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Dissemination Level		
PU	Public	X
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the Consortium (including the Commission Services)	
CO	Confidential, only for members of the Consortium (including the Commission Services)	

If this report is not to be made public, please state here why: not applicable.

Contribution to project objectives – with this deliverable, the project has contributed to the achievement of the following objectives (from Annex I / DOW, Section B1.1.):

N.º	Objective	Yes	No
1	Reduce uncertainties in our knowledge of the functioning of tropical Atlantic (TA) climate, particularly climate-related ocean processes (including stratification) and dynamics, coupled ocean, atmosphere, and land interactions; and internal and externally forced climate variability.	X	
2	Better understand the impact of model systematic error and its reduction on seasonal-to-decadal climate predictions and on climate change projections.	X	
3	Improve the simulation and prediction TA climate on seasonal and longer time scales, and contribute to better quantification of climate change impacts in the region.	X	
4	Improve understanding of the cumulative effects of the multiple stressors of climate variability, greenhouse-gas induced climate change (including warming and deoxygenation), and fisheries on marine ecosystems, functional diversity, and ecosystem services (e.g., fisheries) in the TA.	X	
5	Assess the socio-economic vulnerabilities and evaluate the resilience of the welfare of West African fishing communities to climate-driven ecosystem shifts and global markets.		X

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Comments on Deviations: It was agreed being the Project Coordinator and the Project Officer, Mr. Federico Nogara (email exchange on 14.08.2017) that the original due date for this deliverable, D4.4: "Suggestion for a sustainable long-term monitoring system", could be extended to April 2018 (month 54), so as to benefit from PREFACE participation in on-going discussions on the Tropical Atlantic Observation System (TAOS) that were planned after October 2017. PREFACE has become a key part of an international effort to evaluate the TAOS. This evaluation is a critical part of the review of the PIRATA network of moored buoys in the tropical Atlantic that was initiated 20 years ago. The first dedicated meeting on the evaluation of the PIRATA program was held in Brazil in early November 2017, at a conference to mark the 20th anniversary of the program; PREFACE contributed to organize the conference and for the drafting of a white paper on the PIRATA programme. A follow-up meeting was held during the AGU Ocean Sciences conference in February 2018, during which PREFACE took part in the dedicated committee evaluating the TAOS, along with members from CLIVAR Atlantic Regional Panel, The Ocean Observations Panel for Climate, PIRATA, and the EU H2020 project, AtlantOS.

Executive Summary

This report is Deliverable 4.4 of the PREFACE project, produced by the work package WP4: "Circulation and Wave Response" of the Core Theme 2: "Key oceanic processes in the eastern Tropical Atlantic". The main objective of WP4 consists in providing suggestions for a sustainable long term monitoring system, as based on the analysis of data from the tropical Atlantic observing system with regard to interannual to decadal variability and anomalous climate events. A design for a sustainable long-term monitoring system is recommended, along with report on requirements for a sustainable long term monitoring system.

This report has been delayed compared to the original plan in order to benefit from the Tropical Atlantic Observing System (TAOS) review process. It will therefore be timely to the definition of the BluePrint for an integrated Atlantic Ocean Observing System and to the major OceanObs19 conference in 18 months, the main gathering of all ocean observing systems, occurring every 4th year. The suggestions in the present report will be advocated to the community during OceanObs19. Suggestions provided in the present document arise from scientific discussions made during several recent meetings (PREFACE-PIRATA-TAV conferences, AtlantOS meetings, the TAOS review kickoff,…). Some of the following suggestions were already included in a first version of a PIRATA White Paper issued in January 2018 to the TAOS review committee before their first meeting. Observations efforts made during the PREFACE years, in collaboration with several other projects (PIRATA, SACUS, AWA…) were justified both by scientific issues (ocean and climate processes, in particular in the mixed layer) and societal issues (weather and climate prediction, ocean environment and resources). This deliverable also takes into account progresses obtained thanks to these observations.

The main focus of this report is in the ocean upper ocean layers. In the first part, we describe briefly the existing Tropical Atlantic Observing System as of early 2018, highlighting the major long term *in situ* observing initiatives (although not exhaustively). In a second part, two types of parameters are considered separately, i.e. Essential Ocean Variables (EOVs) prioritized by the Global Ocean Observing System (see http://www.goosocean.org/eov) and other biogeochemical variables of relevance to PREFACE, by presenting their relative importance and their needs for sustainable observations. A prioritized list of suggestions is then drawn for a sustainable long term monitoring system, based on the existing observing systems and potential enhancements and optimizations. This document does not cover observations of fish abundance nor other ocean resources.

The present Tropical Atlantic Monitoring System

All observing systems are not dedicated to monitoring specifically, thus this document is mostly focused on systems providing data time series, possibly with a reasonably short time delay (i.e. in real and delayed modes), made available to Global Data Assembly Centers (GDACs). Thus, short time processes studies are not considered here, even if relevant for improving our understanding of the climate and air-sea exchange systems and numerical/operational models.

The Global Ocean Observing System (GOOS) gathers and provides essential ocean information to get a global view of observing networks and international/regional programs. Major observing networks are ARGO, the Global Drifter Program (-GDP- surface drifters; through the Data Buoy Cooperation Panel -DBCP-), fixed moorings (OceanSITES, including the PIRATA air-sea exchanges buoys network), Voluntary Observing Ships (VOS and SOOP; through the underway Ship Observations Team -SOT- and the Global Ocean Surface Underway Data -GOSUD-), the GO-SHIP hydrographic surveys, and the tide gauges network (Global Sea Level Observing System -GLOSS-). These networks are summarized on Figure 1 below (source: Joint Technical Commission for Oceanography and Marine Meteorology in situ Observing Programs Support Center -JCOMMOBS-, January 2018). Readers can also refer to Legler et al. (2015) for more information about the real-time *in situ* GOOS.

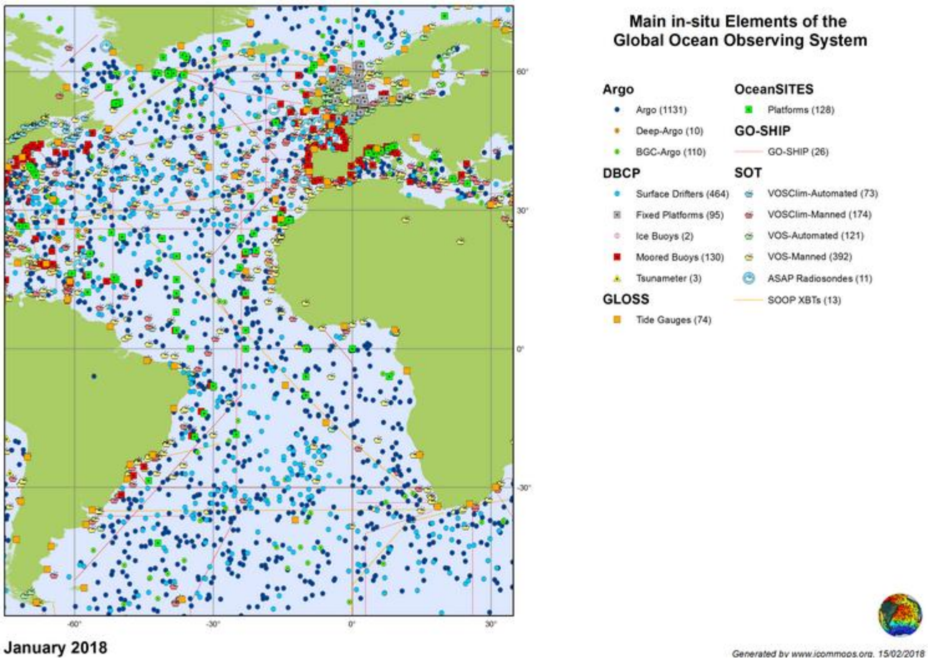


Figure 1: Summary of major observing networks in the Tropical Atlantic. Source: Joint Technical Commission for Oceanography and Marine Meteorology in situ Observing Programs Support Center -JCOMMOBS-, January 2018

These platforms mainly ensure the measurements of EOVs, i.e. temperature, salinity, currents, sea-level, air-sea fluxes, surface meteorology and a few EOV sub-variables, as O_2, pCO_2 and pH. Very few allow time series or measurements of waves and ocean acoustics, despite these being considered as EOVs.

The fixed moorings in the tropical Atlantic are principally those of the PIRATA network, initiated and in place since 1997, and to which PREFACE contributed to with the Kizomba buoy at 8°E, 6°S. PIRATA is now more than 20 years old, well established and recognized as the backbone of the

TAOS; it also serves as the baseline climate record in the tropical Atlantic through sustained observing of GOOS EOVs and Essential Climate Variables (ECVs). The PIRATA buoys are part of OceanSITES. PIRATA maintains 18 air-sea exchanges buoys equipped with atmospheric sensors (T, humidity, rain, solar radiation, wind amplitude and direction), and T/S sensors down to 300m depth. Some buoys are equipped with surface current-meters, 3 with CO_2 sensors and 3 other ones with O_2 sensors. Data are transmitted in real time through the Argos (for original ATLAS buoys) or Iridium (for new T-Flex buoys) systems and made available through the GTS and to some GDACs, the PIRATA PMEL website, and ftp. The T-Flex system has progressively been replacing the ATLAS system since 2015. Ten buoys are now T-Flex, allowing the potential implementation of more sensors with high frequency data transmission in real time. As illustrated in Figure 2, all buoys are also equipped since 2014 with acoustic receivers at 200m depth, as contribution to the Ocean Tracking Network (OTN ; see http://oceantrackingnetwork.org/). Two equatorial sites (23°W and 10°W) are also equipped with turbulence sensors (χpods), in the framework of an Oregon State University (OSU) Ocean Mixing Group program supported by the US National Science Foundation for a 5 years duration (see http://mixing.coas.oregonstate.edu/). See Servain et al. (1998) and Bourlès et al. (2008, 2018) for more details on the PIRATA program and its evolution.

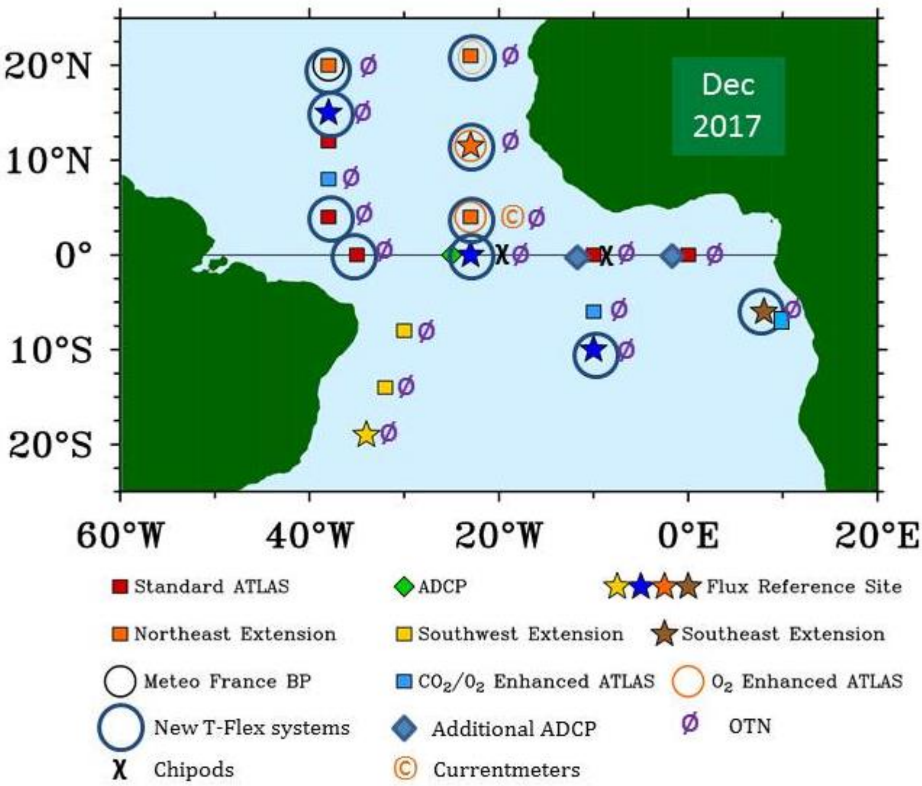


Figure 2: PIRATA air-sea exchanges buoys in the Tropical Atlantic

PIRATA also maintains three current meter (ADCP) moorings along the equator, at 23°W (from 2001), 10°W (from 2006) and 0°E (from 2016, with support from PREFACE), thus monitoring the Equatorial Undercurrent from near the surface down to about 300m depth.

Other moorings contributing to the TAOS are:

- The “Meridional Overturning Variability Experiment” (MOVE), which maintains a 3 moorings array in the Northwest Tropical Atlantic along 16°N, from the year 2000 as a German CLIVAR program, then later, since 2008, integrated in the US Atlantic Meridional Overturning Circulation” (AMOC) program (Figure 3). These moorings measure high-accuracy temperature and salinity throughout the water column, and currents in the two westernmost sites. MOVE is part of OceanSITES and data available through this project website (www.**oceansites**.org).

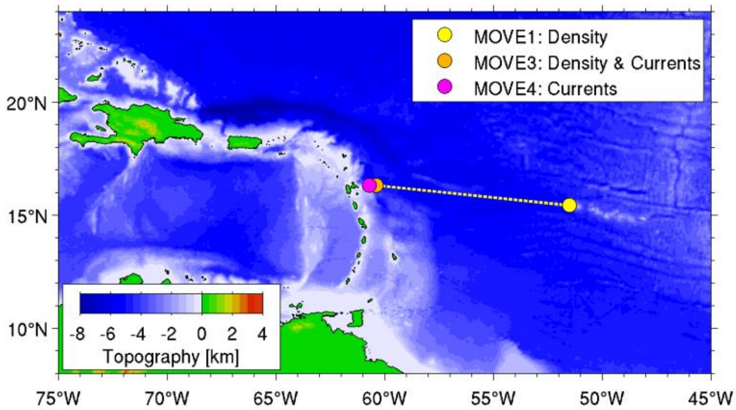


Figure 3: Moorings of the AMOC program.

- The Cape Verde Ocean Observatory (CVOO; http://www.cvoo.de/), initiated through collaborations between GEOMAR and Cape Verdean institutions, is located at 17°35N-24°W and maintains since 2006 a multi-parameter long-term mooring for in-situ observations (including real-time satellite telemetry). Measured parameters are: T, S, currents, but also O_2, CO_2 and particle flux. CVOO is part of JCOMM-related OceanSITES time series network and is an official ICOS station (Integrated Carbon Observation System). CVOO is also part of the Fixed-point Open Ocean Observatories Network (FixO^3, EU FP7), which aims to provide multidisciplinary observations from the air-sea interface to the deep seafloor. Two other platforms exist: DELOS (Deep-ocean Environmental Long-term Observatory System) was installed in 2009 around 8°S-12°E off Angola, and SOG (Southern Oligotrophic Gyre) was installed in 2008 around 18°5’S-25°W (see http://www.fixo3.eu/)

- Mooring arrays were deployed in 2013 at 11°S at the western and eastern boundaries of the tropical South Atlantic Ocean by GEOMAR, within the German funded projects «regional Atlantic circulation and global change» (RACE) for the western moorings, and the funded «Southwest African Coastal Upwelling System and Benguela Niños» (SACUS) for the eastern moorings. The western moorings are equipped with ADCPs and additional single-point current meters, as well as temperature and salinity with MicroCat sensors. This mooring array aims to capture the northward flow of warm and intermediate waters within the North Brazil Under Current (NBUC), the southward flow of North Atlantic Deep Water (NADW) within the Deep Western Boundary Current (DWBC) and the northward flow of Antarctic Bottom Water. The eastern moorings are equipped with ADCP moorings and dedicated to the monitoring of the strength and variability of the Angola Current hugging the continental shelf.

Maintenance and servicing of all these moorings networks induce regular oceanographic cruises. The PIRATA network maintenance is made possible through yearly cruises ensured by each partner country, Brazil in the West, USA in the North-East, and France in the East and the Gulf of Guinea, and repeat hydrologic/current sections at 38°W, 23°W and 10°W. The MOVE array is also serviced by cruises every two years, during which CTD casts are ensured. RACE and SACUS arrays also induce regular cruises, during which hydrographic and current observations are carried out, also along a second zonal section at 5°S in the west. In addition to, or associated with, the RACE and SACUS sites servicing, GEOMAR realizes almost yearly cruises in the Tropical Atlantic for its different programs. Also, the Atlantic Meridional Transect (AMT) program, coordinated by the Plymouth Marine Laboratory in collaboration with the National Oceanography Centre and funded by the Natural Environment Research Council's National Capability, carries out yearly multi-disciplinary research cruises from 1995 across the Tropical Atlantic allowing physical, chemical and biological measurements (see http://www.amt-uk.org).

Most of these cruises are also opportunities to contribute to other programs, e.g. by deploying ARGO profilers and SVP drifters, and also by transmitting in quasi-real time XBT and CTD profiles to GDACs.

The Global Ocean Ship-based Hydrographic Investigations Program (GO-SHIP) contributes to quantify the ocean state and how it is changing through surface to bottom measurements during transoceanic cruises, made on a longer time scale. Reference sections are repeated at an almost regular time interval (at least decadal), and five sections concern the Tropical Atlantic limited to 25°S/N in latitude (A13 along 0°E, A16 and A17 both roughly along 23°W; and in the west A20 and A22 ; see http://www.go-ship.org). These cruises also contribute to other programs by deploying autonomous devices (XBT, SVP, ARGO).

From the early 2000s, ARGO profilers provide temperature/salinity (T/S) profiles down to 2000m every 10 days. In January 2018, up to 1276 profilers were deployed in the Tropical Atlantic, limited to 25° S/N in latitude (profilers deployment locations are shown on Figure 4, courtesy N.Poffa, Ifremer). Profilers are deployed during oceanographic cruises and from VOS. PIRATA cruises ensured the deployment of 192 profilers, including some with specific configuration (higher vertical resolution in the upper layer) in the Gulf of Guinea during the French PIRATA cruises. During these cruises, CTD casts are also done down to 2000m in order to provide T/S profiles needed for the profilers data validation.

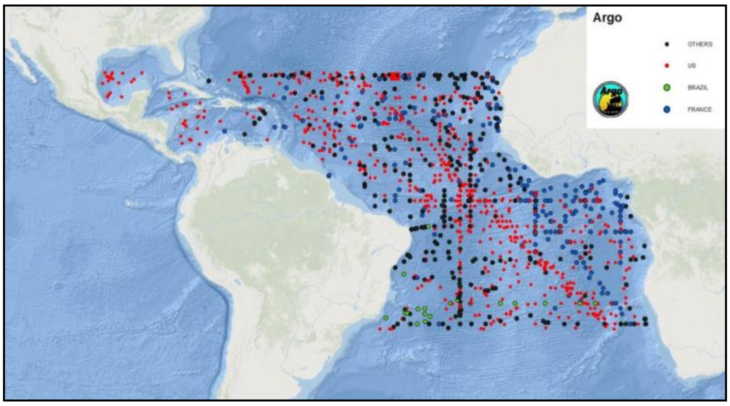


Figure 4: ARGO profilers deployed in the Tropical Atlantic. Courtesy N. Poffa, Ifremer.

The GDP supervises the deployment of SVPs through several opportunities in the open Tropical Atlantic Ocean, as the VOS (SOOP lines AX7, AX8), research cruises (PIRATA US, French and Brazilian; GO-SHIP; GEOMAR; and UK Met Office), Brazilian navy cruises (in the west), and the Wildlife Conservation Society. In average, about 5 drifters are deployed monthly from 2006, including 152 during PIRATA cruises. In Figure 5, drifter deployments and data density are shown.

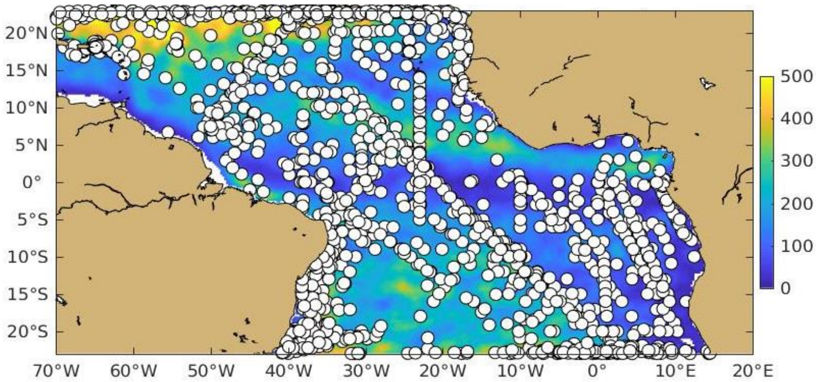


Figure 5: Drifter deployments and data density. Shading represented historical density of data, drifter days per square degree. Courtesy: R. Lumpkin, NOAA/AOML.

NOAA/AOML maintains together with national and international partners the Expandable Bathy-Thermograph (XBT) Program that includes 4 High Density XBT transects in the Tropical Atlantic (Figure 6; courtesy G. Goni). These transects are ensured by voluntary Observing (merchant) Ships on a regular way, and allow monitoring the Tropical Atlantic zonal current system. As mentioned above, research cruises also contribute to the XBT program. As example, the PIRATA cruises allowed to launch more than 3700 XBT from 1997. Data are transmitted in quasi-real time to GDACs.

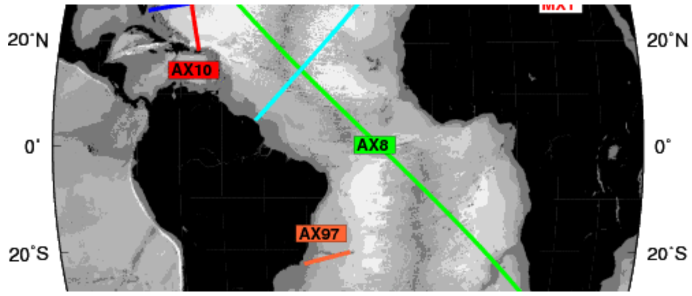


Figure 6: The four High Density Expandable Bathy-Thermograph (XBT) transects in the Tropical Atlantic. Courtesy: G. Goni, NOAA/AOML.

From 1998, some VOS are also equipped with thermosalinographs (TSG), maintained by the GOSUD program. As a contribution to GOSUD, the French CORIOLIS team also collects and validates (from sea surface water samples) the Sea Surface Temperature and Salinity (SST/SSS) data acquired by all the French Research vessel-mounted thermosalinographs during cruises and transits (Gaillard et al., 2015). Some ships are also equipped with pCO_2 sensors, managed by the "Ship Of Opportunity Program" (SOOP)-CO_2 network (Figure 7).

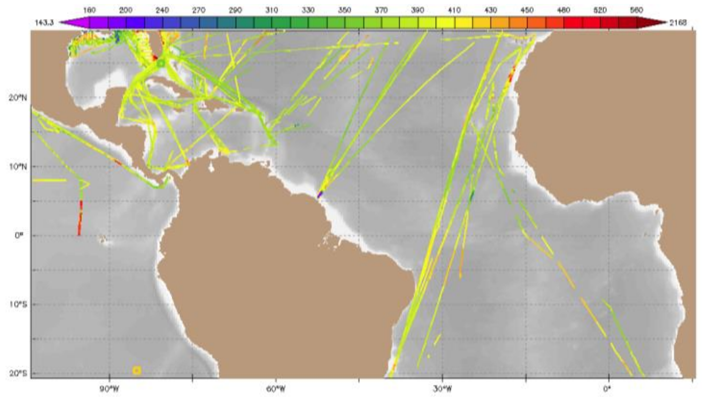


Figure 7: Ships tracks of CO_2 observations. Courtesy: N. Lefèvre, IRD).

Finally, a significant number of tide gauges (along the continental coasts and at some islands) are also managed in the frame of GLOSS.

Scientific priorities for selected parameters

Despite increasing efforts in the past years, and the fact that temperature and salinity are now available in most parts of the Tropical Atlantic Ocean, some large areas are still under sampled by the monitoring systems. Such a statement is even truer for certain key parameters, such as the EOVs: current, atmospheric forcings (wind, fluxes); and the biogeochemistry parameters: O_2, CO_2, nutrients… However, due to the cost of *in situ* measurements (sensors, vessel time, long term servicing…) one has to be realistic and pragmatic. Suggesting enhancements of observing/monitoring systems must respond to scientific priorities (defined from analysis, process studies, numerical experiments and operational systems diagnostics), feasibility studies and societal priorities (adaptation to climate change, coastal and environmental management, ocean resources,…). Improving our knowledge of some processes in order to improve numerical simulations and weather/climate predictions should thus be the guideline.

First, it is essential to continue the existing long time series at fixed positions (mostly all mooring sites and tide gauges). The records at these sites are now long enough to now study decadal variability and climate change. The value of these time series will increase with time and reveal how natural variability in the tropical Atlantic is affected by a changing background state and how trends affect the climate system. That means that PIRATA, OceanSITES and MOVE and CVOO moorings should be if possible maintained on the long term and also considered as part of an integrated TAOS.

Second, the scientific results obtained these recent years evidenced several additional observation priorities. Scientific results will not been detailed in this document but some references are mentioned where can be found all argumentation for each issue.

1. More instrumentation in the near surface layer to better define mixed layer structures, processes, and ocean-atmosphere feedbacks. Such instrumentation are needed for several major issues as:
    a. to quantify the impacts of diurnal and intraseasonal variability on equatorial turbulent mixing and SST fluctuations (e.g. Wenegrat et al., 2014; Wenegrat and McPhaden, 2015; Bourlès, 2016; Jochum, 2017);
    b. to confirm the significant seasonal cycles of turbulent cooling inferred from heat budget residuals at off-equatorial locations and to diagnosis their causes (e.g. Jouanno et al., 2011; Foltz et al., 2013; Giordani et al., 2013; Hummels et al., 2014);
    c. to precise the role of mixed layer dynamics (*i.e.* changes in the Mixed Layer Depth - MLD- and thermocline depth) for the off-equatorial interannual variations in SST (e.g. Foltz et al., 2012; Rugg et al., 2016; Jouanno et al., 2017);
    d. to assess the impact of salinity stratification on turbulent mixing in regions under the influence of river outflow (mostly Amazon, Congo and Niger Rivers) and strong precipitation (Da-Allada et al., 2013, 2017 ; Berger et al., 2014; Camara et al., 2015).
2. Enhancements for carbon cycle and biogeochemical studies. Biogeochemical parameters are needed for multi-disciplinary purposes, and crucial for addressing several issues related to the global carbon cycle, nutrient balances, living marine resources, and ecosystem dynamics (e.g. Hernandez et al. 2017).

a. Sustained monitoring of surface ocean CO_2 in the tropical oceans, which are a CO_2 source to the atmosphere, is a crucial need for closing the global carbon and for better assessing the fate of anthropogenic CO_2. While the eastern tropical Atlantic is a net source of CO_2, fCO_2 and air-sea CO_2 exchanges exhibit everywhere significant intraseasonal to interannual variability associated with ocean conditions that need to be better quantified (e.g. Parard et al., 2010; Lefèvre et al., 2016; Bruto et al., 2017).

b. The Oxygen Minimum Zone (OMZ) in the eastern tropical Atlantic exhibits significant changes (e.g. Brandt et al. 2015, Hahn et al. 2017). There, also may happen very low oxygen events with impacts on biogeochemical cycles and ecosystem (Schütte et al. 2016). In the western part of the basin, low oxygen layers are also observed in intermediate waters (Argo, 2000) and one need to address such features. The OMZ is the south-eastern Tropical Atlantic is very poorly documented too.

c. The upper ocean acidification (OA) is a major issue for marine ecosystems (e.g. Schiller et al. 2016), that could be monitored through at least two measurable parameters of the marine CO_2-system, i.e. some combination of fCO_2/pCO_2, total CO_2 (TCO_2; a.k.a. dissolved inorganic carbon [DIC]), pH, and total alkalinity (AT).

3. Extension of the monitoring systems to regions that are presently under sampled by moored time series and that would benefit from high temporal resolution, multi-variate, and multi-disciplinary sustained time series. As clearly underlined and confirmed during the EU FP7 PREFACE project, observations are crucially needed in the South Atlantic where no time series and relatively few historical in situ measurements are available, particularly in the south-eastern part of the basin (*e.g.* Zuidema et al. 2016). Such new time series measurements would be especially valuable to better determine air-sea fluxes in the tropical South Atlantic and to validate analysis/re-analysis products used for research and forecast model initialization.

These previous priorities do not explicitly address the deep ocean measurements. These ones are however needed to address climate and environmental issues on the long term and should also be taken into consideration, at least for EOVs.

Some of these suggestions do not only concern fixed moorings; technological evolution could also make feasible additional sensors on Argo profilers, surface drifters, gliders, and cruises carried out on a regular way for systems servicing have to be more valorized through the enhancement of in situ measurements.

Suggestions for a sustainable long term monitoring system

1. Fixed moorings.

   The present OceanSITES fixed buoys array has obviously to be maintained on the long term. The 18 PIRATA air-sea exchange buoys constitute the major backbone of this OceanSITES array and are, for most of them, serviced from 1997, *i.e.* more than 20 years. They provide unique and invaluable data that are now long enough to study not only intraseasonal to interannual time scale variability but now also decadal variability and climate change. In the same way, the CVOO buoys also provide data in real time that are essential for operational centers and research. Other components of the OceanSITES array, as MOVE and Fix-O^3, provide data in delayed mode but essential for the tropical Atlantic monitoring.

a. All air-sea exchange buoys should be equipped with long wave radiation and barometer pressure sensors for the estimation of all components of the surface heat flux ("full-flux" sites). This should be achieved for all PIRATA buoys around 2019-2020, once all initial ATLAS systems will be replaced by new T-Flex systems; the implementation of T-Flex systems began in 2015 and at now 10 buoys over 18 are T-Flex. These buoys provide more voluminous data transmission (through Iridium instead of Argos) and allow the potential implementation of more sensors with high frequency data transmission in real time. Also, some key locations (at least 6°S-8°E and 12°N-23°W, i.e. off the African continent: influence of Sahara and continental fires) should be equipped with aerosol traps or sensors in order to better quantify their effect on radiation and fluxes.

b. More PIRATA moorings should be equipped with additional temperature/conductivity (T/C) and velocity sensors in the mixed layer. The most beneficial locations for so enhanced measurements are the locations under the influence of the ITCZ (4°N-23°W, 12°N-23°W, 0°N-35°W, 4°N-38°W and 12°N-38°W) and in eastern equatorial Atlantic (0°N-10°W, 0°N-0°E, 6°S-8°E and 6°S-10°W) where rainfall and river outflow contribute to strong near-surface salinity stratification, and also at 0°N-23°W for better monitoring the zonal heat advection. Other relevant locations for T/C and velocity sensors are the three ones located in the southwest of the basin (19°S-34°W, 14°S-34°W and 8°S-30°W) in order to monitor the South Equatorial Current and the salinity maximum central waters.

c. More CO_2 measurements are particularly needed in the western part of the basin (such an initiative could link the TAOS to SOLAS -www.solas-int.org-). Thus i) the existing pCO_2 sensor installed on the 8°N-38°W PIRATA buoy should be maintained; ii) other sensors should installed at least on two other sites, in the southwest (e.g. 14°S-34°W) and northeast (e.g. 12°N-23°W) so, taking into account the existing ones at 6°S-10°W and 6°S-8°E, allowing measurements in each part of the basin.

d. Technology should allow the additional implementation of pH sensors at some sites. pH can be estimated from pCO_2 measurements (by using an alkalinity/salinity relationship determined from pCO_2 data) but such pH sensor should also be installed on buoys equipped with CO_2 sensors to validate this method.

e. In addition to the ones already installed on three PIRATA buoys along 23°W, additional O_2 sensors would be of great interest in the southwestern part of the basin to monitor low oxygen layers in intermediate waters. The southeastern Atlantic OMZ should also be documented through O_2 sensors, e.g. at 6°S-8°E.

f. As promoted by the OceanSITES program, it should be technically feasible to add T/S measurements (e.g. MicroCat) at depth on some PIRATA moorings.

g. Some wave measurements (amplitude and direction) are more and more needed to address their impact on fluxes and their interaction with currents but also for remote sensing measurements (e.g. sea level, wind, salinity…).

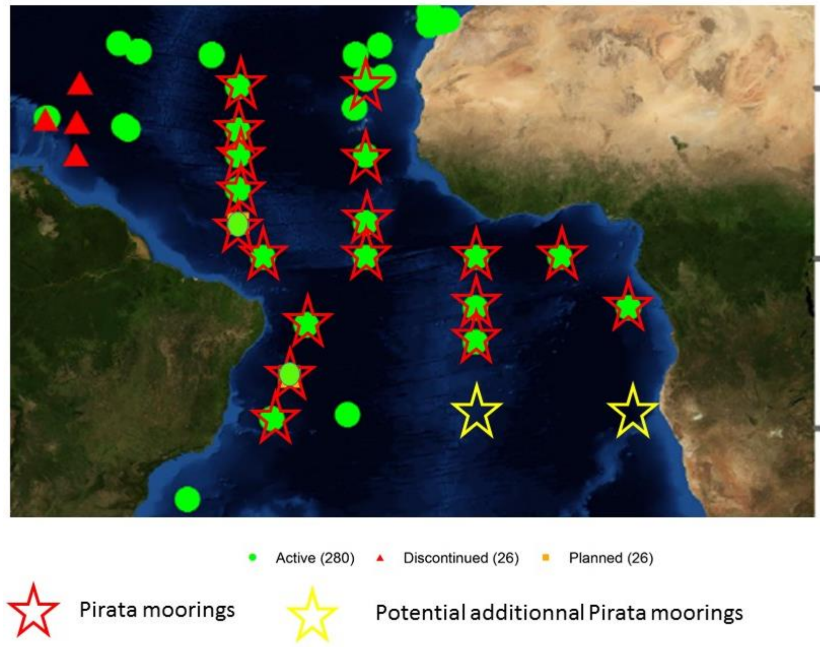
More generally, each mooring system could be used for “piggyback” measurements (e.g. sediment traps, waves, nutrients…), when technically feasible. One have to keep in mind that each observing system has its own mooring design and technology; thus collaboration between systems (OceanSITES, PIRATA, MOVE, CVOO, SACUS/RACE, FixO[3]…) has to be more efficient and effective in order to make the previous suggestions realizable. For example, wave measurements cannot be installed on tense anchorages like PIRATA buoys, because such moorings will disturb measurements. Other mooring systems however could and should be equipped with wave sensors.

Another issue about fixed observing stations is the crucial lack of measurements in the South Atlantic that should allow monitoring the Santa Helena anticyclone variability, the Angola Dome and the coupled atmosphere-ocean processes around the Angola-Benguela Front. Such data sets should also be capable of measuring all components of the surface energy balance (Zuidema et al., 2016). According to such recent analysis and studies and the present PIRATA network design, two air-sea exchange moorings could be added around 10°W-20°S and 8°E-20°S (keeping in mind that moorings have to be maintained out of any Exclusive Economic Zone, for evident administrative reasons).

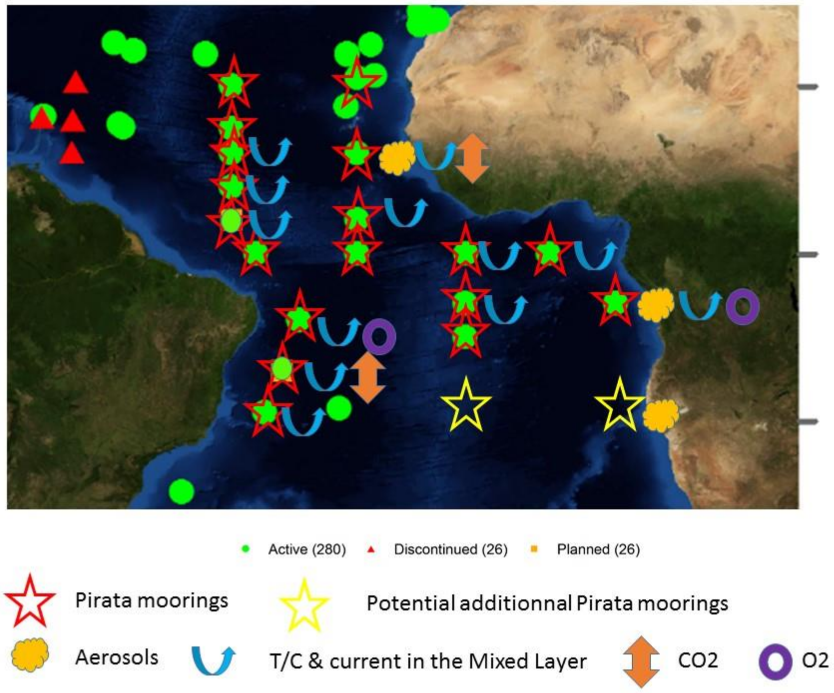
All these suggestions are summarized in the maps presented below (Maps 1&2).

2. Operational systems: Argo, SVP, VOS.

Observations acquired thanks to these projects are important not only for operational prediction systems but also for research and monitoring. More and more autonomous devices are equipped with Iridium data transmission, so allowing more data in real time and smoothness to define and even, for Argo, changes in their configuration (e.g. profiles frequency, vertical resolution). The present evolution of Argo profilers will continue and they begin to be equipped with other than T/C only sensors as, e.g., O_2 and nutrients sensors. Also, deep Argo profilers (that provide profiles down to 4000m depth) will be more and more used. Surface drifters can be equipped with atmospheric sensors that deliver valuable benefits to global weather predictions in the tropical Atlantic (Poli, 2018). They also can be equipped with conductivity/salinity sensors (e.g. Reverdin et al., 2012, 2014); such surface salinity measurements are strongly needed to validate satellite data (e.g. Boutin et al., 2016). Due to the increasingly strong profitability constraints of shipping companies, and the technical constraints of installing some sensors, it seems that it will get more difficult to increase the number of regular lines of VOS… Thus, SVPs and Argo profilers, along with XBT and continuous measurements (TSG, pCO_2, acoustic), should benefit of more coordination between programs organizing regular cruises for the moorings servicing, in order to ensure an enhancement and optimization of the vessel time use.



Map 1: Present OceanSITES moorings. PIRATA buoys are surrounded with red stars. All PIRATA buoys should be "full flux" equipped with T-Flex systems by 2019-2020. Potential additional PIRATA buoys in the Tropical South Atlantic are represented with yellow stars.



Map 2: Same as **Map 1** with suggestions for additional sensors on buoys (not exhaustive). pH and deep ocean sensors are not represented.

3. Regular servicing cruises.

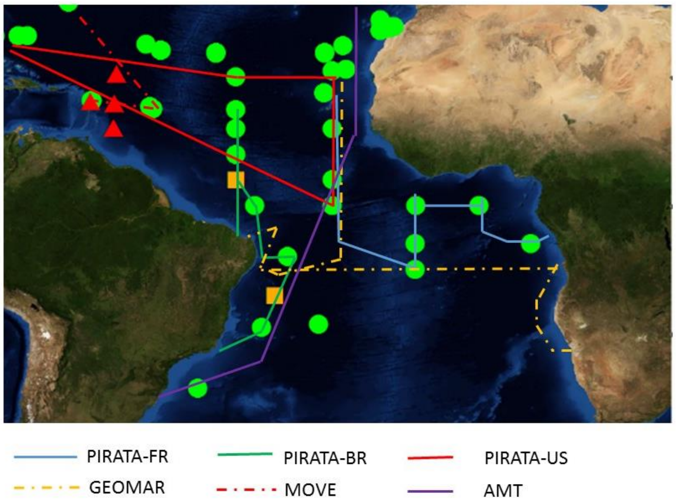
Cruises run at regular time intervals (e.g. yearly for PIRATA, almost yearly for MOVE, SACUS/RACE and other GEOMAR programs, CCVO, $FixO^3$…) have to be more considered as potential platforms for multiple in situ measurements or autonomous devices deployments. As most of the principal EOVs are already measured, it would be very valuable to suggest that every CTD profiles to be enhanced with O_2 sensors and L-ADCP measurements. Also, it would be very relevant to suggest that some $CTDO_2$/LADCP profiles to be done down to 2000m depth, and even 4000m, at least a few ones per cruise, in order to provide needed data for Argo profilers data validation. Sea water samples are generally done for salinity and dissolved oxygen analysis, in order to validate $CTDO_2$ measurements. It would not be too difficult to also sample sea water (along the track at the surface of from bottles during CTD profiles) for nutrients, Chlorophyll pigments, CO_2 parameters (DIC, TA), even not analyzed onboard (these samples can easily be packaged and stored for several months). Then, several international laboratories could ensure the analysis and so partnership could be initiated at an international TAOS level. If Argo profilers equipped with biogeochemistry sensors are deployed, such parameters are absolutely needed in a close future to validate Argo data sets.

In addition to TSG and Ship Mounted ADCP, research vessels can now be equipped with FerryBox and so measure continuously pH, pCO_2, Chlorophyll pigments… Also, when a research vessel is already equipped in, e.g. acoustic sounders (plankton) or multibeam echosounders (bathymetry), it would be relevant to register their data during cruises, even not analyzed by scientists onboard.

All cruises are also opportunities for XBT, SVP and Argo profilers deployments. A better communication could be ensured (e.g. with JCOMMOBS) in order to optimize such operations. Also, all XBT and CTD casts should be sent in quasi-real time to GDACs for operational centers.

A few of these recommendations and measurements are already ensured during some PIRATA cruises (e.g. Bourlès, 2017), and more efficient coordination between the involved community would allow more measurements with a limited additional human and funding power.

The regular cruises are illustrated on the map below (Map 3). It shows the yearly PIRATA and AMT cruises and almost yearly cruises by GEOMAR and MOVE. Such a map clearly indicates that a strong potential exists to get invaluable data sets over most of the Tropical Atlantic basin. In particular, three sections (along 38°W, 23°W and 10°W) are repeated yearly by PIRATA and, in addition to AMT cruises, the 23°W section can even be realized twice a year (PIRATA US and GEOMAR cruises).



Map 3: Present OceanSITES moorings along with the cruises (schematic) tracklines realized on a regular time interval. Full lines are repeated yearly, and dashed lines almost yearly. Colors indicate cruises names.

Concluding remarks

The previous suggestions for a long term monitoring system in the Tropical Atlantic can be summarized as follow:

- Moorings should be equipped with more sensors (T/C, current) in the mixed layer, biogeochemistry parameters (O_2, CO_2, pH) and aerosol traps at some particular locations. All PIRATA buoys have to be “full flux” equipped. If possible, extensions of the PIRATA network should be considered in the South Atlantic.
- Operational autonomous Devices: Argo profilers and SVP will be more and more equipped with additional sensors: O_2, nutrients for Argo, S and atmospheric pressure for SVPs. Such devices have to be deployed taking into account all mooring servicing cruises opportunity.
- Mooring servicing cruises: all cruises run on a regular time interval have to be considered more systematically as platforms for the deployment of autonomous devices, and provide XBT & CTD profiles in real time. More $CTDO_2$/LADCP down to 2000m and even 4000m depth are needed for Argo data validation. Cruises can be also opportunities for more sea water samplings (biogeochemistry parameters) even if not analyzed onboard or by the cruise teams.

The present document did not consider processes experiments. Presently, cruises carried out for processes studies are also concerned by these recommendations. In the same way, the present document did not consider gliders, because it seems difficult to envisage glider sections serviced and maintained on the long term. However, process studies and glider measurements can clearly inform the evolution of the observing system capabilities and are essential to develop long-term observing systems. But a long term monitoring system should only concern the observing systems that are sustained over many years, basin scale in design, and international in scope.

Enhancing or extending an observing/monitoring system is expensive, both in terms of funding as in terms of human power. These latter are not extensible and one has to be as pragmatic as possible to ensure a long term monitoring system. Therefore, several considerations are provided as conclusion:

1) It has to be taken into account that a too large number of data already exist that is not disseminated! A prior effort by scientific community and Principal Investigators would first be to share data, mostly in the case of process studies data sets… This would also avoid repeating some eventual specific experiments.

2) More exchanges and collaborations are needed between observers, modelers, and the satellite community, in order to enhance the value and relevance of observations and also, by evaluating impacts of observations on numerical simulations and all kinds of products, to optimize the networks by taking the full advantage of in situ observing opportunities.

3) Extension of the mooring network, e.g. through additional PIRATA buoys, cannot be ensured by the present PIRATA partners (USA, France, Brazil) as they already have to ensure the needed vessel time to service the 18 existing buoys. They will not be able to get more vessel time to go so far in the southeast. Such an extension could only be envisaged through a cooperation between South Atlantic boarding countries (South Africa, Brazil, Argentina…), with vessel and engineers capacity, possibly

during planed regular cruises in the frame of the SAMOC program. Gliders transatlantic sections could however also be envisaged before additional moorings implementation!

4) Servicing a monitoring network on the long term requires some commitments between institutions in charge of its maintenance. PIRATA is typically a good example of success from 21 years, made possible thanks to a stable base of support in the three involved countries and commitments of each country involved institutions through a Memorandum of Understanding. Such commitments are certainly the first step to establish solid and long term collaborations between the future partners of the Tropical Atlantic Monitoring/Observing System.

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