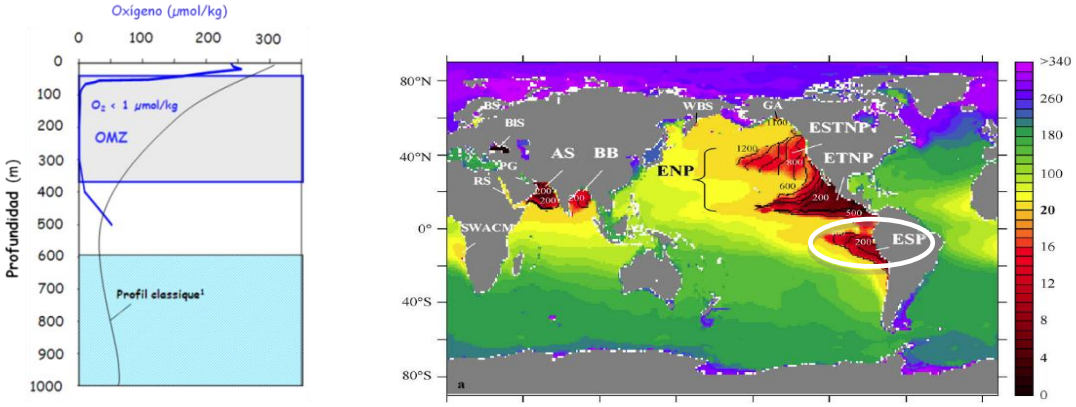
Minutes for AMOP meeting

on October 12-13th 2016 in Marseille (MIO)

October 20th, 2016

"Activity of research dedicated to the Minimum of Oxygen in the eastern Pacific" project (AMOP; www.legos.obs-mip.fr/recherches/projets-en-cours/amop), involving 8 countries including 14 research units in France, had his **main post-cruise meeting** at the MIO (Marseilles) on October 12-13th 2016. The goal of the meeting was to discuss and organize the preliminary scientific results and to define the different tasks for 2017. **Day 1** (9h-18h00) covered the **presentations** of the work for each team dealing with the OMZ, and especially with AMOP, and to set the state-of-art and work in progress (including the data inventory, status evolution, storage, exchanges, report/publication, specific processing). **Day 2** (9h15-18h00) was dedicated to discussions around common questions in **round tables** and working groups, and included a visit of the MIO lab. ~40 AMOP sub-components, with a contribution of 37 scientists, have been briefly presented, with a presence at the MIO of ~20 participants and participation through video-conferencing system. Details on the meeting are following.



Vertical (blue on the left) and horizontal (red on the right indicated by the minimal [O_2] from Paulmier & Ruiz-Pino, 2008) structures of the Oxygen Minimum Zones (OMZs).

List of participants: D. Bourras, M. Boyé, M. Bretagnon, C. Cojak, B. Dewitte, E. Garcia-Robledo (interactive mails), V. Garçon, G. Grégori, J.M. Hernandez-Ayon, D. Lefèvre, H. Maske, I. Montes, C. Panagiotopoulos, A. Paulmier, O. Pizarro, M. Pujo-Pay (vdeo-conferencing), J.F. Rontani, C. Schmechtig, J. Sudre, O. Vergara.

1) WELCOME AND INTRODUCTION

The PI (A. Paulmier) welcomed the participants. He presented the **goal of the meeting**, general **AMOP issue-objective-hypothesis** with central Equation and Surface-Oxycline-Core scheme, recapping the cruise plan, general AMOP modeling-mooring-cruise strategy and outline of the meeting using the central Equation.

$$\frac{\partial O_2}{\partial t} = \underbrace{-\vec{U}.\vec{\nabla}O_2 + A_H\nabla_H^2 O_2 + \frac{\partial}{\partial z}\left(A_V \frac{\partial O_2}{\partial z}\right)}_{\text{Physics}} + F_{air-sea} + \underbrace{P - C}_{\text{Biogeochemistry}} + F_{sed-water}$$

2) SPATIO-TEMPORAL CONTEXT DURING THE AMOP PROJECT

B. Dewitte (co-PI) presented the **OMZ interannual to intra-seasonal and regional to local variability** from **modeling work**, focussing on the physical forcing, and underlining the different biases and issues. Specific presentation of the model ROMS-BIOEBUS, available for the AMOP consortium, has been commented, with a special focus on the fixed AMOP mooring.

O. Pizarro presented variability of the **OMZ** near the coast of **South-Central Chile**, especially from glider and fixed mooring data, comparing with the OMZ off Peru.

PI (A. Paulmier) provided a brief seasonal to interannual (2.75 years) large scale overview of the OMZ structure off Peru through AMOP ***in situ*** **Argo-floats** information.

O. Vergara described the **seasonality** of the regional OMZ ventilation off Peru from **modeling** ROMS-BIOEBUS study.

PI (A. Paulmier) presented **the intra-seasonal, intra-monthly and intra-daily OMZ variability** and potential forcing from the **fixed AMOP mooring** (12°03'S, 77°40'W) during 14 months.

M. Bretagnon provided a description of the **Preservation versus Remineralization configurations** in the OMZ off Peru from the AMOP fixed mooring **sediment traps**.

3) HYDROLOGICAL CONTEXT OF AMOP CRUISE

The PI (A. Paulmier) provided a preliminary analysis of the **hydrology and Water Masses** (WM) during the AMOP cruise, including O_2 and T-S diagrams, which are crucial to document the different terms of the Central O_2 Evolution Equation. The physical terms are forcing the WM circulation, providing then the environmental conditions for the biogeochemical activity.

4) PHYSICAL CONTRIBUTION TO THE O2 BUDGET

B. Dewitte mentioned briefly the different **physical terms of the O_2 evolution equation**, and the strategy used to document them. A special focus on the ROMS-BIOEBUS **model** performance relative to the seasonal/intra-seasonal scales and currents (comparison with S-ADCP data) has been given, since modeling will allow us to fill the spatial and temporal gaps between the different ***in situ*** **observations**. Tri-maran Ocarina (with D. Bourras), atmospheric mast and radiosounds data have just been mentioned as data are yet to be processed. Drifting lines information, including current meters, deployed by C. Gojak and D/ Lefèvre, provides Lagrangian documentation of the circulation, complementary to the Eulerian L/S-ADCP data at the fixed stations.

H. Maske presented the **Free-Rising CTD** (FRIT) data and discussed the interpretations of such a data. Comparisons between down and upcasts profiles have been proposed, at very high vertical

resolution, and including classical CTD data, in order to document and explore the **mixing/stratification mechanisms** in the **near-surface layer**.

I. Montes complemented (mainly on Day 2) information about regional Eastern South Pacific **circulation** and modeling.

5) BIOGEOCHEMICAL CONTRIBUTION TO THE O2 BUDGET

Preliminary results on the **modeling component** were presented by B. Dewitte. While the model requires further tuning and improvement (inclusion of a sediment module), model skill is quite encouraging and allows for a preliminary estimate of the tendency terms of the O_2 equations during the AMOP mooring period and cruise.

D. Lefèvre presented the **net source minus sink biogeochemical O_2 term** from measurements of **net community production and O_2&CO_2 fluxes (on board** + ***in situ*** (**IODA** on the drifting lines) incubations). Only ~25-30% of the deployed IODA data will be exploitable, because of technical problems (.e.g. not insured sealing).

PI (A. Paulmier) presented E. Garcia-Robledo and N.P. Revbesch works on **the O_2 cycling in the OMZ off Peru** during AMOP cruise in 2014, including **Winkler-STOX measurement** of Niskin water samples & CTD data calibration, and especially the **cryptic O_2 cycle** at the **secondary fluorescence peak** below the oxycline, **respiration & primary production** measurements. In complement, on board experiments through O_2 production/consumption Winkler incubation & zooplankton contribution have been briefly mentioned.

H. Maske provided data acquired for **prokaryote respiration** and **bacterial abundance**, aiming to measure the respiration rates for the fraction between 0.2 and 1 µm. Stations with H_2S measurement have also been communicated by J. Villegas-Mendoza during the AMOP meeting. H. Maske presented global **particles** (POC determined without acidification, C/N, S/C) profiles, and comparisons with M. Pujo-Pay POC and PON data (using a different methodology with acidification). Global agreement, but further analysis on specific profiles are planned, as well as on **BSi** data and on PIC determination.

M. Pujo-Pay (on Day 2 by video-conferencing) presented preliminary data of **Particulate and Dissolved Organic Matter**, as well as of **ammonium** for the different cross-shore (at the Center at ~12°S; in the North at ~7-8°S; in the South at 14-15°S) and along-shore (coastal and offshore) vertical sections and for the time-series at the 8 fixed stations. Vertical profiles and parameters versus O_2 diagrams have also been briefly presented.

C. Panagiotopoulos presented **sugar** and **amino acids** analysis corresponding to the **fixed mooring**, and commented a possible methodological issue concerning unexpected information (especially on Day 2): high % of organic carbon (~20-25%) and especially no PIC, and low amino-acids contribution (1-2%). The methodology is being checked again with N. Leblond (OOV), additional samples recovered from a previous dispatch to LOCEAN will be re-analyzed (I. Bouloubassi), and K. Escoubeyron and M. Pujo-Pay will check the amino acids calculations. At the end of the meeting, C. Panagiotopoulos mentioned for the AMOP cruise samples, two strategies: a short analysis in few weeks but for the total sugar only (with maybe detailed sugar analysis for 1 or 2 samples only); a long analysis during several months for a systematic detailed sugar documentation.

J.F. Rontani provided preliminary fixed mooring analysis of **lipids** for photo-oxidation, and especially sterols (e.g. bio-markers for zooplankton and coccolithophorids) and phytols.

PI (A. Paulmier) briefly mentioned the methodology of the particles collected in the fixed and drifting sediment traps, with pictures of the collected organic matter (from N. Leblond), to provide

information dealing with the high organic matter content which has been reported. **Flow cytometry** analysis for **bacteria** and **pico/nano phytoplankton** has been shortly presented by G. Grégori. Note that during the MIO visit, a possibility of genomics analysis has been explored with C. Tamburini and P. Bonin.

M. Boyé presented the **micro/nano/pico-phytoplankton pigments** and **taxonomy** analyses for the continental shelf, the slope and off-shore and three depth layers (0-12 m; 12-25 m; 25-50 m), collected by M. Giraud. The presentation has been focused on the *Chl a*, diatoms, autotrophs dinoflagelates, haptophytes (e.g. coccolithophorids: Ehux, Helicosphera Carteri), chlorophyths (e.g. cyanobacteria including the Prochlorococcus and Synechococcus, and especially the Prasinophycea). PI (A. Paulmier) completed this presentation with **inversed microscope identification** and **counting** including **bio-volumes** and **carbon contribution** (from A. Franco-Garcia), in agreement with the pigments analysis. A brief mention by A. Paulmier has been performed concerning the **zooplankton distribution** (especially copepods) and respiratory enzymatic activity analysis by D. Bonnet and L. Yebra, as well as to the acoustics and radar data allowing higher trophic level (e.g. micro-zooplankton, small pelagic fishes; seabirds (Y. Tremblay)) characterization at the fixed stations.

J.M. Hernandez-Ayon presented the **carbon chemistry** during AMOP cruise (e.g. Total CO_2, pH, recalculated Omega and other carbonate parameters) for **source/sink air-sea fluxes** determination and for ocean **acidification** study in the OMZ off Peru. Different sub-regions have been identified in the OMZ off Peru. Concerning greenhouses gases, other samples for N_2O and CH_4 have also been taken.

Finally, C. Schmechtig presented the **LEFE/CYBER data base**, and the advantages for the AMOP consortium (mainly for sharing the data), with the decision to centralize the information where and when data are available, and then the data itself. Presentations of the AMOP meeting will also be shared through the LEFE/CYBER data interface. Part of the presentations for point 5) has been given on Day 2.

6) ROUND TABLES AND WORKING GROUPS

After the overview provided by the different presentations and the associated questions, a **general short open debriefing** of the presentations and a synthesis of the key potential results and the state-of-art for AMOP have been attempted.

The whole information produced through AMOP *in situ* and modeling strategy should allow to answer the **central issue**, i.e. providing a **comprehensive O_2 budget in the OMZ off Peru** based on the documentation of the different terms of the O_2 evolution equation. This will also deal with determining if the system is an O_2 source or sink for the considered oceanic domain and also at the air-sea interface. **Fixed stations 1 (amop002)**, **3 (amop004)**, **4 (amop011)**, **7 (amop025)** and **8 (amop028)**, due to their coastal, slope, off-shore, and Center, North and South representation, but also to their more complete documentation in terms of parameters or monitoring, have been chosen to focus this O_2 budget. A special attention will be paid at the upper (oxycline), but also lower (Lower O_2 gradient or LOG) OMZ boundaries, and also to the specific AMOP conditions associated with the cruise compared to the documentation through global data base and model outputs. Finally, this budget will focus on the **high frequency temporal variability**, in particular thanks to the specific AMOP sampling with cast each ~3-4 hours during 2-3 days at the fixed stations. AMOP consortium aims to publish this study in a **high impact review journal**.

In addition, a **special issue in Biogeosciences** has been proposed, with a **common introductory cruise descriptive paper**, and **papers on specific issue** associated to each team/parameters. In this framework, each team will take in charge the analysis and publication of his specific results.

Seven relevant team interactions and **potential added value** of working on **common issues** have been discussed and proposed concerning:

i) O_2 calibration **(**e.g. electrochemical, optical and chemical, as well as acoustical (for the oxycline) systematic measurements) as a proposed **Recommendation report/paper for OMZ O_2 measurements protocol**s;

ii) Validation of the modeling + Internal variability (from modeling):

a) Link between observations & model outputs?

b) Sensitivity and other numerical experiments? Lagrangian experiments for drifting lines following the O_2 fluxes terms.

iii) Upwelling description/physical dynamics and fine-scale description/mechanism. Combining also with satellite data. Including focus on the mesoscale activity (eddies) and Lagrangian information collected from Argo-floats & drifting lines.

v) Organic matter enigma in OMZ-EBUS (mainly traps)

vi) Phytoplanktonic community/PP with cytometry/sequencing/pigments/taxo/counting and relation to the OMZ (information from the cruise), focused in the euphotic layer and completed with the corresponding on board & *in situ* incubations data;

vii) O_2 coupling with C cycle and other BG cycles. Process coupling (N, P, Si, S) + Specific incubations with all the parameters. + Bacterial production.

To go further (from ii) to vii)), the participants splitted into two main working groups. The first one (A) was more related to the physical and modeling issues; the second (B) on to biogeochemical issues.

A/ Physical part (points ii), iii) & iv)):

The physical modeling work within AMOP is central since it will support the interpretation of the data collected during the cruise and allows testing ideas emerging from the analysis of the data. On-

going efforts are dedicated to validating and tuning the regional model (parent domain at 1/12°) as well as analyzing the environment conditions (Kelvin wave, winds and heat fluxes). Use of updated Mercator forcing is planned for the first semester of 2017. A child domain at 1/36° will be also evaluated in the first semester of 2017. Three papers are planned:

1) A paper dedicated to the presentation of the **physical and biogeochemical environments during the AMOP cruise**. This paper will consist in the analysis of environmental conditions during 2013-2014 (equatorial variability, local winds, water masses, circulation from altimetry and Argo, sub to mesoscale activity) from available observations and Reanalysis, and a general presentation of the AMOP cruise (data, objectives and strategy, experiments). Circulation of a large paper draft is planned in February 2017.

2) A short paper dedicated to the **OMZ variability** analysis of the **AMOP mooring data**: This paper consists in the analysis of the temperature, salinity and oxygen data at the 5 depths of the mooring (spectral power at hourly to intra-seasonal timescales, vertical structure of the co-variability between T/S and O_2, identification of Production/Consumption pulses from the de-convolution between T and O_2 (cross-analysis with sediment trap data))

3) A paper dedicated to the evaluation of **internal variability** of dissolved oxygen in the regional coupled model. This paper will provide an estimate of expected "errors" on dissolved oxygen and processes at the timescales relevant for AMOP (intra-seasonal to seasonal), as well as a thorough evaluation of the model realism/biases.

B/ Biogeochemical part (points v), vi) & vii)):

The biogeochemical part is focused on the organic matter (1), generated by the planktonic communities producing O_2 (2) and fueling the bacterial system consuming O_2 (3). Three papers are planned:

1) "Which particles are found in the OMZ?", mainly from sediment traps documentation. Here, an additional check has been proposed concerning the high C_{org} value (20-25%), the low amino acids content (1-2%), and especially for the low (undetectable with the used methodology) PIC despite evidence of coccolithophorids (from sterols and pigments) and foraminifera (from direct sample microscope observations). Indeed, the question is to know what is the remaining C_{org} composition.

2) "What is the relation between the phyto/zoo-plankton community and the oxycline (depth, intensity, [O_2], …), density and water masses?". The relation will be explored temporally during the fixed stations time-series but mainly spatially on the different AMOP cruise stations. The boundary between the upper surface and lower subsurface sub-layers needs to be clearly defined, since the vertical depth-integration in the surface layer will depend on the depth of this boundary. The oxycline depth is an option, but also requires a definition as for instance the depth of the maximal dO_2/dz (in case of no-regular O_2 decrease at the oxycline, this definition could focus on an artifact, and should be mentioned). The depth of the euphotic layer (1% of the surface solar radiation) is another option, but there are also speculations on a definition with 0.1% of the incident radiation, considering the "low light" photosynthetic activity (e.g. specific Prochlorococcus). Finally, depth of the mixed layer is a last option, but again a common definition should be proposed, using a temperature or density criteria or other definition.

This study will be supported by the documentation of the phytoplankton community, primary production, flow cytometry (and eventual sequencing), pigments, taxonomy, counting and relation to the OMZ (mainly information from the cruise CTD-O_2). This study should be focused in the euphotic layer, and will use the information of the on board & *in situ* incubation (upper experiments of D.

Lefèvre for NCP), and primary production (estimated through O_2 + C^{14} from E. Garcia-Robledo), complemented by Winkler experiments proposed by A. Paulmier. This study should allow determining the balance between autotrophy and heterotrophy in the surface layer.

3) "How the O_2 cycle is coupled with the carbon and other biogeochemical cycles (N, P, Si, S), through the bacterial consortium?". Using NO_3-NO_2-NH_4-N_2O, PO_4, H_4SiO_4, DOM, POM, DIC, and eventually H_2S. This study should focus on the process coupling (autotrophy/heterotrophy, aerobic/anaerobic). Remember that specific incubations with all the parameters has been performed on board, although in "rough" conditions, and could be useful for this study, as well as the documentation of the bacterial abundance and production. Again, on board & *in situ* incubations (experiments below the surface layer of D. Lefèvre), and O_2 cycling experiments proposed by E. Garcia-Robledo, and complemented by those proposed by A. Paulmier, will be analyzed for this study.

During this working group, **scientific rationale** and **hypotheses**, **methodology** and **data** used, **preliminary results**, and the **working progress**, **expected results**, **impacts** and **AMOP limitations**, and **tentative schedule** have been **discussed**. Finally, brief restitutions mainly dealing with the specific issue and objective have be proposed, and with an open schedule for **next steps/meeting** and **perspectives**. First following step will be to provide the information of the **available AMOP data** and the **AMOP meeting presentations** (end of October 2016), then to send all the data to C. Schmechtig for the **LEFE/CYBER database** (end of November 2016). Since EGU (Vienna, Austria) in April 2017 appears to be too close, **next AMOP meeting** could be in **Lima** (Peru) in **July-August 2017**, with an application in March and a response in June (18 000 USD covering ~9 scientists) combining short "summer school" practical on the new Peruvian RV Carrasco anchored in Callao harbor. A second option could be a conference in **October 2017** in **Chile** (Cf with O. Pizarro). The **final outcomes** shall be presented in **end of 2018**, for instance in September during the **Deoxygenation Conference** (Kiel, Germany) organized by the **IOC-UNESCO GO_2NE** (Global Ocean Oxygen Network).