Summary of the Fourth Meeting of an Ad Hoc Group of Investigators Studying the Tropical Atlantic.

INTRODUCTION: The fourth meeting of the "Friends of the Tropical Atlantic" was held in Miami Florida, from 25 to 27 March (previous meetings were held in Venice, Italy, 2000; Paris, France, 2001; and Kiel, Germany, 2002). The objectives of these meeting are (1) to review results from observational and modeling studies of the tropical Atlantic and the role of the basin in regional and global climate; (2) encourage cooperative studies between observationalists and modelers; (3) promote joint publications and (4) plan future field work. With respect to each objective:

(1) A brief summary of the presentations is given below under the heading What's New in the Tropical Atlantic.

(2) Web sites have been established which present modeling and observational results from the region. The modeling website address is http://www.knmi.nl/~hazelege/tameet/tameetmod.html and the observational website is http://www.aoml.noaa.gov/phod/TAWorkshop/

(3) A list of papers was developed for publication in a special issue of DEEP-SEA RESEARCH. The papers are to be submitted by 1 September. Editors will be P. Rizzoli, F. Schott and R. Molinari. The list is attached as Appendix I.

(4) A draft proposal for an oceanographic component for AMMA is attached as Appendix II.

Objective 1: WHAT'S NEW IN THE TROPICAL ATLANTIC

NEW OBSERVATIONS:

1) Goni, G. and M. Baringer (NOAA/AOML): Quarterly high-density occupations of AX-8.

2) Bourles, B. (IRD): Cruises in the Gulf of Guinea as part of the funded French program EGEE. EGEE represents an oceanographic component of AMMA and will be closely coordinated with other proposed ocean AMMA plans (see APPENDIX II). In addition, within the framework of EGEE, a meteorological station will be installed this summer at Sao Tome Island.

3) Mestas-Nuñez, A. (University of Miami), A. Bentamy (IFREMER), K. Katsaros (NOAA/AOML), and W. Drennan (University of Miami): Estimation of air-sea latent heat flux distributions from satellites. We combine satellite observations of wind speed, humidity and SST to estimate weekly latent heat fluxes over the global oceans using a bulk formulation. The satellite flux estimates have been compared to in-situ observations and atmospheric analyses. We emphasize the role of easterly wind bursts in enhancing evaporation in the tropical/subtropical Atlantic in both hemispheres. At present 3-years (1996-1998) of satellite

latent heat fluxes have been produced. Plans are underway to extend this record length as well as to estimate all the remaining surface heat flux terms in the Atlantic from satellite data.

4) Carton J. and S. Garzoli (University of Maryland, NOAA/AOML): Submitted proposal to deploy 50 surface drifters on five meridional sections that cross the equator.

NEW OBSERVATIONAL RESULTS:

1) 35 W

>> Affler, K. (University of Kiel): The zonal circulation at 35W. Results are reported from a new study by Schott et al. (GRL, in press), in which the total of 13 existing cross-equatorial shipboard current profiling sections taken during the WOCE period between 1990 and 2002 along 35W are analyzed. The mean meridional structure of the zonal top to bottom circulation between the Brazilian coast, near 5S and 5N is determined and mean transports of the individual identified shallow, intermediate and deep current branches are presents. One of the results is that on the equator a mean westward Equatorial Intermediate Current below the Equatorial Undercurrent.

>> Brandt, P. and C. Eden (University of Kiel): The seasonal cycle of the equatorial circulation. The annual harmonics of the current and density fields at 35w in the upper 1000m were calculated from all existing sections. They reveal a strong seasonal signal in the velocity field at intermediate layers near the equator of more than 10 cm/s and in narrow bands centered at 3N and 3S of more than 5 cm/s. Good agreement is found between observed amplitudes and phases of the annual harmonics and those simulated by a regional model of the tropical Atlantic that was forced with NCEP winds for the period 1990 to 2001.

>> Molinari et al. (NOAA/AOML): Identification and characterization of a mean northern hemisphere Tropical Cell at 35W. Twelve sections along 35W provided direct observations of the upper layer velocity field. Average sections of meridional velocity, horizontal divergence and vertical velocity portray a northern hemisphere Tropical Cell (TC). The TC is characterized by equatorial upwelling, surface transport poleward, downwelling at 3-5N and equatorward flow at 100m

2) North Brazil Rings:

>> Johns, W. and S. Garzoli (University of Miami and NOAA/AOML): Identification of different ring types that separate from North Brazil Current. One type has a very small surface signature, thus difficult to observe by satellite altimetry. Estimate of cross equatorial exchanges due to rings is 9 Sv/year, considerably larger than earlier estimates.

>> Richardson, P. (WHOI): Described the paths of 10 rings that were tracked with surface drifters and subsurface RAFOS floats. Most rings translated northward east of the Antilles past Barbados and stalled near 14N-18N. Most drifters entered the Caribbean or grounded on the islands; around half of the 250m and 550m floats (but none of the 900m floats) also entered the Caribbean.

3) Regional characterizations:

>> Fischer, J., F. Schott and W.V.D. Zwet (University of Kiel): Fifteen APEX-SBE floats were deployed in the western tropical Atlantic to drift at shallow levels (200m and 400m) to determine the pathways of the thermocline circulation. An important technical aspect is that the salinities of the shallow floats are of good quality. While the 400m floats stayed near the Brazilian coast, the 200m floats were caught in the eastward flow north and south of the equator

(presumably the North and South Equatorial Undercurrents). Especially the floats in the northern branch crossed the whole Atlantic showing a poleward inclination of the trajectories and reached the upwelling area of the Guinea Dome within the three years since they were deployed. The southern branch along approximately 5S showed only weak poleward inclination and a reversal of the trajectories at the approximate location of the Mid-Atlantic Ridge.

>> Lumpkin, R. (NOAA/AOML): Tropical Atlantic surface currents derived from a mean + seasonal + eddy decomposition of drifter observations. Results include a boreal spring weakening of the NBC retroflection and reversal of the western North Equatorial Countercurrent. By subtracting the Ekman component of the flow, geostrophic pathways for the underlying circulation are revealed including the major bands of the SEC and a surface signature of the South Equatorial Countercurrent.

>> Carton, J. (University of Maryland): Characterization of sub-surface temperature field from results of data assimilation into the SODA model. An ITCZ develops off Brazil in the southern hemisphere between the cold tongue and warm water to the south.

>> Zhang, D. and M. McPhaden (NOAA/PMEL): Tropical-subtropical water mass exchanges in historical hydrographic data. Decadal temperature and salinity anomalies in the surface of subtropical Atlantic Oceans were subducted into the pycnocline. These hemispherically anti-correlated anomalies weakened along their equatorward trajectories, but entered the equatorial zone in 4-6 years with amplitudes comparable to those for decadal time scale SST anomalies. They were upwelled near the equator to produce anomalous SST gradients that are linked to cross equatorial wind field changes. The tropical-subtropical water mass exchanges thus enhanced the coherence of the North and South Tropical SST anomalies in the period band of 8-12 years.

>>Schott, F., P. Brandt, M. Dengler, R. Zantopp and J. Fischer (University of Kiel): The western boundary current at 5-11S. Transport sections from repeat ship surveys at 5S and 11S show that the North Brazil Undercurrent (NBUC) is already well developed at 11S, with about 25 Sv flowing northward in the upper 1000m, i.e., the SEC bifurcation is located well south of 11S. While the NBUC was located over the shelf edge, large cruise-to-cruise differences were found in the location and strength of the North Atlantic Deep Water (NADW) core at both latitudes. Evaluation of the first time series from the moored CLIVAR array at 11S showed large deep variance at about 70 days period that appears to be responsible for the NADW transport variations.

>> Schmid, C. (NOAA/AOML): Comparing model results and observations, explained intraseasonal variability at 800-1000m in terms of superposition of planetary waves; existence of intraseasonal variability in seasonally driven model suggests instability source

>> Enfield, D. (NOAA/AOML): The Western Hemisphere warm pool primarily located in the Intra-Americas Sea (IAS) and western tropical North Atlantic (TNA) plays a key role in the annual development of the inter-American monsoon systems. Its interannual variations in size rival its annual mean and are thought to affect the land climates surrounding the IAS. These variations are tightly connected to thermal variability in the tropical Atlantic and may be one of the important conduits by which the tropical Atlantic affects Western Hemisphere climate in general. The largest warm pools develop in the year following El Nino events but not all El Nino events. Research into why does or does not occur can potentially lead to significant progress in climate prediction.

>> Bourles, B. (IRD) Studies in the equatorial Atlantic: A first study is presented that concerns the analysis of the structure and variability of the EUC in the Atlantic, by using available observations and the CLIPPER numerical model, that simulates a realistic EUC (Arhan, Treguier, Bourles, Michel and Chuchla, in preparation). This study aims to better

understand the mechanisms of the EUC seasonal and interannual variability. Other studies are presented that show: (1) the large scale circulation features at the NADW level through the time evolution of the CFC-11 distributions in the central/eastern equatorial basin, as inferred from the CITHER and Equalant cruises (Andrie et al., in preparation), (2) the Congo River signature and deep circulation (around 4000m) in the Guinea Basin (Braga, Andrie, Bourles, Vangriesheim, Baurand and Chuchla, in revision for DEEP-SEA RESEARCH). A few contributions to ARGO (and its French component CORIOLIS) and EGEE (AMMA) are also presented, i.e., the use of all possible cruises and /or transits carried out in the eastern tropical Atlantic and more especially the Gulf of Guinea to deploy SVP drifters, ARGO profiling floats and XBTs and to obtain TSG and ADCP measurements along the tracklines.

>> Dengler, M., L. Stramma and P. Brandt (University of Kiel): The pathways and transports of surface and central water masses along the western boundary between 12S and 16N in the tropical Atlantic were investigated using six near synoptic direct velocity/hydrographic sections collected during boreal fall 2000.

NEW MODEL RESULTS

1) Jochum, M. and P. Malanotte-Rizzoli (MIT): The South Equatorial Undercurrent is forced by tropical instability waves. The latter were shown to exist on both sides of the equator and throughout the year, as opposed to earlier studies that suggested a northern hemisphere and summer-only phenomena. The contribution of the tropical instability waves to the equatorial heat budget is much smaller than previously thought because of their vertical heat flux, which largely compensates for their meridional heat flux.

2) Campos, E. (University of Sao Paolo): A dipole is found in South Atlantic SST that is correlated with rainfall over Africa and South America.

3) Wang, C. (NOAA/AOML): Eastward subsurface countercurrents (SSCC) are observed to correspond to a meridional circulation of a subthermocline tropical cell (STTC). The STTC is below and weaker than the tropical cell, being characterized by an equatorward flow in the thermocline, an equatorial downwelling, a poleward flow in the subthermocline, and an upwelling about 3-4 degrees from the equator. The essential dynamics of the SSCC can be explained in terms of the conservation of absolute vorticity in the poleward flow of the lower branch of the STTC. As a parcel within the subthermocline moves poleward, its gain of planetary vorticity is compensated by a loss of relative vorticity, resulting in the eastward SSCC. By applying the conservation of potential vorticity, the paper also shows that the poleward shoaling of subthermocline isotherms at the poleward flanks of the thermostad can contribute to the SSCC.

4) Kroeger, J. (University of Maryland): Extra-equatorial mechanisms play a significant role in modulating decadal SST anomalies in the tropical Atlantic as is shown by a suite of experiments based on an eddy resolving, reduced gravity, sigma coordinate PE model forced by observed wind stress and/or computed heat flux from the associated advective atmospheric mixed layer model. Superimposed by the MOC, long-term variability of the dominating southern STC leads to potential SST anomalies in the eastern equatorial region by either (1) equatorward advection of temperature anomalies formed by the subduction process in the subtropics or (2) by changes in the strength of the STC's themselves, varying the amount of cold water that is transported into the tropics.

NEW AND OLD QUESTIONS:

1) What is the structure (if they exist) of northern hemisphere sub-tropical cells (i.e., is upwelling in the eastern basin instead of on the equator)?

2) Is the Equatorial Intermediate Current a mean feature of the circulation or a wave phenomenon?

3) What is the cause of the different vertical profiles of the North Brazil Current retroflection rings?

4) What observations/models are needed to balance the heat and salt budgets of the equatorial Atlantic?

5) What are the advective affects that impact on the Warm Water Pool?

6) Does all the transport of the North Brazil Current rings become entrained into the northern hemisphere?

APPENDIX I: List of potential papers for a special issue of DEEP-SEA RESEARCH

DSR II Tropical Atlantic Special Volume **Proposed submissions**	
M.Rhein, C. Andrie, L. Stramma and Steinfeld	Signatures of newly ventilated LSW in the subtropical/tropical Atlantic
L. Stramma, M. Rhein, P. Brandt, C. Boening, M. Dengler and M. Walter	Warmwatersphere circulation in the western tropical Atlantic in boreal fall 2000
Z.D. Garraffo and S.L. Garzoli.	North Brazil Current variability in a very high resolution North Atlantic simulation
G. Goni, Z.D. Garraffo and Baringer	Surface signals of the main upper ocean currents in the tropical Atlantic
K. Lohmann et al.	STC variability in coupled model evaluation
W. Hazeleger	The impact of seasonality on ventilation of equatorial undercurrents; a Lagrangian description
V. Metha et al.	Atlantic STC in SODA
J. Lorenzzetti et al.	Surface Heat Fluxes in the Tropical Atlantic derived from PIRATA mooring array.
G.Goni and A. Ffield	Sea surface height and temperature signals of the North Brazil Current retroflection and North Brazil Current rings
G. Reverdin et al.	Surface salinity variability in the tropical Atlantic
M. Arhan, A. Treguier, B. Bourles and S. Michel	Structure and variability of the Equatorial Undercurrent
J.Fischer et al.	Lagrangian circulation at thermocline levels studied with APEX floats
P. Brandt et al	Tropical Atlantic seasonal to interannual variability
F. Schott et al.	The circulation off Brazil at 4-12S
M. Jochum and P. Malanotte- Rizzoli	The structure and dynamics of TIW in a numerical simulation of the tropical Atlantic.
B.Bourlès, G.Charria, S.Michel, C.Andrié and A.M.Tréguier	The Antarctic Intermediate Water evolution in the Equatorial Atlantic, as inferred by in situ measurements and numerical

and A.M.Tréguier	results
M. Araujo et al.	Seasonal changes in the mixed and barrier layers at the Western Equatorial Atlantic
Fonseca, G. Goni, Johns and E. Campos	Investigation of the NECC variability observed by altimetry
Zhang and McPhaden	Trop. And subtropical watermass exchanges in the Atlantic
R. Molinari et al.	Circulation across 44W
Goes et al.	Kinematic properties of cross-equatorial flows
Schmid et al.	Forcing mechanisms of intraseasonal variability in the southern tropical Atlantic
Schmid et al.	Equatorial Deep Jets
Lumpkin, R.	Surface circulation of the tropical Atlantic observed by satellite-tracked drifting buoys
S. Garzoli, A. Ffield, W. Johns and Q. Yao	North Brazil Current retroflection and transports

APPENDIX II: An Ocean Component for AMMA (OCCAM)

INTRODUCTION

Numerous studies have demonstrated correlations between SST in the eastern tropical Atlantic Ocean and the West African Monsoon and resulting rainfall over West Africa. However, the present inability of coupled General Circulation Models to simulate accurately SST in the area, contributes to the inability of forecast models to predict accurately West African rainfall. In what follows a plan for oceanographic studies is presented with the central objective of improving the ability of GCM's to more accurately simulate eastern tropical Atlantic SST's, eventually leading to improved West Africa rainfall forecast capabilities.

OBJECTIVES

The objectives of the OCeanographic Component of AMMA (OCCAM) are developed on the basis of the Observing Period framework defined by AMMA. The three different periods and their objectives are:

1) During the Long-term Observing Period: to characterize the mechanisms by which anomalous structures (currents and stratification) in the eastern tropical Atlantic (i.e., the equatorial cold tongue, the ITCZ and north of the ITCZ) affect sea-surface temperature variability.

2) During the Enhanced Observing Period: to characterize the annual cycle of air-sea interaction, in particular the interactions and feedbacks between the ITCZ and the regional (i.e., north as well as south of the ITCZ) SST field.

3) During the Special Observing Period: to estimate the terms in the heat budget including mixing at the base of the mixed layer and surface fluxes in the Atlantic cold tongue and under and north of the ITCZ during different phases of the monsoon (i.e., onset, peak and late).

METHODOLOGY

1) Long Term Observing Period: sustained observations including:

- >> Surface drifters (partially funded)
- >> Lagrangian floats
- >> XBT transects (funded)
- >> Profiling floats (partially funded)
- >> Subsurface current and temperature/salinity moorings along 23 W, 10W and 6E.
- >> Coastal and island stations (funded)
- >> Satellite observations (partially funded)
- >> Surface flux moorings at 5N, 23W and 12N, 23W

2) Enhanced Observing Period:

>> Three seasonal (onset, peak and late monsoon) cruises along the moored sections (23W, 10W and 6E) for at least two years to include (1) intensive atmospheric as well as oceanographic observations crossing the ITCZ and cold tongue and (2) small deliberate tracer experiment injection into the EUC to quantify mixing and the fate of EUC water.

3) Special Observing Periods:

>> Heat budget calculations and process studies for determining the mixing physics from research vessels at selected locations within the cold tongue and under and north of the ITCZ.