December, 2003

U.S. CLIVAR Process Study Brief

A. Process Study Title:

Dynamics of the East Atlantic Marine ITCZ: Interaction with the Large-Scale Environment, African Monsoon, and the Equatorial Cold Tongue

B. Scientific Leaders:

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C. Process-study beginning/ending date

May 15 – September 15, 2006

D. Panel/Working Group

The following scientists have contributed to documenting the scientific issues of this study: P. Chang (Texas A&M), J. Chiang (UC Berkeley), B. Mapes (NOAA/CDC), D. Raymond (NM Tech), and A. Sobel (Columbia U). The field program of this study has been planned as the US contribution to the marine climate component of AMMA jointly with the US AMMA Science Steering Group (and C. Fairall of NOAA/ETL).

1. Objectives and Relevance

The following notions motivate this study:

(a) Skillful seasonal and interannual (S/I) prediction of rainfall over land in the populated areas surrounding the tropical Atlantic (e.g., West Africa and Northeast Brazil) yields considerable societal benefits;

(b) The most crucial step in (a) is correctly forecasting the position and intensity of the Atlantic marine ITCZ (AMI);

(c) The basis for S/I prediction is the interaction of the AMI with slow-evolving modes of tropical climate variability particularly ENSO and the tropical Atlantic (TA) SST meridional gradient and cold tongue (Atlantic “Niño”) modes, known collectively as TAV (TA variability).

(d) The TA SST gradient mode variability is thought to be set up by external influences from the North and South Atlantic (NAO and yet un-named variations in the Southern Hemisphere) and ENSO (see below) that act via their control on the mean strength of the northern and southern trades and thus on the turbulent heat exchange with the underlying ocean. The mechanisms setting up and governing the cold tongue mode are less well understood but equatorial ocean dynamics responding and interacting with the atmosphere and influence from the effect of the adjacent African land mass have been hypothesized.

(e) ENSO affects the AMI via a direct atmospheric bridge, which is hypothesized to involve the adjustment of the entire tropical atmospheric to the convective heating of the equatorial Pacific atmosphere and the resulting stabilization of the adjacent ocean regions such as the Atlantic. During winter, ENSO also affects the strength of the northern trades and hence affects the TA SST gradient mode.

(f) Important questions remain regarding the interaction between atmospheric convection and both local and remote forcing. Particularly with regard to the response of the

AMI to surface vs. upper level conditions and its role in setting up the mean and anomalous state of the TA climate system together with the influences of the surrounding atmosphere, ocean, and land.

(g) Related to the previous point, we find that many current state-of-the-art global climate models (GCMs) have difficulties in simulating realistically the climate systems of the TA. For example, the NCAR CCM3 model, forced with observed SST, displays strong regional biases in the mean position and strength of both annual mean and annual cycle of precipitation in the TA. On the eastern side both annual precipitation and the amplitude of the annual cycle are too weak, while in the west, they are too strong and have the wrong geographical distribution. Errors in coupled models are even larger, expressed in unrealistic SST distribution where the mean zonal gradient in SST is the opposite of the observed, and the AMI moves deep into the Southern Hemisphere during spring. These indicate a lack of accurate representations of key physical and dynamic processes in both atmosphere and ocean in models.

(h) While there is an overall need to better document and understand the three dimensional structure of the atmosphere surrounding the AMI, the amount of modern in situ atmospheric observations available from the TA that can be used in model validation and improvement and in data assimilation is very limited and is focused mostly at the surface. Satellite observations are improving and will benefit greatly from calibration and verification against in-situ data.

(i) There is presently an opportunity for conducting a comprehensive process study to address questions regarding the AMI dynamics and its interaction with the African monsoon system and the Atlantic cold tongue during the boreal spring and summer in both a national and international context.

The overall objective of this study is to provide information needed for improving the understanding of the physical and dynamic processes key to the determination of the predictability of the AMI and its limits, improving their representations in climate models, and assessing their representations in global reananlyses. Central to these processes are the air-sea interaction and convection-circulation interaction associated with the AMI.

1.1 Key questions, issues and/or hypotheses the study will address

In the most general terms, our overarching hypothesis is that the air-sea interaction and convection-circulation interaction associated with the AMI serve as both internal processes and mechanisms for the regional realization of external and internal forcing that govern the S/I variability in the TA. Improved understanding of these interaction processes is, therefore, pivotal to understanding the predictability of the AMI and its limit, and to improving their representations in climate models.

Among others, the AMI process study will focus on the following key scientific issues pertaining to the air-sea and convection-circulation interactions in the region:

(a) What is the role of ITCZ convection in the regional, large-scale air-sea interaction?

It is commonly believed that enhanced deep convection in the ITCZ can accelerate the surface southerly winds across the equatorial cold tongue and into the ITCZ. This process has been built into many conceptual and mechanistic models that explain air-sea interaction in the TA. Recent observations from EPIC2001 suggest, however, that convection in the ITCZ may influence the surface winds through a different mechanism: Deep convection in the ITCZ is very intermittent. When deep convection is absent, a low-level northerly flow across the equator from the ITCZ exist immediately atop the atmospheric boundary layer (ABL) (Zhang et al. 2003). This low-level return flow enhances the vertical wind shear across the top of the ABL and thereby enhances the shear-generated turbulent entrainment. This entrainment helps balance the meridional pressure gradient in the ABL and acts as a brake to the ABL and surface southerly winds (McGauley et al. 2003). When deep convection occurs, the low-level return is reduced and the braking effect of entrainment is released. Based on this process, a new hypothesis on the role of ITCZ convection in air-sea interaction can be proposed:

Hypothesis I: Deep convection in the ITCZ participates in air-sea interaction by releasing the braking effect of entrainment associated with the low-level return flow and thereby enhancing the surface southerly wind across the equatorial cold tongue. Climate models can adequately represent this braking mechanism only if they reproduce the correct ABL entrainment processes and fractions of deep vs. shallow convection in the ITCZ.

Testing this hypothesis needs simultaneous, in-situ measurements of convective structure in the ITCZ and the large-scale circulations in and above the ABL and sea surface conditions across the ITCZ and the cold tongue. Such measurements can be used to assess how the variability in convective structure of the ITCZ is coupled to the large-scale circulation, how this coupling influences air-sea interaction, and what aspects in climate models need to be improved so this mechanism can be accurately represented in the models and their data assimilation products.

(b) What is the role of convection in transferring remotely forced changes in the upper troposphere to the surface?

It has been proposed that convection plays an important role in communicating remotely forced changes in upper troposphere temperature (and static stability) to the planetary boundary layer, and therefore the surface (Chiang and Sobel, 2002). For example, during El Niño, a delayed warming of TA SST, particularly north of the equator, follows the warming of the eastern equatorial Pacific. This has been traditionally seen as caused by teleconnections in the circulation that affect surface winds (hence evaporation). However, using a coupled, single-column model of convection and the ocean mixed layer, Chiang and Sobel showed that the surface warming can be an effect of moist convective adjustment of the atmosphere. This new mechanisms may be important in creating a fast-acting Pacific-Atlantic bridge along the equator, during the winter, when the El Niño is at its peak, (Chiang et al., 2002) and perhaps also during summer, when El Niño is developing and is known to affect precipitation in sub-Saharan Africa (Giannini et al., 2003).

Hypothesis II: Deep convection in the AMI plays a key role in communicating remotely forced upper-tropospheric changes to the surface and thus connecting local air-sea interaction to remote forcing of the interannual variability in the TA.

To test this hypothesis we need measurements of the atmospheric dynamic and thermodynamic fields in both the troposphere and ABL during the absence of deep convection as well as during strong deep convective events in the AMI. In situ observations must be combined with a hierarchical modeling approach (single-column, cloud-resolving, regional, and global models) to quantify the connection between changes in the troposphere due to external influences and in the ABL via deep convection in the AMI. Such connection operates similarly on a wide (up to interannual) range of time scales.

(c) What is the role of the monsoon onset in the springtime development of the AMI?

The springtime development of the ITCZ/cold tongue complex is an outstanding testament of air-sea interaction processes in the tropical climate system. Wallace et al (1989) and Mitchell and Wallace (1992) proposed that this development in the eastern Pacific and Atlantic is initiated by the onset of the North American monsoon. Absent in this hypothesis is the exact mechanism(s) for the strengthening of the surface monsoon flow that enhances the cold tongue and the ITCZ. In the following hypothesis such mechanisms are proposed for the springtime development of the AMI:

Hypothesis III: The surface cross-equatorial flow is initially accelerated by the onset of the West African monsoon through an increase in the surface meridional pressure gradient due to land surface heating. The accelerated cross-equatorial flow enhances the cold tongue and strengthens the AMI. The stronger meridional SST gradient and deep convection in the AMI feed back positively to the surface flow through increasing the meridional pressure gradient (by SST influence on the ABL mass distribution) and releasing the braking effect of entrainment (by the effect of deep convection on the low-level return flow). These processes can be correctly represented in climate models only if they accurately reproduce the air-sea interaction, strength and location of the AMI over both the ocean and land, and the convective structure in the AMI.

Testing this hypothesis needs simultaneous measurements of convective structures in the ITCZ over the ocean and land, the large-scale circulations in and above the ABL, and the sea surface and upper ocean conditions through boreal spring during which the development of the AMI-cold tongue-monsoon complex takes place. One essential element in this hypothesis testing is the oceanic processes responsible for the rapid development of the cold tongue via interacting with the enhanced surface cross-equatorial winds. The relative roles of surface fluxes, horizontal advection, and upwelling in the mixed-layer heat balance need to be quantified. The role of remote influences (e.g., the large-scale ocean circulation) in such local air-sea interaction needs to be explored.

(d) What is the relative importance of aerosol vs. water vapor to convection in the AMI?

It has been well documented that frequent outbreaks of African dust may have a broad range of climatic impacts in many regions of the world. The most typical African dust outbreaks are associated with the passage of the Saharan Air Layer (SAL), which is also very dry (e.g., Carlson 1979; Prospero and Carlson 1972). In the TA, one most prominent effect of the SAL is to suppress precipitation in the AMI. It is possible that the most northward position of the AMI in summer is more confined than the eastern Pacific ITCZ because of the frequent SAL on its northern flank. The exact mechanisms for the SAL to suppress precipitation are, however, not clear. Precipitation can be suppressed by the radiative effects of both aerosol and dry-air layer, excessive aerosol as cloud condensation nuclei (CCN), and dry air entrainment into clouds. Based on previous process studies in the western Pacific (e.g., Mapes and Zuidema 1996; Brown and Zhang 1997; Yoneyma and Parsons 1999), a working hypothesis can be proposed:

Hypothesis IV: Precipitation in the AMI is suppressed by the SAL via primarily dry-air *entrainment into clouds and secondarily the radiative effects of dry air and aerosol on the static instability. Such processes are not adequately represented in most current climate models because of the absence of interactive aerosol (or dust) and dry-air outbreaks and a lack of sensitivity of parameterized convection to environment moisture.*

Testing this hypothesis and quantifying the relative importance of aerosol versus dry air to precipitation in the AMI need detailed measurements of the mean and variability of the large-scale environment for the AMI (temperature, humidity, aerosol) and convective structures in the AMI. Considering that the SAL and African dust and dry-air outbreaks in general are unpredictable on the seasonal and longer timescale, understanding this issue will help identify factors that limit the predictability of the AMI.

1.2 Responsiveness of the process study to the science goals of U.S. CLIVAR

The interest in understanding climate variability in the TA and studying its predictability is consistent with the U.S. CLIVAR goals and provides regional focus for atmosphere-ocean study that will complement other regional studies (see below Section 6). The expected improvements in climate prediction will directly benefit society as the related impacts affect water resource planning, overcoming climate sensitive diseases, and sustaining agriculture in semi-arid regions.

2. Process Study Plans

2.1 Overall approach in addressing the science, answering questions, & testing hypotheses, including geographical location

The general approach in addressing the key issues raised and testing the hypotheses proposed above is to simultaneously collect in situ observations of the convective structures in the AMI, the large-scale environment of the AMI and the surface and upper ocean conditions in the TA. The focus location is the eastern TA where the cold tongue is prominent and the influences of African dust and dry air are strong. The focus time is boreal spring when the AMI /cold tongue complex is under a rapid development and actively interacts with the West African monsoon, and boreal summer when the AMI /cold tongue complex reaches its seasonal peak but still under heavy influences of African dust and dry air. The sampling strategy is to simultaneously measure the vertical-meridional cross sections of the atmosphere and the upper ocean across the cold tongue in spring, and the vertical-meridional cross sections of the atmosphere across and along the AMI and convective structures in the AMI in summer.

2.2 Overall time-line showing start date, duration and costs of key elements (planning, enhanced observations, analysis, and modeling), and anticipated milestones.

2002-2003: preliminary planning: no funding support so far.
2004-2005: detailed planning: (preliminary analysis, travel, meeting) $250K/yr.
2006: field campaign – salary, shipping, etc: $1,500,000
2006: field campaign (May 15, 2006 - September 15, 2006) instruments: $2,400,000
2006 – 2009: analysis and modeling: agencies core funding.

2.3 Agency programs most likely to provide support necessary to implement the study.

NOAA: OGP (CLIVAR, Ocean Obs.)

NSF: ATM (Atmosphere)

NASA: EOS, GMAO (Atmosphere)

3. Observational elements

The main observational elements include (with their possible PIs):

- Aircraft dropsondes measuring the large-scale vertical-meridional cross sections from the ITCZ to the cold tongue (12 – 0˚N) during the spring development (20W) and summer peak (20 and 28˚W) of the ITCZ/cold tongue complex.
- Aircraft dropsondes and flight-level measurements along the ITCZ (from the African coast to 28˚W) during the summer.
- Ship observations (soundings, radars, surface fluxes, upper ocean structures) along 20˚W (0 – 10˚N) during the spring and in the ITCZ (28˚W) during the summer.
- Lines of surface moorings along 10˚W (part of the PIRATA array) and 20˚W.
- Drifters and floats in the TA.

3.1 Linkages to/reliance upon broadscale observing efforts for the ocean, atmosphere, land, and cryosphere?

The AMI 2006 field campaign in the eastern TA is the marine climate component of US AMMA 2006 field program. US AMMA is a partner of International AMMA. The AMMA program as a whole will provide enhanced observations of the atmosphere (dynamic and thermodynamic variables, aerosol), ocean (surface and subsurface) and land surface (vegetation, soil moisture) over West Africa and the eastern TA during the special observational period (SOP) of the 2006 field campaign (May 15 – September 15). AMMA will also provide sustained observations of the atmosphere and land surface over West Africa. In the ocean PIRATA and the newly proposed Tropical Atlantic Climate Experiment (TACE) will provide sustained observations of surface and subsurface conditions periods before and after the 2006 field campaign. Linkages also exist to NASA's new generation of earth observing satellites, which provide high resolution vertical profiling of the atmosphere as well as the continuation and enhancement of surface products such as winds and SST. In the post-filed campaign phase of the program we will seek to build linkages to the CLIVAR climate process team (CPT) efforts and the ongoing model development work at NCAR, NOAA (GFDL and other), and NASA.

3.2 Regional enhancements/enhanced monitoring?

The land component of AMMA is committed to enhancing the sustained observing system of the land climate before during and after the field phase. The oceanic observations of the AMI process study (floats, drifters, and moorings) contribute to the regional sustained observations in the TA. AMMA also includes ship operations in the Gulf of Guinea, complementing the ship operation in the eastern Atlantic. The AMI process study will benefit from an enhancement of the PIRATA array and sustained observations of the ocean that will also be part of the Tropical Atlantic Climate Experiment (TACE).

3.3 Estimated cost per year for each key observational element (do not include costs for observational systems already in-place)

Dropsondes (May - September 2006):	$ 300,000
Aircraft time (NCAR HIAPER) (May - September 2006):	NSF support
Ship time (R/V Ron Brown) (May - September 2006):	NOAA support
Ship instrument (R/V Ron Brown) (May - September 2006):	

	Oceanic micro-structure observations:	$ 400,000
	CTD/ADCP observations:	$ 400,000
	Surface flux observations:	$ 200,000
	GPS soundings:	$ 200,000
surface moorings (PIRATA) (May - September 2006):		
	$100,000 per mooring x 3 =	$ 300,000
drifters (2005 – 2006):		$ 200,000
floats (2005 – 2008):		$ 400,000
TOTAL:		$2,400,000

4. Modeling elements

4.1 Scope of related modeling/data assimilation (how is the modeling linked to the observational efforts - be explicit)

The proposed process study will benefit from a hierarchical modeling approach (from single-column models to full coupled GCM) in identifying key coupled and uncoupled processes. The in situ observations from the AMI process study will be used to build conceptual models of the role of convection in the TA and test the ability of reanalysis datasets to capture the state of the TA climate system in the limits of its spatial scales. In addition, the observations will be used to text and validate mesoscale and global scale model simulations in the TA in terms of their ability of reproducing the large-scale meridional circulation and its interaction with convection in the AMI and with the ocean. The validated models will be used to further the testing of the hypotheses put forward in section1. It is the goal of the proposed process study to add to the effort to understand and correct model biases and to contribute to improvement in climate prediction in the region.

4.2 Required resources (how many people, what institutional modeling efforts will be involved, costs - exclude in-kind costs)

We propose to link between this field program and existing or future research efforts under the CPT initiative. In addition it is expected that the funding agencies participating in the field program will support funding for individual PI proposals regarding analysis and modeling based on the data collected. We expect that some or all the scientist consulted in the various stages of preparing this plan (see item D above) will also participate in the analysis and modeling efforts, representing their institutions and collaborative efforts they are involved with. Modeling centers of NSF, NASA, and NOAA will be called to participate in the data assimilation, model validation, and analysis activities.

5. Feasibility and readiness

5.1 Describe overall feasibility as well as any impediments (including necessary developments such as full ARGO, better models) to implementation.

The AMI process study is built upon the following bases: (a) The research community on tropical Atlantic climate variability has met, discussed, and identified the crucial problems that need to be addressed from a viewpoint of process studies (Kushnir et al. 2003); (b) previous process studies in the tropics, such as TOGA COARE, TEPPS, and EPIC2001, provided experience in field observational strategy and scientific ideas for hypothesis for the AMI process study; (c) AMMA 2006 field program provides a rare opportunity for the AMI process study to be conducted in a much broader context (including upstream observations over land, measurement of convective structures and aerosol, and sustained oceanic observations).

A potential impediment is the availability of NCAR HIAPER, a research airplane that is scheduled to be built in 2005, which is planned to be one essential observational element for this study. If HIAPER is not available, private aircraft will be contracted.

6. National and international links and partners

6.1 Identify the nature (e.g. coordinated observations, joint planning and execution) of linkages to, and partnerships with other national and international programs and activities.

The AMI process study of 2006 constitutes the marine climate component of US AMMA. US AMMA is a partner of International AMMA whose participants include 15 countries from Africa, Europe, and North America. The 2006 field campaign of the AMI process study has been jointly planned with US AMMA as part of its contribution to the Special Observing Period (SOP) of International AMMA. Some ocean observational elements of the AMI process study (drifters, floats, moorings) can be integrated into the sustained observations of TACE.

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