CLIVAR workshop on tropical Atlantic variability

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1. Introduction

[2] Climate variability in the tropical Atlantic region and the land that surrounds it represents a difficult problem in terms of large-scale circulation and ocean-atmosphere-land interactions, with important economic and social impacts (CLIVAR Initial Implementation Plan, June 1998). During recent decades a large multi-decadal swing in the Atlantic climate has been observed and it is believed to be caused by interactions between the Atlantic Ocean and the overlaying atmosphere. These climate swings are directly or indirectly related to the tropical Atlantic region where surface temperature variability and the associated changes in winds, sea level pressure, intertropical convergence zone (ITCZ), and the Hadley circulation occur on interannual to decadal time scales. These covariant fluctuations are collectively called Tropical Atlantic Variability (TAV).

[3] The TAV affects directly the climate of Northwestern Africa, northern South America, Central America, the Caribbean and the southern United States and produces climate responses over the inter-American region that are comparable to those of ENSO [*Enfield*, 1996]. The TAV is also associated with the frequency of land-falling hurricanes in the Americas and Caribbean [*Gray*, 1990; *Landsea et al.*, 1999]. In addition to the relation with the climate of the surrounding regions, understanding of the TAV is necessary to successfully validate the large-scale climate modes in numerical models [e.g., *Lau and Nath*, 1994; *Saravanan and Chang*, 2000].

[4] A number of studies have identified two primary modes of interannual climate variability in the tropical Atlantic [e.g., *Servain and Merle*, 1993]. One of them, the "equatorial" mode, has a time scale of 2–4 years. It is similar to, albeit much weaker than, the Pacific El Niño Southern Oscillation (ENSO) in that it relates changes in the tropical ocean's thermal structure to trade-wind anomalies in the western equatorial ocean. Specifically, when the trades intensify (weaken) in the western Atlantic, the equatorial thermocline slope increases (decreases), and negative (positive) SST anomalies develop in the eastern equatorial ocean, particularly in the Gulf of Guinea. The second mode, the "dipole" mode, has no Pacific counterpart. It is characterized by a north-south interhemispheric gradient of SST anomalies, and its time scale ranges from interannual to decadal [*Moura and Shukla*, 1981; *Servain*, 1991]. During typical dipole episodes, anomalies appear with opposite signs on either side of the ITCZ, although the development is not always simultaneous [*Houghton and Tourre*, 1992]. So far, this mode has been observed mainly in SST and surface wind fields, and little is known about its subsurface manifestations. Recently, it was claimed that these two modes are related to each other and both linked to the west equatorial wind stress variability [*Servain et al.*, 1999, 2000; *Murtugudde et al.*, 2001]. Other studies analyzed the departures of sea surface temperatures from climatology to determine the degree to which SST anomalies of opposite sign in the tropical North and South Atlantic occur [*Enfield et al.*, 1999]. Results indicate that anti-symetric ("dipole") configurations of SST anomalies on basin scales are not ubiquitous in the tropical Atlantic. Unless the data are stratified by both season and frequency, inherent dipole behavior cannot be demonstrated. Upon removing the global ENSO signal in SST anomaly from the data, the regions north or south of the Atlantic ITCZ have qualitatively different temporal variability and are poorly correlated. Dipole configurations do occur infrequently (12–15% of the time), but no more so than expected by chance for stochastically-independent variables. Non-dipole configurations that imply significant meridional SST anomaly gradients occur much more frequently, nearly half of the time.

[5] All studies agree that large-scale SST gradients are key factors in driving the climate response in the tropical Atlantic sector. The temporal variability in the meridional SST gradient across or south of the ITCZ has strong effects on the climates of northeast Brazil and West Africa. There are some indications that the off-equatorial regions play a dominant role in the establishment of the meridional SST gradients. Studies attest to the role of positive feedback mechanisms through surface fluxes for providing persistence to the SST anomalies forcing SST through surface fluxes. Therefore while the SST is an important variable to measure for understanding TAV, surface fluxes measurements are also crucial. Wind fluctuations result in both local surface flux anomalies and in thermocline-depth variations that also modify the effect of the surface fluxes. On the larger scale, recent research indicates that TAV is correlated with the North Atlantic Oscillation (NAO) [*Yang*, 1999] and therefore, directly or indirectly to the meridional overturning circulation (MOC). The role that the MOC plays in giving persistence to the NAO climate phases is still not fully understood. Nor are the mechanisms for interhemispheric exchange of mass and heat. In addition, there is not enough observational evidence at present to trace the time-dependent pathways of the upper limb of the MOC across the tropic Atlantic.

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[6] Several years of research efforts have offered prospects for improving climate prediction based on the tropical Atlantic. Nevertheless, many fundamental questions of crucial importance for achieving predictability remain unanswered. Modeling of the tropical Atlantic has not yet achieve a minimum level of predictability. The reasons are, among others, the lack of observations and the poor understanding of the dynamics of the tropical Atlantic. There is also a need to better define the predictability limits of TAV and related phenomena through diagnostics of data and model experiments.

2. The Tropical Atlantic Observing System

[7] The oceanic in-situ data base in the Atlantic was derived primarily during recent decades from volunteer observing ship (VOS) programs, coastal and island tide gauge stations, and a small number of drifting buoys. However, VOS measurements of surface meteorology and subsurface temperatures are concentrated mainly along well-traveled shipping routes, among which there are large data gaps, especially in the Southern Hemisphere. Satellite estimates of some key variables (surface winds, SST and sea level) are available over the whole Atlantic basin with more uniform spatial and temporal resolution. Indeed, the satellites are valuable tools for providing spatial coherence and cover of surface properties. However, satellites do not deliver direct measurements of the subsurface thermal structure in the ocean, which is essential for understanding processes affecting the evolution of SST and the thermocline depth. Since 1997 a program of moored measurements, similar to the Tropical Atmosphere-Ocean (TAO) array used to study ENSO variability in the equatorial Pacific, has been under development in the Atlantic. This program, called PIRATA (Pilot Research Moored Array in the Tropical Atlantic) [*Servain et al.*, 1998], was designed to improve the understanding of the processes by which the ocean and atmosphere couple in key regions of the tropical Atlantic. PIRATA provides high-resolution time series measurements of surface heat and moisture fluxes, sea surface temperature and salinity, and subsurface temperature and salinity in the upper 500 m. Simultaneously with the start of the deployment of the PIRATA moorings, and the global Drifter Array, a program was started at NOAA/AOML to significantly increase the deployment of surface drifters in the tropical Atlantic. The purpose of the program is to observe the basin-wide scale tropical Atlantic current and SST fields on seasonal to interannual time scales. Currently, 80 drifters per year are deployed from ships of opportunity and research vessels providing an accurate picture of the surface current field and filling up gaps for needed observations of SST. Together with the existing observations provided by the ships of opportunity, the PIRATA array and the surface drifters constituted the initial tropical Atlantic Observing System.

[8] In the year 2000, two new and important components were added: a new high density XBT line (AX8) that runs between Cape Town, South Africa and the north-east coast of the US, and the ARGO program. The main objective of AX8 was to measure the upper ocean thermal structure and to characterize both the mean and the time-dependent upper ocean properties of the tropical portion of the MOC and of the shallow subtropical cell in the Tropical Atlantic. The resolution is 30 km between ±10° and 40 km between ±10 and 20°. The line is occupied four times per year, in different seasons [*Goni and Baringer*, 2002]. ARGO is an international program whose goal is to deploy an array of 3,000 free-drifting profiling floats in a period of five years. Approximately 700 floats will be operating in 2003 in the Atlantic, of which about one third will be in the tropical basin. The profiling floats measure the temperature and salinity of the upper 1000 to 2000 m of the ocean.

3. The Workshops

[9] To address the science underlying the TAV, and in a effort to expand and coordinate international observational programs in the tropical Atlantic towards a sustained observing system a meeting was held in Miami, May 4 through 7, 1999 (http://www.aoml.noaa.gov/phod/COSTA/). As a follow up to this meeting and following one of its recommendations, the CLIVAR Workshop on Tropical Atlantic Variability took place at UNESCO, Paris, September 3 through 6, 2001. The main objectives of the Paris workshop were to review advances in science since the Miami workshop, and to coordinate international efforts toward a sustained observing system in support of understanding, modeling and predicting TAV. The Paris workshop was sponsored by the International CLIVAR Project Office and was attended by 120 scientists from 10 different countries. During the first three days of the workshop, keynote presentations were made during the morning hours directed at the role of local air-sea interaction in TAV, the influence of the tropical Atlantic atmosphere/ocean circulation on climate variability over the Americas and Africa, and the interaction between TAV and the large-scale atmosphere/ocean circulation. A discussion of its relation to the NAO and the MOC was followed by a discussion on the shallow overturning cells and cross-gyre exchange in the region, and by a presentation of potential links to decadal, secular variability and climate change. The third morning was dedicated to the observing system and to discuss observational needs for prediction. Interactive poster sessions were held in the afternoons. At the end of the day, the attendants met in a plenary session, in which rapporteurs lead a discussion of the oral and poster presentations that took place during that day. Following the oral and poster presentations, three working groups were created. The responsibility of the Working Groups was to summarize the science and the observational needs based on the workshop discussions, and to make recommendations towards an implementation plan. At the conclusion of the workshop, a summary of the activities as well as the working group recommendations were presented to the international CLIVAR Atlantic Implementation Panel (http://www.clivar.org/publications/wg_reports/atlantic/3rdmeet.pdf.) for consideration in the formulation of an implementation plan for tropical Atlantic research. In this volume, a compilation of papers presented during the poster sessions of the workshop, and published by GRL, are presented. These papers provide the foundation for the recommendations forwarded to CLIVAR.

[10] Complete information on the workshop as well as the recommendations from the working groups is posted at www.clivar.org/organization/atlantic/TAV.

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