability and improve our capability to simulate this variability. The observations will be used to evaluate and improve the ocean model, and also for assimilation to improve tropical ocean hindcasts designed to resolve variability from seasonal to decadal timescales. Since global climate variability is strongly influenced by air-sea heat and mass exchanges over the tropical oceans, it is important that ocean models and the ocean component of global climate models properly reproduce the distribution and transport of heat in the tropical oceans plus the thermal exchanges with higher latitudes. The HYCOM assimilation system is particularly suited to this study for several reasons. The hybrid vertical coordinate system is quasi-optimal over a broad range of oceanographic conditions: isopycnic in the stratified ocean interior, level in the nearsurface mixed layer, and sigma over shallow water. The model presently contains one assimilation algorithm (optimum interpolation for use with satellite altimetry, SST, and XBT observations), while other state-of-the-art algorithms are being developed and tested. The model is equipped with multiple vertical mixing submodels, so the sensitivity of hindcasts to vertical mixing parameterization will be assessed. It is also equipped with multiple horizontal advection submodels. Satellite and *in-situ* observations will be employed (1) to generate the best possible forcing fields, (2) for model evaluation to guide the tuning and improvement of HYCOM subgrid-scale parameterizations, and (3) for assimilation into model hindcasts for scientific analysis. Full-basin and global HYCOM operational simulations with (at a minimum) satellite altimetry assimilation will provide initial and boundary conditions for the nested tropical ocean simulations proposed here. Process studies will be conducted in several tropical subdomains, both basin-wide and regional, using high-resolution nested simulations, increasing meridional over zonal resolution as necessary to properly resolve zonal currents. Process studies will focus on important climate phenomena such as the Pacific ENSO, the Atlantic Niño, the tropical Atlantic meridional SST gradient, the Western Hemisphere warm pool, and the Indian Ocean dipole. The contribution of different physical processes to tropical climate variability will be thoroughly analyzed.

Tropical And South Atlantic Data And Data Product Availability
Robert L. Molinari, National Ocean and Atmospheric Administration Atlantic Oceanographic and Meteorological Laboratory, Miami, Florida USA

The Atlantic Oceanographic and Meteorological Laboratory (AOML) has been funded to host the Argo Regional Data Center (ARDC) for the South Atlantic. For Argo purposes the South Atlantic extends from 20°N to the southern ocean. The northern limit is chosen so that there is an overlap with the ARDC for the North Atlantic, which extends southward to 20°S and is hosted by IFREMER, France. The primary objective of the ARDC's is to perform the final level of quality control on the Argo profiling data. The method, still being developed, will at least entail comparing the float data with neighboring (time and space windows to be determined) float, CTD, XBT and hydrographic data. AOML has begun to work with countries bounding the South Atlantic to obtain complete sets of these data that might not have yet been submitted to the World

Data Centers. Upon receipt of these data, AOML will apply automatic quality control tests (already developed for Argo) to identify and flag incorrect profiles. An operator will inspect those profiles that fail the automatic tests. The data will then be put on the AOML website so that they are available to interested users (i.e., a TACE resource). AOML is also a participant in the African Monsoon Multidisciplinary Analysis (AMMA) project, a study of the West African Monsoon and it's offshore manifestations. For AMMA, AOML will extend the data domain to somewhere between 30N and 40N. AOML also generates daily global maps of sea surface height from altimetry, sea surface geostrophic currents from the height distributions, surface winds from scatterometer data and sea-surface temperature (SST) from AVHRR observations. A customized product is being developed that will generate these products for only the tropical Atlantic. These products will be available for both Argo and AMMA participants and can also serve as a resource for TACE.

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