A Northeast Extension of the PIRATA Array

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Overview: We propose to augment the PIRATA array of Tropical Atlantic (TA) ATLAS buoys with four new moorings, three in the northeast TA and one in the north central TA. Moored observations in these regions will improve our knowledge of atmosphere-ocean heat exchanges and dynamics impacting the West African Monsoon, marine Intertropical Convergence Zone, upper ocean dynamics affecting heat content and SST variability in the Tropical North Atlantic (TNA) hotspot, possible connections between SST patterns and North Atlantic climate regimes of variability, and the development of atmospheric easterly waves into tropical cyclones. A better understanding of the processes driving SST anomalies in the TNA region will lead to better predictions of rainfall and other climate signals across a broad geographical domain at timescales from seasonal to decadal.

I. Scientific Rational

The Pilot Research Moored Array in the Tropical Atlantic (PIRATA; Servain *et al*., 1998) is a three-party project involving Brazil, France and the United States that seeks to monitor the upper ocean and near surface atmosphere of the Tropical Atlantic via the deployment and maintenance of an array of moored buoys and automatic meteorological stations.

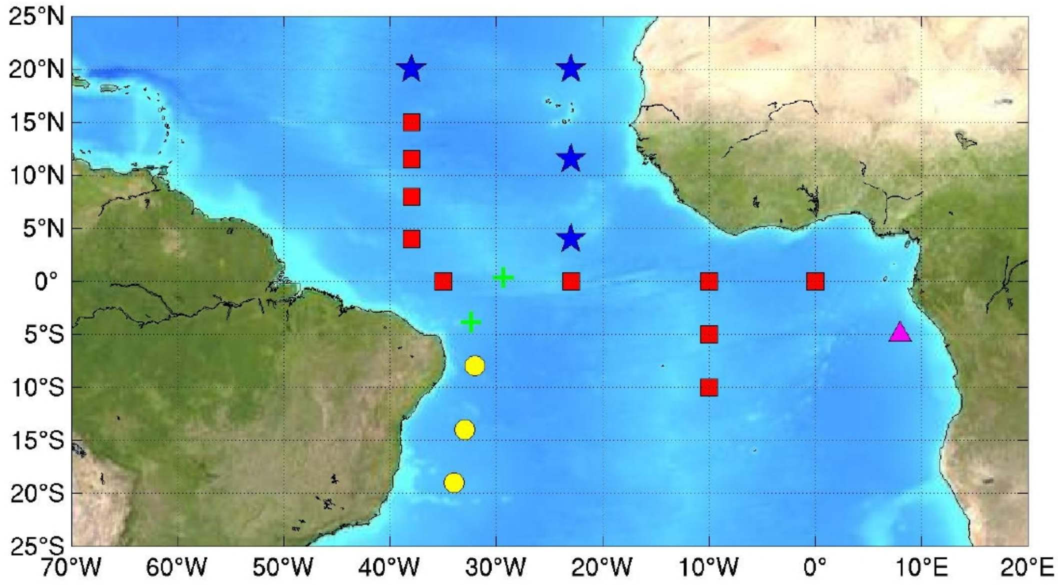

Fig. 1: The Tropical Atlantic, showing the PIRATA backbone (red squares), automatic meteorological stations (green +), southwest extension (yellow circles), southeast extension pilot site (magenta triangle), and the proposed northeast extension (blue stars).

The array consists of a backbone of ten moorings that run along the equator and extend southward along 10ºW to 10ºS, and northward along 38ºW to 15ºN. Given the widely varying dynamics of various subregions of the Tropical Atlantic, future extensions of the array had been anticipated by the PIRATA Science Steering Group to further the scientific scope of the observing system and improve weather and climate forecasts. In August 2005 a Southwest Extension of three moorings was added off the coast of Brazil (PIs: P. Nobre, E. Campos, P. Polito, O. Sato and J. Lorenzzetti). Funding for a Southeast Extension (PI: M. Rouault) has been recently identified; this extension will be implemented as a pilot project – one mooring – to be deployed near 6ºS, 8ºE during the EGEE3-PIRATA FR15 cruise in June 2006.

The northeastern and north central Tropical Atlantic (TA; Fig.1) is a region of strong climate variations from intraseasonal to decadal scales, with impacts upon rainfall rates and storm strikes for the surrounding regions of Africa and the Americas. In this document we propose a formal Northeast Extension (NEE) of the PIRATA array, to consist of four moorings with the first two deployed in June 2006. In Part I we present a brief review of the literature to motivate collecting *in-situ* atmospheric and oceanic observations in this region. In Part II we describe the specific sites proposed for mooring deployment, the observations to be collected, synergistic opportunities with related programs, and plans for deployment and future support for this extension.

Regional overview

The northeastern TA includes the southern edge of the North Atlantic subtropical gyre, defined by the westward North Equatorial Current (NEC), and the northern edge of the clockwise tropical/equatorial gyre defined by the North Equatorial Countercurrent (NECC) (Fig. 2).

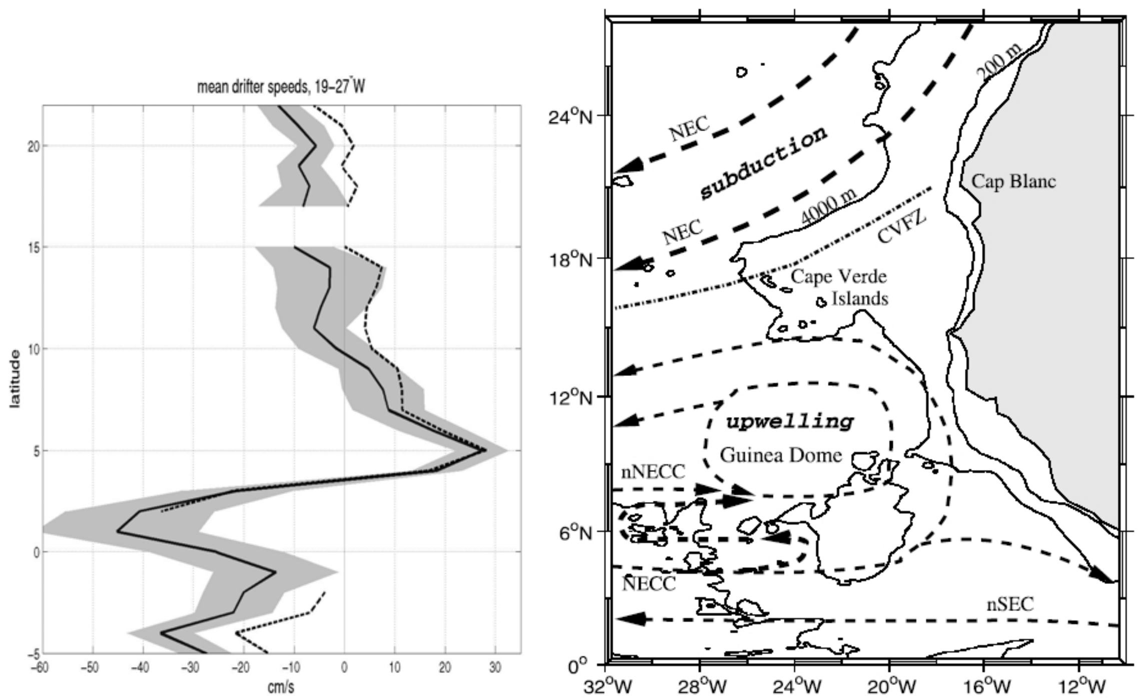

Fig. 2: *Left*: zonal drifter speeds (solid) including Ekman-removed mean (dashed) at 23ºW (adapted from Lumpkin and Garzoli, 2005). *Right*: schematic of surface currents and features in the northeastern TA, from Stramma *et al.* (2005).

The cyclonic Guinea Dome (c.f., Siedler et al., 1992) is centered near 10ºN, 24ºW (Stramma et al., 2005), between the NECC and NEC in the eastern TA. It is driven by trade wind-driven upwelling, and may play an active role in modulating air-sea fluxes in this region (Yamagata and Iizuka, 1995).

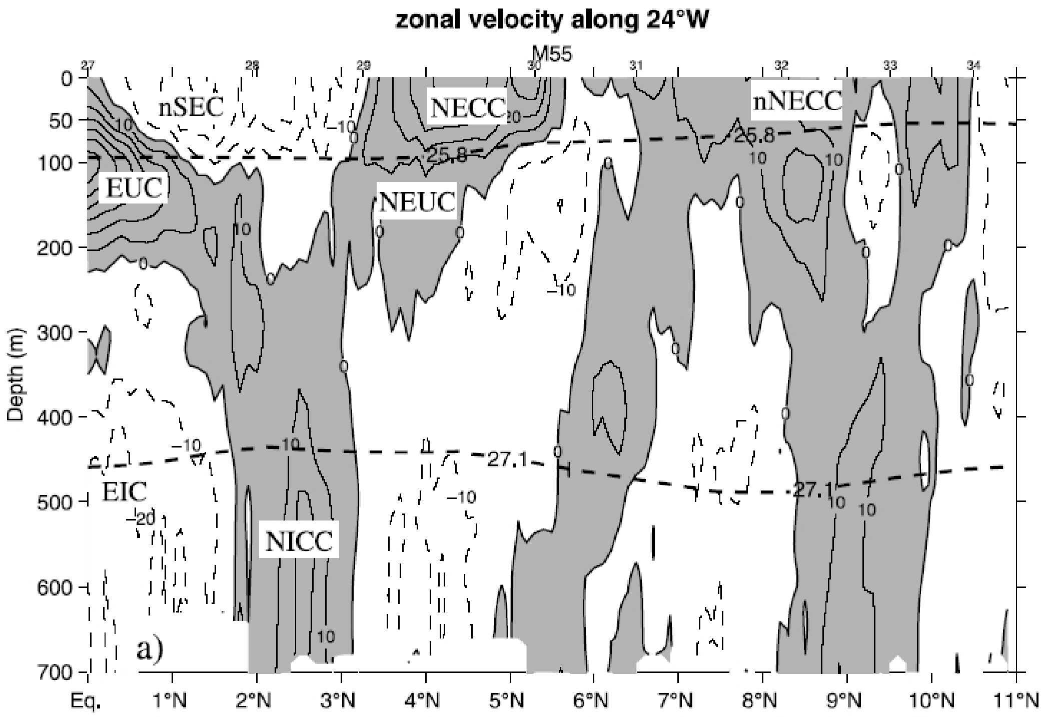

Fig. 3: zonal currents measured by shipboard ADCP, collected along 24ºW during October/November 2002. From Stramma *et al.* (2005).

Subsurface observations (Fig. 3) indicate that the core of the NECC lies above the North Equatorial Undercurrent (NEUC). A northern branch of the NECC joins these eastward currents to feed oxygen-rich water of southern hemisphere origin into the region (Stramma *et al.*, 2005).

Mesoscale to seasonal variability

The TA exhibits strong seasonal variations — the dominant climate signal of the Atlantic basin. The northern and southern hemisphere trade winds converge upon the Intertropical Convergence Zone (ITCZ) which migrates from 10-15ºN in boreal fall to the equator in early boreal spring. Large ITCZ migrations occur in the eastern part of the basin (Fig.4). These are the largest migrations of the marine ITCZ complex in NCEP and COADS climatologies, although comparable migrations may occur in the western Atlantic (Melo and Nobre, 2002). Transient events such as easterly waves, the "seeds" of tropical cyclones that may strike Caribbean and North American coastlines, are modulated and governed by this seasonality. The subsequent variations in the wind stress curl pattern drive reversals of major oceanic currents across the basin (Lumpkin and Garzoli, 2005) and are associated with the formation of the equatorial cold tongue in boreal summer and Tropical Instability Waves at ~5ºN in boreal fall. These seasonal changes in the atmosphere and ocean are strongly associated with the annual cycle of rainfall over the adjacent land masses of the Americas and Africa (*c.f.* Schott *et al*., 2005).

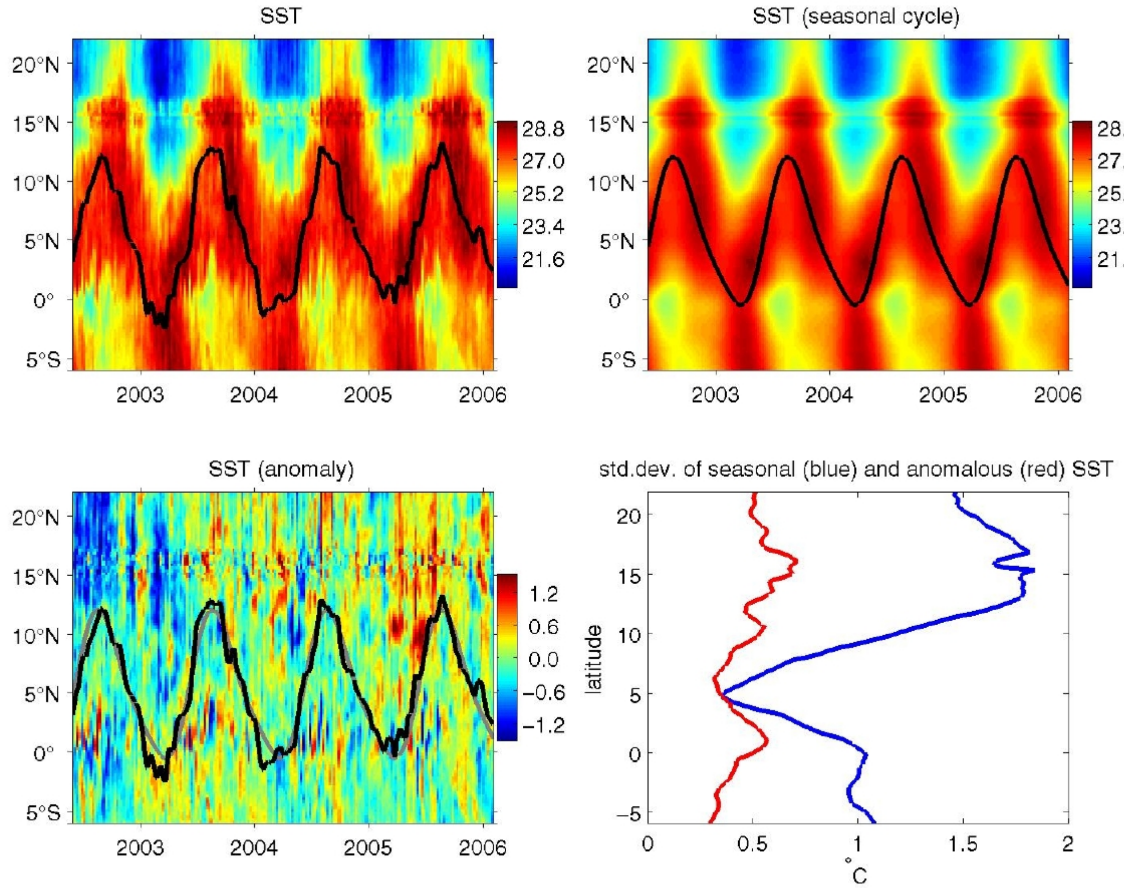

Fig. 4: Hovmuller diagrams of TMI/AMSRE microwave SST at 23ºW. *Top left*: total SST, with the position of the ITCZ (black line) from NCEP/NCAR Reanalysis v.2 winds. *Top right:* seasonal cycle. *Bottom left:* residuals from seasonal cycle. *Bottom right:* standard deviation of seasonal (blue) and residual (red) SST variations.

From an analysis of the surface layer heat balance between 8°-15°N, 38°W in the central northern TA, Foltz *et al* (2003) found that seasonal variations in SST are governed to lowest order by a balance between shortwave heat gain and latent heat loss, e.g. a one-dimensional balance. Further east, some evidence (presented in this proposal) suggests that eddy advection may also play a role in the evolution of SST anomalies, particularly during boreal spring. Additional in-situ observations of mixed layer currents are required to validate typical geostrophic-plus-Ekman models of advection for heat budgets of the region. The new moorings proposed here will allow studies of mixed layer heat budgets similar to Foltz *et al*. (2003), extending results of study from PIRATA sites to the west and south. Understanding and quantifying spatial variations in the significance of surface fluxes, mixing and advection in the northeast TA should be a priority for PIRATA if it is to be a truly basin-scale program.

In addition to the seasonal variations, the northeast TA exhibits strong intraseasonal variability (30—70 day periods; Foltz and McPhaden, 2004) in trade wind strength, which impacts latent heat fluxes. The resulting SST anomalies may subsequently modulate longer period variations, analogous to how the Madden-Julian Oscillation and other high-frequency variations affect

ENSO in the Pacific. A better understanding of the sources and impacts of this intraseasonal variability is needed.

At higher frequencies, nutrient-rich upwelled water along the coastlines and is injected into the interior TNA region by squirts and filaments, advected around mesoscale features associated with instabilities of the gyre-scale flow or interactions between the large-scale flow and islands such as the Cape Verde group (Lafon *et al*., 2004). The dynamics and impacts of this are poorly understood and are the subject of a proposed observational program for the northern TNA region (K. Donohue, pers. comm.), for which continuous time series of upper ocean properties at a few points may be a valuable complement to gridded fields constructed primarily from remote observations.

Between the equator and 5—6ºN, tropical instability waves (TIWs) are a major source of variability at 20—30 day periods. Observations at the equatorial 23ºW mooring have quantified their role in advecting heat into the cold tongue during boreal fall (Grodsky *et al.*, 2005), and the SST signature of the wave is clearly evident to 5ºN (Fig. 5). This analysis has also demonstrated the significance of salinity observations in the upper ocean to accurately estimate the magnitude of baroclinic energy conversion. Observations further north along 23ºW are needed to quantify the role of TIWs in modulating boreal fall SST anomalies north of the NECC.

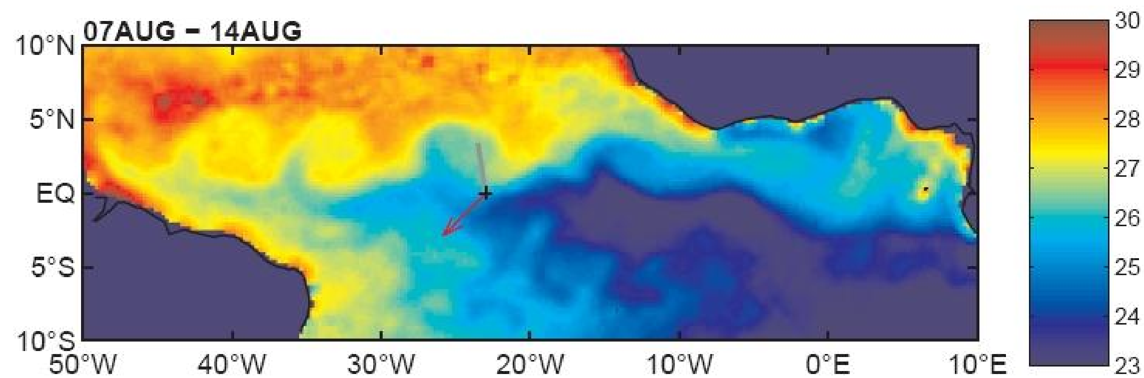

Fig.5: SST in August 2002 (shading), (0, 23ºW) currents at 16m depth (arrow), and direction of SST gradient (grey line). Figure from Grodsky *et al*. (2005).

Ocean advection may also play a role in driving SST anomalies during boreal spring (which projects onto meridional gradient mode variations, described below). For example, Fig. 6 (bottom) shows energetic cyclonic eddies centered at 8ºN, e.g. between the mean latitudes of the North Equatorial Current and North Equatorial Countercurrent. (These are distinct from the anticyclonic TIWs discussed earlier, which are found further south; *c.f.*, Grodsky et al, 2005.) Fig. 6 (top) also shows a time series of the eddy heat flux $\rho c_p v'T'H_e$ across 8°N, 15-45°W, using the CLS altimetry and microwave SST, low passed at 15 days. H_e is an effective depth for the eddy heat transport, assumed in Fig. 6 to be 200m (subsurface observations would greatly improve this estimate). The flux reaches a maximum value of 27×10^6 W/m in March 1999 and has minima below -10×10^6 W/m during the late summers of 1998 and 2001. The eddy flux across 16°N (not shown) is far smaller, indicating that these eddies are associated with a net heat convergence/divergence in the region. An eddy flux of 20×10^6 W/m would correspond to 0.1 PW (1 PW=10^{14}W) of heat, or 30 W/m^2 in the area 8-15°N, 15-45°W. These are substantial values, comparable to the O(50 W/m^2) variations in net summertime heat gain from air-sea fluxes (Fig. 6, middle).

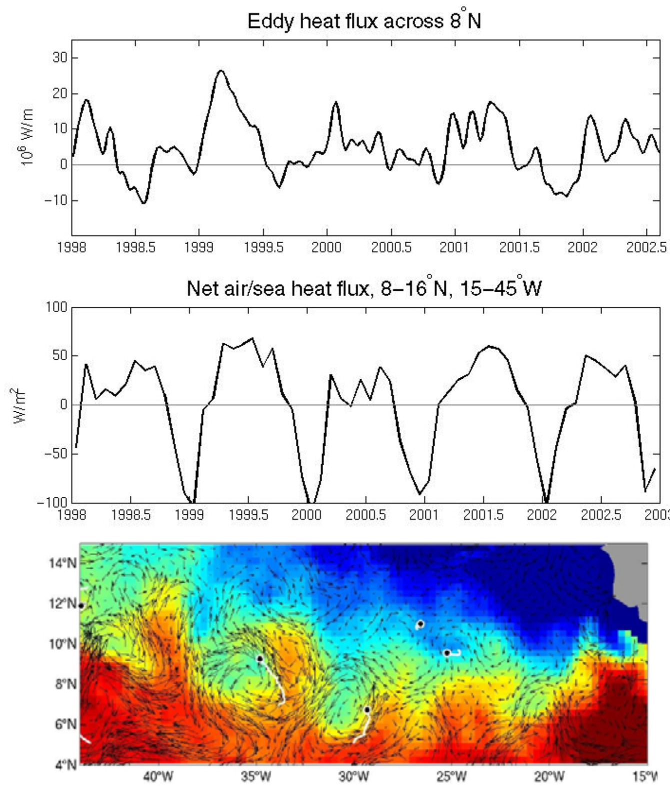

Fig. 6: Top: eddy heat fluxes across 8ºN from altimeter-derived geostrophic currents and microwave-observed SST. Middle: net heat flux for 8-15°N, 15-45°W from NCEP/NCAR Reanalysis version 2. Bottom: SST (shading) on 1 March 1999, from microwave observations. Currents (black arrows) are from AVISO altimetry (Le Traon *et al.*, 2001). Bullets with 10-day tails indicate the positions and previous trajectories of satellite-tracked surface drifters.

This region has suffered from few in-situ observations to calibrate such calculations. These calculations would be greatly improved by the addition of ATLAS moorings and deployments of drifters and profiling floats (which could be piggybacked onto mooring servicing cruises).

Lower frequency variations, discussed next, are often perturbations of the seasonal cycle. For example, the meridional gradient mode reflects (and impacts) the boreal spring pattern, while equatorial mode (a.k.a. "Atlantic Niño" or zonal mode) events reflect the summer pattern. In order to resolve lower frequency climate variations, the seasonal cycle and intraseasonal variations of atmospheric and oceanic processes must be well resolved and understood throughout the region.

Interannual to decadal variability

At timescales longer than the seasonal cycle, TA climate variability is dominated by decadal and interannual fluctuations governed by disparate physics (Carton *et al.*, 1996). The proposed region for a PIRATA extension is the northern center of action of the Meridional Gradient mode of TA climate variability. For example, Chang *et al*. (2001, their Fig.1) shows results of a simultaneous SVD analysis of SST, heat flux and wind stress anomalies, with the largest SST anomalies (>0.35ºC) at 15ºN, 15-30ºW. This mode can modulate the TA climate at decadal scales (Nobre and Shukla, 1996) and may be attributed to an ocean-atmosphere positive feedback (the "WES feedback") between anomalies of SST, wind stress and latent heat flux (Chang *et al.*, 1997). At decadal timescales, ocean advection of SST anomalies is a critical negative feedback for this loop (Seager *et al.*, 2001) and may act to decouple Tropical North Atlantic (TNA) and Tropical South Atlantic (TSA) SST variations (e.g., Houghton and Tourre, 1992; Enfield and Mayer, 1997). As noted later in this document, rainfall rates in much of the surrounding regions are affected by SST variability here (Nobre and Shukla, 1996; Hastenrath, 1984; Enfield, 1996; Enfield and Alfaro, 1999; Giannini *et al*., 2000; Giannini *et al.*, 2004).

In addition to internal dynamics, climate variations of the TNA region may be influenced by teleconnections to ENSO (e.g., Enfield and Mayer, 1997) and the North Atlantic Oscillation. There is little consensus at present regarding the significance of ENSO control of TNA SST variability, with some models (Czaja *et al*., 2002) showing a controlling role and others (Huang *et al*., 2004) indicating little significance. This discrepancy may be due to competing or cooperating ENSO and WES forcing of SST anomalies in the TNA region (Giannini et al., 2004). The NAO is associated with a tripole pattern of SST anomaly in the North Atlantic, with the southernmost lobe centered in the TNA region (*e.g.*, Fig. 1 of Seager *et al*., 2000). The overlap of this NAO pattern and the interhemispheric gradient mode pattern suggest that this region may be a critical pathway for coupling North and Tropical Atlantic climate variability (Chang *et al*., 2001). A recent study (Cassou *et al*., 2004) of long-term trends in the NAO suggested that warm tropical SST anomalies can force low NAO events, while the converse (cold SST forcing high NAO) is less efficient.

In the northern half of the TNA region, atmospheric circulation around the Azores High forces Ekman convergence north of ~15ºN. The resultant subduction occurs where the easterly trades drive evaporation. The confluence of densification from excess E-P and subduction is responsible for the formation of northern hemisphere Subtropical Underwater, SUW (Worthington, 1976). This region was the focus of the Subduction Experiment process study, during which WHOI deployed five moored buoys during June 1991-June 1993 overlapping with the proposed region for the PIRATA northeast extension. SUW takes part in the shallow overturning circulation of the subtropical cells; recent analysis (c.f. Zhang *et al*, 2003) indicates that the subducted water follows convoluted pathways before returning to the surface in the equatorial divergence. The convoluted pathways of these cells may imprint variations with timescales of decades on tropical Atlantic climate variability.

Improving tropical cyclone forecasting

The southern half of this region is the Main Development Region (MDR) of tropical cyclones (Fig. 7). Many major hurricanes that ultimately threaten the eastern United States begin as atmospheric easterly waves that propagate from the African continent. Once over the MDR in the band 10-20ºN, these waves are exposed to convective instability driven by the upper ocean's heat content. The resulting infusion of energy can result in closed cyclonic circulation and development from tropical depression to tropical storm and hurricane. These hurricanes are known as Cape Verde-type hurricanes, to distinguish them from storms forming further west, and they are often the most powerful storms to strike the US east coast. Prominent examples include Andrew (1992), Floyd (1999) and Ivan (2004).

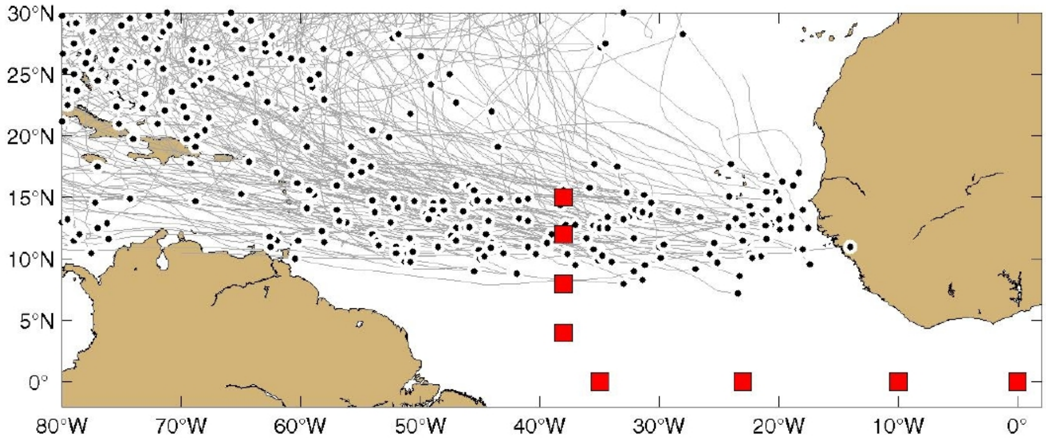

Fig.7: PIRATA backbone moorings (red squares) and trajectories of all tropical cyclones in the AOML/Hurricane Research Division's database (grey lines, 1980-2003), including their earliest known location (black points).

An average season has two Cape Verde hurricanes, but some years have up to five while others have none. There is profound uncertainty regarding the specific atmospheric/oceanic conditions that determine which of the atmospheric waves will develop into tropical cyclones and then hurricanes (on average, one of ten; J. Dunion, personal communication). Specifically, the quantitative effects of the Saharan Aerosol Layer (SAL), sea surface temperature (SST), upper layer oceanic heat content and atmospheric wind shear on this development are unknown.

Seasonal tropical storm and hurricane forecasts are generated annually and based primarily on statistical analyses of historical data that have resulted in predictors (e.g., ENSO index, Atlantic SST, Sahel rainfall, etc.). Recent empirical studies have demonstrated that tropical storm and hurricane activity in the Atlantic Ocean varies on decadal and multi-decadal time-scales and that this variability is correlated with sea-surface temperature anomalies in the MDR (e.g., Shapiro and Goldenberg, 1998). The SST signal in the MDR has been correlated with the North Atlantic Oscillation (NAO) on decadal time-scales. The multi-decadal signal indicates that an extended period of increased hurricane activity is to be expected. Other historical studies have also demonstrated spatial variability in storm formation areas and landfall locations on longer timescales.

Determining biases in air-sea flux products

Many studies have suggested that SST anomalies in this region are, to lowest order, driven by latent heat flux variations, particularly at the longest time scales (e.g., Carton *et al*., 1996). It is thus critical to accurately determine these fluxes in the TNA region. However, this area is frequently under cloud cover and aerosol cover associated with Saharan dust, which can introduce a bias in satellite-derived SST products. This bias can be dramatic at intra-seasonal scales, and Sahel dust concentrations demonstrate large interannual variations (Prospero and Lamb, 2003).

Several studies (c.f., Sun *et al*., 2003; Weill *et al.*, 2003; Yu *et al*., 2004) have demonstrated that a number of products contain systematic biases in their surface meteorology and air-sea turbulent heat fluxes when compared to in-situ observations. For example, Figure 3a shows a time series of latent, sensible and net shortwave heat flux at 23ºW on the equator. At this site, the NCEP/NCAR v.2 product systematically overestimates the magnitude of oceanic latent heat loss compared to observations from the PIRATA buoy. Averaged over the entire PIRATA backbone, most products overestimate the latent flux (Sun *et al*., 2003; also see Fig. 8a). Clearly there are large spatial variations in these biases, casting doubt upon corrections based on a constant coefficient (e.g., Grist and Josey, 2004).

To more clearly demonstrate spatial variations in the heat flux bias, Fig. 8b shows the spatially-varying differences between time-averaged latent and net shortwave heat fluxes from various buoy measurements and NCEP/NCAR Reanalysis Version 2. Buoy arrays include PIRATA, the WHOI subduction array deployed in the TNA region from June 1991 to June 1993 (*c.f.*, Moyer and Weller, 1997), and the WHOI Northwest Tropical Atlantic Station (NTAS) mooring (March 2001 –present). The COARE2.5b bulk flux algorithm was used to calculate turbulent fluxes from the buoy observations. (We note that Yu *et al*., 2004, have published a similar comparison for several products' latent and sensible fluxes; here we have added the NTAS data made public by Al Plueddemann.)

This comparison demonstrates that large, O(20 W/m^2), biases in NCEP latent heat can be found across the TNA region in the time-mean. Similar biases in time-varying ECMWF fields have recently been identified by Weill et al. (2003; c.f., their Fig. 10) who ascribe them to the too-smooth SST fields used in the operational meteorology model. Interannual variations in these biases from, e.g., varying aerosol concentrations are unexplored. Large differences in shortwave fluxes are also seen, but with a more complex spatial structure. The southeastern Subduction mooring measured less net shortwave flux, exacerbated by aerosol build-up on the pyranometer (Medovaya *et al.,* 2002). This problem can be ameliorated with proactive turnaround procedures and data processing for the proposed ATLAS buoys.

With the in-situ observations necessary to correct heat and freshwater flux products in the TNA region, future studies will be able to more accurately determine the physics governing meridional gradient mode variations. Other applications include the ability to calculate subduction rates from air-sea flux-driven calculation, permitting extended time series of subduction and overturning to be estimated for the northern hemisphere subtropical overturning cell (analogous to the subpolar calculation of Marsh, 2000).

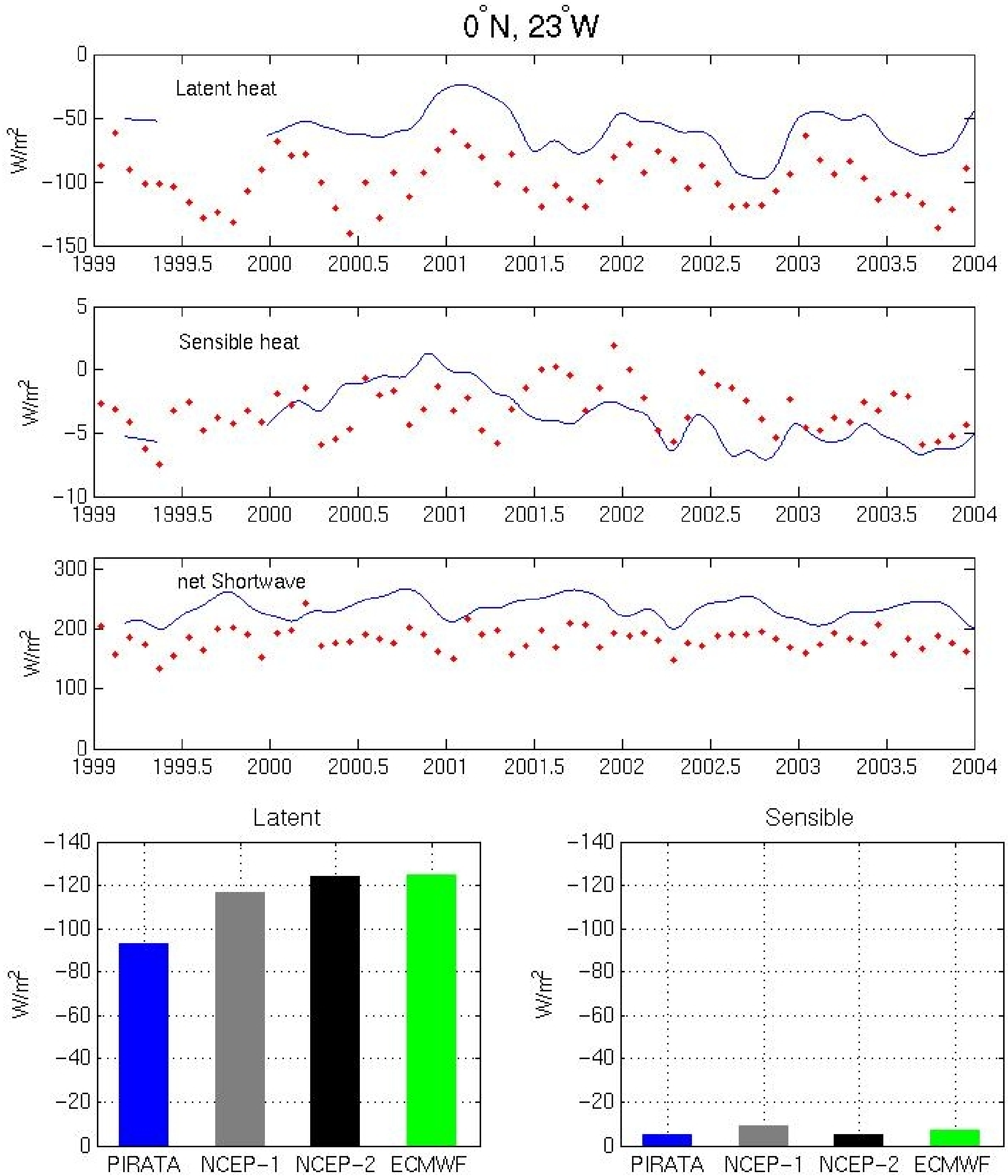

Fig. 8a: Top panels: Lowpassed time series of latent, sensible and net shortwave heat fluxes measured at the equatorial 23ºW PIRATA buoy (solid lines) and from NCEP/NCAR v.2 (red dots). Bottom panels: time-mean turbulent fluxes averaged over the PIRATA array (blue) and from three commonly used air-sea flux products (adapted from Sun *et al*., 2003).

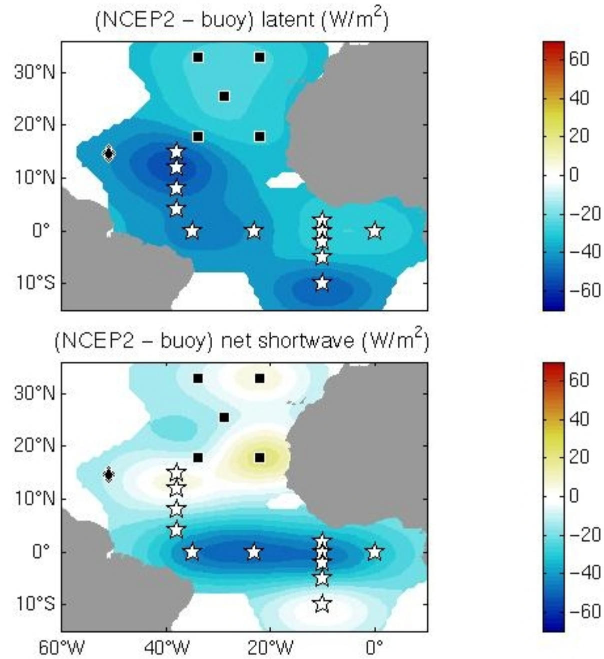

Fig. 8b: differences between NCEP/NCAR and in-situ measurements of latent (top) and net shortwave (bottom) heat fluxes. Time-mean differences were calculated over the period of the buoy measurements, and may mask seasonally varying biases in the NCEP product or observations. Locations of the PIRATA moorings (stars) and WHOI subduction (squares) and NTAS (diamond) moorings are indicated.

Rainfall prediction

Variations in rainfall over drought-prone northeastern Brazil are associated with the meridional gradient mode discussed earlier. Nobre and Shukla (1996) showed that droughts south of the equator are related to an early withdrawal of the ITCZ towards warm SST anomalies in the northeastern tropical Atlantic, and that droughts on one side of the equator are often preceded by anomalously wet years on the other side. Improving the predictions of these events may be improved by increased observations in the NTA center of action. NTA variations have also been shown to affect rainfall in the Caribbean and Central America (Hastenrath, 1984; Enfield, 1996; Enfield and Alfaro, 1999; Giannini *et al*., 2000).

Tropical Atlantic Variability (TAV) plays a major role in rainfall variations of western Africa, with profound social implications for countries such as Nigeria, Senegal, Guinea, Mali, Liberia and the Ivory Coast. The relationship between TAV (in particular, seasonal to decadal variations of the marine ITCZ location) and the West African Monsoon (WAM) is not well known, and is the major oceanographic component of the African Multidisciplinary Monsoon Analysis (AMMA) project. Understanding and improving seasonal predictions of TAV is necessary to improve our ability to predict the WAM. Data collected by moored buoys in the NTA, along with opportunistic atmospheric and oceanic observations (drifting buoys, floats, hydrography, etc.) made possible by the deployment and servicing cruises, will be valuable additions to AMMA.

II. Data Uses, Implementation and Resources

The absence of moorings in the eastern Atlantic introduces a data gap in the northeastern tropical Atlantic. Real-time data from four additional moorings will complement the existing equatorial mooring and provide real-time data for Numerical Weather Prediction (NWP) model initialization in the TNA region.

Mooring specifications

The NEE moorings will be "Next Generation" ATLAS moorings, measuring wind speed and direction, air temperature, relative humidity, precipitation, short wave radiation, sea surface temperature and conductivity, subsurface temperature at 11 depths, subsurface conductivity at five depths, and current speed and direction at one depth in the mixed layer (10m). The increased resolution (older ATLAS moorings have 10 subsurface temperature and three conductivity measurements) will improve resolving mixed layer depth variations and upper ocean baroclinic shear. The proximity of the sites to JASON crossover points down 22º40'W, combined with wind and direct mixed layer current measurements, will allow comparisons with typical Ekman-plus-geostrophic calculations of heat advection (e.e., Foltz *et al.*, 2003). Mixed layer current observations will also be provided in a region of surface divergence where satellite-tracked surface drifting buoys do not reside for long.

Thee ATLAS buoys will extend PIRATA northward along a nominal longitude of 23°W, at 4ºN, 11.5ºN and 20ºN. The 4ºN location will complement the 0, 23ºW PIRATA backbone mooring to help understand the dynamics governing off-equatorial SST evolution. It will also lie at the same latitude as the PIRATA backbone mooring at 38ºW, allowing for examination of off-equatorial zonal propagation of signals. The 11.5ºN location was chosen to lie immediately south of Cape Verde's EEZ, will be a primary site for observations of the ITCZ migration, and will lie at the same latitude as a mooring on 38ºW. The northern location (20ºN) is chosen to place a mooring in the MDR and to observe oceanic and atmospheric properties during southerly excursions of Sahel dust advection. We anticipate that all three will be significant in the overall context of TAV in the TNA region, and improving seasonal prediction of the WAM. One ATLAS buoy will extend the 38ºW PIRATA backbone northward into the MDR, at 20ºN, 38ºW.

We propose that one of the four moorings be a full flux mooring, to complement the other three (15ºN, 38ºW; 0, 23ºW; 10ºS, 10ºW) full flux PIRATA moorings. This mooring would include the addition of long wave radiation, barometric pressure, two additional subsurface conductivities, and two additional current meters. These observations will be invaluable for surface heat flux and the validation of flux estimates based on adapted parameterizations (Brut *et al.*, 2005). The most valuable location for a full-flux mooring is the site at 4ºN, 23ºW. Observations here will quantify the off-equatorial evolution of mixed layer heat anomalies by ocean advection (e.g., anomalous Ekman transport) and by air-sea heat flux anomalies. Observations at this location will greatly complement the 0, 23ºW mooring, where different processes are expected to govern the growth and decay of equatorial SST anomalies, and improve our understanding of variability governing the meridional SST gradient in the eastern marine ITCZ.

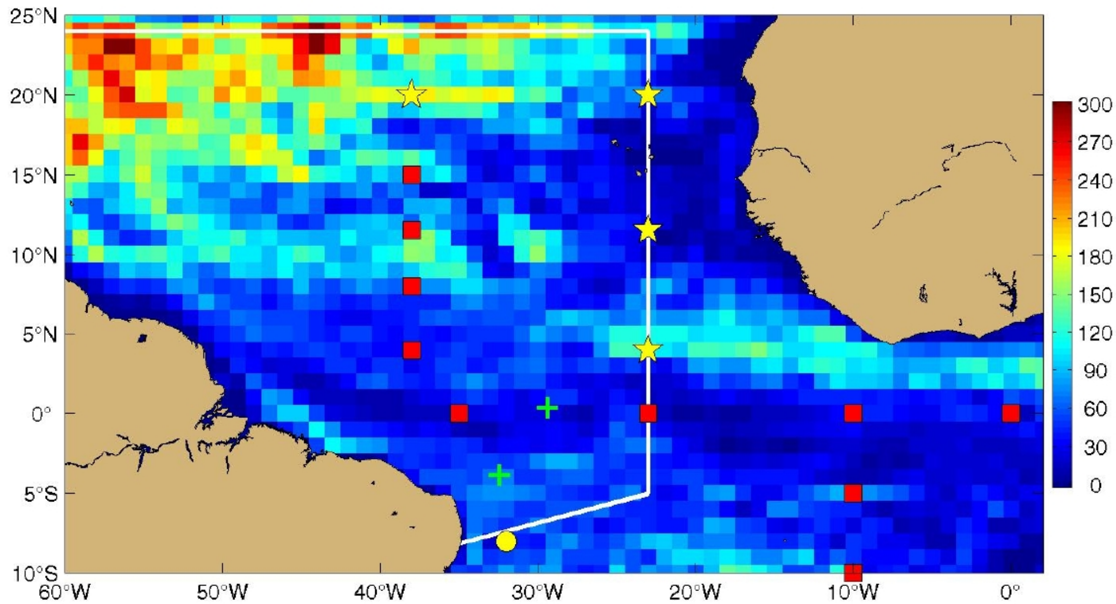

Fig. 9: the NTA region, showing part of the PIRATA backbone (red squares), the northernmost Southwest Extension mooring (yellow circle) and the proposed northeast extension (yellow stars). Leg 1 of the 2006 R/V *Ronald H. Brown* cruise is superimposed (white). Background shading is the historical density of surface drifter observations, in drifter-days per square degree.

Anticipated problems

Piracy and inadvertent damage by fishing activities has become a significant problem for PIRATA moorings in the Gulf of Guinea. Impacts on the NEE moorings will be initially assessed during the first year after the southernmost two moorings will be deployed (June 2006; see “Schedule of implementation” below). To ameliorate the accessibility to coastal boaters, the sites have been chosen to avoid the EEZs of African countries and the Cape Verde islands. In addition, any buoy in an upwelling region will experience enhanced biofouling, and radiometers will suffer from dust deposit. Repairs and servicing will be necessary, ideally supported by ship time at six-month intervals, and will require support from NOAA and any assistance we can receive from our international PIRATA partners.

Data management plan

Data collected by the moorings, along with associated shipboard data, will be freely available and distributed in real-time on the Global Telecommunication System (GTS). Near-time and delayed-mode quality-controlled data distribution will be consistent with the PIRATA data policy. The ATLAS buoy data from the four buoys will be offered alongside the other mooring data at PMEL’s data server.

Synergistic opportunities

In addition to the large-scale climate justifications noted earlier, we hope that the proposed buoys along 23°W will help improve our understanding of the dynamics and impacts of coastal upwelling along the Northwestern coast of Africa (Mauritania, Senegal), opening future prospects for international cooperation aimed at improving the climate impacts of oceanic processes on this region. Deployment and servicing cruises will provide opportunities to deploy drifters, floats, radiosondes, etc. in the NTA region. Oxygen sensors may potentially be added to the moorings; discussions have been initiated with R. Fine (Univ. Miami). Specific projects that will gain from this effort are:

AMMA: The African Multidisciplinary Monsoon Analyses is an internationally coordinated project directed at increased understanding of (1) the dynamics and thermodynamics of the West Africa Monsoon (WAM) and (2) the offshore projections of the WAM such as easterly waves.
The deployment of two moorings along 23W during SOP-I of AMMA will add to the database available to study the role of the ocean in monsoon dynamics. Both the sea surface and subsurface temperature data and surface atmospheric observations, provided in real-time by GTS, will be used by operational groups such as NCEP and ECMWF to forecast the monsoon evolution and by researchers to study the coupling between the ocean and monsoon. Dr. R.L. Molinari is a member of the AMMA International Scientific Committee working with other AMMA participants to coordinate the oceanographic activities during the experiment. In addition, cruises to deploy and service the proposed Northeast Extension will provide opportunities to collect additional observations valuable to AMMA. Such synergistic opportunities are being planned for R/V *Ronald H. Brown* cruises (see below).

ARGO: AOML is supported to be the Regional Argo Data Center for the South Atlantic. AOML is working with western African agencies to convene a meeting of operational and research scientists directed at providing methodologies to integrate and use data from different observing systems such as PIRATA, Argo and Voluntary Observing Ships. Operators of these networks will give presentations on the attributes of the data collected and how to use the information for operational and research purposes.

GDP: AOML houses the Drifter Operations Center of the Global Drifter Program; R. Lumpkin is the scientific director of AOML drifter activities. The TNA has been poorly sampled by drifters (Fig. 9). Deployment and servicing cruises will offer opportunities to reseed the area more frequently, and continuous time series from moored buoys will greatly supplement the overall dataset of SST and mixed layer current observations.

TACE: The eastern Tropical Atlantic and ITCZ has been highlighted as a particularly interesting region in the Tropical Atlantic Climate Experiment (TACE) white paper (Schott *et al*., 2005). In this document, a number of "observations needed for TACE" are identified including:

> *Improved surface flux fields:* Routine observations of SST in regions such as the ITCZ that are frequently under cloud cover suffer from biases, in particular as regards representation of intraseasonal variability. One requirement therefore is moored (ATLAS type) stations for flux calculations and calibration studies for improved applicability of satellite SST measurements in the eastern and ITCZ region.

MERCATOR: The Mercator project, which aims to develop an eddy resolving global data assimilation system, will benefit from in-situ observations in the NTA that can be assimilated into the high-resolution North Atlantic model and the ¼º global model. These data will improve the models' ability to provide nowcasts and forecasts for the Tropical Atlantic basin.

CORIOLIS: The Coriolis project aims to collect in-situ measurements necessary for operational oceanography, delivered by a data center supported by the seven major French oceanographic agencies. Data from these moorings would be made available for the Coriolis project, extending extensive in-situ observations into the NTA region.

OPERATIONAL METEOROLOGY: data on the GTS will be available for use in operational weather and climate forecasting models such as those run by ECMWF, INPE, NCEP and any other group or effort using the GTS stream. In this context, real-time in situ observations of SST may be extremely valuable, as remote observations may be biased by seasonally-modulated plumes of dust from the African continent. In the context of operational meteorology, the daily values of upper ocean observations provided by the buoys will be of particular value; during 2001—2005, the region was relatively poorly-sampled by Argo floats and drifting buoys. As noted earlier, the relative role of upper ocean heat vs., e.g., upper atmospheric shear in the development of easterly waves is unknown; improvements in high frequency operational fields of upper ocean heat content in the TNA region may plausibly improve the timeliness of marine storm warnings and assist in hurricane flight planning.

Data Uses

These ATLAS buoys will collect data in both the ocean and atmosphere boundary layers and the variability on both sides of the ITCZ during all the phases of the West African Monsoon, and will provide real-time data for use by the operational weather forecast community. Servicing the moorings will simultaneously provide opportunities for deploying drifter and float arrays and synoptic surveys of lower atmosphere and upper ocean conditions throughout the region. Because of large-scale divergence in the surface currents, the region is historically sparse for surface drifter observations (Fig. 9); additional deployments will allow future studies along the lines of Grodsky and Carton (2002) and Lumpkin and Garzoli (2005). When combined with the existing in situ networks, data to study climatic signals will become available (i.e., we assume that the moorings will be in place for at least five years to explore/demonstrate their utility to the operational weather and climate research communities).

Similarly, the resulting data will be used to initialize climate forecast models in a data sparse area where models have difficulty in simulating even mean conditions such as the equatorial SST gradient. Coupled with AMMA, TACE and other observations, increased understanding of the dynamics and thermodynamics of the oceanic and atmospheric will result. This increased understanding is needed to improve the presently inadequate forecast models of the region.

Servicing: Servicing will be performed by NOAA vessels and thus will not interfere with the maintenance of the PIRATA backbone. On the contrary, while occupying the 23ºW hydrographic line and deploying/maintaining the northeast extension, opportunities to service PIRATA backbone moorings (especially the 0, 23ºW full flux mooring) may be increased. We hope that, while performing their regular annual servicing of the PIRATA backbone, our partners might also be able to assist maintaining the NEE if necessary.

Schedule of implementation

2005: construction of first pair ATLAS buoys.
2006: deployment of initial two buoys (see below); construction of second pair.
2007: first turnaround cruise for initial pair; deployment of second pair.

<u>2006 schedule</u>: the first two moorings will be deployed from the NOAA R/V *Ronald H. Brown* in 2006 during leg one of the "AMMA 2006" cruise (R. Lumpkin, chief scientist, leg 1). The ship will depart Charleston, South Carolina on 24 May 2006 and arrive at 24ºN, 23ºW on or near 5 June to begin occupying CTD stations along 23ºW, 24ºN to 5ºS. The moorings will be deployed at 11.5ºN (10 June) and at 4ºN (14 June). This cruise will also be used as an opportunity to service the equatorial 23ºW mooring on or near 16 June. The cruise leg will terminate in Recife, Brazil on 19 June.

Source of funding

Funding for the costs of ATLAS mooring components, construction, deployment and recovery will be provided by the US National Oceanic and Atmospheric Administration (NOAA). Costs will be comparable on a per buoy basis to those required to maintain the PIRATA backbone array. NOAA has provided FY05 funds to construct the first two ATLAS moorings, to be deployed in 2006 as described above. Funding to include one full-flux mooring in this PIRATA extension, to be deployed in 2007, will be sought from NOAA's Office of Climate Observations (OCO). Ship time support for NOAA/AOML personnel during the 2006 R/V *Ronald H. Brown* cruise will be provided by NOAA/AOML.

Future support for deployments and servicing is under consideration by NOAA/OCO. Ship time aboard the R/V *Ronald H. Brown* has been requested. Recognizing the value of a six-month servicing schedule, we have requested two cruises of approximately 35 days each during 2007. The PIs of this project are committed to seeking funding in future years, in order to guarantee that this effort becomes a sustained part of the observing system. NOAA ship time requests are made approximately one year in advance of the proposed cruise and subsequent year servicing cruise requests will be made when appropriate.

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