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Deliverable number	D3.19
Deliverable title	Organization & sustainability of PIRATA network Report
Description	A detailed report on the renewed PIRATA network, and its potential sustainability over long-term. This deliverable has been established with the contribution of the PIRATA International Scientific Steering Group and PIRATA partners.
Work Package number	WP3
Work Package title	Enhancement of autonomous observing networks
Lead beneficiary	IRD
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Comments	

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Stakeholder engagement relating to this task*

WHO are your most important stakeholders?	☐ Private company If yes, is it an SME ☐ or a large company ☐? X National governmental body X International organization ☐ NGO ☐ others Please give the name(s) of the stakeholder(s): IRD, Meteo-France, NOAA, INPE, DHN, GEOMAR…
WHERE is/are the company(ies) or organization(s) from?	X Your own country X Another country in the EU X Another country outside the EU Please name the country(ies): France, USA, Brazil, Germany
Is this deliverable a success story? If yes, why? **If not, why?**	X Yes, because PIRATA is operational from 21 years and is a real success for the Tropical Atlantic Observing System, thanks to efficient collaborations between different countries. ☐ No, because …..
Will this deliverable be used? **If yes, who will use it?** **If not, why will it not be used?**	X Yes, by the Tropical Atlantic Observing System community and partners, along with all scientists, operational services and societal organisms interested by meteo/oceano & biogeochemical measurements in the Tropical Atlantic. ☐ No, because …..

NOTE: This information is being collected for the following purposes:

1. To make a list of all companies/organizations with which AtlantOS partners have had contact. This is important to demonstrate the extent of industry and public-sector collaboration in the obs community. Please note that we will only publish one aggregated list of companies and not mention specific partnerships.
2. To better report success stories from the AtlantOS community on how observing delivers concrete value to society.

*For ideas about relations with stakeholders you are invited to consult D10.5 Best Practices in Stakeholder Engagement, Data Dissemination and Exploitation.

Executive summary:

The Prediction and Research Mooring Array in the Tropical Atlantic (PIRATA), initiated in 1997, is recognized as the reference network of oceanic and atmospheric observations in the tropical Atlantic, as for climate dedicated research and for operational climate and ocean prediction. The PIRATA network was initiated in 1997 in the framework of a multinational cooperation. It now comprises 18 permanent meteorological and oceanic buoys along with three equatorial ADCP moorings and two pCO_2 sensors. It was consequently enhanced through numerous additional sensors which were progressively installed on a subset of the buoys. PIRATA is maintained in the long-term thanks to close collaborations between involved partners, and principally thanks to a Memorandum of Understanding (MoU) established between USA (National Oceanic and Atmospheric Administration -NOAA-), Brazil (Instituto Nacional de Pesquisas Espaciais -INPE-) and France (Institut de Recherche pour le Développement -IRD-, and Météo-France) institutions that allows for long term support for PIRATA. Thanks to this MoU being regularly renewed or extended, the PIRATA network can be considered as a sustainable observing system in the tropical Atlantic. Potential enhancements and extensions are proposed, that could be envisaged in the framework of the future Tropical Atlantic Observing System (TAOS). Enhancements priority is given on mixed layer processes, carbon cycle and biogeochemistry, and extensions are required in the south and the northwest regions of the tropical Atlantic. The sustainable availability of ship time is however critical. In addition to the PIRATA core mooring activities, managing ship time for potential extensions or extra on board process studies that can be envisioned is an ongoing major challenge. Also, international institutions will have to pay attention, in each partner's teams and laboratories, on the "human power" needed to ensure on a sustainable way the work at sea and data treatment.

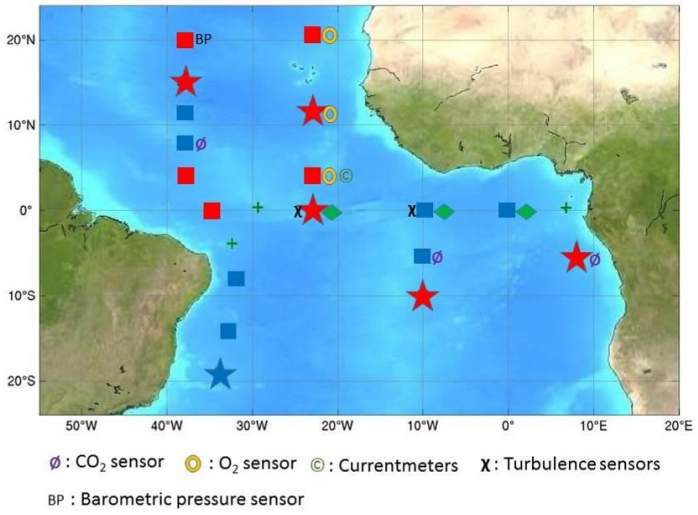
Description of the renewed PIRATA network:

The PIRATA network has considerably evolved since its first steps in 1997, when only 10 meteo-oceanographic buoys, equipped with ATLAS systems (see https://www.pmel.noaa.gov/gtmba), were initially implemented. Thanks to three extensions (South-West by Brazil in 2005, North-East by USA in 2006, and South-East by South Africa and France in 2006-2007 and 2013), it now maintains 18 permanent meteorological and oceanic buoys. Also, thanks to several collaborations (*e.g.* with GEOMAR in Germany, Meteo-France and Centre National de la Recherche Scientifique -CNRS- in France, Fundação Cearense de Meteorologia e Recursos Hídricos -FUNCEME- in Brazil) and in the context of international programs and related funding supports (e.g., EU CARBOOCEAN, PREFACE and AtlantOS programs) a significant number of sensors (mostly in the mixed layer with T/C and current sensors) and parameters (with, notably, O_2 and CO_2 biogeochemistry sensors) have been added on the buoys, to better respond to scientific demands (see AtlantOS Deliverables D3.3 and D3.9 by Bourlès et al., 2017, 2018). Also, starting in 2015, the meteo-oceanographic ATLAS systems have been progressively replaced by the more capable T-Flex systems, developed by NOAA/PMEL. These buoys are able to provide more voluminous data transmission through Iridium instead of Argos. They allow the potential implementation of more sensors with high-frequency real-time data transmission. 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 were also installed at 6°S-8°E (FR cruise), 4°N-23°W, 21°N-23°W and 20°N-38°W (USA 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 and all ATLAS buoys will eventually be replaced by T-Flex.

The PIRATA buoys provide opportunities for other programs to maintain specific sensors. Since 2014, all buoys have been equipped with acoustic receivers at 200 m depth, as a contribution to the Ocean Tracking Network (OTN; http://oceantrackingnetwork.org/). Also in 2014, the 0°N-23°W and 0°N-10°W have been 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 (http://mixing.coas.oregonstate.edu/). Also, in March 2017, 10 additional point acoustic current meters

were implemented at 4°N-23°W between 7 m and 87 m depth for the NOAA/AOML "Tropical Atlantic Current Observations Study" (TACOS) experiment. This mooring was recovered in March 2018 and redeployed with 4 additional current meters between 27 m and 87 m to continue the TACOS observations of upper ocean velocity and its shear.

The yearly PIRATA cruises organized to maintain the network also allow the maintenance of three currentmeter (ADCP) moorings along the equator: at 23°W since 2001, 10°W since 2006 and 0°E since 2016. These ADCPs typically allow monitoring the Equatorial Undercurrent from ~30 m depth down to about 300 m. The PIRATA cruises are also opportunities for ensuring a large number of measurements, through CTD-O_2/ADCP profiles, sea water samplings for analysis of several parameters (*e.g.* salinity, O_2, carbon, nutrients…), deployments of XBTs, surface drifters (SVP) and Argo profilers (see, e.g., Bourlès et al., 2008, and AtlantOS Deliverables D3.3 by Bourlès et al., 2017) for more details. Yearly PIRATA cruises represent also strategical opportunities to build scientific capacity of graduate students and early carrier researchers. The present PIRATA network is shown in the Figure below.



The present PIRATA network: the meteo-oceanic buoys are represented by rectangles and by stars for Full Flux ones. T-Flex are colored in red and ATLAS in blue. ADCP moorings are represented by green diamonds. Additional symbols are explained in the map legend. All meteo-oceanic buoys are equipped with OTN. Green crosses represent islands where some tide gauges and meteorological stations are/were also maintained.

The PIRATA network organization:

PIRATA (initially "Pilot Research Moored Array in the tropical Atlantic") is a multinational program between Brazil, France and United States, established to improve our knowledge and understanding of ocean-atmosphere variability in the tropical Atlantic (Servain et al., 1998). After a "pilot phase" from 1997 to 2001, during which the 10 buoys of the backbone array were fully implemented, institutions in the three supporting countries decided to extend the program for a 5-year "consolidation phase" to allow for a meaningful demonstration that the data would contribute significantly to both scientific research and operational applications. After its successful evaluation by CLIVAR and OOPC in 2006, PIRATA was renamed the "Prediction and Research Moored Array in the Tropical Atlantic" (Bourlès et al. 2008).

PIRATA began in 1997 thanks to the prior financial support of NOAA (USA), INPE and Diretoria de Hidrografia e Navegacão -DHN (Brazil), IRD, Meteo-France and CNRS (France). PIRATA has been maintained since 1997 by a close collaboration between institutions in the USA (NOAA), Brazil (INPE, with contribution of DHN) and France (IRD and Meteo-France). These institutions established a formal partnership in 2001 through a Memorandum of Understanding (MoU) to provide long term support for PIRATA. The MoU was signed for a five years period, then extended until 2008. It was renewed in 2009 and extended again for a five years period in 2014. The present MoU is available until July 2019 and is now under an extension process. All partners are funded by their governments through national research organizations, *i.e.* NOAA in USA, IRD (3/4 of functioning) & Meteo-France (1/4 of functioning) and the French Research Ministry (for vessel time) in France and the Ministry of Science, Technology, Innovations and Communications (MCTIC) through INPE & DHN/Brazilian Navy (for vessel time) in Brazil.

The MoU document contains the terms of organization and management of PIRATA. A PIRATA Resources Board (PRB) is established with Terms of Reference (ToR). The initial members of the PRB are managers representing INPE, IRD, Meteo-France, and NOAA. Although the PRB is presently comprised of representatives from institutions only in Brazil, France, and the United States, the PRB will welcome other institutions and other nations if they wish to contribute to the PIRATA Program. The Chairman of the PRB is designated by the PRB members. The principal tasks of the PRB are: i) to review the requirements for the implementation of PIRATA; 2) to coordinate resources that may be applied to the Program; 3) to encourage scientific and technological initiatives in the participating countries to meet the objectives of PIRATA; and 4) to report on its activities to the Heads of the institutions providing resources.

The PRB is guided by the scientific objectives and research strategy formulated by the PIRATA Scientific Steering Group (PIRATA-SSG), which is regarded as the main scientific and operational body to advise the PRB. The PIRATA-SSG is formed by researchers, managers, and representatives of operational agencies of the Parties or other institutions who are recognized as scientific and operational experts in the area of the tropical Atlantic climate. Members are nominated by the PIRATA-SSG in consultation with appropriate international sponsoring bodies participating in GOOS, GCOS, and CLIVAR, and are approved by the PRB. The Chairman of the PIRATA-SSG is designated by the SSG members. At present, the PIRATA-SGG consists of 13 members: 4 for each partner country and one from Germany (member of GEOMAR, as a major partner from decades in the framework of Tropical Atlantic studies and as contributing to the maintenance of one ADCP mooring at 23°W). The principal tasks of the PIRATA-SSG are: 1) to ensure accomplishment of the scientific and technical objectives as described in the PIRATA Scientific and Implementation Plan, and as accepted by the Parties; 2) to coordinate the technical and logistic support necessary to maintain the array; 3) to ensure the rapid dissemination of PIRATA data (in real-time where possible) to serve both research and operational applications; 4) to promote the utilization of PIRATA data in national and international climate research and operational prediction programs; 5) to evaluate, encourage, and promote pilot extension projects that could build upon jointly with the original PIRATA array; 6) to coordinate with other ongoing and planned observational efforts in the tropical Atlantic region; 7) to invite collaborations with other nations and institutions interested in implementing a sustained climate observing system in the tropical Atlantic; 8) to cooperate with international organizations such as the CLIVAR Atlantic Research Panel, the GOOS/GCOS/WCRP Ocean Observations Panel for Climate (OOPC), and the Joint WMO/IOC Technical Commission for Oceanography and Marine Meteorology (JCOMM) to ensure an integrated approach to observing the climate system in the tropics; and 9) to report regularly on the status of the PIRATA array and scientific results to the PRB, GCOS, GOOS, JCOMM and CLIVAR.

Finally, each supporting country has a PIRATA National Coordinator. The national coordinators are members of the PIRATA-SSG. INPE serves as the coordinator of PIRATA in Brazil, and the national coordinator is indicated by INPE to be the representative of PIRATA-Brazil. The support of DHN, critical to the success of PIRATA, is arranged through INPE. IRD serves as the coordinator of PIRATA in France, in association with Météo-France, and the national coordinator is indicated by IRD to be the representative of PIRATA-France. NOAA serves as the coordinator of PIRATA in United States. A national coordinator is indicated by NOAA to be the representative of PIRATA-United States.

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

<u>Sustainability of the PIRATA network and perspectives:</u>

Presently, the actual PIRATA network is already maintained in a sustainable way and, up to now (and as stated during the last PIRATA yearly meeting in October 2018), all international partners will continue to support the PIRATA network and to be committed through the MoU. All partners are well convinced that it is essential to continue the long time series at the mooring sites that have already been established. The records at these sites are now long enough to study not only intraseasonal to interannual variability but also interannual to decadal variability and climate change. PIRATA already involves several non EU countries (e.g.

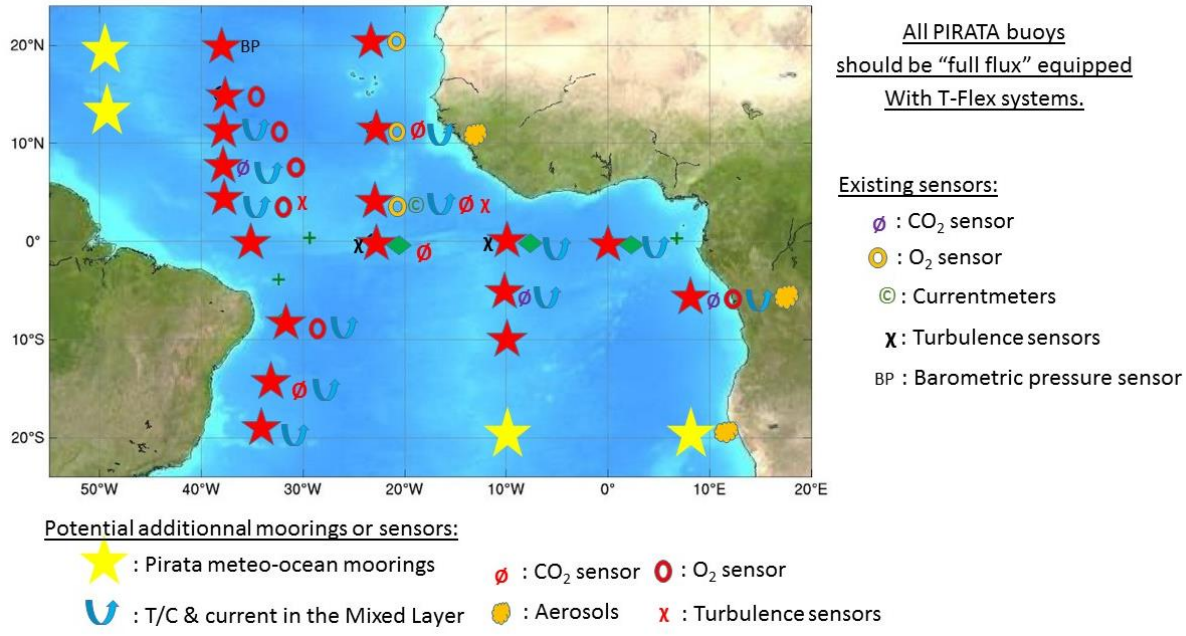
Brazil, USA and South Africa) and we can reasonably think that the PIRATA network, already enhanced with the "PIRATA classical" and new "biogeochemical O_2 and CO_2" sensors, should be well sustainable on the long term by partners who have been working together in the frame of different international programs (*e.g.* PIRATA, AMMA, CLIVAR/TACE, PREFACE, AtlantOS…).

Beyond sustaining the moored time series at sites that have been established and are producing invaluable data for the past two decades, several enhancements have been suggested to the existing array. These are: 1) adding more instrumentation in the near surface layer to better define near-surface structures, processes, and ocean-atmosphere feedbacks; 2) multi-disciplinary enhancements for carbon cycle and biogeochemical studies; and 3) expanding the array into regions that are presently under-sampled (or even not sampled) by moored time series and that would benefit from high temporal resolution, multi-variate, and multi-disciplinary sustained time series.

About the mixed layer processes, such enhancements are justified in order to provide answers to some key questions related i) the quantification of the impacts of diurnal and intraseasonal variability on equatorial turbulent mixing, diapycnal heat fluxes and SST fluctuations, ii) the confirmation of significant seasonal cycles of turbulent cooling inferred from heat budget residuals at off-equatorial locations and the diagnosis of their causes, iii) the precise role of mixed layer dynamics (changes in MLD, thermocline depth, near-inertial oscillations) for the off-equatorial seasonal to interannual variations in SST, and iv) the impact of salinity stratification on turbulent mixing in regions of large river outflow and strong precipitation.

About geochemical measurements, their need is crucial for addressing several issues related to the global carbon cycle, nutrient balances, ocean ventilation and oxygen consumption, living marine resources, and ecosystem dynamics. Biogeochemical observing technology has come a long way in the last decade or so, and they are already being broadly incorporated into other sustained observing networks.

PIRATA network extensions are mostly justified by the real absence of any in situ measurements in the South Atlantic and the need to better monitor the cyclones westward evolution in the northwest.
So, the future tropical Atlantic buoys network could be as shown in the figure below:



Sensor enhancements on existing buoys could be ensured through additional collaborations and funding. On the other hand, potential extensions of the mooring network, *e.g*. through additional PIRATA buoys, will require ship time above and beyond that already being provided by the present PIRATA partners (USA, France, Brazil). Where precisely that ship time might come from is an open question, though it is likely that a South Atlantic extension would require cooperation between South Atlantic bordering countries (South Africa, Brazil, Argentina, Angola…) that have both the necessary vessel and technical capacity.

Thus, the availability of ship time, which is the most expensive component of observing systems, 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 activities and also for potential additional moorings or extra on board process studies that can be envisioned is an ongoing major challenge.

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

Also, a fundamental requirement for the success of PIRATA is the "human power" needed to ensure, in each partner's teams and laboratories, work at sea along with the sensor preparation, calibration and data treatment. This relies upon national/international contributions and funding efforts that depend on political decisions, which are tied to the importance decision-makers will give to climate change monitoring and related issues. This underscores the continued need to communicate effectively the importance of PIRATA and the Tropical Atlantic Observing System to the public and funding agencies.

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