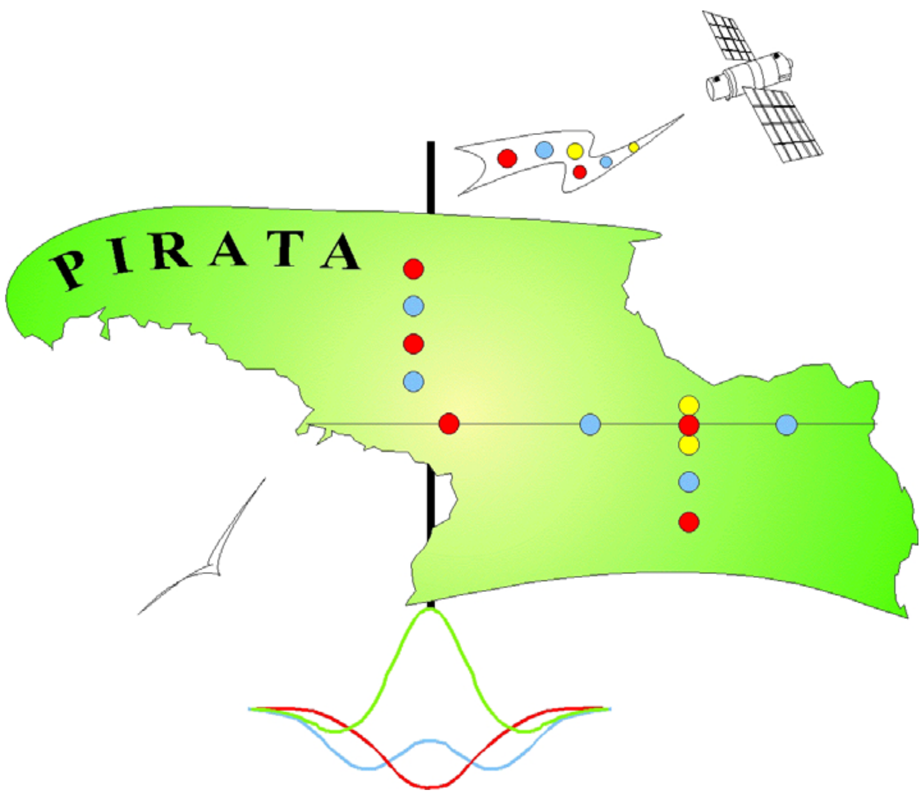
PIRATA

(*Pilot Research Moored Array in the Tropical Atlantic*)

ACCOMPLISHMENTS OF PIRATA: 1997-2005

STATUS AND PERSPECTIVES



By Bernard Bourlès, Antonio J. Busalacchi, Edmo Campos, Fabrice Hernandez, Rick Lumpkin, Michael J. McPhaden, Antonio Divino Moura, Paulo Nobre, Serge Planton, Jacques Servain and Janice Trotte

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Document prepared for a PIRATA review by CLIVAR -AIP - and OOPC

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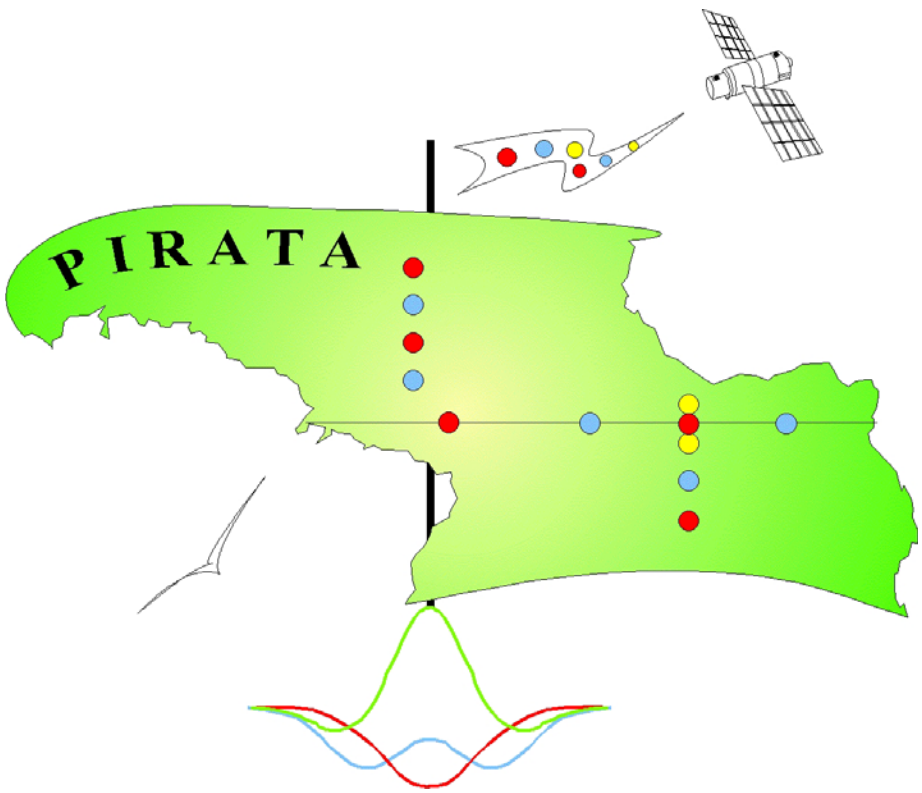

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PLAN

PREAMBLE

During the PIRATA-10 meeting in Fortaleza-Brazil (December 2004) Brazilian, French and U.S. partners affirmed their desire to continue to support PIRATA. During this meeting it was decided that the PIRATA program should be assessed by the major international programs that currently depend upon it, namely CLIVAR and GOOS, in order to determine whether they believe there is a sound scientific basis for its continuation as a permanent component of GOOS and GCOS. Protocols and procedures for this assessment were formalized at the PIRATA-11 meeting in Toulouse-France (October 2005). At this meeting, members of the CLIVAR-Atlantic Panel and the OOPC were invited to provide guidance for the program assessment. The contents and structure of this document represent the results of discussions at PIRATA-11 and the basis upon which to assess the case for continuation of the program.

PIRATA EXECUTIVE SUMMARY

Introduction to PIRATA

PIRATA (Pilot Research Moored Array in the Tropical Atlantic), is a multinational program (tripartite between Brazil, France and United States of America) established to monitor the ocean-atmosphere system in the Tropical Atlantic in order to improve our knowledge and understanding of the Ocean-Atmosphere variability in this particular world region. Actually, the variability of the ocean-atmosphere system in the Tropical Atlantic, from the seasonal to the multi-decade scale, strongly influences the regional hydro-climates (*ie* variations in rainfall) and, consequently, the economies of the adjacent continental regions (principally West Africa and North-East Brazil). PIRATA is motivated by fundamental scientific issues but also by the societal needs for improved prediction of the Tropical Atlantic climatic system (mostly the Intertropical Convergence Zone -ITCZ- displacement) and its impacts on surrounding countries. It has been observed that the long term variability of the Tropical Atlantic can be described principally into two modes: an equatorial mode associated principally with sea surface temperature (SST) anomalies in the eastern equatorial Atlantic (this mode is in some aspects analogous to the El Niño - Southern Oscillation mode over the equatorial Pacific), and a meridional mode, associated essentially with SST anomalies on either side of the ITCZ. Also, the north of the Tropical Atlantic is the main development region for hurricanes affecting the West Indies and the United States of America.

Thus, the more specific goals of the PIRATA program are:

- To improve the description of the seasonal to inter-annual variability in the surface layer (from the surface to a depth of 500 m) in the Tropical Atlantic;
- To improve our understanding of the relative contributions of surface fluxes and oceanic dynamics in the variability of the SST and the sub-surface heat content at seasonal and interannual scale;
- To provide a set of data that could be used to develop and improve the predictive models of the ocean-atmosphere coupled system.

In this way, PIRATA main objectives are to largely contribute or answer to the principal scientific questions in need of answers pertaining to tropical Atlantic Variability, that are:

- What are the forcing and coupling mechanisms between the atmospheric and oceanic components on the Tropical Atlantic? In particular, what are the SST's control mechanisms and what are those of heat fluxes?
- What are the influences of these heat fluxes (and of quantities of movement: the wind) on the variability (position and intensity) of the ITCZ and on the convective systems of the Gulf of Guinea (which is of interest to the West African monsoon), and on those of the western region of the basin (which is of interest to rainfall over South America and to hurricanes over West Indies)?
- What is the relationship between the variability of the SST and that of the heat content of the Tropical Atlantic, and what is its influence on the various variability modes in this region? In particular, what is the dynamic link between the north and south poles of the meridian variability mode of the Atlantic and between it and the equatorial mode?
- What are the teleconnections and their mechanisms between the variability in the Tropical Atlantic region and that in other regions (El Niño Southern Oscillation -ENSO-, North Atlantic Oscillation -NAO-, South Atlantic variability etc.)?

In addition to these scientific objectives, PIRATA also has important technical goals: to design, deploy, and maintain a pilot array of moored oceanic buoys and to collect and transmit via satellite in real time a set of oceanic and atmospheric data to monitor and study the upper ocean and atmosphere of the tropical Atlantic.

PIRATA is principally endorsed by CLIVAR (CLImatic VARiability and predictability), OOPC (Ocean Observations Panel for Climate) and GLOSS (Global Sea Level Observing System) international programs.

The PIRATA Programme

1) PIRATA implementation:

The PIRATA experimental program has developed from 1997 an array of meteo-oceanic (ATLAS type) buoys in the Atlantic, similar to the Tropical Atmosphere–Ocean (TAO) array used to study ENSO variability in the equatorial Pacific. PIRATA commits to provide high resolution time series measurements of surface heat and moisture fluxes, sea surface temperature and salinity, and subsurface temperature and salinity in the upper 500m. PIRATA so contributes to considerably increase the oceanic *in situ* data base in the Atlantic, that was mostly limited before PIRATA to, along with some synoptic oceanographic cruises, measurements from volunteer observing ship (VOS) programs, coastal and island tide gauge stations, a small number of drifting buoys and a few disparate time series of some parameters (e.g. wind, currents…) acquired during particular programs (*e.g.* FOCAL-SEQUAL in 1982-84).

PIRATA also includes two automatic meteorological stations at Fernando de Noronha Island and St. Peter & St. Paul Rocks, along with one currentmeter (ADCP) mooring at 23°W-0°N and a tide gauge at São Tome Island.

Furthermore, while each ATLAS buoy has to be changed at least once a year, a large number of measurements (temperature and salinity profiles, upper layer currents, sea surface temperature and salinity…) are carried out during all the PIRATA cruises, imposed for the ATLAS moorings monitoring. At now, a total of 23 cruises have been dedicated to PIRATA, done by Brazil (responsible for the maintenance of the 5 buoys located in the west of the basin, 8 from August 2005 due to the Southwest extension) and France (responsible for the maintenance of the 5 buoys located in the east and of the currentmeter mooring at 23°W-0°N).

Thus, the PIRATA program provides to the scientific community a free access to many data, summarized as follows:

1) Real time data:

- Meteo-oceanic measurements using ATLAS buoys: The ATLAS buoys are designed to measure surface meteorological variables (wind direction and speed, air temperature and humidity, rainfall and solar radiation) and hydrological sensors between the surface and 500m, namely 2 pressure sensors (at 300m and 500m), 11 temperature sensors (at the surface, 20m, 40m, 60m, 80m, 100m, 120m, 140m, 180m, 300m and 500m) and 4 conductivity sensors (at the surface, 20m, 40m and 120m). The mean daily observations are transmitted by satellite via Argos and are available in near real-time via Internet.

- Meteorological measurements from meteorological stations: data from the two automatic meteorological stations located at Fernando de Noronha Island and St. Peter & St. Paul Rocks, are transmitted by Brazil's SCD satellites at 3-hourly interval, and data available in near real time via internet.

- Sea level measurements: At São Tomé (6°30'E-0°N), a tide gauge station transmits daily via Argos hourly measurements of sea level, sea surface salinity and temperature along with atmospheric pressure.

2) Delayed data:

- Current-meter measurements from moorings: Since late 2001, a mooring located at 23°W-0°N ATLAS is equipped with an ADCP (Acoustic Doppler Current Profiler) which continuously measures the two horizontal components of the current, from the surface to approximately 130m. The *in situ* measurements are available at a rate of one measurement every 4m from a depth of 16m.

- Oceanographic measurements obtained from ships: During each oceanographic campaign dedicated to PIRATA, meteo-oceanic measurements are carried out, which are principally : Current measurements (from 0 to 700m max.) using VM-ADCP acoustic Doppler current profilers; Surface temperature and salinity measurements using a thermosalinograph; Meteorological and navigational measurements using data acquisition units; Hydrological measurements with CTD profiles (continuous pressure, temperature and salinity measurements between the surface and 500m or 1000m); Temperature measurements between the surface and approximately 800m with XBT probes.

2) Scientific contribution:

According to the main initial scientific goals of PIRATA, the number of studies (and papers) done in the framework of, or using data obtained thanks to, PIRATA indicates to what extend it is clear that PIRATA largely contributes and answers to the comprehension of the climate system in the Tropical Atlantic.

Thus, PIRATA contributes to:

a) Provide an improved description of the seasonal-to-interannual variability in the upper ocean and at the air-sea interface:

- According to the state of the art knowledge accumulated during the last decades PIRATA was then established with the early purpose to provide a description of the two main (meridional and equatorial) modes of climate variability in the tropical Atlantic. Thus, PIRATA first allows increasing our description and interpretation on the meridional and equatorial modes of variability.

- PIRATA is providing data to validate and to initialize models of air-sea interaction in the Tropical Atlantic. The PIRATA buoy data are extensively used by both academic and operational communities to validate satellite based surface flux estimates.

- PIRATA data, along with data from PIRATA dedicated yearly cruises (ADCP currents along the same meridional sections, namely 35/38°W and 10°W), allow studies focusing on equatorial currents and equatorial processes.

b) Estimate the relative contributions of the different components of the surface heat flux and ocean dynamics to the seasonal and interannual variations of SST;

c) The development and improvement of predictive models of the coupled Atlantic climate system:

- Ocean state estimation: Over the time period that PIRATA buoys have been deployed, ocean state estimation has progressed from a research activity to the operational generation of ocean products initiated under the framework of GODAE. For many years, PIRATA has been a major source of tropical Atlantic observations to research assimilation schemes for the global ocean. The French MERCATOR operational oceanography project is routinely using PIRATA data processed in real time. Such product generation of operational oceanography for the tropical Atlantic is now possible because the oceanic data from the Atlas buoys are made available in near real-time.

- Forecasting:

i) Weather: the surface meteorological fields from the PIRATA Atlas buoys are assimilated in near real-time into predictive atmospheric models. PIRATA data have significant potential for improving the initial analysis of weather forecasting in the region.

ii) Seasonal Climate Forecasts: PIRATA data are used in operational seasonal forecasts via data assimilated into oceanic models that provide ocean initial conditions using coupled ocean-atmosphere models.

d) Unanticipated advances: PIRATA contributes to advances in areas not fully anticipated at the start of the program. For example, utility and accuracy of rain and salinity sensors from PIRATA Atlas buoys are now well established, and it is now proven that such data are of fundamental importance for the mixed layer heat budget and air-sea exchanges. In the same way, it was not appreciated how strongly the pull from the operational community would be for PIRATA data. The many activities that demand these data for development of ocean assimilation systems and for constraining ocean model analysis in the tropical Atlantic attest to the value that the operational community has assigned to PIRATA data. The ready availability of the data via the GTS and the web in real-time have helped to create this demand, which continues to grow as operational oceanography itself develops and matures.

Furthermore, mostly thanks to the dedicated cruises, PIRATA also contributes to training to implicate scientists from developing African countries in oceanographic and climate research.

Finally, PIRATA is also a contribution for the realization of other programs, for which PIRATA dedicated cruises and Atlas buoys are opportunities for buoys, drifters, XBT probes or profilers deployments (*e.g.* for CLIVAR, ARGO and CORIOLIS), or sea water samplings (*e.g.* for IGBP/SOLAS programs), or biogeochemical measurements. PIRATA also contributes, through the data transmission in real-time from vessels during dedicated cruises, to GODAE and MERCATOR projects.

3) Extensions and prospective:

PIRATA encourages consideration of scientifically sound pilot expansion projects that build upon the original PIRATA array. Extensions are supposed to contribute to fill out the PIRATA array in order to provide better definition of the two key climate modes of variability in the Tropical Atlantic Ocean. After a scientific evaluation, extensions of the array have been initiated, with more planned and funded, greatly magnifying the scope of scientific issues and operational value addressed by PIRATA.

The PIRATA Southwest Extension (3 buoys off Brazil), supported by Brazil, was inaugurated in August 2005. This extension will notably allow monitoring the South Equatorial Current bifurcation into the Brazilian Current and the Northern Brazilian Current, and the interactions between the South West tropical Atlantic SSTs and the South Atlantic Convergence Zone.

The PIRATA Southeast Extension (1 buoy off Congo and Angola), supported by South Africa, will be implemented in boreal summer 2006. Observations in this region will be used to monitor the Benguela Niños, and the potential linkage between the equatorial mode and the Benguela Niños.

The PIRATA Northeast extension (4 buoys along 20°N and 23°W), supported by USA and still under evaluation process, will however begin to be implemented in summer 2006. Observations in this region will allow capturing processes impacting interannual variations in the seasonal migration of the eastern ITCZ.

Also, NOAA has funded enhancement of three sites (15°N-38°W; 0°N-23°W and 10S°-10°W) for full surface flux capability, as part of the OceanSITES program.

Ultimately, the PIRATA array will transition to an operational, international, sustained observing system for weather and climate prediction spanning the widely varying dynamical regimes of the tropical and low-latitude subtropical Atlantic Ocean and providing invaluable opportunities for deployment of Argo floats, surface drifting buoys, and platforms for conducting process studies and future research efforts.

4) Program Management and Support:

An International Scientific Steering Committee (SSC) heads the PIRATA Program. Presently, three scientists of the three countries involved in, *i.e.* Brazil, France and USA compose this PIRATA-SSC. The current SSC composition is:

- From Brazil: Antonio Divino Moura (INMET, Chair), Paulo Nobre (INPE) & Edmo Campos (USP);
- From France: Bernard Bourlès (IRD, Co-Chair), Serge Planton (Météo-France) & Fabrice Hernandez (IRD);
- From USA: Rick Lumpkin (NOAA, Co-Chair), Antonio Busalacchi (SSIC) & Michael McPhaden (NOAA).

A PIRATA Resources Board (PRB) was set up in 1999 in order to meet the objectives of the undertakings of each of the principal institutes that are partners in the PIRATA program, and to ensure that the program would be fully supported by the three countries. The present composition of the PIRATA PRB is Mike Johnson (Chair , NOAA-USA), Jacques Boulègue (IRD, France), Joël Poitevin (Météo-France, France) and Maria Assunção F. Silva Dias (INPE, Brazil).

Final comments:

After a "Pilot phase" from 1997 to 2001, during which the array has been fully implemented, institutions in the three supporting countries decided to extend the program for a 5-year "Consolidation phase" (2001-2005) to allow for a meaningful demonstration that the data would contribute significantly to both scientific research and operational applications.

At now, in 2006, PIRATA is at a key point of its evolution, and conditions of its continuation have to be defined by different parties, with the endorsement of international CLIVAR and OOPC programs. The PIRATA continuation till 2008 has been decided by the supporting Brazilian, French and US organisms, in the same conditions as until now.

Actually, it has to be evaluated if there is a sound scientific basis for the PIRATA continuation as a permanent component of GOOS and GCOS. Anyway, the fixed time series measurements from the PIRATA moorings together with observations from the regular deployment and service cruises has since become the backbone of the tropical Atlantic observing system. The addition of ARGO floats has served to complement the unique, high temporal sampling and limited spatial extent of the original set of PIRATA buoys. The federation of complementary observational platforms provided thanks to PIRATA has become, *de facto*, the Tropical Atlantic Ocean Observing System. From its beginning, PIRATA has also cooperated and communicated on a frequent basis with the CLIVAR Atlantic Panel, OOPC, GOOS, GCOS, GLOSS, GEOSS, JCOMM, and CORIOLIS. Actually, through the concerted efforts of those participating nations and institutions, PIRATA has become a worldwide recognized GOOS and GCOS pilot-project in the region. By way of membership in the PIRATA-SSC, organizations such as INPE, IRD, NOAA, CPTEC, FUNCEME, Météo-France, CNRS, and MERCATOR/GODAE have all been regularly informed and have had input to the direction of PIRATA. In addition, the PIRATA-SSC has been actively involved in the development of new programs as, *e.g.*, TACE and AMMA. With the onset of AMMA in 2001, more than 25 institutions in Africa, Europe, and the United States developed a plan to improve prediction of the West African Monsoon and Atlantic hurricanes. AMMA has been endorsed by CLIVAR and the Global Energy and Water Cycle Experiment (GEWEX). AMMA and TACE require long-term observations in the Atlantic Ocean through at least 2010, and PIRATA is obviously for these programs a key observation system and a closely associated program.

Contacts

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ACCOMPLISHMENTS OF PIRATA: 1997-2005

STATUS AND PERSPECTIVES

A. Scientific Background and PIRATA Objectives

The variability of the ocean-atmosphere system in the Tropical Atlantic, from the seasonal to the multi-decadal scale, strongly influences the regional hydro-climates (*ie* variations in rainfall) and, consequently, the economies of the adjacent continental regions (particularly West Africa and North-East Brazil). Over the last few decades, it has been observed that the long term variability of the Tropical Atlantic could be broken down principally into two modes: 1) an equatorial mode associated with the individual dynamics of the equatorial regions (in some aspects similar to the El Niño - Southern Oscillation -ENSO- mode over the equatorial Pacific), 2) a meridional mode associated essentially with the sea surface temperature (SST) anomalies of the ocean on either side of the inter-tropical convergence zone (ITCZ). This latter mode is often described as a meridional gradient of SST anomalies, and is sometimes called, though improperly, as the "dipole mode". Furthermore, there are numerous oscillations, still not fully identified inside the basin, which make it difficult to identify, much less predict, these two types of variability and their possible relationship.

Elsewhere, the north of the Tropical Atlantic (towards the latitude of Senegal) is the seat of the formation of the tropical depressions that cause the cyclones that may affect the regions of the West Indies and the south-eastern United States. The advective role of the ocean currents in this area of cyclogenesis is still ill-defined. We also know that there is a link between the oceanic and atmospheric circulations of the tropical regions and those of the temperate zones of the Atlantic Ocean, as well as a link with the tropical oscillations in the Pacific Ocean associated with the ENSO mode.

Among the principal scientific questions in need of answers pertaining to tropical Atlantic Variability are:

1) What are the forcing and coupling mechanisms between the atmospheric and oceanic components on the Tropical Atlantic? In particular, what are the SST's control mechanisms and what are those of heat flux?
2) What are the influences of these heat fluxes (and of quantities of movement: the wind) on the variability (position and intensity) of the ITCZ and on the convective systems of the Gulf of Guinea (which is of interest to the West African monsoon), and on those of the western region of the basin (which is of interest to rainfall over South America)?
3) What is the relationship between the variability of the SST and that of the heat content of the Tropical Atlantic, and what is its influence on the various variability modes in this region? In particular, what is the dynamic link between the north and south poles of the meridional variability mode of the Atlantic and between this mode and the equatorial mode?
4) What are the teleconnections and their mechanisms between the variability in the Tropical Atlantic region and that in other regions (ENSO, North Atlantic Oscillation, South Atlantic variability etc.)?
5) To what extent is such climate variability predictable?

The oceanic in situ data base in the Atlantic, before PIRATA (Pilot Research Moored Array in the Tropical Atlantic), derived primarily from volunteer observing ship (VOS) programs, coastal and island tide gauge stations, and a small number of drifting buoys. VOS measurements of surface meteorology and subsurface temperatures are concentrated mainly along well-traveled shipping routes, in between which there are large data gaps. Time series measurements of winds, upper-ocean temperatures, and other datasets collected during the 1982-84 Français- Océan-Climat Atlantique Equatorial / The Seasonal Response of the Equatorial Atlantic (FOCAL/ SEQUAL) experiment (Weisberg and Weingartner 1986; Houghton and Colin 1986; Katz 1987) indicated a broad spectrum of high-frequency variability that would be aliased into infrequent quasi-monthly shipboard surveys. Tide gauge stations provide highly resolved time series of sea level data but are relatively few in number and not optimally located for climate studies. Drifting buoys, which provide estimates of SST and mixed layer velocity, are concentrated mainly north of 20°N and therefore supply little data in critical regions near and south of the equator. Satellite estimates of some key variables (surface winds, SST, and sea level) are available over the whole Atlantic basin with more uniform spatial and temporal resolution. Indeed, the satellites are valuable tools in providing spatial coherence and cover of surface properties, but do not deliver direct measurements of subsurface thermal structure in the ocean, which is essential for understanding processes affecting the evolution of SST.

Therefore, in view of limitations in the database for tropical Atlantic climate studies, PIRATA has developed in the Atlantic a program of moored measurements similar to the Tropical Atmosphere–Ocean (TAO) array used to study ENSO variability in the equatorial Pacific. PIRATA commits to provide high resolution time series measurements of surface heat and moisture fluxes, sea surface temperature and salinity, and subsurface temperature and salinity in the upper 500 m.

In addition to the scientific objectives listed below, PIRATA also has important technical goals: to design, deploy, and maintain a pilot array of moored oceanic buoys, similar to the TAO array used during the Tropical Ocean Global Atmosphere (TOGA) program in the tropical Pacific, and to collect and transmit via satellite in real time a set of oceanic and atmospheric data to monitor and study the upper ocean and atmosphere of the tropical Atlantic.

Within this framework, the more specific scientific objectives of the PIRATA program are as follows (Servain et al., 1998):

- To improve the description of the seasonal to inter-annual variability in the surface layer (from the surface to a depth of 500 m) in the Tropical Atlantic;
- To improve our understanding of the relative contributions of surface fluxes and oceanic dynamics in the variability of the SST and the sub-surface heat content at seasonal and interannual scale;
- To provide a set of data that could be used to develop and improve the predictive models of the ocean-atmosphere coupled system.

It is these original objectives that form the basis for the assessment of the present and future of the PIRATA array.

B. PIRATA accomplishments:

1. PIRATA specifications, technology and performance

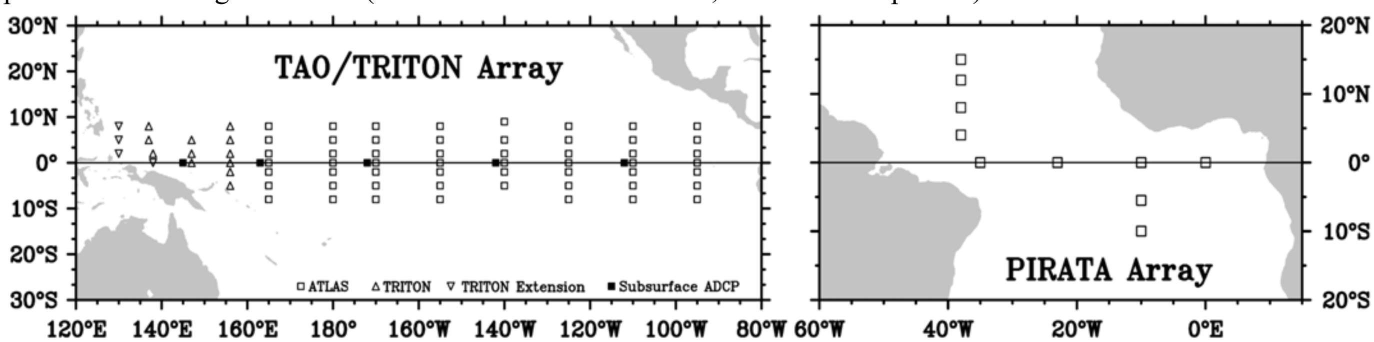
a) PIRATA general presentation:

The PIRATA experimental program was set up in 1997 in the tropical Atlantic Ocean (Servain et al., 1998). It developed as part of the CLImatic VARiability and predictability (CLIVAR) international program and involves teams of scientists from three countries: France, Brazil and the USA. It consists mainly, and initially, of maintaining a network of 12 meteorological-oceanographic measurement buoys anchored at positions representative of the main climatic variability modes in the Tropical Atlantic. The program was initially designed for a "Pilot phase" from 1997 to 2001 during which the array would be fully implemented and various technical and organizational challenges addresses. With the success of the pilot phase, institutions in the three supporting countries decided extend the program for a 5-year "Consolidation phase" (2001-2005) to allow for a meaningful demonstration that the data would contribute significantly to both scientific research and operational applications.

PIRATA also includes two automatic meteorological stations at Fernando de Noronha Island and St. Peter & St. Paul Rocks, along with one currentmeter (ADCP) mooring at 23°W-0°N and a tide gauge at São Tome Island. This network is supported, in particular, by the CLIVAR, Ocean Observations Panel for Climate (OOPC) and Global Sea Level Observing System (GLOSS) international programs.

PIRATA can be considered as being the Atlantic component of a group of networks for observing meteo-oceanic conditions throughout the tropics (the Tropical Moored Buoy network), established from the 1980's in the Pacific with the TAO/TRITON program, developed by the USA (NOAA/PMEL) and Japan (JAMSTEC), with a contribution from the IRD (see site http://www.pmel.noaa.gov/tao/index.shtml), (a presentation of the three networks, but with the PIRATA SWE still not plotted, can be found on the CLIVAR Global Synthesis and Observation Panel -CGSOP- site, at the following address: http://www.clivar.org/organization/gsop/implementation/GSOP_1/reports/GSOP_TIP_2004.pdf).

The development of a network of ATLAS buoys in the Indian Ocean is proposed and already being installed by NOAA, in collaboration with Japan, Australia and India. The Pacific and Atlantic networks are presented in the figures below (PIRATA network until 2005, SWE still not plotted).



The system of ATLAS buoys of the PIRATA network is made operational by the daily transmission of data by satellite (Argos system), followed by real-time access on the internet and on the Global Telecommunication System (GTS). The five buoys maintained by Brazil also transmit data via the Brazilian Data Collection Satellites (SCD family and CBERS). The data are transmitted to INPE's site in Brazil, decoded, and made immediately available in CPTEC/INPE's home page. In addition to a purely scientific use associated with the study of the climatic conditions variability in the Tropical Atlantic, the PIRATA observations are used for near real-time assimilation in French, European, Brazilian and US atmospheric models, and in the MERCATOR operational ocean forecast system in France. The data also contribute to establishing, improving or validating the initial meteo-oceanic conditions required for numerical coupled models used for global climatic forecasts at the seasonal scale.

A PIRATA Resources Board (PRB) was formed in 1999 in order to meet the objectives of the undertakings (financial, human, ship resources …) of each of the principal institutes that are partners in the PIRATA Program. An International Scientific Steering Committee (SSC) heads the PIRATA Program. Presently, three scientists of the three countries involved in, *i.e.* Brazil, France and USA compose this PIRATA-SSC. The historical compositions of the PIRATA-PRB and PIRATA-SSC are given in Appendix 1.

A Memorandum of Understanding (MoU) was officially signed in August 2001 by the representatives of these various partners. This MoU commits the various partner institutes throughout the consolidation phase of the PIRATA program (2001-2006). Key provisions of this MoU commit the U.S. to supply ATLAS mooring equipment and technical support, while institutions in France and Brazil are committed to provide ship time and logistics support. The text of the MoU is given in Appendix 2.

Meetings are regularly organized by the PIRATA PRB and SSC, where all scientists who feel concerned by PIRATA are invited to attend and to present their works. A list of the PIRATA meetings is given in Appendix 3.

During a meeting of the PIRATA SSC (PIRATA-10) held in December 2004 at Fortaleza (Brazil), the various main partners of PIRATA (INPE, DHN, IRD, Météo-France and NOAA) affirmed their intention to continue to support the program. In addition NOAA undertook to finance the buoys in 2006 to give more time to finalize details about the continuation of the project. The Memorandum of Understanding (MoU) signed by the partner bodies in 2001, which expired in September 2004, was extended in its current form for a further two years by the same partners during the PIRATA-10 meeting. During the following meeting of the PIRATA-SSC (PIRATA-11) held in October 2005 at Toulouse (France), the guidelines and objectives of a PIRATA Review have been agreed between the PIRATA-SSC and representatives of CLIVAR-Atlantic and OOPC. The present document is the response to the call for such a review.

b) Measurement sites and measured parameters:

1. Meteo-oceanic measurements using ATLAS buoys:

Based on the historical understanding of climate variability in the region, the specific configuration of the original PIRATA array was chosen to provide measurements related to the two main modes of climatic variability in the tropical Atlantic basin, i.e., the equatorial mode and the meridional mode (also called “dipole mode”). More information on the original justification for PIRATA can be found in Servain et al., 1998. Along the equator, the array extends from the western Atlantic warm pool where the wind forcing is high and the oceanic thermocline is deep, to the cold tongue region in the eastern basin (Gulf of Guinea) where the upwelling is strong and the thermocline is shallow. Then, four ATLAS moorings were placed along the equator at 35°W, 23°W, 10°W and 0°E for monitoring the eastward propagation of equatorial Kelvin waves, while two moorings at 2°N and 2°S along the 10°W meridian line where installed to complete the description of the equatorial wave dynamics. As for monitoring the meridional mode, two branches of ATLAS moorings were placed along the 38°W line at 15°N, 12°N, 7°N and 4°N latitudes, and along the 10°W at 6°S and 10°S latitudes. These two meridional lines cover the regions of higher SST variability associated with the “SST dipole”, with the northwestern meridional line cutting across the ITCZ during most the year.

France, via the PIRATA “Observatoire de la Recherche pour l’Environnement” (ORE), is operationally responsible for the 5 ATLAS buoys located on longitudes 23°W, 10°W and 0°E, while Brazil is responsible for the 5 moorings located in the west. Initially, two additional buoys were planed to be maintained around 10°W-2°N and 10°S-2°S. Deployed in 1998, and rapidly vandalized, these two last buoys were abandoned in 1999 and dropped from the original array at the end of the “Pilot Phase” of the PIRATA Program (2001). More details about the growth of the array with time can be found in Appendix 4.

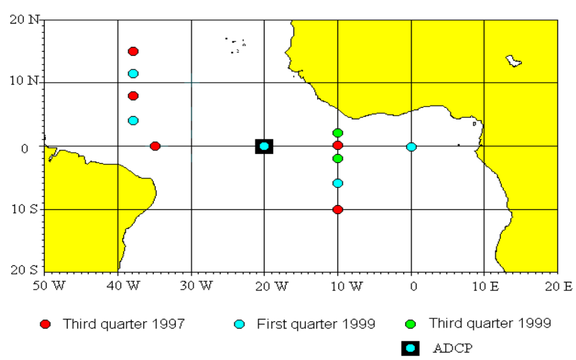


Figure 1: Initial (1997-2004) layout of the PIRATA network. Brazil maintains the 5 ATLAS sites west of 30°W.
France maintains the 5 other ATLAS sites and the ADCP mooring site at 0°N-23°W (initially planed at 20°W as located on the map). The two buoys at 2°N and 2°S along 10°W were deployed only once (not shown on the map).

The ATLAS buoys are designed to measure surface meteorological variables (wind direction and speed, air temperature and humidity, rainfall and solar radiation) and hydrological sensors between the surface and 500m, namely 2 pressure sensors (at 300m and 500m), 11 temperature sensors (at the surface, 20m, 40m, 60m, 80m, 100m, 120m, 140m, 180m, 300m and 500m) and 4 conductivity sensors, enabling the salinity to be calculated (at the surface, 20m, 40m and 120m). The mean daily observations are transmitted by satellite via Service Argos and are available in near real-time on the Internet. Data are also sent through the Global Telecommunications System (GTS) by Argos for real-time distributions to operational centers. The measurements carried out at high frequency (from 1 minute to 1 hour, depending on the parameters) are stored internally and recovered during maintenance operations before being processed, calibrated and made available to the community.

2. Meteorological measurements from meteorological stations:

PIRATA also includes two automatic meteorological stations at Fernando de Noronha Island and St. Peter & St. Paul Rocks, serviced by Brazil. Data collection for both island stations is done with Brazil's SCD satellites at 3-hourly interval, and data available in near real time via internet.

Although not directly part of PIRATA, another meteorological station has been installed at São Tomé Island (island located in the Gulf of Guinea at 6°30'E-0°N) in the framework of EGEE/AMMA, and constitutes an eastern continuation of PIRATA meteorological measurements along the equator. Data are transmitted in real time at the IRD Center of Brest (France), and should be available through PIRATA in a close future.

3. Current-meter measurements from moorings:

In order to monitor the circulation in the surface layer and mixing, the PIRATA network also includes since the end of 2001 a current-meter mooring in the immediate vicinity of the 23°W-0°N ATLAS site. This mooring is equipped with an ADCP (Acoustic Doppler Current Profiler) which continuously measures the two horizontal components of the current, from the surface to approximately 100m. The *in situ* measurements are available at a rate of one measurement every 4m from 16m depth.

From late 2001 to boreal spring 2005, France (under the responsibility of LODYC/LOCEAN-Paris) also maintained a current-meter mooring at 10°W-0°N, close to the ATLAS buoy, in the framework of an associated program dedicated to the study of equatorial jets and of the French PIRATA ORE.

It must be noted that these current-meter data are not transmitted in real-time by satellite. The raw data are only retrieved during the PIRATA French dedicated cruises, *i.e.* about yearly, and are available for the scientific community after calibration and pre-processing.

4. Oceanographic measurements obtained from ships:

The servicing of the PIRATA array implies dedicated cruises that, in agreement with the MoU commitments, should be at least carried out yearly. A list of all the PIRATA cruises is provided in Appendix 5.

During each Brazilian and French oceanographic campaign dedicated to PIRATA, meteo-oceanic measurements and additional operations are carried out, either within the framework of the PIRATA Program, or in collaboration with other associated programs (*e.g.* EQUALANT in 1999-2000, EGEE/AMMA from 2003) or dedicated to operational oceanography (CORIOLIS and MERCATOR, French components of the ARGO and GODAE international programs respectively). These additional measurements are detailed in Appendix 6.

5. Sea level measurements:

The stations located in the oceanic islands represent strategic observatory points that are essential for altimetry and satellite calibration measurements.

At São Tomé (6°30'E-0°N), a tide gauge station was installed by ORSTOM (now IRD) as early as 1989 to meet the requirements of climatic research programs (TOGA, WOCE, CLIVAR). This tide gauge, linked to an Argos beacon for real-time data transmission, is an integral part of a global network for observing the Tropical Atlantic and, since 1997, is integrated into the international PIRATA network. It was positioned by GPS for the international GLOSS program (http://www.pol.ac.uk/psmsl/programmes/gloss.info.html) in December 2002.

The measurements obtained from this tide gauge are: level -height or pressure-, temperature and salinity of the sea, and atmospheric pressure. The measurements are taken hourly and transmitted daily via Argos.

In Brazil, the installation of a tide gauge, geodesically referenced, is planed at St. Peter & St. Paul Rocks in 2006, and should work in an operational way.

c) Data acquisition and calibration protocols:

Concerning the ATLAS buoys, PIRATA mooring hardware, sensors types, calibration procedures, temporal sampling and resolution, data processing, accuracy standards, and data transmission and dissemination protocols are identical to those of ATLAS moorings in the Pacific TAO/TRITON array. An extensive description of technical details can be found on the TAO web pages maintained by PMEL (http://www.pmel.noaa.gov/tao/). For the purposes of this report, the most important statement to make is that ATLAS mooring technology and protocols have been developed over a period 25 years to ensure the highest quality data for climate research and operational applications.

A brief summary of some salient data issues is found in Appendix 7, along with the periods of availability of some of these data sets.

d) PIRATA cruises and related issues

France and Brazil committed to service the ATLAS buoy moorings at least once a year. Due to vessel time availability and cost, each buoy is replaced once a year in mean. From 1997 to December 2005, France carried out 14 cruises and Brazil 8 cruises for PIRATA buoys maintenance. Details on the cruises are provided in Annex 7. To date, more than 400 days at sea have been dedicated to PIRATA from 1997 to 2005.

In France, the problems encountered in order to maintain the 5 ATLAS buoys of the PIRATA network under its responsibility are of two orders: 1) problems associated with vandalism in the Gulf of Guinea, and 2) difficulties to obtain vessel time. In fact, these two problems put into question maintenance, in its current configuration, of the center and eastern parts of the original PIRATA array. However, in view of the extension of the MoU until 2006, the continuation of the current network until the end of 2006 will be ensured (see chapter C for more details).

In Brazil, vandalism has not been a significant problem for the five buoys of the western portion of the PIRATA backbone from 1998. However, we cannot yet state if this is an issue for the three buoys recently moored (August 2005) for the PIRATA SW extension (see below). The main problem encountered in Brazil for the PIRATA cruises has been associated with securing ship time with the only oceanographic research vessel, Antares, available for ATLAS type mooring in this country. Nevertheless, DHN and INPE are investing in a second ship, Amorim do Valle, to adapt that ship to deep water ocean operation of ATLAS moorings.

These problems and their potential issues are presented in more details in Appendix 8.

e) Measurements of Opportunity:

PIRATA cruises are an opportunity to carry out other measurements or instrumentation deployments in the framework of associated programs. Notably, these measurements and deployments constitute an important contribution to ARGO/GODAE (and their French components CORIOLIS/MERCATOR) and GOOS.

- Temperature profiles:

XBT probes are launched during each Brazilian and French cruise dedicated to the PIRATA array servicing. During the French PIRATA cruises, all the temperature profiles (from the surface down to about 700m depth in mean) are transmitted in quasi-real time to the IFREMER Data Center, and profiles are then available and used for assimilation in operational numerical models. The number of temperature profiles varies according to the cruise, but the number of profiles done during the French PIRATA cruises tends to increase in agreement with the recommendations by CORIOLIS/MERCATOR for the equatorial regions (in order to better sample the mesoscale structures and meridional gradients in the equatorial band). In this way, 118 profiles have been done across the whole equatorial Atlantic during the PIRATA-FR12 cruise (January-February 2004) and 113 profiles have been done in the Gulf of Guinea during the last PIRATA-FR14 cruise (June-July 2005).

- Surface drifting buoys:

In the Tropical Atlantic, and principally in the Gulf of Guinea which is a very under-sampled region, the maintenance of the eastern PIRATA backbone provides an opportunity to seed the region with satellite-tracked surface drifting buoys, subsurface floats and profilers, in the framework of the Surface Velocity Program -SVP- and ARGO. Historically, this region has seen few drifter observations due to the westward surface currents along the main South Africa-to-Europe shipping lane. Many SVP drifters, provided by NOAA/AOML (Miami) in the framework of the GDC (Global Drifter Program), have thus been deployed during the French PIRATA cruises. For example, 8 SVP surface drifters have been launched and 12 in 2004 during the PIRATA-FR11 and FR12 cruises respectively, and 20 in 2005 during the PIRATA-FR13 and FR14 cruises.

- Subsurface floats and profilers:

In the framework of ARGO/CORIOLIS, the PIRATA cruises allow us to deploy subsurface floats and ARGO profilers, that provide temperature and salinity profiles from the surface down to 2000m depth every 10 days, transmitted in real-time through the Argos satellite system. ARGO profilers are either provided by France/IFREMER (PROVOR profilers) in the framework of the associated EGEE/AMMA program, or by US/NOAA (SOLO profilers). Thus, about 10 ARGO profilers have been deployed in 2003 in the Gulf of Guinea and, during the 2005 PIRATA-FR13 and FR14 cruises, as many as 24 ARGO profilers have been deployed in the eastern Tropical Atlantic and the Gulf of Guinea (18 French PROVOR and 6 US SOLO).

In collaboration with the German CLIVAR program (IFM/GEOMAR), the 2005 French PIRATA-FR13 and FR14 cruises were also an opportunity to deploy 6 RAFOS, -4 deep and 2 shallow-, 6 APEX and 2 NEMO profilers between the longitudes 23°W and 10°W.

- In the framework of other various programs:

In the framework of EGEE/AMMA and of the French PROOF program (and in contribution to the IGBP/SOLAS programs), the more recent French PIRATA cruises (from 2004) have also been used to do many surface sea water samplings for salinity, nutrients, CO2 parameters, C13 and O18 analysis. Sea surface salinity analysis are notably used also for thermosalinographs calibration, needed for CORIOLIS (differed time data sets). Such samplings are carried out almost every degree (in latitude or longitude) for salinity and nutrients and every two degrees for the other parameters.

PIRATA cruises are also opportunities to sample species found along the ATLAS mooring lines for particular studies. Actually, the pelagic open-sea ecosystems support important fisheries for tunas and tuna-like species in the Atlantic Ocean. Ecological relationships among large pelagic predators, and between them and animals at lower trophic levels, are not well understood. Given the need to evaluate the implications of fishing activities on the underlying ecosystems, it is essential to acquire a reliable understanding of the trophic structure in these vast ecosystems. Knowledge of the trophic ecology of predator fishes has historically derived from stomach content studies that provide only a relative snapshot of the most recent meal at the time of day the animal is captured. Stable N and C isotopes are used with increasing frequency for determining trophic interactions among consumers, and for tracking energy or mass flow through the trophic pathways of ecological communities. Several studies have shown that primary consumers such as filter feeders can capture the spatio-temporal variation at the base of marine food webs (*e.g.* Ménard et al., 2004). In the IRD "Thetis" ("Thons tropicaux et écosystèmes pélagiques") research group, it has been sampled a lot of muscle tissues of tunas and tuna-like species in the western tropical Atlantic Ocean, and the anatifs (*Lepas anatifera*) sampled during the PIRATA-FR12, FR13 and FR14 cruises will be used to define the trophic position of these top predators.

PIRATA buoys have also been used for other kinds of experiments. For example, biogeochemical measurements have been carried out at 8°N, 35°W in March-April 2002, during the PIRATA-BR5 cruise, under the responsibility of Dr Ajit Subramaniam (Lamont/USA). Main objectives were to check if tropical rivers (the Amazon in particular) amplify carbon sequestration. The optical instruments on PIRATA worked only for the first 23 days (the cable got cut and fluorometers were unfortunately lost at that point). But the data that was stored on the mooring was retrieved and a "high resolution" radiometric data has been acquired for initial time.

f) PIRATA data policy and access

One of the priorities of the international PIRATA program is to make the measurements available to the scientific community as soon as possible via internet, *i.e.*:
- in near real-time for daily averaged data from ATLAS buoys, St Peter & St. Paul Rocks and Fernando de Noronha Island Met-data, the São Tomé Island tide gauge data and the thermal profiles obtained during the campaigns;
- as quickly as possible for most data acquired during the cruises dedicated to the program and current-meter data, once measurement processing and required validation phases have been carried out.

- The sets of ATLAS buoy data can be accessed directly via internet, at the address reserved for measurements on the PIRATA site, *i.e*. at:
http://www.pmel.noaa.gov/tao/data_deliv/deliv-pir.html.
PIRATA data collected by the Brazilian satellites can be obtained from CPTEC/INPE home page at http://www.cptec.inpe.br/ or from NODC home page that can be found from http://io.goos.br/.

- The sets of data from dedicated oceanographic campaigns can be accessed either directly via the PIRATA program internet site of the “Centre IRD de Bretagne” on page: http://www.brest.ird.fr/pirata/infos_fr.html, or directly at the ftp address to which they are sent: ftp://ftp.ifremer.fr/ifremer/ird/pirata/pirata-data. The current-meter measurements made using hull-mounted ADCPs require relatively complex processing and checking (in particular, these measurements must be processed taking into account other parameters measured on board such as, for example, navigational parameters or the ship’s attitude) and can thus require longer delays before being made available to the community (according to standard practice, the data must be scientifically validated beforehand). On this subject, a working group was set up in October 2004 in France by the CORIOLIS project, whose role is to promote, simplify and protect the acquisition, checking and processing of current measurements from hull-mounted ADCPs of the French national fleet. The activity reports and meetings of this group can be requested directly from the Group’s managers: Yves Gouriou (yves.gouriou@ird.fr) or Bernard Bourlès (bernard.bourles@ird.fr).

- The sets of data from the meteorological stations of St Peter & St. Paul Rocks and Fernando de Noronha Island: These sets of data constitute one data module of the experimental GOOS Regional Alliance web page (http://goos.io.usp.br), also made available for several other projects.

- The sets of data from the São Tomé Island tide gauge can be accessed via the PIRATA internet page, on the ftp://ftp.ifremer.fr/ifremer/ird/pirata/maregraphe site or directly at the following address: http://www.legos.obs-mip.fr/fr/soa/.

- The sets of current-meter data from the 23°W-0°N ADCP mooring: As for current measurements obtained from ships, these data require relatively complex processing and checking and can therefore require longer delays before being made available to the community. The aim is that they should be systematically available approximately 6 months after the moorings are recovered. The data obtained at 23°W from 2001 to 2002 were transmitted at the beginning of 2004 to the NOAA/PMEL PIRATA Data Center in Seattle (USA). The data acquired in 2004-2005 have been transmitted in the same way in December 2005. They are now available via internet at the following address: http://www.pmel.noaa.gov/tao/disdel/.

- Products done from PIRATA data :
a) Based on the original daily PIRATA data set available at the NOAA/PMEL PIRATA Home Page (USA), more than 300 original plots are computed on a monthly basis at FUNCEME (Brazil). These products provide a routinely updated and extended set of graphic illustrations for seasonal and interannual climatic variability of the

Tropical Atlantic. They are available at the FUNCEME Home page (http://www.funceme.br/DEMET/Index.htm, in the "Projeto PIRATA" subsection).

b) The SST measurements provided by the ATLAS systems are of particular importance for climatological studies. Combined with other in-situ (mainly by the VOS) SST observations, and, eventually, with estimated-by-satellite SST data, hey are obviously integrated in most of the ocean data banks (*e.g*. NODC) that are commonly used in order to built SST products. This is the case for instance for the COADS and the "Smith and Reynolds" SST climatology (see Woodruff et al., 1998; Reynolds et al., 2004). Also combined with the VOS data beyond the whole tropical Atlantic basin, the SST and surface wind data derived from the (presently) 13 PIRATA sites are used to construct the "Servain SST and Pseudo Wind Stress climatologies" (see Servain et al., 1987 and Smith et al., 2004), which is now routinely performed at the FUNCEME (Fortaleza, Brazil), and available at http://www.funceme.br/DEMET/Index.htm (sub-section "Campos numericos do Atlantico tropical"). These products are also available, according an interactive mode, at the IRI Scientific Library (http://iridl.ldeo.columbia.edu/SOURCES/.SERVAIN/).

g) Mooring Data Metrics

1. Data return

PIRATA data return from the deployment of the first buoy in September 1997 to the end of December 2005 has been 71% in real-time and 78% when delayed mode data are accounted for (Figure 2). The difference reflects a combination of Argos transmission failures when a mooring system was otherwise working well and instrumental problems that led to occasional loss of real-time data independent of Argos functionality. The latter type problem arose at times for example when telemetry of subsurface data to the data logger on the buoy failed. The data were in these instances preserved in the subsurface modules but not transmitted with the surface meteorological data.

The pattern of data return in large part reflects the effects of fishing vandalism. This problem is not unique to the Atlantic as similar problems arise in the Pacific TAO/TRITON array and in the tropical Indian Ocean in regions were tuna fishing activity is intense. The greatest losses are in the eastern equatorial cold tongue region of the Gulf of Guinea where biological productivity is high. In particular data returns in this region range between 25-50% vs. typically 75-90+% in the central, western, and southern portions of the array. Data losses at 2°N and 2°S were initially so severe that occupation of these sites was terminated after initial deployments in 1999 as describe above.

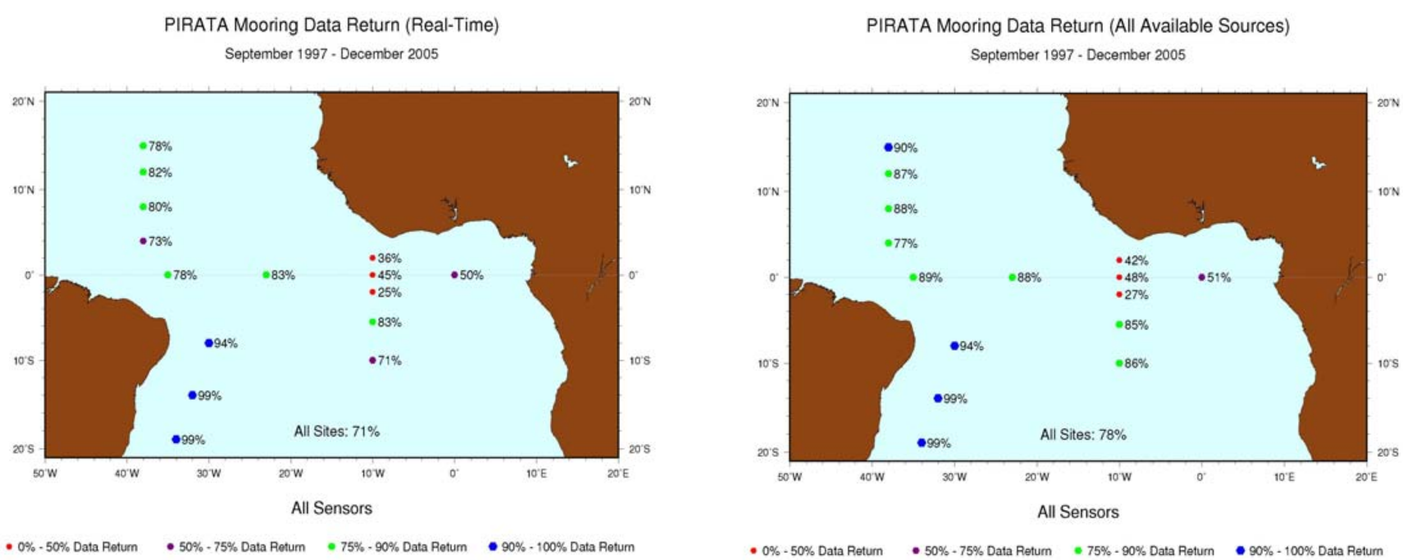


Figure 2: PIRATA data return in real time (left panel) and delayed mode (right panel).

Data return also varies by sensor type (Table 1). Rain, conductivity and wind data returns are relatively low compared to other sensors. Rain and conductivity sensors are sensitive to noise contamination and fouling in the marine environment (for example, biological growth for conductivity and bird guano for rainfall). In addition, rainfall and wind sensors are high up on the buoy tower and relatively exposed to tampering by vandals and to damage from fishing vessel hulls in cases where ships tie up to the buoy. The wind sensor also is also visually appealing which probably attracts souvenir hunters. Moving parts of the wind sensors (*e.g.* propellers) are moreover subject to mechanical wear.

	Winds	SW Rad	Rain	RH	AirT	SST	T(z)	Conduct.
Real-time	66	80	66	80	79	73	72	64
Delayed	72	81	71	82	82	81	80	72

Table 1: Data return in real-time and delayed mode by sensor type for September 1997 to December 2005.

2. User data requests and files delivered

In 1999, PMEL instituted a data tracking procedure to quantify the number of PIRATA data user requests and files delivered via its web interface. Growth in demand for the time series has been rapid and continues to increase significantly every year (Figure 3). This growth reflects the growing visibility of PIRATA in the research community and the increasing value of the data for climate and related studies as the length of the time series increases. In 2005, the most recent year for which statistics are available, 30,230 PIRATA data files were delivered in 4157 separate user requests.

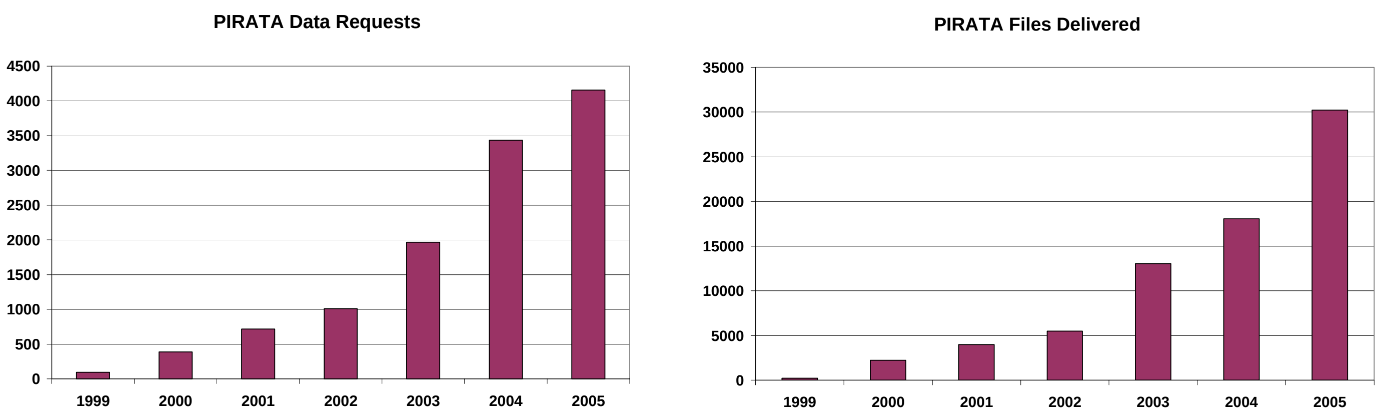


Figure 3: PIRATA data user requests (left panel) and files delivered (right panel) over the period 1999-2005.

3. Data throughput on the Global Telecommunications System (GTS)

Service Argos places ATLAS mooring data on the GTS for real-time distribution to operational weather, climate and ocean forecasting centers. Prior to February 2005, anywhere from about 300 to 800 hourly meteorological data would find there way to these centers (Figure 4). Then, in February 2005, data throughput began to increase dramatically. There were three reasons for this increase:

a) Service Argos began to deliver data to users from a multi-satellite relay system instead of 2-satellite relay system at no extra charge. This change allowed more coverage throughout the day for receiving transmissions from remote platforms. As a result, the increase from October-December 2004 to February-April 2005 was about 70%.

b) PMEL reprogrammed its buoy data transmission firmware to transmit during four 4-hour winds per day instead of the previous two 4-hour windows. The first PIRATA moorings with the new transmission scheme were deployed in May 2005. In principle, this change would have lead to a doubling of the throughput under the previous 2-satellite system and it accounted for the rapid rise in throughput beginning in May 2005.

c) Three new PIRATA moorings were deployed at part of the Southwest Extension in August 2005 (details about the PIRATA extensions are provided in Chapter C), which lead to an additional 30% increase on GTS transmission.

As a result of these three developments, GTS throughput has increased by a factor of 4-5 from late 2004 to late 2005. In its present configuration, PIRATA should continue to provide 4000-4500 unique hourly values per month of wind and other surface meteorological variables to the GTS. The temporary drop in data transmissions in November 2005 reflects a Service Argos system problem that has since been corrected. PIRATA GTS data should therefore be even more valuable for constraining operational weather, climate, and ocean analyses and forecasts than they have in the past (see Chapter 2.c).

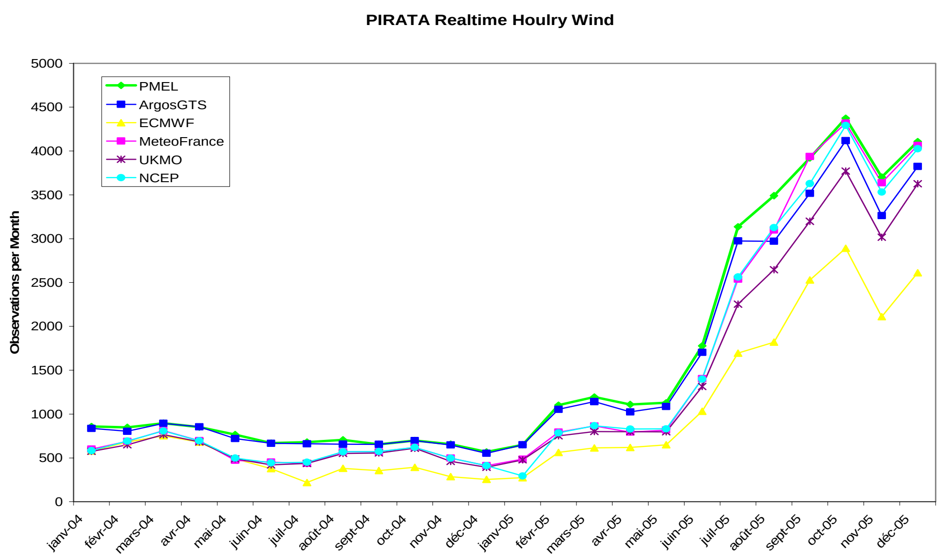


Figure 4: Hourly wind data delivered on the GTS to various meteorological centers for 2004-05. Data received at PMEL directly by Service Argos and the data that Service Argos puts on the GTS are shown for reference.

h) Capacity building and training

French PIRATA cruises provide opportunities to embark African students or scientists, in order to develop regional cooperation, to provide training courses on measurement techniques and operations, and to incorporate when possible scientists from developing countries in oceanographic and climate research. Furthermore, scientists of the Economic Exclusive Zone countries may participate as official observers but can also be trained in data acquisition and initial processing. Furthermore such trainings are needed a) for the next possible contribution of Senegal to AMMA through oceanographic cruises between Dakar and Cape-Verde that should be carried out with their own R/V ITAF-DEME of ISRA/CRODT, and b) for the strong demand by some African countries to be involved in international operational programs as ARGO.

In this way, and thanks to historical relationship between IRD and some African laboratories, a few scientists from Senegal (LPA-Dakar) and Ivory Coast (LAPA-Abidjan) have participated in most of the French PIRATA cruises, and thus obtained experience in sea water sampling, CTD acquisition, profiler deployments and XBT launches. At present, a few PhD thesis have been achieved or are in progress in France (1 from LPA-

Dakar; 2 from Univ. Cocody/Abidjan), and three scientists from Ivory Coast have benefited from three to six months visiting periods funded by IRD in French oceanographic laboratories (LEGOS in Toulouse and Brest, LOCEAN in Paris) for working on in situ data (including some PIRATA data) analysis.

From 2005, in close association with the EGEE/AMMA program and cruises, this training is enlarged to additional countries. Thus, in addition to one student from Senegal and one scientist from Ivory Coast, three scientists from Bénin (Centre de Recherche Hydrologique et Océanographique du Bénin, CRHOB, Cotonou), one from Togo (Université de Lomé, Dept of Geomorphology), one from Nigeria (Nigerian Institut for Oceanography and Marine Research, NIOMR, Lagos) have been invited to both EGEE 1 and EGEE 2 cruises (one people per leg), and one from Congo (IRD Center of Pointe Noire) were invited to participate and to contribute to the EGEE-1 and EGEE-2 cruises, linked to the PIRATA-FR13 and FR14 cruises. Thus, a total of 8 scientists from African countries have participated to the three French cruises, associated to the PIRATA Program, carried out in 2005.

Brazilian PIRATA cruises represented an opportunity to promote the study of physical oceanography in Brazil, as well as to acquire the necessary expertise to anchor ATLAS systems in deep waters. Brazilian engineers have been trained at PMEL on the complete set of operations related to the recovering and mooring ATLAS systems, as well as the procedures for sensors' calibration. Today, DHN officers and INPE engineers together are capable to conduct a PIRATA maintenance cruise without the need of technical assistance from PMEL's technicians.

The next steps to be taken in Brazil toward a sustainable development of a tropical Atlantic oceanic and atmospheric observational system is the establishment of in country laboratorial facilities (at INPE/Natal, INPE/CPTEC and IO/USP) to recover and re-calibrate ATLAS sensors, reducing the time and easing the logistics of PIRATA array maintenance. Brazil is also investing in a second oceanographic vessel, Amorim do Valle, to service the array.

Training of Brazilian technicians on ADCP data processing has also been done in cooperation with the French colleagues from IRD (Jacques Grelet, Francis Gallois). Jacques Grelet offered a one week course at DHN in Niteroi, Brazil, in March 2004. Today, the hull mounted ADCP data collected by Antares PIRATA cruises are being processed at CPTEC with the aid of the CODAS software.

There has also been the participation of scientists on PIRATA Brazil cruises, for example, during the PIRATA-BR5 cruise, in March-April 2002, Dr Ajit Subramaniam (Lamont/USA) conducted biogeochemical measurements around the 8°N-38°W ATLAS buoy with the main objective to check whether tropical rivers, like the Amazon, amplify carbon sequestration.

2) PIRATA contributions to tropical Atlantic climate and ocean science:

a) To provide an improved description of the seasonal-to-interannual variability in the upper ocean and at the air-sea interface

Prior to PIRATA, only a limited amount of sub-surface oceanic data sets were available in the tropical Atlantic. These were obtained during specific scientific experiments (e.g. FOCAL – SEQUAL projects in 1982-84) using research vessels and sparse measurements made by other means. Therefore, it was not possible to construct an accurate time description of the sub-surface climate in that region. The need for long time series lead scientists -noting the success of the TAO array in the tropical Pacific- to design a specific array of instrumented moored buoys for the continuous measurement of surface and sub-surface data for a period of several years in the tropical Atlantic. According to the state of the art knowledge accumulated during the last decades PIRATA was then established with the early purpose to provide a description of the two main (meridional and equatorial) modes of climate variability in the tropical Atlantic.

The following Figure 5 shows the (5-day average) time evolution of wind, SST, SSS and sub-surface thermal structure at three key locations (15°N-38°W, 0°N-23°W, 10°S-10°W) of the PIRATA array. The data return have been consistently good for the first 9 years (September 1997 up to now) of the PIRATA Program.

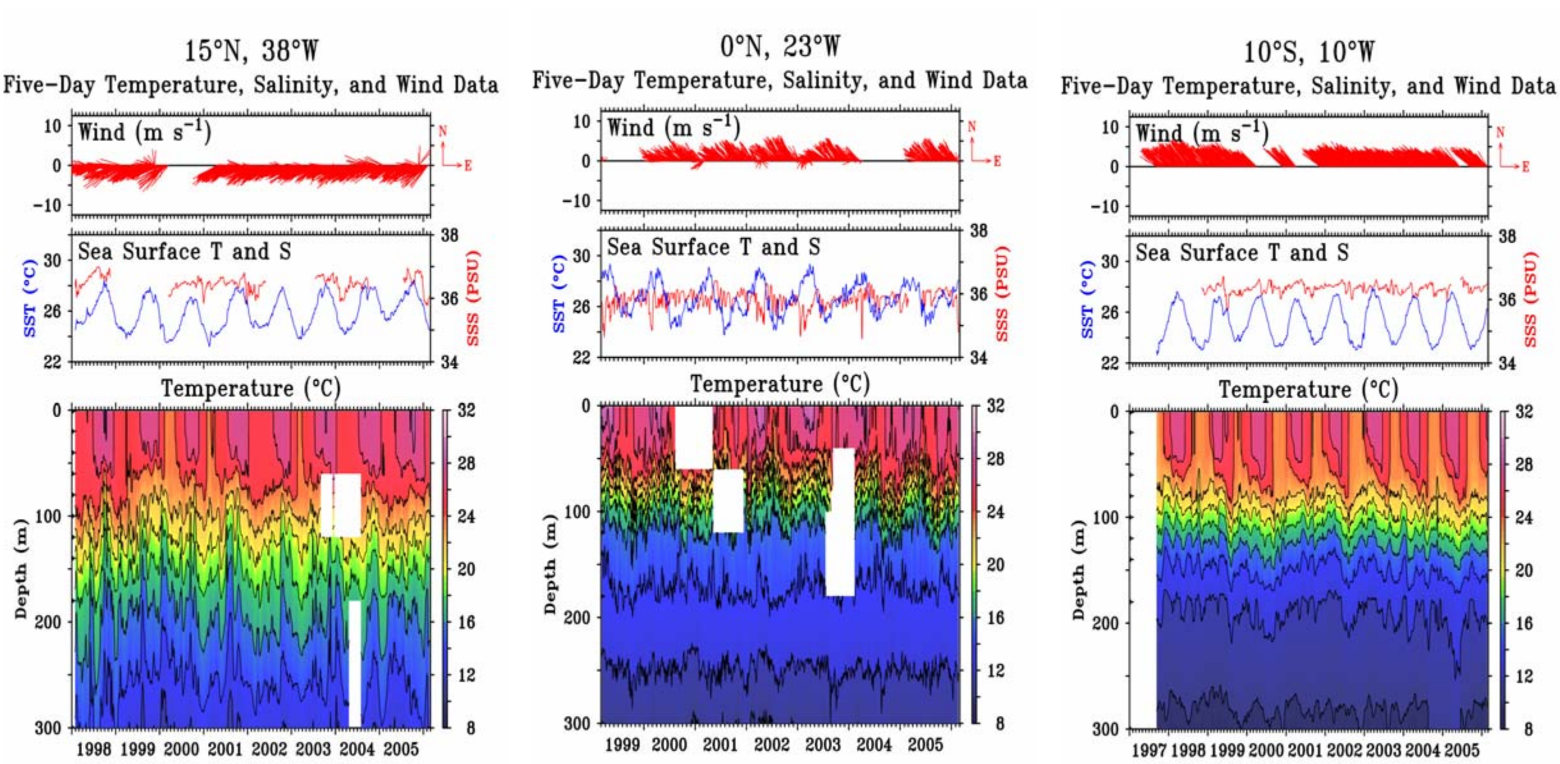


Figure 5: 5-day average time evolution of wind (upper panels), sea surface temperature and salinity (middle panel, blue and red lines respectively) and sub-surface thermal structure (from the surface down to 300m depth, lower panel) as measured from September 1997 to December 2005 at three locations, of the PIRATA Program array, i.e. namely 15°-38°W (left), 0°n-23°W (middle) and 10°S-10°W (right).

The Figure 6 displays the meteorological data (rainfall, air temperature, relative humidity, solar radiation) gathered at the same locations during the same periods.

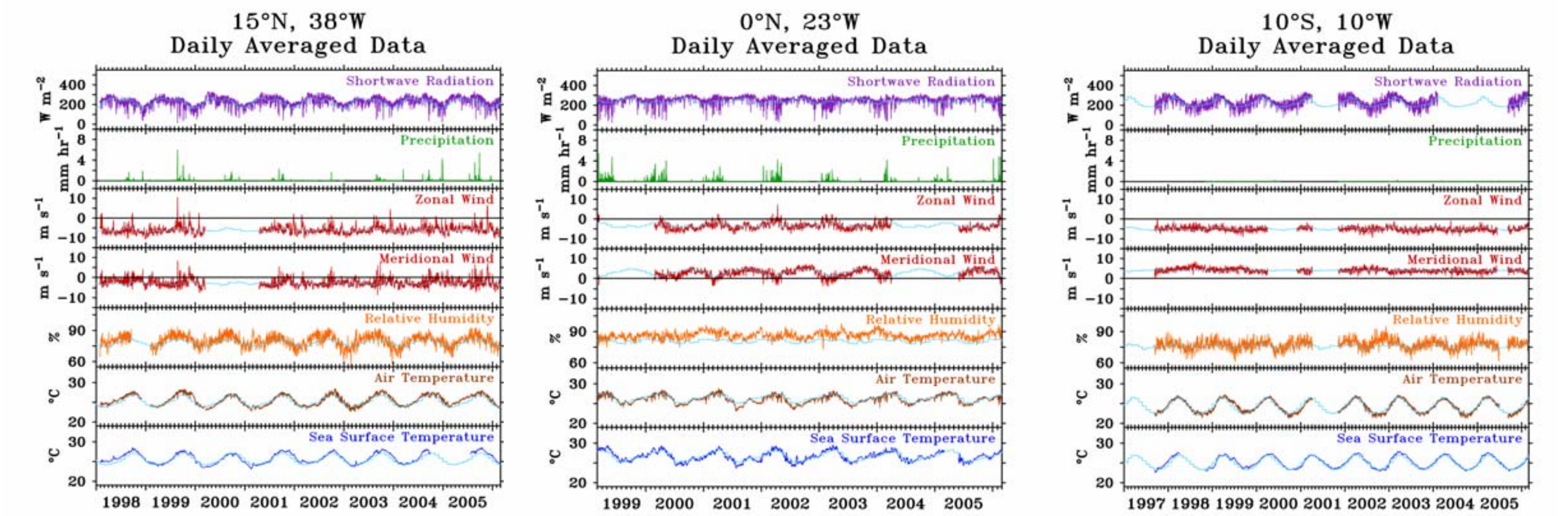


Figure 6: Daily average time evolution of surface meteorological variables, namely(from top to bottom) shortwave radiation (purple), precipitation (green), zonal and meridional wind (red), relative humidity (orange), air temperature (brown) and sea surface temperature (blue), as measured from September 1997 to December 2005 at three locations of the PIRATA Program array, i.e. namely 15°-38°W (left), 0°n-23°W (middle) and 10°S-10°W (right). Light blue lines in are climatological mean seasonal cycle.

Now, for the first time, these series can help us in providing a good description of the climate system at seasonal to interannual time scales at several locations in the tropical Atlantic.

1) Meridional and equatorial modes of variability studies:

A first look at the PIRATA data, gathered during the period 1998 at 2000, was performed by Servain et al. (2003) to verify how the measurements are representative of the two meridional and equatorial modes. The results show that a simple index derived by subtracting the daily SST anomaly measured at 15°N-38°W from the SST anomaly measured at 10°S-10°W (*i.e.* the two meridional extremes of the array) could represent well the signature of the north-south SST anomaly gradient. With the data set available up to now (1998 - 2005), a more robust result confirms this finding which is quite comparable with monthly measurements made by ships (the so-called "dipole index"; Servain, 1991), (Figure 7).

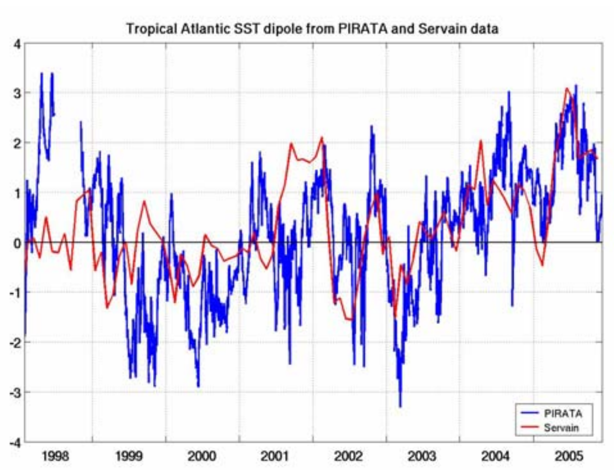


Figure 7: Monthly tropical Atlantic "SST dipole index" as estimated from merchant ships observations (Servain, 1991; red line), and daily "SST dipole index" as estimated from the PIRATA SST data (blue line), using the two extremes meridional buoys (15°-38°W minus 10°S-10°W)

The four ATLAS buoys located along the equator (35°W; 23°W, 10°W and 0°E) can estimate the zonal fluctuations of the thermocline depth (vertical thermal structure), as well as the SST zonal gradient, which are associated with the east-west equatorial mode. These measurements provide for a daily monitoring of the equatorial wave propagation (Figure 8).

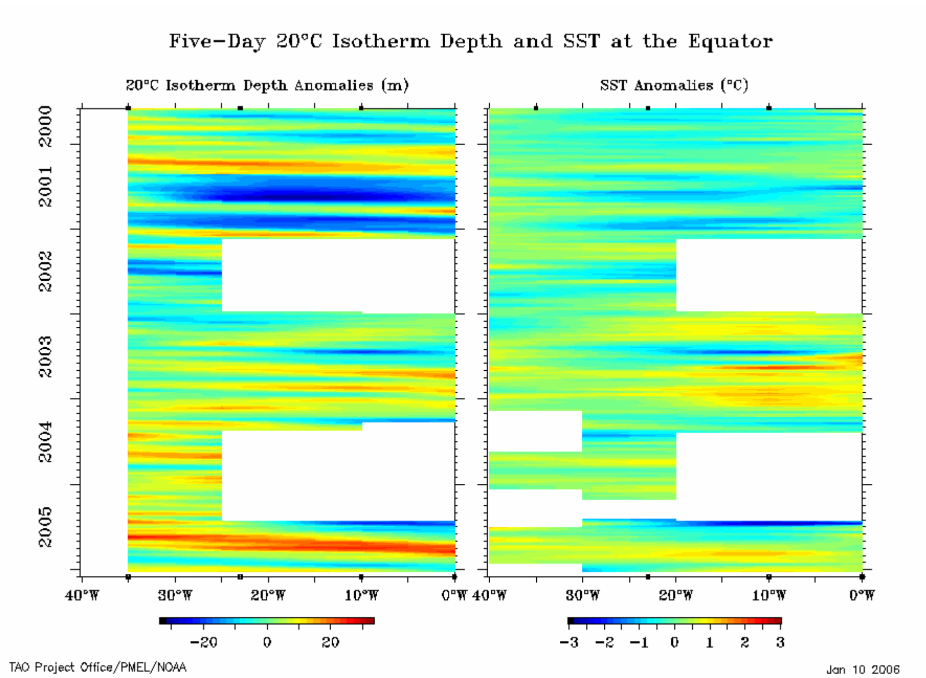


Figure 8: Illustration of equatorial east-west wave propagation events as inferred by the 20°C isotherm depth (Z20) and SST anomalies deduced form the daily PIRATA data set provided by the four PRIATA buoys located along the equator.

A 2-month lagged relationship between the two modes (the equatorial mode in advance) was statistically observed (Servain et al., 1999) and numerically discussed (Servain et al., 2000; Murtugudde et al., 2001). Using the early PIRATA data set (1999-2000), a first check of that relationship was performed by Servain et al. (2003). By using an extended PIRATA data set up to 2005, and in spite of numerous data gaps, these results seem to be confirmed (Figure 9).

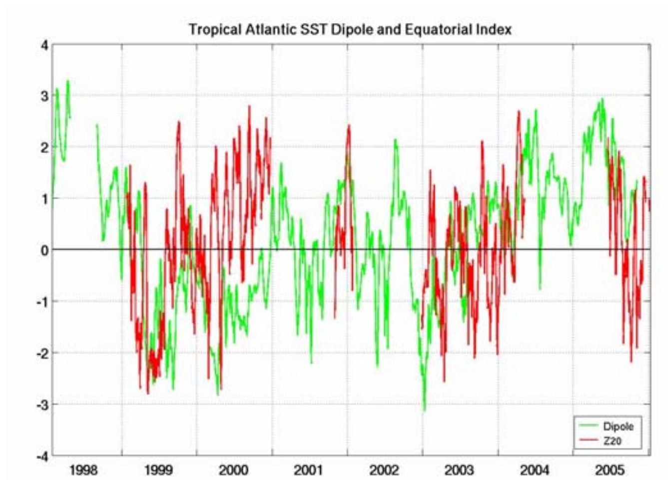


Figure 9: Daily time series of the PIRATA SST dipole index (green line), as computed by the difference of the SST anomalies between the 15°N-38°W and 10°S-10°W PIRATA buoys, superimposed to daily time series of the PIRATA Z20 equatorial slope (red line), as computed by the difference of the Z20 anomalies between the 0°N-35°W and 0°N-10°W PIRATA buoys. The time axis is related to the Z20 index with the SST dipole index lagging by 2-month.

2) Air-sea fluxes related studies:

The observational network in the tropical Atlantic has expanded considerably in the recent years. In addition to the PIRATA network, ARGO floats, VOS XBT lines, near-surface drifters, as well as several focused scientific experiments and a variety of remotely-sensed observations currently contribute to assemble a much better data coverage over the Tropical Atlantic as ever before. As part of this observing system, PIRATA is providing data to validate and to initialize models of air-sea interaction in the Tropical Atlantic. The PIRATA buoy data sets have also been extensively used by both academic and operational communities to validate satellite based surface flux estimates. Following are some examples of the PIRATA contribution with respect to the understanding of air-sea fluxes in the Tropical Atlantic.

Using PIRATA data, Foltz et al. (2004) addressed the atmospheric and oceanic causes of the seasonal cycle of mixed layer salinity in the Tropical Atlantic based on direct observations and model data. Data sets include up to five years (September 1997 - December 2002) of measurements from PIRATA buoys. The mixed layer salt balances at nine PIRATA mooring locations were analyzed. They found that the seasonal cycles of evaporation, precipitation, entrainment, and mean horizontal salt advection all contribute to seasonal mixed layer salinity variability in the northwest. The balance is similarly complex along the equator.

Several studies (*e.g.*, 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 10 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. 3a). Clearly there are large spatial variations in these biases, casting doubt upon corrections based on a constant coefficient (*e.g.*, Grist and Josey, 2004).

Durand et al. (2005) have found significant correlations between the tropical Atlantic latent heat flux and convective cloud coverage over the Brazilian northeast. According to this study, their correlation patterns confirm the importance of the northwestern branch of the PIRATA backbone to monitor the air-sea fluxes and give additional support for the pertinence of the PIRATA buoys position.

The high quality buoy observations of the PIRATA array are also being used for comparison and calibration of different remotely sensed data. Comparison analysis indicates that in general the remotely sensed fluxes are underestimated with respect to the buoy observations, while numerical model data overestimate the fluxes (Bentamy et al., 2002). Wentz et al. (2000) used PIRATA SST data to compare microwave and infrared derived SST fields to observations. They showed that satellite estimates were within 0.6 °C of observations, which is partly due to satellite-buoy spatial and temporal sampling mismatch and the difference between the ocean skin temperature and bulk temperature. They also showed that microwave SST retrievals provided insights in tropical instability waves, marine boundary layer dynamics, and the prediction of hurricane intensity.

França and Carvalho (2004) used PIRATA buoy SST data to show that the accuracy of GOES derived SST estimates are better than 0.7 °C using in situ SST collected from moored and drifting buoys. Yu et al. (2004) evaluated the degree of improvement made by the use of a variational objective analysis developed at WHOI to compute daily latent and sensible heat fluxes for the Atlantic Ocean using in situ PIRATA data for verification. They showed that the mean and daily variability of the latent and sensible heat fluxes from the WHOI analysis are an improvement over the NWP fluxes at all of the measurement sites. The study also suggests that further improvement in the accuracy of latent and sensible heat fluxes will depend on the availability of high-quality SST observations and improved representation/observations of air humidity in the tropical Atlantic. Sun et al. (2003) compared surface meteorological variables and turbulent heat fluxes in NCEP and ECMWF analysis with PIRATA buoy data. They showed that ECMWF and particularly the NCEP analyses do not represent well the 2–3-week variability in the tropical Atlantic.

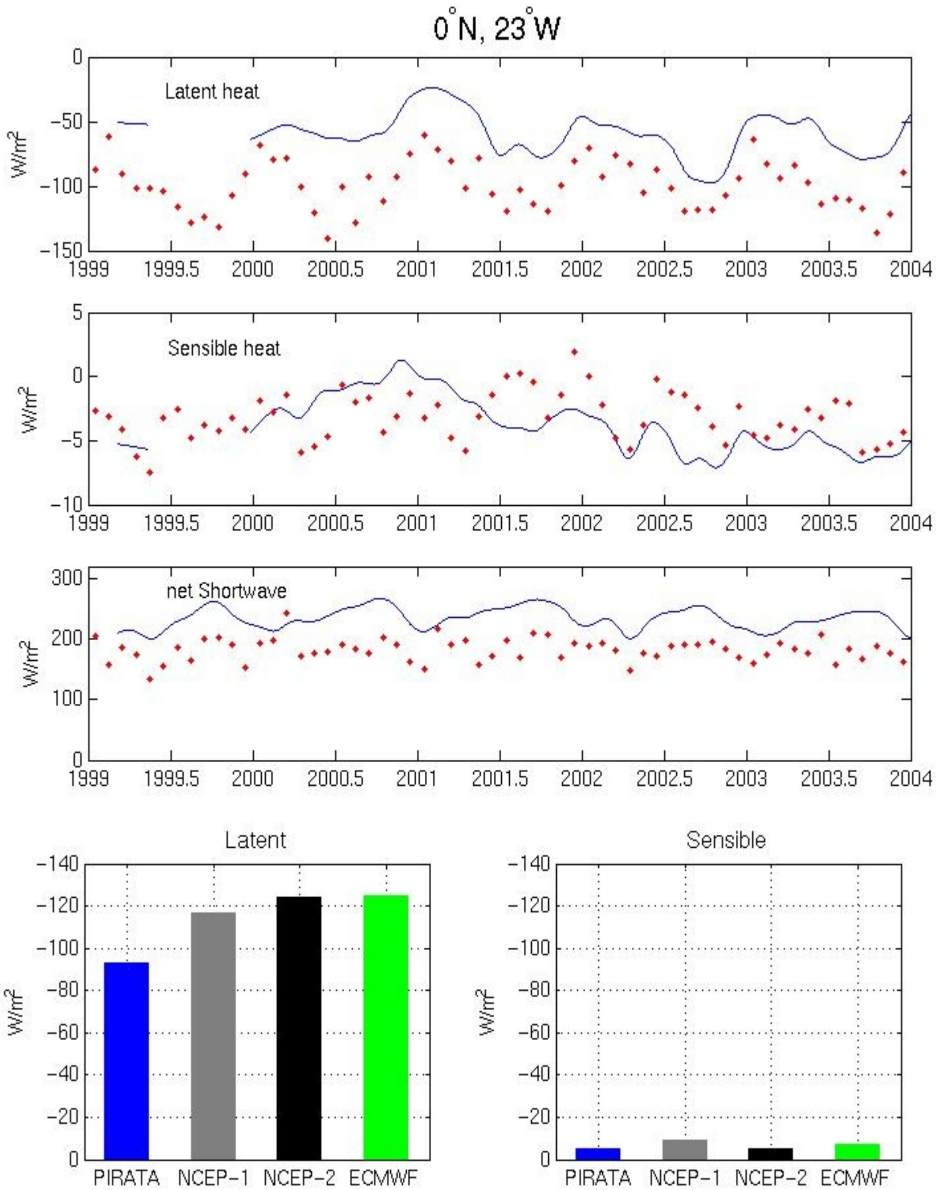


Figure 10: Top panels: Low-passed time series of latent, sensible and net shortwave heat fluxes measured at the 23ºW-0°N PIRATA buoy (solid lines) and from NCEP/NCAR v.2 (red dots). Bottom panels: time-mean turbulent fluxes averaged over the PIRATA array (blue) and from three commonly used air-sea flux products (adapted from Sun et al., 2003).

The EUMETSAT Ocean and Sea Ice Satellite Application Facility (OSI SAF) is producing the Sea Surface Temperature (SST) and the radiative fluxes, Surface Solar Irradiance (SSI) and Downward Longwave Irradiance (DLI), through the combined use of GOES-12, MSG-1 (METEOSAT-8) and NOAA-17 satellites. The processing scheme has been fully operational since July 2004. Documentation, images of the day and validation results are available on the OSI SAF web server: http://www.osi-saf.org and the whole archive is available through the IFREMER server ftp://ftp.ifremer.fr/pub/ifremer/cersat/SAFOSI. MSG being located by 0°N-0°E, the PIRATA network is particularly well situated to validate the MSG derived SST. SST fields are calculated and validated in the full satellite resolution. Validation is based on comparisons with buoy measurements available through the GTS: the satellite derived SSTs are extracted in boxes (5 pixel x 5 pixels) centered on the buoy location. When the cloud coverage of the box is less than 10%, the data are used for detailed validation studies. For the year 2005, 1974 such cases have been recorded for day and night conditions from the PIRATA network, showing a bias and standard deviation of -0.21°K (satellite derived SST slightly lower) and 0.38°K respectively. For the same period, the results recorded for all Atlantic buoys were -0.01°K and 0.47°K, respectively, for 112938 cases. The small negative bias recorded on the PIRATA network is likely due to the

local conditions under these latitudes: high water vapor content, Saharan dust induced errors in the SST calculation. Indeed, similar results are recorded when considering all buoys in the 20°S-20°N latitude band: bias: -0.18°K, standard deviation: 0.47°K for 23292 cases. Note that the PIRATA buoy measurements (as well as MSG derived SST) are being used in studies on diurnal warming cycle (e.g.: *Stephen Hallsworth, PhD Thesis, University of Edinburgh: Modeling the diurnal variation of sea surface temperature using a one-dimensional ocean turbulence model).*
The radiative fluxes are produced on a regular grid at 0.1° resolution in latitude and longitude and are derived from GOES and MSG images processed every hour. The products are validated against *in situ* measurements, as follows: the satellite derived flux, averaged on a 0.3-degree square box centered on the measurement station, is compared to the measured flux, centered on the time of the satellite data and obtained from the original in situ data by integration or interpolation; the error is the satellite value minus measured value.

At present, the PIRATA buoys data are not used in the operational validation scheme but only in the "development" scheme, which is run in parallel. To summarize the use of PIRATA data within the OSI SAF: SST measurements are considered as reliable and provide validation results quite comparable to those of the other sources available on the GTS. As for the radiation measurements, further investigation is needed to assess whether the bias represents an actual overestimation of the satellite product or is due to a poor quality of the buoy measurements. This could be done by comparing coincident measurements on ship and buoys when available.

PIRATA winds were also compared with QuikSCAT/SeaWinds satellite estimates. Ebuchi et al. (2002) showed that wind speeds and directions observed by QuikSCAT agree well with the buoy data. The root-mean-squared differences of the wind speed and direction for the standard wind data products are of the order of 1 m s^{-1} and 23°, respectively. Also, they found a weak positive correlation of the wind speed residuals with the significant wave height, but no statistically significant correlations with SST or atmospheric stability (Ayina et al., 2006).

In the modeling realm, Dourado and Caniaux (2004) used a one-dimensional model of the oceanic boundary layer using PIRATA data at 10°S-10°W. They found that the differences between the skin and bulk temperature are amplified when the wind slows down. Belyaev et al. (2001) showed that assimilation of the PIRATA data produces an improved representation of the thermal state of the ocean and allows a better estimation of other oceanographic quantities, like meridional heat fluxes and zonal currents. Barron et al. (2006) used PIRATA data for evaluating a sigma-z implementation of the NCOM.

3) Equatorial currents and process studies:

A few studies dedicated to the description of the mean equatorial circulation and its variability along the equator were possible by using different VM-ADCP data sets partly obtained thanks to PIRATA cruises (*eg*., the EQUALANT cruises in 1999 and 2000 were closely associated with PIRATA). Actually, the equatorial Atlantic exhibits a very complex system of zonal currents, at different depths and latitudes (namely, from South to North, the South Equatorial Undercurrent -SEUC-, the Equatorial Undercurrent -EUC-, the North Equatorial Undercurrent -NEUC-, along with the North Equatorial CounterCurrent -NECC-). These currents are principally fed in the western Equatorial Atlantic through retroflection of the North Brazil Current, but also through recirculation of the North Equatorial Current -NEC-. Their transports and variability is of particular importance in regard of the Meridional Overturning Circulation -MOC-, but also because they advect eastward a considerable amount of warm and salty waters formed in the subtropics, and thus may contribute to the mixed layer balance and sea surface temperature variability. By using VM-ADCP data sets from many cruises, whist Schott et al. (2003) described the mean circulation along the longitude 35°W, and estimated a mean EUC transport of about 21Sv, Molinari et al (2003) put into evidence at the same longitude the existence of Tropical Cells (TC) in the northern hemisphere, from the first time from in situ data only. They shown that equatorial upwelling and off-equatorial downwelling, found between 3ºN and 6ºN, represent the southern and northern boundaries of a northern hemisphere TC. Bourlès et al. (2002) used the whole EQUALANT VM-ADCP data sets to describe the fate of the EUC, SEUC and NEUC system from the west (35°W) to the African coast (6°E).

They showed the poleward deviation of the SEUC and NEUC during their eastward route, in agreement with theoretical considerations that suggest that these currents are mostly dictated by the eastward shoaling of the thermocline and propagate nearly inertially. They also put into evidence the disappearance of the EUC east of 0°E in boreal summer 2000, so raising the question of the EUC behavior in the Gulf of Guinea. A dedicated study is going on, by using all the PIRATA cruises carried out in this area, to address this topic along with another study about the zonal currents mean transports and their variability along the 10°W section, already carried out more than 10 times with VM-ADCP during PIRATA cruises (Kolodziejczyk et al., in preparation).

We have to mention here that all the PIRATA VM-ADCP data, or from cruises associated to PIRATA, obtained along meridional sections (35°W, 23°W, 10°W) have been used in order to build a reference simulation of the French CLIPPER numerical model. The CLIPPER run has been particularly dedicated to Equatorial Atlantic studies, and the mixing parameterization chosen after a series of tests in order the simulations to reproduce the EUC in the best way (Michel and Tréguier, 2002). Arhan et al. (2006) used this reference simulation to diagnose the annual cycle of the EUC. These authors evidence two well-defined EUC transport maxima (one during boreal summer and autumn in the central part of the basin, and the other one found in April-May near the western boundary) and suggest that two different dynamical regimes shape up the EUC seasonal cycle: In summer and autumn, local forcing by the equatorial zonal wind component, and main supply from the ocean interior; in winter and spring, remote forcing by the low-latitude rotational wind component, and supply from the western boundary currents. In the same way, Peter et al. (2006) also used this reference simulation, along with the PIRATA in situ data for validation, to study the mass and heat balance in the mixed layer over the whole tropical Atlantic Basin. These last authors show that, at the equator, the sea surface temperature balance is established to be the result of both cooling by subsurface processes (through vertical mixing at the base of the mixed layer, vertical advection and entrainment), and heating by both atmospheric net heat fluxes and eddies (mainly tropical instability waves). Horizontal advection by the currents seems to play only a minor role in the heat budget. Off the equatorial band, the sea surface temperature variability seems mainly governed by atmospheric forcing except in the northeastern part of the basin where strong eddies generated at the location of the thermal front significantly contribute to the heat budget in boreal summer.

The PIRATA ADCP mooring, located at 23°W-0°N, allowed to study the EUC transport variability thanks to long time series from 2001 to 2002 (Provost et al., 2004; Grosdky et al, 2005; Provost et al., 2005) and from 2004 to 2005 (Brandt et al., 2006; it can be noted here that VM-ADCP data are also used in order to check and validate the ADCP data acquired from the moorings). These studies particularly evidence the important influence of the Tropical Instability Waves -TIW- on the EUC transport. Brandt et al. (2006) estimate a mean EUC eastward transport of 14.1 Sv, and the time series from ADCP mooring data, combined with VM-ADCP sections data, indicate significant seasonal and intraseasonal cycles, in both horizontal components of the current velocity (Figure 11). The observed vertical motion of the EUC appears to be associated with the seasonal cycle of the zonal wind field (Provost et al., 2004), but a full dynamical interpretation is still pending. A semiannual cycle in the EUC meridional velocity fluctuation is also evidenced, so confirming earlier analysis in the ADCP data from 2002 presented by Grodsky et al. (2005).

Giarolla et al. (2005) also used the 2001-2002 ADCP mooring data in order to validate equatorial Atlantic oceanic modeling. They used an eddy resolving version of MOM to simulate the Atlantic Equatorial Under Current (EUC). They showed that the high resolution model was able to simulate both strength and depth variations of the EUC, while a lower resolution version of the model presented significant slow velocities bias of the EUC. Their joint EOF analysis of both observed and simulated velocities showed that the two first EOF modes explained nearly 80% of the monthly velocity variance of the upper 100m at the ADCP site. Figure 12 shows thirty days running means of both observed (colors) and simulated (contour lines) of zonal velocities at 23°W-0°N during 2002. Such improvements are particularly relevant for seasonal climate prediction problem, since most coupled ocean-atmosphere models present strong systematic errors over the equatorial Atlantic, showing a zonal SST gradient that is the opposite of observations (Davey et al., 2002). Several aspects of the coupled models factor in to generate such enormous SST bias. One of them is the excessively relaxed thermocline slope, which is due in part to erroneous eastward heat advection due to a too shallow model EUC.

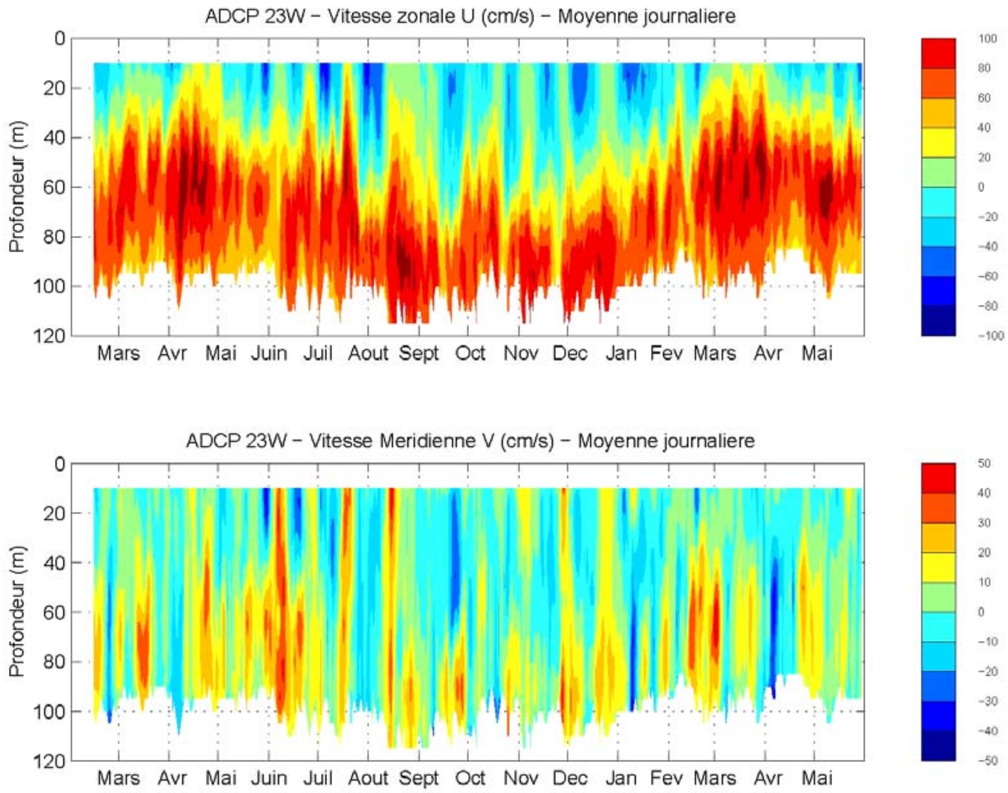


Figure 11: U -top- and V -bottom- components of the current velocity from the sea surface down to 100m depth, from February 2004 to May 2005 at 23°W-Equator (A.Kartavtseff, LOCEAN-Paris, person. comm..)

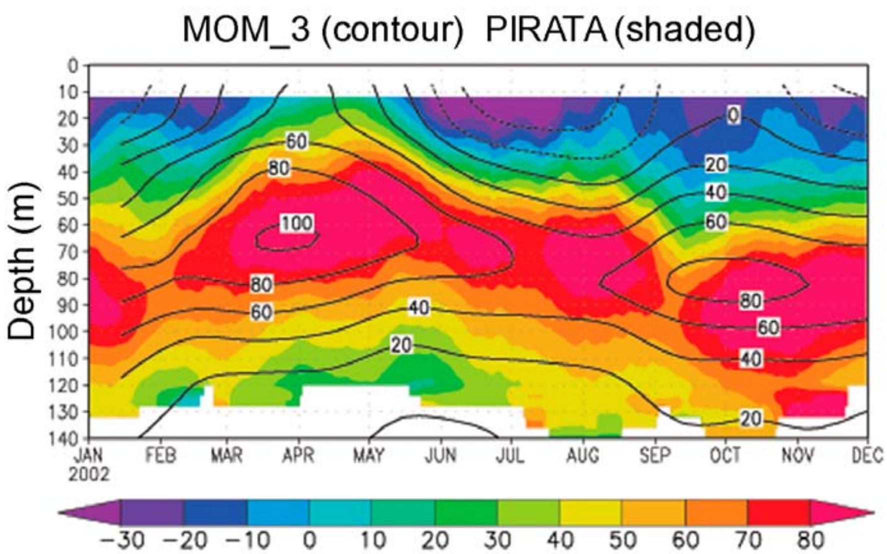


Figure 12: 30 days running means of both observed (PIRATA ADCP; colors) and simulated (MOM model: contour lines) of zonal velocities at 23°W-0°N during 2002.

PIRATA winds obtained along the equator were also used in order to analyze the influence of the zonal trade wind variability on the sea surface slope variability and on the structure and variability of the equatorial jets observed in the subsurface and deep ocean layers (Provost et al., 2005; Bunge et al., 2006).

Time series of temperature and salinity available within the upper layers thanks to the PIRATA buoys are of particular importance for studies dedicated to salinity effect on the mixed layer and air-sea exchanges. In a pioneer study about the barrier layer in the western tropical Atlantic carried out from in situ data only, Pailler et al. (1999) note that the wind, SST and SSS measurements obtained in 1998 from the 7°N-38°W PIRATA buoy strongly support the linkage between the SST increase and the presence of a barrier layer due to fresh surface waters mostly advected into the region from the Amazon mouth. More recently, in situ PIRATA SST data sets have been used for validation of methodology which has been designed for SST and currents analysis from drifters measurements obtained in the framework of the Surface Velocity Program -SVP- (Lumpkin and Garraffo, 2005).

b) Relative contributions of the different components of the surface heat flux and ocean dynamics to the seasonal and interannual variations of SST

SST variations play a major role in the migration of the ITCZ at seasonal and longer timescales (*e.g.*, Okumura and Xie, 2004), with significant implications for regional climate impacts in the adjacent land masses of the Americas and Africa (*e.g.*, Nobre and Shukla, 1996, Schott et al., 2005). Warm and cold SST "Benguela Niño" events can have a major impact on countries bordering the southeastern Atlantic (Florenchie et al., 2004). SST may also play a critical role in coupling climate variations of the northern and southern hemispheres of the Atlantic (Chang et al., 1997), although upper ocean heat advection may play a significant role as a negative feedback mechanism in this process (Seager et al., 2001).

Studies of tropical Atlantic SST variations typically use numerical simulations (*e.g.*, Carton and Zhou, 1997) or analysis of gridded, observation-based products. Both types of studies must be validated against *in situ* observations such as those provided by the PIRATA array. In addition to providing high-frequency SST observations at the mooring sites, PIRATA buoys provide continuous time series of temperature and salinity through the mixed layer. Direct velocity measurements are currently obtained at a few sites, with more planned in the future; these will become critical to assess the role of ocean heat advection in warm and cold events (*e.g.*, Vauclair et al., 2004). For even the most simple 1D balances, heat flux products must be evaluated; PIRATA observations have been used for this in several recent studies (*e.g.*, Sun et al., 2003; Yu et al., 2004; Enfield and Lee, 2005).

Foltz et al. (2003) evaluated the seasonal heat balance in the upper Tropical Atlantic at several of the PIRATA mooring sites, using the buoy observations, gridded products and drifting buoy observations to evaluate the role of surface fluxes, lateral advection, and vertical entrainment. They found that SST variations were predominantly driven by the seasonal cycle of latent heat loss and shortwave gain at the northwestern (15°N-38ºW) and southeastern (10°S-10ºW) mooring sites. At the equatorial sites along 10°W-35ºW, horizontal advection of heat (particularly in boreal summer) and vertical entrainment played a lowest-order role along with net surface heat flux in setting the upper ocean heat budget. Within the cold tongue, mean and eddy heat advection opposed each other at the seasonal time scale. In a related study, PIRATA observations have also proved valuable in documenting the seasonal salt budgets of the Tropical Atlantic (Foltz et al., 2004).

In addition to the seasonal variations, the Tropical Atlantic 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. Preliminary investigations of these variations at three of the PIRATA mooring sites (Foltz and McPhaden, 2005) have quantified the impact of the wind-driven latent heat fluctuations upon heat storage.

High frequency SST variations are also driven by atmospheric tidal motions and instability waves (Wainer et al., 2005). For example, advection of SST anomalies by Tropical Instability Waves (TIWs) drives significant meridional eddy heat fluxes. The intensity of TIWs is greatest during the boreal summer and fall, in phase with the seasonal strengthening of the southeasterly trade winds and the Atlantic equatorial cold tongue and suggesting that the intensity of the cold tongue may be modulated by TIW heat fluxes (*e.g.*, Peter et al., 2006). In a recent study of temperature, salinity, ADCP velocity and wind data from the 0°N-23ºW PIRATA mooring, Grodsky et al. (2005) showed that TIW eddy heat fluxes increased cold tongue SSTs by 0.35ºC during the summer months of 2002. They also showed that including the salt fluxes increased the magnitude of the baroclinic energy conversion, demonstrating the value of high-resolution mixed layer salinity observations.

c) Contribution to the development and improvement of predictive models of the coupled Atlantic climate system.

Although the North Atlantic Ocean has historically been one of the best observed regions of the world's oceans, the same cannot be said for other portions of the Atlantic. With respect to prediction of the coupled climate system specific to the tropical Atlantic sector, we still do not have a good understanding of which physical variables are limiting forecast skill and require enhanced observations. From our experience in the Pacific we know that sufficient subsurface data is of major importance for the initialization of both hindcasts used to develop and test coupled prediction systems and forecasts of evolving conditions in the tropical Pacific. Surface flux observations also provide a valuable means for evaluating the surface fluxes from NWP and coupled climate models. The initial PIRATA array backbone has provided sustained observations along the equator and the two meridional sections utilized in the routine generation of assimilated ocean products for both state estimation and initialization of coupled atmosphere-ocean prediction models. The rapid development of operational oceanography and the generation of ocean products from systems such as MERCATOR have generated an operational demand for PIRATA observations. The recent extension of PIRATA to the SW and the proposed extensions to the NE and SE offer a valuable enhancement of the existing observational network that underpin such products.

1) Ocean state estimation

Over the time period that PIRATA buoys have been deployed, ocean state estimation has progressed from a research activity to the operational generation of ocean products initiated under the framework of GODAE. For many years, PIRATA has been a major source of tropical Atlantic observations to research assimilation schemes for the global ocean such as the Simple Ocean Data Assimilation (SODA) of Carton et al. (2000a, b). The success of such efforts has paved the way for the development of operational ocean products.

The MERCATOR project (see http://www.mercator-ocean.fr/html/mercator/index_fr.html), for example, grew out of an initial focus in the North Atlantic to one for the global ocean. This French operational oceanography project is routinely using PIRATA data processed in real time by the French data centre CORIOLIS (see http://www.coriolis.eu.org/). Such product generation of operational oceanography for the tropical Atlantic is now possible because the oceanic data from the ATLAS buoys are made available in near real-time (as a result of their transmission by the Global Telecommunication System).

Since 2003, MERCATOR has been running a fully multivariate operational system (named PSY1V2) over the North and Tropical Atlantic that assimilates sea level (from satellite altimetry), SST, and temperature and salinity at depth. Compared to the former system that assimilated only satellite altimetry to constrain the sea level at the basin and mesoscales, the multivariate assimilation scheme corrects the water masses representation and evolution with the in-situ temperature and salinity data (see Benkiran et al., 2004). In this regard, the PIRATA network supplies daily means of observed temperatures (11 between the surface and 500m depth) and salinity (4 between the surface and 120m depth). It is assumed that these observations have a positive influence on MERCATOR's operational nowcasts. These measurements make it possible, in a region otherwise undersampled in the upper ocean, to delimit the unique equatorial dynamics of the region and to constrain estimates of heat content of importance when linking to the extra-tropics. Moreover, the high temporal sampling afforded by PIRATA makes it possible to observe tropical waves that distort the thermocline and would otherwise be aliased by infrequent observations.

Thus, the contribution made by the assimilation of the PIRATA data into the MERCATOR operational forecasting system should be very positive. To verify this, impact and sensitivity studies are carried out at MERCATOR, and the specific impact of PIRATA data is assessed as follows:

- Verify what is the impact of PIRATA in the real time forecasting framework
- Verify the impact of PIRATA data for estimating the ocean circulation
- Verify the impact of PIRATA data compared to others data type

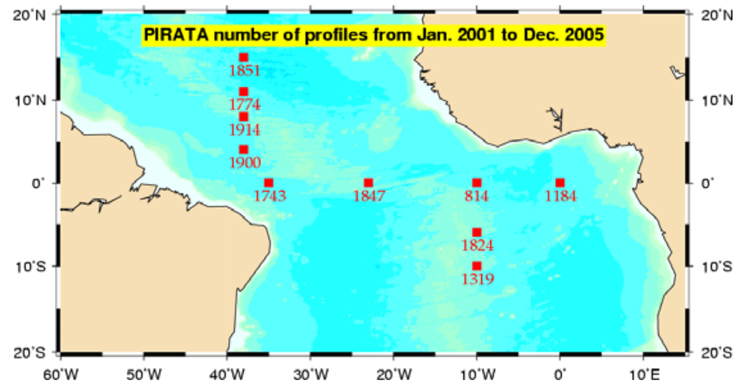


Figure 13: Number of daily profiles transmitted by the CORIOLIS data center to Mercator operational system from January 2001 to December 2005.

First we consider the subsurface thermal observations from PIRATA available since 2001 when MERCATOR first became operational. Figure 13 indicates that the ten PIRATA moorings have provided unequal number of daily measurements; less in the eastern tropical Atlantic and approximately one subsurface temperature profile per day over five years for the western moorings.

Figure 14 shows the annual number of subsurface profiles transmitted to MERCATOR Ocean. The mean rate of one PIRATA profile per day is reached in 2003 and 2004, but in other years is 20-30% less. While these numbers stay more or less stable, we observe that drifting buoy type (TR), CTD (CT), or other mooring data (MO) vary considerably from one year to the other and from region to region as a function of dedicated field programs and experiments. For instance the two German "MOVE" moorings in 2003 provided a number of profiles equivalent to that from the PIRATA moorings. However, these data were not obtained in real time. Note Figure 14 displays the delayed mode dataset for 2001 to 2003, and the real time data for 2003 to 2005. In 2003, both the MOVE and TR data were not available in real time. The large number of MOVE data in delayed mode in 2004 and 2005 reflects the high temporal resolution of the internally recorded time series. For comparison, if the 10-minute internally recorded PIRATA data were used instead of daily averages for computing the statistics in FHZ-2, the number profiles would increase by a factor of approximately 144 (*e.g.* 613,440 profiles in 2004).

We also observe that the amount of PIRATA data (3347) is slightly higher than in delayed mode (3630) due to more drastic off line quality control. The two other data types transmitted in real time provided by international observation programs are the XBT and the Argo profiling floats. The number of XBTs has been growing from 1500 to 2500 profiles for 2002 to 2005 (the larger number of profiles in 2001 can be explained by dedicated experiments in the Gulf of Mexico). This number is always lower than the number of PIRATA profiles each year. XBT data are distributed along the commercial lines associated with the ship of opportunity -VOS- programs. Over the past five years, the number of ARGO floats has been growing significantly in relation with the development of the program: less than 3000 in 2001, more than 5000 profiles per year in 2005. Note, again, in 2003 the lower number of delayed mode data compared to real time, due to post-processing that excluded erroneous profiles (around 20%, compared to the 7% of PIRATA data). This important number of rejected profiles might exhibit quality concerns with ARGO profiles, due to instrumental errors and biases increasing during the life of the floats.

In order to determine precisely the number of salinity and temperature measurements provided by the different datasets as a function of depth, the data distribution has been analyzed more specifically in the tropical Atlantic area (the blue rectangle plotted for year 2005 in figure 14). The number of measurements per month for all depths is plotted in figure 15. The total number of measurements (blue line) for temperature and salinity exhibit peaks resulting from an increase of CTD or XBT measurements from field experiments, in particular all the PIRATA campaigns. Note that the number of salinity observations is 5 to 10 times lower than temperature measurements. For temperature and salinity, the number of PIRATA measurements (in red) is approximately constant. However salinity data were not available from the CORIOLIS center in 2001 and 2002. Both salinity and temperature monthly averages show the growing contribution of ARGO floats. The relatively low number of

PIRATA data in figure 15 reflects the relatively coarse vertical resolution and more limited vertical range of PIRATA data compared to CTDs, XBTs and floats.

To detail which depth and water masses are sampled through these measurements, the data and type have been plotted as a function of depth in figure 16. Near the surface, PIRATA measurements provide an equivalent number of temperature measurements as the ARGO or XBT programs. In 2003 and 2004, the PIRATA array provided more salinity measurements. As discussed below, the fixed location of regular, high temporal resolution profiles of both temperature and salinity proves very important for reducing systematic ocean model biases. In 2005 the increasing number of deep floats raised the ARGO salinity contribution. Below and above the thermocline, we can, again, observe that the contribution of ARGO floats is growing, and the number of PIRATA data is more or less stationary and 5 to 10 times less over the entire water column.

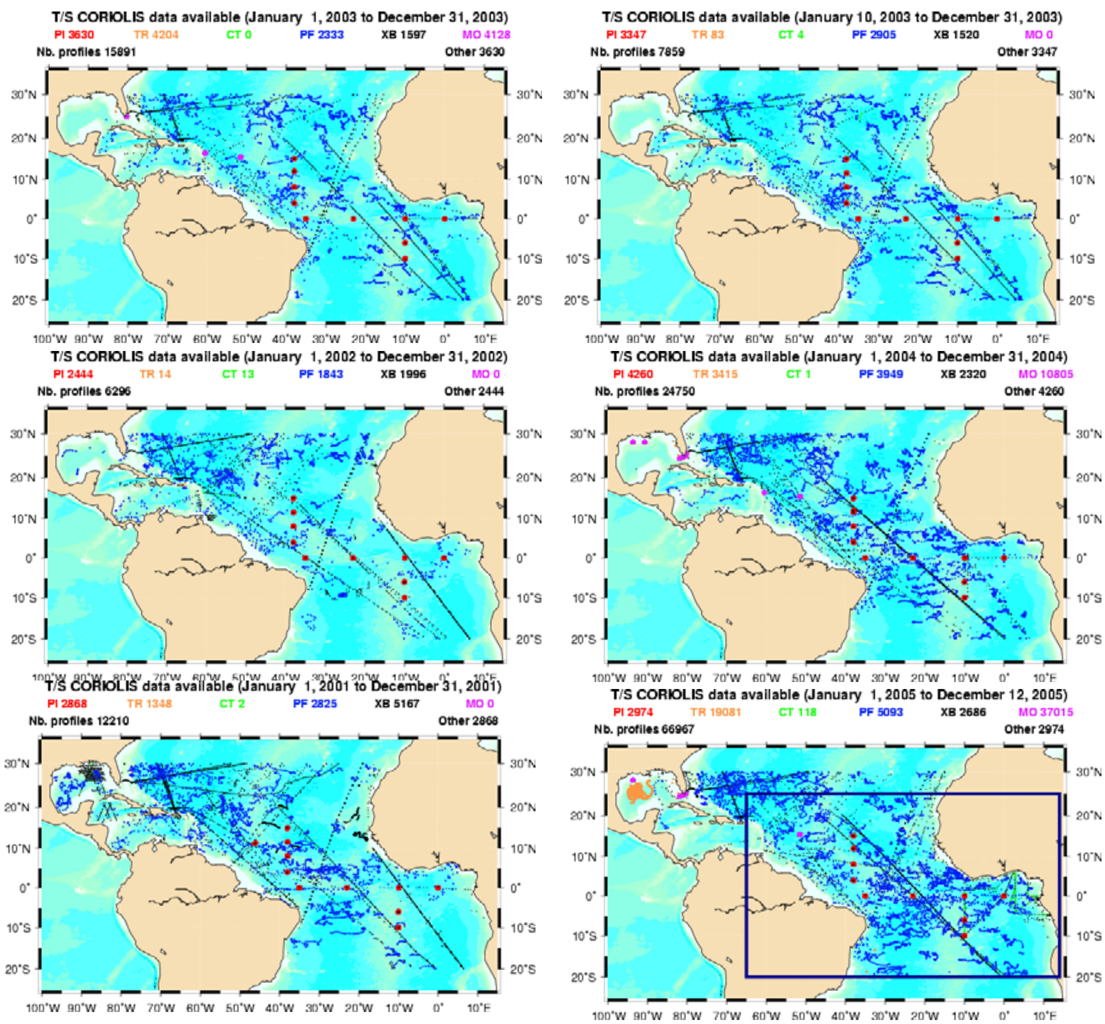


Figure 14: CORIOLIS data (profiles of T/S) available in the tropical Atlantic each year. In the left column delayed dataset in 2001 (bottom), 2002 (center) and 2003 (top). In the right column, near real-time data used by the operational system in 2003 (top), 2004 (center) and 2005 (bottom). Titles give the corresponding periods, and number of data type PI, TR, CT, PF, XB and MO for respectively PIRATA, instrumented drifting buoys, CTD-like, profiling floats (ARGO program), XBT, and moorings others than PIRATA. Colors for data are corresponding to the data type. "Others" are non-identified data. For PIRATA, delayed mode profiles would increase by a factor of approximately 144 if internally recorded 10-minute values were used instead of daily averages.

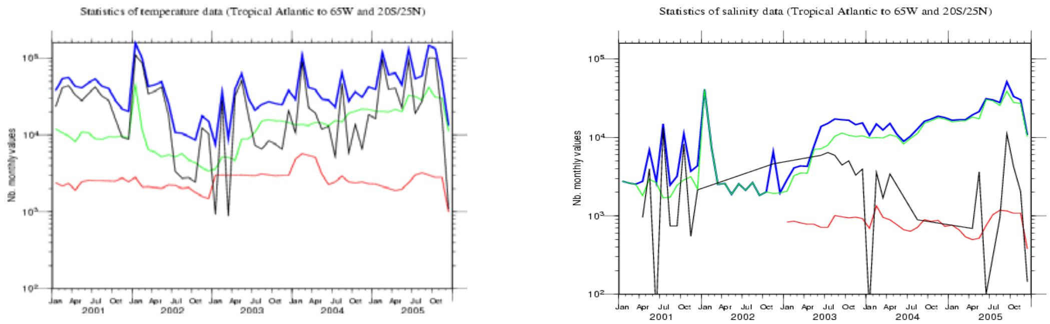


Figure 15: For temperature (left) and salinity (right), monthly averages of values for all depth in the tropical area (as defined by the blue zone in figure 14) are plotted. Respectively all data, PIRATA data, ARGO and CTDs, and others (XBT, XCTD, drifting buoy etc..) in blue, red, green and black lines.

In summary in the tropical band, three kind of operational programs are providing data in real time. XBTs are obtained regularly along ship lines, with additional data from field experiments, sampling only temperature from the surface to below the thermocline, with relatively higher observational errors. The temporal sampling is obviously low. The ARGO project is providing an increasing number of temperature and salinity data from the surface to below the thermocline. ARGO data quality is strongly dependent on instrumental life and its spatial sampling depends on the dispersion of the floats. ARGO is now providing basin-scale information of the full tropical Atlantic at the monthly scale. In contrast, the PIRATA moorings are providing daily temperature and salinity at dedicated and "strategic" locations. These observations, by design, are principally above the thermocline. The PIRATA data are of high quality, but data return also suffers from vandalism.

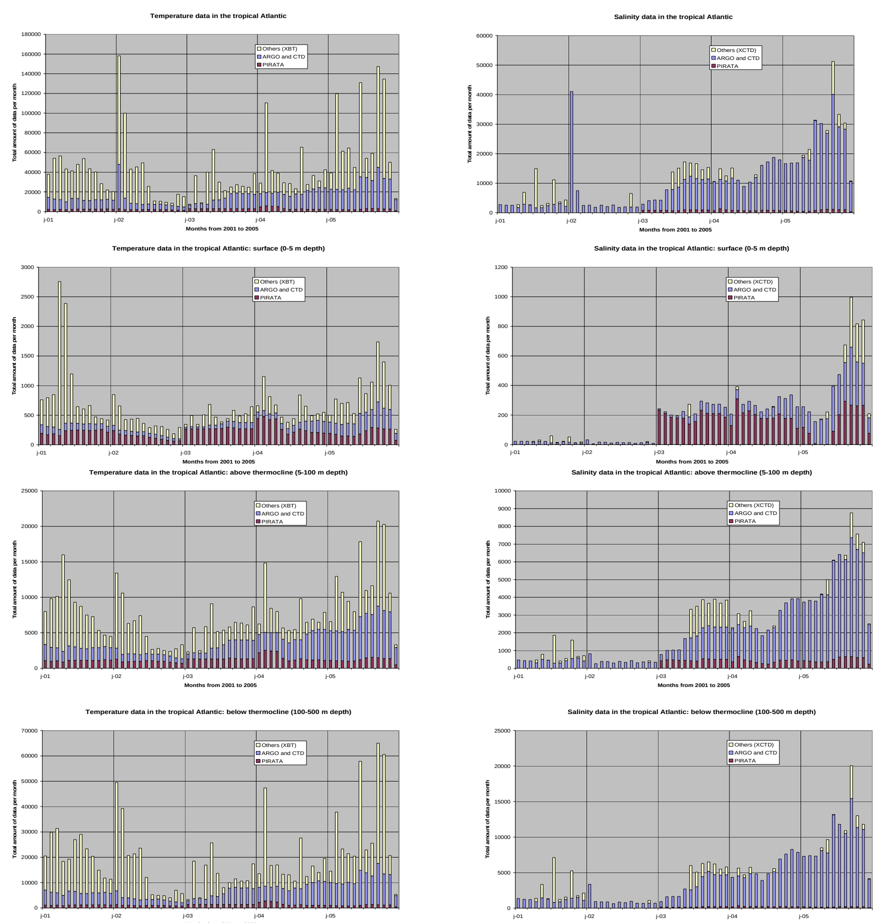


Figure 16: Distribution of temperature (left) and salinity (right) measurements for all data (top), similar to figure 15, for depth between 0 and 5 meters (2nd row), depth between 5 and 100 meters (3rd row) and 100 to 500 meters (bottom).

Given this overview of the PIRATA data volume relative to other platforms in the tropical Atlantic, we seek to know how important such observations are for constraining the dynamics in the tropical band, and whether this information is more relevant than the other data types, including satellite altimetry and radiometry. In this regard, impact studies have been performed using the MERCATOR Ocean PSY1V2 operational system (see http://www.mercator-ocean.fr/html/systemes_ops/index_en.html). This system uses a multivariate scheme that assimilates satellite altimetry, SST, and in situ temperature and salinity. It is based on a 1/3° resolution OPA model of the North and Tropical Atlantic, from 70°N to 20°S, forced by daily ECMWF wind stresses, heat and salt fluxes (see figure 17). In the operational mode, once a week (on Wednesday), the operational cycle is performed, starting two weeks before in hindcast and nowcast mode, followed by two weeks of forecasts. The assimilation scheme gathers every observation available during the previous two weeks, computes differences with model variables (temperature, salinity and sea level) and projects the misfits using 20 vertical multivariate EOFs in order to determine the innovation vector (*i.e.* analysis-observation difference). This vector corrects the model fields every week. Figure 17 shows the one week forecast of tropical Atlantic thermocline temperature in December 2005: the west/east thermocline slope, with warm water in the western side, the eddy activity of the North Brazil Current retroflection and North Equatorial Counter Current are clearly visible.

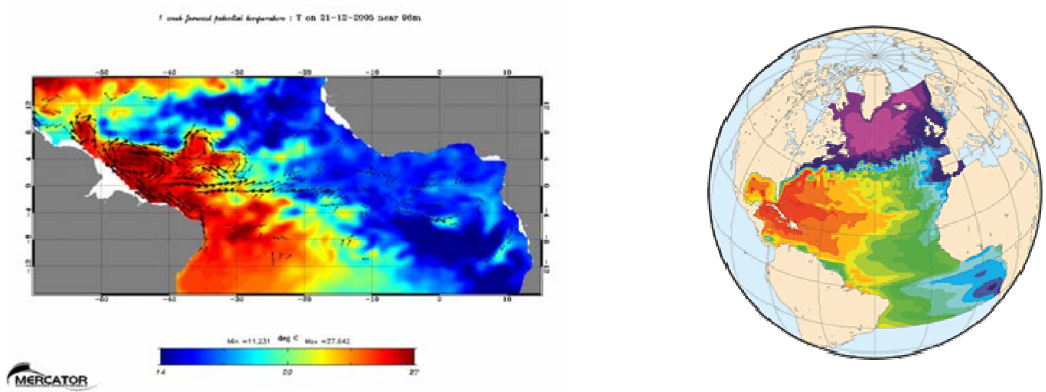
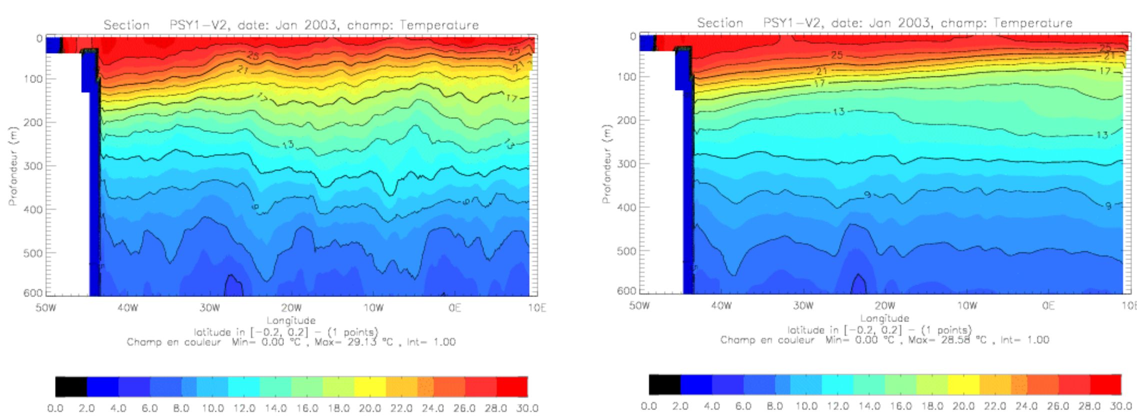


Figure 17: description of the PSY1V2 Mercator operational system:
Left: 100 m ,one-week forecast temperature the 21st of December 2005, from the 14th of December run.
Right: PSY1V2 : 1/3° horizontal resolution operational system from 70°N to 20°S, with 43 vertical level, varying from 12 m at the surface, to 200 m below 1500 m.

As recommended by the PIRATA-SSC in 2004, a PIRATA data impact study (the so-called PERENE, for "PIRATA EuleRian Essential Network Evaluation") was performed for 2003. Indeed, 2003 has been the year, until now, with the best PIRATA data return: all the 10 ATLAS buoys of the original PIRATA array were operational all along this year. Two special runs were based on the dataset shown in figure 14 for 2003. One run was performed with all available data, the second run with all, but the daily PIRATA data. The simulations start with the climatological field (the 1st of January 2003) for temperature and salinity, and the ocean at rest for the velocity field. Figure 18 illustrates the water mass spin up after one month. With the PIRATA data, the structure of the equatorial thermocline and currents (not shown) are significantly more realistic.

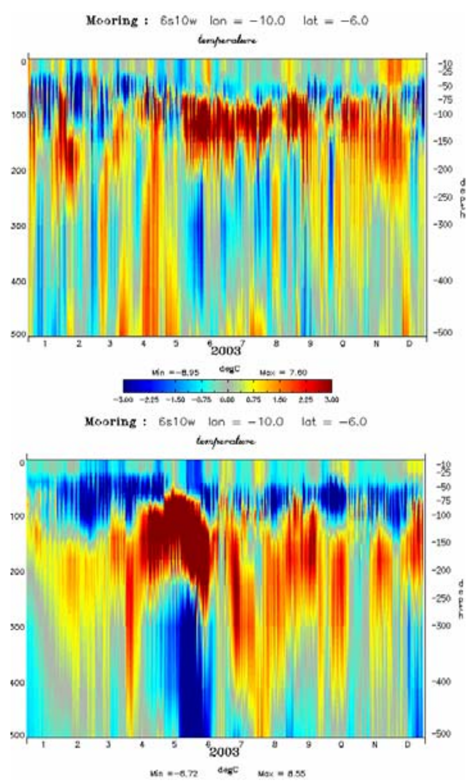
Figure 18: Vertical section at the equator, average of temperature for January.
Left: simulation with PIRATA data assimilation;
Right: simulation without PIRATA assimilation.



From a first set of run, at mooring locations, the temperature and salinity field from the two model simulations were compared with PIRATA data. The table below shows that both temperature and salinity model field were improved using PIRATA data. The improvement on salinity was more important. However, these overall statistics show that net improvements were lower than expected (there is still more than 2°C/0.4psu difference). A more careful analysis showed us that these differences depend on the depth, season and location, as shown by figure 19. Differences (more than 3°C) from 30 to 200 m depth are strongly reduced when PIRATA data are assimilated. However, differences in both run show a negative/positive band that exhibits a too vertically diffused thermocline, even if this effect is reasonably reduced when assimilating PIRATA data. Note also that differences below the thermocline are well reduced, witnessing the positive impact of PIRATA temperature sensors at depth.

	with PIRATA data	without PIRATA data
Temperature difference	2.20°C	2.78°C
Temperature correlation	0.98	0.94
Salinity difference	0.41 psu	0.50 psu
Salinity correlation	0.69	0.49

Tropical current structures and variability were also examined. PIRATA data allow rectifying the zonal current structure as shown by Figure 20. As shown above, the thermocline is less diffusive, but all currents are meridionally and vertically better positioned. The impact of PIRATA temperature and salinity data is thus obvious: by correcting (even imperfectly) the water masses, the full tropical dynamics is constrained in the MERCATOR system.



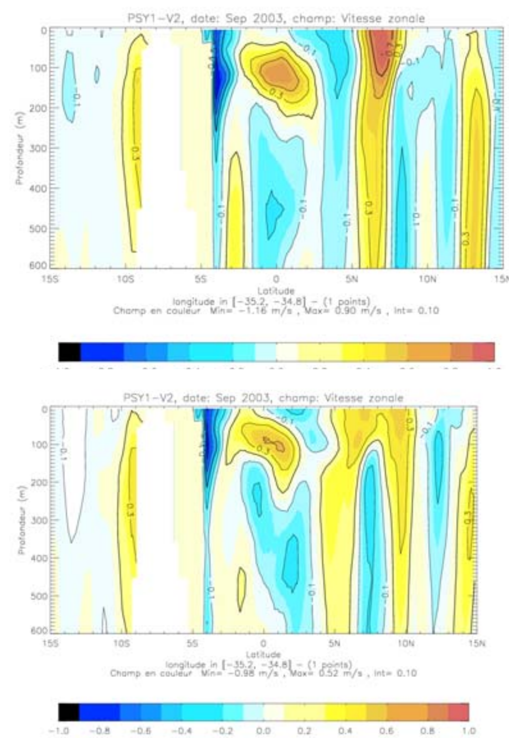


Figure 19 (left): Time series of temperature differences at 10°W/6°S, during 2003. For the two simulations: with (top) and without (bottom) PIRATA data.

Figure 20 (right): Meridional vertical section of zonal velocity at 35°W (from 15°S to 15°N). Velocity field averaged in September 2003, for the simulation with (top) and without (bottom) PIRATA data.

Daily output were also compared to independent current measurements from the ADCP at 10°W-0°N between May and December 2003 (see also section B.1.b.3). Figure 21 shows that currents in the model are noisy due to assimilation shocks. Meridional velocity are poorly correlated to observed data, however, zonal velocity better match the observation, in particular after July, when we noticed that salinity data were effectively assimilated (before, salinity PIRATA data were available for these simulations). Vectorial correlations clearly show that the assimilation of temperature and salinity data improve the EUC description in the model run.

This first set of dedicated experiments and the impact on temperature field raised several problems in the assimilation technique: the first impact of the PIRATA dataset has thus been to force the MERCATOR team to revisit and to improve the assimilation scheme that was successfully implemented in the operational system (Benkiran 2005, see http://www.mercator-ocean.fr/documents/lettre/lettre_13_art1_en.pdf). From it, a new set of simulations has been performed (*i.e.*, with and without T/S PIRATA data).

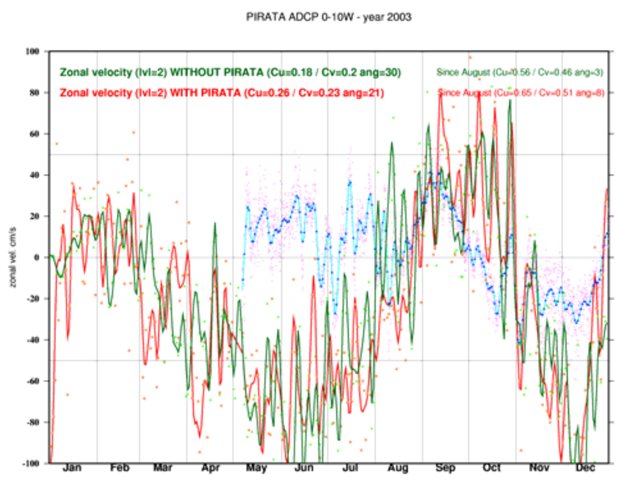


Figure 21: Zonal velocity at 26m depth from ADCP measurements at 10°W-0°N (purple) and 5-day low-pass filtered (blue). Daily outputs from the 2 runs, also 5-day low-pass filtered, are superimposed (red, assimilating PIRATA data, and green without PIRATA data). Vectorial correlations are indicated for the two run.

These new simulation confirm that T/S PIRATA data improve both the water masses and the dynamics into the MERCATOR forecasting system. Figure 22 shows that the slope and the intensity of the EUC are strengthened when using PIRATA data, and dubious currents near the surface or at depth are also reduced. Figure 23 shows that the thermal content, the position and vertical extent of the thermocline, and variations at depth are better represented when assimilating PIRATA data.

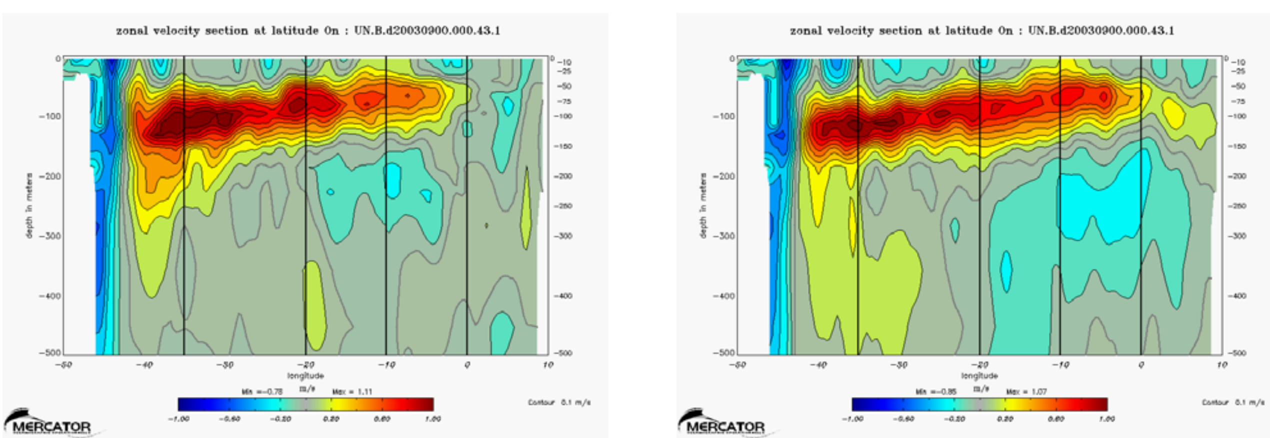


Figure 22: Equatorial vertical section of monthly average (September 2003) of zonal velocity. With (left) and without PIRATA data (right). The vertical black lines indicate the location of the PIRATA moorings.

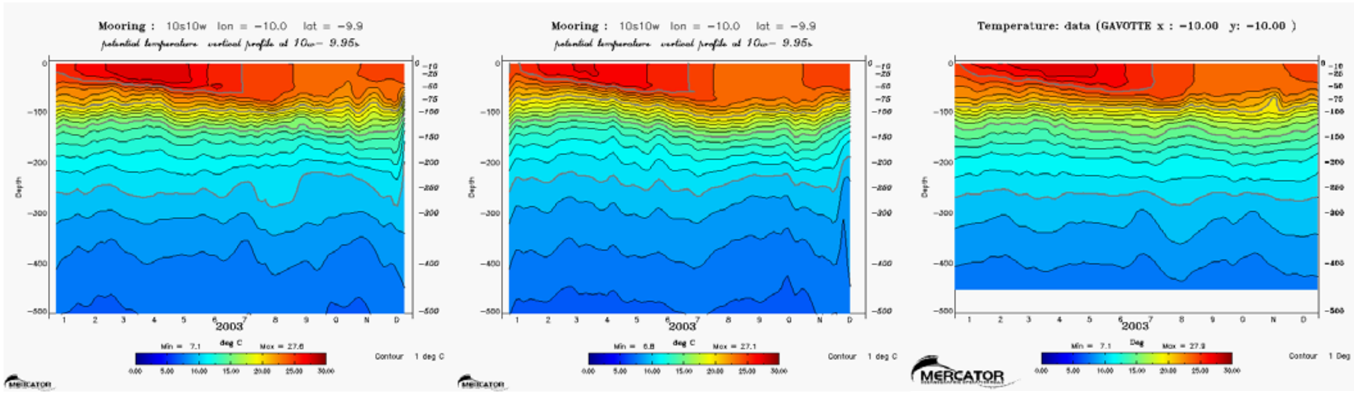


Figure 23: Time series of temperature in 2003 at 10°W-10°S. From the simulations with (left) and without (middle) PIRATA data, and the corresponding PIRATA observations (right).

Although preliminary, impacts studies such as this indicate the frequency and extent of the PIRATA measurements constrain the upper ocean thermal structure in a region for which equatorial dynamics require high-resolution temporal sampling. Thus, the contribution made by the assimilation of the PIRATA data into PSY2-V1 is very positive, at least given the current state of development of the MERCATOR system prototypes and the observation networks in place in the Tropical Atlantic Ocean.

Moreover, such studies can also be performed to measure the future impact of the network extension. Figure 24 shows that the tropical band is particularly sensitive to temperature and salinity variations: In 2003, most of the differences with the climatology at the thermocline level are located between 20°N and 20°S; witnessing a possible systematic bias in the model, or the signature of an interannual variability higher than at other latitudes. Then, the salinity increment statistics clearly show that needs for corrections are the highest in the tropical band, even more than in the Gulf Stream area. Both figures indicate a need for more observations in the Gulf of Guinea, the North Brazil Current and its retroflection area, and the eastern tropical Atlantic.

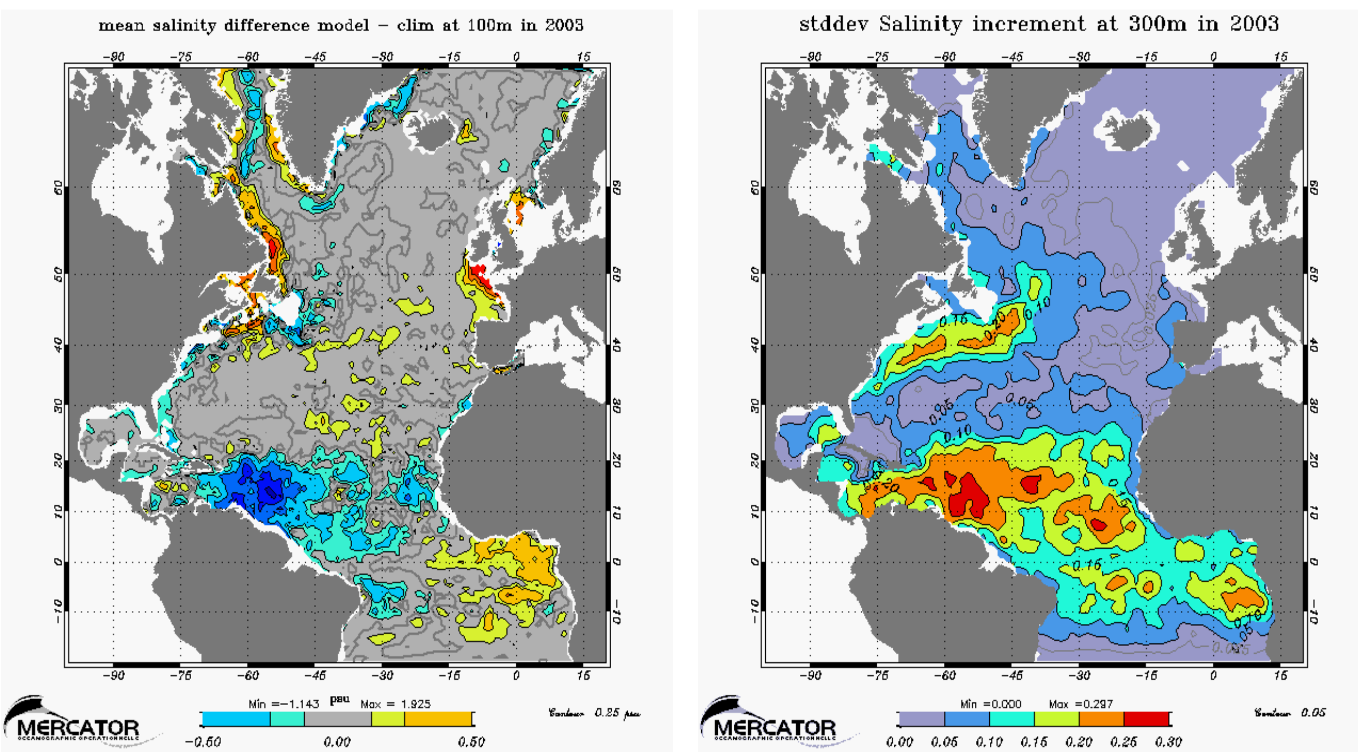


Figure 24: Left: annual averaged difference of temperature at 100m depth between the PSY1V2 Mercator forecasting system and the Levitus climatology. Right: Annual statistics of the salinity increment at 300m depth in the Mercator multivariate assimilation scheme.

2) Forecasting

i) Weather:

As with the ocean data assimilation, the surface meteorological fields from the ATLAS buoys are assimilated in near real-time (via Global Telecommunication System transmission) into predictive atmospheric models (e.g. by the weather forecasting departments of Météo-France, the European Centre for Medium-Range Weather Forecasting (ECMWF), the UK Met-Office, and the National Centers for Environmental Prediction (NCEP). An impact study of PIRATA data in the data assimilation system of Météo-France was conducted in 2005 by the Centre National de Recherche Météorologique (CNRM) of Météo-France. Since the network has been established, the number of PIRATA observations of sea surface temperature, wind and air temperature being assimilated has been rising steadily. This increase is the result of an improvement in the operation of the sensors and of the associated transmissions on the moorings. It is worth noting, the frequency of observations acquired up until early 2005, compared to the maximum theoretical number per buoy, was low (10 to 20%), mainly due to the limited data transmission window to the Argos satellites. In 2005, multiple satellite passes by Argos, and increased transmission time for newly deployed moorings, increased considerably the real-time data feed that now reaches 40 to 50% of the total number of observations recorded internally on the mooring. The impact study does not provide the specific impact of the PIRATA data set on the model forecast scores over the region. However, the root mean square difference between the PIRATA observations and the model guess field resulting from a 6-hour forecast provides a measure of the potential impact of the assimilated data if given sufficient weight in the assimilation scheme. The order of magnitude of the difference is typically 0.4°K for SST, 1.3 ms^{-1} for wind speed, 18° for wind direction and 0.6°K for air temperature. This shows that PIRATA data have significant potential for improving the initial analysis of weather forecasting in the region. Another study conducted at ECMWF (Bidlot, 2005), albeit not devoted specifically to PIRATA data but to all mooring and drifting buoy data, pointed to the need to account for the true level of wind measurement in the data assimilation system. This impact study using the actual anemometer reading when assimilating surface wind from DRIBU's moored and drifting buoys, showed a reduction of the negative bias between the model and the ATLAS mooring observations in the Tropical Pacific. This procedure also resulted in an improvement of the medium range forecast scores (5 to 10 days) in the most parts of the region as well as for the 1000Hpa geopotential and wind speed at 10m.

ii) Seasonal Climate Forecasts:

PIRATA data are used in operational seasonal forecasts via data assimilated into oceanic models that provide ocean initial conditions using coupled ocean-atmosphere models. In particular, specific data assimilation systems were implemented at ECMWF for a newly provided multi-model seasonal forecast utilizing ECMWF, UK Met-Office and Météo-France coupled models (the so-called MERCATOR assimilation system in this last case). In the USA, NCEP has recently initiated an operational ocean analysis for the Atlantic Ocean in support of both operational oceanography and coupled ocean-atmosphere climate forecast. For monthly forecasts, a real-time ocean analysis is required. Previous attempts relying on delayed mode observations with an update cycle of order 10 days proved unacceptable. An analysis of the impact of PIRATA observations on the ECMWF ocean assimilation system has been performed recently, but as in the case of NWP, the impact on the seasonal forecast scores has not been analyzed specifically (Balmaseda, personal communication). Basically, the PIRATA temperature data change the ocean mean state by correcting the diffuse thermocline of the ocean model. If the assimilation scheme is univariate with respect to temperature this can corrupt the salinity field and the sea level (Troccoli et al., 2002). A multivariate scheme that updates the salinity field when assimilating temperature data improves the fields, thus pointing to the importance of the salinity observations from PIRATA. However, due to the model systematic error, the interannual variability of the analysis is affected by the changes in the observing system. In particular, the PIRATA data in the Atlantic have a large impact on the interannual variability of the analysis. The impact is positive if we consider only the PIRATA period (after 1999). Care should be taken however when analyzing longer historical records, when the changes in the mean state caused by the data themselves can be misleading and interpreted as spurious interannual variability (Segshneider et al., 2000; Balmaseda, 2002, 2003; Balmaseda et al., 2005; Stockdale et al., 2005; Vidard et al., 2005).

d) Unanticipated advances

In addition to addressing its primary scientific goals, PIRATA contributed to advances in areas not fully anticipated at the start of the program. In particular, PIRATA goals highlighted surface heat fluxes and SST variability and their role in contributing to modes of climate variability in the basin. However, program objectives did not explicitly refer to fresh water fluxes and ocean salinity variations because it was less clear what PIRATA might contribute to the study of this variability. The reason in part was that PIRATA was conceived and designed at a time of technology evolution from the standard ATLAS system used extensively in the Pacific's TAO (Hayes et al., 1991) to a newer generation ATLAS that would include optional rain and salinity measurements as part of the measurement suite (Milburn et al., 1996). These newer systems are now routinely used in TAO/TRITON and PIRATA, but at the time PIRATA was inaugurated, the specific sensors used in the new generation mooring were not thoroughly field tested and validated. The accuracy and utility of these sensors has now been established (e.g. Serra et al., 2001; Delcroix et al., 2005) and the data have supported a number studies that broadly address PIRATA's goals of improved description and understanding of seasonal-to-interannual variability and provision of data sets to develop and improve predictive climate models.

Examples include studies on the time and space scales of sea surface salinity in the Atlantic (Delcroix et al., 2005), the value of ocean salinity data in ocean assimilation systems for the Atlantic (Segschneider et al., 2000, 2001; Troccoli et al., 2002), and definition of the barrier layer in the western Pacific and Atlantic and its importance in the surface layer heat balance (Pailler et al., 1999; Foltz and McPhaden, 2005). Grodsky et al. (2005) identified the importance of accounting for effect of salinity on the density field in estimating the baroclinic energy conversion in tropical instability waves. PIRATA data have also contributed studies of open ocean rainfall variability in the tropical Atlantic. In particular, Serra and McPhaden (2003, 2004) used the time series data to define the diurnal cycle of rainfall over the ocean and to evaluate TRMM microwave and radar rainfall measurements.

Foltz et al. (2003) relied heavily on PIRATA rainfall and salinity data to diagnose the seasonal cycle of the mixed layer salt balance in the western tropical Atlantic. The balance is strongly influenced by seasonally varying precipitation associated with the latitudinal migration of the ITCZ. However, Foltz et al. (2003) also demonstrated that, unlike the mixed layer heat balance, which is primarily one dimensional off the equator in the Atlantic, horizontal advection is highly significant in the mixed layer salt balance. Major influences include seasonally varying Ekman currents in the presence of strong mean meridional salinity gradients associated with ITCZ rainfall, and advection of water diluted by Amazon River discharge in the western basin. Quantitative evaluation of these salt balance terms (Figure 25) would not have been possible without the PIRATA data set.

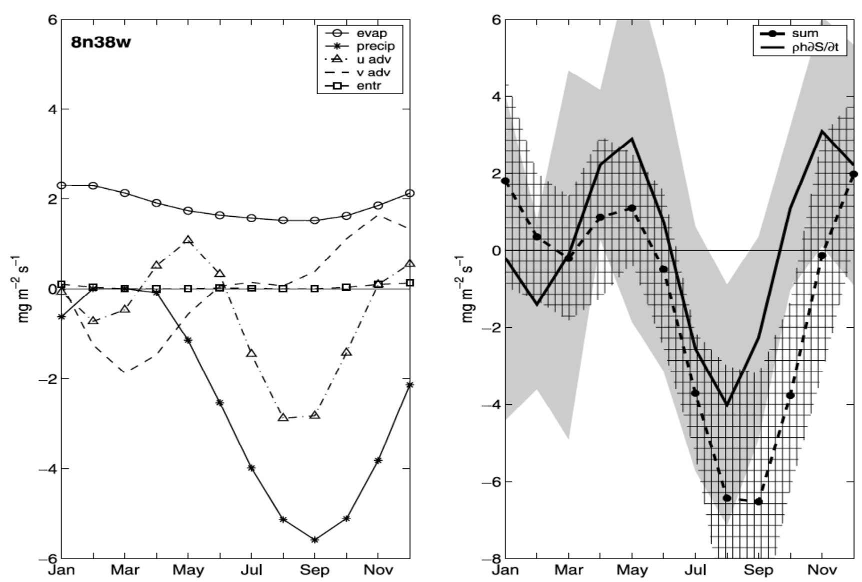


Figure 25: Terms in the mixed layer salinity balance at 8°N-35°W from Foltz et al (2003). "Sum" in the right panel represents the sum of the terms in the left panel. Shading in the right panel indicates uncertainties for the sum and storage estimates.

It was also unanticipated at the start of PIRATA how valuable the data from repeated mooring cruises would be. The program was based on moorings as the centerpiece of the measurement effort. However, as with the TAO/TRITON array, annual cruises in the tropical Atlantic have lead to an accumulated archive of CTD and ADCP sections which have contributed to advances in the description and understanding of the complex current system of the region, as described in Section 2.a above. These cruises have also provided shipboard thermosalinograph data which were used in the Delcroix et al. (2005) SSS scale analysis and which are routinely incorporated into the Global Surface Underway Data (GOSUD) project archive (http://www.gosud.org/). The availability of the ships servicing the PIRATA array as platforms of opportunity has in addition made possible other scientific advances, such as studies of ocean circulation in the upper 1600 m (Bunge et al., 2006).

Finally, although it was anticipated that PIRATA would contribute to operational oceanography as a component of GOOS and GCOS, it was not appreciated how strongly the pull from the operational community would be for PIRATA data. The many activities that demand these data for development of ocean assimilation systems and for constraining ocean model analysis in the tropical Atlantic, as described in Section 2.c above, attest to the value that the operational community has assigned to PIRATA data. The ready availability of the data via the GTS and the WWW in real-time have helped to create this demand, which continues to grow as operational oceanography itself develops and matures.

3. PIRATA and the Tropical Atlantic Observing System with Links to Relevant Programs in the Region

Oceanographic and meteorological observations in the Tropical and South Atlantic Ocean are rapidly becoming more important for both weather and climate forecasting. As discussed in previous chapters, prior to PIRATA the main source of sustained observations in the tropical Atlantic were the SOP XBT and SVP, each with their attendant sampling limitations. The fixed time series measurements from the PIRATA moorings together with observations from the regular deployment and service cruises has since become the backbone of the tropical Atlantic observing system. The addition of ARGO floats has served to complement the unique, high temporal sampling and limited spatial extent of the original set of PIRATA buoys. PIRATA also provides a broad scale context in the tropical Atlantic for more heavily instrumented moorings of the Ocean Sustained Interdisciplinary Timeseries Environment observation System (OceanSITES) program by providing high quality measurements relevant to the estimation of surface turbulent heat fluxes and shortwave radiation. Three PIRATA mooring sites have been identified and funded beginning in 2006 for enhancements that will make them capable of the estimating all components of the surface heat flux (including long wave radiation) and for improving the definition of mixed layer depth (See section C1).

Compared to what the situation was when PIRATA began nine years, this loose federation of complementary observational platforms has become, de facto, the Tropical Atlantic Ocean Observing System,. Over this time period, PIRATA has also cooperated and communicated on a frequent basis with the CLIVAR Atlantic Panel (including its national participants such as Germany, France, Brazil, and the USA), OOPC, GOOS, GCOS, GLOSS, GEOSS, JCOMM, and CORIOLIS. Actually, through the concerted efforts of those participating nations and institutions, PIRATA has become a worldwide recognized GOOS and GCOS pilot-project in the region. By way of membership in the PIRATA-SSC, organizations such as INPE, CPTEC, FUNCEME, IRD, Météo-France, CNRS, MERCATOR/GODAE, and NOAA have all been regularly informed and have had input to the direction of PIRATA. In addition, PIRATA has also coordinated with fixed duration field programs such as the French EGEE (French “ocean and air-sea flux” component of AMMA). The PIRATA-SSC has been actively involved in the development of new programs as, *e.g.*, TACE and AMMA. With the onset of AMMA in 2001, more than 25 institutions in Africa, Europe, and the United States developed a plan to improve prediction of the West African Monsoon and Atlantic hurricanes. AMMA has been endorsed by CLIVAR and the Global Energy and Water Cycle Experiment (GEWEX). AMMA requires long-term observations in the Atlantic Ocean through at least 2010.

PIRATA must also be considered as a relay mechanism to gather operationally extra measurements in the Atlantic basin, such as CO2, currents and waves, as well as additional measurements for the existing ATLAS systems. Ship time requirements for PIRATA during maturity shall be sensitive to support other systems in addition to PIRATA, and therefore scoping observational requirements in the South Atlantic region, as a whole.

The Brazilian Ocean Observing System Program, called GOOS/Brazil, has incorporated PIRATA as part of its activities since its conception, in 1997. Support to PIRATA operational activities have therefore been prioritized in the country. It is worth noting that PIRATA constitutes an element of the Regional Alliance in Oceanography for the Upper Southwest and Tropical Atlantic (OCEATLAN) that has been launched in March 2005, and serving as the GOOS Regional Alliance for the Tropical Atlantic. PIRATA data figures as one module of the experimental GOOS Regional Alliance web page (http://goos.io.usp.br) where data is made available for several other projects carried out in the Atlantic basin. The Web site will also provide links to national oceanographic data centers where data from the vessels performing PIRATA operations will also be available. More recently, PIRATA has been recognized as an integral part of an Inter-regional Alliance for Oceanography and Antarctic Research (OCEANIBSA) that gathers representatives from India, Brazil and South Africa, since Sept. 2005. The PIRATA Southeast Extension, as proposed by South Africa, is to be considered as a major contribution to OCEANIBSA, whenever approved.

C. PIRATA – Future Perspectives

1. Extensions and enhancements

The PIRATA array faces a number of strategic and logistical demands that must be addressed in the immediate future. At the same time, extensions of the array have been initiated, with more planned and funded, greatly magnifying the scope of scientific issues and operational value addressed by PIRATA.

a) Extensions

During the PIRATA-6 Meeting (Miami, 1999) the PIRATA-SSC wrote a resolution (see Appendix 9) to encourage consideration of scientifically sound pilot expansion projects that build upon the original PIRATA array. Moreover, in this note, the PIRATA-SSC invited collaborations with other nations and institutions interested in implementing a sustained climate observing system in the tropical Atlantic.

Thus, under the initiative of the PIRATA-SSC Chairman, and with the collaboration and financial help of a few international institutes (*e.g.*, WMO, UNESCO-IOC, ...), three special meetings (see Appendix 3) were organized in order to provide the foundations of such extensions. The first one of these meetings occurred at Cape Town (South Africa) in December 1999 and was dedicated to a South-East Extension (PIRATA-SEE). A second one was organized in March 2000 at Casablanca (Morocco), where the first basis of a North-East extension (PIRATA-NEE) was discussed. The third one held at Fortaleza (September 2000) with an initial attempt for a launching of the South-West Extension (PIRATA-SWE). For each one of these regional meetings, representatives of institutes from most of the regional countries participated, as well as representatives of other countries and international institutes. Due to large differences in the local and regional scientific priorities and, especially, due to large differences in the regional financial, human, and shipping resources, these three extensions had varying stages of development. After international scientific evaluations and external review of these proposed extensions projects, the two first PIRATA extensions (PIRATA-SWE and PIRATA-SEE detailed below) are now underway. The potential regional participants of PIRATA-NEE did not succeed to realize their initial attempt. However, this last extension was finally proposed by USA in 2005, with funding for implementation identified (see below). Future extensions may be initiated in cooperation with these existing activities.

Thus, with the deployment of three moorings off the coastal waters of Brazil in August 2005, the first major extension of the array coverage was implemented. The two additional extensions have also been proposed, with funding for implementation identified, as detailed below. PIRATA array as it should be in 2007 is presented in Figure 26.

i) PIRATA South-West Extension (PIRATA-SWE)

Proposed by Brazil in 2000 and positively evaluated by the PIRATA community in 2005 (Nobre et al., 2005), the PIRATA Southwest Extension (PIRATA-SWE) was inaugurated in August 2005, with three ATLAS buoys moored at 8°S-30°W, 14°S-32°W and 19°S-34°W. The mission was carried out by the team of Brazilian engineers trained at PMEL and DHN officers with two DHN ships, the Antares and Amorim do Valle. The data transmitted by the three ATLAS systems of the PIRATA-SWE are collected by both the Service Argos satellites and the Brazilian SCD data collection satellites and made available in the GTS by Service Argos and made independently available at CPTEC/INPE web page at www.cptec.inpe.br. The data from the PIRATA-SWE are being used at CPTEC to assess weather forecast skill of surface variables done at CPTEC with its suite of atmospheric and coupled ocean-atmosphere GCMs. Other studies are currently underway to compare the first available data of the PIRATA-SWE with global and regional oceanic models (*e.g.* Araujo et al., in preparation).

ii) PIRATA South-East Extension (PIRATA-SEE)

The PIRATA Southeast Extension (PIRATA-SEE) was proposed by Mathieu Rouault on behalf of the PIRATA-SE Extension committee under the responsibility of the University of Cape Town (South Africa). It is a only a one year demonstration project due to the risk of vandalism and it is funded by the Benguela Current Large Marine Ecosystem program (BCLME). An extension of PIRATA in the South East Atlantic (PIRATA-SEE) around 6°S-8°E would have applications to marine ecosystem processes, fisheries-environment interaction, climate variability and forecasting. It will provide much needed capacity building and training. Besides gaining information on the physics of the seasonal cycle of sea surface temperature, ocean surface heat content and other key parameters, the extension could be used to monitor Benguela Niños (Shannon et al., 1986) or other oceanic warm events detrimental to society as they approach the region. Abnormal warm events are detrimental to fisheries and are associated with above average rainfall and floods over Angola and Namibia (Hirst and Hastenrath, 1983; Rouault et al., 2003). Floods have also an impact on the transport, refrigeration, retail and insurance industries. These impacts on fisheries, together with those on rainfall and the fact that Benguela Niños are an oceanographic phenomenon with relatively long lead times, suggests that better monitoring of the tropical SE Atlantic region is important and could have significant societal benefits. Warm and cold events off Angola are linked to the tropical Atlantic variability especially along the equator all the way to Brazil (Florenchie et al., 2003). It will be implemented during the EGEE3-PIRATA FR15 cruise in June 2006. If the 2006 test year for this buoy is successful (*i.e.*, it is not rapidly compromised by vandalism), IRD could continue to maintain this site and may be able to offer platforms for completing the extension with a second mooring as originally proposed in the BCLME feasibility study (Rouault, 2004).

iii) PIRATA North-East Extension (PIRATA-NEE)

A Northeast Extension was proposed to the PIRATA SSC in 2005 by Rick Lumpkin and Bob Molinari (NOAA/AOML) and Michael McPhaden (NOAA/PMEL). It is presently in review for consideration as a formal extension of the PIRATA array. Observations in this region will capture processes impacting interannual variations in the seasonal migration of the eastern ITCZ; the impacts of intraseasonal wind bursts, which may be analogous to MJO variations impacting the onset of ENSO events in the western Pacific; biases in remotely-inferred air-sea fluxes and SST due to, *e.g.*, Sahal dust outbreaks; and the dynamics governing evolution of upper ocean heat in the Tropical North Atlantic (TNA) region where atmospheric easterly waves develop (and often fail to develop) into Cape-Verde tropical cyclones and ocean advection (presumably) provides a negative feedback mechanism to WES coupling of the northern and southern hemispheres.

Funding has been identified via the NOAA's Office of Climate Observations (OCO) for the first two moorings of this extension, to be constructed at PMEL, and to support ship time (NOAA/AOML and OCO) to enable their deployment. This cruise will be aboard the NOAA vessel *Ronald H. Brown* during AMMA Leg One (chief scientist R. Lumpkin, 27 June-17 July, 2006). The cruise will be used to conduct a hydrographic survey down 23ºW, from 24ºN to 5ºS, and to deploy ATLAS buoys at nominal latitudes of 11.5ºN and 6ºN. This cruise will also be used as an opportunity to service the 0°N-23ºW PIRATA backbone mooring for summer 2006.

Future support for the deployment of additional moorings at 20ºN, 23ºW and 20ºN, 38ºW and servicing of the 2006 moorings have been proposed to NOAA's Office of Climate Observations. Ship time aboard the R/V *Ronald H. Brown* for 2007 has also been requested. Deployments and servicing in 2007 would expand the proposed Northeast Extension to a four-mooring array, including a proposed full-flux mooring. In explicit recognition of the ideal six-month servicing schedule for ATLAS moorings (particularly given increased biofouling in upwelling regions and large anticipated dust deposit), the 2007 ship time has been requested for two shorter (approximately 30d) legs, optimally separated by six months.

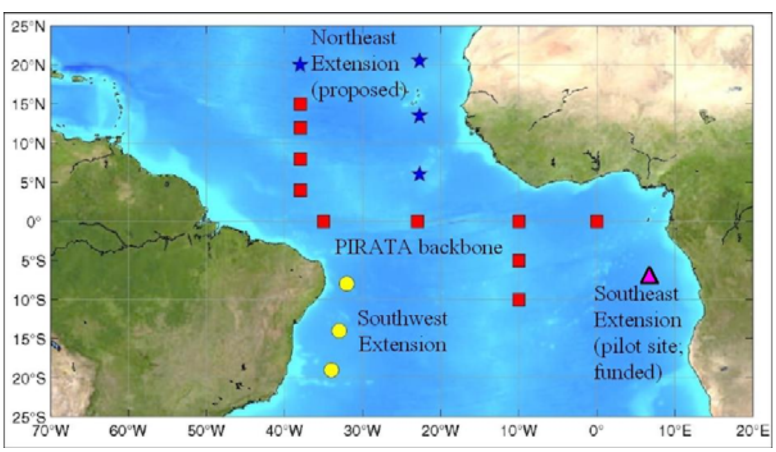


Figure 26: PIRATA array as it should be in 2007, when SE and NEE extensions will be completed. The SW extension has been achieved in August 2005.

iv) PIRATA fluxes reference sites

As part of the OceanSITES program (http://www.oceansites.org/OceanSITES/), three PIRATA mooring sites (15°N-38°W, 0°N-23°W, and 10°S-10°W) will be instrumented with long wave radiation and barometric pressures sensors, current meters at 10 m depth, and enhanced temperature and salinity measurements in the upper 60 m. The additional sensors will allow for estimation of all components of the surface heat flux and improve the estimation of mixed layer depth. The northernmost and southernmost sites are at key locations in the centers of action of the dipole mode. The 0°N-23°W site is in the equatorial wave-guide where oceanic and atmospheric variability associated with Atlantic Niños is prominent. The enhanced measurement suite at these locations, funded by NOAA as a long term commitment to PIRATA, will lead to a better understanding of the fluxes of heat, moisture, and momentum across the air-sea interface, the local response of the upper ocean to atmospheric forcing, and oceanic feedbacks to the atmosphere. The first deployment of current meters at 10 m, and conductivity/temperature sensors at 10 m and 60 m, occurred in mid-2005 at the three sites. Additional instrumentation for mixed layer conductivity/temperature, air pressure and long wave radiation will be added in 2006.

b) Future of the PIRATA backbone:

Feedback from the scientific and operational community has made clear the need for increased meridional resolution of the equatorial waveguide. For example, off-equatorial moorings could greatly complement the 0°N-23ºW mooring which already includes upper ocean current measurements. Further east, additional observations in the Gulf of Guinea region could improve simulation of the cold tongue, absent in current coupled ocean-atmosphere models, in addition to improving seasonal forecasts by greater resolution of downstream Kelvin and other equatorial wave motion.

Two routes may be used to address this need. In the immediate future, cooperation with related TACE activities is essential. For example, as mentioned in Section 2, the IFM/GEOMAR (Kiel-Germany) will deploy a network of 5 subsurface currentmeter moorings around 23°W-0°N in June-July 2006, operation during which they will ensure the replacement of the PIRATA ADCP mooring. This experiment duration is planed until late boreal winter 2008, and its continuation, even partial, could be a great opportunity for both PIRATA and TACE objectives. In the same way, a currentmeter mooring network is planed by RSMAS (Miami/USA) to be deployed along the equator in the Gulf of Guinea in close collaboration with EGEE/AMMA and PIRATA, cruises of these programs being the unique opportunity to service such a network during the TACE years (2007-2011).

In the longer term, the formal PIRATA array will expand to explicitly address the need for equatorial waveguide resolution. Maintenance of the proposed Northeast Extension (see above) will provide ship time opportunities for additional moorings along 23ºW if funding for the moorings can be identified. Plans for off-equatorial growth to the east must be developed in parallel with strategies to address piracy and other identified problems in this region.

2) Vision for the future of PIRATA

a) Pirata commitments and issues

We anticipate that distinctions between the ten-mooring PIRATA backbone, additions to the backbone, and the various extensions will blur as PIRATA partners cooperate to deploy and service individual moorings in the growing array. Ultimately, the PIRATA array will transition to an operational, international, sustained observing system for weather and climate prediction spanning the widely varying dynamical regimes of the tropical and low-latitude subtropical Atlantic Ocean and providing invaluable opportunities for deployment of Argo floats, surface drifting buoys, and platforms for conducting process studies and future research efforts.

1) National commitments:

The actual Memorandum of Understanding (MoU) has been extended until 26 February 2008 (and signed by the parties in November 2005 after the Toulouse PIRATA XI meeting), in order to continue the PIRATA operations uninterrupted during the re-writing of a new MoU that may take some time. Anyway, each involved country has to ensure the field operation and in the following a summary of the national commitments to continuation of the program is presented. In order to provide some information about the efforts provided by each involved country, a summary of the national resources contributions is provided in Appendix 10.

i) France, through the IRD leadership, will ensure the continuation of the field operation in the next years. France also committed to ensure the deployment of the PIRATA-SE extension ATLAS buoy around 6°S-8°E, in June 2006. If the 2006 test year for this buoy is successful (i.e. no vandalism realized), IRD could continue to ensure its maintaining (see also next chapter c). Most of the PIRATA cruises will be ensured in 2006 and 2007 in close relationship with the EGEE/AMMA operations in the Gulf of Guinea, and the 23°W-0°N site will be serviced in close collaboration with IFM-GEOMAR (Germany) for the ADCP mooring and with NOAA/AOML for the ATLAS buoy.

Furthermore, a strong financial effort is carried out by IRD in order to put the R/V ANTEA fully repaired and operational for PIRATA activities by boreal fall 2006. Once the ANTEA is back operationally, this vessel will be partly dedicated (although the fulfillment of usual procedures to get vessel time) to operational activities in the Tropical Atlantic, *i.e.* principally in the framework of PIRATA, ARGO an its French component CORIOLIS.

Finally, a particular effort will be dedicated in order for the data from the meteorological station located at São Tomé island (6°30'E-0°N) to be transmitted via the GTS (at now, due to WMO administrative rules, they cannot be transmitted through the GTS in real-time). These data could eventually also be considered as being part of the PIRATA data sets in a close future.

ii) Brazil, through the leadership of INPE/MCT and DHN/MD, will ensure the continuation of the field operation in the next years. INPE is also committed to collecting the ATLAS data using its family of data collection satellites, with real time decoding and data availability done at CPTEC. Also, INPE is investing in the construction of a calibration laboratory for meteorological sensors at CPTEC, in Cachoeira Paulista, SP, and a laboratory for oceanic buoy operations, recovery and calibration at INPE's campus in Natal.

iii) USA will continue to ensure a) the ATLAS buoys and sensors funding, b) ATLAS buoys sensors monitoring and data treatment, and c) PIRATA data website maintenance.

2) Issues:

The PIRATA program has to deal with two main problems, as mentioned in a previous chapter (see B.1.d), namely vandalism in the Gulf of Guinea and vessel time availability. Details on these problems are provided in Appendix 8.

i) Vandalism in the Gulf of Guinea: PIRATA has clearly to think about, in close relationship with other international programs interested in this particular area (*e.g.* TACE/CLIVAR), an eventual solution for solve this problem in the near future (*i.e.* after the 2008 deadline of the actual MoU). Actually, the maintenance of the buoys located on the equator at 10°W and 0°E pose a real problem for the rest of the program. One option would be to remove them or move them to another site in the basin (discussion began during the last congress, PIRATA 11). A partial solution would be to maintain *in situ* just the oceanographic moorings that cannot be seen from the surface and that do not serve as a concentration point for fish. The preliminary survey in progress of the meteorological measurements from the São Tomé Island station, installed in 2003 as part of the EGEE/AMMA program, should make it possible to check whether the atmospheric measurements obtained at this location are representative of the surrounding oceanic conditions, thus making it possible to partially compensate for the deletion of the buoy located at 0°E-0°N…. The problem to maintain only oceanographic moorings is the access in real-time of the *in situ* measurements. Actually, the possibility would be to deploy a system that allows the surfacing of an Argo transmitter, in order to regularly and autonomously send the data. This conducts to face with technological problems that should be addressed in the framework of an inter-program effort and international funding.

However, the main question to address is the real need for operational ocean and meteorological predictions of these two particular sites (10°W-0°N and 0°E-0°N). The studies and analysis actually carried out in the framework of MERCATOR (see chapter B.2.c), in order to estimate the real impact of ocean PIRATA *in situ* data in the numerical predictions, would allow us to partly answer to this question. Such a work would be done for meteorological *in situ* data used for climate predictions.

ii) Vessel time: Problems linked to vessel time availability are detailed in Appendix 8.
In February 2003, an Atlantic Observations Working Group (AOWG) was established under the auspices of the PIRATA-PRB to assess ship time needs for PIRATA and other Tropical and South Atlantic observing system elements. From this report (summarized in Appendix 8), it appears that we are not yet close to finding a solution to the problem of having regular ship time available for operational oceanography; the solution currently favored being that of increased use of the ships available in the area…

Nonetheless, short and medium term solutions can be solved through a straight collaboration between countries involved in Tropical Atlantic studies, as will be begun and done in 2006 thanks to common works on the field with IFM-GEOMAR and NOAA/AOML.

b) New Science and Applications

1) Relationships to be enhanced with other regional and international programs:

i) With GOOS:

In Brazil, with the onset of an operational oceanography program that constitutes the Brazilian contribution to the Global Ocean Observing System (GOOS), the implementation of a Permanent Network of Sea Level Monitoring (GLOSS/Brazil Network), under the leadership of DHN, became natural. The objective of the GLOSS-Brazil Network is to generate reliable data for the determination and definition of long-term trends of mean sea level.
For those approved sites of the Network, the following tide gauge stations may be of direct interest to PIRATA:

Stn nº	Station name	Responsible institution	Classification	Expected Situation in 2006	Expected Situation in 2007
7	Salvador	IBGE-CHM	Principal	Operational	Operational
8	Fortaleza	IBGE	Principal	To be installed	Operational
9	Ponta da Madeira	CVRD	Secondary	Operational	Operational
10	Ilha Trindade	CHM	Principal	To be installed	Operational
11	Ilha de Fernando de Noronha	CHM	Principal	To be installed	Under evaluation
12	Estação São Pedro e São Paulo	INPE/ PIRATA	Secondary	To be installed	Operational

A full coverage of the proposed Permanent Network is expected for the next four years to come, pending financial resources available.

ii) With TACE and CLIVAR-Germany:

It is to be noticed here that the two ADCP dedicated to the 23°W-0°N site are not optimal for monitoring the circulation of the region. They are shallow ADCP, *i.e.* they are installed at a depth (100m depth) that cannot allow current measurements within the whole Equatorial UnderCurrent (EUC that can reach 150m-200m depth at this longitude). Thus, the purchase of two other ADCP (two Workhorses) has to be strongly encouraged or endorsed by the PIRATA-SSC. The two shallower ADCP, bought by Brazil in 1999-2000, could be used to monitor the EUC around 10°W or 0°-0°, where the EUC is closer to the surface and generally above 100m depth. This new site could be also serviced by France, and very useful in the framework of the TACE/CLIVAR experiment.

The future PIRATA-FR cruises (2007-2011) will also be opportunity to close collaboration with TACE by servicing currentmeter moorings planed by RSMAS (Miami/USA) to be deployed in the Gulf of Guinea (see also chapter B.1.b).

iii) With the TENATSO program:

The Tropical Eastern North Atlantic Time-Series Observatory (TENATSO) is a collaborative program proposed by scientific teams from Germany (IFM-GEOMAR, Max Planck and Leibniz Institutes), United Kingdom (University of York) and Cape Verde (Instituto Nacional de Meterologia e Geofisaca & (Instituto Nacional de desenvolvimento das Pescas), coordinated by D.W. Wallace (IFM-GEOMAR) and funded by Europe in the framework of its 'Specific Support Action'. Contributing to the Global Earth Observing System of Systems (GEOSS) and supported by UK-SOLAS, TENATSO will support pre-operational atmosphere and ocean observation capability in the tropical Eastern North Atlantic Ocean, specifically at Cape Verde (16°N-24°W). That region plays a key role in air-sea interaction, and is ideally located for both atmosphere and ocean observation. Such an observatory will provide information linking biological productivity and atmospheric composition, and even though the TENATSO Cape Verde time-series has a different scientific orientation, the proposed station/mooring actually could fill a "gap" in the PIRATA array, and a close collaboration has obviously to be established between both programs.

iv) With other programs:

In the future, we expect PIRATA to continue to serve as platform for collaboration in proposed oceanic experiments such as (E)TACE and WAVEs. Programmatically, PIRATA will be one among many contributions to GEOSS.

Up to this point in time PIRATA data have not been used to a considerable extent by the CLIVAR VACS and VAMOS communities. This is expected to change as a result of the various PIRATA extensions. Clearly, TAV is crucially important for predicting the West African Monsoon (WAM) system. The PIRATA moorings are a key part of the observing system that supports this. For example, it is expected that via AMMA there will be more activities using PIRATA observations for studies of the coupled WAM, in particular the observations from the proposed NE extension. To the SE, PIRATA is seen as being important for the Benguela Current LME with respect to monitoring Benguela Nino's and interannual variability in the region. Regional operational centers such as the South African Weather Service are becoming more aware of the significance of TAV for southern Africa climate. The CLIVAR VACS panels see PIRATA observations as being supportive of the regional research programs being developed for southern Africa.

2) Other projects and PIRATA linked opportunities:

i) PIRATA CO_2

A proposal has been submitted three years ago in the framework of the French CARBOAT (CARBone dans l'Océan Atlantique Tropical) program (coordinator : Nathalie Lefevre, IRD-LOCEAN/Paris). This program will be carried out in the framework of PROOF and directly linked to PIRATA, EGEE/AMMA and ARAMIS (coordinator: Sabine Arnault: IRD-LOCEAN/Paris) programs, and in association with East Anglia University (Pr Andrew Watson). This project will assess the seasonal and interannual variability of the CO_2 flux in the tropical Atlantic Ocean. This region is a source of CO_2 to the atmosphere because of the equatorial upwelling bringing CO_2-rich waters to the surface. These waters warm up as they are transported in the South Equatorial Current which increases the surface partial pressure of CO_2 (pCO_2). However, there is recent evidence of CO_2 under-saturations in this region due to the impact of the productive Amazon waters. To better understand and predict the variability of the air-sea CO_2 flux, two main processes will be studied: the impact of the Amazon outflow and the equatorial upwelling.

Part of the program will consist to install pCO_2 sensor on PIRATA moorings (6°S- 10°W and 4°N-38°W) to provide time-series of pCO_2 which will document a) the eastward transport of the Amazon waters when it occurs (around September with the retroflection of the North Brazil Current; there is evidence of the importance of the Amazon on the air-sea flux of CO_2 for the tropical Atlantic but, presently, this region is poorly known and not covered by any exiting project) and b) the variability of the carbon cycle in the Eastern part of the basin. These data will be used to validate and improve global models of the carbon cycle. Seasonal maps of pCO_2 will be produced, which will help in constraining the atmospheric inversions done in the PROOF project FLAMENCO2. The sensors used are adapted from the CARIOCA drifting buoys, already successfully used in open ocean (*e.g.*, Bates et al., 2000; Hood and Merlivat, 2001). Contacts have already been taken with PIRATA, in order to check the feasibility to deploy pCO_2 sensors on ATLAS buoys. The first deployment will be carried out in June 2006 during the EGEE-3 /PIRATA-FR15 cruise, at the site 6^{o}S- 10^{o}W. The second one at the site 4^{o}N-38^{o}W should be carried out in 2007 during a Brazilian PIRATA cruise. The sensors are autonomous, and transmit data in real-time through its own Argo system. This program is mostly funded by the CARBO-OCEAN European integrated project (see http://www.carboocean.org/).

Another proposal has been submitted in Brazil (PIs: Rosane G. Ito and Edmo Campos, University of Sao Paulo; Paulo Nobre, INPE/CPTEC). In order to complete the CARBO-OCEAN network in the Atlantic, it is proposed to do CO_2 measurements near the Brazil shelf, and in particular near the three mooring sites of the PIRATA-SWE Array. This region is likely to be variable in CO_2 as it is the region where the South Equatorial Current bifurcates, originating two important western boundary currents: the Brazil and North Brazil Currents. It is thus proposed to install a CO_2 sensor on the PIRATA mooring located at 8^{o}S-30^{o}W in order to complete the time-series planned in CARBO-OCEAN (WP4 Atlantic network). The PIRATA cruises dedicated to service the three PIRATA-SWE buoys will also be the opportunity to make onboard measurements of pCO_2. These cruises are repeated once a year, on board a Brazilian vessel and could be easily adapted for this task.

ii) Hydrophones deployments in the Equatorial Atlantic:

A proposal is in progress at IFREMER (responsible: Louis Geli; IFREMER/DGM) in order to deploy hydrophones along the cable of the ATLAS moorings. This project is closely linked to a farmer proposition by Robert Dziak (NOAA/PMEL). A summary of this proposal is provided in the following.

During the last decade, several underwater acoustic experiments for monitoring the long-term ocean seismicity have been carried out in the Pacific and Atlantic oceans under the NOAA-OSU Acoustics Project (e.g. Dziak et al., 2003). These studies utilize earthquake-generated Tertiary (T-) waves excited by scattering from a rough seafloor in the abyssal setting. Due to the efficiency of sound propagation in the oceans, hydro-acoustic data can provide for significant improvements in the location and detection capability afforded by land-based seismic stations. The analysis of hydro-acoustic data has revolutionized our understanding of mid-ocean ridge eruptive processes and provided insights into the dynamics of large transform faults in the Pacific. For instance, seismic precursors have been observed prior to large earthquakes at Pacific transform faults. Do such precursors also occur within the large equatorial transform faults in the Atlantic, where the deformation rate is five times less than in the Pacific ?

To monitor the seismicity of the Atlantic Equatorial Fracture Zones (e.g., McGuire et al., 1994 about the Romanche Fracture Zone), it is proposed to use the moorings of the PIRATA Programme. The PIRATA moorings are instrumented from the sea surface down to 500 m. Therefore, clamping an hydrophone on a cable at a depth of 700 m below sea-level presents no risk for the PIRATA sensors. Here, it is proposed to conduct a feasibility study to compare the noise recorded by an hydrophone clamped on a PIRATA cable to the noise recorded by a near-by subsurface mooring. Contacts have been established with PIRATA in France in order to study the feasibility of such an experiment.

D. Concluding remarks:

The information and results presented in this document show that, in spite of inherent and unavoidable difficulties and problems, a multinational program with main scientific issues and heavy field operations can be carried out and maintained for the long term. The PIRATA successive teams achieved to maintain the PIRATA array during the 8 years of its two phases (pilot and consolidation phases), and deal now with additional array extensions. The PIRATA data sets are largely used for scientific purposes and clearly contribute to a better understanding of the Tropical Atlantic climate variability. Most of the scientific objectives that motivated the beginning of the PIRATA program, and summarized in Servain et al. (1998), have been addressed and received partial answers thanks to the data sets it provided. Recent analysis begins to show the usefulness of the PIRATA data for operational oceanography and climate predictions. The recent important increasing of the data amount transmitted in real-time (thanks to higher frequency of data transmission from the buoys and the data delivery from the Argos new multi-satellites relay system) obviously makes the PIRATA data sets more useful and even indispensable for more skillful predictions. Furthermore, the 2005 PIRATA-SW extension and the next PIRATA-NE and SE extensions will considerably increase the number of data sets made freely available to the scientific community.

The next few years will be crucial in regard to the fate of PIRATA, for two main reasons:

1) while the PIRATA backbone will be maintained, the three PIRATA extensions will be tested, evaluated, and we should be able to verify by 2008 if they are also useful in the framework of a "permanent' array and if their servicing is thinkable (due to additional vessel time constraints) on the long term;

2) the terms of the likely, or at least necessary and desirable for the scientific community, continuation of the PIRATA experience and future commitments between involved organisms and partners will be defined in the next MoU, and the actual needed PIRATA review processes will obviously have an important influence on the MoU contents.

Closer collaborations between PIRATA and other programs are needed and have clearly to be established. Presently, the relatively small PIRATA scientific community is involved in other climate scientific programs concerning the tropical Atlantic climate, for example, with TACE that will focus on intensive measurements in the eastern equatorial Atlantic and the Gulf of Guinea. Programs like this may identify alternative sampling strategies that, for example, may help to solve, one of the main problem PIRATA has to deal with, namely the vandalism in the Gulf of Guinea.

To conclude, the fixed time series measurements from the PIRATA moorings have since become the main backbone of the tropical Atlantic observing system. The addition of ARGO floats has served to complement the unique, high temporal sampling and limited spatial extent of the original set of PIRATA buoys. The federation of complementary observational platforms provided thanks to PIRATA has become, *de facto*, the Tropical Atlantic Ocean Observing System. From its beginning, PIRATA has also cooperated and communicated on a frequent basis with the CLIVAR Atlantic Panel, OOPC, GOOS, GCOS, GLOSS, GEOSS, JCOMM, and CORIOLIS. Actually, through the concerted efforts of those participating nations and institutions, PIRATA has become a worldwide recognized GOOS and GCOS pilot-project in the region. By way of membership in the PIRATA-SSC, organizations such as INPE, IRD, NOAA, CPTEC, FUNCEME, Météo-France, CNRS, and MERCATOR/GODAE have all been regularly informed and have had input to the direction of PIRATA. In addition, the PIRATA-SSC has been actively involved in the development of new programs as, *e.g.*, TACE and AMMA. AMMA and TACE require long-term observations in the Atlantic Ocean through at least 2010, and PIRATA is obviously for these programs a key observation system and a closely associated program.

E. Acknowledgements:

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APPENDIX 1: PIRATA PRB AND SSC MEMBERSHIP

Membership: PIRATA Scientific Steering Committee (SSC) and PIRATA Resources Board (PRB)

a) PIRATA Resources Board (PRB) Composition: 1999 - 2006

1999-2003
Mike Johnson (Chair), NOAA, USA
Daniel Cariolle, Météo-France, France
Volker Kirchhof, INPE, Brazil
Jacques Merle, IRD, France

2003-2004
Mike Johnson (Chair), NOAA, USA
Jacques Boulègue, IRD, France
Daniel Cariolle, Météo-France, France
Volker Kirchhof, INPE, Brazil

2005-2006
Mike Johnson (Chair), NOAA, USA
Jacques Boulègue, IRD, France
Joël Poitevin, Météo-France, France
Maria Assunção F. Silva Dias, INPE, Brazil

b) PIRATA-SSC Membership: 1995 - 2006

1995-1998
Antonio Divino Moura (Co-Chair), INPE, Brazil
Jacques Servain (Co-Chair), IRD, France
Antonio Busalacchi, NASA/GSFC, USA
Michael McPhaden, NOAA/PMEL, USA
Gilles Reverdin, CNRS, France
Marcio Vianna, INPE, Brazil
Steve Zebiak, LDEO/IRI, USA

1999-2001
Jacques Servain (Chair), IRD, France
Antonio Busalacchi, NASA/GSFC, USA
Ping Chang, Texas A&M Unviv., USA
Michael McPhaden, NOAA/PMEL, USA
Antonio Divino Moura, INPE, Brazil
Serge Planton, Météo-France, France
Gilles Reverdin, CNRS, France
Marcio Vianna, INPE, Brazil
Ilana Wainer, USP, Brazil

2001-2002
Jacques Servain (Chair), IRD/LEGOS, France
Bernard Bourlès, IRD/LEGOS, France
Antonio Busalacchi, ESSIC, University of Maryland, USA

João Lorenzzetti, INPE, Brazil
Michael McPhaden, NOAA/PMEL, USA
Antonio Divino Moura, INPE, Brazil
Serge Planton, Météo-France, France
Ilana Wainer, USP, Brazil
Shang Ping Xie, Univ. Hawaii, USA

2003-2004
Jacques Servain (Chair), IRD/LEGOS, France
Bernard Bourlès, IRD/LEGOS, France
Antonio Busalacchi, ESSIC, University of Maryland, USA
Edmo Campos, USP, Brazil
Michael McPhaden, NOAA/PMEL, USA
Paulo Nobre, INPE, Brazil
Serge Planton, Météo-France, France
Shang Ping Xie, Univ. Hawaii, USA

2004-2005
Antonio Divino Moura (Chair), INMET, Brazil
Bernard Bourlès (Co-Chair), IRD/LEGOS, France
Antonio Busalacchi, ESSIC, University of Maryland, USA
Edmo Campos, USP, Brazil
Rick Lumpkin, NOAA/AOML, USA
Michael McPhaden, NOAA/PMEL, USA
Paulo Nobre, INPE, Brazil
Serge Planton, Météo-France, France
Jacques Servain, IRD/LOCEAN, France

2005-2006
Antonio Divino Moura (Chair), INMET, Brazil
Bernard Bourlès (Co-Chair), IRD/LEGOS, France
Rick Lumpkin (Co-Chair), NOAA/AOML, USA
Antonio Busalacchi, ESSIC, University of Maryland, USA
Edmo Campos, USP, Brazil
Fabrice Hernandez, IRD/US025, France
Michael McPhaden, NOAA/PMEL, USA
Paulo Nobre, INPE, Brazil
Serge Planton, Météo-France, France

APPENDIX 2: PIRATA Memorandum of Understanding

MEMORANDUM OF UNDERSTANDING (MOU)

between
Instituto Nacional de Pesquisas Espaciais
and
Institut de Recherche pour le Développement and Météo-France
and
National Oceanic and Atmospheric Administration
Office of Global Programs
for
Implementation and Maintenance of the
Pilot Research moored Array in the Tropical Atlantic – PIRATA
A Partnership in Climate Research and Ocean Observation

The Instituto Nacional de Pesquisas Espaciais (INPE) of Brazil, the Institut de Recherche pour le Développement (IRD) and Météo-France of France, and the National Oceanic and Atmospheric Administration Office of Global Programs (NOAA/OGP) of the United States of America, hereinafter referred to as the "Parties", are interested in increasing the effectiveness of their activities in climate research and ocean observation through sustaining the Pilot Research moored Array in the Tropical Atlantic (PIRATA);
The parties recognize that collaboration in sustaining PIRATA can be to their mutual benefit, the mutual benefit of their countries, and the benefit of many countries in Africa, the Americas, and Europe;
The parties believe that efforts such as sharing of tasks, cooperation on facilities utilization, exchange of scientific and technical information, and sharing of costs and human resources can result in the effective and efficient accomplishment of mutually beneficial objectives;
Therefore, the Parties have reached the following understanding:

SECTION 1
SCIENTIFIC OBJECTIVES OF THE PIRATA PROGRAM

The purpose of the PIRATA program is to study the ocean-atmosphere interactions in the tropical Atlantic that are relevant to regional climate variability on intra-seasonal, seasonal, interannual, and longer time scales.
Specifically, the scientific goals of PIRATA are:

- To improve our understanding of the relative contributions of the different components of the surface heat flux, momentum flux, fresh water flux, ocean dynamics, and the surface and upper ocean thermal and haline structures to seasonal and longer time scale variability in the tropical Atlantic;
- To provide a data set that can be used to develop and improve predictive models of the coupled Atlantic climate system.

A full description of the Scientific Objectives is contained in the PIRATA Science and Implementation Plan, Annex 1.

SECTION 2
TECHNICAL OBJECTIVES OF PIRATA

To reach the scientific objectives of the PIRATA Program, the Parties will deploy and maintain an array of ATLAS moorings in the tropical Atlantic. The ocean observations along with meteorological observations from the array will be transmitted to shore via satellite and will be available in near real-time on the Internet. These data can be assimilated in Ocean-Atmosphere Coupled General Circulation Models in order to implement seasonal climate forecasts and other applications with direct benefit to the Parties and other agencies in Brazil, France, the United States, and in other countries.
A full description of the Technical Objectives is contained in the PIRATA Science and Implementation Plan, Annex 1.

SECTION 3
THE PILOT PHASE OF PIRATA

PIRATA was initially designed by a group of scientists involved in CLIVAR (Climatic Variability and Predictability) Program research, and implemented beginning in 1997 through this multi-national scientific collaboration. The project was built on the scientific success of the TOGA (Tropical Ocean and Global Atmosphere) Program and made use of the mooring technology established in the tropical Pacific where ATLAS moorings make up the bulk of the TAO/TRITON array now being operated multi-nationally as a contribution to CLIVAR, the Global Climate Observing System (GCOS), and the Global Ocean Observing System (GOOS).

PIRATA was originally conceived as a pilot study with a 3-year field phase (1997-2000) in support of CLIVAR, GCOS, and GOOS objectives. Technical, logistic and organizational issues associated with maintenance of the array were addressed within a research framework by the Brazil-France-United States scientific collaboration.

SECTION 4
THE CONSOLIDATION PHASE OF PIRATA

Following the successful completion of the PIRATA array and evaluation of the scientific results during the pilot phase, representatives of the Parties, in consultation with international CLIVAR, GCOS, and GOOS, resolved to maintain the array through a consolidation phase from 2001 through 2005. The Parties wish to establish this MOU to strengthen the collaboration of the pilot phase and provide a stable framework under which PIRATA can continue through the consolidation phase. The MOU documents the partnership between the Parties and their intentions to contribute the resources necessary to sustain such a multi-national effort including provision of ship time, scientific instruments, ATLAS moorings, fabrication and maintenance, instrument calibration, logistics, delivery of data, training and technology transfer.

SECTION 5
ORGANIZATION AND MANAGEMENT OF PIRATA

PIRATA Resources Board:

A PIRATA Resources Board (PRB) is established with Terms of Reference (TOR) (see Annex 2). The initial members of the PRB are managers representing INPE, IRD, Meteo-France, and NOAA/OGP. Although the PRB is presently comprised of representatives from institutions only in Brazil, France, and the United States, the PRB will welcome other institutions and other nations if they wish to contribute to the PIRATA Program. The Chairman of the PRB is designated by the PRB members.

The principal tasks of the PRB are:

- To review the requirements for the implementation of PIRATA;
- To coordinate resources that may be applied to the Program;
- To encourage scientific and technological initiatives in the participating countries to meet the objectives of PIRATA;
- To report on its activities to the Heads of the institutions providing resources.

The PRB is guided by the scientific objectives and research strategy formulated by the PIRATA Scientific Steering Group (PIRATA-SSG), which is regarded as the main scientific and operational body to advise the PRB.

PIRATA Scientific Steering Group:

A PIRATA Scientific Steering Group (PIRATA-SSG) is formed by researchers, managers, and operational representatives of the Parties or other institutions who are recognized as scientific and operational experts in the area of the tropical Atlantic climate. Members are nominated by the PIRATA-SSG in consultation with appropriate international sponsoring bodies participating in GOOS, GCOS, and CLIVAR, and are approved by the PRB. The Chairman of the PIRATA-SSG is designated by the SSG members.

The principal tasks of the PIRATA-SSG are:

- To ensure accomplishment of the scientific and technical objectives as described in the PIRATA Scientific and Implementation Plan, 1998 (PIRATA-SIP98), and as accepted by the Parties;
- To coordinate the technical and logistic support necessary to maintain the array;
- To ensure the rapid dissemination of PIRATA data (in real-time where possible) to serve both research and operational applications;
- To promote the utilization of PIRATA data in national and international climate research and operational prediction programs;
- To evaluate, encourage, and promote pilot extension projects that could build upon the original PIRATA array;
- To coordinate with other ongoing and planned observational efforts in the tropical Atlantic region;
- To invite collaborations with other nations and institutions interested in implementing a sustained climate observing system in the tropical Atlantic;
- To cooperate with international organizations such as the CLIVAR Ocean Observation Panel (COOP), the GOOS/GCOS/WCRP Ocean Observations Panel for Climate (OOPC), the Tropical Moored Buoy Array Implementation Panel (TIP), and the Joint WMO/IOC Technical Commission for Oceanography and Marine Meteorology (JCOMM) to ensure an integrated approach to observing the climate system in the tropics;
- To report regularly on the status of the PIRATA array and scientific results to the PRB, GCOS, GOOS, and CLIVAR.

PIRATA National Coordinators:

INPE serves as the coordinator of PIRATA in Brazil. The support of the Diretoria de Hidrografia e Navegação (DHN) is critical to the success of PIRATA. The support of DHN is arranged through INPE. A national coordinator is indicated by INPE to be the representative of PIRATA-Brazil. The national coordinator is a member of the PIRATA-SSG.

IRD serves as the coordinator of PIRATA in France, in association with Météo-France. A national coordinator is indicated by IRD to be the representative of PIRATA-France. The national coordinator is a member of the PIRATA-SSG.

NOAA Pacific Marine Environmental Laboratory (PMEL) serves as the coordinator of PIRATA in United States. The programmatic support of the NOAA Office of Global Programs (OGP) is critical to the success of PIRATA. A national coordinator is indicated by NOAA/PMEL to be the representative of PIRATA-United States. The national coordinator is a member of the PIRATA-SSG.

The coordination between the Parties is ensured jointly through the PRB and the PIRATA-SSG, especially through the Chairmen of these two committees and the national coordinators.

SECTION 6

NATIONAL COMMITMENTS OF THE PARTIES IN PIRATA

In planning for future resources in support of the PIRATA Program, it is recognized that the Parties are dependent upon year-to-year funding allocations from their governments, and thus commitments for future funding and logistical support can not be guaranteed. Given this proviso, the Parties affirm that PIRATA is a high priority for Brazil, France, and the United States, and that the institutions are making plans for continued support as follows:

INPE (in cooperation with DHN), IRD, Météo-France, NOAA/OGP (in cooperation with NOAA/PMEL) will maintain the PIRATA array through the Consolidation Phase, from 2001 to 2005, as it is presently configured (Annex 3) or as the array may be modified by agreement of the PIRATA-SSG and the PRB in order to meet scientific or operational requirements. In particular:

- NOAA will refurbish moorings of the initial consolidation phase inventory until facilities in Brazil and/or France/African countries are prepared to take over refurbishment tasks. The initial inventory of 15 moorings for the consolidation phase consists of ATLAS moorings left over from the pilot phase.
- NOAA will supply up to two replacement ATLAS mooring systems each year if required because of damage or loss.
- NOAA will provide existing plans and specifications to INPE and IRD for ATLAS moorings and instrumentation in order for Brazil and France to develop refurbishment and construction capabilities in-country. It is noted that the ATLAS system is constantly being improved as technology advances. INPE and IRD are invited to send regularly PIRATA technicians to Seattle in order to observe and learn PMEL new techniques, procedures, and developmental work, and to obtain a copy of the latest available documentation. Travel costs related to these visits are the responsibility of INPE and IRD.
- NOAA will provide primary data delivery and processing of the ATLAS measurements.
- NOAA will pay Argos data processing costs for the ATLAS system measurements.
- NOAA will provide a PIRATA web site at PMEL.

(i) INPE will assume responsibility for the logistics required to transport PIRATA equipment between Seattle and Brazilian depots.

(ii) INPE will take the necessary actions so that adequate ship time is available to maintain the PIRATA array on the Brazilian side (INPE works with DHN to provide the ship time). The Brazilian side includes the five ATLAS moorings in the western tropical Atlantic, from 15°N to the equator along 35°-38°W, besides possible future moorings as part of a western extension (WE) south of the equator.

(iii) Shipboard ADCP and CTD data collected during PIRATA operations on the Brazilian side will be archived and disseminated by INPE.

(iv) INPE will provide for the deployment, maintenance, and the real-time delivery of the data (including the Argos costs) of one meteorological buoy anchored close to 0°-44°W, as planned in the PIRATA-SIP98.

(v) INPE will provide for the deployment, maintenance, and the real-time delivery of the data (including the Argos costs) of a tide-gauge located at Fernando de Noronha archipelago, and of a meteorological station located at St. Peter & St. Paul archipelago.

(vi) A mirror PIRATA web site will be maintained by INPE with additional national contributions and information.

- IRD and Météo-France will assume responsibility for the logistics required to transport PIRATA equipment between Seattle and French/African country depots.
- IRD will ensure that adequate ship time is available to maintain the PIRATA array on the African side. The African side includes the five ATLAS moorings in the eastern tropical Atlantic, in the region 0° to 10°S, and 0° to 20°W, and the ADCP mooring close to 0°, 20°W.
- Shipboard ADCP and CTD data collected during PIRATA operations on the African side will be archived and disseminated by IRD.
- IRD will provide for the deployment, maintenance, and the real-time delivery of the data (including the Argos costs) of one tide-gauge located at São Tomé Island, as planned in the PIRATA-SIP98.
- A mirror PIRATA web site will be maintained by IRD with additional national contributions and information.

It is recognized that successful climate observation requires continuity in measurement programs for many years. The Parties are committed to sustaining the ocean observing system in the Atlantic Ocean over the long term and will work during the consolidation phase, together and with other institutions, to plan for the future. The Parties will consider options for making PIRATA operations more efficient and effective, such as further consolidation of facilities, services, and ship support as experience and capabilities advance. Possibilities might include unification of the PIRATA operational depots and a dedicated ship to service the entire tropical Atlantic domain, besides the participation of other countries/institutions that could provide ship time necessary for complete functioning of an enhanced PIRATA array.

SECTION 7
THE RELATIONSHIP BETWEEN THE PARTIES AND
FUTURE PIRATA EXTENSION PROJECTS

The commitments of the Parties described in this MOU do not apply to PIRATA extension projects that may be implemented during the consolidation phase by countries other than Brazil, France, and the United States. However, the Parties are supportive of scientifically sound extension projects and look forward to working with other institutions and countries as they seek to develop their plans. Amendments to this MOU may be signed between the parties, or with new partners, to coordinate activities related to the implementation and operation of extension projects that have been approved and recommended by the PIRATA-SSG to the PRB.

SECTION 8
COOPERATION WITH INTERNATIONAL IMPLEMENTATION PANELS

The Parties are committed to working cooperatively with the international implementation panels of the Intergovernmental Oceanographic Commission (IOC) and the World Meteorological Organization (WMO) to implement the Atlantic component of GCOS and GOOS. These panels include the Data Buoy Cooperation Panel (DBCP), the Global Sea-Level Observing System (GLOSS), the Ship of Opportunity Implementation Panel (SOOPIP), the Tropical Moored Buoy Implementation Panel (TIP), and the Joint WMO/IOC Technical Commission for Oceanography and Marine Meteorology (JCOMM).

SECTION 9
EXCHANGE OF INFORMATION

The activities specified under this MOU involve the collection and exchange of environmental data which are not intended to be protected. The Parties support the widest possible dissemination of the information resulting from the PIRATA Program. Each participant should have the right to use, disclose, publish, or disseminate such information for any and all purposes. Information transmitted between Parties or developed jointly under this MOU will be accurate to the best knowledge of the Parties. The Parties do not assure the suitability of the information transmitted for any particular use or application by the receiving Party or by any third party.

SECTION 10
GENERAL PROVISIONS

This MOU is between institutions – the Parties – and is not intended to, and does not, obligate the governments of the counties of Brazil, France, or the United States. This MOU is not intended to, and does not, create any binding obligations under international law. Nothing in this MOU is intended to affect other cooperation or collaboration between the Parties. All activities under this MOU will be in accordance with the applicable laws of the respective countries.

All questions related to the MOU arising during its term will be settled by the Parties by mutual agreement.

This MOU will enter into effect upon the signature by all Parties and remain in effect for two years, renewable for another term if agreed by the parties. The MOU may be amended or extended by mutual written agreement, and may be terminated at any time by any of the Parties upon six months written notice to the other Parties.

This MOU may be referenced as the "PIRATA MOU."

ANNEX 1

PIRATA, Pilot Research Moored Array in the Tropical Atlantic, Science and Implementation Plan for an Observing System to support Tropical Atlantic Climate Studies. As reported in the Bulletin of the American Meteorological Society, October 1998.

ANNEX 2
PIRATA Resources Board
Terms of Reference
19 October 1999 (as amended)

1. Establishment

The PIRATA Resources Board (PRB) has been established by the Resolution adopted by the institutions from Brazil, France, and the United States of America that are currently committing resources to the PIRATA Program.

2. Composition
The membership of the PRB is comprised of representatives of institutions allocating resources to accomplish the overall goals of the PIRATA Program. The initial composition of the PRB shall include representatives of the following institutions:

Brazil:	INPE -- Instituto Nacional de Pesquisas Espaciais;
France:	IRD - Institute de Recherche pour le Developpement;
	Meteo-France;
United States:	NOAA/OGP - National Oceanic and Atmospheric Administration/ Office of Global Programs;

And the Chair of the PIRATA Scientific Steering Group, as Observer.

3. Functions
The main function of the PRB is to provide a multi-institutional Forum for the coordination of resources for implementation of the PIRATA Program, including the following:
3.1 To review the requirements for the implementation of PIRATA;
3.2 To coordinate resources that may be applied to the Program;
3.3 To encourage scientific and technological initiatives, in the participating countries, to meet the objectives of PIRATA;
3.4 To report on its activities to the Heads of the institutions providing resources.

4. Scientific and Technical Advisory Bodies
In discharging its tasks, the PRB should be guided by the scientific objectives and research strategy formulated by the PIRATA Scientific Steering Group, which is regarded as the main scientific body to advise the PRB, and by the CLIVAR Scientific Steering Group in its general strategy to implement an international climate research program.

5. Organization of Sessions
5.1 The PRB shall hold sessions at dates and places, to be decided in the previous session, which will be communicated by the Chair of the Board and arranged by the secretariat. Invitations to attend the sessions shall be sent to:
- All PRB members;
- Experts invited as Observers by the Chair of the PRB, including firstly the Chair of the PIRATA Scientific Steering Group, as necessary for the deliberations in that specific session of the PRB.

5.2 At the close of each session, the PRB will elect from its members a Chair who will serve in that capacity until the close of the next session. An individual shall serve no more than two consecutive years as Chair.
5.3 Sessions will be conducted in English and reports published in that language. Translations of reports into French and Portuguese are the responsibility of institutions in France and Brazil, respectively.
5.4 Secretariat support for the Board will be arranged by the PRB as appropriate.

ANNEX 3
PIRATA Array Configuration
March, 2001

1. ATLAS Moorings:
    a) Along 38° W: - 4° N - 8° N - 11.5° N - 15° N
    b) Along the equator: - 0° - 10° W - 20° W - 35° W
    c) Along 10° W: - 6° S - 10° S
2. ADCP mooring close to 0°, 20°W *
3. Island Tide Gauge Stations: - Atol das Rocas * - St. Peter & St. Paul Rocks - São Tomé Island

4. Meteorological Stations: - Atol das Rocas * - St. Peter & St. Paul Rocks - Equator at 44° W *

* Not yet operating

APPENDIX 3: PIRATA Meetings

PIRATA Meetings: 1995 - 2006

a) International PIRATA meetings:

PIRATA-0: TAO-TIP-4, Fortaleza, Brazil, September 1995

PIRATA 1-First Meeting: February 1996, Natal, Brazil

PIRATA-2, Brest, France, August 1996

PIRATA-3, Seattle, WA, USA, March 1997

PIRATA-4, Niteroi, Brazil, November 1997

PIRATA-5, Abidjan, Côte d'Ivoire, November 1998

PIRATA-6, Miami, USA, May 1999

PIRATA-7, Natal, Brazil, April 2000

PIRATA-8, Paris, France, August 2001

PIRATA-9, Angra dos Reis, Brazil, Feburary 2003

PIRATA-10, Fortaleza, Brazil, December 2004

PIRATA-11, Toulouse, France, October 2005

b) Extensions PIRATA meetings:

PIRATA-SEE, Cape Town, SA, December 1999

PIRATA-NEE, Casablanca, Morroco, March 2000

PIRATA-SWE, Fortaleza, Brazil, September 2000

c) SSC meeting dedicated to this review document:

PIRATA-Review, Natal, Brazil, February 2006

d) Joint Assembly – AGU Spring Meeting, Montreal, 17-21 May 2004

May 19, Special session: Scientific Results for the PIRATA Program 1997-2004
Conveners: Jacques Servain, Shang-Ping Xie, Edmo Campos (12 oral communications)

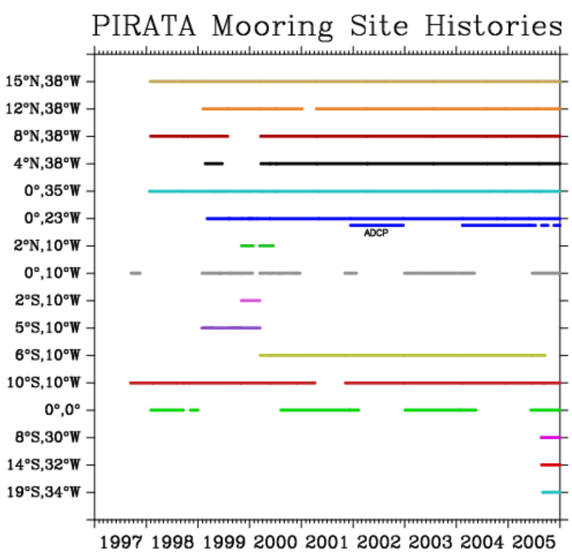
APPENDIX 4 : GROWTH OF THE MOORING ARRAY

The first PIRATA moorings were deployed by France at 0°, 10°W and 10°S, 10°W in September 1997 and 0°, 0° in January 1998 (Figure A3.1). Three additional moorings were deployed by Brazil along 35°-38°W in January 1998. The array increased to 10 moorings in early 1999 with the occupation of addition sites in both the eastern and western basin. At this time, the first deployment intended for 6°S, 10°W was shifted to 5°S because of the presence of several fishing vessels in the vicinity of 6°S observed during the deployment cruise. Later deployments were shifted back to 6°S consistent with the original array design.

The array of 12 moorings was fully implemented by late 1999 with the deployment of moorings at 2° and 2°S, 10°W (Fig. A3.1). These moorings were rapidly lost however, presumably due to fishing vandalism that had earlier plagued other sites in the Gulf of Guinea. Thus, the PIRATA SSC decided to decommission these sites to limit the loss of equipment. PIRATA stabilized in a 10-mooring configuration from 2001 to 2005. With deployment of the three Southwest Extension moorings in August 2005, the array size increased 13 mooring sites.

In all, 81 ATLAS mooring systems have been deployed since the inception of the program. Seven of these systems (or 9% of the total) were completely lost due to fishing vandalism. Six of the seven mooring system losses occurred in the Gulf of Guinea and one at 4°N, 38°W. Damage to and loss of instrumentation and other buoy components as a result of fishing vandalism has occurred elsewhere in the array as well.

The first deployment of the ADCP mooring planned for 0°, 23°W occurred in December 2001. The mooring was not replaced after recovery for lack of necessary equipment. The site was re-instrumented in February 2004 and will be continuously maintained thereafter as part of the array.



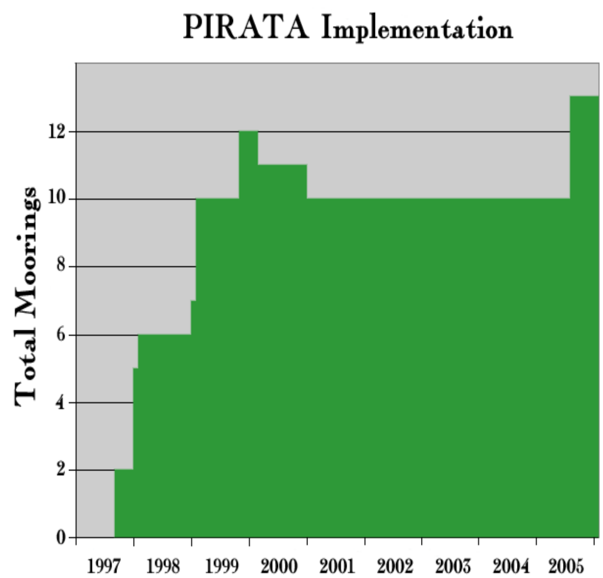


Figure A3.1. *Implementation and maintenance of the PIRATA array of ATLAS moorings during 1997-2005. Left panel show site-by-site deployment time lines and right panel shows summary of deployed moorings. Gaps in the left panel indicate periods when moorings were lost, not deployed, or not transmitting. Deployment history for the ADCP at 0°, 23°W is also shown in the left panel; the dashed line at the end indicates the most recent deployment which will be recovered in mid-2006.*

APPENDIX 5: LIST OF THE PIRATA CRUISES

The French and Brazilian campaigns carried out since 1997 for the PIRATA program are summarized in the table below:

CRUISE NAME	DEPARTURE DATE	ARRIVAL DATE	VESSELS NAME
PIRATA-FR1	September 9, 1997	September 16, 1997	Antéa
PIRATA-BR1	January 20, 1998	January 31, 1998	Antares
PIRATA-FR1b	January 30, 1998	February 3, 1998	Antéa
PIRATA-FR2	October 30, 1998	November 10, 1998	Antéa
PIRATA-FR3	January 23, 1999	February 1, 1998	Antéa
PIRATA-BR2	February 3, 1999	March 8, 1999	Antares
PIRATA-FR4	July 13, 1999	August 21, 1999	Thalassa
PIRATA-FR5	October 25, 1999	November 8, 1999	Antéa
PIRATA-FR6	March 8, 2000	March 19, 2000	Le Suroit
PIRATA-BR3	March 14, 2000	March 23, 2000	Antares
PIRATA-FR7	July 23, 2000	August 21, 2000	Thalassa
PIRATA-FR8	November 17, 2000	December 3, 2000	Atalante
PIRATA-BR4	March 31, 2001	May 8, 2001	Antares
PIRATA-FR9	October 20, 2001	November 11, 2001	Atalante
PIRATA-FR10	December 6, 2001	December 21, 2001	Atalante
PIRATA-BR5	March 27, 2002	April 17, 2002	Antares & Amorim do Valle
PIRATA-FR11	December 17, 2002	January 3, 2003	Le Suroit
PIRATA-BR6	July 8, 2003	August 10, 2003	Antares
PIRATA-FR12	January 28, 2004	February 20, 2004	Atalante
PIRATA-BR7	Juillet 2004	Août 2004	Antares
PIRATA-FR13	May 24, 2005	June 2, 2005	Le Suroit
PIRATA-FR14	June 7, 2005	June 23, 2005	Le Suroit
PIRATA-BR8 *	June 26, 2005	September 8, 2005	Antares & Amorim do Valle

** : includes the Southwest extension cruise PIRATA-SWE 1*

APPENDIX 6: SHIPBOARD MEASUREMENTS

During each oceanographic campaign dedicated to PIRATA, meteo-oceanic measurements or additional operations are carried out, either within the framework of the PIRATA program, or in collaboration with other associated programs (eg EQUALANT in 1999-2000, EGEE/AMMA from 2003) or dedicated to operational oceanography (CORIOLIS and MERCATOR, French components of the ARGO and GODAE international programs respectively).

1. Continuous measurements using the ship's equipment:

- Current measurements (from 0 to 700m max.) using VM-ADCP acoustic Doppler current profilers;
- Surface temperature and salinity measurements using a thermosalinograph;
- Meteorological and navigational measurements using data acquisition units.

2. Station measurements:

- Hydrological stations with CTD profiles (continuous pressure, temperature and salinity measurements between the surface and 500m or 1000m), notably at buoy sites and along the meridional radials (at least every degree of latitude).

3. Underway operations:

- Launching of XBT probes (acquisition of temperature profiles between the surface and approximately 800m);
- Deployment of drifting surface buoys (SVP; sea surface temperature measurement and daily transmission by satellite of these measurements and the position of the buoy, also enabling the surface currents to be deduced; in collaboration with the NOAA/USA Global Ocean Observing System (GOOS) program);
- Since 2003, occasional deployments of ARGO (PROVOR or SOLO) type drifting profilers (acquisition of thermohaline profiles from the surface to 2000m every 10 days) within the framework of ARGO/CORIOLIS;
- Since 2003, regular samples of surface seawater for analysing the salinity (notably within the framework of ARGO/CORIOLIS and the calibration of temperature/salinity recorders), nutrient salts and carbon parameters, from the O18 and C13 (notably in the framework of the EGEE in the Gulf of Guinea and the associated FlamenCO2/PROOF program).
- Very occasionally, meteorological probe balloons (radio-soundings) are also launched and bathymetric readings taken using multi-beam echo sounders (EM12).

APPENDIX 7: MOORING DATA ACQUISITION, PROCESSING PROTOCOLS AND PERIODS OF AVAILABILITY FOR PIRATA DATA

The data acquisition and calibration protocols depend on the measurements.

a) Measurements from ATLAS buoys:

All the details of the sensors, the acquisition frequencies, the resolution and the accuracy of the measurements, and the processing and calibration procedures are explained on the internet page of the NOAA/AOML site dedicated to the TAO network (http://www.pmel.noaa.gov/tao/proj_over/mooring.shtml), program equivalent to PIRATA in the Pacific established in the 1980's (see http://www.pmel.noaa.gov/tao/). These procedures provide optimum measurement quality given the specific constraints associated with the measurement acquisition terrain (in the middle of the ocean), the lifespan of the instruments on site, the power (batteries) and the on-site measurement storage capacity.

To summarize, the protocol follows the following chronology:

- Measurements and saving in situ of each of the variables acquired at high frequency (1 mn to 1 hr);
- Integration over the previous 24 hours of all these variables via a centralizing system that works by interrogating each sensor in succession;
- Two 4-hour satellite transmission windows via Argos (upgraded to four 4-hour windows beginning in May 2005) for daily averaged and spot hourly samples; data made available in real-time via the GTS. ;
- Quality control of both real-time and delayed mode (i.e. post-mooring recovery) internally recorded data at PMEL/NOAA in Seattle (USA);
- All mooring data are made freely and openly available to the scientific community via the internet;

The operating full periods of the ATLAS buoys are summarized in the table below:

PIRATA ATLAS moorings	Operating periods (month/year)
23°W-0°N	01/1999 to 01/2005
10°W -0°N	09/1997 to 11/1997
	02/1999 to 12/2000
	11/2001 to 01/2002
	01/2003 to 05/2004
10°W-6°S	01/1999 to 01/2005
10°W-10°S	01/1999 to 01/2005
0°W-0°N	01/1998 to 12/1998
	08/2000 to 01/2002
	01/2003 to 05/2004

It can be noted that the moorings located along the equator at 10°W and 0°E had periods during which the buoys did not operate. In fact, these buoys are often the subject of vandalism (see next Appendix). They are located in zones with high concentrations of fish and thus act as fish aggregating buoys. The major concentration of small fish below these buoys attracts tuna and, consequently, fishing fleets that damage or even destroy the buoys or tear them with their nets… the length of the period for which data is available therefore depends on the possibility of deploying to the area! In fact, in order to maintain the buoys (given optimum battery operation, the concentration of organic matter on the sensors – particularly for salinity due to fouling, the effect of corrosion on the buoy securing devices and mooring cables etc.) the buoys would have to be replaced twice a year. Given the difficulty of obtaining ship time (we also return to this problem later), we have never been able to achieve this objective and, generally speaking, each buoy is replaced at best once per year. For example, the two buoys at 10°W-0°N and 0°W-0°N, which appear to have been destroyed in May 2004 (no more data received), could not be replaced until the following campaign in 2005.

b) ADCP moorings:

The surface current-meter measurements obtained at 23°W-0°N using an ADCP (a Narrow Band 514 ADCP) were processed in accordance with the procedures detailed in a data report (see reference below). The software supplied by the manufacturer, RDI, had to be adapted in order to be able to process the measurements by re-establishing them in binary format compatible with the processing software. A correction for magnetic variation and the speed of sound is applied before final processing of the measurements, which is complicated by signal reflections on the surface. The processing details are supplied in the report. We thus obtain measurements of the two horizontal components of the speed of the current between 26m and 320m with a vertical resolution of 8m. In order to be able to estimate the accuracy of the measurements, a comparison was made with measurements independent of current, obtained using the hull-mounted ADCP of the ships used to deploy or recover the mooring.

The current-meter measurements obtained in the surface layers from an ADCP were produced in two locations and in accordance with two different schedules. The operating periods of the ADCPs are summarized in the table below:

PIRATA current-meter moorings	Operating periods (month/year)
23°W-0°N	12/2001 to 12/2002
	02/2004 to 05/2005 *
10°W -0°N **	12/2001 to 12/2002
	05/2003 to 02/2004
	02/2004 to 06/2005 *

**: The moorings has been recovered during the the PIRATA FR13 and EGEE 1 campaigns. The operation end dates therefore correspond to the month the moorings are recovered and not the month of the end of availability of measurements, which will depend on the correct operation of the current-meters when submerged.*
**: *Part of the French PIRATA component only*.

The two ADCPs were deployed in December 2001 on both sites. As they therefore needed maintaining, neither could be re-positioned immediately after their recovery in December 2002. Only the ADCP mooring at 10°W-0°N was able to be put back in the water in May 2003 thanks to advantage being taken of a transit by the French Navy's hydrographic vessel Beautemps Beaupré, and no current measurements could be made at 23°W-0°N throughout 2003.

Reference:
- Kartavtseff, Annie, Mouillage courantométrique PIRATA 10°W ; Mai 2003- Février 2004; *Rapport interne LODYC* n°*2004-01*, May 2004.

c) oceanographic measurements obtained from ships:

The measurements obtained during the campaigns dedicated to the PIRATA Program are of different types and have all undergone appropriate processing when necessary.

- <u>The hydrological data</u> obtained using a CTD probe (Seabird SBE19 or SBE911+) were processed in accordance with international standards using the processing system supplied by the manufacturer (SEABIRD; "SBEProcessing") and, when seawater samples are available, allowing accurate analyses of the salinity and oxygen, the procedures implemented in accordance with the WOCE international standards, and those developed in part at the IRD during the ETAMBOT and EQUALANT programs, were applied (see References: *Gouriou, Y., Calibration des mesures CTD-O_2, dans « Campagne ETAMBOT 2, Recueil de données, Vol.1/2: Introduction, Mesures 'en route', Courantométrie ADCP, mesures CTDO_2, Coupes de distributions verticales », Doc. Scient. du Centre ORSTOM de Cayenne, O.P. 24*, 1997; *Chuchla, R., B. Bourlès and Y. Gouriou, Calibration des mesures CTD-O2, Campagne EQUALANT 99, N.O. Thalassa 13 Juillet – 21 Aôut 1999, Rapport de campagne à la mer, Rapport interne LODYC n°2000-01*, 2000; Chuchla, R., and B. Bourlès, Calibration des mes CTD-O_2, Campagne Equalant-2000, rapport de campagne à la mer, *Doc. Scient. et Techn. du Centre IRD de Bretagne, n°2001-89*, 2001).

- Current data from hull-mounted ADCP were processed according to the ADCP available and, thus, the ships used, either by the CODAS software (Reference: *"Common Oceanographic Data Access System, version 3, developed at the University of Hawaii" eg Bahr, F., E. Firing and S. Jiang, Acoustic Doppler current profiling in the western Pacific during the US-PRC TOGA Cruises 5 and 6, JIMAR Contr. 90-0228, U. of Hawaii, 162 pp*., 1990), or using CASCADE software developed in the Laboratoire de Physique des Océans (*Ocean Physics Laboratory*) in Brest (Reference: *« Cascade »: un logiciel de traitement des données ADCP de Coque, version 3.0, by C.Kermabon and F.Gaillard, Rapport interne DRP/LPO 02/03*, 2002).

- The thermal profiles obtained from XBT probes were processed using the MK12 software produced by the manufacturer, SIPPICAN. Profiles or elements of profiles noted visually as being suspect are eliminated. The data available and supplied are raw and not interpolated. Since 2003, the profiles obtained from ships of the French national fleet are transmitted in real-time to the CORIOLIS project and are thus also available via this program's internet site (http://www.ifremer.fr/coriolis/) or via the IFREMER "Centre de Données Océanographiques" site, the SISMER (Système d'Informations Scientifiques pour la Mer) at the following address: http://www.ifremer.fr/sismer/).

- Sea surface temperature and salinity measurements made using ships' temperature/salinity recorders are not processed. The measurements are taken every 10 to 15 seconds and a mean value is filed every 5 to 10 minutes, the time intervals varying from one ship to the next. On board IFREMER's ships, in addition to the temperature measured in the apparatus, often situated at a distance from the water intake, hull temperature measurements are available from an external SeaBird sensor. If that is the case, it is the latter that are considered.

All the data from PIRATA dedicated campaigns are processed at the "Centre IRD de Bretagne" and have been the subject of individual reports and a detailed overall data report, directly accessible on the PIRATA internet site (http://www.brest.ird.fr/pirata/infos_fr.html), and regularly updated throughout campaigns at sea.
The reference of this report is as follows:
- Grelet Jacques, Jacques Servain, Joao Lorenzzetti & Marcio Vianna, with the participation of Annie Kartavtseff, Rémy Chuchla & Bernard Bourlès, « Recueil de Données Météo-Océaniques effectuées durant les Campagnes PIRATA: Années 1997-2003, Centre IRD de Bretagne, B.P. 70, 29280 Plouzané, Septembre 2003.

d) sea level measurements:

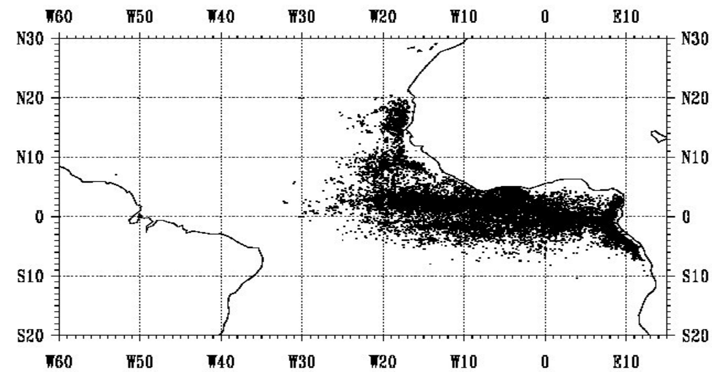
The measurements acquired using the São Tomé tide gauge are: depth, temperature and salinity of the sea and atmospheric pressure. The measurements are taken every hour and transmitted daily via ARGOS to the LEGOS, in Toulouse, where they are filed, made available to the community and also checked. The checking procedure applied is that of the ROSAME observation network ("Service d'Observations INSU" recognized approved program since 1997). The data can also be accessed in real-time on the LEGOS "Service d'Observations et d'Archives" site (http://www.legos.obs-mip.fr/fr/soa/). The full set of data is also accessible via the PIRATA site (ftp://ftp.ifremer.fr/ifremer/ird/pirata/maregraphe).

The São Tomé tide gauge was positioned by GPS for the international GLOSS programme (http://www.pol.ac.uk/psmsl/programmes/gloss.info.html) in December 2002. Since that date, the measurements acquired (level -depth or pressure-, temperature and salinity of the sea, and atmospheric pressure) every hour and transmitted daily via ARGOS, have been received without interruption, other than a few hours during the maintenance operations that took place in October 2003 and August 2004. The detailed reports of the missions concerning these tide gauge installation and maintenance operations, coupled with the maintenance operations on the meteorological station also established at São Tomé as part of the EGEE/AMMA programme, can be found either on the "Centre IRD de Bretagne" internet site (http://www.brest.ird.fr/activites/act_LEGOS_Brest.htm), or on the following "anonymous" ftp site: ftp.ifremer.fr/ifremer/ird/bourles/saotome .

APPENDIX 8 : VANDALISM AND VESSEL TIME ISSUES

1) Problems associated with vandalism:

As mentioned previously, there have been numerous periods without measurements (indicated by the absence of data transmission via ARGOS) for the two buoys located on the equator at longitudes 10°W and 0°E. During the "pilot phase" of the program, from 1997 to 2001, we unfortunately lost 4 buoys (sometimes only a few weeks after they were deployed). In fact, in the initial PIRATA program, two additional buoys were installed at 10°W on the latitudes of 1°30'N and 1°30'S, both of which were very soon vandalized, and it was therefore decided to remove them completely from the network as early as 2000. During operations on site, it became clear that the ATLAS buoys had indeed disappeared or been completely destroyed, essentially due to acts of vandalism associated with the presence of a large fleet of tuna seiner and line fishing boats, as illustrated in the figure beside, which shows the tuna catches in 1991 to 1999, and this by French fishermen alone... However, the sites away from the equator, and those in the western part of the network were not subjected to acts of vandalism of this type. Thus, the year 2003 alone enabled us to obtain a full set of data without any vandalism noted throughout the entire buoy network.



Catches of tuna (1991-1999)

It can be noticed here that a technological study has been initiated in France , in 2002, led by J.Servain. The aim of this study was to install on the ATLAS buoy a special acoustic instrument dedicated to move fishes away from the buoys ("Acousthon proposal"). This project unfortunately failed (close to the test phase achievement in 2004 and in spite of its prior funding by IRD), mostly due internal problems of the enterprise in charge of the technology development of the acoustic system…

2) Problems associated with the provision of ship time:

In order to conduct maintenance operations on the ATLAS buoy current-meter network and of the PIRATA program one, of course, need a ship.

Possible issue of the problem :

The problem of ship time for PIRATA operations in Brazil is linked to the fact that DHN, the sole provider of ship time for PIRATA in Brazil, currently has only one vessel, RV Antares, that is adequately equipped to service ATLAS type moorings in deep see. The use of a second ship, Amorim do Valle, is contingent to the investment of resources.

In France, IRD undertook the PIRATA program in the certain knowledge that it would be able to use its oceanographic ship ANTEA in the maintenance operations on the ATLAS buoys… Unfortunately, this ship is the subject of technical and legal problems since November 1999! That implies that, since 1999, the national "Fleet and Equipment" commission has one less available ship to count on for seagoing operations and campaigns in the Tropical Atlantic. The problem thus arises of the ship time needed to maintain the PIRATA network and, more generally, for seagoing activity within the framework of operational oceanography. In fact, the ship time dedicated to the measurements used operationally and, therefore, to the PIRATA network should, no doubt, in the years to come be able to be allocated without having to pass systematically every year for scientific assessment by the IFREMER "Physical, Chemical and Biological Oceanography" Commission, other than for essential and obvious programming requirements and a logical check of correct program monitoring. In fact, the working missions carried out within the framework of PIRATA should also be recognized as an opportunity for activities within the framework of the CORIOLIS and ARGO programs, in relatively little-sampled regions. It would therefore appear that the GMMC should be able to support the requests for ship time dedicated to operational oceanography that could be around two months annually and which would, therefore, be reserved in part for PIRATA. If that was possible, it would make it possible to avoid:

1) having long periods of time without being able intervene on site, as happened in December 2002 to January 2004, on the limit of the endurance and safety of the ATLAS buoys;
2) a national research body having to charter a ship from the national fleet, to ensure ATLAS buoys servicing in order to fulfill international undertakings given in a "Memorandum of Understanding", as the IRD did for the PIRATA FR13 campaign (in May –June 2005)…

It can be noted here that a study has been undertaken by Jacques Servain, initiator of the PIRATA program in France, aimed at the possibility of medium term provision of a ship dedicated to operational oceanography in the Tropical Atlantic, which would then make it possible to maintain an entire network of ATLAS buoys and also deploy probes, buoys and profilers within the framework of the GODAE and ARGO (ARGO and CORIOLIS in France) programs. This idea of a dedicated ship "NOR 50" made it possible to initiate an overall study into the various possibilities for providing ship time in the Tropical Atlantic, deploying from countries on the Atlantic seaboard potentially capable of such maintenance. This study resulted in the creation, on the initiative of the PIRATA Resource Board during the PIRATA-9 congress in January 2003, of a committee (the Atlantic Observations Working Group) nominated to study the question, whose final report was unveiled in November 2004 during the PIRATA 10 congress. From reading this report, it would appear that we are not yet close to finding a solution to the problem of having regular ship time available for operational oceanography; the solution currently favored being that of increased use of the ships available in the area. The summary and main conclusions of the AOWG report are provided below.

Ship Time Needs for PIRATA and the Tropical and South Atlantic Observing System

A Special Report by the
Atlantic Observations Working Group
[Final draft for submission to the PIRATA Resources Board]

November 2004

1.0 Purpose

In February 2003, an Atlantic Observations Working Group (AOWG) was established under the auspices of the PIRATA Resources Board to assess ship time needs for PIRATA and other Tropical and South Atlantic observing system elements. The purpose of this report is to summarize the work of the AOWG.

2.0 Background

Since PIRATA was first established as a pilot array, it had been recognized that maintenance cruises on a 6-month schedule would probably be required to maintain a level of data return similar to TAO/TRITON in the Pacific. TAO/TRITON moorings are maintained on a 6-month schedule. Resources were not available, however, to support 6-month maintenance for PIRATA, and a 12-month schedule was adopted. PIRATA data return rates confirmed that the 12-month schedule was not adequate – data return for TAO/TRITON averages about 85% while data return for PIRATA averages about 65%. The PIRATA Steering Group feels that one way to improve data return would be to increase frequency of maintenance visits to 6-month turn-around. This would double the present requirement for ship time.

Three PIRATA extension projects have been proposed to the Scientific Steering Group and are presently being evaluated by PIRATA, the international Climate Variability and Predictability Programme (CLIVAR), and other regional and global programs. These extension projects have potential to add of order nine more moored stations similar to the present PIRATA moored stations, thus approximately doubling the size of PIRATA from the present 10 stations to 19 stations. This could double again the ship time requirement.

Oceanographic and meteorological observations in the Tropical and South Atlantic are rapidly becoming more important to many nations for weather and climate forecasting, and for other marine services. PIRATA has become a major contribution to the Global Ocean Observing System (GOOS) and the Global Climate Observing System (GCOS). Other moored arrays, the surface drifting buoy array, the Argo profiling float array, ship-based networks, and tide gauge stations are also contributing to Atlantic GOOS and GCOS. Consequently, ship time requirements are increasing for other observing systems in addition to PIRATA.

The international CLIVAR Programme and the Ocean Observations Panel for Climate (OOPC) jointly sponsored a South Atlantic Climate Observing System Workshop (SACOS) in February 2003 to begin scoping observational requirements in the South Atlantic region. Beginning in 2001, more than 25 institutions in Africa, Europe, and the Americas developed a plan for an African Monsoon Multidisciplinary Analysis (AMMA) project to improve prediction of the West African Monsoon and Atlantic hurricanes. During 2003, the AMMA project was endorsed by CLIVAR and the Global Energy and Water Cycle Experiment (GEWEX). AMMA requires long-term observations in the Atlantic Ocean through at least 2010. PIRATA is a backbone element of both the SACOS and the AMMA observing systems.

3.0 Objectives

Assessing the ship time needs for Tropical and South Atlantic observations was undertaken by the AOWG with six objectives in mind.

1. Low cost. The best course to follow would be one that can be implemented at the least possible cost.
2. System-wide needs. PIRATA and the other present and anticipated international observing system needs over the foreseeable future were considered.
3. Operational efficiency. In order to provide good observing system support, the ship time assets should be located as close as possible to the working grounds; i.e., in the Atlantic basin. The assets should be designed for supporting oceanographic and surface meteorological observations. The assets must be available for routine scheduling to support sustained observations. Because of the international aspect of building a global ocean observing system, international shipping, receiving, and transit clearance processes should be as convenient as possible.
4. Long-term solution. The solution should provide facilities for the long term. The pilot phase of PIRATA provided only a short-term solution to ship time. It is now time to look to the long term since is becoming clear that the international demands for sustained ocean and atmospheric observations in the Atlantic basin are ever increasing.
5. Capacity building. Many of the Atlantic basin nations are only just beginning to develop the scientific capacities and capabilities to become substantial contributors to the global ocean observing system. The best solution would be one that encourages development of regional capabilities that in turn would require sustained oceanographic ship operations.
6. Political feasibility. The best solution would be the one that appears advantageous and achievable by institutions residing in several different countries, each being subject to the unique regulations of their own governments.

4.0 Options

Six options were evaluated against the objectives:

1. The status quo. In this option, Brazil would continue to provide ship time to service the western part of the PIRATA array once per year. France would provide ship time to service the eastern part of the array once per year. Once per year maintenance requires about 60 days at sea per year. In 2003 Brazil fielded 24 days and France fielded 31 days. Under the present Memorandum of Understanding for the PIRATA consolidation phase, the United States does not contribute to ship time – under the three-way partnership Brazil and France contribute ship time and the United States contributes replacement moorings and equipment.
2. U.S. ship time augmentation. The United States would augment present Brazil and France ship time by contributing approximately 60 additional ship days per year to bring the maintenance schedule to twice per year, similar to TAO/TRITON in the Pacific.

3. Augmentation with excess ship capacity from other countries. The PIRATA consortium would look for ship time from other countries/institutions in the region to augment the present Brazil and France contributions.

4. The NOR-50. French colleges have developed a prospectus for construction of a new oceanographic ship specially designed for maintenance of the PIRATA moorings. In the Pacific, the United States has adopted this philosophy – NOAA presently operates the *Ka'imimoana* which is an oceanographic vessel specially fitted for maintenance of TAO moorings. The NOR-50 prospectus is appended to this report. In summary the NOR-50 would be a small, fast ship designed to visit each PIRATA site twice per year; it would have time available to ply other Atlantic waters for rapid deployment of drifting arrays as well. The prospectus assumes that France and the United States would share in the cost of construction of the NOR-50 and that the vessel would utilize a ship base in North East Brazil as primary homeport for PIRATA operations.

5. An all-purpose dedicated oceanographic vessel. This option adopts a philosophy similar to the NOR-50 (i.e., a dedicated ship) except that in this option the ship would be designed with full oceanographic and meteorological observational capabilities. It would not be designed for just PIRATA and the drifting arrays. It would be able to also support other observational projects; e.g., repeat hydrographic and ocean carbon inventory surveys.

6. A converted ship that can perform PIRATA array maintenance and deploy drifting arrays only. This would be a dedicated ship similar to the NOR-50, but would operate at a more conventional speed. Its useful life after conversion would be about 10 years.

5.0 Evaluation

To provide an assessment of this issue, the AOWG considered each of the six objectives in turn. For each objective, the six options were rated against each other to rank their perceived ability to meet the objective most effectively.

For Objective 1, low cost, the approximate annual cost in 2003 U.S. dollars was estimated to maintain the present array of 10 moored stations, visiting each station twice per year (except for the Status Quo option which provides for only one visit per year). For the newly constructed dedicated ship options (Options 4 and 5), the estimated capital cost of construction was amortized over 20 years and added to the estimated operating cost to arrive at an estimated annual cost. The converted ship costs (Option 6) were estimated in a similar manner, except that the estimated capital cost of conversion was amortized over 10 years. The costs for the six options were ranked relative to each other.

In evaluating Objectives 2, 3, 4, 5, and 6, the AOWG members rated each option on a scale of 1 to 5. A rating of 1 indicated that the option had low probability of meeting the objective. A rating of 5 indicated that the option had an excellent probability of meeting the objective. The ratings of the AOWG members were averaged to give an overall rating. For each objective, summary comments were provided giving some of the main considerations and concerns of the AOWG members as the options were evaluated.

…….details on evaluation not provided…………

6.0 Summary

6.1 Pros and Cons.

Option 1: Status Quo.

- Pros: Low cost.
- Cons: Does not provide adequate capability for maintaining PIRATA over the long term.

Option 2: U.S. ship time augmentation.

- Pros: Relatively easy to implement.
- Cons: Does not provide for capacity building. Because the U.S. research fleet is already fully committed, PIRATA would have to compete for ship time at a high charter costs.

Option 3: Augmentation with excess ship capacity in other counties.

- Pros: Excellent for capacity building. Takes advantage of presently underutilized capabilities. Provides high flexibility for satisfying the evolving system-wide requirements of SACOS, AMMA, as well as PIRATA and its extensions.
- Cons: Increased complexity in scheduling, logistics, and technical training in several counties.

Option 4: NOR-50.

- Pros: Highly efficient operations. Relatively low cost. Excellent long-term solution.
- Cons: Difficult to implement politically. Long lead time to acquire funding. Limited experience with this new ship design.

Option 5: All purpose dedicated ship.

- Pros: Efficient operations. Excellent long-term solution for both PIRATA and the broader Atlantic observing system.
- Cons: High cost. Difficult to implement politically. Long lead time to acquire funding.

Option 6: Converted dedicated ship.

- Pros: Initial limited capability, but additional capability could be added in stages if the ship selected is of sufficient size. This avoids a large initial capital cost, and ultimately the ship could have capabilities close to the all purpose ship.
- Cons: Cannot be operated at the marginal cost of consumables. Potentially could be slow (10 knots). Useful life is about half of a new ship. Long lead time to acquire funding.

6.2 Summary of rating scores.

The table below summarizes the rating scores from Section 5 and gives an overall average score. The overall average score assumes that all Objectives are of equal weight, which of course they are not. No attempt was made to weight the scores.

Option 1 Status Quo	Option 2 U.S. ship time augmentation	Option 3 Other country ship time	Option 4 NOR-50	Option 5 All purpose dedicated ship	Option 6 Dedicated conversion	
Annual cost, in U.S. dollars	$430 K*	$1630 K	$800 K	$770 K	$2270 K	$1620 K
Relative Ranking	6	2	4	5	1	3

** The Status Quo provides only one visit per year.*

7.0 Conclusions

The AOWG commends the PIRATA institutions for seeking a long-term solution to maintenance of PIRATA. It is clear that better data return from PIRATA is needed; the Scientific Steering Group's recommendation to increase maintenance frequency to six months is sound.

PIRATA is only one contribution to the Atlantic observing system. In addition, the "final" and permanent PIRATA design is not yet known. Yet the requirement is clear for a sustained Tropical Atlantic observing system. It would be good to have a better view of the future ship requirements for proposed/envisioned PIRATA extensions and for the other systems in the region. This would provide better arguments for comparing the Options.

The NOR-50 solution is the most economical and efficient solution for PIRATA. This option, however, is also one of the most difficult to implement politically.

The best solution for today is likely Option 3, working with other countries to utilize their capabilities. This seems relatively cost effective but implementing this option would continue to be complicated and uncertain logistically unless another county's ship time could be dedicated to cope with the PIRATA requirements on a regularly scheduled basis.

The option that achieved the highest summary rating by the AOWG was Option 6, a converted ship dedicated to PIRATA and deployment of the drifting arrays. This option achieved the highest average numerical rating, but just barely – the NOR-50 and working with other countries rated only slightly lower. The converted ship solution would be similar to the strategy that has been employed by the United States for TAO maintenance in the Pacific. This solution would be a good long-range target. The difficulties would include locating a suitable surplus vessel and then acquiring the funding needed for conversion and operations, which would probably require long lead-time and high level government commitments.

APPENDIX 9 : PIRATA-6 meeting SSC resolution

RESOLUTION BY THE PIRATA STEERING GROUP

PIRATA-6
Miami, Florida
5 May 1999

Progress in implementation of the Pilot Research Moored Array in the Tropical Pacific (PIRATA) was reviewed at PIRATA-6 in Miami, Florida on 3-4 May 1999. Deployment of the moored buoy array began in late 1997, and by early May 1999 nine sites were occupied and successfully transmitting data in real-time. Implementation is on schedule and nearly complete. The full array of 12 moorings will be in place for one year before the field phase is scheduled to end in early 2001.

The first phase of PIRATA implementation coincided with a warm event which occurred in the whole tropical Atlantic. That dramatic event developed during the end of the largest ENSO event ever registered and was concomitant with one of the five worst droughts in NE Brazil this century. The buoy array captured the development of the upper ocean thermal anomalies, and the seasonal evolution of oceanic and atmospheric variability on which they were superimposed. Real-time PIRATA data available on the GTS were used in operational oceanic and atmospheric analyses and forecasts during this period. Preliminary diagnosis of the data also supports hypotheses concerning ocean-atmosphere coupling in the region.

PIRATA was originally conceived as a pilot study with a 3-year field phase in support of CLIVAR, GCOS, and GOOS objectives. It is becoming clear that a complete array for one year will provide insufficient time to evaluate whether PIRATA should be part of a permanent climate observing system. On the other hand, it is also clear that PIRATA data are already providing valuable new information for climate studies of relevance to the Americas and Africa.

Therefore, based on the initial successes of the program, the PIRATA Steering Group recommends a transitional phase towards the development of a sustained climate observing system for an additional five years, to 2006. This extension will allow for a full demonstration of the utility of PIRATA data, and a smoother transition to operational status, if warranted.

In addition, recognising that this extension will require a sustained level of support in terms of funding, ship-time, and equipment, the PIRATA Steering Group recommends that a PIRATA Resource Board, with terms of reference, be established to ensure that adequate resources will be available for the duration of the program. This Resource Board would initially consist of representatives from the institutions in Brazil, France and the United States that presently provide support for the array.

Finally, in recognition of the widespread interest in developing a sustained observing system in the tropical Atlantic for climate studies, as evident from the international participation at the Climate Observing System for the Tropical Atlantic (COSTA) workshop that followed the PIRATA-6 in Miami, the PIRATA Steering Group resolves to coordinate with ongoing and planned observational efforts in the region. Furthermore, building upon recommendations put forward at the COSTA workshop, the Steering Group encourages consideration of scientifically sound pilot expansion projects that build upon the original PIRATA array. Moreover, the Steering Group invites collaborations with other nations and institutions interested in implementing a sustained climate observing system in the tropical Atlantic.

APPENDIX 10 : NATIONAL RESSOURCE CONTRIBUTIONS

Recalls:

By prior agreement the responsibility for purchasing ATLAS mooring systems were shared by Brazil (5 systems), France (5 systems) and the USA (10 systems). All moorings during the pilot study are built by PMEL, which is also be responsible for shipping, calibration, laboratory check outs, instrument refurbishment's. Logistic support in terms of ship-time for developing and maintaining the PIRATA moored array is mainly the responsibility of Brazil and France.

After the PIRATA "Pilot phase", it has been stated in the PIRATA MoU (Memorandum of Understanding) that, during the "Consolidation phase":

- NOAA (USA) refurbishes moorings of the initial consolidation phase inventory until facilities in Brazil and/or France/African countries are prepared to take over refurbishment tasks. The initial inventory of 15 moorings for the consolidation phase consists of ATLAS moorings left over from the pilot phase. NOAA supplies up to two replacement ATLAS mooring systems each year if required because of damage or loss. It is noted that the ATLAS system is constantly being improved as technology advances. NOAA also pays Argos data processing costs for the ATLAS system measurements.
- INPE (Brazil) assumes responsibility for the logistics required to transport PIRATA equipment between Seattle and Brazilian depots. INPE takes the necessary actions so that adequate ship time is available to maintain the PIRATA array on the Brazilian side (INPE works with DHN to provide the ship time). The Brazilian side includes the five ATLAS moorings in the western tropical Atlantic, from 15°N to the equator along 35°-38°W, besides possible future moorings as part of a western extension (WE) south of the equator. INPE also provides for the deployment, maintenance, and the real-time delivery of the data (including the Argos costs) of one meteorological buoy anchored close to 0°-44°W, as planned in the PIRATA-SIP98.
- IRD and Météo-France (France) assumes responsibility for the logistics required to transport PIRATA equipment between Seattle and French/African country depots. IRD ensures that adequate ship time is available to maintain the PIRATA array on the African side. The African side includes the five ATLAS moorings in the eastern tropical Atlantic, in the region 0° to 10°S, and 0° to 20°W, and the ADCP mooring close to 0°, 20°W. IRD provides for the deployment, maintenance, and the real-time delivery of the data (including the Argos costs) of one tide-gauge located at São Tomé Island, as planned in the PIRATA-SIP98.

In order to provide an idea of the national funding effort by each involved country, the global expenses running for the last three years are given in the following. This list is not exhaustive, and the estimates of the coast may vary from one country to another. However, no base funded salaries or other laboratory infrastructure costs are included in any of the estimates.

France funding (2003-2005):

a) Usual "running" funding since 2003 (vessel time excluded):

	METEO FRANCE	IRD	ORE (Research Ministry)	**Total:**
2003:	22,430 €	38,000 €	11,287 €	71,717 €
2004:	22,430 €	67,000 € [1]	20,317 €	109,747 €
2005:	22,430 €	105,000 € [2]	18,900 €	143,330 €

1 *: 30k€ overcost added due to the material transport by air freight for PIRATA FR-12*

2 *: 70k€ overcost only due to the chartering of the R/V LE SUROIT for PIRATA FR-13*

b) vessel time costs :
in 2003 : 30 days of R/V Suroit (at 15k€/day) => 420k€
in 2004: 26 days of R/V Atalante (at 20k€/day) => 520 k€
in 2005 : 29 days of R/V Suroit (at 15k€/day) => 435 k€

That means that in average (calculated over the last three years), the total amount dedicated to the PIRATA program in France (salary not taken in account) is around 550k€ per year (*i.e.* 660k$).

Brazil funding (2003-2005):

In 2003, values include all costs due to material transportation, R/V Antares maintenance (consumables & repairs), cruises per diems and meetings.

In 2004, they also include acquisition of 2 ATLAS systems for the PIRATA-SW extension, calibration equipment acquisition, and R/V Amorim do Valle engineering and upgrade.

In 2005, they include acquisition of 1 ATLAS system (the 3rd one for the PIRATA-SWE), a tide gauge acquisition for ASPSP, and the INPE/Natal LBO Civil construction.

All presented fundings are from INPE.

	kR$	**kUS$**
2003:	108,5	43,4
2004:	874,0	349,6
2005:	1045,0	418,0

An average over the three last years would not be representative as, mostly due to the Southwestern extension, funding effort increased significantly in 2004 and 2005. Thus, we can consider that the amount dedicated to the PIRATA program in Brazil (average of 2004 and 2005, salary <u>and vessel time costs</u> not taken in account) is around 385k$ per year (i.e. around 310k€).

USA funding (2003-2005):

1) Direct grants to PMEL
2003 $600K
2004 $600K
2005 $810K (includes $170K for initiating NE extension)

2) Support of Brazilian PIRATA cruises (none before 2004):
2004 $50K
2005 $50K

That means that the total amount dedicated to the PIRATA program in USA in 2005 was 860k$ (*i.e.* around 690k€), as representative for the next years, due to the Northeastern extension.

(Note: from 1998 to 2002, the direct grants to PMEL amounted to $600K per year plus $75K in 1997. Thus, the total NOAA contributions to PIRATA 1997-2005 in USD is $5,085K through direct grants and $100K through support of Brazilian cruises, *i.e.* a grand total of $5,185K).

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APPENDIX 12: ACRONYMS

ABBREVIATION	FRENCH & PORTUGUESE TERMS (WHERE APPLICABLE)	ENGLISH MEANING
ADCP		Acoustic Doppler Current Profiler
AMMA	Analyses Multidisciplinaires de la Mousson Africaine	Multidisciplinary analyses of the African monsoon
ARGO		Part of the Integrated Global Observation Strategy
BCLME		Benguela Current Large Marine Ecosystem
CARBOAT	Carbone dans l'Océan Atlantique Tropical	Carbon in the Tropical Atlantic ocean
CDO	Comité Des Organismes	"Bodies" committee
CERSAT	Centre ERS d'Archivage et de Traitement	French ERS processing and archiving facility
CLIVAR		Climatic Variability and Predictability (international programme)
CLIVAR AIP		CLIVAR Atlantic sector Implementation Panel
CMS	Centre de Météorologie Spatiale	Space meteorology Centre (Lannion)
CNRM	Centre National de Recherches Météorologiques de Météo-France (Toulouse)	National meteorological research centre (Météo-France / Toulouse)
CODAS		Common Oceanographic Data Access System
CSOA	Commission Spécialisée "Océan Atmosphère"	Specialist "Ocean/Atmosphere" commission of the INSU/CNRS
CPTEC	Centro de Previsão de Tempo e Estudos Climáticos	Weather Prediction and Climate Studies Center
ECLAT	Etudes climatiques dans l'Atlantique Tropical	Climatic studies in the Tropical Atlantic
ECMWF		European Centre for Medium-Range Weather Forecasting
EGEE	Etude de la circulation océanique dans le Golfe de GuinEE	Oceanographic French component of AMMA
ENSO		El Niño Southern Oscillation
FUNCEME	Fundação Cearense de Meteorologia e Recursos Hídricos	Ceara Foundation for Meteorology and Hydrological Resources
GCOS		Global Climate Observations System
GEOSS		Global Earth Observation System of Systems
GLOSS		Global Sea Level Observations System
GODAE		Global Ocean Data Assimilation Experiment
GOOS		Global Ocean Observations System
GTS	Système mondial de télécommunications (SMT)	Global Telecommunication System
IFREMER	Institut Français de Recherche pour l'Exploitation de la Mer	French Research Institute for Sea Exploitation
IGBP		International Geosphere-Biosphere Programme
INPE	Instituto Nacional de Pesquisas Espaciais	Brazilian national institute for space research
INSU/CNRS	Institut National des Sciences de l'Univers	National universal sciences institute
IOP		Intensive Observation Period
IRD	Institut de recherche pour le développement	Development research institute
IRI		International Research Institute for Climate and Society
ITCZ		Inter-Tropical Convergence Zone
LAPA	Laboratoire de la Physique de l'Atmosphère (Abidjan, RCI)	Atmosphere Physic Laboratory
LPAO	Laboratoire de Physique de l'Atmosphère et de l'Océan (Dakar, Sénégal)	Ocean and Atmosphere Physic Laboratory

LEGOS	Laboratoire d'Etudes en Géodésie et Océanographie Spatiale	Geodesic studies and space oceanography laboratory
LOCEAN	Laboratoire d'Océanographie et du Climat: Expérimentations et Approches Numériques	Oceanography and climate laboratory: Experiments and digital approaches
LODYC	Laboratoire d'océanographie dynamique et de climatologie	Dynamic oceanography and climatology laboratory
LPO	Laboratoire de Physique des Océans	Ocean Physics Laboratory (IFREMER Brest)
MoU		Memorandum of Understanding
NAO		North Atlantic Ocean
NCEP		National Centers for Environmental Prediction
NOAA		National Oceanic and Atmospheric Administration
OOPC		Ocean Observations Panel for Climate
ORE	Observatoire de Recherche pour l'Environnement	Environmental Research Observatory
PERENE		PIRATA EuleRian Essential Network Evaluation
PIRATA		Pilot Research Moored Array in the Tropical Atlantic
PIRATA-NEE	Extension Nord-Est de PIRATA	PIRATA North-Eastern Extension
PIRATA-SEE	Extension Sud-Est de PIRATA	PIRATA South-Eastern Extension
PIRATA-SWE	Extension Sud-Ouest de PIRATA	PIRATA South-Western Extension
PIRATA-SSC	Comité de Direction Scientifique de PIRATA	PIRATA Steering Scientific Committee
PROOF	Processus biogéochimiques dans l'Océan et Flux	French acronym for "Biogeochemical processes in the Ocean and Fluxes"
PRB		Pirata Resources Board
SISMER	Système d'Informations Scientifiques pour la Mer	Scientific data system for the sea
SOLAS		Surface Ocean - Lower Atmosphere Study
SST		Sea Surface Temperature
SVP		Surface Velocity Program
TACE		Tropical Atlantic Climate Experiment
VACS		Variability of the African Climate System
VAMOS		Variability of South America Monsoon System
WAM		West African Monsoon
WOCE		World Ocean Circulation Experiment