EURO ARGO - PABIM

by the PABIM Consortium

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1 The future challenges for marine biogeochemistry.

The anthropogenic greenhouse effect and the associated temperature rise of the planet represent the main challenging issue for the Earth sciences of the next century. Marine ecosystems are a key component of the Earth system, as they modulate the transfer of greenhouse gases (mainly CO_2) to the ocean surfaces. Moreover, oceanic ecosystems mitigate the effects of anthropogenic carbon injection into the atmosphere, via the so-called "biological pump".

Ocean biogeochemistry is then confronting a major challenge, the determination of the extent and efficacy of the climatic feedback of the carbon "biological pump" in the context of climate changes.

However, the approaches currently utilized to assess ecosystems dynamics are inadequate to address the climate change issues:

1. manifestly, ocean biogeochemistry lacks in observations. The number of *in situ* biogeochemical observations is 2-3 orders of magnitude lower than the number of observations for the physical compartment. Moreover, large areas of the ocean are practically undersampled, as adverse environmental conditions and logistic prevent the conduction of oceanographic cruises for most of the year. Ocean color satellites greatly improved the knowledge of biomass distribution, although they are limited 1. to the biological compartment only 2. to the surface and near surface layers.
2. the temporal variability of the main processes of marine ecosystems ranges from hourly to decadal, showing a continuum of scales, which is extremely hard to discriminate without dedicated observations; very few oceanic regions have been sufficiently explored to allow both long-trend and high-frequency analysis, thus most of the feedbacks between processes occurring at different temporal scales are very poorly characterized.
3. numerical simulations, which represent an essential tool to dissect scales and provide future scenarios, begin to produce realistic results. However, models are still far to obtain the expected accuracy, as they are inadequately constrained by observations.

Autonomous measuring platforms represent the "*deux ex machina*" to unblock the impasse. They could solve all the present limitations, opening novel pathways on the exploration and comprehension of the oceanic ecosystems. Physical oceanography already cumulates huge benefits from the use of autonomous measuring platforms. It indicates the way to the biogeochemical ocean sciences, which should evolve towards autonomous systems in order to enhance their observation capacity.

As a final point, climate change means alteration and modification of the physical forcing, and, in the oceans, ecosystems strongly depend on the physical forcing. It is definitively obvious that a complete description of the biogeochemical marine dynamic requires coupled physical observations, as physical properties govern and drive the evolution of the oceanic ecosystems. The role of the biogeochemical process on the physics is less obvious and more subtle. A purely physical model of the oceans does not require any biogeochemical observation. On the other hand, a climatic model (i.e. coupling atmosphere, oceans, ecosystems, humans) does require both physical and biogeochemical observations. Therefore, if one of the main objectives of a future observation system is to further the understanding of the role of the ocean in the climatic change, both physical and biogeochemical measurements are required.

2 What is the present day status of autonomous platforms for biogeochemical ocean sciences?

Biological and chemical measurements are intrinsically more complex than the physical ones. Traditionally based on laboratory analysis of water samples, biogeochemical observations were dependent on ship-based sampling. Even when automatic sensors were developed (i.e. fluorometers), they were still too large and too energy consuming to be effectively mounted on autonomous platforms.

However, things are changing. Miniaturized, low energy consuming, biogeochemical sensors are being developed. Several companies have begun to commercialize instrumental biogeochemical pucks specifically designed for autonomous platforms. More and more performing batteries allow sustaining highly energy demanding instruments. New generation telecommunication satellites ensure high rate transmission all over the world, multiplying by 10 the quantity of transmissible data at the same cost as the old systems (i.e. ARGOS).

Technological improvements directly impacted on science, and in the last 5 years a bloom of dedicated actions focused on the development and on the scientific exploitation of biogeochemical profiling floats appeared.

These recent efforts have demonstrated the feasibility and the potentialities of the autonomous observations of marine ecosystems. However, the different actions were conducted without coordination, as they were often achieved by individual laboratories or on a project basis, to address punctual and specific scientific questions.

Presently, a forward step is required.

Using new technologies, the exploration of the marine ecosystems should migrate from a series of dedicated studies to a larger, ideally global, observation system, able to ensure continuous and coherent data for long time periods.

The main effort should be then dedicated to the conceptual design and to the set-up and the operational management of an array of biogeochemical profiling floats.

Here, an attempt to define this array is proposed.

3 The identification of the "core" parameters

Concerning autonomous platforms, the choice of the measured variables was initially guided by the available technology. Now, the miniaturized instruments commercially available allow the measurement of a vast set of biogeochemical parameters (i.e. chlorophyll concentration, dissolved oxygen concentration, backscattering, CDOM concentration, underwater light, transmittance, etc.).

Every parameter is (or has to be) considered scientifically relevant, as its evaluation always adds an important piece of information on the knowledge of the marine ecosystem functioning. However, a set of "core" parameters needs to be selected in order to design an operational array of biogeochemical profiling floats [1].

For the definition of a "core parameter", four requirements have to be considered:

1. A core parameter should be a robust **proxy of a biogeochemical oceanic process or variable**.
2. A core parameter should have **already been measured extensively and for a long time** with referenced methods.
3. A core parameter obtained from profiling floats should be **easily comparable with observations collected with classical methods** (i.e. ships, satellites, moorings). If climatologies are produced from previous observations, data from autonomous floats should be easily incorporated
4. The measurement of a core parameter with an autonomous profiling float should be **cost effective** and **low energy** consuming.

At the moment, only the Chlorophyll Concentration and the Dissolved Oxygen Concentration meet these four requirements, and then they will refer as "core parameter".

However, the simultaneous collection of additional variables could relevantly improve the calibration and the validation of the Chlorophyll and of the Oxygen data, as well as, they could allow a better ecological interpretation of the "core parameter" profiles. In other terms, although the present day availability of additional parameters avoids their widespread utilization as core parameters, the situation could rapidly evolve, resulting in an increase scientific relevance of the ensemble of the data collected by bio-geochemical floats

In the next, the "Chlorophyll Concentration" and the "Dissolved Oxygen Concentration" parameters will be described separately, and a discussion on their measurement from profiling floats will be done.

3.1 The Chlorophyll Concentration

Chlorophyll is a pigment found in most plants, algae and cyanobacteria. It serves the primary function to absorb and transfer solar energy to chemical energy, allowing plants to obtain energy from sun radiation (Kirk, 1994). Because it is colored, specific to, and shared amongst all primary producers, chlorophyll concentration is considered the best proxy for oceanic biomass (Huot et al, 2007) and is then a key parameter of biological oceanography.

During photosynthesis, photosynthetic organisms (i.e. primary producers or autotrophs) consume the CO_2 present in the water, which derives primarily by exchange with the atmospheric CO_2. Included in organic molecules, carbon is partially removed by surface layers when dead organisms fall on deep and bottom layers. With this mechanism (the "CO_2 biological pump"), oceanic primary producers act as regulators of the global CO2 concentration on the Earth (Takahashi et al. 2002). Marine primary produces play than a key role in the global climate mechanism. Understanding the spatio-temporal variability of the autotrophs distribution, using as a proxy the chlorophyll concentration, is then a primary goal of the present day oceanography.

[1] In this context, a specific working group of the International Ocean Color Coordination Group (IOCCG, http://www.ioccg.org/groups/argo.html) is devoted to furnish a first set of proposition for the "core parameters". Most of the recommendations presented in this text derived by an interactive discussion between the PABIM and the BIO-ARGO working groups

The climate, and his forcing factors, does not represent the only issue requiring more information on the chlorophyll concentration. Several studies addressed on the biological mechanisms used by autotrophs to growth (i.e. Geider et al. 2001), on the phytoplankton control of the chemical elements in the ocean (i.e. Rixen et al; 2005), or on the role played by phytoplankton organisms in the food web, and his final impact on fisheries resources (i.e. Platt et al. 2003).

Consequently, chlorophyll concentration is routinely measured in the ocean, as well as is a "core" parameter of the global physical-biological oceanic models.

The most promising method to evaluate the chlorophyll concentration ([Chla]) on a profiling float is based on the fluorescence.

Part of the photons absorbed by a Chla molecule in the blue part of the spectrum is re-emitted as less energetic photons in the red part. This rapid (~ns) process is known as fluorescence and actually corresponds to the relaxation of the excited Chl*a* molecule to its ground state. The light emitted through Chl*a* fluorescence, F (mole quanta m^{-3} s^{-1}), can be roughly expressed through:

$$F = E \bullet [Chla] \bullet a^* \bullet \Phi_f \quad (1)$$

E is the excitation irradiance (mole quanta m^{-2} s^{-1}). It corresponds to either sun irradiance (and the subsequent process is the so-called sun-induced fluorescence) or to irradiance provided by a light source; only the later is considered here. [Chla] corresponds to the concentration in Chl*a* (mg m^{-3}), a* to the Chl*a*-specific absorption coefficient (m^2 mg $Chla^{-1}$) and Φ_f, the fluorescence yield (mole emitted quanta mole absorbed $quanta^{-1}$). Interestingly, it appears from equation 1 that the retrieval of [Chla] from the measurement of F depends on the excitation irradiance, which is relevant to the instrumentation, and on an absorption term (product [Chla] a*) and a fluorescence efficiency term (Φ_f), both of which being relevant to phytoplankton photo-physiology.

The fluorescence emission of Chl*a* is centered at 685 nm. The excitation of the Chl*a* molecule is triggered by the blue photons not only absorbed by the Ch*la* molecule itself but also by other photosynthetic pigments (mostly carotenoids but also phycobiliproteins for some phytoplankton groups) which subsequently transfer their absorbed energy to the Chl*a*. As a consequence the spectral domain of Chla excitation matches the spectral domain of phytoplankton absorption.

3.2 The Dissolved Oxygen Concentration

Dissolved oxygen concentration (O_2 hereafter) is a key parameter to understand both dynamics and biogeochemistry of the world oceans: it has been used for a long time as a tracer to follow water masses pathways and quantify mixing rates; on the other hand, O_2 variability is associated with many biological processes, production, respiration, remineralization.

One important scientific question is to understand how the current global climatic change could affect these dynamic and biological processes on the long run. Several studies, based on cruise O_2 measurements or on the sparse existing repeat sampling locations have already provided some indications, and stress the importance of obtaining long term, global O_2 data. Firstly, O_2 responds very quickly to changes in general circulation (e.g. Shaffer et al., 2000), and a pilot study (Körtzinger at al., 2004) has shown that deep convection in the North Atlantic could be efficiently monitored through long-term O_2 measurements. Observations in several parts of the world ocean show a general decrease in O_2 (Johnson & Gruber, 2007; Deutsch et al., 2005; Ono et al, 2001; Schaffer et al., 2000).

Models have indeed predicted an overall decline in O_2 under global warming (Matear & Hirst, 2003; Bopp et al., 2002), mostly in extra-tropical regions. That decline should be associated with an expansion of tropical Oxygen Minimum Zones (OMZ), with far reaching consequences on coastal ecosystems, and this appears to be confirmed by observations (Stramma et al., 2008). The ocean's "carbon pump" has an important effect on atmospheric CO_2 and thus on global climate. Biological mechanisms govern that system, and the strength of that pump can be measured through variability of O_2 (Jenkins & Doney, 2003); if global O_2 data were available, the net biological carbon export could be estimated.

Historically, O_2 has been first measured through a chemical titration method (Winkler, 1888) which cannot be practically used on an autonomous platform. Nowadays, sensors are based on two techniques, an electrochemical method and an optical method.

The electrochemical method.

It is based on a technique described by Clark et al. (1953), originally devised for medical applications. The Clark cell works on the principle of reduction of molecular oxygen at a cathode.

Under a constant voltage, the current flow from cathode to anode is proportional to oxygen partial pressure in the surrounding fluid. The electrodes are covered with an oxygen permeable membrane to prevent fouling and to maintain a well-defined chemical medium at the electrode surface. O_2 must diffuse through this membrane in order to reach the cathode and initiate a current flow. The Clark cell principle has been used in shipboard CTD systems since the 1970s. In a marine environment sensors based on that principle were affected by drift problems due to changes in membrane tension, fouling, depletion of electrolyte, impairment of the anode, plating of anode metal on

the cathode, the presence of chemical contaminants in the sensor's plastic body, etc. In recent years, the basic arrangement has been largely improved, mainly by improving the technical design of the sensors. Simultaneous measurements of temperature, salinity and pressure are necessary to compute O2 values from the partial pressure measurement.

The optical method

An optical method was recently developped, operating on the principle of fluorescence quenching (Tengberg et al., 2006). Blue light excites molecules of a fluorescent dye that are included in a foil on the sensor optical surface. The excited dye molecules emit photons with a lower energy state (red light).

When oxygen molecules diffuse into the film, they collide with excited dye molecules before they emit their photons, and energy is transferred to O_2 rather than lost by fluorescence emission. This reduces the time period (of order 10s of μs) over which the fluorescence is emitted by the dye. The sensor operates by detecting the decrease in fluorescence lifetime that is produced by interaction of the dye molecules with oxygen. Detecting changes in fluorescence lifetime, rather than fluorescence intensity, has significant advantages for sensor stability. If some of the fluorescent dye is lost due to bleaching, fouling or diffusion from the film, fluorescence intensity will decrease, but the fluorescence lifetime is unchanged. Besides, time delays are one of the physical parameters that can be measured with the best accuracy. The sensor response is here also proportional to oxygen partial pressure in water, so environmental conditions (pressure, temperature, salinity) must be known to compute O_2.

4 Toward an operational biogeochemistry

A sufficient number of profiling floats could be used to characterize a large oceanic region and its spatio-temporal variability. Integrated with satellite surface observations, the acquired profiles could provide a 3D/4D picture and a long term monitoring of large oceanic regions.

This is what is presently done for the physical state of the ocean by the Argo network, integrating Argo profiles with satellite SST and SLA observations. To ensure a long-term global coverage and to keep favorable the benefits-costs ratio, the profiling frequency cannot be excessively high (i.e. for Argo is 10/5 days).

Existing biogeochemical floats could be used in a similar manner, because:

1. satellites provide surface observations of most of the parameters measured by biogeochemical floats, with the noticeable exception of the oxygen;
2. new communication systems and advanced energy batteries can sustain, on a single float, the several different sensors required to characterize the ocean biogeochemistry (i.e. LOV PROVBIO have 3 sensors more than an Argo standard floats, which means seven additional measured variables). Additionally, they can support an increased vertical resolution, which is crucial for upper layers biogeochemistry;

An example of a pilot study is represented by the operation conducted in the Mediterranean by the LOV in the 2008 (see also appendix). Two biogeochemical profiling floats and 8 Argo like buoys are presently (since August 2008) operational in the basin, with an automatic and real time acquisition of the correspondent satellite imageries (furnished by the GLOBCOLOR project).

Furthermore, large scale missions should ensure a long-term monitoring of the sensors accuracies, to prevent the risks of artificial drift in the scientific results.

4.1.1 Measurement Recommendations

Chlorophyll concentration

From eq 1 it is nevertheless obvious that fluorescence is also not a perfect estimator of [Chla] because it depends on measurement conditions (see above) as well as on phytoplankton photo-physiology (through a* and Φf).

With respect to developing procedures for mitigating the effect of physiological causes impacting the F vs [Chla] relationship, and in fine, for reducing the uncertainties in the estimation of [Chla], several recommendations can be made.

The first recommendation is to perform profiles at night. Night measurements, being not affected by fluorescence quenching, indeed provide the most reliable estimates of [Chla] in the upper layer. Nevertheless this recommendation can cope with certain types of floats/missions but not with others. In particular when irradiance profiles have to be performed as well as sea truths simultaneous to satellite overpass, day (and often around noon) profiles are obviously required.

For such daily profiles, multispectral irradiance measurements can be helpful in correcting the effect of fluorescence quenching. From an estimation of Kd at an appropriate wavelength (e.g. 440 or 490 nm) in an appropriate surface layer (e.g. the first penetration depth), [Chla] can be derived from bio-optical models (Morel and Maritorena, 2001). This estimation can serve to back correct [Chla] derived from fluorescence measurement in the layer of interest.

In well-mixed conditions, all biological properties are expected to be homogenous within the mixed layer. However, fluorescence profiles in surface layers at noon sometimes present some features departing from this mixing rule and typical of fluorescence quenching. These subsets of profiles can be a posteriori corrected by extrapolation of deep fluorescence value towards the surface layer. The simultaneous measurement of other bio-optical properties (e.g. bbp) can help in deciding for such correction.

When the float and the satellite measurements are simultaneous, the satellite [Chla] can also be used to constrain the surface [Chla] (e.g. first penetration depth) derived from the fluorescence measurement. This correction scheme would have to be used with caution, as it would prevent to use in situ measurement for sea truth of satellite ones.

Finally, given the variability in observed chl-fluorescence relationships, +/-50% in [Chla] accuracy should be a targeted objective for measurements performed by a fluorescence sensor mounted on a float.

Dissolved oxygen Concentration

Generally, it is always recommended to obtain CTD O2 profiles at the time of deployment, in order to calibrate the floats data and to identify pre-deploiement bias.

Concerning the optode-based method, a particular attention should be paid to the calibration issues. The sensor measures a time delay (DPHASE), which is proportional to oxygen partial pressure in sea water. Dissolved Oxygen Concentration (DOXY) is then derived by the DPHASE, using a 4th degree polynomial equation, whose coefficients are temperature dependent. To increase the reliability and the consistency of the DOXY observations, some points should be addressed.

The actual configuration of the float allows transmitting either DPHASE or DOXY. Because of the non-linearity of the equation, a first recommendation is to the transmit of DOXY instead of DPHASE, when a float transmits bin averaged values at low vertical sampling, When a float transmit spot sampling values or bin-averaged values at high vertical resolution, it is possible to transmit DPHASE and TEMP_DOXY (the temperature measurement from the optode) to compute on shore DOXY.

When using optode based sensors, a correction for salinity and pressure effect is necessary. For that reason, it is recommended to locate the oxygen sensor nearby the CTD sensor. In addition, the same correction algorithm must be used for all floats, and recorded in the metadata.

Another recommendation concerns the possibility to keep available the raw data transmitted by the float and to store the corrected values from the salinity and pressure effect in a separate field, which allows a further recalibration of the data.

A last point is dedicated to the data storage. In the current Argo data stream, the unit of oxygen data (DOXY variable) is *micromole/kg*. However, the oxygen measurements are sent from Argo floats in another unit such as *µmole/l* for Optode based method and *ml/l* for the Seabird SBE sensor. A unit conversion is thus carried out by the data centers as follow:

$$O_2\ [\mu mole/kg] = O_2\ [\mu mole/l] \ / \ \rho \qquad (2a)$$

$$O_2\ [\mu mole/l] = 44.6596 \times O_2\ [ml/l] \qquad (2b)$$

where ρ is the potential density of seawater [kg/l] at zero pressure and at the potential temperature (e.g., 1.0269 kg/l).

The conversion of *µmole/l* in *ml/l* (that is the conversion from Optode unit to SBE unit) only requires the knowledge of one constant (44.6596). On the other hand, the conversion of *ml/l* in the official Argo unit (*µmole/kg*) is more problematic, because it requires the knowledge of the potential density.

This conversion is a potential source of error, because datacenter might use different definition of the potental density and because some data (salinity) might be missing or erroneous.

We thus recommend to change the official Argo unit and to use either *ml/l* or *µmole/l*. Adopting a new measuring unit should decrease the potential sources of error in the final data set, and should improve the coherence of the observations.

4.1.2 A (tentative) quality control

A network of biogeochemical profiling floats should allow a real time availability of the data, which could be then used mainly for the assimilation in numerical models, but also for ecological monitoring and for natural risk prevention and assessment for decision makers (i.e. red tides).

A real time protocol requires an automatic data quality control (QC), which could slightly differ from the actual Argo system. This point, extremely important, is actively debated.

For the moment, a (tentative) procedure is proposed:

1. the existing Argo QC should be adjusted to biogeochemical observations. The tests on the float position, on the profile date and on the anomalous values could be easily fitted to biogeochemical floats and data.

2. Argo tests on the coherence with historical available observations should be adapted on biogeochemical observations. In this context, a reflection should be done on the availability and on the accuracy of climatologies of Chlorophyll and Oxygen.
3. additional tests are proposed to verify the coherence between physical and biogeochemical observations.
4. another test is proposed to verify the coherence between float profile and simultaneous ocean color satellite observations (only for the Chlorophyll Concentration).
5. for dissolved oxygen data real time quality control could be constrained by temperature through the saturation value; a maximum super saturation value must be defined (150%) . In delayed mode, QC procedure based on objective interpolation of existing data can be envisioned, in similar ways to what has been done for salinity. The relative scarcity of oxygen data may impose limits on the final accuracy of the data that will need to be determined.

5 International Context

- BIO-ARGO IOCCG, white paper for Ocean Obs (Venezia 2009)
- "Friends of oxygen on ARGO", white paper for Ocean Obs (Venezia 2009).
- OCB (NSF/NASA/NOAA program on the Ocean Carbon & Biogeochemistry OCB) the workshop this year is on the Observing Biogeochemical Cycles at Global Scales with profiling floats and Gliders (Chairman Ken Johnson).
- EU GMES (Kopernicus); "Ocean FTS - in situ measurements, data harmonization and standardization"
- GEO/GEOSS Implementation plan, point 4.1.7 : "Ecosystem observations will be better harmonized and shared, spatial and topical gaps will be filled, and in situ data will be better integrated with space-based observations."

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7 Appendix 1. Examples of the French activities

7.1 The PROVBIOs in the Mediterranean Sea

The Mediterranean is an endangered Sea (Gibelin and Déqué, 2003), because the strong anthropogenic pressure on its coasts and its relative small size could accentuate the impact of the global warming. The Mediterranean ecosystems, and all the related economical activities (i.e. fisheries, tourism etc) could be then strongly perturbed by the climatic changes.

For these reasons, in the 2008, the Mediterranean was selected as a pilot site to test the new generation of biogeochemical profiling floats, which are developed in the framework of the French Project "PABO" (ANR, PI Hervé Claustre). The new PROVBIO floats are based on the widely used PROVOR model, which was specifically modified adding two fluorimeters (calibrated for Chlorophyll and CDOM concentrations), an irradiance sensor (measuring in water incident light at three different wavelengths), transmittance and backscattering meters (which give information on the stock and size of organic particles present in the water). Moreover, to support the increased amount of information to be transmitted, the original ARGOS antenna of the PROVOR was replaced by a more performing IRIDIUM system, which, additionally, allows a two-way communication with the floats (i.e. users on land have the possibility to modify internal parameters of the floats, as, for instance, the temporal frequency of cycling or the vertical resolution).

Two PROVBIOs were deployed in 2008, in two ecological contrasting regions of the Mediterranean (D'Ortenzio and Ribera d'Alcalà, 2008).

The first float (NW_B02) was initially deployed the 1st May 2008, in the Nord Western Mediterranean Sea, close to the French long term in situ optical mooring BOUSSOLE (approximately 8°E, 43.5°N, see figure 1). Float was programmed to a cycle frequency of 1 day. After 15 days, the cycling frequency was changed to 5 days, and it was kept constant until now.

The second float (LW_B06) was deployed in the Levantine Basin, on the site of Eratosthenes seamount (approximately 32.5°E, 33.7°N, see figure 2), during the French cruise "BOUM" (P.I. Thierry Moutin). The deployment zone was selected because a permanent anticyclonic structure is recurrently observed there (Malanotte Rizzoli et al. 1999). The rationale was to "entrap" the float in the density structure, in order to obtain repeated profiles of the same oceanic area (ou water mass). The LV_B06 float was programmed similarly to the NW_B02: after an initial phase at 1 day cycling frequency (from 27/06/08 to 30/06/08), the float strategy was modified to perform a 5-days cycling.

Figure 3 shows the temporal evolution of the potential density and of the chlorophyll concentration fields obtained from the NW_B02 PROVBIO float. The summer stratification of the water column impacted on the vertical distribution of the chlorophyll concentration, which was then characterized by a Deep Chlorophyll Maximum (DCM) at about 50-70 meters depth. The beginning of the fall in September, with the associated atmospheric cooling and the more intense wind mixing, induced a progressive deepening of the mixed layer depth, with a consequent de-stratification of the water column. As the winter advances, DCM was progressively destroyed, as chlorophyll concentration was redistributed uniformly in the mixed layer, by the intense mixing.

Dynamical conditions of the LW_06 float are relevantly different (see figure 4). The PROVBIO, as initially expected, remained trapped in the cyclonic structure related to the Eratosthenes seamount, and it profiled the same area for most of the summer and of the fall. The summer stratification was more important than in the Western Mediterranean basin, and, although winter conditions are observed, mixed layer depth was never greater 50 meter. Consequently, a DCM was permanently observed at about 100 meters depth, although the characteristics of the vertical profiles of chlorophyll concentration changed from summer to winter. The absolute values of chlorophyll concentration, always observed in the DCM, tended to decrease with time, passing from 1-2 micron g/l in summer to 0.5-0.7 micron g/l in fall.

The two Mediterranean PROVBIO's are still operational (December 2008), and their evolution could be followed on real-time on the Laboratoire d'Oceanographie de Villefranche web site (www.obs-vlfr.fr/OAO), as transmitted data are processed and plotted on the web site with a temporal delay of less than an hour (Poteau et al., "How we manage near real time data from PROVBIO", poster presentation, annual meeting of the Group Mission Mercator Coriolis, Toulouse, 13-14-15 October 2008). Technical monitoring of the floats indicates that energy level is still high, and a complete annual cycle of measurement is then possible.

In conclusion, the firsts two Mediterranen PROVBIOs produced, in less than a year, an invaluable data set on the physical-biological interaction, in two contrasting ecological regions of the basin. Considering the quality of the data, the ratio cost/benefits for this first PROVBIO experiment is extremely favorable.

Presently (December 2008), 6 other PROVBIO are operational: 2 in the North Atlantic (from June 2008), 2 in the North Pacific near Hawaii (from august 2008) and 2 in the South Pacific (from December 2008).

7.2 PROVOR-DO in the South-East Pacific:

In the framework of the GMMC (Group Mission Meractor Coriolis) funded FLOPS project, 6 PROVOR-DO floats, equipped with Aanderaa optodes have been deployed in the South-East Pacific (Figure 5), 4 in October 2007

and 2 in February 2008. 4 of them have been returning oxygen data since their deployments; 2 have returned only partial or bad profiles. The problem has been traced to a software error in floats internal programming. Teams at IFREMER and Kannad are currently working to correct that problem for future PROVOR-DO floats, including the 2 remaining ones of the FLOPS project (see later). After the error are corrected these floats will be deployed offshore Peru, hopefully at the beginning of 2009.

Figure 6 shows a comparison of one of the PROVOR-DO data with $CTDO_2$ data obtained a short time after deployment. Data from the Aanderaa optode need to be compensated for salinity and pressure effects; as shown on the figure, that correction may reach about 15% of dissolved oxygen concentration at 2000 m depth. After correction the PROVOR-DO profiles are closer to the $CTDO_2$ profile.

Float technology improvements

Since their deployments, 4 of the 8 FLOPS and OVIDE PROVOR-DO floats have been returning oxygen data. The 4 others (2 FLOPS floats and the 2 OVIDE floats) have returned only partial or bad profiles. The problem has been traced to a software error in floats internal programming. Teams at IFREMER and Kannad are currently working together to correct that problem in the future PROVOR-DO floats, including the 2 remaining ones of the FLOPS project. After the error are corrected these floats will be deployed offshore Peru, hopefully at the beginning of 2009.

In the first generation of the PROVOR-DO floats, the optode was located in the bottom part of the float (Figure 7). For a better quality of the data, the sensor should be placed on top of the float, nearby the CTD. As part of the OVIDE project, two floats have been built with the optode sensor located on top of the float. This new generation of float will be tested in 2009.

8 Figures

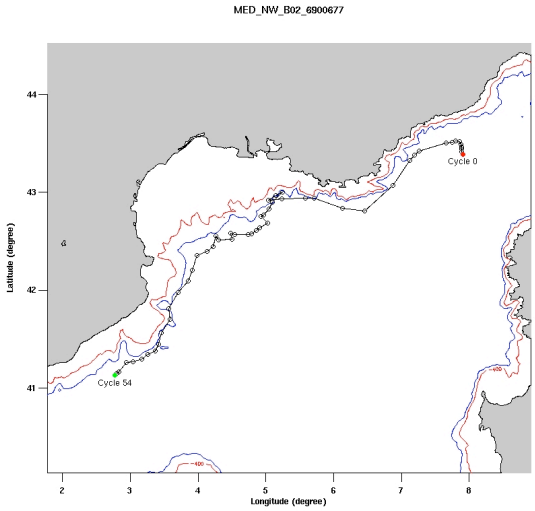

Figure 1. Geographical locations and trajectories of the of NW_B02 PROVBIO float : deployment (red point), profiles (black points), current position (12 December 2008, green point). See also: www.obs-vlfr.fr/OAO.

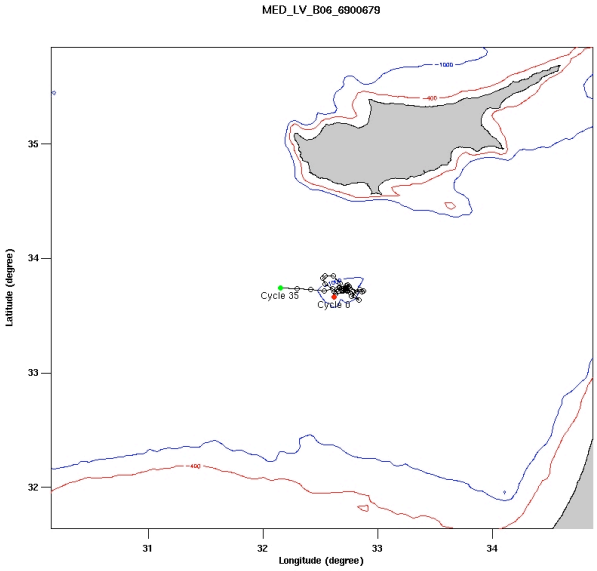

Figure 2. Geographical locations and trajectories of the LV_B06 PROVBIO float: deployment (red point), profiles (black points), current position (12 December 2008, green point). See also: www.obs-vlfr.fr/OAO.

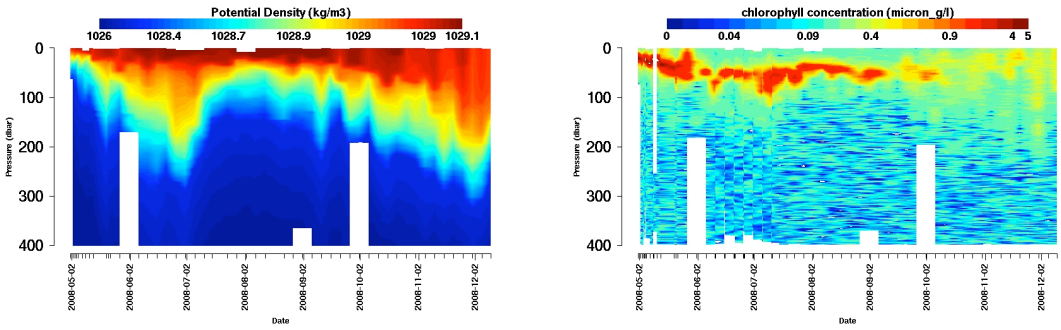

Figure 3. Chlorophyll concentration and potential density from the NW_B02 PROVBIO float.

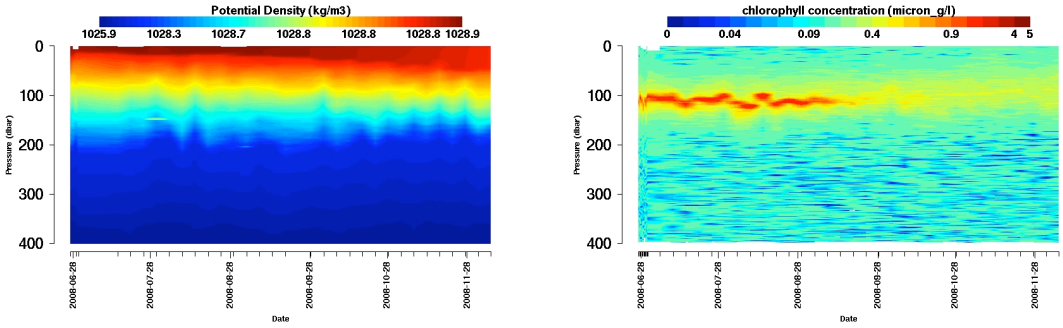

Figure 4. Chlorophyll concentration and potential density from the LV_B06 PROVBIO float

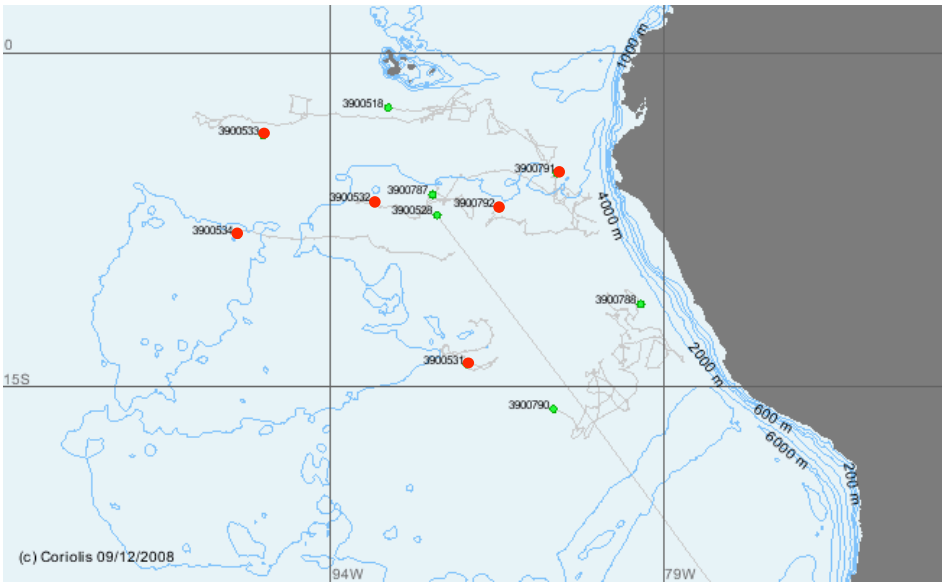

Figure 5: Trajectories of PROVOR floats of the FLOPS project offshore Peru. PROVOR-DO floats in red

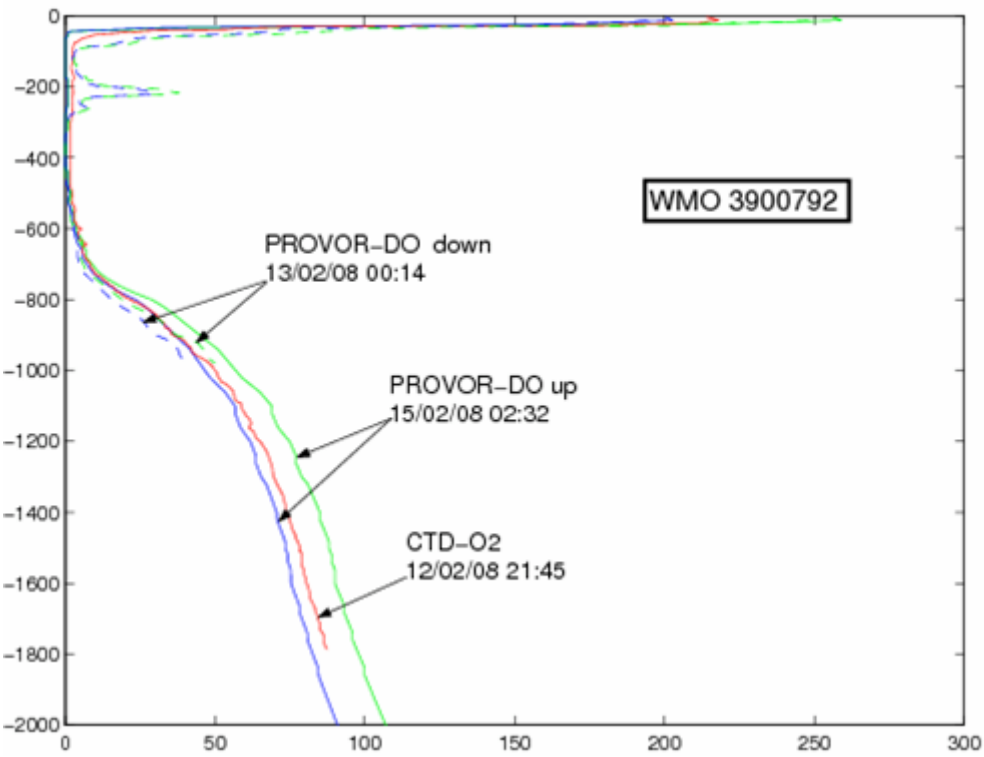

Figure 6: First dissolved oxygen concentration profiles from float WMO3900792 : dashed lines, down profiles; full lines, up profiles. In green before correction of S and P effects, in blue after correction. In red, $CTDO_2$ profile obtained just after deployment.

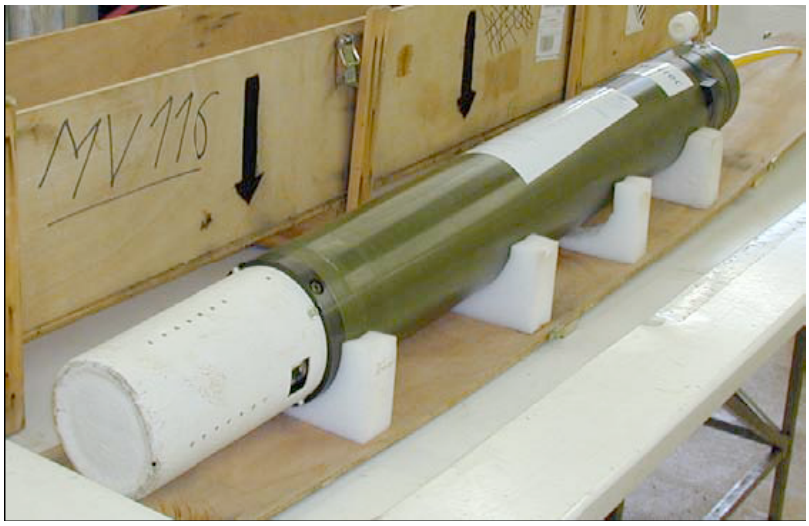

Figure 7: Position of the optode sensor on the first generation of PROVOR-DO float.