Project	AtlantOS – 633211
Deliverable number	3.9
Deliverable title	PIRATA data system upgrade Report
Description	Technical report mostly related to biogeochemical sensors (O_2 and CO_2 sensors) data, their real-time transmission and O_2 and CO_2 data control quality and their integration to existing systems, in relation with the WP7.
Work Package number	WP 3
Work Package title	Enhancement of autonomous observing networks
Lead beneficiary	IRD
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Comments	[in case the deliverable is late please explain why]

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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 ☐ International organization ☐ NGO ☐ others Please give the name(s) of the stakeholder(s): IRD, GEOMAR, NOAA
WHERE is/are the company(ies) or organization(s) from?	X Your own country ☐ Another country in the EU ☐ Another country outside the EU Please name the country(ies): FRANCE, GERMANY, USA
Is this deliverable a success story? If yes, why? **If not, why?**	X Yes, because planed tasks (additional geochemical sensors and technical aspects) have been achieved. ☐ No, because …..
Will this deliverable be used? **If yes, who will use it?** **If not, why will it not be used?**	X Yes, by AtlantOS and PIRATA partners and all scientists, operational services and societal organisms interested by geochemical 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 now 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 the framework of a multinational cooperation and is maintained on the long-term thanks to close collaborations and a Memorandum of Understanding between USA (NOAA), Brazil (INPE) and France (IRD, Météo-France) organizations and now comprises 18 permanent ATLAS buoys along with one ADCP mooring (at 23°W-Equator). As part of AtlantOS, the main objective is to make PIRATA more efficient and relevant in terms of filling observational gaps- essentially by implementing and operationally maintain additional sensors to existing ATLAS moorings and demonstrating a preview of what could be the "future PIRATA network".

Following the Deliverable 3.3, in which some PIRATA enhancements have been detailed, this deliverable mostly focus on the extension of PIRATA toward new biogeochemical sensors, i.e. O_2 and CO_2.

O_2 sensors:

Since 2009, offline O_2 measurements have been conducted at two PIRATA Northeast Extension (PNE) moorings (4°N, 23°W and 11.5°N, 23°W) at 300 m and 500 m depth. During the last PNE cruise with US ship Ronald H. Brown (RB-17-01 leg 2, 19-Feb-2017 to 25-Mar-2017), the number of O_2 sensors was increased and eight oxygen sensors were installed overall in three moorings at 4°N, 23°W (300 m and 500 m), at 11.5°N, 23°W (80 m, 300 m and 500 m) and at 20.5°N, 23°W (80 m, 150 m and 300 m). At the respective mooring sites, former ATLAS buoys were replaced by T-Flex buoys already in late 2015 or during the recent cruise in 2017.

Thanks to a close collaboration between the institutes PMEL (NOAA, USA) and GEOMAR, O_2 sensor data at PIRATA mooring sites 11.5°N, 23°W and 20.5°N, 23°W could be implemented into the T-Flex real time data stream for the first time and online O_2 data is available (https://www.pmel.noaa.gov/tao/pirata/tflex/) for these two moorings since their deployment on 09-Mar-2017 and 13-Mar-2017, respectively. The basis to achieve an inductive coupling of the subsurface O_2 sensors to the T-Flex buoy was given by the update to T-Flex buoys itself as well as further software development of the T-Flex buoys by PMEL. GEOMAR completely developed and provided the corresponding software and hardware of the O_2 sensors logger units, which were equipped with a Seabird Inductive Modem Module (IMM, Fig. 1) for inductive coupling.

Apart from very few data gaps due to inductive data transmission errors between the T-Flex buoy and O_2 sensors, the online O_2 data is completely available with a resolution of 1 hour (internal measurement interval is 20 min). The data is preliminary calibrated (Fig. 2), which is based on calibration measurements against a CTD reference cast and lab calibrations conducted immediately prior to deployment. No online O_2 sensor data is available for the 4°N, 23°W PIRATA mooring, but will be available after recovery of the mooring during next PNE cruise. The key issue here was a software conflict of the T-Flex buoy with other sensors (Aquadopp current meters) attached to the mooring, which didn't allow an inductive communication of the T-Flex buoy with the O_2 sensors.

(a) (b)

Fig. 1: (a) O_2 sensor consisting of Aanderaa oxygen optode (here: model type 4330) and logger unit including the inductive modem module (IMM). (b) Interior of logger unit and IMM.

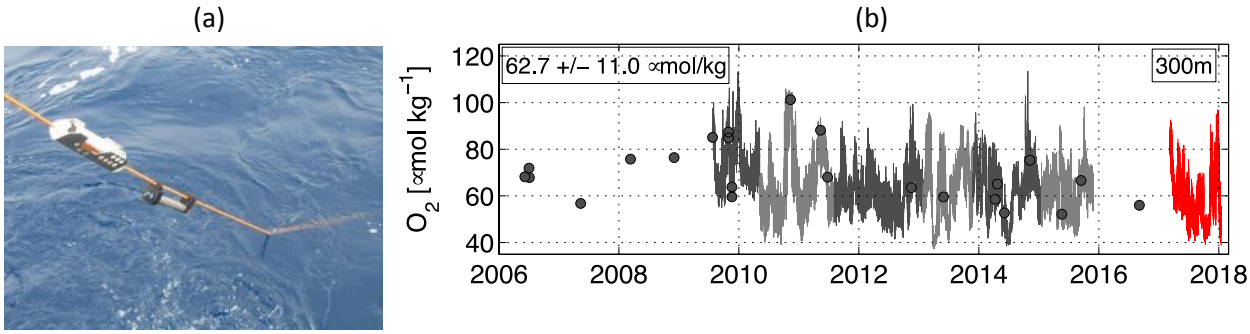

Fig. 2: (a) Deployment of O_2 sensor (instrument closer to water surface) together with MicroCAT during cruise RB-17-01 leg 2. (b) Oxygen time series from the PIRATA mooring site 11.5°N, 23°W at 300 m depth. Dark and light grey lines denote periods of individual mooring periods. Red solid line denotes online O_2 data from the currently deployed PIRATA T-Flex buoy. Dots denote CTD measurements from PIRATA and GEOMAR cruises close to the mooring position.

The O_2 sensors will be calibrated against CTD and lab reference measurements after the mooring recovery to get a final data calibration. In general, best data quality is achieved, when the sensors are calibrated during the respective PIRATA service cruises immediately prior to deployment and after recovery of a mooring.

During the next PNE cruise, which is scheduled for March 2018, the eight O_2 sensors in the three PNE moorings along 23°W will be completely replaced. Real time O_2 data transmission will be continued at the mooring sites 11.5°N, 23°W and 20.5°N, 23°W. Again, no real time O_2 data will be available for the 4°N, 23°W mooring due to the above mentioned unsolved problems regarding the inductive communication of the T-Flex buoy with Aquadopp instruments.

The systematic implementation of inductively coupled O_2 sensors into the T-Flex online data stream is a milestone achievement for real time oxygen observations in the upper ocean. Near surface oxygen variability, which is strongly related to variability in other biogeochemical variables often appears on short time scales. A prominent example are episodically developing low oxygen events, which are induced within isolated eddies that are associated with high biological productivity in their eddy core and biogeochemical conditions evolving very different from the surrounding waters. Online oxygen data will help to better monitor and faster identify such events, which will provide the option for a broad community to conduct intense in situ observations of such events.

Since 2008, the German collaborative research centre SFB754 has strongly pushed forward the understanding of oxygen variability in tropical oxygen minimum zones with a particular focus on the

eastern tropical North Atlantic. Oxygen was monitored in the eastern tropical North Atlantic for one decade. Due to the predefined ending of the SFB754 in late 2019, oxygen observations will not be continued. The already successful implementation of moored oxygen observations in the PNE array will lead to a selected continuation of these long-term observations, which are of substantial importance for evaluating current and future oxygen changes related to natural and anthropogenic climate variability. This also includes the validation of coupled physical-biogeochemical general ocean circulation models, which are not yet capable of reproducing observed oxygen variability patterns.

CO2 sensors:

During the French PIRATA cruise in March 2017, the CO_2 sensor installed since 2006 on the PIRATA ATLAS buoy at 6°S, 10°W was replaced on the 10th of March. An additional CO_2 sensor was deployed for the first time on the PIRATA T-Flex buoy at 6°S, 8°E on the 19th of March 2017 to extend the PIRATA network.

The ATLAS buoys of the PIRATA network, provided by the PMEL, are gradually updated to T-Flex buoys equipped with iridium transmission. One important modification of this design is the filling of the float (Fig. 3a, buoy on the right), which reduces the space below the float for the submarine part of the CO_2 sensor. Because of this change of design, the submarine part of the CO_2 sensor had to be shorten to fit in the tripod of the buoy (Fig. 3b).

a)

b)

Fig. 3. a) Old buoy on the left and new T-Flex buoy on the right b) submarine part of the existing CO_2 sensor installed on an old buoy.

Two CO_2 sensors were built by NKE to be deployed on a T-Flex buoy. The submarine part of this new CO_2 sensor was located in a cylinder made more compact. It includes the CO_2 sensor, a seawater pump and a dye pocket (Fig. 4).

Fig. 4. Submarine part built by NKE for the T-Flex buoy at 6°S, 8°E.

In comparison with the existing CO_2 sensors, the electronics of the new CO_2 sensor has been updated and the Argos message transmitted by the sensor has been shortened.

The CO_2 sensor at 6°S, 10°W is still on an ATLAS buoy and has not been changed. However, on a longer term, all ATLAS buoys will be exchanged by T-Flex buoys and the CO_2 sensors will have to be re-designed to fit in the new buoy system. French funding has been secured to modify the CO_2 sensors accordingly so that the time-series could continue. The adaptation of the old CO_2 sensors by NKE has already started.

The sensors at 6°S, 10°W and 6°S, 8°E worked well for a few months. At 6°S, 10°W the sensor stopped working on the 23rd of October 2017 when the lithium batteries discharged. At 6°S, 8°E the sensor is still working but the fCO_2 gives too high values, which suggests biofouling on the sensor. Both sensors will be retrieved during the next PIRATA cruise in 2018 and sent back to be checked in the laboratory. The data will be processed and validated once high resolution salinity data are available. After validation, the data will be sent to the SOCAT database (WP7) for further quality control. They will be made available publicly at the time of the annual SOCAT release.

The mooring at 8°N, 38°W was not found during the last Brazilian PIRATA cruise in November 2017 so the CO_2 sensor that were installed on this buoy is lost. A new buoy was deployed at 8°N, 38°W including a CO_2 sensor but this sensor did not work. One hypothesis for the malfunction of the sensor is a battery failure. However, the sensor needs to be retrieved to really understand what happened at this site.

Time series are available on:

Realtime Data from PIRATA ATLAS Systems (with links to other sites with cruises data sets):
https://www.pmel.noaa.gov/gtmba/pirata

Realtime Data from PIRATA TFLEX Systems (including O_2 data):
http://www.pmel.noaa.gov/tao/pirata/tflex/

Delayed mode quality controlled CO_2 data sets:
The validated data are transmitted to SOCAT (WP7) and they are made publicly available during the annual release of SOCAT.
https://www.socat.info/

It is important to mention that some PIRATA moorings are now reporting oxygen and pCO_2 observations. Within the AtlantOS WP7, an action with OceanSITES (via NOAA/PMEL in USA) is underway to add oxygen data to the PIRATA – OceanSITES data flow. For pCO_2 observations, a link with the French research infrastructure 'Integrated Carbon Observation System' (ICOS) should be established through Copernicus in situ (ICOS is a new partner in Copernicus Marine phase 2).