US CLIVAR WORKSHOP ON THE DYNAMICS AND PREDICTABILITY OF THE ATLANTIC ITCZ AND ITS REGIONAL CLIMATIC INFLUENCES

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FINAL REPORT

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1. Introduction

The tropical Atlantic (TA) region is regarded generally as the section of the Atlantic Basin, which lies between the tropics of Cancer and Capricorn. It includes the continental areas of Central and eastern South America and of West Africa and the marine areas surrounded by them. The dominant climatic features of this region are the massive convection centers over Africa and South America, the relatively narrow Intertropical Convergence Zone (ITCZ) deep convection that stretches between them, across the ocean, just north of the equator, and the trade wind systems that converge into it from north and south in which shallow convection areas are embedded. At the ocean surface, there are features that roughly resemble the main features of the equatorial Pacific Ocean, that is: an eastern ocean "cold tongue" area and a matching warm pool region on the western side of the basin. The surface features are linked to a three-dimensional circulation, the meridional (Hadley) and zonal circulation cells in the atmosphere and the horizontal equatorial current systems of the upper ocean as well as the shallow meridional overturning cells that connect the equatorial ocean with the northern and southern subtropics. These features are subject to an intricate, mainly latitudinal, seasonal migration and contain transient components, such as easterly waves and tropical storms, which travel from east (Africa) to west (Central and North America) across the basin.

In the normal seasonal variation of the TA climate system, the variability in strength and position of the marine ITCZ (hereafter the Atlantic Marine ITCZ, AMI) are of particular importance as they are linked with the year-round variation of rainfall over the ocean and the adjacent land regions, with direct impact on the economies of some of the world's most densely populated and poorest countries, which rely heavily on agriculture. The climate of this region creates the necessary conditions for debilitating tropical diseases such as dengue, malaria, cholera, and meningitis, which are sensitive to the rhythms of variability in rainfall, temperature, and humidity. The largest global source of dust lies in subtropical Africa, which in addition to its impact on humans has considerable influence on the global radiative balance. Also within this region, tropical storms of hurricane intensity regularly inflict tremendous destruction and loss of life on the northern half of the TA, with impact reaching into the Gulf of Mexico and Atlantic coasts of the USA.

The region's vulnerability to climate is underscored by its sensitivity to interannual climate variability. TA interannual-to-decadal climate variability is appreciable and variation in climate conditions (such as storminess, rainfall, humidity, temperature, and dustiness) can lead to disruption of the normal supply of water for agriculture and other human and wildlife needs, to the appearance and severity of various epidemics, and to the probability of tropical storm damages. This report is meant to provide a summary of the presentations and discussions that were held during the Workshop and make recommendations for future actions.

Understanding TA climate variability and predictability, with the goal of improving its prediction and identifying and quantifying its relationship to various societal impacts, are clearly important research goals as was recognized by both the international and national programs on Climate Variability and Predictability (CLIVAR). However despite such programmatic emphasis actual progress in TA climate prediction has been slow to come. Motivated by the need to address this issue we proposed a community effort to focus on the AMI, its response to external influences and its interaction with the underlying ocean and surrounding landmasses. In response to this proposal the U.S. CLIVAR Office, with the help of the research funding agencies, NASA, NSF, and NOAA, sponsored the *Workshop on the Dynamics and Predictability of the Atlantic ITCZ* *and its Regional Climatic Influences* (hereafter the AMI Workshop). The Workshop was convened in September of 2002 at the International Research Institute for Climate Prediction (IRI) in Palisades, New York.

2. Workshop Goals

The workshop was convened with the following two goals in mind:

- Review the status of TA research and prediction activities.
- Identify and prioritize the one-few areas/problems offering best opportunity to improve understanding of TA climate and its predictability, and contribute to improved predictions.
- Recommend action needed to effectively address these areas/problems.

3. Participation

Participation in the AMI Workshop was based on the response to an initial survey of the likely interested institutions and individual scientists issued by an ad-hoc steering committee (Y. Kushnir of LDEO and A. Robertson, N. Ward, and S. Zebiak of the IRI). In the final count, the overall number of participants reached 70 plus. The Workshop was directed primarily to the US science community that is actively involved in TA climate research. Several of the national centers engaged in climate prediction research were represented. A small number of invitees from the international community added to the discussion by presenting their national interest and expertise in TA climate prediction. The list of participants is enclosed as Appendix 1.

4. Agenda

The meeting agenda was divided into four parts:

1. Oral presentations concerned with the prospects and challenges in TA climate prediction.
2. Oral presentations concerned with the physical basis for TA climate prediction.
3. Presentation of national and international research and observation programs relating to TA climate.
4. Discussions in plenary and subgroups in order to identify and prioritize the issues/problems and recommend a plan of action to advance understanding and prediction of TA climate variability.

The detailed agenda is attached in Appendix 2.

5. Highlights of Oral Presentations

Prospects and challenges in TA climate prediction

Presentations in this part of the meeting were chosen to illustrate three points: (1) that conducting and advancing climate prediction in the TA region can lead to clear societal benefits, (2) that several prediction centers are issuing and evaluating climate forecast products for the region, and (3) that there are considerable challenges that need to be addressed regarding these forecast products.

Regional climate forecast applications:

Presentations by U. Lall (Columbia University and IRI) and M. Thomson (IRI) demonstrated the readiness of the forecast applications research community to utilize climate forecast information to derive tools for decision makers in the areas of water resource management and public health.

U. Lall discussed an ongoing project aimed at reducing drought vulnerability in the state of Ceara, Northeast Brazil. This part of Brazil is densely populated and relatively poor, with a large segment of the population employed in or dependent on agriculture. The semi-arid nature of the area makes it vulnerable to sporadic droughts with direct impact on the agricultural sector of the economy. Rainfall variability in this region is closely linked to changes in the equatorial Pacific and the TA. Climate forecasts of the regional rainfall display considerable skill. This IRI project seeks to combine climate forecast information with models of water reservoir management to reduce the drought-related risks to the agricultural (and industrial) sectors due to droughts and improve overall water management in the region. At present a model for integrated management of water resources has been proposed, which is based on a statistical forecast of rainfall and streamflow from SST data in key regions of the equatorial Pacific and the TA. Improving the regional rainfall and streamflow forecasts and making them more reliable, more long-range, and more detailed (geographically) is crucial for improving water management in the region.

M. Thomson spoke about the IRI climate and health program in subtropical Africa. In this region, climate affects insect borne diseases such as Malaria, Dengue, and Yellow Fever, and non-insect borne diseases, primarily meningitis. The spread of these diseases is affected by temperature, rainfall, humidity, dust, and wind conditions. Thomson's presentation focused primarily on Meningitis epidemics, which are seasonally dependent, breaking out in mid-boreal winter and peaking in boreal spring. The epidemics are distributed across subtropical North Africa and are most intense in the semi-arid region south of the Sahara (the Sahel region). Recent work has been based on the hypothesis linking the severity of Meningitis outbreaks to conditions of low humidity and dust. Such conditions are found to irritate the human mucus membranes in the nose and throat and appear to allow the Meningitis bacteria to easily invade the blood stream and be more easily transmitted from one person to another. Meningitis outbreaks can be alleviated by early vaccination. Under current procedures, initiation of vaccination is based on monitoring the number of cases with unavoidable loss of life. Predicting the geographical distribution and intensity of low humidity and dust, combined with a model that links between the climate anomalies and other factors that affect the spread of the disease, such as type of soil and land cover and population density, can help assess risks of an epidemic far in advance and begin vaccination early before the outbreak of the disease, making for a more effective control of the epidemic.

Status of TA climate prediction

Three presentations by L. Goddard (IRI), C. Nobre (CPTEC/INPE), and T. Stockdale (ECMWF, delivered in his absence by S. Zebiak) discussed the status of TA climate prediction. The presentations were not meant to be comprehensive but rather serve as examples of the present capability of different climate prediction centers.

L. Goddard presented an evaluation of a TA climate forecasts, derived by forcing a GCM with persisted, global SST anomalies. The IRI uses a two-tiered numerical procedure in which an atmospheric GCM is forced with the anticipated evolution of global SST derived from a numerical forecast or by assuming the persistence of the initial SST anomaly field. In the tropical Pacific, persistence is a very good predictor of the short-range evolution of the SST field up to two seasons ahead. Persistence works less well in the TA, although even there it exhibits considerable skill on a one-season time interval. In a paper published in 2002, Goddard and Mason evaluated the precipitation forecast error over South America and Africa in the persistent SST model integrations. They find that the skill of the forecast is lower than the skill in hindcasting the rainfall variability using actually observed SST. They also calculated the dominant patterns of the precipitation forecast error for tropical South America and West Africa (separately) and their associated SST error patterns, finding that errors in predicting rainfall over South America in the boreal spring are related to errors in correctly prescribing the cross-equatorial SST gradient within the TA. The errors in predicting West African rainfall are associated with errors in specifying equatorial Atlantic SST. Addressing the issue of forecasting the SST boundary conditions for the atmospheric GCM runs, Goddard compared existing schemes based on multivariate statistical techniques (e.g., Canonical Correlation Analysis, CCA) with the persistence forecasts. She concluded that these statistical methods could improve the SST prediction in the north TA (NTA) but not along the equator or in the south TA (STA). Improvements in NTA SST prediction in the boreal spring can help improve rainfall prediction for the Northeast Brazil region.

P. Nobre discussed the operational and experimental procedures used in Brazil to predict the Northeast precipitation anomaly in the rainy season (boreal winter and spring). He reviewed experimental statistical and numerical methods directed at predicting TA SST anomalies as part of a two-tiered procedure. The statistical procedure is based on a CCA analysis of monthly SST anomalies with SST initial conditions at various time leads. The numerical approach is based on forcing an ocean GCM with a statistical CCA model of the surface wind stress, developed by Nobre and Zebiak. The windstress model responds to pre-existing conditions in either the TA and tropical Pacific together or the latter basin alone. In both cases the quality of the SST forecast over the NTA is good but over the STA the forecast quality is rather poor.

The presentation sent to the Workshop by T. Stockdale from ECMWF addressed the performance of the Center's ocean data assimilation and climate prediction systems in the TA region. The ECMWF forecast system is based on a forty-member ensemble of coupled model runs initiated once a month with assimilated data. The ocean assimilation scheme is based on a GCM driven by surface winds and incorporating all available observations. All the products are global. Stockdale first presented information showing that the assimilation procedure performs far worse in the TA region than in the Pacific and Indian Oceans. The source of the TA problems is not clear. The presentation then focused on the prediction of TA SST in three regions, north, south and equatorial TA. Of all these regions the forecast is worst on the equator (Atlantic cold-tongue) and best in the South Atlantic. The quality of the forecast is also seasonally dependent with boreal spring being the worst time for prediction. This seasonal dependence is crucial because it is during the boreal spring season that the climate variability in the TA is largest.

The TA physical system: Patterns and processes

This section of the AMI Workshop included presentations dealing with the state of scientific understanding of the TA climate system, focusing on the AMI. The presentations addressed the structure, annual cycle, and variability of the AMI (S. Hastenrath), the sensitivity of the AMI to external influences (R. Saravanan) and to TA internal ocean-atmosphere interaction (P. Chang), the regional ocean circulation (J. Carton) and the influences of climate interactions over land in determining the mean and variability of the AMI (D. Neelin and M. Suarez). Other presentations addressed the simulation of the AMI and rainfall over land in numerical models, particularly regional models (K. Cook and L. Sun) and the processes that govern convection in the marine environment and the interaction between convection and the large-scale circulation (J. Chiang and A. Sobel, D. Raymond, and C. Zhang).

As these presentations showed we can summarize the properties and dynamics of the AMI and its associated circulation features as follows:

- The AMI is characterized by a coherent, across-basin relationship between the precipitation maximum, surface low-pressure trough, tradewind convergence, and a maximum in SST.
- This coherent structure migrates north and south throughout the year. In boreal spring it reaches its most southern position. Its core reaches 5°S in the west, over the northeast coast of Brazil, but stays slightly north of the equator in the Gulf of Guinea region in the east. In boreal summer it moves furthest away from the equator to 8-10°N.
- The underlying surface conditions in the two extreme seasons are quite different: In boreal spring a relatively weak and broad region of marine convection, strongest in the western equatorial region, is located over a wide strip of warm SSTs with weak latitudinal gradients. In the boreal summer the band of AMI precipitation is sharp and stretches across the entire ocean basin with largest values in the east. The band of warm SST is relatively narrow surrounded by strong latitudinal gradients, particularly to the southeast, where the Atlantic cold tongue resides.
- The pattern of seasonal AMI migration can vary considerably from year to year and these changes are the predominant source of climate variability in the TA region. The most notable climate impacts in the region, the variability of rainfall over NE Brazil and the coastal regions surrounding the Gulf of Guinea and the changes in rainfall and dust in sub-Saharan Africa (Sahel), are tied in with anomalies in the AMI seasonal position and intensity. The coherence of the AMI anomalies across the basin is largest in boreal spring and weakest in boreal fall and winter.

- There is a close link between anomalies in the AMI position and intensity and anomalies in SST within the TA Basin. During the boreal spring, rainfall variability is well correlated with the difference between NTA and STA SST, associated with broad, basin-size SST anomalies in the tradewind belts. During the boreal summer the variability is well correlated with SST anomalies along the equator and to the south in the eastern equatorial cold tongue region. In both cases the rainfall increases on the anomalously warmer side of the mean ITCZ.
- The AMI also exhibits a strong sensitivity to remote influences from outside the TA region, in particular from the eastern equatorial Pacific (EEP) region. ENSO warm events weaken the AMI rainfall in the boreal late winter and spring. This influence works in part through a direct atmospheric bridge (through the equatorial wave guide) and in part through the influence exerted by ENSO via the PNA pattern on tradewind intensity and SST in the western NTA. The sensitivity of the AMI to SST variability north and south of the equator exposes the AMIC to influences of other phenomena that affect the intensity of the trades, such as the North Atlantic Oscillation (NAO) and similar low-frequency oscillations in the Southern Hemisphere.
- Observations and models suggest that regional air-sea coupling plays an important role in AMI variability. There are two types of feedback seen in the TA:
    - A positive thermodynamic feedback in the western TA, off the northeast Brazilian seaboard, that consists of the interaction between the near-equatorial surface wind field and the cross-equatorial SST gradient. When the latter is imposed on the region in boreal winter, a shift in the AMI towards the warmer hemisphere occurs (see above), accompanied by an anomalous cross equatorial flow in the same direction. This change in the surface winds creates evaporation anomalies, which act to enhance the existing SST gradient. The interaction is strongest in boreal spring and weakens through the boreal summer.
    - A positive dynamical feedback in the eastern TA, in the cold tongue region, in which the warming/cooling of the upper ocean is associated with a weakening/strengthening in equatorial easterlies that lead to the enhancement of the anomalous state of the coupled system. This feedback is strongest in the boreal summer and fall and has been compared to the ENSO feedback in the EEP region.
- There is evidence that the deep convection in the ITCZ and the surrounding shallow convection play an active role in shaping the characteristic pattern of AMI variability. AMI convection participates in communicating remote effects from the EEP to the TA Ocean surface and shapes the surface wind in response to SST variability. Shallow and deep

convection affect the persistence of SST anomalies by responding to the associated changes in boundary layer stability and interacting with the incoming solar radiation.

- Theoretical (modeling) work suggests that the rainfall over the land regions surrounding the TA is influenced by evaporation over land and by the land-surface albedo changes. The evidence for the effect of land surface interaction on the circulation over the oceans is however weak.
- Global climate models display various levels of systematic errors in the TA region. These errors tend to be largest in coupled models but their sources can be detected in the uncoupled versions of those models. The most disturbing error is the tendency of most coupled GCM to reverse the sign of the east-west SST gradient on the equator (i.e., put the colder SST on the western side of the basin). Associated with this error is a tendency for coupled models to move the AMI considerably south of the equator in the boreal spring.
- Regional models can be useful for downscaling the effect of TA variability and increasing the geographical accuracy of the SST related rainfall variability compared to global models.

6. Survey of Existing TA Research and Observation Programs

The scope, research agendas, and achievements of the following programs were presented in the meeting:

- VAMOS – the program on the variability and predictability of the American monsoon systems. The Monsoon Experiment South America (MESA) focuses on the Amazon and La Plata Basins and the low-level jet. The various elements of the ongoing VAMOS field programs, LBA, LLJ, VEPIC, and LAPLASIN were also described. A common element to VAMOS and the present AMI focus is the interest in the relationship between SST variability and rainfall over South America, the circulation and supply of moisture to the convection systems over land, and the connection between marine and land convection systems.
- VACS – the program on the variability of the African summer monsoon system with a focus on the West African region. Under VACS plans to conduct an intensive, multi-stage and multi-disciplinary field program (AMMA) are underway. The relevance of the VACS/AMMA effort to the AMI focus is similar to that of VAMOS/MESA program – here too the ocean influence over land and the links between the land and marine convection systems is crucial for understanding the physical processes involved and their predictability.
- PIRATA – this ocean and air-sea observational program extended the equatorial Pacific moored array into the Atlantic in an effort to enhance and close gaps in the equatorial observation network and aid in research and prediction in the TA region. Its continued existence would be important to the continued research and prediction effort in the TA.

- Ocean Observations - Simultaneously with the start of the deployment of the PIRATA moorings, and to 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 inter-annual 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. 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 is 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 four different seasons. 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.

Other, more tentative initiatives to study the TA region were also presented. A proposal to US CLIVAR to study the regions ocean dynamics with emphasis on the shallow subtropical circulation and its role in decadal SST variability was described as well as a proposal for a South Atlantic climate observing and research system.

7. Working Group Discussions and Recommendations

Following the oral presentations discussions in plenary and in working groups were conducted to address the goals of the Workshop. Three working groups (WGs) were proposed to allow more focused discussion on the elements of the TA climate system:

- A WG on marine ITCZ convection interaction with the large-scale atmospheric circulation (hereafter the ITCZ WG) – chaired by D. Raymond and A. Sobel.
- A WG on the regional ocean circulation and SST variability (hereafter the SST WG) – chaired by S. Garzoli and S. Raynaud.
- A WG on the Land climate system and its effect over the adjacent ocean areas (hereafter the Land WG) – chaired by N. Zeng and C. Cassou.

In addition, C. Penland and A. Giannini prepared a report on TA climate predictability. A synopsis of the working group discussions is provided below.

The ITCZ WG

Definition of the problem

The ITCZ WG discussed two major issues: (i) understanding, modeling, and predicting the strength and position of the AMI, and (ii) understanding the influences of the AMI on the rest of the TA climate system. Since the other two WGs were meant to focus on land and ocean processes respectively, this WG focused on atmospheric processes. At the same time it was recognized that the atmospheric issues in AMI prediction are intimately coupled to the ocean and land issues, perhaps more so in the TA than elsewhere.

A primary issue in AMI research and prediction are model (particularly coupled model) biases. Nearly all of coupled models produce major quantitative and qualitative errors in the mean state of the TA climate, to the extent that their mean SST field east-west gradient is of the opposite sign to that observed. It seems hopeless to attempt to simulate interannual variability with such models at present. The causes of the mean state errors are not well understood. Atmospheric models with fixed SST naturally do better, but still have problems. The modelers in the group reported that many different sorts of errors are possible, and that the solutions over the TA are sensitive to many parameters. One problem that does seem to occur in many models is an error in the strength of the ITCZ convection, even if its position is well simulated. In particular, many models produce an ITCZ, which is too weak over the ocean, while being either of realistic strength or too strong over land. The ITCZ is also too broad in most models although it isn't clear whether this is simply a resolution issue. Whether in coupled or uncoupled models, the errors in simulations of the TA are emblematic of our lack of detailed understanding of the interplay of different processes and influences over the TA.

The broad scientific questions

Two, closely related, broad scientific questions appeared to tie many different issues together:

- How different are the TA and Tropical Pacific? In many respects the AMI does look like the Pacific counterpart, particularly in the eastern part of the basins. One clear difference between the Atlantic and Pacific, however, is that thermodynamic air-sea interactions (i.e., surface fluxes) are much more important in the Atlantic than the Pacific for predicting SST variability. Since surface fluxes are a weak point in GCMs this may be a reason why coupled models have problems in the TA.
- How important are land and ocean, respectively, in controlling the TA climate? We might expect that because of the smaller dimensions of the basin and the proximity to large centers of land convection, the Atlantic would be more influenced by land processes and less by air-sea coupled feedbacks local to the basin, compared with the Pacific.

Addressing these questions will help deal with more specific problem such as: how much of the surface wind variability is due directly to convection variations over the Pacific associated with ENSO, how much is due to forcing from the extra-tropics

(NAO), how much is related to air-sea feedback, how much to convective variability over the continents, and finally, to what extent are interaction between these sources of variability important (e.g., is ENSO influence mediated or affected by convection over South America)?

In considering the relative roles of land and ocean, we are led back to the subdivision between what controls the AMI and how the AMI influences the rest of the TA climate system. It is probably simpler to address the latter question (e.g., in simple "dry" numerical models, with imposed heat sources inferred from observations).

The issue of what governs the AMI strength and location is less straightforward, in that it is closely related to the general, longstanding issue of what controls deep convection over the tropical oceans. In numerical models physical parameterizations are keys areas of uncertainty. Many projects have aimed to solve the "cumulus parameterization problem", and it is felt that this AMI project should not explicitly take that as its goal. Instead it is recognize that the convection in a model is determined not just by the convective scheme but, as in nature, by the large-scale environment, and take as a goal a better characterization of the dynamical and thermodynamical environment over the TA region and an understanding of how that influences convection. This is not entirely uncoupled from the parameterization problem, but is not exactly the same thing either.

Proposed Research

A. Modeling

It is proposed to conduct a program of *numerical modeling* work aimed first at answering those questions that can be answered with reasonable confidence using current models, and second, to the extent that current models are inadequate to answer particular questions conclusively, to *formulate focused hypotheses that can be tested with new observations*. There is a need for simulations in which the modeler intervenes in the model, often in unrealistic ways, to pull apart key mechanisms. Examples are removing continents, or fixing SST in one region while using a mixed layer (or fully coupled) ocean model in another region. Such work has already started as reported in the presentation by M. Suarez using the NASA NSIP GCM and P. Chang and R. Saravanan, using the NCAR CCM3.

With regard to remote influences on the TA region it is recommended to expand the study of currently proposed hypotheses. For example J. Chiang and A. Sobel proposed that El Nino may affect remote tropical regions by a thermodynamic mechanism whereby the tropospheric temperature throughout the tropics is elevated, and then this warming is transmitted to the surface by a reduction in deep convection, which leads to positive SST anomalies. This mechanism emphasizes the coupling between convection, surface fluxes, and ocean mixed layer thermodynamics. It is a different mechanism than the surface wind speed – evaporation one usually cited as leading to the northern TA warming in El Niño and it is important to better assess its role in nature and the ability of GCMs to simulate this effect.

Another type of study that can prove useful is targeted diagnostics applied to existing data and simulations, aimed at understanding physical relationships between key variables related to deep convection and to the large-scale environment. Bulk diagnostics focused on spatially independent relationships between physical and dynamical variables (in the form e.g., of scatter plots) provide an alternative to looking at actual model parameters from the physics packages. They also allow models to be compared in a way that ignores geography and so provide an alternative to "bulls-eye matching". Such relatively simple diagnostics can be directly compared to observations even if the observations have limited spatio-temporal coverage. Moreover, following the same philosophy, the dynamical influences imposed by such simple parametric relationships can be explored using simple models of the tropical circulation, in which bulk relationships are prescribed. Changing the value of some parameter changes the circulation in ways that can be easily understood, and allows determining a given GCM location in that parameter space and provide insight into properties of that GCM's circulation. Recent work in EPIC has shown strong relationships of this kind that can be used to test models.

B. Sustained Observations

In considering observational needs it is important to assess what atmospheric data are already available for the TA. Satellite data sets offer good coverage and arguably good quality data for a number of surface and vertically integrated quantities, such as SST and cloud cover (NOAA geostationary and polar orbiting satellites, TRMM), radiation fields (from direct observation and derived quantities), surface wind and windstress (QuickSat), column water vapor (SSMI), precipitation (SSMI, MSU, TRMM, and derived, multi-sensor data sets such as GPCP), deep layer mean temperatures (MSU) etc. New generations of satellites (MODIS, Aqua, Terra) will be able to provide more vertical resolution. The PIRATA buoys offer surface observations with basic spatial coverage over the TA, as do synoptic observations from ships-of-opportunity. What are almost entirely lacking are relatively high-resolution, in-situ, upper-air observations to constrain the vertical structure of the atmospheric temperature, humidity, and winds over the ocean. Since it is advantageous to better characterize the environment within which convection develops over the TA, the absence of vertically detailed information is a serious drawback, which any observational program should attempt to remedy. Without such observations, it is difficult to assess and correct regional model biases. One such model error is the poor simulation of the trade inversion over regions adjacent to the ITCZ. Due to the lack of an inversion and/or excessive numerical diffusion in the vertical, moisture is vented away from the boundary layer even in the absence of deep convection. This results in the boundary layer's being too dry when it arrives in the ITCZ region, and thus in an atmosphere that is too stable to convection. It is plausible to suppose that such an error could be responsible for an ITCZ that is too weak over the ocean. This example shows that upper-air observations should be targeted not only at the ITCZ region itself, but also at surrounding regions, which supply it with energy at low levels, in order to constrain models over those adjacent regions.

Both in our working group and in discussions of the whole group on the last day of the workshop, there was debate over whether a short-term but intensive field program or sparser but long-term observations were preferable. The former could be tailored to provide high temporal and spatial sampling rates in a geographically limited region. The latter could be collected by merchant ships equipped with radiosonde launching and tracking equipment or from research vessels, with the disadvantage of being irregular in time and space.

C. Motivation for an AMI Field Campaign

Intensive field campaigns typically produce a suite of relatively detailed datasets that are collected from a number of observation platforms (on board of ships and aircrafts). They measure, in addition to traditional variables, many special quantities such as turbulence fluxes, cloud microphysics, aerosol, radiation fluxes, and radar reflectivities. These data are usually of high resolution in time and space, but are limited on spatial and temporal coverage. One of the most extensive field campaigns held in the tropical regions was GATE. It focused on the AMI during summer using shipboard radiosonde launchers and radars. The most recent field campaigns targeting the ITCZ are TEPPS and EPIC2001, both conducted in the eastern Pacific. TEPPS was launched from a ship and EPIC2001 used both ship and aircraft observations to explore the marine environment of the ITCZ. Datasets from these two programs have been very informative, revealing some features of the eastern Pacific ITCZ that had not been observed before and suggested new mechanisms for convection-circulation interaction. As many other field campaigns, data from TEPPS and EPIC2001 have been very useful to diagnoses of detailed physical processes and validating cloud and mesoscale models, but their benefit to global models has yet to be demonstrated. EPIC2001 is a good example of how a field campaign can be conducted for the study of the ITCZ. Similar designs of intensive field campaigns can be feasibly implemented in the Atlantic. For example, taking 38°W as the targeted longitude, one ship can be anchored in the center of the ITCZ to measure continuous, detailed convective activity at a fixed location while an airplane is used for launching dropsondes between 0° and 15°N with a less regular time schedule to sample the large-scale environment. An alternative plan would be taking 30W as the targeted longitude and launching dropsondes between 10°S and 15°N (an effort which may require two airplanes) but will add information regarding the Southern Hemisphere cross-equatorial flow.

Decisions on field campaigns in the Atlantic Ocean should be based on the following considerations. (i) To what degree are detailed physical processes (e.g., turbulence and radiation fluxes, cloud microphysics) and the ITCZ structure in the Atlantic expected to be unique in comparison with the eastern Pacific? (ii) How much can data collected by intensive field campaigns benefit the improvement of forecast models in addition to existing data from land and ocean stations and satellites? (iii) How much can data collected from a field campaign and combined with diagnostic and modeling studies help test existing scientific hypotheses and formulate new ones? The modeling and diagnosis parts of the research plan described above should provide guiding information for the decisions on intensive field campaigns. The justification of intensive field campaigns in the tropical Atlantic Ocean should be built upon the success and lessons learned from GATE and EPIC2001. International collaborations are needed to maximize the return from an intensive field campaign.

Regarding the choice of observing period, one suggestion was to plan for two campaigns, one in the boreal spring, when the AMI is closest to the equator and one in the boreal summer when the AMI is furthest from the equator. The two are crucial AMI seasons from the point of view of climate impacts, both are important and can provide a comparative study of the maintenance of the convection under two differences large-scale and surface conditions.

Questions that can potentially be addressed by intensive field campaigns include: (i) What is the relationship between the properties of AMI convection and the large-scale environment (e.g., surface and pbl winds, upper tropospheric humidity and temperature, and structure and transition of the tradewind inversion)? (ii) What are effects of the unique source of aerosol (African dust storms) on the microphysical processes of clouds in the AMI? (iii) How do the dry air and dust transport from Africa affect the convective systems and the related dynamics and thermodynamics of the AMI? (iv) Are there systematic differences between the atmospheric boundary layer structure in the tropical Atlantic and the Pacific Oceans, can these differences be explained in terms of the adjacent lands and how does that affect AMI dynamics?

The SST WG

Definition of the problem

Surface forcing plays an important role in AMI variability. Aside from the possible direct influence ("atmospheric bridge") of ENSO on the AMI during boreal winter and spring, both remote and local influences play their part through affecting the upper ocean, primarily SST. The SST WG organized its discussion around the topic of the relative roles of local atmospheric forcing and ocean dynamics in determining TA SST variability. A large part of the discussion was motivated by the need to understand SST predictability and improve its prediction. That is because most of the current prediction procedures employ a two-tiered system (i.e., predicting SST first and then using it to force an atmospheric model) to simplify the modeling set-up and to overcome the large biases exhibited by coupled models. Even where coupled models are considered, a better understanding of upper ocean dynamics is a primary goal.

The broad scientific questions

As described above (section 5) some two-tiered schemes use persistence as an SST predictor. The understanding of what determines SST persistence in the TA Basin should therefore be one important research goal of an AMI program. In general, SST persistence is determined by 3-D ocean heat advection, entrainment into the mixed layer as it changes its depth, and the exchange of heat with the atmosphere. One, or more, of the following ocean transport mechanisms can play a role: transport by the mean circulation, transport by the anomalous circulation, and transport by ocean waves. Only rudimentary knowledge, based mostly on models, exists with regard to the importance of these mechanisms in the TA region. The relative roles of local ocean response to atmospheric forcing (upwelling) and remote influences (advection) are not well observed. The atmospheric role in forcing SST changes (through variations in wind speed or direction) and damping them (through the adjustment of the planetary boundary layer temperature and humidity) can be more readily observed but not with high enough accuracy to properly assess the role of the ocean (as discussed by J. Carton in his presentation). Moreover, it is hypothesized (and supported by some models) that positive air-sea feedbacks play an important role in the TA region. These should also be subject of further study, particularly with regard to the mechanisms responsible for these feedbacks and their geographical distribution.

Proposed Research

A. Observations

A decision on what sort of ocean observations should be performed to support a program on the AMI depends on the hypothesized mechanisms, time scales, and the geographical areas that the AMI is most sensitive to. Observations (and models) show that the latter are the regions underlying the trade wind belts, where SST variability (thought to be forced mainly by windspeed changes) modifies the large-scale, cross-equatorial SST gradient, a quantity the AMI is most sensitive to during the boreal spring when the climatological SST gradient is weakest. The dynamics of SST variability thus seems relatively simple. However the forces determining SST persistence in the tradewind regions are not well understood.

One of the ideas proposed is that air-sea coupling, in which the wind-forced SST variability affects atmospheric boundary stability and therefore the formation of stratocumulus decks that, in turn, modify the incoming solar radiation to counter turbulent flux damping. This mechanism can be studied by deploying surface buoys with instruments to measure air-sea fluxes, including radiative fluxes and combining such local measurements with the spatially distributed data from satellites to obtain the large-scale picture.

Another phenomenon that models indicate might be important in the tradewind belts, is the broad upwelling overlying the termination of the subsurface limbs of the shallow Subtropical Cells (STCs). As hinted by some model results, variations in the hydrographic properties of the water transported by the STCs to the thermocline could play a role in SST variability. This needs to be however, confirmed by observations. A Proposal to monitor the STCs in the TA has been drafted by the oceanographic community (as reported during the AMI Workshop by S. Garzoli and P. Malanotte-Rizzoli). This consists of enhancing the deployment of ARGO floats and the long-term monitoring in the VOS XBT lines. Such effort could be deployed as part of either a long-term monitoring program or a short-term (a year or two), intense observation effort. It should be mentioned here that SST variability and persistence in both NTA and STA regions is important to AMI prediction and thus both these regions should ideally be monitored whether independently or simultaneously. This is particularly important in light of modeling evidence that the relationship between different forcing and damping mechanisms are not the same in these two regions.

In the STA, SST variability is also closely linked with variability in the Atlantic cold tongue. The latter is less well understood than its surface-flux driven, tradewind region counterparts. In general it is expected (and indeed shown in models) that ocean dynamics plays a much larger role here than under the trades. The leading hypothesis is that an ocean-atmosphere coupling akin to El Niño is active here and that it is most prominent in boreal summer and fall. There also appears to be a connection between the off-equatorial tradewind region SST variability in the boreal spring and the cold tongue variability in the ensuing summer. ENSO has also been implicated in the generation of TA cold tongue SST variability but the certainty of this connection is debateable. The mechanisms for generating and maintenance of eastern equatorial Atlantic SST variability need more study and because this variability is strongly linked to variability in the AMI position and intensity and changes in rainfall along the coast of the Gulf of Guinea, it is important to understand it and improve its prediction. Here too, there exist some proposals by the US and international oceanographic communities to study the dynamics of this region by enhancing the PIRATA array, adding flux moorings in the eastern equatorial Atlantic, seeding the area with floats to resolve circulation patterns, and collecting hydrographic data by research vessels that maintain and supply the PIRATA moorings. Data collection in this area should consider the short and long time scale mechanisms, the former being the local response of thermocline depth and SST to wind forcing and upper ocean advection and the latter being the transport of heat by the STCs.

B. Modeling

The SST WG recommended continued use of models to test hypotheses, guide instrument deployment efforts, and to assimilate routine observations. Part of the modeling effort should be dedicated to studying the sources for biases in the ocean component of the various models.

Issues that should be addressed by ocean models are:

- Overall simulation of SST and SST variability with prescribed atmospheric forcing.
- Processes that determine the mixed layer heat budget.
- Simulation of equatorial and tradewind region upwelling.
- Ocean-atmosphere interaction in coupled models.
- Use of models for data assimilation.

The LAND WG

Definition of the problem

It is generally agreed that seasonal to interannual variability in the tropical convergence zones are mostly influenced by ocean-atmosphere interaction, with land processes playing a secondary role. However, this WG's ultimate goal is to predict climate over continental regions where people live, the importance of land-surface processes is much more elevated, in particular, in the semi-arid West Africa Sahel and northeastern Brazil (Nordeste) within the TA region, where the impact of climate variability is far reaching and the sensitivity to land processes is highest.

This WG attempted to look at the two aspects of land processes' role in climate variability: the feedback effect in modifying variability arising from ocean and atmosphere, which is often manifested as enhancement of low frequency variability and damping of high frequencies and the direct impact on regional to global climate due to anthropogenic land disturbances such as deforestation, desertification and seasonal agricultural practices.

The broad scientific questions and recommendations

Four major issues have been emphasized (in order of priority):

- Quantifying the importance of memories in soil moisture (1 month to 1 year) and vegetation (weeks to decades) as a function of location and timescale, and utilize these memories to improve climate prediction. Progress has been made for soil moisture in regions such as North America, while vegetation interaction is just beginning. Key mechanisms need to be identified and the degree to which they modify climate variability needs to be quantified.

- Understanding the relative importance of the following processes to continental climate anomalies: (i) Remote SST influence, such as ENSO anomalies; (ii) Local SST: changes in the Atlantic SST patterns; (iii) Land feedbacks.

  Specific questions under this topic include:

  - What is the relationship between the marine and land ITCZs or convection centers: competitive (east-west thermal contrast) or cooperative (north-south thermal contrast)?
  - Is a continental climate anomaly such as over the Sahel the result of a shift in the ITCZ or a change in its intensity?
  - What are the relative roles of various land features such as albedo, dust, evapotranspiration, and surface roughness?
  - How do the African easterly waves interact with the monsoon circulation?

  These questions are critical for making SST-based forecasts useful for predicting continental climate.

- There is a critical need in improving the model simulation of key climatological features:

  - Diurnal cycle of convection
  - Seasonal cycle of the convection centers and the ITCZ movement
  - Land-sea contrast, an issue that might be closely related the current deficiencies in simulating TA SST by coupled atmosphere-ocean models.

- There is a strong need for better communication between observation and modeling, and between atmosphere-ocean and land-surface communities. Field experiments should focus more on climate related issues, rather than merely mesoscale structures. And more effort is needed in synthesizing existing data into frameworks easily accessible for modelers. Observationalists need to come up with coherent scenarios that can be tested by models, while modelers need to appreciate more what their model cannot do. Land-surface community needs to identify the 1st order processes most relevant to climate variability and quantify their importance in a concerted way.

A Statement on predictability

Although the planned WG discussion on the issue of predictability was not achieved due to time constraints, this topic was discussed and debated through the oral presentations and the discussions in plenary and the three working groups (ITCZ, SST, and Land). The following statement summarizes the issue of TA climate predictability including recommendations for future research.

Prediction of weather and climate in the Atlantic Rim is heavily affected by the behavior of the AMI. The AMI is not only a source of precipitation for the land over which it passes, but is potentially also as a source of forcing of the large-scale circulation due to the release of latent heat and the formation of Rossby wave sources.

The strong correlation between TA sea surface temperature (SST) and convection implies that predictability of convection is inevitably connected with predictability of the SST. Perfect knowledge of the SST would not, of course, imply perfect knowledge of the convection, particularly because the continuous interaction between the atmosphere and ocean. Nevertheless, the slower timescales of ocean dynamics compared with those of the atmosphere does allow one to hope that improved predictability of SST would translate into some improvement in the predictability of convection, at least in a probabilistic sense.

The coupling between ocean and atmosphere makes separation of predictable signals from “noise” difficult to accomplish. For example, observation and empirical models imply that remote stochastic forcing may be processed through ocean dynamics before its disruptive influence is felt by equatorial SSTs, resulting in misleadingly low correlations between SST prediction error and the ultimate source of some of that error. Knowledge of ocean dynamics, therefore, is necessary to assess the effect of some stochastic forcing on SST predictability. On the other hand, numerical modeling studies with mixed layer models, which do not handle oceanic advection by construction, show that significant predictability comes from direct forcing by the atmosphere.

Although the experiences gained through these numerical and empirical investigations appear contradictory, they are not. In either case the correlations with prediction error, though significant, are low enough to allow a role for alternative hypotheses. Estimates of the relative importance of ocean and atmospheric dynamics must wait for further investigation.

Fortunately, there are at least two identified sources of predictability for TA SST: the annual cycle and remote forcing from the tropical Pacific. Although experimental forecasts of TA SST exploit one or both of these phenomena, it is not believed that they are being utilized for all their potential. In spite of the advances made in characterizing the annual cycle of TA climate, much work is still to be done, particularly in terms of understanding the annual cycle of the TA ocean-dynamics. The influence of the tropical Pacific on TA climate is also beset with uncertainty, since the relative importance of direct forcing of the tropical atmosphere in the Atlantic-East Pacific region and the secondary effects of El Nino-forced northern hemisphere teleconnections is not well understood. Further, El Nino-forced teleconnections internal to the Southern Hemisphere are likely to play a role but have not been adequately studied.

There are presumably many reasons that TA predictability has not been as intensely studied as its more prominent counterpart in the Pacific. Firstly, the dynamics of TA SST is as not as well understood. Secondly, the smaller signal to noise ratios compared to the Pacific case make it is hard to isolate the signal and study its physical and predictive properties. Thirdly, also as a result of the signal-to-noise-ratio, it has not been clear throughout history that TA climate variability has global ramifications; although the local impacts are considerable.

In considering what may be the direction of research into TA predictability, the following questions come to mind:

- What sorts of observations are available? Current plans to improve observational systems in the TA region should be encouraged and, if possible, extended.
- What more can we learn about the role of the annual cycle in predicting the AMI?
- What are the physical processes by which the TA and Pacific regions interact? Which ones are predictable?
- While many studies have shown that TA climate variability is strongly connected to the North Atlantic Oscillation, is there actually any predictability that can be gleaned from this connection? Or, after accounting for spurious "predictability" imposed by frequency filtering, does the NAO act as predictability-destroying noise?
- Does the Indian Ocean have a direct influence on the TA? If so, how?
- Are deterministic predictions skillful? If not, can useful probabilistic predictions be made?

We may, perhaps, begin to address the last question by an appeal to the community: We might, in a manner emulating the Experimental Long-Lead Forecast Bulletin (ELLFB), invite researchers to use their neural nets, statistical tools, GCM's, etc., to try and predict TA SSTs with results to be published in an ELLFB-like format. Unlike the ELLFB, however, we suggest that negative results be valued and published as well as positive ones. Not only would this discourage duplication of effort, but also some dynamical information about the nature of TA predictability would inevitably result.

8. Summary

The immediate outcome of the AMI Workshop has been the demonstration of the considerable interest and readiness that exists in the climate research community towards working on the TA climate problem. There was unanimous agreement that the Workshop facilitated much needed interaction and exchange of ideas regarding the recent progress and remaining challenges in this research area and that continued interaction would be very useful for continued progress. There was also agreement that there is considerable potential for progress in the area of TA climate prediction.

The Workshop attendees were also unanimous about the utility of the focus on the AMI as a way to bring together all the physical elements of the TA climate variability problem while working towards improved forecasts and forecast applications for society. The AMI is the center element of a complex of regional influences, over ocean and land. Focusing on the AMI enables clear definition of the relevant patterns of climate variability, delineate the link to societal impacts, and highlight the interactivity of the three climate system component: atmosphere, ocean, and land in the region.

Looking back at the Workshop goal to determine the areas that offer best opportunity for advancing the understanding and ability to predict tropical Atlantic climate, we conclude that it will be most advantageous to pursue the following objectives:

- **Define the critical climate issue in the TA region** in terms of the variability in **AMI position and precipitation intensity** and link this to other **regional influences** such as variations in winds, SST, air-temperature and humidity, dust, and storms.
- Pay particular attention to the **seasons** when maximum variability and/or societal impacts are experienced, *i.e.*, **boreal spring** and **boreal summer**.
- Seek to improved understanding of the mechanisms of **remote influences** and **local atmosphere-ocean interaction** and their relative roles in determining the position and intensity of the AMI with particular emphasis on the key season. In particular, **focus on the interaction between the equatorial Pacific (ENSO)** and the TA atmosphere-ocean system and the ways by which extratropical Atlantic influences – from the **North and South Atlantic** - and **local interaction** within the TA intervene to affect variability and predictability of the regional climate.
- Resolve the relation/interaction between the variability of the marine climate and that over land and investigate **land-atmosphere interactions** mainly in terms of their role in modifying and impacting the variability over land.
- Work to overcome **model biases** in simulating TA climate and develop **modeling strategies** (atmosphere, ocean, atmosphere-ocean coupling, and land-atmosphere coupling) to study the dynamics, accurately simulate, and predict the seasonal and interannual variability of the ITCZ and its regional impacts. Emphasize using a hierarchical modeling approach to test dynamical hypotheses against new and old data. Work towards improved coupled models that can correctly simulate local coupled ocean-atmosphere-land response to external forcing. Improvement in models should result in gains in data assimilation and in climate prediction.

- Maintain the **network of in-situ sustained observations** over ocean and land in support of the research, monitoring and prediction of the AMI variability and its regional influences. Work to identify the gaps in the existing network and identify methodologies to resolve them via intensive use of remote sensing from satellite and/or the implementation of additional in-situ platforms where necessary (e.g., adding radiosonde observations from VOS lines). Determine the need for **special observations of key climate processes** (field programs) in support of research to address critical gaps in knowledge or in model development.

While well-warranted attention is being paid to the study of climate over the land areas surrounding the TA and the neighboring oceans, in particular the equatorial Pacific, these efforts are incomplete without proper attention to processes within the marine environment of the TA. It is in the interaction with the ocean where the potential for predictability lies and where a key control over the TA rainfall systems resides. Adding a proper attention to the marine climate system will create an overarching, strong comprehensive science program for improving the understanding and prediction of climate variability in the tropics with maximum benefits to society.

In seeking to achieve progress in prediction, it is clear that continued emphasis on combining a hierarchical modeling approach with observations is important. Such studies should aim at resolving the roles of local and remote forcing, and of land and ocean surface conditions and interactions on the simulation and prediction of the AMI and its associated rainfall.

In addition, there is a real need for a better observational network in the area. We need to continue the effort towards maintaining the ocean-observing program in the area, as it seems that progress in climate prediction in the region is impeded by insufficient data for properly initializing prediction models. Enhancing the sustained ocean observation network to provide information of vertical and horizontal heat transport in the near equatorial region will also help resolve the critical role of local atmosphere-ocean interaction and address the discrepancies in coupled models.

More difficult is the issue of atmospheric observations. Absence of routine observations of the vertical structure over the ocean are a known issue and aside from the relatively sparse PIRATA network, in-situ surface marine observations are concentrated along narrow ship lanes and are not regular. While remote sensing from satellites in expanding, they require continued calibration and their long-term continued operation is not guaranteed. The increasing gaps in in-situ land observations and the lack of upper-air observations over the marine areas are impeding progress in understanding the dynamics of the AMI and the reason for the poor simulation of this phenomenon in global climate models. A sustained network of in-situ observation is important to maintain continuity and provide a steady observational baseline for the ever-evolving remote sensing programs.

9. Subsequent Activities

The AMI Workshop was part of ongoing activities regarding the coordination and implementation of TA research and observations. In the aftermath of the Workshop, proposals were prepared and submitted to US CLIVAR Program concerning field campaigns to study the ocean and atmosphere elements of the climate system in the region. In particular a preliminary proposal entitled: "*The Atlantic Marine ITCZ Complex: Interaction with the upper ocean and the large-scale regional environment*" was prepared by a group of scientists (P. Chang, Texas A&M; J. Chiang, U.C. Berkeley; Y. Kushnir, LDEO; B. Mapes, NOAA/CDC; D. Raymond, New Mexico Tech; A. Sobel, Columbia University, C. Zhang, RSMAS/MPO), based on the recommendation of the AMI Workshop, particularly the ITCZ WG. This proposal was submitted to the January 2003 meeting of the US CLIVAR SSC. The proposal provided the justification and rough outline of resources involved in conducting two special observing programs in the TA, addressed at collecting data to help resolve and understand the AMI structure and maintenance during the key seasons: boreal spring and boreal summer. The US CLIVAR SSC reviewed the proposal and found the subject important to CLIVAR. Despite the tentative nature of the proposal the SSC found the proposed field programs promising and encouraged the continued development of the proposal with intent to conduct a boreal summer pilot field study as part of the AMMA project and a more comprehensive field campaign directed towards the boreal spring state of the AMI.

A concerted effort to coordinate the plans for and observational AMI with the AMMA special observation period (SOP) plans in the West Africa began immediately after the AMI Workshop. Several meeting held in the US and Europe in which representatives of the US and international research community took part. These meetings formed the background for continued planning towards a field program, parallel to AMMA SOP in the eastern TA in the year 2006 with foci on three elements of the TA summertime circulation: (i) the dynamics and predictability of the Atlantic cold tongue region, (ii) the maintenance and variability of the AMI in the eastern TA, and (iii) the links to the West African summer monsoon system.

Continued focus on climate prediction in the TA will be provided by International CLIVAR Workshop on Atlantic Predictability, which will be held in the spring of 2004 at Reading, UK. The Predictability Workshop will bring together scientists from the research community, the large operational climate prediction centers, and the various national forecasting centers in the region, to discuss the predictability and prediction around the entire Atlantic region including the TA. The predictability workshop will aim at providing an up to date assessment of the state of knowledge concerning the predictability of climate in the Atlantic Sector, improving communication between the operational prediction centers and the research community, identifying the gaps in knowledge and in observations, and recommending priorities for future research, observations and prediction systems.

APPENDIX 1: List of Participants

Count	FIRST NAME	LAST NAME	INSTITUTE
1	Julio	Bacmeister	NSIPP-UMBC
2	Anjuli	Bamzai	NOAA-OGP
3	Tony	Barnston	IRI
4	Marcelo	Barreiro	Texas A&M University
5	Michela	Biasutti	JISAO - Univ. of Washington
6	Suzana	Camargo	IRI
7	Edmo	Campos	University of Sao Paulo
8	James	Carton	University of Maryland
9	Christophe	Cassou	NCAR
10	Ping	Chang	Texas A&M University
11	Gennady	Chepurin	University of Maryland
12	John	Chiang	University of Washington
13	Kerry	Cook	Cornell University
14	Arnaud	Czaja	MIT
15	Yongjiu	Dai	IRI
16	David	DeWitt	IRI
17	Leonard	Druyan	GISS/CCSR Columbia University
18	Alexey	Fedorov	Princeton University
19	Amy	Ffield	LDEO
20	Rong	Fu	Georgia Institute of Technology
21	Silvia L.	Garzoli	NOAA/AOML
22	Alessandra	Giannini	NCAR
23	Lisa	Goddard	IRI
24	Semyon	Grodsky	University of Maryland
25	David	Halpern	Jet Propulsion Laboratory
26	Stefan	Hastenrath	University of Wisconsin
27	Bohua	Huang	COLA/IGES
28	Terrence	Joyce	WHOI
29	Noel	Keenlyside	Max Planck Institute for Meteorology
30	Yochanan	Kushnir	LDEO
31	Upmanu	Lall	IRI
32	Peter J.	Lamb	CIMMS/University of Oklahoma
33	alban	lazar	LODYC-Univ. Paris 6
34	Kevin	Leaman	Univ. of Miami, RSMAS
35	Herve	LeTreut	LMD-Jussieu, France
36	W. Timothy	Liu	Jet Propulsion Lab., Caltech
37	Zhengyu	Liu	University of Wisconsin-Madison
38	Paola	Malanotte-Rizzoli	MIT
39	Brian	Mapes	Climate Diagnostics Center
40	Ron	Miller	NASA - GISS

Count	FIRST NAME	LAST NAME	INSTITUTE
41	Ben	Mohamed	IRI
42	Kenneth	Mooney	NOAA
43	Antonio	Moura	IRI
44	J. David	Neelin	UCLA
45	Sharon	Nicholson	Florida State University
46	Paulo	Nobre	CPTEC/INPE Brazil
47	Cecile	Penland	NOAA-CIRES/Climate Diagnostics Ctr.
48	David	Raymond	New Mexico Tech
49	Stephane	Raynaud	CAO/CIMS/NYU
50	Andy	Robertson	IRI
51	Chet	Ropelewsky	IRI
52	Ramalingam	Saravanan	NCAR
53	Siegfried	Schubert	NASA - GSFC
54	Richard	Seager	LDEO
55	Jacques	Servain	FUNCEME Brazil
56	Adam	Sobel	Columbia University
57	Max	Suarez	NASA - GSFC
58	Liqiang	Sun	IRI
59	Madeleine	Thomson	IRI
60	Chris	Thorncroft	SUNY at Albany
61	Jim	Todd	NOAA/Office of Global Programs
62	Yves	Tourre	MEDIAS-France
63	Martin	Visbeck	LDEO
64	Chunzai	Wang	NOAA/AOML
65	Neil	Ward	IRI
66	Shang-Ping	Xie	SOEST
67	Steve	Zebiak	IRI
68	Ning	Zeng	University of Maryland
69	Qiong	Zhang	Center for Climatic Research, Univ. of Wisconsin-Madison
70	Chidong	Zhang	RSMAS, University of Miami

APPENDIX 2: AGENDA

US CLIVAR WORKSHOP ON THE DYNAMICS AND PREDICTABILITY OF THE ATLANTIC ITCZ AND ITS REGIONAL CLIMATIC INFLUENCES

Wednesday, 18 September 2002 AM:

8:30 – 9:00	*Registration, coffee & light breakfast*
9:00 – 9:30	Introduction: meeting goals and overview of the problem (S. Zebiak, Y. Kushnir, A. Robertson, N. Ward).

PART I: CLIMATE PREDICTION – THE CHALLENGE

9:30 – 9:55	"Integrated resource management and development to improve resilience to drought in Northeast Brazil": Upmanu Lall (Columbia U.).
9:55 – 10:20	"A climate and health initiative for West Africa": Madeleine Thomson (IRI).
10:20 – 10:45	*Coffee break*
10:45 – 11:10	"Challenges in predicting tropical Atlantic SSTs and their associated climate impacts": Lisa Goddard (IRI).
11:10 – 11:35	"Towards predicting Tropical Atlantic SST and rainfall in Brazil": Paulo Nobre (CPTEC/INPE, Brazil).
11:35 – 12:00	Discussion & questions to speakers.
12:00 – 1:30	*Lunch*

Wednesday, 18 September 2002 PM:

PART II: THE PHYSICAL SYSTEM – PATTERNS AND PROCESSES

1:30-1:55	"The Atlantic ITCZ: structure, annual cycle, interannual and longer-term variability": Stefan Hastenrath (University of Wisconsin).
1:55 – 2:20	"Remote influences on the tropical Atlantic climate system": Ramalingam Saravanan, (NCAR).

2:20 – 2:45 "Coupled variability in the tropical Atlantic": Ping Chang (Texas A&M University).

2:45 – 3:15 "Simulating the Atlantic ITCZ climate with regional models" (2 talks): Liquiang Sun (IRI) and Kerry Cook (Cornell University).

3:15 – 3:40 "The TA ocean circulation and its role in determining SST": Jim Carton (UMD).

3:40 – 4:10 Coffee break

4:10 – 4:45 "The role of land surface processes in regional climate dynamics" (2 talks): David Neelin, (UCLA) and Max Suarez (NASA/GSFC).

4:45 – 5:30 "The role of convection in ITCZ and large-scale dynamics" (3 talks): John Chiang/Adam Sobel (JISAO/Columbia U.), Dave Raymond (New Mexico Tech), Chidong Zhang (U. Miami/RSMAS).

5:30 – 6:00 Discussion & questions to speakers.

6:00 RECEPTION

Thursday, 19 September 2002 AM:

8:30 – 9:00 Coffee & light breakfast

9:00 – 9:45 Plenary – discussion of workshop goals and formation of working groups by three subjects:

--- The marine ITCZ

--- Continental climates

--- SST variability

9:45 – 10:00 Coffee break

)0 – 12:30 Working group discussions (The groups' assignment is to determine and prioritize the outstanding issues in each subject and prepare a presentation to the plenary. The groups should also attempt to draw a tentative research/observation plan to address these issues).

12:30 – 1:30 Lunch

Thursday, 19 September 2002 PM:

1:30 – 3:00	Reconvene in plenary for initial working group reports and discussions.
3:00 – 3:20	*Coffee break*
3:20– 5:20	Programmatic and International issues: CLIVAR & international programs relevant to the tropical Atlantic: VAMOS/LBA, EPIC, VACS/AMMA, PIRATA, Tropical Atlantic Process Studies Plans (under US CLIVAR), South Atlantic, European activities etc.
5:20 – 6:00	Discussion

Friday, 20 September 2002 AM:

8:15 – 8:45	*Coffee & light breakfast*
8:45 – 9:15	Plenary – revisiting Wednesday's working groups summaries and recasting them in terms of two objectives: --- The planning of processes, observational, and modeling studies --- The planning predictability and impact studies The goals are to outline a plan of action to advance the understanding and prediction of the Atlantic ITCZ and its climatic linkages.
9:15 – 10:45	Breakout group discussions of the two objectives
10:45 – 11:00	*Coffee break*
11:00 – 12:00	Plenary – summary of breakout groups' discussions and future assignments.
12:00	Adjourn