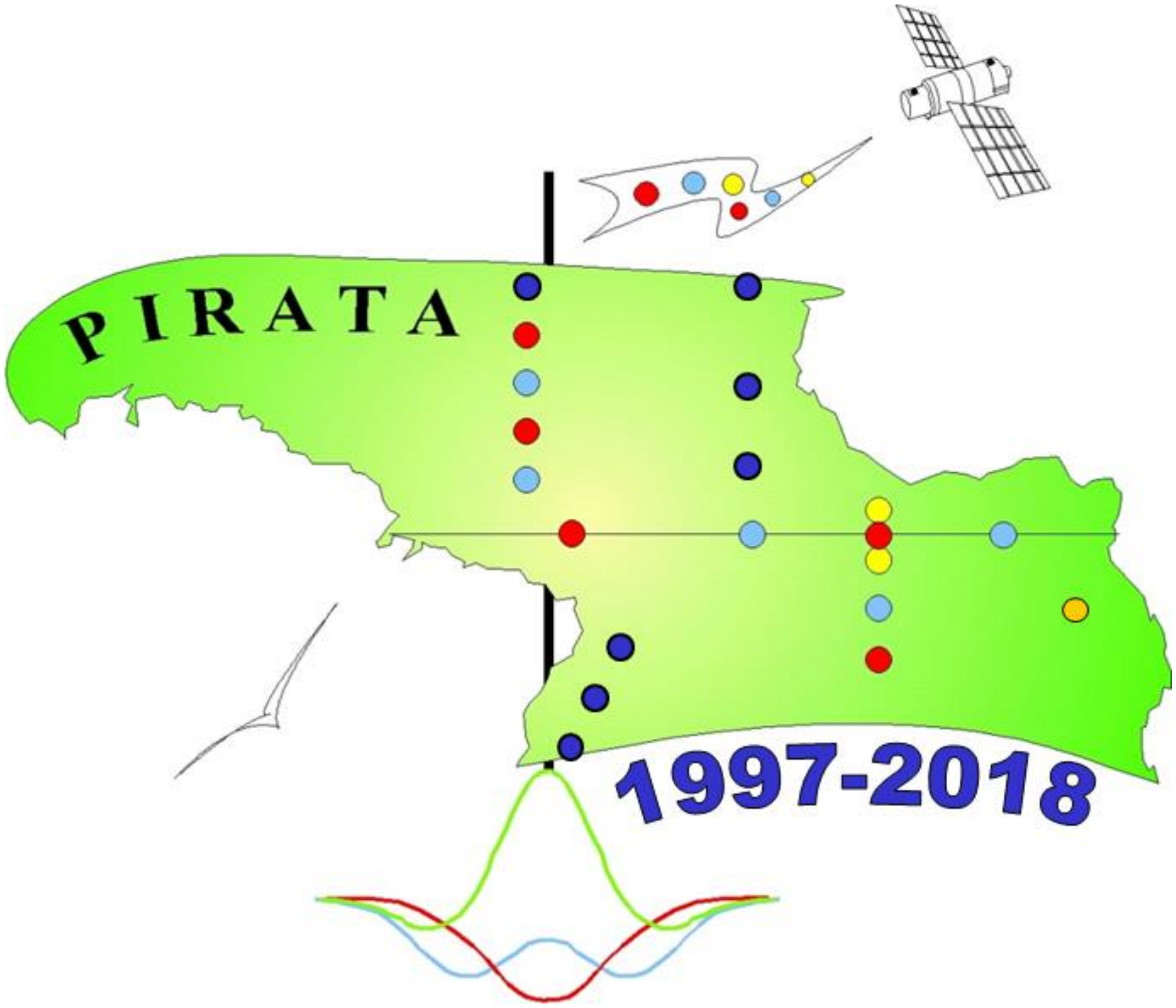
# PIRATA "white paper"

*Contributors: Bernard Bourlès, Moacyr Araujo, Mike McPhaden, Peter Brandt, Edmo Campos, Leticia Cotrim, Marcus Dengler, Gregory Foltz, Hervé Giordani, Johannes Hahn, Fabrice Hernandez, Rebecca Hummels, Nathalie Lefèvre, Joke Lübbecke, Rick Lumpkin, Paulo Nobre, Mathieu Rouault, Adrienne Sutton, Renellys Perez.*

**2nd version, March 7th 2018**



# PLAN:

# 1 Introduction

PIRATA (Prediction and Research Moored Array in the Tropical Atlantic) is a multinational program established to improve our knowledge and understanding of ocean-atmosphere variability in the tropical Atlantic, a region that strongly influences the regional hydro-climates and, consequently, the economies of the regions bordering the Atlantic Ocean (e.g. West Africa, North-Eastern Brazil, the West Indies and the United States). PIRATA is motivated not only by fundamental scientific questions but also by societal needs for improved prediction of climatic variability and its impacts (Servain et al., 1998; Bourlès et al., 2008). PIRATA works thanks to a close collaboration between institutions of USA (NOAA), Brazil (INPE, with contribution of DHN) and France (IRD and Meteo-France) that are committed from 2001 through a MoU in order to maintain PIRATA on the long term.

PIRATA, initiated in 1997, is based around an array of moored buoys providing meteorological and oceanographic measurements transmitted in real-time, disseminated via Global Telecommunication System (GTS) and Global Data Servers. Then, through yearly mooring maintenance, recorded high frequency data are collected and calibrated. The dedicated cruises of yearly maintenance allow complementary acquisition of a large number of measurements along repeated ship track lines and also provide platforms for deployments of other components of the observing system. Several kinds of operations are carried out in collaboration with other international programs.

PIRATA provides invaluable data for numerous and varied applications, among which are analyses of climate variability on intraseasonal-to-decadal timescales, equatorial dynamics, mixed-layer temperature and salinity budgets, air-sea fluxes, data assimilation, and weather and climate forecasts.

PIRATA is now 20 years old, well established and recognized as the backbone of the tropical Atlantic sustained observing system, and also serves as the baseline climate record in the tropical Atlantic through sustained observing of GOOS Essential Climate and Ocean Variables. Several enhancements have been achieved during recent years, including progressive updating of mooring systems and sensors, also in collaboration with and as a contribution to other programs (such as GOOS, EU PREFACE and AtlantOS).

The purpose of the present “PIRATA white paper” is to describe the PIRATA program and its contributions in order to help design a strategy for an enhanced and optimal Tropical Atlantic Observing System to be formulated with the CLIVAR Atlantic Region Panel (ARP) in collaboration with the Ocean Observations Panel for Climate (OOPC) and other organizations before the OceanObs 2019 conference.

## 2 Present status of the PIRATA network

### a) Ocean-atmosphere interaction buoys:

During the first years of PIRATA, when the program was named "Pilot Research Moored Array in the Tropical Atlantic", PIRATA principally maintained an array of 10 meteorological and oceanic buoys in the Atlantic (Servain et al., 1998). All buoys were ATLAS systems equipped with atmospheric sensors (air temperature, relative humidity, wind direction and amplitude, short wave radiation) and oceanic sensors (11 temperature, 4 conductivity and 2 pressure sensors; see https://www.pmel.noaa.gov/gtmba/sensor-specifications for details). Daily averages are transmitted in real time through the Argos system and made available through the GTS, the PIRATA PMEL website, and ftp.

After its evaluation by CLIVAR and OOPC in 2006 (Bourlès et al., 2006), the network progressively evolved and the number of buoys increased up to 17 in 2007, after extensions in the Southwest (3 buoys) and the Northeast (4 buoys). Then, PIRATA became "Prediction and Research Moored Array in the Tropical Atlantic (Bourlès et al., 2008). A 18th buoy, funded by Benguela Current Large Marine Ecosystem in 2006, was deployed in the Southeast, off Congo, during a one-year test in 2006-2007; this location has been re-established in 2013, once a 2nd buoy was funded by the FP7 European PREFACE program.

The PIRATA network meteo-oceanic buoys are part of the OceanSITES program (http://www.oceansites.org/OceanSITES/). In addition to the number of buoys itself, numerous additional sensors were progressively installed, as summarized below:

- Since 2005-2006, 6 buoys are equipped with additional sensors: 1 long wave radiation, 1 barometer pressure, 15 temperature and 8 conductivity sensors along with 1 currentmeter at 12m depth. These additional sensors allow for estimation of all components of the surface heat flux and improve the estimation of mixed layer depth. Thus these buoys (namely at 15°N-38°W, 12°N-23°W, 0°N-23°W, 19°S-34°W, 10°S-10°W, 6°S-8°E) are referred as "flux reference" sites.
- Since 2006 at 6°S-10°W and 2008 at 8°N-38°W, $CO_2$ CARIOCA (CARbon Interface Ocean Atmosphere) sensors are installed to monitor the fugacity of $CO_2$ ($fCO_2$) at about 1m depth, funded by the FP6 European project CARBOOCEAN (2005-2009).
- Since 2008, $O_2$ sensors are installed at 4°N-23°W and 12°N-23°W at 300 and 500m depth to monitor the Oxygen Minimum Zone, funded by SFB754 and GEOMAR.
- In 2011, the buoy located at 20°W-38°W has been equipped with a barometric pressure sensor, funded by Meteo-France.
- In 2011, additional temperature and conductivity sensors (with 9 T/C sensors down to 100m) were implemented at 6°S -10°W and 10°S-10°W, funded by IRD and CNRS.

Also, the PIRATA buoys provide opportunities for other programs to maintain some particular sensors, either as contribution of long-term observations or as process studies. These include:

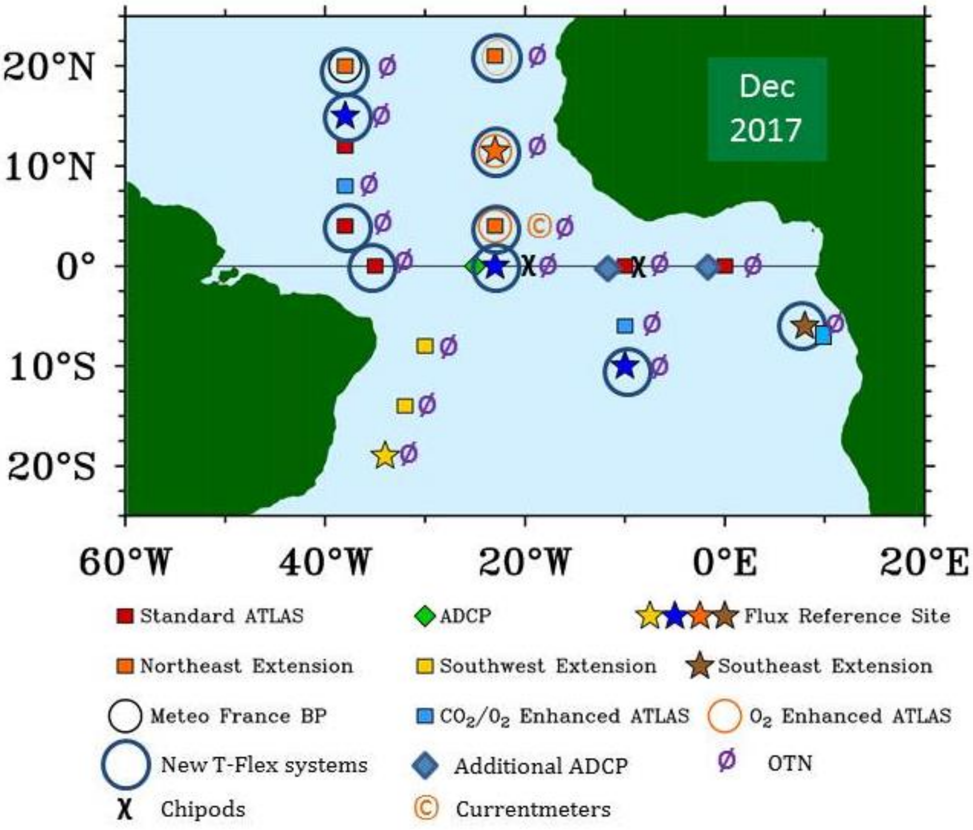
- Since 2014, all buoys are equipped with acoustic receivers at 200m depth, as contribution to the Ocean Tracking Network (OTN ; PI: J.Whoriskey; see http://oceantrackingnetwork.org/);
- Since 2014, the 0°N-23°W and 0°N-10°W are equipped with turbulence sensors (χpods), in the framework of an Oregon State University (OSU) Ocean Mixing Group program supported by the US National Science Foundation for a 5 years duration (PI : J.Moum ; see http://mixing.coas.oregonstate.edu/ ).

From 2015, the ATLAS systems have been progressively replaced by newer more capable T-Flex systems, developed by NOAA/PMEL (see https://www.pmel.noaa.gov/gtmba/moorings ). These buoys are with new modular design and off-the-shelf electronics, and provide more voluminous data transmission through Iridium instead of Argos. They allow the potential implementation of more sensors with high frequency data transmission in real time. All the ATLAS buoys will eventually be replaced by T-Flex, beginning with “Flux reference sites”. Three T-Flex systems were installed in late 2015 and early 2016 at 12°N-23°W, 0°N-23°W and 10°S-10°W. In March 2017, 4 T-Flex systems have also been installed at 6°S-8°E (FR cruise), 4°N-23°W, 21°N-23°W and 20°N-38°W (US cruise), and 3 T-Flex implemented in November-December 2017 at 0°N-35°W, 4°N-38°W and 15°N-38°W (BR cruise). Thus, at present there are 10 T-Flex systems operating in the array.

In March 2017, 10 additional current meters were implemented at 4°N-23°W between 7m and 87m depth for the NOAA/AOML “Tropical Atlantic Currents Observations Study” (TACOS) experiment.

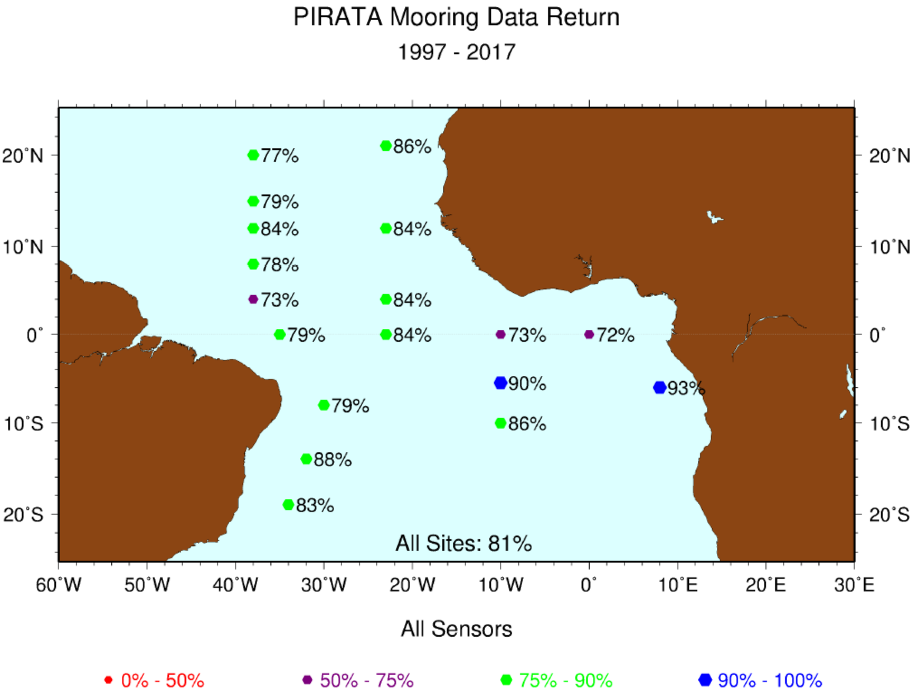
In March 2017, a new $CO_2$ CARIOCA sensor (as IRD contribution to AtlantOS) has been implemented at 6°S-8°E. Also, $O_2$ sensors with real-time data transmission at 20°N-23°W and 12°N-23°W and internally recorded data only at 4°N-23°W have been implemented as a GEOMAR contribution to AtlantOS.

⇨ Present network map:

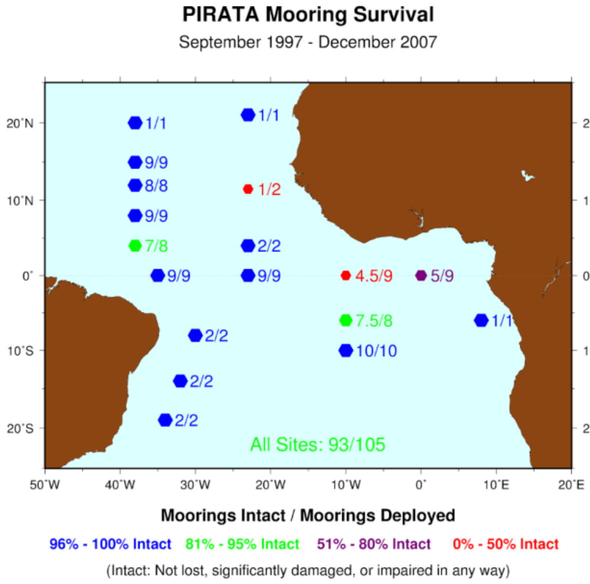


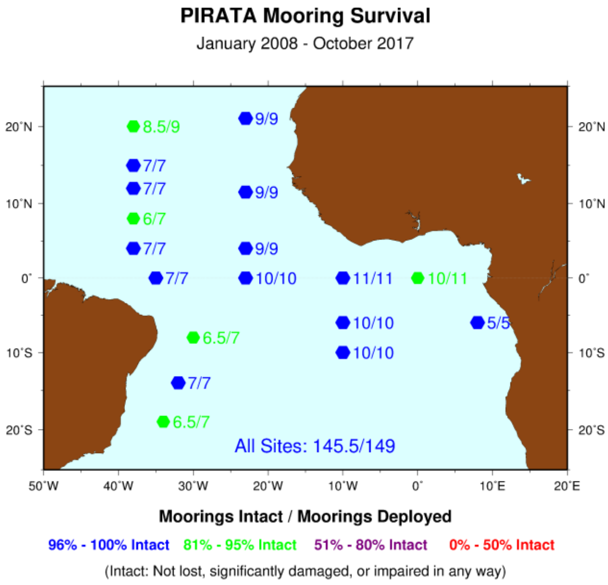
The overall Delayed Mode data return (for all moorings and all sensors; see figure below) is 81% over the entire period of the program (1997-2017), which exceeds the 80% data return standard used to gauge the success of the TAO array in the Pacific (McPhaden et al. 1998). Annual data return and number of moorings operating has been steady and similar for several years and, from 2003, dedicated maintenance cruises have kept moorings within their design lifetime.

T

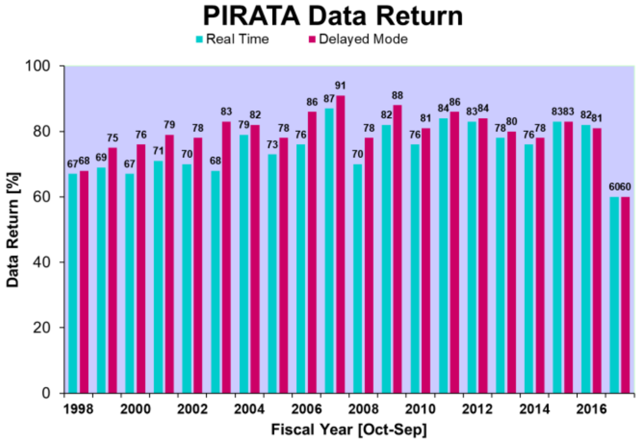


The lowest values observed at the sites 0°N-10°W and 0°N-0°E are induced by vandalism due to fishing activity in this area. However, vandalism has been considerably reduced in the past decade: from 1997 to 2007, these two buoys showed Mooring Survival values of 4.5/9 and 5/9 respectively while on the 2008-2017 period they showed values of 11/11 and 10/11 (see figures below) and the overall ratio is 145.5/149 (*i.e.* remarkably close to 1). In late 2017, the PIRATA mooring survival rate was 100% for 13 sites (out of 18) from 2008, which is an excellent overall result and a measure of PIRATA's success.

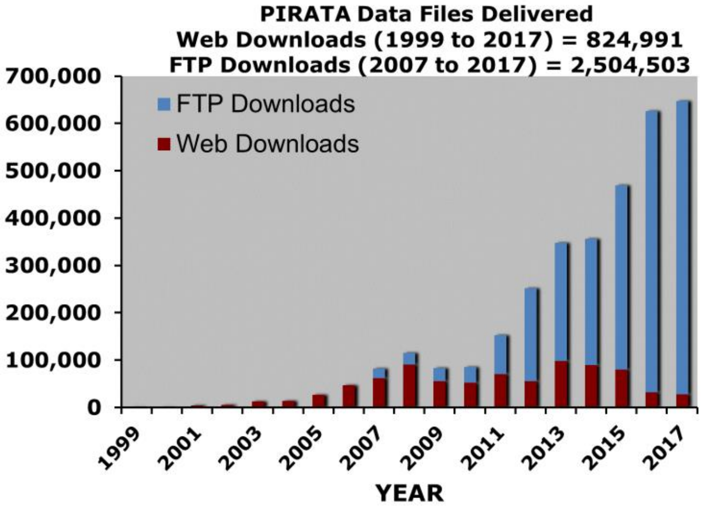




The annual PIRATA data return, in Real Time and Delayed Mode, varied between from 67% to 91% until 2016 and was almost stable around 80% after 2003 (see figure below). The last and exceptional low value of 60% in 2017 (presently in late October 2017) is due to primarily vessel issues that resulted several month's delay of the Brazilian cruise (that was carried out from November 2017 to January 2018). However, Delayed Mode data return values will be higher once data the retrieved sensors are processed and made available.



PIRATA buoys data files delivered through the web and ftp considerably increased after 2011, once files made available through ftp (figure below). More than 600,000 files were retrieved in 2016 and 2017, illustrating the strong scientific and operational demand in PIRATA data.



Also noteworthy is that in the early 2010's an effort was started to develop a Brazilian prototype of the ATLAS Buoy. This initiative was entirely sponsored by Brazilian agencies and conducted with technical support from NOAA/PMEL. In April of 2013 the first Atlas buoy, entirely assembled in Brazil (the "Atlas-B"), was successfully moored at 28°S-44°W, a position originally proposed for a fourth buoy of the PIRATA South-Western Extension (*Cole et al., 2013; Campos et al., 2014).* Presently the Atlas-B is being prepared to be moored in the Vema Channel (39.43°W, 31.13°S). In this new position, the Atlas-B will be equipped with sensors to monitor the flow of the Antarctic Bottom Water, in addition to the regular monitoring of properties at the ocean surface and in the upper 500 meters of the water column."

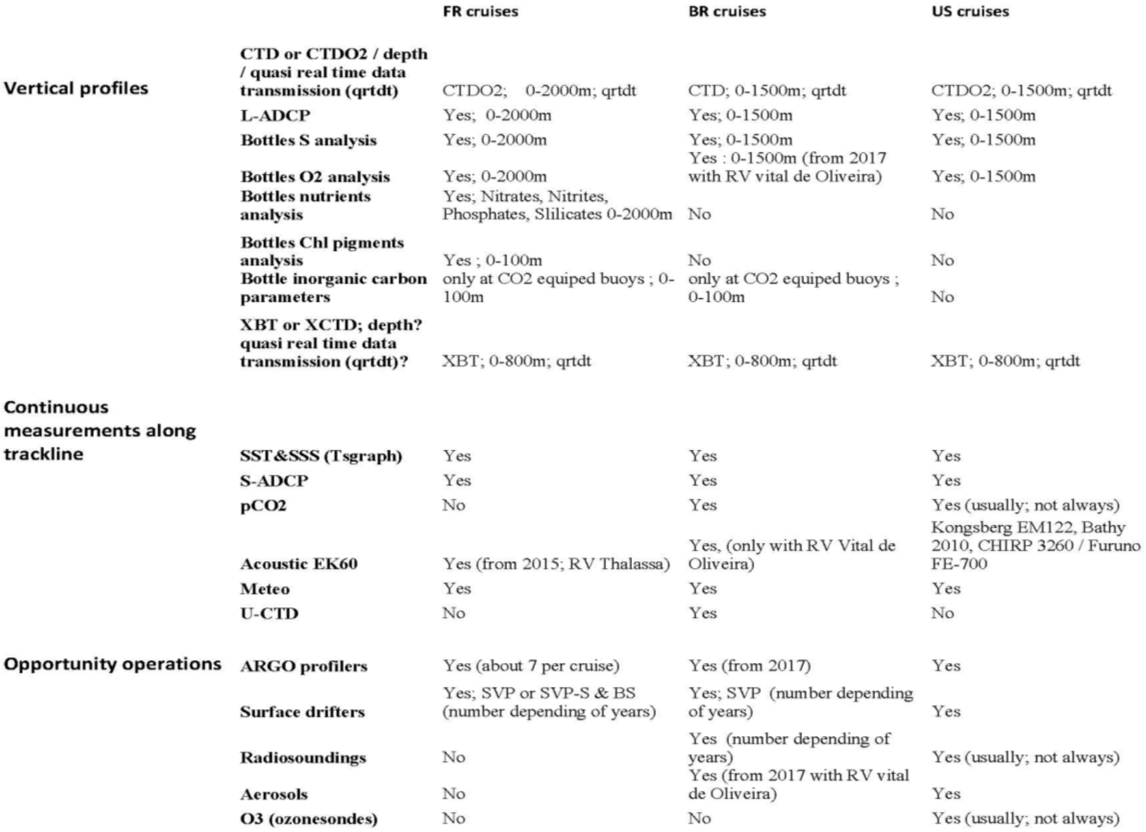
### b) ADCP moorings:

PIRATA also maintains ADCP moorings at 0°N-23°W (from 2001) and 10°W-0°N (from 2006, initially as IRD contribution to AMMA/EGEE; see Bourlès et al., 2007). These ADCPs allow monitoring the Equatorial Undercurrent from near the surface down to about 300m depth. For some periods, current meters at intermediate depths were also installed at 10°W-0°N (1999-2000 and 2003-2005) and at 0°N-23°W (2001-2002 and 2004-2006) in the frame of an associated French program (see, *e.g.*, Bunge et al., 2008). The mooring at 0°N-23°W (from 2001) includes additionally deep velocity measurements, partly top to bottom, in the frame of GEOMAR contributions to different German projects. A new current meter mooring (also with ADCP installed at 300m depth looking upward) has been deployed at 0°N-0°E in March 2016 during the PIRATA FR26 cruise. This mooring, deployed as IRD contribution to the EU FP7 PREFACE program, could be maintained as part of PIRATA in the future. Each mooring is serviced about every 2 years, and data are made available through the PIRATA-FR website (http://www.brest.ird.fr/pirata/) or through their DOI (http://doi.org/10.17882/51557).

### c) Operations during yearly servicing cruises:

PMEL surface moorings (ATLAS and T-Flex) have a design life of one year, thus requiring yearly cruises to maintain the array. These yearly cruises are carried out by Brazil (western part), USA (north-eastern part) and France (eastern part). These cruises provide a large number of shipboard measurements (mostly CTD casts along systematically repeated sections at 38°W, 23°W and 10°W) and contribute to several other programs (e.g., by deploying Argo profilers and SVP drifters; radiosondes, CTD and XBT data transmission in real time, aerosols, $O_3$, sea water analysis for nutrients, $CO_2$, Chl pigments, acoustic measurements…). All operations are summarized in the table below, depending upon the country (see also Bourlès et al. AtlantOS Deliverable, 2017).

Note that CTDO$_2$-LADCP casts have been done down to 5,500m depth during the last BR cruise made in 2017 onboard the R/V Vital de Oliveira, along with S, O2, pH and nutrients analysis from bottle samplings in addition of other analysis for GEOTRACES.



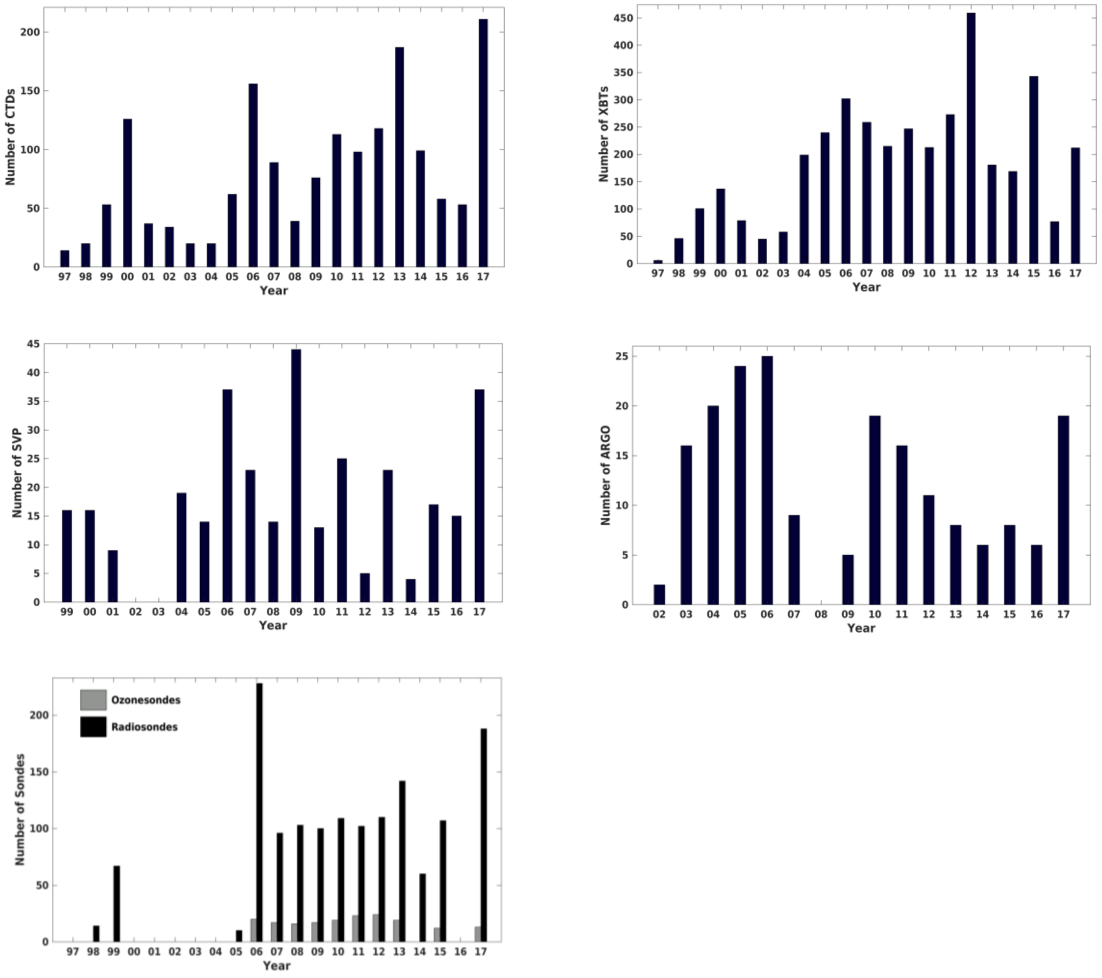
| | | **FR cruises** | **BR cruises** | **US cruises** |
|---|---|---|---|---|
| **Vertical profiles** | **CTD or CTDO2 / depth / quasi real time data transmission (qrtdt)** | CTDO2; 0-2000m; qrtdt | CTD; 0-1500m; qrtdt | CTDO2; 0-1500m; qrtdt |
| | **L-ADCP** | Yes; 0-2000m | Yes; 0-1500m | Yes; 0-1500m |
| | **Bottles S analysis** | Yes; 0-2000m | Yes; 0-1500m | Yes; 0-1500m |
| | **Bottles O2 analysis** | Yes; 0-2000m | Yes : 0-1500m (from 2017 with RV vital de Oliveira) | Yes; 0-1500m |
| | **Bottles nutrients analysis** | Yes; Nitrates, Nitrites, Phosphates, Slilicates 0-2000m | No | No |
| | **Bottles Chl pigments analysis** | Yes ; 0-100m | No | No |
| | **Bottle inorganic carbon parameters** | only at CO2 equiped buoys ; 0-100m | only at CO2 equiped buoys ; 0-100m | No |
| | **XBT or XCTD; depth? quasi real time data transmission (qrtdt)?** | XBT; 0-800m; qrtdt | XBT; 0-800m; qrtdt | XBT; 0-800m; qrtdt |
| **Continuous measurements along trackline** | **SST&SSS (Tsgraph)** | Yes | Yes | Yes |
| | **S-ADCP** | Yes | Yes | Yes |
| | **pCO2** | No | Yes | Yes (usually; not always) |
| | **Acoustic EK60** | Yes (from 2015; RV Thalassa) | Yes, (only with RV Vital de Oliveira) | Kongsberg EM122, Bathy 2010, CHIRP 3260 / Furuno FE-700 |
| | **Meteo** | Yes | Yes | Yes |
| | **U-CTD** | No | Yes | No |
| **Opportunity operations** | **ARGO profilers** | Yes (about 7 per cruise) | Yes (from 2017) | Yes |
| | **Surface drifters** | Yes; SVP or SVP-S & BS (number depending of years) | Yes; SVP (number depending of years) | Yes |
| | **Radiosoundings** | No | Yes (number depending of years) | Yes (usually; not always) |
| | **Aerosols** | No | Yes (from 2017 with RV vital de Oliveira) | Yes |
| | **O3 (ozonesondes)** | No | No | Yes (usually; not always) |

Most of the data sets acquired during the yearly cruise are made freely available through the national PIRATA websites, i.e. http://www.brest.ird.fr/pirata/ for the French cruises, http://www.aoml.noaa.gov/phod/pne/ for the US cruises and http://pirata.ccst.inpe.br/en for the Brazilian cruises.

French CTD-$O_2$, Vessel Mounted ADCP and moorings ADCP data are also available through their DOI (http://doi.org/10.17882/51534, http://doi.org/10.17882/44635 and http://doi.org/10.17882/51557 respectively). The PIRATA-FR cruises and related information are also accessible through their DOI 10.18142/14. Moored and ship-based $CO_2$ data are available through the Surface Ocean $CO_2$ Atlas (SOCAT; www.socat.info).

At present, a total of 61 cruises (27 by France, 17 by Brazil, 17 by US) have been carried out in the tropical Atlantic, with repeated full sections along 38°W (15), 23°W (16 + several associated cruises by GEOMAR made during TACE and other projects) and 10°W (~20).

Thanks to these yearly repeated cruises, PIRATA also significantly contributes to to operational systems (e.g. MERCATOR and weather centers) by transmitting XBT and CTD profile data in near-real time and to the Atlantic Ocean Observing System in general (e.g. Argo, GDP/DBCP, etc), as illustrated by figures below. Thus, at now (January 2018), a total of 1683 CTD, 3861 XBT, 302 SVPs, 192 Argo profilers, 1007 radiosondes and 194 ozone sondes have be deployed during the PIRATA cruise in the tropical Atlantic (figure below).



*Deployment number of i) CTD (up-left), XBT (up-right), SVP (middle-left), Argo profilers (middle-right), radiosondes and ozonesonds (down) from 1997 to 2017 during PIRATA cruises.*

## 3 Scientific progresses and unexpected results

### *a. Major results since last review in 2006*

### Mixed layer heat and freshwater budgets

### Heat budget

### Equatorial heat budget

Sea surface temperature (SST) in the equatorial Atlantic experiences a strong seasonal cycle that interacts with the atmosphere to influence the African monsoon circulation, rainfall, oceanic upwelling, and air-sea fluxes of heat and carbon. Superimposed on the strong seasonal cycle of SST are interannual variations that affect rainfall over South America and Africa and SST in the equatorial Pacific. Understanding the processes that drive equatorial Atlantic SST is therefore a high priority. Earlier studies identified the potential importance of upwelling and vertical turbulent mixing for generating seasonal cooling in the equatorial Atlantic during boreal spring and summer (Hastenrath 1977, Merle 1980, Molinari et al. 1985, Carton and Zhou 1997, Foltz et al. 2003, Peter et al. 2006). Over the past decade, this importance has been confirmed and progress has been made on identifying the processes responsible for the seasonal cycle of vertical turbulent mixing.

A collection of more than 700 microstructure profiles from multiple research cruises during 1994-2008 were used to quantify vertical turbulent cooling of the mixed layer in the central and eastern equatorial Atlantic during May-December (Hummels et al. 2013, 2014). This period encompasses the sharp drop in SST as the Atlantic Cold Tongue (ACT) is established during May-July and includes the following recovery of SST during August-December. The main result from these studies is that vertical turbulent cooling of the mixed layer is largest near the equator (2ºS-2ºN) and decreases significantly at off-equatorial locations. Mixing decreases eastward along the equator, with values up to 50 W m$^{-2}$ at 2ºE and not exceeding 10 W m$^{-2}$ at 6ºE. Boreal summer was found to be the season with the highest rates of turbulent cooling throughout the equatorial ACT region, consistent with earlier estimates from the heat balance residual (Foltz et al. 2003). Enhanced shear from tropical instability waves likely contributes to the peak in turbulent cooling during this season. Hummels et al. (2013) were able to close the seasonal mixed layer heat budget on the equator at 10ºW using PIRATA data and vertical cooling rates calculated from the microstructure measurements. The results confirm that vertical turbulent mixing is the largest cooling term at 0º, 10ºW.

Modeling studies and indirect estimates of vertical turbulent cooling of the mixed layer support the observational results of Hummels et al. (2013, 2014) and begin to identify processes responsible for the seasonal cycle of turbulent cooling. In a modeling study, Jouanno et al. (2011) showed that the semiannual cycle of SST in the central equatorial Atlantic (10ºW-20ºW) is driven mainly by vertical turbulent mixing, which is strongest in May-June and November-December. The seasonal cycle of mixing results from changes in vertical shear between the Equatorial Undercurrent (EUC) and westward South Equatorial Current (SEC), which are dominated by seasonal strengthening of the SEC in May-June and November-December. Surprisingly, Jouanno et al. (2011) showed that vertical turbulent cooling decreases east of 10ºW despite shoaling of the thermocline and EUC, which generate stronger current shear. They suggested that increased near-surface stratification limits turbulent mixing despite stronger shear. This stratification results in large part from very low-salinity surface water in the Gulf of Guinea. Giordani et al. (2013) came to a similar conclusion, emphasizing that seasonal strengthening of the trade winds drives upwelling, shoaling the mixed layer and thermocline and therefore controlling vertical current shear and mixing. There is therefore general agreement that vertical turbulent cooling on the equator peaks in boreal summer and is strongest between 10ºW and 23ºW, decreasing significantly eastward into the Gulf of Guinea (Jouanno et al. 2011, Giordani et al. 2013, Hummels et al. 2013, 2014, Foltz et al. 2017).

Observational studies of the equatorial mixed layer heat balance have also concluded that vertical turbulent mixing drives seasonal cooling in the eastern Atlantic. Using measurements from the PIRATA mooring at 0º, 23ºW, Foltz et al. (2013) showed a semiannual cycle in the heat budget residual, with largest negative values (i.e., cooling from turbulent mixing) in May-July and November. This seasonality is consistent with that found by Jouanno et al. (2011) and Hummels et al. (2014). However, the implied cooling rates in Foltz et al. (2013) have an annual mean significantly higher than those calculated by Hummels et al. (2014) using microstructure measurements. Consistent with previous studies, Foltz et al. (2013) showed a close correspondence between vertical current shear below the mixed layer and vertical turbulent cooling of the mixed layer, with stronger shear linked to stronger cooling. The observational studies of Wade et al. (2011) and Schlundt et al. (2014) further confirm the importance of vertical mixing for generating the ACT in the eastern Atlantic, with strongest cooling boreal spring-summer. In addition to PIRATA data, these studies also used Argo profiles and shipboard CTD measurements. In the western half of the ACT (west of about 20ºW), there is agreement that zonal advection acts with turbulent mixing to cool SST (Jouanno et al. 2011, Giordani et al. 2013, Foltz et al. 2013, Hummels et al. 2014, Schlundt et al. 2014). However, the magnitude of the cooling is unclear because of difficulty quantifying zonal mixed layer currents.

An active field of research involves the processes that control turbulent mixing in the eastern equatorial Atlantic beyond large-scale seasonal changes in thermocline depth and vertical current shear. There is growing evidence that diurnal and intraseasonal variations of surface heat fluxes, winds, and currents are important for understanding the seasonal cycle. Hummels et al. (2013) show a large increase in meridional currents and their shear at 10ºW during the passage of a tropical instability wave (TIW) and suggest that TIWs may contribute substantially to shear variance during the second half of the year. Jouanno et al. (2013) showed that wind-forced Rossby-gravity waves, with periods of 8-10 days and 15-20 days, modulate thermocline depth and currents in the Gulf of Guinea. The increased shear associated with the waves drives vertical mixing, generating significant cooling of SST. These waves are unrelated to TIWs located farther west.

There is also evidence that the diurnal cycle modulates turbulent mixing in the central equatorial Atlantic. Using PIRATA measurements at 0º, 23ºW and enhanced upper-ocean velocity measurements during October 2008 to June 2009, Wenegrat and McPhaden (2015) showed that there is a strong seasonal modulation of the diurnal cycle of SST and vertical current shear in the upper ocean. During summer and fall, trade winds are steady and the diurnal cycle of SST is weak, resulting in weak stratification and the nighttime descent of a "shear layer" into the equatorial undercurrent. These conditions are favorable for generating "deep cycle" turbulence and enhanced cooling of the mixed layer. These findings are consistent with results obtained in the equatorial Pacific (Smyth et al. 2013, Pham et al. 2013, Moum et al. 2013), though the strength of diurnal mixing appears to be weaker in the Atlantic. Wenegrat et al. (2014) also showed using this same 0°, 23°W data set that the turbulent vertical viscosity depends fundamentally on the inverse of vertical current shear in the surface layer, a result heretofore not appreciated in simple parameterizations of turbulent viscosity in terms of the surface wind stress.

### Off-equatorial heat budget

Outside of the equatorial band (2ºS-2ºN), there is evidence that cooling from vertical mixing is much weaker (Hummels et al. 2013, Foltz et al. 2013, Foltz et al. 2017). As a result, surface heat fluxes often play a more dominant role in shaping the seasonal cycle of SST (Foltz et al. 2013, Cintra et al. 2015). However, there remain significant seasonal variations in the heat budget residuals at some off-equatorial locations, implying that vertical mixing may be important. Foltz and McPhaden (2009) used PIRATA measurements to show significant seasonal variations of the heat budget residual at 12°N, 38°W and 15ºN, 38ºW. The largest residual cooling occurs in boreal summer and fall, when winds are weakest and solar radiation is strong. The explanation put forth from Foltz and McPhaden (2009) is that the salinity-induced barrier layer is thickest during boreal winter, suppressing vertical turbulent cooling of SST. During summer and fall the barrier layer is much thinner, promoting stronger turbulent mixing and SST cooling. However, Foltz et al. (2017) showed that the heat balance residual is consistently largest (i.e., strongest implied vertical turbulent cooling) during the season with weakest winds and strongest diurnal SST variability, based on measurements from 17 PIRATA moorings. These results suggest that other processes, such as rectification of the diurnal cycle or enhanced current shear in a thinner mixed layer, may explain the seasonal cycle of turbulent cooling.

On interannual timescales, Rugg et al. (2016) confirmed that changes in latent heat loss and shortwave radiation are most important outside of the equatorial band. They also showed that anomalies of mixed layer depth, likely driven by anomalous winds, are an important component of the heat budget between 10ºS and 10ºN, where the mean mixed layer depth is thinnest. The thin mean mixed layers result in larger percentage changes for a given anomaly, significantly altering the rate at which the climatological surface heat flux changes mixed layer temperature. Rugg et al. (2016) also confirmed an earlier study showing that anomalously strong vertical turbulent cooling was responsible for generating cold SST anomalies under the Intertropical Convergence Zone (ITCZ) during the boreal spring of 2009 (Foltz et al. 2012). The cooling was caused by pronounced anomalous shoaling of the thermocline that was driven by anomalous northwesterly winds. The resultant SST anomalies generated a strong anomalous meridional SST gradient across the equator, which shifted the ITCZ southward and resulted in extreme flooding in Northeast Brazil. Despite the importance of vertical cooling during 2009, Rugg et al. (2016) showed that there is inconsistency in its strength from event to event.

### Salinity budget

Strong precipitation and river outflow in the tropics lead to upper-ocean salinity stratification that tends to decrease the mixed layer depth and reduce vertical mixing, while horizontal gradients of salinity contribute to the geostrophic circulation of the upper ocean. The continued successes of the Argo and PIRATA programs during the past decade, and the launch of two satellites (SMOS and Aquarius/SAC-D; *e.g.* Boutin et al. 2016) to measure Sea Surface Salinity (SSS) remotely, have contributed to significant advances in our understanding of the tropical Atlantic salinity budget during that period. Whereas earlier studies presented mainly large-scale and qualitative analyses due to limited in situ data, more recent efforts have started to quantify the processes involved in seasonal changes in SSS and their spatial variations.

One major difference between the mixed layer heat and salinity budgets is that for the salinity budget, horizontal advection is generally much more important. This is likely due to multiple factors, including stronger spatial gradients of the surface freshwater flux due to strong precipitation in the ITCZ, strong freshwater input from rivers, and a lack of damping of SSS by the atmosphere as occurs for SST. One region where advection is very important is the northwestern tropical Atlantic, where low-salinity water is transported northwestward during the first half of the year (Foltz and McPhaden 2008, Coles et al. 2013, Da-Allada et al. 2013). In the central tropical North Atlantic, northward advection of low-salinity water from Amazon outflow and the ITCZ balances increasing tendencies in SSS due to evaporation and vertical mixing, resulting in a weak seasonal cycle of SSS (Foltz and McPhaden 2008, Camara et al. 2015). In the eastern tropical North Atlantic and under the mean position of the ITCZ, the seasonal cycle of precipitation is most important (Da-Allada et al. 2013). Grodsky et al. (2014) show a local salinity maximum in the northwestern tropical Atlantic during boreal winter to early spring. It results from minimum in Amazon discharge in fall, combined with transport of saltier equatorial and Southern Hemisphere water northward/westward, then eastward in the North Equatorial Counter Current (NECC). Therefore, in most regions of the tropical Atlantic, the mixed layer salinity budget represents a balance of multiple terms, including horizontal advection. On very large scales, for which advection becomes unimportant, Tzortzi et al. (2013) show that seasonal variations of precipitation and river runoff are most important.

Several recent studies investigated the mixed layer salinity budget in the equatorial Atlantic and Gulf of Guinea. In the Gulf of Guinea, river runoff and precipitation are compensated by vertical mixing and entrainment (Da-Allada et al. 2013). The net effect is an increase in SSS during May. Berger et al. (2014) came to a similar conclusion, showing that river runoff, vertical mixing, precipitation, and advection are important in the eastern Gulf of Guinea. Da-Allada et al. (2017) showed that the boreal spring maximum in SSS in the ACT is explained by an increase in zonal shear and strong salinity stratification at the base of the mixed layer during December-May. Strong salinity stratification is due to ITCZ rainfall and freshwater advection from the east. Camara et al. (2015) also show that strong vertical mixing in the eastern equatorial region balances freshwater advection. However, Schlundt et al. (2014) conclude that horizontal advection and E-P are most important for the slight increase in SSS during onset of ACT in the eastern equatorial Atlantic. Though important in the heat budget, vertical mixing was found not to be important for salinity budget.

On interannual timescales, there is some evidence that changes in ocean circulation dominate in the western tropical Atlantic (Coles et al. 2013, Foltz et al. 2015, Fournier et al. 2017). However, there are also strong interannual variations in Amazon outflow that can contribute (Grodsky et al. 2014).

## Equatorial circulation

One focus of the PIRATA observing system lies on the upper ocean circulation and its response to atmospheric forcing. Velocity measurements are taken by different current meters installed at the buoy systems or at subsurface current meter moorings nearby as well as by vessel mounted ADCPs used during PIRATA service cruises. The acquired datasets could be strongly enhanced through cooperation with different international and national projects like *e.g.* the Tropical Atlantic Climate Experiment (TACE), 2006-2011 (Johns et al. 2014) or the German Collaborative Research Center 754 (SFB 754) “Climate-Biogeochemistry Interactions in the Tropical Ocean”, 2008-2019 (Brandt et al. 2015).

Subsurface moorings were deployed along the equator at 23°W (with almost continuous measurements starting in December 2001), at 10°W (from 2006), and at 0°E (in 2007-2011 during TACE and then from 2016 in the framework of PIRATA and PREFACE). Repeat velocity sections were taken and analyzed along 38°W in the tropical North Atlantic, along 23°W and 10°W across the equator as well as further east and closer to the African continent. Much attention was devoted to the variability of the Equatorial Undercurrent (EUC), which is besides the western boundary current the strongest current in the tropical Atlantic. Previous studies suggested that the seasonal variability of the EUC in the central Atlantic cannot be explained by a quasi-stationary local momentum balance as for example the near-surface velocity maximum of the EUC at 23°W in boreal spring occurs during the seasonal minimum of the easterly winds (Johns et al. 2014). Improved understanding of the seasonal cycle was gained by analyzing full-depth multi-year moored velocity measurements at 23°W allowing a decomposition of the seasonal cycle into the baroclinic mode-frequency space. This decomposition revealed distinct energy peaks located on the characteristic of resonant equatorial basin modes, which are defined by complete cycles of eastward and westward propagation by equatorial Kelvin and Rossby waves respectively. The periods of such basin modes are a function of the phase speeds of the two wave types for the specific baroclinic mode and the basin widths. The importance of such resonance for the seasonal cycle in a realistic setting of the Atlantic Ocean was first shown for the second baroclinic mode semi-annual cycle by numerical modeling (Thierry et al. 2004). The full-depth mooring data could confirm the resonance behavior for the semi-annual cycle, but could additionally show a resonance for the fourth baroclinic mode annual cycle. The sum of the semi-annual and annual basin modes is able to explain largely the seasonal variability in the central equatorial Atlantic with an annual cycle in the EUC transport characterized by a maximum in boreal fall and a semi-annual cycle in the EUC core velocity, with velocity maxima in boreal spring and fall. The local timing of the seasonal velocity variability associated with the resonant basin mode cycle is not set by local wind forcing, but is a consequence of the integrated seasonal wind forcing in the inner tropics (Brandt et al. 2016).

Additionally to the equatorial subsurface PIRATA moorings, moorings at 0.75°N and 0.75°S were deployed at 23°W, 10°W and at 0.75°S - 0°E during the TACE program (Johns et al. 2014, Brandt et al. 2014). Together with the analysis of repeat ship sections (e.g. Hormann et al. 2007, Kolodziejczyk et al. 2009), the seasonal cycle of EUC transport could be described along the equator. The seasonal cycle of the EUC transport varies along the equator having transport maxima at 23°W in boreal fall and at 0°E in boreal spring and a semiannual cycle in between at 10°W (Johns et al. 2014). On interannual time scales, boreal summer EUC transport tends to be anomalously strong during cold Atlantic Niño events and weak during warm events (Brandt et al. 2014). Such behavior was associated by Richter et al. (2013) with so-called canonical events forced by zonal wind anomalies in the western equatorial Atlantic during boreal spring and associated Kelvin wave propagation. However, Richter et al. (2013) also identified non-canonical warm events forced instead by meridional advection from a warmer northern hemisphere toward the equator. For the non-canonical cold event in 2009, Burmeister et al. (2016) showed that meridional advection played only a minor role suggesting that this mechanism might be asymmetric with regard to cold and warm events.

Within the PIRATA program yearly cruises observations in the otherwise not well sampled Gulf of Guinea were carried out regularly, which allowed a strongly improved description of the regional circulation, of its variability and impacts. The termination of the EUC in the eastern equatorial Atlantic is characterized by a large variability in its position and strength, which is particularly reflected in the variability of the salinity distribution (Kolodziejczyk et al. 2014). The EUC generally transports high salinity waters eastward contributing via diapycnal mixing to the establishment of the seasonal sea surface salinity minimum along the equator one month before the onset of ACT in June (Da-Allada et al. 2017). At the termination of the EUC, high saline waters are mainly supplied to the westward currents north and south of the EUC, instead of being source waters for poleward eastern boundary currents. The strong weakening of the EUC at 10°W and 0°E during July and August (Johns et al. 2014) together with enhanced mixing during the ACT season interrupt the eastward salt transport, which is then reestablished in September with the strengthening of the EUC (Kolodziejczyk et al. 2014). Closer to the coast in the northern part of the Gulf of Guinea, the existence of the Guiana Undercurrent could be revealed. This eastward current, which is not directly supplied out of the North Equatorial Undercurrent, flows at subsurface north of the main path of the surface Guiana Current (Herbert et al. 2016). Further to the west at 23°W, the large number of shipboard velocity sections allowed the estimation of a robust mean flow characterized by an eastward surface flow between about 4°N and 9°N including the cores of the NECC and the northern branch of the NECC (Brandt et al. 2015). These eastward current bands were also identified along the 38°W PIRATA section (Urbano et al. 2008). Despite the energetic mean zonal current bands, there is the weaker mean meridional flow associated with the shallow overturning in the tropical Atlantic. It is composed of the tropical cells confined to the upper 100 m between about 5°S and 5°N (Perez et al. 2014) and the subtropical cells connecting the equatorial upwelling with the subduction regions in the subtropics (Zhang et al, 2003; Schott et al. 2004). Foltz et al. (2015) could show, by incorporating PIRATA near-surface salinity data, the importance of the poleward surface flow of the northern subtropical cell for the meridional transfer of freshwater originating in the Amazon River discharge and rainfall below the ITCZ and resulting variability of SSS on seasonal and interannual time scales.

The equatorial Atlantic is characterized by strong intraseasonal variability that is well captured in upper ocean velocity data but similarly temperature and salinity measurements. PIRATA in-situ measurements became extremely relevant in comparison to remote sensing data or for validating model results. Using satellite data, Athie and Marin (2008) could show that two types of intraseasonal waves dominate in the equatorial Atlantic: westward propagating tropical instability waves west of 10°W and shorter-period, wind-driven Yanai waves in the Gulf of Guinea east of 10°W. Generally, intraseasonal variability has a great importance for the mixed layer heat budget (Hummels et al. 2013) due to the associated divergence in meridional and vertical heat fluxes, but at the same time intraseasonal waves are found to provide the energy to the deep ocean to maintain the equatorial Atlantic circulation (Ascani et al. 2015). High-resolution model simulations that were validated against moored observation taken at the equator, 23°W were used to calculate eddy production rates and show that barotropic and baroclinic instabilities contribute to generate TIWs in the central equatorial Atlantic (von Schuckmann et al. 2008), thereby confirming early results obtained from analyzing observational data (Grodsky et al. 2005). In general, the simulation of TIWs revealed a dependence of wave amplitude on the wind products used. By including short-term wind variability in the forcing that is in agreement with direct wind measurements at the PIRATA buoys, Athie et al. (2009) were able to show that simulated TIW characteristics become more realistic also with respect to the substantial interannual variability of TIW energy (Perez et al. 2012). TIW-related anomalies have been also observed in upper ocean temperature and salinity data (Grodsky et al. 2005). Besides the mixed layer temperature, mixed layer salinity was found to play an important role to TIW-related surface density anomalies, energy conversion associated with TIW-mean flow interaction and its seasonality (Lee et al. 2014).

## Ocean-Atmosphere-Land coupling; Meridional Mode, Zonal Mode or Atlantic Niño, and Benguela Niños

Interannual to decadal variability in the tropical Atlantic Ocean is typically described in terms of two climate modes, a meridional mode that is represented by an interhemispheric SST gradient and a zonal or Atlantic Niño mode that is associated with SST variations in the eastern equatorial ACT region (e.g. Chang et al. 2006). The Atlantic Niño mode is similar to the El Niño-Southern Oscillation in the Pacific but more damped, mainly due to a weaker thermocline feedback (Lübbecke and McPhaden 2013). Pronounced SST anomalies also occur in the Gulf of Guinea and along the Southwestern African coast off Angola. The latter have been termed Benguela Niños (Shannon et al. 1986). Benguela Niños tends to occur before Atlantic Niño (Rouault et al, 2009, Lübbecke et al. 2010) and Lübbecke et al. (2010) suggest they should be seen as the same phenomenon.

These climate modes are of importance especially due to their impact on precipitation over the adjacent continents. Variations in rainfall over Northeast Brazil are closely related to SST variability in the tropical Atlantic Ocean (e.g. Hounsou-gbo et al. 2015). In particular SST variability in the ACT is related to the West African Monsoon (Brandt et al. 2011, Caniaux et al. 2011), and Benguela Niños have an impact on rainfall over western Africa and coastal central Africa (Reason and Rouault 2006, Rouault et al. 2009, Lutz et al. 2015).

Over the last decade, a number of studies have addressed the physical mechanisms of and the interaction between the tropical Atlantic climate modes. Measurements from the PIRATA array have been very valuable in many of these studies. PIRATA data have been used to investigate the processes at play in individual meridional or Atlantic Niño event years and to provide direct observation against which model output can be compared and validated (Foltz and McPhaden 2006a, 2008, 2009; Foltz et al. 2012). The PIRATA time series are now long enough to be used to investigate interannual variability.

The coupled ocean-atmosphere study of Bottino and Nobre (2018, in preparation) on the role of cloud cover parameterization on the rainfall distribution over the tropical Atlantic has suggested that the correct representation of deep atmospheric convection over the Amazon and Congo Basins are associated with the accurate representation of upper level atmospheric circulation pattern and the seasonal meridional migration of the Atlantic ITCZ. Giarolla et al (2015) also documented that such improvements on continental atmospheric convection impacted positively on the simulation of the Atlantic Equatorial Undercurrent and the Atlantic cold tongue.

The meridional and the Atlantic Niño modes have been dynamically linked through the reflection of Rossby- into equatorial Kelvin waves (Foltz and McPhaden 2010b) and the discharge of off-equatorial heat content (Zhu et al. 2012). Imbol Koungue et al. (2017) provide a comprehensive study of all major Kelvin waves occurring along the Equator detected by the PIRATA array from 1998 to 2015. The connection of the meridional and Atlantic Niño mode also shows up in the warm water volume mode discussed by Hu et al. (2013). The meridional mode has also been linked to variability of the Guinea Dome in the northern tropical Atlantic (Doi et al. 2010). Atlantic Niños are further connected to Benguela Niños through the propagation of equatorial Kelvin waves (Lübbecke et al. 2010). Benguela Niños are primarily forced remotely from the equator via equatorial Kelvin waves followed by poleward coastally trapped waves (Florenchie et al. 2003, Rouault et al. 2007, 2018, Imbol Koungue et al. 2017), even though local wind forcing might play a role as well (Richter et al. 2010). For the 2001 and 2011 Benguela Niño events, the associated equatorial Kelvin wave propagation can actually be detected in the PIRATA data (Rouault et al. 2007, 2018). Imbol-Kounge et al. (2017) show that all Benguela Niños are first detected by the PIRATA moorings along the equator one month before they start to appear in Angola.

There are some specific warm and cold events that happened and were investigated during the PIRATA period. One example is the 2005 ACT in the eastern equatorial Atlantic that has been related to an early onset of the ACT and strong intraseasonal wind bursts (Marin et al. 2009). That event was also accompanied by exceptionally warm SST anomalies in the tropical North Atlantic, contributing to one of the most active and destructive hurricane seasons on record (Foltz and McPhaden 2006b). PIRATA was a key component of the international AMMA (African Monsoon Multidisciplinary Analysis) program, mostly through EGEE and associated cruises (2005-2007). Through in situ observations in addition to numerical simulations and satellite products, both programs allowed to show that: i) zonal wind anomalies in the western equatorial Atlantic during late boreal winter to early summer precondition boreal summer cold/warm events in the eastern equatorial Atlantic that manifest in a strong interannual ACT variability; ii) local intraseasonal wind fluctuations, linked to the St. Helena anticyclone, contribute to the variability of ACT onset and strength, particularly during years with preconditioned shallow thermoclines; iii) the impact of ACT SST anomalies on the wind field in the Gulf of Guinea is clearly evidenced, and so contributes to the northward migration of humidity and convection and possibly the West African monsoon (WAM) jump (Hormann and Brandt 2007, 2009; Marin et al. 2009; Brandt et al. 2010; De Coëtlogon et al. 2010; Caniaux et al. 2011).

Another example is the pronounced meridional mode event that took place in spring 2009 which has been explained with an anomalously strong high pressure system in the subtropical north Atlantic and anomalous upwelling (Foltz et al. 2012). This event then led to a cold event in the eastern equatorial Atlantic in the following boreal summer through Rossby wave and reflected Kelvin wave propagation (Foltz and McPhaden, 2010a; Burmeister et al. 2016). Atlantic Niños typically occur in boreal summer when the ACT is present and the thermocline is shallow. Okumura and Xie (2006) found that there is also a secondary peak in the eastern equatorial Atlantic SST variability that occurs in November/December. They termed this mode Atlantic Niño 2. Although with modest amplitude, it involves active interactions of zonal wind, upwelling, thermocline depth, and SST. It affects interannual fluctuations in rainfall in coastal Congo-Angola during the early rainy season and may also later affect precipitation in northeast Brazil in March-April.

### *b. Piggy back project results*

#### Understanding $CO_2$ variability

The present day global ocean is a net annual sink of atmospheric $CO_2$. However, the tropical oceans are a $CO_2$ source to the atmosphere with large interannual variability controlled primarily by physical drivers. Sustained observing of surface ocean $CO_2$ in the tropics is critical for closing the global carbon budget (land, air, and ocean) and for understanding the fate of anthropogenic $CO_2$.

One of the objectives of the European CARBOOCEAN project was to monitor $CO_2$ fugacity ($fCO_2$) in the Atlantic Ocean. A European network of $CO_2$ observations has been set up in which the $CO_2$ monitoring at the PIRATA sites was included. The sensors were built at the Technical Division INSU (Institut National des Sciences de l'Univers) in France and are calibrated in this laboratory each year, before and after deployment. One of the $CO_2$ sensor was installed in June 2006 at 6°S, 10°W and the other one was installed in March 2008 at 8°N, 38°W, both during PIRATA cruises (Lefèvre et al., 2008), recording $fCO_2$ hourly as well as SST and dissolved oxygen in the surface layer of the ocean. To avoid data gaps, two more sensors were funded by INSU in France as spares for the sensors already deployed. The $CO_2$ network was maintained during the European projects FP7 CARBOCHANGE (2011-2015) with additional support from IRD and INSU. These observations are part of the research infrastructure ICOS (Integrated Carbon Observation System) France Océan. A new $CO_2$ sensor has been installed on the T-Flex buoy at 6°S, 8°E in March 2017 and its spare has been built, both funded by the European H2020 Atlantos project. The buoy is located close to the Congo River mouth. The objective of monitoring $CO_2$ at this site is to better understand the impact of rivers on the $CO_2$ distribution in the tropical Atlantic.

The mooring at 6°S, 10°W is located south and west of the seasonal ACT and is affected by its propagation from June to September (Lefèvre et al., 2008). It is also located above the mid-Atlantic ridge and subject to internal waves that increase surface $fCO_2$ and nutrients in the mixed layer (Parard et al., 2014). The region is a net source of $CO_2$ to the atmosphere (Parard et al., 2010). The net community production calculated from carbon and oxygen data averages 16.6 ± 6.1 mmol C $m^{-2}d^{-1}$ and exhibits a significant year to year variability (Lefèvre and Merlivat, 2012). High frequency $fCO_2$ variability is observed throughout the time series but it is particularly pronounced after the upwelling season (Parard et al., 2010). The intraseasonal, seasonal and interannual variability of $fCO_2$ at this site has been explored by Lefèvre et al. (2016). On seasonal timescales, the $fCO_2$ variations are mainly driven by sea surface salinity. At interannual timescales, some important differences appear in 2011-2012: lower $fCO_2$ and fluxes are observed from September to December 2011 and are explained by higher advection of salty waters at the mooring, in agreement with the wind. In early 2012, the anomaly is still present and associated with lower sea surface temperatures. No significant long-term trend is detected over the period 2006-2013 on $CO_2$ and any other physical parameter. However, as atmospheric $fCO_2$ is increasing over time, the outgassing of $CO_2$ is reduced over the period 2006-2013 as the flux is mainly controlled by the difference of $fCO_2$ between the ocean and the atmosphere.

In the western tropical Atlantic, hourly measurements of $fCO_2$ and meteo-oceanographic data at 8°N-38°W site indicated two distinct seasonal periods (Bruto et al., 2017). During the first half year (January to July), the area is influenced by the North Equatorial Current with small salinity variations and the $fCO_2$ (mean $fCO_2$ 378.9 µatm) is mainly controlled by SST changes. From August to December the air-sea $CO_2$ exchange (mean $fCO_2$ 421.9 µatm) is associated with SSS variations induced by ITCZ rainfall and fresh water arrival from the Amazon River plume, which is transported eastward by the NECC after the retroflection of the North Brazil Current. Observed high-frequency (less than 24 hours) $fCO_2$ increases at 8°N-38°W are associated with rapid increases in SST resulting from diurnal cycle of solar radiation, combined with low wind speed periods that contributes to SST rising by inhibiting vertical mixing of colder waters. In contrast, observed high frequency $fCO_2$ decreases are associated with lower SSS values caused by heavy rainfall episodes.

The PIRATA cruises are also a good opportunity to collect additional data (such as seawater samples for inorganic carbon and alkalinity analyses) and to provide spatial information near the moorings. In 2006, underway $fCO_2$ was measured during the French

PIRATA cruise on board the R/V Atalante. A strong north-south $CO_2$ gradient was observed and associated with the two zonal currents (NECC-Guinea Current system and SEC) with low $fCO_2$ measured in the warm and fresher waters north of ~2°N (Lefèvre, 2009). During this cruise, the highest $fCO_2$ were measured close in the coastal upwelling close to the Angola coast whereas biological activity explained a significant $CO_2$ drawdown near the Congo outflow. The seawater samples collected in the eastern tropical Atlantic since 2005 have confirmed the results and provided a robust alkalinity-salinity relationship for this region (Koffi et al., 2010), which allows the determination of all the inorganic carbon parameters at the 6°S, 10°W site.

Similar work was done in the western tropical Atlantic with underway $fCO_2$ measurements made in 2009 and 2010 during the Brazilian PIRATA cruises on board the Antares. The $fCO_2$ variability was mainly driven by physical processes and seasonal maps could be realized by developing empirical relationships (Lefèvre et al., 2014). Seawater samples collected for inorganic carbon and alkalinity as well as available data in this region led to new robust empirical relationships and highlighted the role of the salinity in the variability of the carbon properties (Bonou et al., 2016).

## Oxygen Minimum Zone and equatorial ventilation

Oxygen minimum zones (OMZs) at intermediate depth (300 – 700m) are present in the eastern basins of the tropical North and South Atlantic, representing the shadow zones of the ventilated thermocline (Luyten et al. 1983) in the tropical Atlantic. They are separated by an equatorial oxygen maximum (Brandt et al. 2012), which is generated by energetic mean and variable zonal currents between 5°S and 5°N.

In the past decade, repeat shipboard and moored observations taken within the German collaborative research centre SFB754 in cooperation with the PIRATA program have significantly contributed to an improved understanding of the physical processes setting the mean state and the dynamics of the OMZ in the eastern tropical North Atlantic (ETNA; Karstensen et al. 2008, Fischer et al. 2013, Hahn et al. 2014, Brandt et al. 2015, Hahn et al. 2017). The frequent repetition of the 23°W hydrographic section has revealed a dominant pattern of oxygen change in the ETNA between the years 2006 and 2015, characterized by a strong deoxygenation in the upper 400m and a moderate oxygen increase between 400 and 1000m. Changes in the large-scale circulation are considered as a major driver for the observed decadal oxygen change (Hahn et al. 2017). A larger scale multi-decadal oxygen decrease since the 1960s (Stramma et al. 2008, Brandt et al. 2015) was suggested to be driven by anthropogenic changes (Schmidtko et al. 2017), but natural variability of the climate system may play a comparable role (Frölicher et al. 2009, Keeling et al. 2010, Helm et al. 2011).

Moored oxygen observations from various latitudes in the ETNA have shown different regimes with oxygen variability on intraseasonal to interannual time scales. At the equator, interannual oxygen variability was observed to be associated with a 4.5-yr cycle of the equatorial deep jets that contributes to a net eastward oxygen flux along the equator (Brandt et al. 2012). Intense mesoscale oxygen variability on intraseasonal time scales is present at the lateral boundaries of the OMZ resulting in a net meridional oxygen flux and being a major oxygen supply path toward the OMZ core (Hahn et al. 2014).

In the past years, also the existence of extremely low-oxygen events in the ETNA has been revealed, which have severe impacts on local biogeochemical cycles and ecosystem.

These so called dead-zone events, which occur at depths of about 50-300m, are mostly associated with anticyclonic Mode Water eddies. They effectively transport water masses from the biologically productive eastern boundary upwelling system offshore into the open ocean. Strong oxygen reduction within eddies was found to be associated with an isolation of the eddy cores from its surroundings and enhanced consumption (Karstensen et al. 2015, Schütte et al. 2016).

In March 2017, oxygen time series at PIRATA buoys 11°N, 23°W and 20.5°N, 23°W were implemented into the online data stream of the T-Flex system for the first time. Providing real-time oxygen observations is a key element for the online monitoring of oxygen variability particularly including low-oxygen events.

### Equatorial Deep Jets and possible climate impacts

PIRATA subsurface moorings typically deployed nearby the surface buoys are often used to install additional deep instrumentation. Along the equator deep velocity measurements partially covering the whole water column were carried out at 23°W starting in 2002 with a gap in 2003 and at 10°W from 1999 to 2005 with a gap in 2002/2003 (Bunge et al. 2008, Brandt et al. 2011). Deep velocity data revealed besides a dominance of intraseasonal variability in the meridional velocity component, strong semi-annual, annual and interannual variability of the zonal velocity component (Bunge et al. 2008). While the seasonal variability is generally associated with upward phase and correspondingly downward energy propagation suggesting a dominant forcing at the ocean surface by the wind stress, the interannual variability was found to be associated with downward phase and upward energy propagation. The interannual variability has a distinct spectral peak at a period of about 4.5 years and is associated with relatively small vertical wavelengths of about 300 to 700m corresponding roughly to the 16th baroclinic mode. It forms a system of vertically stacked jets, the so-called Equatorial Deep Jets (EDJ). The EDJ are found to be responsible for the transport of tracers along the equator, like e.g. CFCs (Gouriou et al. 2001) or oxygen (Brandt et al. 2008), and particularly contributes to the ventilation of the eastern equatorial Atlantic (Brandt et al. 2012). The upward energy propagation of the EDJ together with a statistical relation between the EDJ cycle and equatorial surface velocity, sea surface temperature, wind stress and rain pattern led moreover to the suggestion of a climate impact of the EDJ (Brandt et al. 2011). Due to the very regular oscillations of the EDJ (because of their similarities with equatorial basin modes) such an impact could possibly improve climate predictions in the tropical Atlantic on interannual time scales. However, EDJ are typically not well simulated in realistic state-of-the-art ocean general circulation models (Ascani et al. 2015). Idealized simulations (Ascani et al. 2015) and the reconstruction of EDJ forcing derived from the 23°W mooring data (Claus et al. 2016) suggest an energy transfer from downward propagating intraseasonal Yanai waves to the EDJ at intermediate depths. More rigorously, Greatbatch et al. (2017) could show by analyzing idealized simulations and velocity data from three moorings along 23°W between 0.75°N and 0.75°S that it is the meridional flux of zonal momentum associated with intraseasonal variability, which acts to maintain the EDJ against dissipation. The inclusion of EDJ or their effects in coupled climate simulations remains an open issue to be solved in the future.

### Microstructure measurements

Extensive microstructure measurement programs carried out in 80s and 90s have greatly improved understanding of turbulent mixing processes in the upper thermocline of the tropical Pacific (e.g. Gregg et al., 1985; Moum and Caldwell 1985; Peters et al. 1988, 1994; Moum et al. 1989, 2009; Lien et al. 1995). However, prior to PIRATA, mixing studies had not been carries out in the tropical Atlantic. Complimentary microstructure measurement programs during the PIRATA service and other cruises started in 2005 covering the central and eastern tropical Atlantic (e.g. Hummels et al. 2014). Observational foci were the PIRATA sites within the ACT region. In addition to vessel-based microstructure profiling, gliders with attached turbulence probes were deployed. Starting in 2014, chipods measuring time series of the dissipation rate of thermal variance (Moum et al. 2013) were attached to the PIRATA moorings on the equator at 23°W and 10°W to monitor the variability of upper-ocean turbulent mixing processes.

The major finding was that dissipation rates of turbulent kinetic energy in the upper thermocline of the equator (2°N–2°S) is strongly enhanced compared to off-equatorial locations (e.g. Hummels et al. 2013, Schlundt et al. 2014). The equatorially enhanced mixing rates are associated with the presence of strong vertically-sheared zonal flow induced by the eastward flowing EUC and the seasonally varying westward flowing SEC, forming a marginally stable environment in terms of Kelvin-Helmholtz Instability (Hummels et al. 2013, Wenegrat and McPhaden 2015). Seasonal and regional variability of diapycnal mixing within the ACT varies in concert with the background conditions, namely vertical shear of horizontal velocities enhancing and stratification reducing mixing events and associated diapycnal fluxes (e.g. Hummels et al. 2013). These findings compared well to mixing studies from the equatorial Pacific that had shown similar intense mixing at the equator previous (e.g. Gregg et al. 1985, Smyth et al. 2013). The main consequence of the equatorially enhanced turbulence below the mixing layer, both in the tropical Atlantic and Pacific, is the strongly enhanced diapycnal fluxes of heat, freshwater and nutrients that contribute to controlling the mean state and variability of SST, SSS and primary production (e.g. Gregg et al. 1985, Chang 1994, Wang and McPhaden 1999, Moum et al. 2013, Hummels et al. 2013, Schlundt et al. 2014, Sandel et al. 2015). Furthermore, the results from the measurement program verified results from model studies that had shown elevated mixing to occur within the ACT region along with consequences for the heat and freshwater budget of the ACT and the Gulf of Guinea region (Jouanno et al. 2011, 2017, Da-Allada et al. 2013, 2014, 2017, Camara et al. 2015, Planton et al. 2017).

### Near inertial ocean mixing

Recent studies carried out in the framework of the EU FP7 PREFACE programme (not published yet; refer to Bourlès 2016, Preface deliverable D3.2 and to Jochum 2017, dedicated Preface deliverable D3.3), focused on the near inertial waves (NIWs), a process that is poorly resolved in climate models. Jochum et al. (2013) showed that NIW induced mixing brings cool subsurface water to the surface, and thereby modifies the tropical SST gradient and ITCZ position. The NIWs are principally generated by surface winds, with additional contributions from nonlinear interactions and other minor processes. Model-based estimates of the annual wind power input to the global surface ocean inertial frequencies span the range 0.3-1.4 TW, with significant uncertainty arising from sensitivity to the spatial and temporal resolution of the wind products employed and unresolved processes in the modeled ocean response. Thus, significant uncertainty surrounds the fate of wind generated near-inertial energy in the ocean. Both observational and modeling studies have suggested that the majority of wind generated near-inertial energy is confined to the upper ocean, generating large shear across the mixed layer base. The resultant entrainment can lead to substantial deepening of the mixed layer following storms, with notable impacts on air-sea heat exchange and biogeochemical cycles. NIW strength is sensitive to details of atmospheric forcing, and there are only few observational constraints.

The study used the long time series of continuous and concurrent high frequency surface wind from 6 of the 18 existing PIRATA ocean-atmosphere interaction moorings, and near-surface ocean velocity data. The wind power input to near-inertial currents was computed at each mooring, and the key characteristics of the inertial activity and wind power input to upper ocean near-inertial currents were explored. Time-mean near-inertial current speeds at the PIRATA moorings range from 3.6 $cms^{-1}$ to 13.0 $cms^{-1}$ that is consistent with estimates from near-surface drifters. Analysis of these data provides new constraints on inertial energy injection and decay in the tropical ocean which are critical for refinement of existing near-inertial mixing parameterization, due to acute climate sensitivity to turbulence in the tropical thermocline. This study also provides evidence for a robust relation between near-inertial kinetic energy and mixed layer heat content, calls for better constraints on the vertical variation of upper ocean velocity, and highlights the value of furnishing the tropical moorings with additional current meters. In the long-term, a new parameterization scheme for the near-inertial mixing parameterization could be proposed that should improve significantly numerical simulations and predictions.

## Products development and validation with PIRATA data

Since the last review of PIRATA in 2006, there have been over 60 papers published in the refereed literature using PIRATA data for satellite validation and for the generation, calibration, and validation of various satellite and/or in situ data products. The variables involved are SST (skin and bulk), SSS, surface wind speed and wind stress, specific humidity and air temperature, surface turbulent heat fluxes, short wave radiation, downwelling long wave radiation, precipitation, surface currents, and sea level. A full list of all the papers is contained in the PIRATA bibliography (provided below, regularly actualized and accessible through http://www.aoml.noaa.gov/phod/pne/pdf/PIRATA_references.pdf). Here we highlight just a few studies to illustrate the broad application and utility of the PIRATA data.

PIRATA data have been incorporated into the surface marine meteorological International Comprehensive Ocean-Atmosphere Data Set (ICOADS) (Woodruff et al. 2011, Freeman et al. 2017). They have been used for assessing various SST products with high temporal (hourly to daily) resolution and spatial resolution (Kara and Barron 2007; Clayson and Weitlich 2007, Marullo et al. 2010, Reynolds and Chelton 2010). They have been used to validate Aquarius SSS measurements (Tang et al. 2014), to assess vertical variability of near-surface salinity in the tropics and the consequences of that variability for L-band radiometer calibration and validation (Henocq et al. 2010) and for assessing the temporal aliasing in satellite-based surface salinity measurements (Vinogradova and Ponte 2012). PIRATA data have been used in generating the AOFlux (Yu and Weller 2007) and Tropflux (Praveen Kumar et al. 2012) surface turbulent heat flux products and in the Tropflux wind stress product (Praveen Kumar et al. 2013). They were also incorporated into the Large and Yeager (2009) global climatology of interannually varying air-sea fluxes. The buoy data have been used to validate a high-resolution global ocean vector wind analysis constructed from passive radiometers and active scatterometers from 1987-present (Yu and Jin 2012) and in the evaluation of a variety of surface wind products (Peng et al. 2013). PIRATA data have been used extensively in studies to evaluate various tropical rainfall products (e.g., Bowman et al, 2009; Prakash et al. 2011, 2013; Xie et al. 2017) and surface radiation retrievals from satellites (Pinker et al. 2009, Wang and Pinker 2009).

PIRATA data have been incorporated into several climatologies based on in situ measurements, such as for SST and SSS. Reverdin et al. 2007 established a monthly mapping of SSS from a variety of sources including PIRATA moorings, between 30°S and 50°N, to study large scale variability. They showed that seasonal SSS anomalies are found to respond with a 1-2 month lag to freshwater flux anomalies at the air-sea interface or to the horizontal Ekman advection. Such product has been used in several studies related to SSS, *e.g.* Da Allada et al. 2014 who evidenced a SSS increase up to 0.5 over the period 2002–2009 in the Gulf of Guinea, off the Niger Delta.

As contribution to GOSUD, members of the French CORIOLIS team established a process consisting to systematically collect and validate (from sea surface water samples) the SST/SSS data acquired by all the French Research vessel-mounted thermosalinographs during cruises and transits (Gaillard et al. 2015), including PIRATA-FR cruises. This “Sea Surface Salinity and Temperature from French REsearch Ships” (SSST-FRESH) dataset is very valuable for the calibration and validation of the new satellite observations delivered by the Soil Moisture and Ocean Salinity (SMOS) and Aquarius missions. In the same way, the In Situ Analysis System (ISAS) was established to produce gridded fields of temperature and salinity that preserve as much as possible the time and space sampling capabilities of the Argo network of profiling floats, using all types of vertical profile as well as time series, including PIRATA ones. ISAS gridded fields are entirely based on in-situ measurements. The system aims at monitoring the time evolution of ocean properties for climatological studies and allowing easy computation of climate indices. A careful delayed mode processing of the ISAS 2002-2015 dataset is made available through the French Sea scientific open data publication (Kolodziejczyk, Prigent-Mazella, and Gaillard, SEANOE, doi 10.17882/52367). ISAS has been used in several articles related to the tropical Atlantic to validate numerical simulations or as product for process studies (e.g. Da Allada et al. 2017, Jouanno et al. 2017).

Instrumental biases, data drop-outs, and the coarse vertical resolutions of the oceanic measurements, sometimes complicate the use of PIRATA mooring data for research. An enhanced PIRATA data set (ePIRATA) has therefore been developed for the 17 PIRATA moorings with record lengths of at least seven years (http://www.aoml.noaa.gov/phod/epirata/; Foltz et al. 2018). Data in ePIRATA are corrected for instrumental biases, temporal gaps are filled using supplementary data sets, and the subsurface temperature and salinity time series are mapped to a uniform 5-m vertical grid. Important aspects of this data set are that all original PIRATA data that pass quality control and do not require bias correction are retained without modification, and detailed error estimates are provided for each daily-averaged oceanic and atmospheric parameter. The terms in the mixed layer heat and temperature budgets are calculated and provided, with error bars, as part of the ePIRATA data set. In addition to its value for upper-ocean and climate research and model validation, ePIRATA presents a framework for assessing the value of additional PIRATA sensors for reducing uncertainties in upper-ocean temperature and salinity, mixed layer depth and currents, and mixed layer heat and temperature budget components.

To address the relevance of thermistor chains on free-drifting buoys and evaluate the potential future use of such material equipped with other physico-chemical parameters (such as salinity or dissolved oxygen) an analysis has been carried out in the framework of the EU AtlantOS program to revisit data collected by such equipment, some deployed in 2006 and 2015 during PIRATA cruises in the Gulf of Guinea (Rousselot et al. 2017, Preface deliverable D3.5). The analysis is based upon the co-localization of nearby buoys, thermosalinograph data, Argo data, PIRATA buoys and CTD profiles data. A new model must have been applied to settle the sensors to their ‘real’ immersion when the bottom of the chain uplifts, resulting in biases that usually don't exceed 0.2°C. The reduced level of inaccuracy renders this kind of instruments an even more useful tool for surface ocean observation. So corrected data sets has been provided to the CORIOLIS GDAC.

Yearly PIRATA cruises may be opportunities for some specific operations. The PIRATA-FR15/EGEE-3 cruise carried out in May-July 2006 allowed documenting the ocean-atmosphere system with high frequency meteorological measurements and 251 radiosoundings (Bourlès et al. 2007). Such data sets, also used in combination with modelling experiments and ECMWF analyses, allowed to investigate the links between sea surface temperature (SST) and the marine atmospheric boundary layer in the Gulf of Guinea, and the air–sea interaction impact on the water cycle (e.g. Leduc-Leballeur et al. 2011). They also allowed to test cumulus, microphysics and radiative parametrizations used in the Weather Research and Forecasting model (WRF), showing that such parameters exert a large influence on the simulated seasonal distribution of regional convective rainfall (Meynadier et al. 2015). Turbulent fluxes at the air-sea interface were also estimated from flux measurements obtained from a dedicated mast installed on the Research Vessel Atalante during this particular cruise. Turbulent fluxes were calculated with an eddy covariance method and with a spectral method. Calculation of eddy correlation fluxes required a correction of flow distortion at turbulent scales, which was performed with a new statistical technique. Application of the spectral flux calculation method revealed that an imbalance term was required, in agreement with results from earlier experiments, and indicated that the value of the Kolmogorov constant (0.55) should not be modified. Bulk exchange coefficients calculated are in good agreement with earlier parameterizations in medium wind conditions (Bourras et al 2009). Turbulent fluxes at the air-sea interface were also estimated from flux measurements obtained from a micrometeorological tower installed on the RV Vital de Oliveira during the PIRATA-BR XVII cruise during October 2017-January 2018.

Radio-soundings and oceanic data from oceanographic campaigns in 2006 (EGEE-3/PIRATA-FR15) and 2014 (PIRATA-FR24), airborne measurements in 2016 (DACCIWA campaign), in situ data from PIRATA buoys, and high-frequency satellite data (as MSG classifications in 2008, 2012 and 2014, AMSU data or TRMM precipitation), in addition to coupled regional simulations (WRF-NEMO) and reanalyses (ECMWF ERA-I and NCEP-CFSR), have also been used to study the atmospheric response to diurnal cycle in the Gulf of Guinea. The diurnal cycle of deep convection (and its change of phase, from a midday oceanic convection to a late afternoon continental convection), as well as its dynamical conditions in the low-level atmosphere, could be regionally mapped (unpublished results: see Bourlès, 2016, Preface deliverable D3.2). The question investigated is what frequency of ocean-atmosphere exchanged is required in a coupled regional model needs to correctly represent diurnal cycle and seasonal evolution in the northeastern tropical Atlantic in boreal spring and summer (when the seasonal onset of a cold equatorial upwelling intensifies the air-sea interaction), and what vertical resolution is needed in the lower atmosphere.

The NCEP reanalysis and reanalysis from the CFSR (Saha et al. 2010) product allowed, as typical example, a study based on satellite observations and WRF simulations forced by different SST patterns, to analyze the role of the air-sea interaction in the Gulf of Guinea in setting precipitation at the Guinean coast, during the onset of the West African Monsoon (Meynadier et al. 2016). Such study clearly showed that the seasonal ACT setup strongly constrains the low level atmospheric dynamics between the equator and the Guinean coast. The local SST meridional gradient has noticeable effects on the marine boundary layer stability and hydrostatically-changed meridional pressure gradient, which strongly impacts moisture flux convergence near the coast. It particularly showed that the SST influences the wind through a local modification of the pressure gradient (Lindzen and Nigam's mechanism). The fast adjustment of the vertical stratification in the mixed-layer is also significant in the equatorial area after the ACT onset, but not before, emphasizing a threshold effect.

The water vapour in the lower atmosphere is a key component of earth's climate system. It is expected that the recent warming of the earth surface will strongly influence sea surface evaporation and precipitation patterns. The PIRATA-FR24 cruise was the opportunity to measure water vapour isotopic composition ($^1H_2{}^{16}O$, $H_2{}^{18}O$ and $^1H_2H^{16}O$) of the Atlantic marine boundary layer, by using a Picarro and weather station measurements. The most enriched water vapour isotope values were observed during periods dominated by the trade wind regime with limited atmospheric convection. The most depleted isotopic values were recorded during periods of strong convective activity in the Gulf of Guinea. These data sets also allowed evidencing the impact of tropical upwellings and mesoscale SSS patterns on water vapour composition, suggesting that high-resolution isotope sampling can identify advection processes, even if salinity variations are small (Benetti et al. 2016, 2017)

Recently, Trolliet et al. 2017 carried out a study using PIRATA buoy solar irradiance measurements for satellite product validation, as a continuation of the study by Boilley and Wald 2015. The data sets comprise the re-analyses MERRA-2 and ERA-5 and three satellite-derived data sets: HelioClim-3v5, SARAH-2 and CAMS Radiation Service v2, and are compared to qualified measurements of hourly irradiance made at five buoys of the PIRATA network for the period 2012-2013. The re-analyses often report cloud-free conditions while actual conditions are cloudy and reciprocally, actual cloudless conditions as cloudy. The medium and high level clouds exhibit more bias than the low level clouds. The re-analyses poorly correlate with the optical state of the atmosphere derived from the measurements. The actual irradiance field is spatially distorted by re-analyses, especially for MERRA-2. Performances are similar between the three satellite-derived data sets. They correlate well with the optical state of the atmosphere and reproduce well the dynamics of the solar irradiance. The three data sets exhibit overestimation with the lowest biases reached by CAMS Radiation Service v2. The bias of HelioClim-3v5 is fairly similar from one location to the other, which means that the actual spatial gradients are well reproduced. This study revealed that PIRATA network is a unique and valuable means to study and monitor the surface irradiance in the tropical Atlantic Ocean and deserves support for operations to further enrich the data records.

### PIRATA data use for numerical model validation

PIRATA buoy and cruise data are currently used extensively for model validation. To be sure, most of the results summarized above (equatorial circulation, mixed layer processes, TIWs, deep jets…) are based on numerical models validated with in situ and other measurements including the PIRATA data (e.g. Hormann and Brandt 2007, von Schuckmann et al. 2008, Kolodziejczyk et al. 2009, 2014, Jouanno et al. 2011, 2013, Brandt et al. 2014, 2016, Imbol Kongue et al. 2017…). One other example of such was the shipboard ADCP data from the Brazilian maintenance cruises for the period of 1998-2005, which were used to validate previous numerical simulations of the existing of the northern branch of the NECC by Urbano et al. (2007). Also, the PIRATA ADCP buoy data were used to validate ocean and coupled ocean-atmosphere modeling of the Atlantic EUC by Giarolla et al (2005, 2013). In Giarolla et al. (2015), the Brazilian Earth System Model - BESM-OA2.5 representation of both the phase and amplitude of the equatorial ACT is contrasted with those of other CMIP5 models. The thermally indirect nature of the South Atlantic Convergence Zone has been demonstrated by the use of both PIRATA-SWE data (temperature, rainfall, and solar radiation) and coupled ocean-atmosphere simulations with BESM-OA2.3 model (Nobre et al. 2012). In the same way, PIRATA data was used to validate numerical simulations, which show that the observed increase in the Agulhas Leakage might be correlated with changes in thermodynamic properties and ocean-atmosphere fluxes in the western Tropical Atlantic (Castellanos et al., 2016 and 2017).

Recently, hydrographic and acoustic measurements obtained during the French PIRATA cruise from 2015 onboard the R/V Thalassa were used in a numerical model dedicated for investigating spatiotemporal dynamics of fish populations under the influence of both fishing and environment, the "Spatial Ecosystem And POpulation DYnamic Model" (SEAPODYM; *e.g.*, Lehodey et al., 2015; see also www.seapodym.org). Observing System Simulation Experiments (OSSE) were carried out with the SEAPODYM Mid-Trophic Level (MTL) component, in order to analyze the biomass distribution of micronekton in the Eastern tropical Atlantic and to assess the benefit of using different observation networks in data assimilation procedures. Such experiments cleary evidenced that, due to its localisation and its sampling scheme during cruises, the PIRATA network is one of the best observation network for data assimilation in SEAPODYM-MTL (Delpech et al., personal communication), proving that PIRATA may also be relevant for biological research.

## PIRATA data use in operational meteorology and oceanography

Operational oceanography it is now well established in many countries with the aim to provide reliable ocean products devoted to describe and predict marine environment status and dynamics for a wide range of users and policy makers (Schiller et al. 2016). Depending on their socio-economic interest, countries are developing regional, global forecasting systems, or both. First these systems were designed to describe the physical ocean dynamics, including sea ice, based on ocean model corrected on weekly or daily basis by assimilation (Tonani et al. 2015), with forecast length of 3 to 15 days. Then, some of these systems incorporated coupling with the biogeochemical modelling, in order to provide low trophic level description, carbon and oxygen content variability (Gehlen et al. 2015), and, by the way pH variation, to support the global change monitoring (Gehlen et al. 2011). In the very recent years, coupling with atmospheric or wave model has also been started, in order to better represent for short term forecast the correct fluxes between ocean and atmosphere (Brassington et al. 2015).

The operational systems of Mercator Océan are based on the NEMO/PISCES ocean models and a Kalman filter that assimilates the PIRATA data (details are available in Lellouche et al. 2013). Temperature and salinity profiles are assimilated on a daily basis. Note that Mercator Océan systems are forced by ECMWF atmospheric fluxes that are also using PIRATA measurements (meteorological but also surface ocean temperature).

Real time forecasting global systems offer now eddy-permitting to eddy resolving capabilities, assimilating satellite altimetry and radiometry derived information, and in-situ temperature and salinity observations. Most of the time, these systems assimilate the available vertical profiles from Argo, XBT lines, CTD from oceanographic cruises, and data from mooring, including the TAO-RAMA-PIRATA arrays. Timeliness is the main limitation for many operational systems that might have assimilation window of few hours (e.g., Blockley et al. 2014). PIRATA temperature and salinity mooring data are transmitted in quasi-real time to the GTS and to some GDACs, and most global operational systems are assimilating them. The direct impact of PIRATA data on real time hindcast has been evaluated positively several times (Lea et al. 2014; Oke et al. 2015; see also discussion below on Observing System Experiments –OSEs- and Observing System Simulation Experiments –OSSEs-).

Ocean and coupled operational systems have been recently used for establishing reanalyses, as Ocean ReAnalysis Pilot 5 from an eddy-permitting ocean (Zuo et al. 2017), and air-sea heat fluxes (Valdivieso et al. 2017). Liu et al. 2017 proposed an evaluation of satellite and reanalysis-based global net surface energy flux and uncertainties.

Operational Ocean centres, but also meteorological centres that carry on short to medium terms predictions (seasonal to interannual forecast) through coupled ocean-atmosphere systems are also producers of global ocean reanalyses. During the recent ocean reanalyses intercomparison project under the auspices of CLIVAR/GSOP and GODAE OceanView, most of the global eddy permitting reanalyses over the past 20 years were assimilating PIRATA data (Balmaseda et al. 2015) through the use of the qualified dataset CORA (Cabanes et al. 2013) or EN4 (Good et al. 2013). One of the obvious benefits of the PIRATA array has been to provide, since 1998 temperature and salinity profiles in the Tropical Atlantic where Argo floats were hardly providing information before 2002.

The in-situ temperature and salinity profiles that are available in real time are also used for validation by operational centres, even if assimilated. In the frame of GODAE OceanView, but also as part of the Copernicus Marine Environment Monitoring Service, dedicated working groups have been designing these past years' real time assessment methods based on the existing available dataset. In particular, the Class-4 metrics approaches where temperature and salinity forecast are compared to observations in order to determine skill scores and the performances of operational systems in real time (Hernandez et al. 2015).

## 4 Capacity Building

France, mostly through IRD, contributes from many years to developing capacities and scientific collaborations with West African countries. During the early years of PIRATA, the French cruises left from Abidjan in Ivory Coast, where the French Research Vessel ANTEA was based. Several African scientists and students were invited to participate to the French PIRATA cruises and the associated EGEE cruises (2005-2007). In the continuation of AMMA/EGEE (the oceanic component of the African monsoon), as support of research programs in oceanography such as PIRATA and also a regional collaborative network for coastal measurements (PROPAO; Sohou et al. 2014), IRD, University Paul Sabatier of Toulouse and the UNESCO International Chair in Mathematical Physics and Applications (ICMPA) of the University of Abomey-Calavi (Cotonou, Benin) initiated a regional Master 2 program dedicated to Physical Oceanography and Applications. This Master's grew from a strong need for capacity building in the West African region, as demanded by regional partners. The Master's program was thus launched in 2008. The host organization ICMPA supplies the foundation for instruction and lecturers from outside Benin deliver their courses in the form of one or two-week intensive study periods. The University of Toulouse has been a core partner since the start of the diploma, providing lecturers, and from the academic year 2011-2012 the diploma has been jointly offered by the two universities. IRD provided initial financial support over the period 2008-2010. Then, the French oil company Total fully supported this program from 2009 to 2015, and provided instruction on applied aspects of ocean science and offshore development. IRD provides again full financial from 2015. This program has been reinforced in 2015 with the addition of lecturers from the University

Federal of Pernambuco (UFPE, Recife, Brazil), partner of PIRATA, and the offshore service company Fugro GEOS, from England. This Master's program has grown into a unique regional education program, with students from Benin, Togo, Nigeria, Ivory Coast, Cameroon, Ghana, Senegal, Congo and France. Each year it provides instruction to about ten students on all aspects of physical oceanography, from the basic dynamics of ocean currents, waves and tides to the action of ocean circulation on geochemistry, biology and sediments including coastal erosion. The objective is to form the new generation of ocean scientists (some of whom may become involved in running of the PIRATA) and to build capacity in local institutions and for research and commercial collaborations. It also aims to raise consciousness at all levels concerning the important environmental challenges presently facing the region and strongly influencing future growth and development. This program was the first international diploma in Oceanography to be twinned between an African and a European university, and can claim the first Master level qualifications in physical oceanography delivered to women in West and Central Africa. Over the last 9 years, about 90 students from 9 countries of which 30 are either currently studying for or already gained a PhD. Of the 60 students for which we have information, all are either in employment or further education. The doctoral students have spread to all Atlantic boarding continents, working in Benin, Ivory Coast, Cameroon, Senegal, South Africa, France, Germany, Brazil and Canada, and this master's program is regularly assessed and is currently evolving into an international cooperation between Benin, France, Brazil, continuing to reinforce north-south links and developing south-south partnerships, perfectly in phase with the "Belem Statement on Atlantic Research and Innovation Cooperation" (see https://www.atlanticresource.org/aora/belem-statement) and some of the EU PREFACE and AtlantOS program objectives. Until now, UFPE funded and supervised up to 5 PhD and 2 post docs on PIRATA related scientific topics. At now, in addition to many Master 2 training periods works related to the Tropical Atlantic Ocean, up to 15 PIRATA related peer reviewed publications (see PIRATA references and figure in annex) were done by former students of this West African Master during their PhD or post docs, attesting this program success. It seems important now to find other funding resources to maintain this effort on a longer term!

Summer schools were organized, linked to the EU FP7 PREFACE project and PIRATA, during which several African students could benefit from training on Tropical Atlantic issues or using PIRATA data. Two summer schools on "Remote Sensing and its Oceanographic Applications" were organized by IRD, through a local IRD research and capacity building program called TOMATO ("TélédétectiOn et MAThématiques pour l'Océan", 2014-2016), and held on 18th-24th October 2014 and on 11-17th October 2015 in Cotonou (Benin) at ICMPA. Also linked to the EU FP7 PREFACE project and PIRATA, the Nansen Tutu Center organized a summer school in December 2014 in Cape Town (South Africa), with a focus on the Benguela upwelling system and the Tropical Atlantic.

The last PIRATA 22 meeting, organized along with PREFACE in Fortaleza (Brazil) in November 5-10, 2017, also corresponded to the 20th anniversary of the PIRATA program and was thus an opportunity to organize a dedicated "summer school" intended for students and young scientists. This summer school was sponsored and organized by the Copernicus Marine Environment Monitoring Service (CMEMS), with a local contribution by LABOMAR, FUNCEME and UFPE. Lectures were ensured by people from CMEMS and MERCATOR-Ocean group, and by PIRATA partners (from IRD, France; NOAA/AOML, USA; IOUSP/LABOMAR, DHN a,d University de Rio de Janeiro, Brazil; University of Cape Town, South-Africa). Up to 44 students and young scientists attended, mostly from Brazil but also from Benin, Côte d'Ivoire and Cameroon, who could be familiarized with tropical

Atlantic climate, circulation and observing system, operational oceanography, regional and global reanalyses, and other topics.

Also, PIRATA cruises are opportunity for training young scientists to operations at sea and data acquisition and treatment. Particularly, the French PIRATA (and associated EGEE) cruises allowed to about 30 African scientists or students to participate until 2014. Due to piracy activities in the Gulf of Guinea, the cruises are tentatively no more allowed to stop in any port of this area from 2015. Young scientists and African students (during their PhD or post docs at UFPE, Recife) are also invited to actively participate to Brazilian cruises. PNE cruises carried out in collaboration with the AEROSE program (see http://ncas.howard.edu/research-programs/aerose/) also allow training in shipboard measurements for a significant number of students and young scientists.

## 5 Requirements and vision for PIRATA Observing System

PIRATA was established 20 years ago and has been a great success story in ocean observing. The PIRATA partners established a stable, sustained ocean observing system that has evolved with time to address changing scientific priorities and to take advantage of new technological advances. The array, established at a time when there was virtually no in situ observing system in the tropical Atlantic outside of a few XBT lines, has served as a nucleus for an integrated multi-platform observing system that includes Argo, the global drifter program (GDP), and GO-SHIP lines, among other sustained observing system elements. Through its yearly servicing cruises, PIRATA has helped to build other observing system components as well like Argo and the GDP by offering opportunities for equipment deployments. PIRATA buoys and yearly cruises have also enabled process and pilot studies by providing platforms for other types of sensors and experiments proposed by other projects and approved by the PIRATA partners (SSG and PRB) based on their scientific value and technical feasibility. For instance, the PIRATA-BR XVII cruise onboard of the Brazilian RV Vital de Oliveira opened room for 11 research projects from Brazilian Universities and Research Institutes; and was a GEOTRACES endorsed cruise. It sampled the full ocean depth (at 10 m of the ocean bottom) from 15°N, 38°W to 20°S, 350W at every degree of latitude.

Looking forward, we believe PIRATA should continue to develop effective strategies for a sustained, multidisciplinary and integrated ocean observations in support of research, operational forecasting, and climate assessments for the benefit of society. We have several specific recommendations outlined in this section that provide our vision for how to accomplish that in the context of the overall integrated satellite and in situ Tropical Atlantic Ocean Observing System. Our recommendations build on the successes of PIRATA, the advantages of moored buoys systems for ocean-atmosphere interactions studies, and the unique partnership that has sustained the PIRATA array for the past 20 years.

First and foremost, it is essential to continue the long time series at the mooring sites that have already been established in PIRATA. The records at these sites are now long enough to study not only intraseasonal to interannual time scale variability, which were the original targets of array when it was first put in place, but now also decadal variability and climate change. The value of these time series will increase with time as the records get longer to reveal how natural variability across a wide spectrum of time scales in the tropical Atlantic is affected by a changing background state (e.g. Servain et al. 2014) and how variability and trends affect the climate system.

Beyond sustaining the moored time series at sites that have already been established and are producing invaluable data for the past two decades, we see several enhancements to the existing array. These are: 1) adding more instrumentation in the near surface layer to better define mixed layer structures, processes, and ocean-atmosphere feedbacks; 2) multi-disciplinary enhancements for carbon cycle and biogeochemical studies; and 3) expanding the array to regions that are presently undersampled by moored time series and that would benefit from high temporal resolution, multi-variate, and multi-disciplinary sustained time series. We describe these enhancements in more detail below.

Key questions have been evidenced related to the tropical Atlantic mixed layer heat budget, suggesting future directions for related research, are:

- The quantification of the impacts of diurnal and intraseasonal variability on equatorial turbulent mixing and SST fluctuations.
- The confirmation of significant seasonal cycles of turbulent cooling inferred from heat budget residuals at off-equatorial locations and the diagnosis of their causes.
- The precise role of mixed layer dynamics (changes in MLD, thermocline depth) for the off-equatorial interannual variations in SST.
- The precise impact of salinity stratification on turbulent mixing in regions of river outflow and strong precipitation.

Observational programs already underway in the tropical Atlantic will help to address some of these goals. These include moored microstructure measurements from equatorial PIRATA moorings, additional salinity sensors on PIRATA moorings in the western tropical Atlantic, and a process study involving deployment of 10 current meters in the upper 100 m on the 4ºN, 23ºW PIRATA mooring. However, additional sustained measurements of salinity, temperature, and velocity in the upper 100 m at selected locations will be needed for a comprehensive analysis of the mixed layer heat budget on diurnal to intraseasonal timescales. The most beneficial locations for enhanced salinity measurements are in the ITCZ region and eastern equatorial Atlantic, where heavy rainfall and river outflow contribute to strong near-surface salinity stratification. Additional velocity measurements may be most useful in the upper 30 m at 0º, 23ºW, given uncertainties in the magnitude of zonal heat advection; and in the ITCZ region and trade wind regimes of both hemispheres, where there are noticeable location-to-location differences in vertical turbulent cooling inferred from heat budget residuals.

In the same way, key questions have arisen related to the tropical Atlantic mixed layer salinity budget, suggesting future directions for related research:

- To improve estimates of horizontal advection of mixed layer salinity, given its importance in regions of high salinity variability.
- The quantify contributions from vertical turbulent mixing to mixed layer salinity and the impacts of the barrier layer formation.
- To determine the relative roles of ocean circulation, river outflow, and evaporation minus precipitation for interannual variations of SSS.

As for the mixed layer heat budget, observational programs already underway in the tropical Atlantic will help to address some of these goals. Additional salinity and velocity measurements in the upper 100 m on PIRATA moorings will likely be most beneficial for closing the salinity budget, as for example at 6°S, 8°E where the Congo River outflow induces strong vertical stratification with impacts on local and regional circulation, mixing, and SST.

The need for biogeochemical measurements is 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). Some PIRATA buoys are already equipped with $CO_2$ and $O_2$ sensors though more of these and other biogeochemical sensors would be very valuable. For example, although the western tropical/equatorial Atlantic does not exhibit an oxygen minimum zone, like on the eastern side, Argo floats $O_2$ data from 2014 to present indicates that, for this area, one may find low oxygen layers in intermediate waters (Argo, 2000). Although the intermediate water is not hypoxic, oxygen saturation levels reach 20%. What establishes these features? Are they related to the highly productive Amazon plume and/or to the current system? Thus, additional $O_2$ measurements in the area of the South West PIRATA extension could be envisioned to address these issues.

Likewise, enhancing ocean surface $pCO_2$ measurements on the PIRATA buoys would improve the knowledge of tropical Atlantic air-sea $CO_2$ fluxes, the region's $CO_2$ flux influence on the global carbon budget, and the behaviour of ocean biogeochemistry under increasing levels of atmospheric $CO_2$. More $CO_2$ measurements, particularly in the western part of the PIRATA array, will link the programme to the international SOLAS project (www.solas-int.org), to the regional (and primarily coastal) initiatives on ocean acidification (OA) studies. These studies include BrOA – Brazilian OA network (www.broa.furg.br), and LAOCA – Latin American OA network (www.laoca.cl), and the global initiatives, GOA-ON and SOCAT.

Also, in order to document surface ocean acidification (OA) trends, it is necessary to monitor 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). At present, there are available commercially autonomous sensors for $fCO_2/pCO_2$ and pH that are already used in combination by NOAA through their Ocean Acidification buoys, e.g. the RAMA Bay of Bengal Ocean Acidification (BOBAO) mooring. Similar capabilities should be introduced into PIRATA.

PIRATA also provides opportunities for collaborative studies involving "piggyback" operations sponsored by other groups or organizations, such as sediment trap deployments from PIRATA cruise to study downward particles fluxes or deep T/S measurements on moorings as promoted by the OceanSITES program. PIRATA has long history of working in collaboratively and welcomes further involvement of self-supported activities that are consistent with PIRATA's broad mission and technically feasible.

Geographical extension of the PIRATA buoy network can also be envisioned, through either new resource commitments by the partners and/or through the involvement of other partners and countries. In particular, observations are crucially needed in the South Atlantic where no time series and relatively few historical in situ measurements are available, particularly in the southeastern part of the basin (*e.g.* Zuidema et al. 2016). For example, new time series measurements would be especially valuable to accurately determine air-sea fluxes in the Saint-Helene anticyclone and to validate analysis/re-analysis products used for research and forecast model initialization.

The availability of ship time on research vessels capable of deep sea mooring operation to service the array is critical. Flexibility among ship operators to work together to ensure adequate and time ship time is essential to ensure the yearly mooring/repeat hydrography operations. Managing ship time for the core mooring activites and also for extra on board process studies that can be envisioned is an ongoing major challenge.

The impact of PIRATA buoys and other open ocean data in operational systems was addressed by Cummings and Smedsta (2014) who studied the impact of the assimilation of various operational observing systems on reducing HYCOM 48-h forecast error. They first showed that forecast error and data impact results clearly indicate that global HYCOM forecast errors are greatest in the tropics, especially for salinity. They particularly noted that the impacts of Argo and the tropical fixed mooring arrays are equivalent and can be considered complementary when initializing ocean forecast models. Argo samples deeper with improved vertical resolution, but fixed moorings observe more frequently and have the potential for direct measurements of other variables that can be used in ocean model assimilation (ocean currents) and air/sea coupling (meteorological variables such as air temperature and wind speed). Another advantage of the moorings is that they can resolve the high frequency components of oceanic and atmospheric variability that are missed by Argo and other measurement systems that measure less often in time.

In a similar way, going-on studies are carried out in the framework of the EU AtlantOS program to assess the impact of near real-time in-situ observations (physical and biogeochemical) for model validation and for data assimilation with different monitoring systems and in different context: i) Global ocean short term monitoring and forecasting systems and ii) Ocean-atmosphere seasonal forecasting system. In France and within the MERCATOR Ocean team, such an analysis focuses particularly on Argo profilers, drifters and PIRATA moorings in the Tropical Atlantic. Goal is to also identify the important ocean regions to observe in order to reduce the error forecast for coupled seasonal prediction. First preliminary results obtained through the thermocline (20°C) depth as ocean variable suggest that, while assimilation of Argo data appears to be important related to moorings and CTD/XBT profiles as deduced from absolute differences between simulations, the individual and regional impact of moorings is important. Moorings measurements appear crucial for validation and calibration of operational systems (accuracy and interannual trends) over long time periods and for reanalysis, and PIRATA buoys data sets are critical for assimilation and independent validation. The key issue is to gain a better benefice of buoys data, through the evolution of data assimilation schemes (Remy and Gasparin, personal communication).

In Brazil, a preliminary Observing System Experiment to evaluate the importance of PIRATA data to the Oceanographic Modeling and Observation Network (REMO) ocean data assimilation system and HYCOM has been initiated. At this step, it assimilates SST, SLA, Argo T/S, and only recently it can assimilate XBT and PIRATA data using synthetic S. First results suggest that OSE with PIRATA needs longer assimilation run to better show the impact of PIRATA data, but clearly show that locally the impact of PIRATA T and mostly S measurements is substantial (Tanajura, personal communication).

To address the impact of PIRATA surface buoys pressure data on weather forecasts, a specific study by Poli (2018) revealed that the collection of surface pressure data from moored and drifting buoys in the Tropical Atlantic delivers valuable benefits to global weather predictions in the tropical Atlantic. Using the same approach as Cardinali (2009), *i.e.* an adjoint-based Forecast Sensitivity Observation Impact applied to the operational ECMWF system, Poli found that the impact factor of PIRATA observations of surface pressure at around 110. This value is less than for the average of drifting buoys reporting surface pressure in the vicinity (128), or drifting buoys on the surface of the globe (over 400, most platforms being away from the Tropics). This result is consistent with the wise meteorological expectation that surface pressure observations have comparatively less impact when collected near the equator than in the mid-latitudes. However, this number still exceeds that obtained for all other components of the global observing system. For comparison, over the same time period and in the same global prediction system, the impact factor for other surface marine observations is around 5, while the impact factor is near 4 for surface land-based observing systems, around 2 for upper-air observing systems (including aircraft and radiosondes), and around 0.8 for satellites, in spite the fact that the observations assimilated operationally by ECMWF come from (in decreasing order) satellites, upper-air (radiosondes, aircraft), land-surface, and sea-surface.… These results clearly suggest that the collection of surface pressure data from moored (PIRATA) and drifting (DBCP) buoys in the Tropical Atlantic delivers valuable benefits to global weather predictions. This confirms the results by Centurioni et al. 2017, using the same methodology to show the importance of sea surface pressure data from drifters for forecast systems, especially in regions where no other in situ observations are available.

## 6 Conclusions

Since 1997, PIRATA partners have established and efficiently sustained a moored buoy network in the tropical Atlantic to support research, operational analyses and forecasting, and climate assessments. PIRATA has vastly increased the amount of data available from the tropical Atlantic, not only from the moorings themselves, but also from the cruises that allow for the collection of specialized shipboard data and for the deployment of floats, drifters, and XBTs that help build other components of the ocean observing system. PIRATA data have proven to be valuable for constraining oceanic and atmospheric reanalysis products and for satellite validation, and for development of new in situ and/or satellite/in situ data products. PIRATA data and data products are readily available through the Global Data Centers (Coriolis/IFREMER in France and NDBC/NOAA in the USA) and from other dedicated web databases (PIRATA, TACE, PREFACE, and others). The mooring data are also transmitted to operational centers worldwide via the Global Telecommuncations System for weather, climate, and ocean forecasting.

The long records now available from PIRATA moorings allow for studies of decadal variability and climate change, extending beyond the original intraseasonal to interannual time scale focus of the array. The very high frequency (minutes to hours) buoy measurements on the other hand allow for studies of the diurnal cycle and its interactions with lower frequencies, short time scale Kelvin waves propagation, instability wave dynamics, and other modes of high frequency variability. PIRATA's multi-decade, multi-variate, high temporal resolution records of oceanic and surface atmospheric variables are a unique and valuable contribution to the Global Ocean Observing System (GOOS) and the Global Climate Observing System (GCOS) in the tropical Atlantic (*e.g.* Legler et al. 2015). The moorings and the ships used in the program have in addition served as valuable platforms of opportunity for other programs to study, for example, ocean mixing, ocean biogeochemistry, oxygen and carbon cycle processes, and marine animal behavior.

PIRATA has also efficiently contributed to capacity building in developing countries bordering the tropical Atlantic. Graduates of the Master2 program initiated in 2008 in Benin West Africa, include about 30 doctoral students who have spread to both sides of the Atlantic (Benin, Ivory Coast, Cameroon, Senegal, South Africa, France, Germany, Brazil and Canada).

This Master's program is currently evolving into an international cooperation between Benin, France and Brazil, continuing to reinforce north-south links and developing south-south partnerships, as envisioned with the "Belem Statement".

As described above, PIRATA could be more effective and relevant to a broader range of scientific problems through targeted enhancements that include higher vertical resolution T/S and more velocity measurements in the mixed layer, more biogeochemical and carbon cycle measurements, and filling observational gaps in the array. Studies are presently going on to determine the complementarity of data sets for reanalysis of T, S, current, and other fields. Also, OSEs and OSSEs are going on, notably in the framework of the EU AtlantOS project that will provide important information on the relative merits of potential priority enhancements in PIRATA (additional ocean sensors, new parameters to measure, etc). These enhancements would require new resources from the existing partner nations supporting the array and/or involvement of additional partners and programs. A *sine qua non* for moving forward however is our assertion that the existing array of 18 well-functioning and well-supported sites be the starting point for discussion of any enhancements.

PIRATA data are supplied in real-time to customers in operational weather, climate, and ocean services. However, quantifying the potential economic value of the mooring data to society, whether independent of, or together with, other data sources in the Tropical Atlantic Observing System, is a challenge. We know that oceanic and atmospheric measurements are essential for assessing the impacts of ocean warming, sea level rise, extreme weather events, deoxygenation, ocean acidification, marine ecosystems, living marine resources, and pollution (*e.g.* Schiller et al. 2016). The methods by which one quantitatively gauges the economic value of a particular observing system component, however, is subjective at best. End users in society typically see a product that includes many different data sets assimilated into a model analysis and forecast system. The value of that product depends not just on the data that goes into it, but the quality of the models and assimilation systems used. In addition, data may be used in model development independent of any specific product delivered to users. So while it is important to pose the question of "what is the economic value proposition" for PIRATA data, it is very difficult to come up with a credible answers at this point in time given the state of the art in data assimilation, ocean-atmosphere modeling, and operational forecasting.

We can nonetheless claim that since inception, PIRATA has fundamentally advanced our understanding of large scale ocean dynamics, ocean-atmosphere interactions, and the tropical Atlantic Ocean's role in climate. It has also supported building other components of the GOOS and GCOS like Argo and the GDP and it feeds data every day in real-time to operational weather, climate and ocean forecasting centers around the world. Finally, it has supported ocean and coupled ocean-atmosphere model development, satellite validation, and development of a wide range of oceanic and atmospheric products that are used extensively around the world. It has achieved this success because PIRATA leadership has continuously evolved the array to keep pace with changing scientific priorities and taken advantage of new technologies as they become available; and because the program is well managed with a stable base of support in three countries.

## References (used in the text):

Argo, 2000. Argo float data and metadata from Global Data Assembly Centre (Argo GDAC). *SEANOE*. http://doi.org/10.17882/42182

Ascani, F., E. Firing, J. P. McCreary, P. Brandt, and R. J. Greatbatch, 2015: The deep equatorial ocean circulation in wind-forced numerical solutions. *J. Phys. Oceanogr.*, 45, 1709-1734, doi:10.1175/JPO-D-14-0171.1

Athie, G., F. Marin, A.-M. Treguier, B. Bourlès and C. Guiavarc'h, 2009: Sensitivity of near surface Tropical Instability Waves to sub-monthly wind forcing in the tropical Atlantic. *Ocean Modelling*, 30, 241-255.

Balmaseda, M.A., F. Hernandez, A. Storto, M.D. Palmer, O. Alves, L. Shi, G.C. Smith, T. Toyoda, M. Valdivieso da Costa, B. Barnier, D.W. Behringer, T.P. Boyer, Y.-S. Chang, G.A. Chepurin, N. Ferry, G. Forget, Y. Fujii, S. Good, S. Guinehut, K. Haines, Y. Ishikawa, S. Keeley, A. Köhl, T. Lee, M. Martin, S. Masina, S. Masuda, B. Meyssignac, K. Mogensen, L. Parent, A.K. Peterson, Y.M. Tang, Y. Yin, G. Vernieres, X. Wang, J. Waters, R. Wedd, O. Wang, Y. Xue, M. Chevallier, J.-F. Lemieux, F. Dupont, T. Kuragano, M. Kamachi, T. Awaji, A.C. Caltabiano, K. Wilmer-Becker, and F. Gaillard, 2015: The Ocean Reanalyses Intercomparison Project (ORA-IP), *Journal of Operational Oceanography*, 8:sup1, s80-s97, 10.1080/1755876X.2015.1022329.

Berger, H., A. M. Treguier, N. Perenne, and C. Talandier, 2014: Dynamical contribution to sea surface salinity variations in the eastern Gulf of Guinea based on numerical modelling. *Clim. Dyn.*, 43, 3105-3122, doi:10.1007/s00382-014-2195-4.

Blockley, E.W., M.J. Martin, A.J. McLaren, A.G. Ryan, J. Waters, D.J. Lea, I. Mirouze, K.A. Peterson, A. Sellar, and D. Storkey, 2014: Recent development of the Met Office operational ocean forecasting system: an overview and assessment of the new Global FOAM forecasts, *Geosci. Model Dev.*, 7 (6), 2613-2638, 10.5194/gmd-7-2613-2014.

Bonou, F.K., Noriega, C., Lefèvre, N., Araujo, M., 2016. Distribution of $CO_2$ parameters in the Western Tropical Atlantic Ocean. *Dynamics of Atmospheres and Oceans*, 73, 47-60.

Bourlès, B., A. J. Busalacchi, E. Campos, F. Hernandez, R. Lumpkin, M.J. McPhaden, A.D. Moura, P. Nobre, S. Planton, J. Servain and J. Trotte, PIRATA (*Pilot Research Moored Array in the Tropical Atlantic*): Accomplishments of PIRATA: 1997-2005, Status and perspectives, *Document prepared for a PIRATA review by CLIVAR -AIP - and OOPC*, 89 p., April 2006.

Bourlès, B., P. Brandt, G. Caniaux, M. Dengler, Y. Gouriou, E. Key, R. Lumpkin, F. Marin, R.L. Molinari, C. Schmid. 2007, African Monsoon Multidisciplinary Analysis (AMMA): Special measurements in the Tropical Atlantic, *CLIVAR Exchanges Letters, 41 (Vol. 12, n°2), 7-9.*

Bourlès, B., R. Lumpkin, M. J. McPhaden, F. Hernandez, P. Nobre, E. Campos, L. Yu, S. Planton, A. J. Busalacchi, A. D. Moura, J. Servain and J. Trotte, 2008: The PIRATA Program: History, Accomplishments, and Future Directions. *Bulletin of the American Meteorological Society*, 89 (8), http://dx.doi.org/10.1175/2008BAMS2462.1.

Bourlès, B., P. Freitag, and M. McPhaden. 2008, Moored buoy networks: the key to understanding the tropical Oceans, *Argos Forum #67*.

Bourlès, B., 2016, *PREFACE EU FP7 603521 Deliverable 3.2* "Enhancing prediction of tropical Atlantic climate and its impacts: Report air-sea interactions".

Bourlès, B., P. Brandt and N. Lefèvre, 2017, *AtlantOS EU H2020 633211 Deliverable 3.3* "Enhancement of autonomous observing networks: PIRATA network improvement report".

Boutin, J., Y. Chao, W. Asher, T. Delcroix, R. Drucker, K. Drushka, N. Kolodziejczyk, T. Lee, N. Reul, G. Reverdin, J. Schanze, A. Soloviev, L. Yu, J. Anderson, L. Brucker, E. Dinnat, A. Santos-Garcia, W. Jones, C. Maes, T. Meissner, W. Tang, N. Vinogradova, and B. Ward, 2016: Satellite and In Situ Salinity: Understanding Near-Surface Stratification and Sub-footprint Variability. *Bull. Amer. Meteor. Soc.*, http://dx.doi.org:/10.1175/BAMS-D-15-00032.1

Bowman, K. P., C. R. Homeyer and D. G. Stone, 2009: A Comparison of Oceanic Precipitation Estimates in the Tropics and Subtropics. *J. Appl. Meteor. Climatol.*, 48, 1335–1344, http://dx.doi.org/10.1175/2009JAMC2149.1.

Brandt, P., V. Hormann , B. Bourlès, J. Fischer , F. Schott , L. Stramma , M. Dengler, 2008: Oxygen tongues and zonal currents in the equatorial Atlantic, *J. Geophys. Res.*, 113, C04012, doi:10.1029/2007JC004435.

Brandt, P., G. Caniaux, B. Bourlès, A. Lazar, M. Dengler, A. Funk, V. Hormann, H. Giordani and F. Marin, 2011: Equatorial upper-ocean dynamics and their interaction with the West African Monsoon. *Atmospheric Science Letters*, 12, 24-30, http://dx.doi.org/10.1002/asl.287.

Brandt, P., A. Funk, V. Hormann, M. Dengler, R. J. Greatbatch, J. M. Toole, 2011: Interannual atmospheric variability forced by the deep equatorial Atlantic Ocean, *Nature*, 473, 497-500, doi: 10.1038/nature10013.

Brandt, P., R. J. Greatbatch, M. Claus, S.-H. Didwischus, V. Hormann, A. Funk, J. Hahn, G. Krahmann, J. Fischer, and A. Körtzinger, 2012: Ventilation of the equatorial Atlantic by the equatorial deep jets, *J. Geophys. Res*., 117, C12015, doi:10.1029/2012JC008118.

Brandt, P., A. Funk, A. Tantet, W. E. Johns and J. Fischer, 2014: The Equatorial Undercurrent in the central Atlantic and its relation to tropical Atlantic variability. *Clim. Dyn*., 43 (11), 2985-2997, http://dx.doi.org/10.1007/s00382-014-2061-4.

Brandt, P., H. W. Bange, D. Banyte, M. Dengler, S. H. Didwischus, T. Fischer, R. J. Greatbatch, J. Hahn, T. Kanzow, J. Karstensen, A. Körtzinger, G. Krahmann, S. Schmidtko, L. Stramma, T. Tanhua, and M. Visbeck, 2015: On the role of circulation and mixing in the ventilation of oxygen minimum zones with a focus on the eastern tropical North Atlantic, *Biogeosciences*, 12, 489–512, https://doi.org/10.5194/bg-12-489-2015.

Brandt, P., M. Claus, R. J. Greatbatch, R. Kopte, J. M. Toole, W. E. Johns, and C. W. Böning, 2016: Annual and semi-annual cycle of equatorial Atlantic circulation associated with basin mode resonance. *J. Phys. Oceanogr*., 46, 3011–3029, http://dx.doi.org/10.1175/JPO-D-15-0248.1.

Brassington, G.B., M.J. Martin, H.L. Tolman, S. Akella, M.A. Balmaseda, C.R.S. Chambers, E. Chassignet, J.A. Cummings, Y. Drillet, P.A.E.M. Jansen, P. Laloyaux, D.J. Lea, A. Mehra, I. Mirouze, H. Ritchie, G. Samson, P.A. Sandery, G.C. Smith, M. Suarez, and R. Todling, 2015: Progress and challenges in short- to medium-range coupled prediction, *Journal of Operational Oceanography*, 8 (sup2), s239-s258, 10.1080/1755876X.2015.1049875.

Bruto, L., A. Moacyr, C. Noriega, D. Veleda, and N. Lefèvre, 2017: Variability of CO2 fugacity at the western edge of the tropical Atlantic Ocean from the 8°N to 38°W PIRATA buoy. *Dyn. Atmos. Oceans*, 78, 12017, http://doi.org/10.1016/j.dynatmoce.2017.01.003.

Bunge, L., C. Provost, B.L. Hua, and A. Kartavtseff, 2008: Variability at intermediate depths at the equator in the Atlantic Ocean in 2000–06: annual cycle, equatorial deep jets, and intraseasonal meridional velocity fluctuations. *J. Phys. Oceanogr*., 38, 1794–1806. doi:10.1175/2008JPO3781.1.

Burmeister, K., P. Brandt, and J. F. Lübbecke, 2016: Revisiting the cause of the eastern equatorial Atlantic cold event in 2009. *J. Geophys. Res. Oceans*, 121, 4777–4789, http://dx.doi.org/10.1002/2016JC011719.

Cabanes, C., A. Grouazel, K. von Schuckmann, M. Hamon, V. Turpin, C. Coatanoan, F. Paris, S. Guinehut, C. Boone, N. Ferry, C. de Boyer Montégut, T. Carval, G. Reverdin, S. Pouliquen, and P.-Y. Le Traon, 2013: The CORA dataset: validation and diagnostics of in-situ ocean temperature and salinity measurements, *Ocean Sci*., 9 (1), 1-18, 10.5194/os-9-1-2013.

Camara, I., N. Kolodziejczyk, J. Mignot, A. Lazar, and A. T. Gaye, 2015: On the seasonal variations of salinity of the tropical Atlantic mixed layer. *J. Geophys. Res*., 120, 4441-4462, doi:10.1002/2015JC010865.

Campos, E., C.A.S. França, N. Vicentini, L. Francisco, L.V. Nonnato, A.R. Piola, L. Barreira, R. Cole, P. Nobre, and J. Trotte-Durha, 2014. Atlas-B: Development and Testing of a Brazilian Deep- Ocean Moored Buoy for Climate Research. *J. Shipping and Ocean Engineering*, v. 2, p. 11-20.

Caniaux, G., H. Giordani, J.L. Redelsperger, F. Guichard, E. Key, and M. Wade, 2011: Coupling between the Atlantic Cold Tongue and the West African Monsoon in boreal Spring and Summer. *J. Geophy. Res.*, 116, C04003, http://dx.doi.org/10.1029/2010JC006570

Cardinali, C., 2009: Monitoring the observation impact on the short-range forecast. *Q.J.R. Meteorol. Soc.*, 135: 239–250. doi:10.1002/qj.366

Carton, J. A., and Z. X. Zhou, 1997: Annual cycle of sea surface temperature in the tropical Atlantic Ocean. *J. Geophys. Res*., 102, 27,813-27,824.

Castellanos, P., E. Campos, I. Giddy and W. Santis, 2016: Inter-comparison studies between high-resolution HYCOM simulation and observational data: the South Atlantic and the Agulhas Leakage system. *J. Mar. Sys.*, 159, 76-88, doi: 10.1016/j.jmarsys.2016.02.010.

Castellanos, P., E.J.D. Campos, J. Piera, O.T. Sato and M.A.F. Silva Dias, 2017: Impacts of the Agulhas Leakage on the Tropical Atlantic Western Boundary Systems. *J. Clim.* Vol. 30, pp. 6645 – 6659, doi:10.1175/JCLI-D-15-087.s1.

Centurioni, L., A. Horanyi, C. Cardinali, E. Charpentier, and R. Lumpkin, 2017: A Global Ocean Observing System for Measuring Sea Level Atmospheric Pressure: Effects and Impacts on Numerical Weather Prediction. Bull. Amer. Meteor. Soc. doi:10.1175/BAMS-D-15-00080.1.

Chang, P., T. Yamagata, P. Schopf, S.K. Behera, J. Carton, W.E. Kessler, G. Meyers, T. Qu, F. Schott, S. Shetye, and S.P. Xie, 2006: Climate fluctuations of Tropical Coupled Systems – The Role of Ocean Dynamics. *J. Climate (Special Section),* 19, 5122-5174, http://dx.doi.org/10.1175/JCLI3903.1.

Claus, M., R. J. Greatbatch, P. Brandt and J. M. Toole, 2016: Forcing of the Atlantic equatorial deep jets derived from observations, *J. Phys. Oceanogr.*, 46, 3549-3562, doi: 10.1175/JPO-D-16-0140.1.

Clayson, C.A., and D. Weitlich, 2007: Variability of tropical diurnal sea surface temperature. *J. Climate*, 20, 334-352, http://dx.doi.org/10.1175/JCLI3999.1.

Cole, R., L. Barreira, and E. Campos, 2013. Development and Deployment of Brazil's First Buoy System. *Marine Technology Reporter*, 46-51.

Coles, V. J., M. T. Brooks, J. Hopkins, M. R. Stukel, P. L. Yager, and R. R. Hood, 2013: The pathways and properties of the Amazon River Plume in the tropical North Atlantic Ocean. *J. Geophys. Res*., 118, doi:10.1002/2013JC008981.

Cummings, J.A. and O. M. Smedstadt, 2014, Ocean Data Impacts in Global HYCOM, *J. Atmos. Ocean. Technol*., doi:10.1175/JTECH-D-14-00011.1

Da-Allada, C. Y., G. Alory, Y. du Penhoat, E. Kestenare, F. Durand, and N. M. Hounkonnou, 2013: Seasonal mixed-layer salinity balance in the tropical Atlantic Ocean: Mean state and seasonal cycle. *J. Geophys. Res*., 118, 332-345, doi:10.1029/2012JC008357.

Da-Allada, C. Y., G. Alory, Y. du Penhoat, J. Jouanno, N. Hounkonnou, and E. Kestenare, 2014: Causes for the recent increase for sea surface salinity in the northeast Gulf of Guinea. *African J. of Mar. Science*, 36 (2): 197–205, http://dx.doi.org/10.2989/1814232X.2014.927398.

Da-Allada, C. Y., Y. du Penhoat, J. Jouanno, G. Alory, and N. M. Hounkonnou, 2014: Modeled mixed-layer salinity balance in the Gulf of Guinea: seasonal and interannual variability. *Ocean Dyn*., 64, 1783-1802, doi:10.1007/s10236-014-0775-9.

Da-Allada, C. Y., J. Jouanno, F. Gaillard, N. Kolodziejczyk, C. Maes, N. Reul, and B. Bourlès, 2017: Importance of the Equatorial Undercurrent on the sea surface salinity in the eastern equatorial Atlantic in boreal spring. *J. Geophys. Res. Oceans*, 122, 521–538, http://dx.doi.org/10.1002/2016JC012342.

De Coëtlogon G, Janicot S, Lazar A. 2010. Intraseasonal variability of the ocean – atmosphere coupling in the Gulf of Guinea during boreal spring and summer. *Quarterly Journal of the Royal Meteorological Society* 136: 426–441. DOI:10.1002/qj.554.

Doi, T., T. Tozuka and T. Yamagata, 2010: The Atlantic Meridional Mode and Its Coupled Variability with the Guinea Dome. *J. Climate*, 23, 455–475, http://dx.doi.org/10.1175/2009JCLI3198.1.

Fischer, T., D. Banyte, P. Brandt, M. Dengler, G. Krahmann, T. Tanhua, and M. Visbeck, 2013: Diapycnal oxygen supply to the tropical North Atlantic oxygen minimum zone, *Biogeosciences*, 10, 5079–5093, https://doi.org/10.5194/bg-10-5079-2013.

Florenchie, P., J. R. E. Lutjeharms, C. J. C. Reason, S. Masson, and M. Rouault, 2003: The source of Benguela Niños in the South Atlantic Ocean. *Geophys. Res. Lett.*, 30, 10–13, doi:10.1029/2003GL017172.

Foltz, G. R., S. A. Grodsky, J. A. Carton, and M. J. McPhaden, 2003: Seasonal mixed layer heat budget of the tropical Atlantic Ocean. J. Geophys. Res., 108, 3146, doi:10.1029/2002JC001584.

Foltz, G.R. and M.J. McPhaden, 2006a: The role of oceanic heat advection in the evolution of tropical North and South Atlantic SST anomalies. *J. Climate, 19,* 6122-6138.

Foltz, G.R. and M.J. McPhaden, 2006b: Unusually warm sea surface temperatures in the tropical North Atlantic during 2005. *Geophys. Res. Lett., 33,* L19703, doi:10.1029/2006GL027394.

Foltz, G. R., and M. J. McPhaden, 2008: Seasonal mixed layer salinity balance of the tropical North Atlantic Ocean. *J. Geophys. Res. Oceans*, 113, C02013, doi:10.1029/2007JC004178.

Foltz, G. R., and M. J. McPhaden, 2009: Impact of barrier layer thickness on SST in the central tropical North Atlantic. *J. Climate*, 22, 285-299.

Foltz, G., and M. J. McPhaden, 2010a: Abrupt equatorial wave-induced cooling of the Atlantic cold tongue in 2009. *Geophys. Res. Lett.*, 37 (24), http://dx.doi.org/10.1029/2010gl045522.

Foltz, G. R., and M. J. McPhaden, 2010b: Interaction between the Atlantic meridional and Nino modes. *Geophys. Res. Lett.*, L18604, http://dx.doi.org/10.1029/2010GL044001.

Foltz, G. R., M. J. McPhaden, and R. Lumpkin, 2012: A strong Atlantic Meridional Mode event in 2009: The role of mixed layer dynamics. *J. Climate*, 25, 363-380, doi: 10.1175/JCLI-D-11-00150.1.

Foltz, G. R., C. Schmid, and R. Lumpkin, 2013: Seasonal cycle of the mixed layer heat budget in the northeastern tropical Atlantic Ocean. *J. Climate*, 26, 8169-8188, doi:10.1175/JCLI-D-13-00037.1.

Foltz, G. R., C. Schmid, and R. Lumpkin, 2015: Transport of surface freshwater from the equatorial to the subtropical North Atlantic Ocean. *J. Phys. Oceanogr*., 45, 1086-1102, doi:10.1175/JPO-D-14-0189.1.

Foltz, G. R., C. Schmid, and R. Lumpkin, 2018: An enhanced PIRATA data set for tropical Atlantic ocean-atmosphere research. *J. Climate*, in press, doi:10.1175/JCLI-D-16-0816.1.

Fournier, S., D. Vandemark, L. Gaultier, T. Lee, B. Jonsson, and M. M. Gierach, 2017: Interannual variation in offshore advection of Amazon-Orinoco plume waters: Observations, forcing mechanisms, and impacts. *J. Geophys. Res*., 122, 8966-8982. doi:10.1002/2017JC013103.

Freeman, E., S. D. Woodruff, S. J. Worley, S. J. Lubker, E. C. Kent, W. E. Angel, D. I. Berry, P. Brohan, R. Eastman, L. Gates W. Gloeden, Z. Ji, J. Lawrimore, N. A. Rayner, G. Rosenhagen, and S. R. Smith, 2016: ICOADS Release 3.0: a major update to the historical marine climate record. *Int. J. Climatol*., http://dx.doi.org/10.1002/joc.4775.

Frölicher, T. L., F. Joos, G. K. Plattner, M. Steinacher, and S. C. Doney, 2009: Natural variability and anthropogenic trends in oceanic oxygen in a coupled carbon cycle-climate model ensemble, *Global Biogeochem. Cy*., 23, 15, GB1003, https://doi.org/10.1029/2008gb003316.

Gaillard, F., D. Diverres, S. Jacquin, Y. Gouriou, J. Grelet, M. Le Menn, J. Tassel and G. Reverdin, 2015. Sea surface temperature and salinity from French research vessels, 2001–2013. *Sci. Data* 2:150054 doi: 10.1038/sdata.2015.54.

Gehlen, M., N. Gruber, R. Gangstø, L. Bopp, and A. Oschlies, 2011: Biogeochemical consequences of ocean acidification and feedbacks to the earth system, in *Ocean Acidification, edited by J.-P. Gattuso, and L. Hansson, pp. 230-248, Oxford University Press*, Oxford, UK.

Gehlen, M., R. Barciela, L. Bertino, P. Brasseur, M. Butenschön, F. Chai, A. Crise, Y. Drillet, D. Ford, D. Lavoie, P. Lehodey, C. Perruche, A. Samuelsen, and E. Simon, 2015: Building the capacity for forecasting marine biogeochemistry and ecosystems: recent advances and future developments, *Journal of Operational Oceanography*, 8 (sup1), s168-s187, 10.1080/1755876X.2015.1022350.

Giarolla, E., P. Nobre, M. Malagutti, and P. Pezzi, The Atlantic Equatorial Undercurrent: PIRATA observations and simulations with GFDL Modular Ocean Model at CPTEC, 2005: *Geophys. Res. Lett.*, 32, L10617, http://dx.doi.org/10.1029/2004GL022206.

Giarolla, E., L. S. P. Siqueira, M. J. Bottino, M. Malagutti, V. B. Capistrano, and P. Nobre, 2015: Equatorial Atlantic Ocean dynamics in a coupled ocean–atmosphere model simulation. *Ocean Dynamics*, 65 (6), 831-843.

Giordani, H., G. Caniaux, and A. Voldoire, 2013: Intraseasonal mixed-layer heat budget in the equatorial Atlantic during the cold tongue development in 2006. J. Geophys. Res., 118, 650-671, doi:10.1029/2012JC008280.

Good, S. A., M. J. Martin, and N. A. Rayner, 2013: EN4: Quality controlled ocean temperature and salinity profiles and monthly objective analyses with uncertainty estimates, *J. Geophys. Res. Oceans*, 118, 6704–6716, doi:10.1002/2013JC009067.

Gouriou, Y., and Coauthors, 2001: Deep circulation in the equatorial Atlantic Ocean. *Geophys. Res. Lett*., 28, 819–822, doi:10.1029/2000GL012326.

Greatbatch, R. J., M. Claus, P. Brandt, J.-D. Matthießen, F. P. Tuchen, F. Ascani, M. Dengler, J. M. Toole, C. Roth and J. T. Farrar, 2017: Evidence for the maintenance of slowly varying equatorial currents by intraseasonal variability, *Geophys. Res. Lett*., submitted.

Grodsky, S. A., J. A. Carton, C. Provost, J. Servain, J. A. Lorenzzetti, and M. J. McPhaden, 2005: Tropical instability waves at 0°N, 23°W in the Atlantic: A case study using Pilot Research Moored Array in the Tropical Atlantic (PIRATA) mooring data, *J. Geophys. Res*., 110, C08010, doi:10.1029/2005JC002941.

Grodsky, S. A., J. A. Carton, and F. O. Bryan, 2014: A curious local surface salinity maximum in the northwestern tropical Atlantic. *J. Geophys. Res*., 484-495, doi:10.1002/2013JC009450.

Hahn, J., P. Brandt, S. Schmidtko, and G. Krahmann, 2017: Decadal oxygen change in the eastern tropical North Atlantic. *Ocean Sci*., 13, 551-576, https://doi.org/10.5194/os-13-551-2017.

Hastenrath, S., 1977: Hemispheric asymmetry of oceanic heat budget in the equatorial Atlantic and eastern Pacific. *Tellus*, 29, 523-529.

Helm, K. P., N. L. Bindoff, and J. A. Church, 2011: Observed decreases in oxygen content of the global ocean, *Geophys. Res. Lett*., 38, L23602, https://doi.org/10.1029/2011gl049513.

Henocq, C., J. Boutin, G. Reverdin, F. Petitcolin, S. Arnault and P. Lattes, 2010: Vertical Variability of Near-Surface Salinity in the Tropics: Consequences for L-Band Radiometer Calibration and Validation. *J. Atmos. Oceanic Technol*., 27, 192–209, http://dx.doi.org/10.1175/2009JTECHO670.1.

Herbert, G., B. Bourlès, P. Penven, and J. Grelet, 2016: New insights on the upper layer circulation north of the Gulf of Guinea. *J. Geophys. Res. Oceans*, 121, 6793–6815, http://dx.doi.org/10.1002/2016JC01195.

Hernandez, F., E. Blockley, G.B. Brassington, F. Davidson, P. Divakaran, M. Drévillon, S. Ishizaki, M. Garcia-Sotillo, P.J. Hogan, P. Lagemaa, B. Levier, M. Martin, A. Mehra, C. Mooers, N. Ferry, A. Ryan, C. Regnier, A. Sellar, G.C. Smith, S. Sofianos, T. Spindler, G. Volpe, J. Wilkin, E.D. Zaron, and A. Zhang, 2015: Recent progress in performance evaluations and near real-time assessment of operational ocean products, *Journal of Operational Oceanography*, 8 (sup2), s221-s238, 10.1080/1755876X.2015.1050282.

Hernandez, O., J. Jouanno, V. Echevin and O. Aumont, 2017: Modification of sea surface temperature by chlorophyll concentration in the Atlantic upwelling systems, *J. Geophys. Res. Oceans*, 122, 5367–5389, doi:10.1002/2016JC012330.

Hormann, V., and P. Brandt, 2007: Atlantic Equatorial Undercurrent and associated cold tongue variability, *J. Geophys. Res*., 112, C06017, doi:10.1029/2006JC003931.

Hormann, V. and P. Brandt, 2009: Upper equatorial Atlantic variability during 2002 and 2005 associated with equatorial Kelvin waves. *J. Geophys. Res.*, 114, C03007, http://dx.doi.org/10.1029/2008JC005101.

Hounsou-gbo, G. A., M. Araujo, B. Bourlès, D. Veleda, and J. Servain, 2015: Tropical Atlantic contributions to strong rainfall variability along the Northeast Brazilian coast. *Advances in Meteorology*, 2015, Article ID 902084, http://dx.doi.org/10.1155/2015/902084

Hu, Z-Z, A. Kumar, B. Huang, and J. Zhu, 2013: Leading Modes of the Upper-Ocean Temperature Interannual Variability along the Equatorial Atlantic Ocean in NCEP GODAS. *J. Climate*, 26, 4649–4663, http://dx.doi.org/10.1175/JCLI-D-12-00629.1.

Hummels, R., M. Dengler, and B. Bourlès, 2013: Seasonal and regional variability of upper ocean diapycnal heat flux in the Atlantic cold tongue, *Prog. Oceanogr*., 111, 52-74, doi:10.1016/j.pocean.2012.11.001.

Hummels, R., M. Dengler, P. Brandt, and M. Schlundt, 2014: Diapycnal heat flux and mixed layer heat budget within the Atlantic cold tongue. *Clim. Dyn*., 43, 3179-3199, doi:10.1007/s00382-014-2339-6.

Imbol Koungue, R. A., S. Illig, and M. Rouault, 2017: Role of interannual Kelvin wave propagations in the equatorial Atlantic on the Angola Benguela Current system. *J. Geophys. Res. Oceans*, 122, 4685–4703, http://dx.doi.org/10.1002/2016JC012463.

Jochum, M., B. Briegleb, G. Danabasoglu, W. Large, N. Norton, S. Jayne, M. Alford, and F. Bryan, 2013: The impact of oceanic near-inertial waves on climate. *J. Clim*., 26, 2833–2844.

Jochum, M., 2017, *PREFACE EU FP7 603521 Deliverable 3.3* “Enhancing prediction of tropical Atlantic climate and its impacts : Report on Near Inertial Waves”.

Johns, W. E., P. Brandt and P. Chang, 2014: Tropical Atlantic variability and coupled model climate biases: results from the Tropical Atlantic Climate Experiment (TACE). *Clim. Dyn*., 43 (11), 2887, http://dx.doi.org/10.1007/s00382-014-2392-1.

Johns, W. E., P. Brandt, B. Bourlès, A. Tantet, A. Papapostolou and A. Houk, 2014: Zonal Structure and Seasonal Variability of the Atlantic Equatorial Undercurrent. *Clim. Dyn*., 43 (11), 3047-3069, http://dx.doi.org/10.1007/s00382-014-2136-2.

Jouanno, J., F. Marin, Y. duPenhoat, J. Sheinbaum, and J. Molines, 2011: Seasonal heat balance in the upper 100 m of the Equatorial Atlantic Ocean. *J. Geophys. Res*., 116, C09003.

Jouanno, J., O. Hernandez, E. Sanchez-Gomez, and B. Deremble, 2017: Equatorial Atlantic interannual variability and its relation to dynamic and thermodynamic processes, 2017, *Earth Syst. Dynam.*, 8, 1061–1069, https://doi.org/10.5194/esd-8-1061-2017.

Kara, A. B., and C. N. Barron, 2007: Fine-resolution satellite-based daily sea surface temperatures over the global ocean. *J. Geophys. Res.*, 112, C05041, http://dx.doi.org/10.1029/2006JC004021.

Karstensen, J., L. Stramma, and M. Visbeck, 2008: Oxygen minimum zones in the eastern tropical Atlantic and Pacific oceans. *Progr. Oceanogr.*, 77, 331-350, https://doi.org/10.1016/j.pocean.2007.05.009 .

Karstensen, J., B. Fiedler, F. Schütte, P. Brandt, A. Körtzinger, G. Fischer, R. Zantopp, J. Hahn, M. Visbeck, and D. Wallace, 2015: Open ocean dead zones in the tropical North Atlantic Ocean, *Biogeosciences*, 12, 2597–2605, https://doi.org/10.5194/bg-12-2597-2015 .

Keeling, R. F., A. Körtzinger, and N. Gruber, 2010: Ocean deoxygenation in a warming world, *Annu. Rev. Mar. Sci.*, 2, 199–229, https://doi.org/10.1146/annurev.marine.010908.163855.

Koffi, U., N. Lefèvre, G. Kouadio, and J. Boutin, 2010: Surface $CO_2$ parameters and air-sea $CO_2$ flux distribution in the eastern equatorial Atlantic Ocean. *Journal of Marine Systems* 82, 135-144.

Kolodziejczyk, N., B. Bourlès, F. Marin, J. Grelet and R. Chuchla, 2009: The seasonal variability of the Equatorial Undercurrent and the South Equatorial Undercurrent at 10°W as inferred from recent in situ observations, *J. Geophys. Res.*, 114, C06014, http://dx.doi.org/10.1029/2008JC004976.

Kolodziejczyk, N., F.Marin, B.Bourlès, Y.Gouriou, and H. Berger, 2014: Seasonal variability of the Equatorial Undercurrent termination and associated salinity maximum in the Gulf of Guinea. *Clim. Dyn.*, 43 (11), 3025—2046, http://dx.doi.org/10.1007/s00382-014-2107-7.

Large, W. G., and S.G. Yeager, 2009: Global climatology of an interannually varying air–sea flux data set. Climate Dynamics, 33 (2-3), 341-364, http://dx.doi.org/10.1007/s00382-008-0441-3.

Lea, D.J., M.J. Martin, and P.R. Oke, 2014: Demonstrating the complementarity of observations in an operational ocean forecasting system, *Quarterly Journal of the Royal Meteorological Society*, 140 (683), 2037-2049, 10.1002/qj.2281.

Leduc-Leballeur, M., L. Eymard, and G. de Coëtlogon, 2011: Observation of the marine atmospheric boundary layer in the Gulf of Guinea during the 2006 boreal spring. *Q.J.R. Meteorol. Soc.*, 137, 992–1003, http://dx.doi.org/10.1002/qj.808.

Lee, T., G. Lagerloef, H.-Y. Kao, M. J. McPhaden, J. Willis, and M. M. Gierach, 2014: The influence of salinity on tropical Atlantic instability waves. *J. Geophys. Res. Oceans*, 119, 8375–8394, http://dx.doi.org/10.1002/2014JC010100.

Lehodey, P., A. Conchon, I. Senina, R. Domokos, B. Calmettes, J. Jouanno, O. Hernandez and R. Kloser, 2015: Optimization of a micronekton model with acoustic data. – *ICES Journal of Marine Science*, 72(5): 1399-1412.

Lellouche, J.-M., O. Le Galloudec, M. Drévillon, C. Régnier, E. Greiner, G. Garric, N. Ferry, C. Desportes, C.-E. Testut, C. Bricaud, R. Bourdallé-Badie, B. Tranchant, M. Benkiran, Y. Drillet, A. Daudin, and C. De Nicola, 2013: Evaluation of global monitoring and forecasting systems at Mercator Océan, *Ocean Sci.*, 9 (1), 57-81, 10.5194/os-9-57-2013.

Luyten, J. R., J. Pedlosky, and H. Stommel, 1983: The Ventilated Thermocline, *J. Phys. Oceanogr.*, 13, 292–309, https://doi.org/10.1175/1520-0485(1983)013<0292:tvt>2.0.co;2.

Lefèvre, N., A. Guillot, L. Beaumont, and T. Danguy, 2008: Variability of fCO2 in the Eastern Tropical Atlantic from a moored buoy. *J. Geophys. Res.*, 113, C01015, http://dx.doi.org/10.1029/2007JC004146.

Lefèvre, N., 2009: Low $CO_2$ concentrations in the Gulf of Guinea during the upwelling season in 2006. *Marine Chemistry* 113, 93-101.

Lefèvre, N., and L. Merlivat, 2012: Carbon and oxygen net community production in the eastern tropical Atlantic estimated from a moored buoy. *Global Biogeochemical Cycles* 26(GB1009): doi:10.1029/2010GB004018.

Lefèvre, N., D.F. Urbano, F. Gallois and D. Diverrès, 2014 : Impact of physical processes on the seasonal distribution of $CO_2$ in the western tropical Atlantic. *J. Geophys. Res.* 119, doi: 10.1002/2013JC009248.

Lefèvre N., D. Veleda, M. Araujo, and G. Caniaux, 2016: Variability and trends of carbon parameters at a time-series in the Eastern Tropical Atlantic. *Tellus* B, 68, doi: http://dx.doi.org/10.3402/tellusb.v3468.30305

Legler, D., H. J. Freeland, R. Lumpkin, G. Ball, M. J. McPhaden, S. North, R. Cowley, G. Goni, U. Send, and M. Merrifield, 2015: The current status of the real-time in situ global ocean observing system for operational oceanography. *J. Operational Oceanography*, 8 (S2), 189-200, http://dx.doi.org/10.1080/1755876X.2015.1049883

Lentini, J. Servain, M. Araujo, and E. Marone, 2015: Physical processes that drive the seasonal evolution of the Southwestern Tropical Atlantic Warm Pool. *Dyn. Atmos. Ocean*, 72, 1-11, doi:10.1016/j.dynatmoce.2015.08.001.

Lübbecke, J. F., C. W. Böning, N. S. Keenlyside, and S. P. Xie, 2010: On the connection between Benguela and equatorial Atlantic Niños and the role of the South Atlantic Anticyclone. *J. Geophys. Res. Ocean.*, 115, 1–16, doi:10.1029/2009JC005964.

Lübbecke, J., and M. J. McPhaden, 2013: A comparative stability analysis of Atlantic and Pacific Niño modes. *J. Climate*, 26, 5965-5980. http://dx.doi.org/10.1175/JCLI-D-12-00758.1.

Lutz, K., J. Jacobeit, and J. Rathmann, 2015: Atlantic warm and cold water events and impact on African west coast precipitation. *International Journal of Climatology*, *35*(1), pp.128-141.

Marin, F., G. Caniaux, B. Bourlès, H. Giordani, Y. Gouriou, and E. Key, 2009: Why were sea surface temperatures so different in the eastern equatorial Atlantic in June 2005 and 2006? *J. Phys. Oceanogr*., 39, 1416-1431, http://dx.doi.org/10.1175/2008JPO4030.1.

McPhaden, M.J., A.J. Busalacchi, R. Cheney, J.R. Donguy, K.S. Gage, D. Halpern, M. Ji, P. Julian, G. Meyers, G.T. Mitchum, P.P. Niiler, J. Picaut, R.W. Reynolds, N. Smith, K. Takeuchi, 1998: The Tropical Ocean-Global Atmosphere (TOGA) observing system: A decade of progress. *J. Geophys. Res.*, *103*, 14,169-14,240.

Marullo, S., R. Santoleri, V. Banzon, R. H. Evans, and M. Guarracino, 2010: A diurnal-cycle resolving sea surface temperature product for the tropical Atlantic. *J. Geophys. Res*., 115, C05011, http://dx.doi.org/10.1029/2009JC005466.

Merle, J., 1980: Seasonal heat budget in the equatorial Atlantic Ocean. *J. Phys. Oceanogr*., 10, 464-469.

Meynadier, R., G. de Coëtlogon, S. Bastin, L. Eymard and S. Janicot, 2015: Sensitivity testing of WRF parameterizations on air–sea interaction and its impact on water cycle in the Gulf of Guinea, *Q. J. R. Meteorol. Soc.* 141: 1804–1820, DOI:10.1002/qj.2483.

Meynadier R., G. de Coëtlogon, S. Bastin, L. Eymard and S. Janicot, 2016: Seasonal influence of the sea surface temperature on the low atmospheric circulation and precipitation in the eastern equatorial Atlantic, *Clim. Dyn*., 47:1127–1142, DOI 10.1007/s00382-015-2892-7.

Molinari, R. L., J. F. Festa, and E. Marmolejo, 1985: Evolution of sea surface temperature in the tropical Atlantic Ocean during FGGE, 1979, 2. Oceanographic fields and heat balance of the mixed layer. *J. Mar. Res*., 43, 67-81.

Moum, J. N., A. Perlin, J. D. Nash, and M. J. McPhaden, 2013: Seasonal sea surface cooling in the equatorial Pacific cold tongue controlled by ocean mixing. *Nature*, 500, 64-67, doi:10.1038/nature12363.

Nobre, P., R. A. De Almeida, M. Malagutti , and E. Giarolla, 2012: Coupled Ocean-Atmosphere Variations over the South Atlantic Ocean. *J. Climate*, 25, 6349–6358, http://dx.doi.org/10.1175/JCLI-D-11-00444.1.

Oke, P.R., G. Larnicol, E.M. Jones, V.H. Kourafalou, A.K. Sperrevik, F. Carse, C.A.S. Tanajura, B. Mourre, M. Tonani, G.B. Brassington, M. Le Henaff, G.R. Halliwell, R. Atlas, A.M. Moore, C.A. Edwards, M. Martin, A.A. Sellar, A. Alvarez, P. De Mey, and M. Iskandarani, 2015: Assessing the impact of observations on ocean forecasts and reanalyses: Part 2, Regional applications, *Journal of Operational Oceanography*, 8 (sup1), s63-s79, 10.1080/1755876X.2015.1022080.

Okumura, Y., and S. P. Xie, 2006: Some Overlooked Features of Tropical Atlantic Climate Leading to a New Niño-Like Phenomenon. *J. Climate*, 19, 5859–5874, http://dx.doi.org/10.1175/JCLI3928.1.

Parard, G., N. Lefèvre, and J. Boutin, 2010: Sea water fugacity of $CO_2$ at the PIRATA mooring at 6$^o$S, 10$^o$W. *Tellus* B 62(5): 636-648.

Parard, G., J. Boutin, Y. Cuypers, P. Bouruet-Aubertot, and G. Caniaux, 2014: On the physical and biogeochemical processes driving the high frequency variability of CO2 fugacity at 6°S, 10°W: Potential role of the internal waves. *J. Geophys. Res. Oceans*, 119, 8357–8374, http://dx.doi.org/10.1002/2014JC009965

Peng, G., H-M Zhang, H. P. Frank, J.-R. Bidlot, M. Higaki, S. Stevens, and W. R. Hankins, 2013: Evaluation of Various Surface Wind Products with OceanSITES Buoy Measurements. *Wea. Forecasting*, 28, 1281–1303, http://dx.doi.org/10.1175/WAF-D-12-00086.1.

Perez, R., V. Hormann, R. Lumpkin, P. Brandt, W. E. Johns, F. Hernandez, C. Schmid, and B. Bourlès, 2014: Mean meridional currents in the central and eastern equatorial Atlantic. *Clim. Dyn.*, 43 (11), 2943-2962, http://dx.doi.org/10.1007/s00382-013-1968-5.

Peter, A., M.L. Henaff, Y. duPenhoat, C. Menkes, F. Marin, J. Vialard, G. Caniaux, and A. Lazar, 2006: A model study of the seasonal mixed layer heat budget in the equatorial Atlantic. *J. Geophys. Res*., 111, C06014.

Pham, H.T., S. Sarkar, and K.B. Winters, 2013: Large-eddy simulation of deep-cycle turbulence in an equatorial undercurrent model, *J. Phys. Oceanogr*., 43, doi:10.1175/JPO-D-13-016.1 .

Pinker, R. T., H. Wang, and S.A. Grodsky, 2009: How good are ocean buoy observations of radiative fluxes? *Geophys. Res. Lett*., 36, L10811, http://dx.doi.org/10.1029/2009GL037840.

Planton, Y., A. Voldoire, H. Giordani, and G. Caniaux, 2017: Main processes of the Atlantic cold tongue interannual variability, *Clim. Dyn*., in press. doi: 10.1007/s00382-017-3701-2.

Poli, P., Note on the impact of meteorological data from PIRATA moorings on global weather forecasts, doi:10.5281/zenodo.1164620, 2018.

Prakash, S., C. Mahesh, R.M. Gairola, and S. Pokhrel, 2011: Surface Freshwater Flux Estimation Using TRMM Measurements Over the Tropical Oceans. *Atmospheric and Climate Sciences*, 01:04, 225-234, http://dx.doi.org/10.4236/acs.2011.14025.

Prakash, S., C. Mahesh, and R. M. Gairola, 2013: Comparison of TRMM Multi-satellite Precipitation Analysis (TMPA)-3B43 version 6 and 7 products with rain gauge data from ocean buoys. *Remote Sensing Lett.*, 4 (7), 677-685, http://dx.doi.org/10.1080/2150704X.2013.783248.

Praveen Kumar, B., J. Vialard, M. Lengaigne, V. S. N. Murty, and M.J. McPhaden, 2012: TropFlux: Air-Sea Fluxes for the Global Tropical Oceans: Description and evaluation. *Clim. Dynamics*, 38, 1521-1543, http://dx.doi.org/10.1007/s00382-011-1115-0.

Praveen Kumar, B., J. Vialard, M. Lengaigne, V.S.N. Murty, M.J. McPhaden, M.F. Cronin, F. Pinsard, and K. Gopala Reddy, 2013: TropFlux wind stresses over the tropical oceans: evaluation and comparison with other products. *Clim. Dynamics*, 40, 2049-2071, http://dx.doi.org/10.1007/s00382-012-1455-4.

Reason, C.J.C., and M. Rouault, 2006: Sea surface temperature variability in the tropical southeast Atlantic Ocean and West African rainfall. *Geophys. Res. Lett.*, 33, L21705, http://dx.doi.org/10.1029/2006GL027145

Reverdin, G., E. Kestenare, C. Frankignoul, and T. Delcroix, 2007: Surface salinity in the Atlantic Ocean (30_S–50_N), *Progr. Oceanogr*., 73, 311–340, doi:10.1016/j.pocean.2006.11.004.

Reynolds, R.W., and D.B. Chelton, 2010: Comparisons of Daily Sea Surface Temperature Analyses for 2007–08. *J. Climate*, 23, 3545-3562, http://dx.doi.org/10.1175/2010JCLI3294.1.

Richter, I., S.K. Behera, Y. Masumoto, B. Taguchi, N. Komori, and T. Yamagata, 2010: On the triggering of Benguela Niños: Remote equatorial versus local influences. *Geophys. Res. Lett.*, 37, L20604, http://dx.doi.org/10.1029/2010GL044461.

Richter, I., S.K. Behera, Y. Masumoto, B. Taguchi, H. Sasaki, and T. Yamagata, 2013: Multiple causes of interannual sea surface temperature variability in the equatorial Atlantic Ocean, *Nat. Geosci*., 6 (1), 43–47, doi:10.1038/ngeo1660.

Romanova, V., A. Koehl, and D. Stammer, 2011: Seasonal cycle of near-surface freshwater budget in the western tropical Atlantic. *J. Geophys. Res*., 116, C07009, doi:10.1029/2010JC006650.

Rouault, M., S. Illig, C. Bartholomae, C.J.C. Reason and A. Bentamy, 2007: Propagation and origin of warm anomalies in the Angola Benguela upwelling system in 2001. *J. Mar. Syst*., 68, 477-488.

Rouault, M., J. Servain, C.J.R. Reason, B. Bourlès, M. Rouault, and N. Fauchereau, 2009: Extension of PIRATA in the tropical South-East Atlantic: an initial one-year experiment. African Journal of Marine Science 2009, 31(1): 63–71

Rouault, M., S. Illig, J.F. Lübbecke, and R.A. Imbol Koungue, 2018: Origin, development and demise of the 2010-2011 Benguela Niño. *J. Marine Systems*, published online.

Rousselot, P., G. Reverdin, P. Blouch, and P. Poli, 2017, *AtlantOS EU H2020 633211 Deliverable 3.5* “Enhancement of autonomous observing networks: Study of the potential for existing bathythermic string drifters”.

Rugg, A., G.R. Foltz, and R.C. Perez, 2016: Role of mixed layer dynamics in tropical North Atlantic interannual sea surface temperature variability. *J. Climate*, 29, 8083-8101, doi:10.1175/JCLI-D-1500867.1.

Saha S, Moorthi S, Pan H, Wu X, Wang J, Nadiga S, Tripp P, Kistler R, Woollen J, Behringer D, Liu H, Stokes D, Grumbine R, Gayno G, Wang J, Hou Y, Chuang H, Juang H, Sela J, Iredell, M, Treadon R, Kleist D, Van Delst P, Keyser D, Derber J, Ek M, Meng J, Wei H, Yang R, Lord S, van den Dool H, Kumar A, Wang W, Long C, Chelliah M, Xue Y, Huang B, Schemm J, Ebisuzaki W, Lin R, Xie P, Chen M, Zhou S, Higgins W, Zou C, Liu Q, Chen Y, Han Y, Cucurull L, Reynolds R, Rutledge G, Goldberg M, 2010. Supplement to the NCEP climate forecast system reanalysis. *Bull Am Meteorol Soc*, 91:1015–1057.

Sandel V., R. Kiko, P. Brandt, M. Dengler, L. Stemmann, P. Vandromme, U. Sommer and H. Hauss, 2015: Nitrogen Fuelling of the Pelagic Food Web of the Tropical Atlantic. *PLoS ONE* 10(6): e0131258. doi:10.1371/journal.pone.0131258.

Schiller, A., F. Davidson, P.M. DiGiacomo, K. Wilmer-Becker, 2016: Better Informed Marine Operations and Management: Multidisciplinary Efforts in Ocean Forecasting Research for Socioeconomic Benefit, *Bull Am Meteorol Soc*, doi:10.1175/BAMS-D-15-00102.1.

Schlundt, M., P. Brandt, M. Dengler, R. Hummels, T. Fischer, K. Bumke, G. Krahmann, and J. Karstensen, 2014: Mixed layer heat and salinity budgets during the onset of the 2011 Atlantic cold tongue. *J. Geophys. Res*., 119, 7882-7910, doi:10.1002/2014JC010021.

Schmidtko, S., L. Stramma, and M. Visbeck, 2017: Decline in global oceanic oxygen content during the past five decades, *Nature*, 542, 335–339, https://doi.org/10.1038/nature21399.

Schott FA, McCreary JP, Johnson GC, 2004: Shallow overturning circulations of the tropical–subtropical oceans. In: Wang C, Xie S-P, Carton JA (eds) Earth climate: The ocean–atmosphere interaction. *Geophys Monogr 147. American Geophysical Union*, Washington, DC, pp 261–304.

Schütte, F., J. Karstensen, G. Krahmann, H. Hauss, B. Fiedler, P. Brandt, M. Visbeck, and A. Körtzinger, 2016: Characterization of dead-zone eddies in the eastern tropical North Atlantic, *Biogeosciences*, 13, 5865–5881, https://doi.org/10.5194/bg-13-5865-2016.

Servain J., A. Busalacchi, M.J. McPhaden, A.D. Moura, G. Reverdin, M. Vianna and S. Zebiak, 1998: A Pilot Research Moored Array in the Tropical Atlantic (PIRATA). *Bull. Amer. Meteorol. Soc.*, **79**, 2019-2031, http://dx.doi.org/10.1175/1520-0477.

Shannon, L. V., A. J. Boyd, G. B. Bundrit, and J. Taunton-Clark, 1986: On the existence of an El Niño–type phenomenon in the Benguela system. *J. Mar. Syst.*, 44, 495–520.

Smyth, W. D., J. N. Moum, L. Li, and S.A. Thorpe, 2013: Diurnal shear instability, the descent of the surface shear layer, and the deep cycle of equatorial turbulence. *J. Phys. Oceanogr*., 43, 2432-2455, doi:10.1175/JPO-D-13-089.1.

Sohou, Z., B. Bourlès, R. Djiman, A. Aman, R. Folorunsho, A.K. Armah, R. Chuchla, and V. Racapé, 2014: PROPAO : a network of coastal temperature autonomous sensors in the north of the Gulf of Guinea, *Proceeding of the Colloquium in Physical Oceanography and Applications, Cotonou, Republica of Benin, 7 November 2012, ed. M.H.Hounkonnou and Y.duPenhoat*, ISBN 978-99919-1899-0, June 2014.

Stramma, L., and M. Visbeck, 2008: Oxygen minimum zones in the eastern tropical Atlantic and Pacific oceans. *Progr. Oceanogr*., 77, 331-350, https://doi.org/10.1016/j.pocean.2007.05.009.

Stramma, L., G. C. Johnson, J. Sprintall, and V. Mohrholz, 2008: Expanding Oxygen-Minimum Zones in the Tropical Oceans, *Science*, 320, 655–658, https://doi.org/10.1126/science.1153847.

Tang, W., S. H. Yueh, A. G. Fore, and A. Hayashi, 2014: Validation of Aquarius sea surface salinity with in situ measurements from Argo floats and moored buoys. *J. Geophys. Res. Oceans*, 119, 6171–6189, http://dx.doi.org/10.1002/2014JC010101.

Thierry, V., A.M. Treguier, and H. Mercier, 2004: Numerical study of the annual and semi-annual fluctuations in the deep equatorial Atlantic Ocean. *Ocean Model*, 6, 1-30.

Tonani, M., M. Balmaseda, L. Bertino, E. Blockley, G. Brassington, F. Davidson, Y. Drillet, P. Hogan, T. Kuragano, T. Lee, A. Mehra, F. Paranathara, C.A.S. Tanajura, and H. Wang, 2015: Status and future of global and regional ocean prediction systems, *Journal of Operational Oceanography*, 8 (sup2), s201-s220, 10.1080/1755876X.2015.1049892.

Trolliet, M., J. Walawender, B. Bourlès, A. Boilley, J. Trentmann, P. Blanc, M. Lefèvre, and L. Wald, Estimating downwelling solar irradiance at the surface of the tropical Atlantic Ocean: A comparison of PIRATA measurements against several re-analyses and satellite-derived data sets, Manuscript under review for journal *Ocean Sci. Discuss*., https://doi.org/10.5194/os-2017-95.

Tzortzi, E., S.A. Josey, M. Srokosz, and C. Gommenginger, 2013: Tropical Atlantic salinity variability: New insights from SMOS. *Geophys. Res. Lett*., 40, 1-5, doi:10.1002/grl.50225.

Urbano, D.F., R.A.F. De Almeida, and P. Nobre, 2008: Equatorial Undercurrent and North Equatorial Countercurrent at 38°W: A new perspective from direct velocity data, *J. Geophys. Res*., 113, C04041, http://dx.doi.org/10.1029/2007JC004215.

Vinogradova, N. T. and R.M. Ponte, 2012: Assessing temporal aliasing in satellite-based surface salinity measurements. *J. Atmos. Oceanic Techn*., 29, 1391-1400, http://dx.doi.org/10.1175/JTECH-D-11-00055.1.

Von Schuckmann, K., P. Brandt, and C. Eden, 2008: Generation of Tropical Instability Waves in the Atlantic Ocean, *J. Geophys. Res*., 113, C08034,http://dx.doi.org/10.1029/2007JC004712.

Wade, M., G. Caniaux, and Y. duPenhoat, 2011: Variability of the mixed layer heat budget in the eastern equatorial Atlantic during 2005-2007 as inferred using Argo floats. *J. Geophys. Res*., 116, C08006.

Wang, H., and R.T. Pinker, 2009: Shortwave radiative fluxes from MODIS: Model development and implementation. *J. Geophys. Res.*, 114, D2021, http://dx.doi.org/10.1029/2008JD010442.

Wenegrat, J.O., M.J. McPhaden, and R.-C. Lien, 2014: Wind stress and near-surface shear in the equatorial Atlantic Ocean. *Geophys. Res. Lett*., 41, 1226–1231, http://dx.doi.org/10.1002/2013GL059149.

Wenegrat, J. O., and M. J. McPhaden, 2015: Dynamics of the surface layer diurnal cycle in the equatorial Atlantic Ocean (0, 23W). *J. Geophys. Res. Oceans*, 120, doi:10.1002/2014JC010504.

Woodruff, S. D., S. J. Worley, S. J. Lubker, Z. Ji, J. E. Freeman, D. I. Berry, P. Brohan, E. C. Kent, R. W. Reynolds, S. R. Smith, and C. Wilkinson, 2011: ICOADS Release 2.5: extensions and enhancements to the surface marine meteorological archive. *Int. J. of Clim.*, 31, 7, 951-967, http://dx.doi.org/10.1002/joc.2103.

Xie, P., R. Joyce, S. Wu, S. Yoo, Y. Yarosh, F. Sun, and R. Lin, 2017: Reprocessed, Bias-Corrected CMORPH Global High-Resolution Precipitation Estimates from 1998. *J. Hydrometeor.*, 18, 1617–1641, https://doi.org/10.1175/JHM-D-16-0168.1

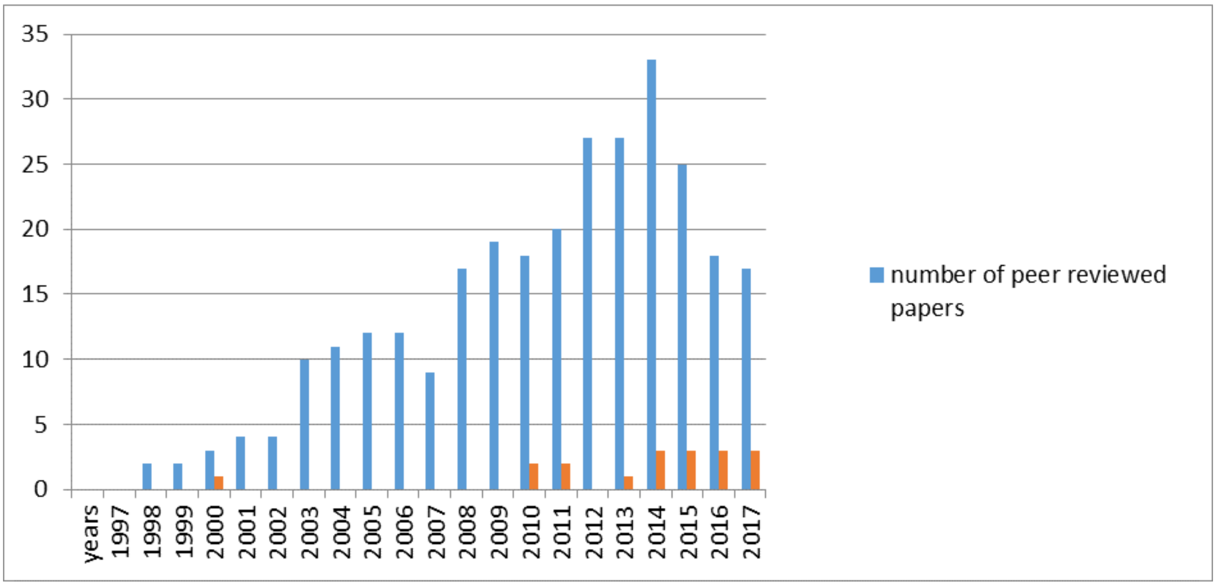
Yu, L., R.A. Weller, 2007: Objectively Analyzed air-sea heat Fluxes (OAFlux) for the global ice-free oceans. *Bull. Amer. Meteor. Soc*., 88(4), 527-539, http://dx.doi.org/10.1175/BAMS-88-4-527.

Zuidema, P., P. Chang, B. Medeiros, B. Kirtman, R. Mechoso, E. Schneider, T. Toniazzo, I. Richter, R. Small, K. Bellomo, P. Brandt, S. de Szoeke, J. Farrar, E. Jung, S. Kato, M. Li, C. Patricola, Z. Wang, R. Wood, and Z. Xu, 2016: Challenges and Prospects for Reducing Coupled Climate Model SST Biases in the Eastern Tropical Atlantic and Pacific Oceans: The U.S. CLIVAR Eastern Tropical Oceans Synthesis Working Group. *Bull. Amer. Meteor. Soc*., 97, 2305–2327, http://dx.doi.org/10.1175/BAMS-D-15-00274.1.

Yu, L., and X. Jin, 2012: Buoy perspective of a high-resolution global ocean vector wind analysis constructed from passive radiometers and active scatterometers (1987–present*). J. Geophys. Res*., 117, C11013, http://dx.doi.org/10.1029/2012JC008069.

Zhang, D., M.J. McPhaden, and W.E. Johns, 2003: Observational evidence for flow between the subtropical and tropical Atlantic: The Atlantic subtropical cells. *J. Phys. Oceanogr*., 33, 1783–1797.

**Time evolution of PIRATA related papers: total from 1997 = 290; total from 2006: 242**



## PIRATA Bibliography (from last review in 2006):

1. Abe, H., and N. Ebuchi, 2014: Evaluation of sea-surface salinity observed by Aquarius. *J. Geophys. Res. Oceans*, 119, 8109–8121, http://dx.doi.org/10.1002/2014JC010094.
2. Abraham, J. P., et al., 2013: A review of global ocean temperature observations: Implications for ocean heat content estimates and climate change. *Rev. Geophys.*, 51, 450–483, http://dx.doi.org/10.1002/rog.20022.
3. Andrew, J. A. M., H. Leach, and P. L. Woodworth, 2006: The relationships between tropical Atlantic sea level variability and major climate indices. Ocean Dynamics, 56 (5-6), 452-463, http://dx.doi.org/10.1007/s10236-006-0068-z.
4. Arhan, M., A. M. Tréguier, B. Bourlès, and S. Michel, 2006: Diagnosing the annual cycle of the equatorial undercurrent in the Atlantic ocean from a general circulation model. *J. Phys. Oceanogr*., 36, 1502-1522, http://dx.doi.org/10.1175/JPO2929.1.
5. Arruda, W. Z. and C. A. Domingos Lentini, 2011: A remote sensing derived upper ocean heat content dataset for the equatorial Atlantic: comparison with PIRATA project data. *Revisita Brasileira de Geofisica*, 29 (1), 43-56, http://dx.doi.org/10.1590/S0102-261X2011000100003.
6. Ascani, François, Eric Firing, Julian P. McCreary, Peter Brandt, and Richard J. Greatbatch, 2015: The Deep Equatorial Ocean Circulation in Wind-Forced Numerical Solutions. *J. Phys. Oceanogr.*, 45, 1709–1734, http://dx.doi.org/10.1175/JPO-D-14-0171.1
7. Athie, G. and Marin, F., 2008: Cross-equatorial structure and temporal modulation of Intra-seasonal variability at the surface of the Tropical Atlantic Ocean. *J. Geophys. Res.*, 113, C8, http://dx.doi.org/10.1029/2007JC004332.
8. Athie, G., F. Marin, A-M. Treguier, B. Bourlès and C. Guiavarc'h, 2009: Sensitivity of near surface Tropical Instability Waves to sub-monthly wind forcing in the tropical Atlantic. *Ocean Modelling*, 30, 241-255.
9. Balmaseda, M.A., D. P. Dee, A. P. Vidard and D. L. T. Anderson, 2007: A multivariate treatment of bias for sequential data assimilation: Application to the Tropical Oceans. *Q. J. Roy. Meteor. Soc*., 133(622), 167-179.
10. Balmaseda, M. A., K. Mogensen and A. T. Weaver, 2012: Evaluation of the ECMWF ocean reanalysis system ORAS4. *Q.J.R. Meteorol. Soc*, 674, 1132—1161, http://dx.doi.org/10.1002/qj.2063.
11. Baklouti, M., J.-L. Devenon, A. Bourret, J.-M. Froidefond, J.-F. Ternon, and J.-L. Fuda, 2007: New insights in the French Guiana continental shelf circulation and its relation to the North Brazil Current retroflection, *J. Geophys. Res*., 112, C02023, http://dx.doi.org/10.1029/2006JC003520.
12. Benetti, M., H.C. Steen-Larsen, G. Reverdin, Á.E. Sveinbjörnsdóttir, G. Aloisi, M.B. Berkelhammer, B. Bourlès, D. Bourras, G. de Coetlogon, A. Cosgrove, A.K. Faber, J. Grelet, S. B. Hansen, R. Johnson, H. Legoff, N. Martin, A.J. Peters, T.J. Popp, T. Reynaud, and M.N. Winther, 2016: Stable isotopes in the

atmospheric marine boundary layer water vapour over the Atlantic Ocean, 2012-2015, *Nature Scientific Data*, 4, 160128, http://dx.doi.org/10.1038/sdata.2016.128.

13. Benetti, M., G. Reverdin, G. Aloisi, and Á. Sveinbjörnsdóttir, 2017: Stable isotopes in surface waters of the Atlantic Ocean: Indicators of ocean-atmosphere water fluxes and oceanic mixing processes. *J. Geophys. Res. Oceans*, 122, 4723–4742, http://dx.doi.org/10.1002/2017JC012712.
14. Bentamy, A., S. A. Grodsky, J. A. Carton, D. Croizé-Fillon, and B. Chapron, 2012: Matching ASCAT and QuikSCAT winds. *J. Geophys. Res*., 117, C02011, http://dx.doi.org/10.1029/2011JC007479.
15. Berger, H., A. M. Treguier, N. Perenne, and C. Talandier, 2014: Dynamical contribution to sea surface salinity variations in the eastern Gulf of Guinea based on numerical modelling. *Clim. Dyn*., 43 (11), 3105––3122, http://dx.doi.org/10.1007/s00382-014-2195-4.
16. Berry, D. I. and E. C. Kent, 2017: Assessing the health of the in situ global surface marine climate observing system. Int. J. Climatol., 37, 2248–2259. http://dx.doi.org/10.1002/joc.4914.
17. Boilley, A. and L. Wald, 2015: Comparison between meteorological re-analyses from ERA-Interim and MERRA and measurements of daily solar irradiation at surface. *Renewable Energy*, 75, 135-143, http://dx.doi.org/10.1016/j.renene.2014.09.042.
18. Bonou F. K., C.D. Noriega, N. Lefèvre, M. Araujo, 2016: Distribution of CO2 parameters in the Western Tropical Atlantic Ocean. *Dyn. Atmosph. and Oceans*, 73, 47-60, http://dx.doi.org/10.1016/j.dynatmoce.2015.12.001.
19. Bourlès, B., R. Lumpkin, M. J. McPhaden, F. Hernandez, P. Nobre, E. Campos, L. Yu, S. Planton, A. J. Busalacchi, A. D. Moura, J. Servain and J. Trotte, 2008: The PIRATA Program: History, Accomplishments, and Future Directions. *Bulletin of the American Meteorological Society*, 89 (8), http://dx.doi.org/10.1175/2008BAMS2462.1.
20. Bourras, D., A. Weill, G. Caniaux, L. Eymard, B. Bourlès, S. Letourneur, D. Legain, E. Key, F. Baudin, B. Piguet, O. Traullé, G. Bouhours, B. Sinardet, J. Barié, J.P. Vinson, F. Boutet, and C Berthod, 2009: Turbulent air-sea fluxes in the Gulf of Guinea during the EGEE-AMMA experiment. *J. Geophys. Res*., 114, C04014, http://dx.doi.org/10.1029/2008JC004951.
21. Boutin, J., Y. Chao, W. Asher, T. Delcroix, R. Drucker, K. Drushka, N. Kolodziejczyk, T. Lee, N. Reul, G. Reverdin, J. Schanze, A. Soloviev, L. Yu, J. Anderson, L. Brucker, E. Dinnat, A. Santos-Garcia, W. Jones, C. Maes, T. Meissner, W. Tang, N. Vinogradova, and B. Ward, 2016: Satellite and In Situ Salinity: Understanding Near-Surface Stratification and Sub-footprint Variability. *Bull. Amer. Meteor. Soc*., http://dx.doi.org:/10.1175/BAMS-D-15-00032.1.
22. Bowman, K. P., C. R. Homeyer and D. G. Stone, 2009: A Comparison of Oceanic Precipitation Estimates in the Tropics and Subtropics. *J. Appl. Meteor. Climatol*., 48, 1335–1344, http://dx.doi.org/10.1175/2009JAMC2149.1.
23. Boyer, T., S. Levitus, J. Antonov, J. Reagan, C. Schmid, and R. Locarnini, 2012: Subsurface Salinity. In State of the Climate in 2011, ed. J. Blunden and D. S. Arndt, *Bull. Amer. Meteor. Soc*., 93, S1–S282, http://dx.doi.org/10.1175/2012BAMSStateoftheClimate.1.
24. Brandt, P., F. A. Schott, C. Provost, A. Kartavtseff, V. Hormann, B. Bourlès, and J. Fischer, 2006: Circulation in the central equatorial Atlantic: Mean and intraseasonal to seasonal variability. *Geophys. Res. Lett.*, 33(7), http://dx.doi.org/10.1029/2005GL025498.
25. Brandt, P., V. Hormann, B. Bourlès, J. Fischer, F. A. Schott, L. Stramma and M. Dengler, 2008: Oxygen tongues and zonal currents in the equatorial Atlantic. *J. Geophys. Res*., 113, C04012, http://dx.doi.org/10.1029/2007JC004435.
26. Brandt, P., V. Hormann, A. Körtzinger, M. Visbeck, G. Krahmann, L. Stramma, R. Lumpkin and C. Schmid, 2010: Changes in the ventilation of the oxygen minimum zone of the tropical North Atlantic. *J. Phys. Oceanogr*., 40 (8), 1784-1801, http://dx.doi.org/10.1175/2010JPO4301.1.
27. Brandt, P., G. Caniaux, B. Bourlès, A. Lazar, M. Dengler, A. Funk, V. Hormann, H. Giordani and F. Marin, 2011a: Equatorial upper-ocean dynamics and their interaction with the West African Monsoon. *Atmospheric Science Letters*, 12, 24-30, http://dx.doi.org/10.1002/asl.287.
28. Brandt, P., A. Funk, V. Hormann, M. Dengler, R. Greatbatch and J. Toole, 2011b: Interannual atmospheric variability forced by the deep equatorial Atlantic Ocean. *Nature*, 18 May 2011, http://dx.doi.org/10.1038/nature10013.
29. Brandt, P, R. J. Greatbatch, M. Claus, S-H. Didwischus, V. Hormann, A. Funk, J. Hahn, G. Krahmann, J. Fischer, and A. Körtzinger, 2012: Ventilation of the equatorial Atlantic by the equatorial deep jets. *J. Geophys. Res*., 117, C12015, http://dx.doi.org/10.1029/2012JC008118.
30. Brandt, P., A. Funk, A. Tantet, W. E. Johns and J. Fischer, 2014: The Equatorial Undercurrent in the central Atlantic and its relation to tropical Atlantic variability. *Clim. Dyn*., 43 (11), 2985-2997, http://dx.doi.org/10.1007/s00382-014-2061-4.
31. Brandt, P., H. W. Bange, D. Banyte, M. Dengler, S.-H. Didwischus, T. Fischer, R. J. Greatbatch, J. Hahn, T. Kanzow, J. Karstensen, A. Körtzinger, G. Krahmann, S. Schmidtko, L. Stramma, T. Tanhua, and M.

Visbeck, 2015, On the role of circulation and mixing in the ventilation of oxygen minimum zones with a focus on the eastern tropical North Atlantic, *Biogeosciences*, 12, 489–512, doi:10.5194/bg-12-489-2015.

32. Brandt, P., M. Claus, R. J. Greatbatch, R. Kopte, J. M. Toole, W. E. Johns, and C. W. Böning, 2016: Annual and semi-annual cycle of equatorial Atlantic circulation associated with basin mode resonance. *J. Phys. Oceanogr*., 46, 3011–3029, http://dx.doi.org/10.1175/JPO-D-15-0248.1.
33. Brown, P. J. and C. D. Kummerow, 2014: An Assessment of Atmospheric Water Budget Components over Tropical Oceans. *J. Climate*, 27, 2054–2071, http://dx.doi.org/10.1175/JCLI-D-13-00385.1.
34. Bruto, L., A. Moacyr, C. Noriega, D. Veleda, and N. Lefevre, 2017: Variability of CO2 fugacity at the western edge of the tropical Atlantic Ocean from the 8°N to 38°W PIRATA buoy. *Dyn. Atmos. Oceans*, 78, 12017, http://doi.org/10.1016/j.dynatmoce.2017.01.003.
35. Bunge L., C. Provost, J. Lilly, M. D'Orgeville, A. Kartavtseff and J.L. Melice, 2006: Structure of the horizontal velocity in the first 1600 m of the water column at the equator in the Atlantic at 10ºW, *J.Phys..Oceanogr*., 36, 1287-1304, http://dx.doi.org/10.1175/JPO2908.1.
36. Bunge, L., C. Provost, and A. Kartavtseff, 2007: Variability in horizontal current velocities in the central and eastern equatorial Atlantic in 2002. *J. Geophys. Res*., 112, C02014, http://dx.doi.org/10.1029/2006JC003704.
37. Bunge L., C. Provost, L. Hua and A. Kartavstseff, 2008: Variability at intermediate depths at the equator in the Atlantic Ocean in 2000-2006: annual cycle, equatorial deep jets and intraseasonal meridional velocity fluctuations *J. Phys. Oceanogr.*, http://dx.doi.org/10.1175/2008JPO3781.1
38. Bunge, L., and A.J. Clarke, 2009: Seasonal Propagation of Sea Level along the Equator in the Atlantic. *J. Phys. Oceanogr*., 39, 1069–1074, http://dx.doi.org/10.1175/2008JPO4003.1.
39. Burls, N. J., C. J. C. Reason, P. Penven, and S. G. Philander, 2011: Similarities between the tropical Atlantic seasonal cycle and ENSO: An energetics perspective. *J. Geophys. Res*., 116, C11010, http://dx.doi.org/10.1029/2011JC007164.
40. Burmeister, K., P. Brandt, and J. F. Lübbecke, 2016: Revisiting the cause of the eastern equatorial Atlantic cold event in 2009. *J. Geophys. Res. Oceans*, 121, 4777–4789, http://dx.doi.org/10.1002/2016JC011719.
41. Cabanes, C., A. Grouazel, K. von Schuckmann, M. Hamon, V. Turpin, C. Coatanoan, S. Guinehut, C. Boone, N. Ferry, G. Reverdin, S. Pouliquen, and P.-Y. Le Traon, 2012: The CORA dataset: validation and diagnostics of ocean temperature and salinity in situ measurement. *Ocean Sci. Discuss*., 9, 1273-1312, http://dx.doi.org/10.5194/osd-9-1273-2012.
42. Camara, I., N. Kolodziejczyk, J. Mignot, A. Lazar, and A. T. Gaye, 2015: On the seasonal variations of salinity of the tropical Atlantic mixed layer. *J. Geophys. Res. Oceans*, 120, 4441–4462, http://dx.doi.org/10.1002/2015JC010865.
43. Caniaux, G., H. Giordani, J.L. Redelsperger, F. Guichard, E. Key, and M. Wade, 2011: Coupling between the Atlantic Cold Tongue and the West African Monsoon in boreal Spring and Summer. *J. Geophy. Res.*, 116, C04003, http://dx.doi.org/10.1029/2010JC006570.
44. Castellanos, P., E. J. D. Campos, I. Giddy, and W. Santis, 2016: Inter-comparison studies between high-resolution HYCOM simulation and observational data: The South Atlantic and the Agulhas leakage system. *J. Marine Sys*., 159, 76—88, http://dx.doi.org/10.1016/j.jmarsys.2016.02.010.
45. Castro, S. L., G. A. Wick, and W. J. Emery, 2012: Evaluation of the relative performance of sea surface temperature measurements from different types of drifting and moored buoys using satellite-derived reference products, *J. Geophys. Res*., 117, C02029, http://dx.doi.org/10.1029/2011JC007472.
46. Chang, P., T. Yamagata, P. Schopf, S.K. Behera, J. Carton, W.E. Kessler, G. Meyers, T. Qu, F. Schott, S. Shetye, and S.P. Xie, 2006: Climate fluctuations of Tropical Coupled Systems – The Role of Ocean Dynamics. *J. Climate (Special Section)*, 19, 5122-5174, http://dx.doi.org/10.1175/JCLI3903.1.
47. Chakraborty, A. and R. Kumar, 2013: Generation and validation of analysed wind vectors over the global ocean. Remote Sensing Lett., 4 (2), 113-122, http://dx.doi.org/10.1080/2150704X.2012.701344.
48. Chakraborty, A., R. Sharma, R. Kumar, and S. Basu, 2014a: An OGCM assessment of blended OSCAT winds. *J. Geophys. Res. Oceans*, 119, 173–186, http://dx.doi.org/10.1002/2013JC009406.
49. Chakraborty, A., R. Sharma, R. Kumar, and S. Basu, 2014b: A SEEK filter assimilation of sea surface salinity from Aquarius in an OGCM: Implication for surface dynamics and thermohaline structure. *Journal of Geophysical Research: Oceans* 119:8, 4777-4796, http://dx.doi.org/10.1002/2014JC009984.
50. Cintra, M. M., C. A.D. Lentini, J. Servain, M. Araujo, and E. Marone, 2015: Physical processes that drive the seasonal evolution of the Southwestern Tropical Atlantic Warm Pool. *Dyn. Atmos. and Oceans*, 72, 1-11.
51. Claus, M., R. Greatbatch, P. Brandt, and J. Toole, 2016: Forcing of the Atlantic Equatorial Deep Jets Derived from Observations. *J. Phys. Oceanogr*., 46, 3549–3562, http://dx.doi.org/10.1175/JPO-D-16-0140.1.
52. Clayson, C. A. and D. Weitlich, 2007: Variability of tropical diurnal sea surface temperature. *J. Climate*, 20, 334-352, http://dx.doi.org/10.1175/JCLI3999.1.

53. Coles, V. J., M. T. Brooks, J. Hopkins, M. R. Stukel, P. L. Yager and R. R. Hood, 2013: The pathways and properties of the Amazon River plume in the tropical North Atlantic Ocean. *J. Geophys. Res*., 118, 6894–6913, http://dx.doi.org/10.1002/2013JC008981.
54. Da-Allada, C. Y., G. Alory, Y. du Penhoat, E. Kestenare, F. Durand, and N. Hounkonnou, 2013: Seasonal mixed-layer salinity balance in the tropical Atlantic Ocean: Mean state and seasonal cycle, *J. Geophys. Res*., 118, 332–345, http://dx.doi.org/10.1029/2012JC008357.
55. Da-Allada, C. Y., G. Alory, Y. du Penhoat, J. Jouanno, N. Hounkonnou, and E. Kestenare, 2014a: Causes for the recent increase for sea surface salinity in the northeast Gulf of Guinea. *African J. of Mar. Science*, 36 (2): 197–205, http://dx.doi.org/10.2989/1814232X.2014.927398.
56. Da-Allada, C. Y., Y. du Penhoat, J. Jouanno, G. Alory, and N. M. Hounkonnou, 2014b: Modeled mixed-layer salinity balance in the Gulf of Guinea: seasonal and interannual variability. *Ocean Dyn*., 64, 1783-1802, doi:10.1007/s10236-014-0775-9.
57. Da-Allada, C. Y., J. Jouanno, F. Gaillard, N. Kolodziejczyk, C. Maes, N. Reul, and B. Bourlès, 2017: Importance of the Equatorial Undercurrent on the sea surface salinity in the eastern equatorial Atlantic in boreal spring. *J. Geophys. Res. Oceans*, 122, 521–538, http://dx.doi.org/10.1002/2016JC012342.
58. Di Nezio, Pedro N., Gustavo J. Goni, 2011: Direct Evidence of a Changing Fall-Rate Bias in XBTs Manufactured during 1986–2008. *J. Atmos. Oceanic Technol*., 28, 1569–1578. http://dx.doi.org/10.1175/JTECH-D-11-00017.1.
59. Ding, H., N. S. Keenlyside, and M. Latif, 2009: Seasonal cycle in the upper equatorial Atlantic Ocean. *J. Geophys. Res*., 114, C09016, http://dx.doi.org/10.1029/2009JC005418.
60. Djakouré, S., P. Penven, B. Bourlès, J .Veitch, and V. Koné, 2014: Coastally trapped eddies in the north of the Gulf of Guinea. *J. Geophys. Res*.,119, http://dx.doi.org/10.1002/2014JC010243.
61. Doi, T., T. Tozuka and T. Yamagata, 2010: The Atlantic Meridional Mode and Its Coupled Variability with the Guinea Dome. *J. Climate*, 23, 455–475, http://dx.doi.org/10.1175/2009JCLI3198.1.
62. Drévillon, M., R. Bourdallé-Badie, C. Derval, Y. Drillet, J.-M. Lellouche, E. Rémy, B. Tranchant, M. Benkiran, E. Greiner, S. Guinehut, N. Verbrugge, G. Garric, C.-E. Testut, M. Laborie, L. Nouel, P. Bahurel, C. Bricaud, L. Crosnier, E. Dombrowsky, E. Durand, N. Ferry, F. Hernandez, O. Le Galloudec, F. Messal, and L. Parent, 2008: The GODAE/Mercator-Ocean global ocean forecasting system: results, applications and prospects, *J. Op. Oceanogr.*, 1 (1), 51-57.
63. Embury, O., C. J. Merchant, and G. K. Corlett, 2012: A reprocessing for climate of sea surface temperature from the along-track scanning radiometers: Initial validation, accounting for skin and diurnal variability effects. *Remote Sensing of Environment*, 116, 62-78, http://dx.doi.org/10.1016/j.rse.2011.02.028.
64. Etienne, H., and M. Benkiran, 2007: Multivariate assimilation in Mercator project: New statistical parameters from forecast error estimation. *J. Mar. Sys.*, 65(1-4), 430-449.
65. Ferreira, B. P., M.B.S.F. Costa, M.S. Coxey, A.L. Gaspar, D.R.A. Veleda and M. Araujo, 2013: The effects of sea surface temperature anomalies on oceanic coral reef systems in the southwestern tropical Atlantic. *Coral Reefs*, 32 (2), 441-454, http://dx.doi.org/10.1007/s00338-012-0992-y.
66. Foltz, G.R., and M.J. McPhaden, 2006: Unusually warm sea surface temperatures in the tropical North Atlantic during 2005. *Geophys. Res. Lett*., 33, L19703, http://dx.doi.org/10.1029/2006GL027394.
67. Foltz, G.R. and M.J. McPhaden, 2008a: Seasonal mixed layer salinity balance of the tropical North Atlantic Ocean. *J. Geophys. Res.*, 113, C02013, http://dx.doi.org/10.1029/2007JC004178.
68. Foltz, G.R., and M.J. McPhaden, 2008b: Impact of Saharan dust on tropical North Atlantic SST. *J. Climate*, 21, 5048-5060, http://dx.doi.org/10.1175/2008JCLI2232.1.
69. Foltz, G.R., and M.J. McPhaden, 2009: Impact of barrier layer thickness on SST in the central tropical North Atlantic. *J. Climate*, 22(2), 285-299, http://dx.doi.org/10.1175/2008JCLI2308.1.
70. Foltz, G., and M. J. McPhaden, 2010a: Abrupt equatorial wave-induced cooling of the Atlantic cold tongue in 2009. *Geophys. Res. Lett.*, 37 (24), http://dx.doi.org/10.1029/2010gl045522.
71. Foltz, G. R., and M. J. McPhaden, 2010b: Interaction between the Atlantic meridional and Nino modes. *Geophys. Res. Lett*., L18604, http://dx.doi.org/10.1029/2010GL044001.
72. Foltz, G. R., M. J. McPhaden and R. Lumpkin, 2012: A strong Atlantic Meridional Mode event in 2009: the role of mixed layer dynamics. *J. Climate*, 25, 363—380, http://dx.doi.org/10.1175/JCLI-D-11-00150.1.
73. Foltz, G. R., C. Schmid and R. Lumpkin, 2013a: Seasonal cycle of the mixed layer heat budget in the northeastern tropical Atlantic Ocean. *J. Climate*, 26, 8169-1811, http://dx.doi.org/10.1175/JCLI-D-13-00037.1.
74. Foltz, G. R., A. T. Evan, H. P. Freitag, S. Brown, and M. J. McPhaden, 2013b: Dust accumulation biases in PIRATA shortwave radiation records. *J. Atmos. Ocean. Tech*., 30, 1414-1432. http://dx.doi.org/10.1175/JTECH-D-12-00169.1.
75. Foltz, G., C. Schmid and R. Lumpkin, 2015: Transport of surface freshwater from the equatorial to the subtropical North Atlantic Ocean. *J. Phys. Oceanogr*., 45 (4), 1086-1102, http://dx.doi.org/10.1175/JPO-D-14-0189.1.

76. Foltz, G., C. Schmid, and R.Lumpkin, 2018: An enhanced PIRATA data set for tropical Atlantic ocean-atmosphere research. J. Climate. doi:10.1175/JCLI-D-16-0816.1, in press.
77. Freeman, E., S. D. Woodruff, S. J. Worley, S. J. Lubker, E. C. Kent, W. E. Angel, D. I. Berry, P. Brohan, R. Eastman, L. Gates W. Gloeden, Z. Ji, J. Lawrimore, N. A. Rayner, G. Rosenhagen, and S. R. Smith, 2016: ICOADS Release 3.0: a major update to the historical marine climate record. *Int. J. Climatol*., http://dx.doi.org/10.1002/joc.4775.
78. Galloudec, F. Messal, and L. Parent, 2009: The GODAE/Mercator-Ocean global ocean forecasting system: results, applications and prospects, *J. Operational Oceanography*, 1 (1), 51-57.
79. Giarolla, E., L. S. P. Siqueira, M. J. Bottino, M. Malagutti, V. B. Capistrano, and P. Nobre, 2015: Equatorial Atlantic Ocean dynamics in a coupled ocean–atmosphere model simulation. *Ocean Dynamics*, 65 (6), 831-843.
80. Giordani, H., and G. Caniaux, 2011: Diagnosing vertical motion at the equatorial Atlantic. *Ocean Dynamics*, 61, 1995–2018, http://dx.doi.org/10.1007/s10236-011-0467-7.
81. Giordani, H., G. Caniaux, and A. Voldoire, 2013: Intraseasonal mixed-layer heat budget in the equatorial Atlantic during the cold tongue development in 2006. *J. Geophys. Res. Oceans*, 118, 650–671, http://dx.doi.org/10.1029/2012JC008280.
82. Giordani, H., and G. Caniaux, 2014: Frontogenesis in the equatorial front formation in 2006. *Clim. Dyn*., 43 (11), 3147-3162, http://dx.doi.org/10.1007/s00382-014-2293-3.
83. Goes, M., G. Goni, and K. Keller, 2013: Reducing Biases in XBT Measurements by Including Discrete Information from Pressure Switches. *J. Atmos. Oceanic Technol*., 30, 810–824, http://dx.doi.org/10.1175/JTECH-D-12-00126.1.
84. Grodsky, S.A., A. Bentamy, J.A. Carton and R.T. Pinker, 2009: Intraseasonal Latent Heat Flux Based on Satellite Observations. *J. Climate*, 22, 4539–4556, http://dx.doi.org/10.1175/2009JCLI2901.1.
85. Grodsky, S. A., J. A. Carton, S. Nigam and Y. M. Okumura, 2012: Tropical Atlantic Biases in CCSM4. *J. Climate*, 25, 3684–3701, http://dx.doi.org/ http://dx.doi.org/10.1175/JCLI-D-11-00315.1.
86. Grodsky, S. A., J. A. Carton, and F. O. Bryan, 2014a: A curious local surface salinity maximum in the northwestern tropical Atlantic. *J. Geophys. Res. Oceans*, 119, 484–495, http://dx.doi.org/10.1002/2013JC009450.
87. Grodsky, S. A., G. Reverdin, J. A. Carton, and V. J. Coles, 2014b: Year-to-year salinity changes in the Amazon plume: Contrasting 2011 and 2012 Aquarius/SACD and SMOS satellite data. *Remote Sensing of Environment*, 140, 14-22, http://dx.doi.org/10.1016/j.rse.2013.08.033.
88. Grodsky, S. A., B. K. Johnson, J. A. Carton, and F. O. Bryan, 2015: Interannual Caribbean salinity in satellite data and model simulations. *J. Geophys. Res. Oceans*, 120, 1375–1387, http://dx.doi.org/10.1002/2014JC010625.
89. Goes, M., G. Goni, and K. Keller, 2013: Reducing Biases in XBT Measurements by Including Han, W., P.J. Webster, J.L. Lin, W.T. Liu, R. Fu, D. Yuan, and A. Hu, 2008: Dynamics of Intraseasonal Sea Level and Thermocline Variability in the Equatorial Atlantic during 2002–03. *J. Phys. Oceanogr*., 38, 945–967, http://dx.doi.org/10.1175/2008JPO3854.1.
90. Goes, M., E. Babcock, F. Bringas, P. Ortner, and G. Goni, 2017: The impact of improved thermistor calibration on the Expendable Bathythermograph profile data. *J. Atmos. Oceanic Technol.*, https://doi.org/10.1175/JTECH-D-17-0024.1.
91. Hahn, J., P. Brandt, R. J. Greatbatch, G. Krahmann and A. Körtzinger, 2014: Oxygen variance and meridional oxygen supply in the Tropical North East Atlantic oxygen minimum zone. *Clim. Dyn*., 43 (11), 2999-3024, http://dx.doi.org/10.1007/s00382-014-2065-0.
92. Han, W., P.J. Webster, J.L. Lin, W.T. Liu, R. Fu, D. Yuan, and A. Hu, 2008: Dynamics of Intraseasonal Sea Level and Thermocline Variability in the Equatorial Atlantic during 2002–03. *J. Phys. Oceanogr*., 38, 945–967, http://dx.doi.org/10.1175/2008JPO3854.1.
93. Henocq, C., J. Boutin, G. Reverdin, F. Petitcolin, S. Arnault and P. Lattes, 2010: Vertical Variability of Near-Surface Salinity in the Tropics: Consequences for L-Band Radiometer Calibration and Validation. *J. Atmos. Oceanic Technol*., 27, 192–209, http://dx.doi.org/10.1175/2009JTECHO670.1.
94. Herbert, G., B. Bourlès, P. Penven, and J. Grelet, 2016: New insights on the upper layer circulation north of the Gulf of Guinea. *J. Geophys. Res. Oceans*, 121, 6793–6815, http://dx.doi.org/10.1002/2016JC01195.
95. Hernandez, O., J. Jouanno, and F. Durand, 2016: Do the Amazon and Orinoco freshwater plumes really matter for hurricane-induced ocean surface cooling?, *J. Geophys. Res. Oceans*, 121, 2119–2141, http://dx.doi.org/10.1002/2015JC011021.
96. Hersbach, H., 2010: Comparison of C-Band Scatterometer CMOD5.N Equivalent Neutral Winds with ECMWF. *J. Atmos. Oceanic Technol*., 27, 721–736, http://dx.doi.org/10.1175/2009JTECHO698.1.
97. Hormann, V. and P. Brandt, 2009: Upper equatorial Atlantic variability during 2002 and 2005 associated with equatorial Kelvin waves. *J. Geophys. Res*., 114, C03007, http://dx.doi.org/10.1029/2008JC005101.

98. Hormann, V., R. Lumpkin and G. Foltz, 2012: Interannual North Equatorial Countercurrent Variability and its Relation to Tropical Atlantic Climate Modes. *J. Geophys. Res.*, 117, C04035, http://dx.doi.org/10.1029/2011JC007697.
99. Hormann, V., R. Lumpkin and R. C. Perez, 2013: A generalized method for estimating the structure of the equatorial Atlantic cold tongue: application to drifter observations. *J. Atmos. Oceanic Techn.*, 30, 1884–1895, http://dx.doi.org/10.1175/JTECH-D-12-00173.1.
100. Hounsou-gbo, G. A., M. Araujo, B. Bourlès, D. Veleda, and J. Servain, 2015: Tropical Atlantic contributions to strong rainfall variability along the Northeast Brazilian coast. *Advances in Meteorology*, 2015, Article ID 902084, http://dx.doi.org/10.1155/2015/902084.
101. Hounsou-Gbo, G. A., J. Servain, M. Araujo, E. S. Martins, B. Bourlès, and G. Caniaux, 2016: Oceanic Indices for Forecasting Seasonal Rainfall over the Northern Part of Brazilian Northeast. *American Journal of Climate Change*, 5 (2), 261-274.
102. Hu, Z-Z, A. Kumar, B. Huang, and J. Zhu, 2013: Leading Modes of the Upper-Ocean Temperature Interannual Variability along the Equatorial Atlantic Ocean in NCEP GODAS. *J. Climate*, 26, 4649–4663, http://dx.doi.org/10.1175/JCLI-D-12-00629.1.
103. Hummels, R., M. Dengler, and B. Bourlès, 2013: Seasonal and regional variability of upper ocean diapycnal heat flux in the Atlantic Cold Tongue. *Prog. Oceanogr.*, 111, 52—74, http://dx.doi.org/10.1016/j.pocean.2012.11.001.
104. Hummels, R., M. Dengler, P. Brandt, and M. Schlundt, 2014: Diapycnal heat flux and mixed layer heat budget within the Atlantic Cold Tongue. *Clim. Dyn.*, 43 (11), 3179—3199, http://dx.doi.org/10.1007/s00382-014-2339-6.
105. Imbol Koungue, R. A., S. Illig, and M. Rouault, 2017: Role of interannual Kelvin wave propagations in the equatorial Atlantic on the Angola Benguela Current system. *J. Geophys. Res. Oceans*, 122, 4685–4703, http://dx.doi.org/10.1002/2016JC012463.
106. Ivar do Sul, J. A., M. F. Costa, M. Barletta and F. J. A. Cysneiros, 2013: Pelagic microplastics around an archipelago of the Equatorial Atlantic. *Marine Pollution Bulletin*, 75, 305—309, http://dx.doi.org/10.1016/j.marpolbul.2013.07.040.
107. Jin, X., L. Yu, D.L. Jackson, and G.A. Wick, 2015: An Improved Near-Surface Specific Humidity and Air Temperature Climatology for the SSM/I Satellite Period. *J. Atmos. Oceanic Technol.*, 32, 412–433, http://dx.doi.org/10.1175/JTECH-D-14-00080.1.
108. Johns, W. E., P. Brandt, B. Bourlès, A. Tantet, A. Papapostolou and A. Houk, 2014a: Zonal Structure and Seasonal Variability of the Atlantic Equatorial Undercurrent. *Clim. Dyn.*, 43 (11), 3047-3069, http://dx.doi.org/10.1007/s00382-014-2136-2.
109. Johns, W. E., P. Brandt and P. Chang, 2014b: Tropical Atlantic variability and coupled model climate biases: results from the Tropical Atlantic Climate Experiment (TACE). *Clim. Dyn.*, 43 (11), 2887, http://dx.doi.org/10.1007/s00382-014-2392-1.
110. Jouanno, J., F. Marin, Y. du Penhoat, J. Sheinbaum, and J.-M. Molines, 2011a: Seasonal heat balance in the upper 100 m of the equatorial Atlantic Ocean. *J. Geophys. Res.*, 116, C09003, http://dx.doi.org/10.1029/2010JC006912.
111. Jouanno, J., F. Marin, Y. Du Penhoat, J.-M. Molines, and J. Sheinbaum, 2011b: Seasonal modes of surface cooling in the Gulf of Guinea. *J. Phys. Oceanogr.*, 41, 1408-1416, http://dx.doi.org/10.1175/JPO-D-11-031.1.
112. Jouanno, J., F. Marin, Y. Du Penhoat, and J.M. Molines, 2013: Intraseasonal modulation of the surface cooling in the Gulf of Guinea. *J. Phys. Oceanogr.*, 43 (2), http://dx.doi.org/10.1175/JPO-D-12-053.1.
113. Kako, S., A. Isobe, and M. Kubota, 2011: High-resolution ASCAT wind vector data set gridded by applying an optimum interpolation method to the global ocean. *J. Geophys. Res.*, 116, D23107, http://dx.doi.org/10.1029/2010JD015484.
114. Kako, S., A. Okuro, and M. Kubota, 2017: Effectiveness of using multisatellite wind speed estimates to construct hourly wind speed datasets with diurnal variations. *J. Atmos. Oceanic Technol.*, 34, 631–642, http://dx.doi.org/10.1175/JTECH-D-16-0179.1.
115. Kara, A. B., and C. N. Barron, 2007: Fine-resolution satellite-based daily sea surface temperatures over the global ocean. *J. Geophys. Res.*, 112, C05041, http://dx.doi.org/10.1029/2006JC004021.
116. Kara, A. B., A. J. Wallcraft, and M. A. Bourassa, 2008: Air-sea stability effects on the 10 m winds over the global ocean: Evaluations of air-sea flux algorithms. *J. Geophys. Res.*, 113, C04009, http://dx.doi.org/10.1029/2007JC004324.
117. Karagali, I., J. L. Høyer, and C. J. Donlon, 2017: Using a 1-D model to reproduce the diurnal variability of SST. *J. Geophys. Res. Oceans*, 122, http://dx.doi.org/10.1002/2016JC012542.
118. Kato, S., N.G. Loeb, F.G. Rose, D.R. Doelling, D.A. Rutan, T.E. Caldwell, L. Yu, and R.A. Weller, 2013: Surface Irradiances Consistent with CERES-Derived Top-of- Atmosphere Shortwave and Longwave Irradiances. *J. Climate*, 26, 2719– 2740, http://dx.doi.org/10.1175/JCLI-D-12-00436.1.

119. Klepp, C., 2015: The Oceanic Shipboard Precipitation Measurement Network for Surface Validation: OceanRAIN. *Atmospheric Res*., 163, http://dx.doi.org/10.1016/j.atmosres.2014.12.014.
120. Koffi, U., N. Lefevre, G. Kouadio and J. Boutin, 2010: Surface CO2 parameters and air-sea CO2 flux distribution in the eastern equatorial Atlantic Ocean. *J. Mar. Sys*., 82, 135-144, http://dx.doi.org/10.1016/j.jmarsys.2010.04.010.
121. Kolodziejczyk, N., B. Bourlès, F. Marin, J. Grelet and R. Chuchla, 2009: The seasonal variability of the Equatorial Undercurrent and the South Equatorial Undercurrent at 10°W as inferred from recent in situ observations, *J. Geophys. Res*., 114, C06014, http://dx.doi.org/10.1029/2008JC004976.
122. Kolodziejczyk, N., F.Marin, B.Bourlès, Y.Gouriou, and H. Berger, 2014: Seasonal variability of the Equatorial Undercurrent termination and associated salinity maximum in the Gulf of Guinea. *Clim. Dyn*., 43 (11), 3025—2046, http://dx.doi.org/10.1007/s00382-014-2107-7.
123. Kolodziejczyk, N., G. Reverdin, and A. Lazar, 2015: Interannual Variability of the Mixed Layer Winter Convection and Spice Injection in the Eastern Subtropical North Atlantic. *J. Phys. Oceanogr*., 45, 504–525, http://dx.doi.org/10.1175/JPO-D-14-0042.1.
124. Large, W. G., and S. G. Yeager, 2009: Global climatology of an interannually varying air–sea flux data set. Climate Dynamics, 33 (2-3), 341-364, http://dx.doi.org/10.1007/s00382-008-0441-3.
125. Lebel, T., D. J. Parker, C. Flamant, B. Bourlès, B. Marticorena, E. Mougin, C. Peugeot, A. Diedhiou, J. M. Haywood, J. B. Ngamini, J. Polcher, J.-L. Redelsperger and C. D. Thorncroft, 2010: The AMMA field campaign: multiscale and multidisciplinary observations in the West African region. *Quart. J. Royal Met. Soc*., http://dx.doi.org/10.1002/qj.486.
126. Leduc-Leballeur, M., Eymard, L. and de Coëtlogon, G., 2011: Observation of the marine atmospheric boundary layer in the Gulf of Guinea during the 2006 boreal spring. *Q.J.R. Meteorol. Soc*., 137, 992–1003, http://dx.doi.org/10.1002/qj.808.
127. Lee, T., G. Lagerloef, H.-Y. Kao, M. J. McPhaden, J. Willis, and M. M. Gierach, 2014: The influence of salinity on tropical Atlantic instability waves. *J. Geophys. Res. Oceans*, 119, 8375–8394, http://dx.doi.org/10.1002/2014JC010100.
128. Lefèvre, N., A. Guillot, L. Beaumont, and T. Ganguy, 2008: Variability of fCO2 in the Eastern Tropical Atlantic from a moored buoy. *J. Geophys. Res.*, 113, C01015, http://dx.doi.org/10.1029/2007JC004146.
129. Lefèvre, N. and L. Merlivat, 2012: Carbon and oxygen net community production in the eastern tropical Atlantic estimated from a moored buoy. *Global Biogeochem. Cycles*, 26, GB1009, http://dx.doi.org/10.1029/2010GB004018.
130. Lefèvre, N., G. Caniaux, and S. Janicot, 2013: Increased CO2 outgassing in January-March 2010 in the tropical Atlantic following the 2009 Pacific El Niño. *J. Geophys. Res*, 118 (4), 1645-1657, http://dx.doi.org/10.1002/jgrc.20107.
131. Lefèvre, N., D. F. Urbano, F. Gallois, and D. Diverrès, 2014: Impact of physical processes on the seasonal distribution of the fugacity of CO2 in the western tropical Atlantic. *J. Geophys. Res. Oceans*, 119, 646–663, http://dx.doi.org/10.1002/2013JC009248.
132. Lefèvre N., D. Veleda, M. Araujo, G. Caniaux, 2016: Variability and trends of carbon parameters at a time-series in the Eastern Tropical Atlantic. *Tellus B*, 68, 30305, http://dx.doi.org/10.3402/tellusb.v68.30305.
133. Legler, D., H. J. Freeland, R. Lumpkin, G. Ball, M. J. McPhaden, S. North, R. Cowley, G. Goni, U. Send and M. Merrifield, 2015: The current status of the real-time in situ global ocean observing system for operational oceanography. *J. Operational Oceanography*, 8 (S2), 189-200, http://dx.doi.org/10.1080/1755876X.2015.1049883
134. Lellouche, J.-M., O. Le Galloudec, M. Drévillon, C. Régnier, E. Greiner, G. Garric, N. Ferry, C. Desportes, C.-E. Testut, C. Bricaud, R. Bourdallé-Badie, B. Tranchant, M. Benkiran, Y. Drillet, A. Daudin, and C. De Nicola, 2012, Evaluation of real time and future global monitoring and forecasting systems at Mercator Océan. *Ocean Sci. Discuss*., 9, 1123-1185, http://dx.doi.org/10.5194/osd-9-1123-2012.
135. Levitus, S., J. Antonov, T. Boyer, J. Reagan and C. Schmid, 2011: Subsurface Salinity. In State of the Climate in 2010, ed. J. Blunden, D. S. Arndt, M. O. Baringer, *Bull. Amer. Meteor. Soc*., 92 (6),S1-S236, http://dx.doi.org/10.1175/1520-0477-92.6.S1.
136. Li, H., F. Xu, W. Zhou, D. Wang, J. S. Wright, Z. Liu, and Y. Lin, 2017: Development of a global gridded Argo data set with Barnes successive corrections. *J. Geophys. Res. Oceans*, 122, 866–889, http://dx.doi.org/10.1002/2016JC012285.
137. Lins, I.D., M. Araujo, M.C. Moura, M.A. Silva and E.L. Droguett, 2013: Prediction of Sea Surface Temperature in the Tropical Atlantic by Support Vector Machines. *Computational Statistics and Data Analysis*, 61:187–198, http://dx.doi.org/10.1016/j.csda.2012.12.003.
138. Liu, C., R. P. Allan, M. Mayer, P. Hyder, N. G. Loeb, C. D. Roberts, M. Valdivieso, J. M. Edwards, and P.-L. Vidale, 2017: Evaluation of satellite and reanalysis-based global net surface energy flux and uncertainty estimates. *J. Geophys. Res. Atmos*., 122, 6250–6272, http://dx.doi.org/10.1002/2017JD026616.

139.Lübbecke, J. and M. J. McPhaden, 2012: On the inconsistent relationship between Atlantic and Pacific Niños. *J. Climate*, 25, 4294-4303, http://dx.doi.org/10.1175/JCLI-D-11-00553.1.

140.Lübbecke, J. and M. J. McPhaden, 2013: A comparative stability analysis of Atlantic and Pacific Niño modes. *J. Climate*, 26, 5965-5980. http://dx.doi.org/10.1175/JCLI-D-12-00758.1.

141.Lübbecke, J. F., N. L. Burls, C. J. C. Reason, and M. J. McPhaden, 2014: Variability in the South Atlantic anticyclone and the Atlantic Niño mode. *J. Climate*, 27, 8135–8150, http://dx.doi.org/10.1175/JCLI-D-14-00202.1.

142.Lübbecke, J. F., J. V. Durgadoo, and A. Biastoch, 2015: Contribution of Increased Agulhas Leakage to Tropical Atlantic Warming. *J. Climate*, 28, 9697–9706, http://dx.doi.org/10.1175/JCLI-D-15-0258.1.

143.Ma, Y., and R. T. Pinker, 2012, Modeling shortwave radiative fluxes from satellites, *J. Geophys. Res*., 117, D23202, http://dx.doi.org/10.1029/2012JD018332.

144.McPhaden, M.J., K. Ando, B. Bourlès, H. P. Freitag, R. Lumpkin, Y. Masumoto, V. S. N. Murty, P. Nobre, M. Ravichandran, J. Vialard, D. Vousden, W. Yu, 2010: The global tropical moored buoy array. in *Proceedings of OceanObs'09: Sustained Ocean Observations and Information for Society (Vol. 2)*, Venice, Italy, 21-25 September 2009, Hall, J., Harrison, D.E. and Stammer, D., Eds., ESA Publication WPP-306, http://dx.doi.org/10.5270/OceanObs09.cwp.61.

145.Marin, F., G. Caniaux, B. Bourlès, H. Giordani, Y. Gouriou and E. Key, 2009: Why were sea surface temperatures so different in the eastern equatorial Atlantic in June 2005 and 2006? *J. Phys. Oceanogr*., 39, 1416-1431, http://dx.doi.org/10.1175/2008JPO4030.1.

146.Martins, S., M., N. Serra, and D. Stammer, 2015: Spatial and temporal scales of sea surface salinity variability in the Atlantic Ocean. *J. Geophys. Res. Oceans*, 120, 4306–4323, http://dx.doi.org/10.1002/2014JC010649.

147.Marullo, S., R. Santoleri, V. Banzon, R. H. Evans, and M. Guarracino, 2010: A diurnal-cycle resolving sea surface temperature product for the tropical Atlantic. *J. Geophys. Res*., 115, C05011, http://dx.doi.org/10.1029/2009JC005466.

148.May, J., C. Rowley, and C. Barron, 2017a: NFLUX satellite-based surface radiative heat fluxes. Part I: Swath-level products. *J. Appl. Meteor. Climatol*., 56, 1025–1041, http://dx.doi.org/10.1175/JAMC-D-16-0282.1.

149.May, J.C., C. Rowley, and C.N. Barron, 2017b: NFLUX Satellite-Based Surface Radiative Heat Fluxes. Part II: Gridded Products. *J. Appl. Meteor. Climatol*., 56, 1043–1057, http://dx.doi.org/10.1175/JAMC-D-16-0283.1.

150.Merchant, C. J., O. Embury, N. A. Rayner, D. I. Berry, G. K. Corlett, K. Lean, K. L. Veal, E. C. Kent, D. T. Llewellyn-Jones, J. J. Remedios, and R. Saunders, 2012: A 20 year independent record of sea surface temperature for climate from Along-Track Scanning Radiometers, *J. Geophys. Res*., 117, C12013, http://dx.doi.org//10.1029/2012JC008400.

151.Meyers, P. C., L. K. Shay and J. K. Brewster, 2014: Development and Analysis of the Systematically Merged Atlantic Regional Temperature and Salinity Climatology for Oceanic Heat Content Estimates. *J. Atmos. Oceanic Technol*., 31, 131–149, http://dx.doi.org/10.1175/JTECH-D-13-00100.1.

152. Meynadier, R., G. de Coëtlogon, S. Bastin, L. Eymard and S. Janicot, Sensitivity testing of WRF parameterizations on air–sea interaction and its impact on water cycle in the Gulf of Guinea, 2015, *Q. J. R. Meteorol. Soc.* 141: 1804–1820, DOI:10.1002/qj.2483.

153.Morrissey, M. L., H. J. Diamond, M. J. McPhaden, H. P. Freitag and J. S. Greene, 2012: An Investigation of the Consistency of TAO–TRITON Buoy-Mounted Capacitance Rain Gauges, *J. Atmos. Oceanic Technol.*, 29, 834–845, http://dx.doi.org/10.1175/JTECH-D-11-00171.1.

154.Nalli, N. R., E. Joseph, V. Morris, C. Barnet, W. Wolf, D. Wolfe, P. J. Minnett, M. Szczodrak, M. Izaguirre, R. Lumpkin, H. Xie, A. Smirnov and J. Wei, 2011: Multi-year observations of the tropical Atlantic atmosphere: Multidisciplinary applications of the NOAA Aerosols and Ocean Science Expeditions (AEROSE). *Bull. Amer. Meteor. Soc.*, 92, 765–789, http://dx.doi.org/10.1175/2011BAMS2997.1.

155. Nalli, N. R., C. D. Barnet, A. Reale, D. Tobin, A. Gambacorta, E. S. Maddy, E. Joseph, B. Sun, L. Borg, A.K. Mollner, V. R. Morris, X. Liu, M. Divakarla, P. J. Minnett, R.O. Knuteson, T.S. King, W.W. Wolf**,** 2013: Validation of satellite sounder environmental data records: Application to the Cross-track Infrared Microwave Sounder Suite. *J. Geophys. Res. Atmos*., 118, 13,628–13,643, http://dx.doi.org/10.1002/2013JD020436.

156.Nalli, N., C. Barnet, T. Reale, Q. Liu, V. Morris, J. Spackman, E. Joseph, C. Tan, B. Sun, F. Tilley, L. Leung, and D. Wolfe, 2016: Satellite Sounder Observations of Contrasting Tropospheric Moisture Transport Regimes: Saharan Air Layers, Hadley Cells, and Atmospheric Rivers. *J. Hydrometeor*., 17, 2997–3006, http://dx.doi.org/10.1175/JHM-D-16-0163.1.

157.Nobre, P., R. A. De Almeida, M. Malagutti , and E. Giarolla, 2012: Coupled Ocean-Atmosphere Variations over the South Atlantic Ocean. *J. Climate*, 25, 6349–6358, http://dx.doi.org/10.1175/JCLI-D-11-00444.1.

158. Nubi, O. A., B. Bourlès B., C. A. Edokpayi and M. N. Hounkonnou, 2016: On the Nutrient distribution and phytoplankton biomass in the Gulf of Guinea equatorial band as inferred from In-situ measurements. *J. Oceanogr. and Marine Sci*., 7 (1), 1-11, http://dx.doi.org/10.5897/JOMS2016.0124.
159. Okumura, Y. and S. P. Xie, 2006: Some Overlooked Features of Tropical Atlantic Climate Leading to a New Niño-Like Phenomenon. *J. Climate*, 19, 5859–5874, http://dx.doi.org/10.1175/JCLI3928.1.
160. Parard, G., Lefèvre, N. and Boutin, J., 2010: Sea water fugacity of CO2 at the PIRATA mooring at 6°S, 10°W. *Tellus B*, 62, 636–648, http://dx.doi.org/10.1111/j.1600-0889.2010.00503.x.
161. Parard, G., J. Boutin, Y. Cuypers, P. Bouruet-Aubertot, and G. Caniaux, 2014: On the physical and biogeochemical processes driving the high frequency variability of CO2 fugacity at 6°S, 10°W: Potential role of the internal waves. *J. Geophys. Res. Oceans*, 119, 8357–8374, http://dx.doi.org/10.1002/2014JC009965.
162. Peng, G., H-M Zhang, H. P. Frank, J.-R. Bidlot, M. Higaki, S. Stevens and W. R. Hankins, 2013: Evaluation of Various Surface Wind Products with OceanSITES Buoy Measurements. *Wea. Forecasting*, 28, 1281–1303, http://dx.doi.org/10.1175/WAF-D-12-00086.1.
163. Peng, G., J.-R. Bidlot, H. P. Freitag, and C. J. Schreck III, 2014: Directional Bias of TAO Daily Buoy Wind Vectors in the Central Equatorial Pacific Ocean from November 2008 to January 2010. *Data Science Journal*, 13:0, 79-87, http://dx.doi.org/10.2481/dsj.14-019.
164. Penny, S. G., D. W. Behringer, J. A. Carton, and E. Kalnay, 2015: A Hybrid Global Ocean Data Assimilation System at NCEP. *Mon. Wea. Rev*., 143, 4660–4677, http://dx.doi.org/10.1175/MWR-D-14-00376.1.
165. Perez, R. C., R. Lumpkin, W. E. Johns, G. R. Foltz and V. Hormann, 2012: Interannual variations of Atlantic tropical instability waves. *J. Geophys. Res*., 117, C03011, http://dx.doi.org/10.1029/2011JC007584.
166. Perez, R., V. Hormann, R. Lumpkin, P. Brandt, W. E. Johns, F. Hernandez, C. Schmid and B. Bourlès, 2014: Mean meridional currents in the central and eastern equatorial Atlantic. *Climate Dynamics*, 43 (11), 2943-2962, http://dx.doi.org/10.1007/s00382-013-1968-5.
167. Peter, A.C., M. Le Henaff, Y. du Penhoat, C.E. Menkes, F. Marin, J. Vialard, G. Caniaux, and A. Lazar, 2006: A model study of the seasonal mixed layer heat budget in the equatorial Atlantic. *J. Geophys. Res.*, 111, C06014, http://dx.doi.org/10.1029/2005JC003157.
168. Pilotto, I.L., S. C. Chou, and P. Nobre, 2012: Seasonal climate hindcasts with Eta model nested in CPTEC coupled ocean–atmosphere general circulation model. *Theoretical and Applied Climatology*, 110:3, 437-456, http://dx.doi.org/10.1007/s00704-012- 0633-y.
169. Pimenta, F., W. Kempton and R. Garvine, 2008: Combining meteorological stations and satellite data to evaluate the offshore wind power resource of Southeastern Brazil. *Renewable Energy*, 33 (11), 2375-2387.
170. Pinker, R. T., H. Wang, and S. A. Grodsky, 2009: How good are ocean buoy observations of radiative fluxes? *Geophys. Res. Lett*., 36, L10811, http://dx.doi.org/10.1029/2009GL037840.
171. Pinker, R. T., A. Bentamy, K. B. Katsaros, Y. Ma, and C. Li, 2014: Estimates of net heat fluxes over the Atlantic Ocean. *J. Geophys. Res. Oceans*, 119, 410–442, http://dx.doi.org/10.1002/2013JC009386.
172. Polo, I., A. Lazar, B. Rodriguez-Fonseca, and S. Arnault, 2008: Oceanic Kelvin Waves and Tropical Atlantic intraseasonal Variability. Part I: Kelvin wave characterization. *J. Geophys. Res*., 113, C07009, http://dx.doi.org/10.1029/2007JC004495.
173. Portabella, M., A. Stoffelen, 2009: On Scatterometer Ocean Stress. *J. Atmos. Oceanic Technol*., 26, 368–382, http://dx.doi.org/10.1175/2008JTECHO578.1.
174. Prakash, S., Mahesh C., R. M. Gairola, S. Pokhrel, 2011: Surface Freshwater Flux Estimation Using TRMM Measurements Over the Tropical Oceans. *Atmospheric and Climate Sciences*, 01:04, 225-234, http://dx.doi.org/10.4236/acs.2011.14025.
175. Prakash, S., C. Mahesh and R. M. Gairola, 2013: Comparison of TRMM Multi-satellite Precipitation Analysis (TMPA)-3B43 version 6 and 7 products with rain gauge data from ocean buoys. *Remote Sensing Lett.*, 4 (7), 677-685, http://dx.doi.org/10.1080/2150704X.2013.783248.
176. Praveen Kumar, B., J. Vialard, M. Lengaigne, V. S. N. Murty and M. J. McPhaden, 2012: TropFlux: Air-Sea Fluxes for the Global Tropical Oceans: Description and evaluation. *Clim. Dynamics*, 38, 1521-1543, http://dx.doi.org/10.1007/s00382-011-1115-0.
177. Praveen Kumar, B., J. Vialard, M. Lengaigne, V.S.N. Murty, M.J. McPhaden, M.F. Cronin, F. Pinsard and K. Gopala Reddy, 2013: TropFlux wind stresses over the tropical oceans: evaluation and comparison with other products. *Clim. Dynamics*, 40, 2049-2071, http://dx.doi.org/10.1007/s00382-012-1455-4.
178. Prigent, C., F. Aires, F. Bernardo, J.-C. Orlhac, J.-M. Goutoule, H. Roquet, and C. Donlon, 2013: Analysis of the potential and limitations of microwave radiometry for the retrieval of sea surface temperature: Definition of MICROWAT, a new mission concept. *J. Geophys. Res. Oceans*, 118, 3074–3086, http://dx.doi.org/10.1002/jgrc.20222.

179. Reason, C. J. C. and M. Rouault, 2006: Sea surface temperature variability in the tropical southeast Atlantic Ocean and West African rainfall. *Geophys. Res. Lett.*, 33, L21705, http://dx.doi.org/10.1029/2006GL027145.

180. Reverdin, G., F. Marin, B.Bourlès and P. L'Herminier, 2008: XBT temperature errors during French research cruises (1999-2007). *J. Atm. Oc. Tech.*, 26(11), 2462–2473, http://dx.doi.org/10.1175/2009JTECHO655.1.

181. Reynolds, R.W. and D.B. Chelton, 2010: Comparisons of Daily Sea Surface Temperature Analyses for 2007–08. *J. Climate*, 23, 3545-3562, http://dx.doi.org/10.1175/2010JCLI3294.1.

182. Rhein, M., M. Dengler, J. Sültenfuß, R. Hummels, S. Hüttl-Kabus, and B. Bourles, 2010: Upwelling and associated heat flux in the equatorial Atlantic inferred from helium isotope disequilibrium. *J. Geophys. Res*., 115, C08021, http://dx.doi.org/10.1029/2009JC005772.

183. Ricciardulli, L., and F. J. Wentz, 2015: A Scatterometer Geophysical Model Function for Climate-Quality Winds: QuikSCAT Ku-2011. *Journal of Atmospheric and Oceanic Technology*, 32:10, 1829-1846. http://dx.doi.org/10.1175/JTECH-D-15-0008.1.

184. Richter, I., S. K. Behera, Y. Masumoto, B. Taguchi, N. Komori, and T. Yamagata, 2010: On the triggering of Benguela Niños: Remote equatorial versus local influences. *Geophys. Res. Lett.*, 37, L20604, http://dx.doi.org/10.1029/2010GL044461.

185. Rodrigues, R. R. and M. J. McPhaden, 2014: Why did the 2011-12 La Niña cause a severe drought in the Brazilian Northeast? *Geophys. Res. Lett*., *41*, 1012–1018, http://dx.doi.org/10.1002/2013GL058703.

186. Rodríguez-Fonseca, B., E. Mohino, C. R. Mechoso, C. Caminade, M. Biasutti, M. Gaetani, J. Garcia-Serrano, E. K. Vizy, K. Cook, Y. Xue, I. Polo, T. Losada, L. Druyan, B. Fontaine, J. Bader, F. J. Doblas-Reyes, L. Goddard, S. Janicot, A. Arribas, W. Lau, A. Colman, M. Vellinga, D. P. Rowell, F. Kucharski, and A. Voldoire, 2015: Variability and Predictability of West African Droughts: A Review on the Role of Sea Surface Temperature Anomalies. *J. Climate*, 28, 4034–4060, http://dx.doi.org/10.1175/JCLI-D-14-00130.1

187. Roehrig, R., D. Bouniol, F. Guichard, F. Hourdin, and J.-L. Redelsperger, 2013: The Present and Future of the West African Monsoon: A Process-Oriented Assessment of CMIP5 Simulations along the AMMA Transect. *J. Climate*, 26, 6471–6505, http://dx.doi.org/10.1175/JCLI-D-12-00505.1.

188. Rouault, M., S. Illig, C. Bartholomae, C.J.C. Reason and A. Bentamy, 2007: Propagation and origin of warm anomalies in the Angola Benguela upwelling system in 2001. *J. Mar. Syst*., 68, 477-488.

189. Rouault, M., J. Servain, C.J.R. Reason, B. Bourles, and N. Fauchereau, 2009: Extension of PIRATA in the tropical South-East Atlantic: an initial one-year experiment. *African Journal of Marine Science*, 31(1): 63–71.

190. Rouault, M., S. Illig, J. Lübbecke, and R. A. Imbol Koungue, 2017: Origin, development and demise of the 2010–2011 Benguela Niño. *J. Marine Sys*., http://dx.doi.org/10.1016/j.jmarsys.2017.07.007.

191. Rugg, A., G. R. Foltz, and R. C. Perez, 2016: Role of mixed layer dynamics in tropical North Atlantic interannual sea surface temperature variability. *J. Climate*, 29, http://dx.doi.org/10.1175/JCLI-D-15-0867.1.

192. Salles, R., P. Mattos, A.-M. Dubois Iorgulescu, E. Bezerra, L. Lima, and E. Ogasawara, 2016: Evaluating temporal aggregation for predicting the sea surface temperature of the Atlantic Ocean. *Ecological Informatics*, **36**, 94-105, https://dx.doi.org/10.1016/j.ecoinf.2016.10.004.

193. Santorelli, A., R. T. Pinker, A. Bentamy, K. B. Katsaros, W. M. Drennan, A. M. Mestas-Nuñez, and J. A. Carton, 2011: Differences between two estimates of air-sea turbulent heat fluxes over the Atlantic Ocean. *J. Geophys. Res*., 116, C09028, http://dx.doi.org/10.1029/2010JC006927.

194. Sato, O. T., and P. S. Polito, 2008: Influence of salinity on the interannual heat storage trends in the Atlantic estimated from altimeters and Pilot Research Moored Array in the Tropical Atlantic data. *J. Geophys. Res.*, 113, C02008, http://dx.doi.org/10.1029/2007JC004151.

195. Schlundt, M., P. Brandt, M. Dengler, R. Hummels, T. Fischer, K. Bumke, G. Krahmann, and J. Karstensen, 2014: Mixed layer heat and salinity budgets during the onset of the 2011 Atlantic cold tongue. *J. Geophys. Res.-Oceans*, 119, 7882–7910, http://dx.doi.org/10.1002/2014JC010021.

196. Scott, R.B., C. N. Barron, M. Drévillon, N. Ferry, N. Jourdain, J-M. Lellouche, E. J. Metzger, M-H. Rio, and O. M. Smedstad, 2012: Estimates of surface drifter trajectories in the Equatorial Atlantic: a multi-model ensemble approach. *Ocean Modelling*, 67 (7), 1091—1109, http://dx.doi.org/10.1007/s10236-012-0548-2.

197. Sena Martins, M., N. Serra, and D. Stammer, 2015: Spatial and temporal scales of sea surface salinity variability in the Atlantic Ocean. *J. Geophys. Res. Oceans*, 120, 4306–4323, http://dx.doi.org/10.1002/2014JC010649.

198. Servain, J., G. Caniaux, Y. K. Kouadio, M. J. McPhaden, and M. Araujo, 2014: Recent climatic trends in the tropical Atlantic. *Clim. Dyn*., 43 (11), 3071-3089, http://dx.doi.org/10.1007/s00382-014-2168-7.

199. Silva, M., M. Araujo, J. Servain, P. Penven and C. A. D. Lentini, 2009: High-resolution regional ocean dynamics simulation in the southwestern tropical Atlantic. *Ocean Modelling*, 30, 256—269.

200. Silva, M., M. Araujo, J. Servain and P. Penven, 2009: Circulation and Heat Budget in a Regional Climatological Simulation of the Southwestern Tropical Atlantic. *Tropical Oceanography, Recife*, 37 (1-2), 41-57.
201. Siqueira, L. S. P. and P. Nobre, 2006: Tropical Atlantic Sea Surface Temperature and heat flux simulations in a coupled GCM. *Geophys. Res. Lett.*, 33, L15708, http://dx.doi.org/10.1029/2006GL026528.
202. Skielka, U. T., J. Soares and A. P. de Oliveira, 2010: Study of the equatorial Atlantic Ocean mixing layer using a one-dimensional turbulence model. *Brazilian J. of Oceanogr.*, 58 (3), 57—69.
203. Skielka, U. T., J. Soares, A. P. Oliveira and J. Servain, 2011: Diagnostic of the diurnal cycle of turbulence of the Equatorial Atlantic Ocean upper boundary layer. *Natural Science*, 3 (6), 444-455, http://dx.doi.org/10.4236/ns.2011.36061.
204. Soldatov, V. Y., N. Costica, and V. F. Krapivin, 2010: Diagnosis of Transition Processes in the Ocean-Atmosphere System. *Control Engineering and Applied Informatics*, 12 (2), 22-29.
205. Stockdale, T.N, M.A. Balmaseda, and A.P. Vidard, 2006: Tropical Atlantic SST prediction with coupled ocean-atmosphere GCMs. *J. Climate*, 19(23), 6047-6061, http://dx.doi.org/10.1175/JCLI3947.1.
206. Storto, A., S. Dobricic, S. Masina and P. Di Pietro, 2011: Assimilating Along-Track Altimetric Observations through Local Hydrostatic Adjustment in a Global Ocean Variational Assimilation System. *Mon. Wea. Rev*., 139, 738–754, http://dx.doi.org/10.1175/2010MWR3350.1.
207. Sukov, A. I., V. Yu. Soldatov, V. F. Krapivin, A. P. Cracknell and C. A. Varotsos, 2008: A sequential analysis method for the prediction of tropical hurricanes. *Int. J. of Remote Sensing*, 29 (9), 2787-2798, http://dx.doi.org/10.1080/01431160801927228.
208. Sun, C., and A. H. Monahan, 2013: Statistical Downscaling Prediction of Sea Surface Winds over the Global Ocean. *J. Climate*, 26, 7938–7956, http://dx.doi.org/10.1175/JCLI-D-12-00722.1.
209. Tang, W., S. H. Yueh, A. G. Fore, and A. Hayashi, 2014: Validation of Aquarius sea surface salinity with in situ measurements from Argo floats and moored buoys. *J. Geophys. Res. Oceans*, 119, 6171–6189, http://dx.doi.org/10.1002/2014JC010101.
210. Tchilibou, M., T. Delcroix, G. Alory, S. Arnault, and G. Reverdin, 2015: Variations of the tropical Atlantic and Pacific SSS minimum zones and their relations to the ITCZ and SPCZ rain bands (1979–2009). *J. Geophys. Res. Oceans*, 120, 5090–5100, http://dx.doi.org/10.1002/2015JC010836.
211. Ubelmann, C., J. Verron, J.-M. Brankart, P. Brasseur, and E. Cosme, 2012: Assimilating altimetric data to control the tropical instability waves: an observing system simulation experiment study. *Ocean Dynamics*, 62:6, 867-880, http://dx.doi.org/10.1007/s10236-012-0539-3.
212. Urbano, D. F., R. A. F. De Almeida, and P. Nobre, 2008: Equatorial Undercurrent and North Equatorial Countercurrent at 38°W: A new perspective from direct velocity data, *J. Geophys. Res*., 113, C04041, http://dx.doi.org/10.1029/2007JC004215.
213. Valdivieso, M., Haines, K., Balmaseda, M. et al., 2017: An assessment of air–sea heat fluxes from ocean and coupled reanalyses. *Clim. Dyn*., 49, 983-1008, http://dx.doi.org/10.1007/s00382-015-2843-3.
214. Veleda, D., R. Montagne and M. Araujo, 2012: Cross wavelet bias corrected by normalizing scales. , *J. Atmos. Oceanic Technol.*, 29, 1401-1408, http://dx.doi.org/10.1175/JTECH-D-11-00140.1.
215. Vidard, A., D. L. T. Anderson, and M. Balmaseda, 2007: Impact of ocean observation systems on ocean analysis and seasonal forecasts. *Mon. Weather Rev*., 135(2), 409-429, http://dx.doi.org/10.1175/MWR3310.1.
216. Vinogradova, N. T. and R. M. Ponte, 2012: Assessing temporal aliasing in satellite-based surface salinity measurements. *J. Atmos. Oceanic Techn*., 29, 1391-1400, http://dx.doi.org/10.1175/JTECH-D-11-00055.1.
217. Voldoire, A., M. Claudon, G. Caniaux, H. Giordani, and R. Roehrig, 2014: Are atmospheric biases responsible for the tropical Atlantic SST biases in the CNRM-CM5 coupled model? *Clim. Dyn*., 43 (11), 2963—2984, http://dx.doi.org/10.1007/s00382-013-2036-x.
218. Von Schuckmann, K., P. Brandt, C. Eden, 2008: Generation of Tropical Instability Waves in the Atlantic Ocean, *J. Geophys. Res*., 113, C08034, http://dx.doi.org/10.1029/2007JC004712.
219. Wade, M., G. Caniaux, Y. duPenhoat, M. Dengler, H. Giordani and R. Hummels, 2010: A one-dimensional modeling study of the diurnal cycle in the equatorial Atlantic at the PIRATA buoys during the EGEE-3 campaign. *Ocean Dynamics*, 61 (1), 1-20, http://dx.doi.org/10.1007/s10236-010-0337-8.
220. Wade, M., G. Caniaux, and Y. du Penhoat, 2011: Variability of the mixed layer heat budget in the eastern equatorial Atlantic during 2005–2007 as inferred using Argo floats. *J. Geophys. Res*., 116, C08006, http://dx.doi.org/10.1029/2010JC006683.
221. Wallcraft, A. J., A. B. Kara, C. N. Barron, E. J. Metzger, R. L. Pauley and M. A. Bourassa, 2009: Comparisons of monthly mean 10 m wind speeds from satellites and NWP products over the global ocean. *J. Geophys. Res*., 114, D16109, http://dx.doi.org/10.1029/2008JD011696.
222. Wang, H., and R. T. Pinker, 2009: Shortwave radiative fluxes from MODIS: Model development and implementation. *J. Geophys. Res.*, 114, D2021, http://dx.doi.org/10.1029/2008JD010442.

223. Wang, K., and R. E. Dickinson, 2013: Global atmospheric downward longwave radiation at the surface from ground-based observations, satellite retrievals, and reanalyses, *Rev. Geophys*., 51, 150–185, http://dx.doi.org/10.1002/rog.20009.

224. Wenegrat, J. O., M. J. McPhaden, and R.-C. Lien, 2014: Wind stress and near-surface shear in the equatorial Atlantic Ocean. *Geophys. Res. Lett*., 41, 1226–1231, http://dx.doi.org/10.1002/2013GL059149.

225. Wenegrat, J.O., and M.J. McPhaden, 2015: Dynamics of the surface layer diurnal cycle in the equatorial Atlantic Ocean (0°, 23°W). *J. Geophys. Res. Oceans*, 120, 563-581, http://dx.doi.org/10.1002/2014JC010504.

226. Wenegrat, J. O. and M. J. McPhaden, 2016: A simple analytical model of the diurnal Ekman layer. *J. Phys. Oceanogr*., 46, http://dx.doi.org/10.1175/JPO-D-16-0031.1.

227. Wentz, F. J., 2015: A 17-Yr Climate Record of Environmental Parameters Derived from the Tropical Rainfall Measuring Mission (TRMM) Microwave Imager. *Journal of Climate*, 28:17, 6882-6902, http://dx.doi.org/10.1175/JCLI-D-15-0155.1.

228. While, J., and M. Martin, 2013: Development of a variational data assimilation system for the diurnal cycle of sea surface temperature. *J. Geophys. Res. Oceans*, 118, 2845–2862, http://dx.doi.org/10.1002/jgrc.20215.

229. Wild, M., D. Folini, M.Z. Hakuba, C. Schär, S. Seneviratne, S. Kato, D. Rutan, C. Ammann, E. F. Wood, and G. König-Langlo, 2014: The energy balance over land and oceans: an assessment based on direct observations and CMIP5 climate models. *J. Climate Dynamics*, 11-Dec-2014, http://dx.doi.org/10.1007/s00382-014-2430-z.

230. Woodruff, S. D., S. J. Worley, S. J. Lubker, Z. Ji, J. E. Freeman, D. I. Berry, P. Brohan, E. C. Kent, R. W. Reynolds, S. R. Smith, and C. Wilkinson, 2011: ICOADS Release 2.5: extensions and enhancements to the surface marine meteorological archive. *Int. J. of Clim.*, 31, 7, 951-967, http://dx.doi.org/10.1002/joc.2103.

231. Xiangze, J. L. Yu, D. L. Jackson, and G. A. Wick, 2015: An Improved Near-Surface Specific Humidity and Air Temperature Climatology for the SSM/I Satellite Period. *J. Atmos. Oceanic Technol.*, 32, 412–433, http://dx.doi.org/10.1175/JTECH-D-14-00080.1

232. Xie, P., R. Joyce, S. Wu, S. Yoo, Y. Yarosh, F. Sun, and R. Lin, 2017: Reprocessed, Bias-Corrected CMORPH Global High-Resolution Precipitation Estimates from 1998. *J. Hydrometeor.*, 18, 1617–1641, https://doi.org/10.1175/JHM-D-16-0168.1

233. Xu, F. and A. Ignatov, 2010: Evaluation of in situ sea surface temperatures for use in the calibration and validation of satellite retrievals. *J. Geophys. Res. Oceans*, 115 (C9), http://dx.doi.org/10.1029/2010JC006129

234. Xu, Z., M. Li, C. M. Patricola and P. Chang, 2014: Oceanic origin of southeast tropical Atlantic biases. *Clim. Dyn*., 43 (11), 2915-2930, http://dx.doi.org/10.1007/s00382-013-1901-y.

235. Xue, Y., M. A. Balmaseda, T. Boyer, N. Ferry, S. Good, I. Ishikawa, A. Kumar, M. Rienecker, A. J. Rosati and Y. Yin, 2012: A Comparative Analysis of Upper Ocean Heat Content Variability from an Ensemble of Operational Ocean Reanalyses. *J. Climate*, 25, 6905-6925, http://dx.doi.org/10.1175/JCLI-D-11-00542.1.

236. Yin, Y., O. Alves and P. R. Oke, 2011: An Ensemble Ocean Data Assimilation System for Seasonal Prediction. *Mon. Wea. Rev*., 139, 786–808, http://dx.doi.org/10.1175/2010MWR3419.1.

237. Yu, L., X. Jin, and R.A. Weller, 2006: Role of net surface heat flux in seasonal variations of sea surface temperature in the tropical Atlantic Ocean. *J. Climate*, 19, 6153–6169, http://dx.doi.org/10.1175/JCLI3970.1.

238. Yu, L., R.A. Weller, 2007: Objectively Analyzed air-sea heat Fluxes (OAFlux) for the global ice-free oceans. *Bull. Amer. Meteor. Soc*., 88(4), 527-539, http://dx.doi.org/10.1175/BAMS-88-4-527.

239. Yu, L., and X. Jin, 2012: Buoy perspective of a high-resolution global ocean vector wind analysis constructed from passive radiometers and active scatterometers (1987–present*). J. Geophys. Res*., 117, C11013, http://dx.doi.org/10.1029/2012JC008069.

240. Zhu, J., B. Huang and Z. Wu, 2012: The Role of Ocean Dynamics in the Interaction between the Atlantic Meridional and Equatorial Modes. *J. Climate*, 25, 3583–3598, http://dx.doi.org/10.1175/JCLI-D-11-00364.1.

241. Zuidema, P., P. Chang, B. Medeiros, B. Kirtman, R. Mechoso, E. Schneider, T. Toniazzo, I. Richter, R. Small, K. Bellomo, P. Brandt, S. de Szoeke, J. Farrar, E. Jung, S. Kato, M. Li, C. Patricola, Z. Wang, R. Wood, and Z. Xu, 2016: Challenges and Prospects for Reducing Coupled Climate Model SST Biases in the Eastern Tropical Atlantic and Pacific Oceans: The U.S. CLIVAR Eastern Tropical Oceans Synthesis Working Group. *Bull. Amer. Meteor. Soc*., 97, 2305–2327, http://dx.doi.org/10.1175/BAMS-D-15-00274.1.

242. Zuo, H., M. A. Balmaseda, and K. Mogensen, 2017: The new eddy-permitting ORAP5 ocean reanalysis: description, evaluation and uncertainties in climate signals. *Clim. Dyn*. 49, 791–811, http://dx.doi.org/10.1007/s00382-015-2675-1.

**List of acronyms:**

ACT: Atlantic Cold Tongue
ADCP: Acoustic Doppler Current Profiler
AOML: Atlantic Oceanographic and Meteorological Laboratory
AMMA: Multidisciplinary analyses of the African monsoon
AMSU: Advanced Microwave Sounding Unit
ATLAS: Autonomous Temperature Line Acquisition System
AtlantOS: Optimising and Enhancing the Integrated Atlantic Ocean Observing Systems
CAMS: Copernicus Atmosphere Monitoring Service
CARIOCA: CARbon Interface Ocean Atmosphere
CFSR: Climate Forecast System Reanalysis
CLIVAR Climate and Ocean: Variability, Predictability and Change Program
ARP: CLIVAR Atlantic Region Panel
CMEMS: Copernicus Marine Environment Monitoring Service
CNRS: Centre Nationale de la Recherche Scientifique
CORA: Coriolis Ocean database ReAnalysis
CTD-$O_2$: Conductivity Temperature Depth – dissolved Oxygen
DBCP: Data Buoy Cooperation Panel
DHN: Diretoria de Hidrografia e Navigacão
DOI: Digital Object Identifier
ECMWF: European Centre for Medium-Range Weather Forecasts
EGEE: Etude de la circulation océanique dans le Golfe de GuinEE
ERA-I: ECMWF Reanalysis-Interim
ETNA: Eastern Tropical North Atlantic
EUC: Equatorial UnderCurrent
$fCO_2$: fugacity of $CO_2$
FUNCEME: Fundação Cearense de Meteorologia e Recursos Hídricos
GDAC: Global Data Assembly Centre
GDP: Global Drifter Program
GEOMAR: Helmholtz Centre for Ocean Research Kiel
GEOTRACES: An international study of the marine bioGEOchemical cycles of TRACE elements and their isotopes
GOA-ON: Global Ocean Acidification Observing Network
GODAE: Global Ocean Data Assimilation Experiment
GOSUD: Global Ocean Surface Underway Data
GSOP: CLIVAR Global Synthesis and Observations Panel
GTS: Global Telecommunication System
HYCOM: HYbrid Coordinate Ocean Model
ICMPA: International Chair in Mathematical Physics and Applications
INPE: Instituto Nacional de Pesquisa Espacial
INSU : Institut National des Sciences de l’Univers
IOUPS: Instituto Oceanográfico da Universidade de São Paulo
IRD: French Institut de Recherche pour le Développement
ISAS: In Situ Analysis System
ITCZ: Intertropical Convergence Zone
MoU: Memorandum of Understanding
MSG: Météosat Seconde Génération
NOAA: National Oceanic and Atmospheric Administration
NCEP: National Centers for Environmental Prediction

NEMO: Nucleus for European Models of the Ocean
NIW: Near Inertial Wave
OMZ: Oxygen Minimum Zone
OOPC: Ocean Observations Panel for Climate
OSE/OSSE: Observation System Experiment / Observation System Simulation Experiment
OTN: Ocean Tracking Network
PIRATA: Prediction and Research Moored Array in the Tropical Atlantic
PISCES: Pelagic Interactions Scheme for Carbon and Ecosystem Studies
PMEL: Pacific Marine Environmental Laboratory
PRB: PIRATA Resource Board
PREFACE: Enhancing prediction of tropical Atlantic climate and its impacts
RAMA: Research Moored Array for African-Asian-Australian Monsoon Analysis and Prediction
SEC: South Equatorial Current
SSG: PIRATA Steering Scientific Group
SOCAT: Surface Ocean $CO_2$ Atlas
SOLAS: International Surface Ocean - Lower Atmosphere Study
SMOS: Soil Moisture and Ocean Salinity
SSS: Sea Surface Salinity
SST: Sea Surface Temperature
SVP: Surface Velocity Profiler
TACE: Tropical Atlantic Climate Experiment
TAO: Tropical Atmosphere Ocean Array
TIW: Tropical Instability Wave
TRMM: Tropical Rainfall Measuring Mission
UFPE: Universidade Federal de Pernambuco
WRF: Weather Research and Forecasting model
XBT: eXpendable Bathy Thermograph