Development and validation of the new ProvBioII float

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Abstract

In the last ten years, a productive collaboration has grown between the Laboratoire d'Océanographie de Villefranche (LOV), NKE and IFREMER to implement biogeochemical sensors on profiling floats. A first project (2003) was dedicated to the design of the so-called ProvBio floats (models A and B) that consisted of a PROVOR-CTS3 float instrumented with three new optical sensors: a Wetlabs transmissometer (C-Rover), a 3-wavelength Satlantic radiometer (OCR-503) and an "ECO3" Wetlabs sensor, measuring chlorophyll-a fluorescence, colored dissolved organic matter and particle backscattering coefficients (see *First Success of ProvBio floats*, Coriolis Letter n°5). Then, the integration of biogeochemical sensors continued in the framework of ProNuts project (2009, *autonomously profiling the nitrate concentrations in the ocean: the pronuts project*, Coriolis Letter n°8), by equipping a PROVOR with a nitrate concentration sensor. In parallel within the framework of the Carbocean EU project, the ProvCarbon and ProvDo floats were developed as in 2006 by fitting on a PROVOR a C-Rover and a 3830 Aanderaa optode, respectively. They were used to investigate new tools to assess marine carbon sources and sinks. These initial developments have led to a first invaluable dataset and to subsequent papers (Xing et al. 2012, Xing et al. 2011) and report (IOCCG 2011).
Nevertheless, the above projects have grown partially dissociated, as related to specific and project-related needs, while a more integrated solution may have a lot of advantages. Undoubtedly, the scientific exploitation of data would be strongly improved if a unique multidisciplinary float, able to measure all accessible parameters, was available. Such a multidisciplinary float would also strongly reduce costs, by sharing the float itself, and by reducing deployment, validation and communication costs. The idea to merge all these sensors on the same profiling float was thus at the origin of the ProvBioII float project, which was developed in the framework of the remOcean and NAOS programs.

A new float with extended capacities

The main general objective of the ProvBioII float was to build the capability to easily and safely implement new sensors on a PROVOR platform and to use them with the maximum of flexibility. This capability was initially required for the commercial sensors chosen for the remOcean program, but it will be also useful for future integration of new sensors. In order to reach these main objective, successive new developments were required, which represented the different steps of the ProvBioII acquirement, realized in the last years. They will be presented hereafter.

Double board architecture

The ProvBioII float electronics is based on a double board architecture, which physically separates the float navigation from the sensors driving. While previous floats used one electronic board to manage float mission and sensors, the new ProvBioII float uses two dedicated boards. The master one, the so-called "navigation board", is used to drive the navigation (hydraulics), the positioning (GPS) and the communications (Bluetooth and Iridium). The navigation board is actually the I535, which is already implemented on the PROVOR CTS3.1. The navigation board controls and exchanges data with a second electronic board, the so-called "acquisition board", used to manage the acquisition of sensors (including the CTD probe). The double board architecture was selected, instead of a unique powerful board, for two main reasons.

- First, the double architecture allows dissociating the "vital" functions (i.e. navigation and communication) from the "non-vital" (i.e. data acquisition and sensors management). Considering science functions as "non-vital" could be considered not pertinent, as a float still moving and communicating without providing data could be considered as useless. However, in the case of a malfunction of the acquisition board or sensor, vital task separation would allow to maintain the link with the float, which could be a crucial step to identify problems and to possibly fix them.
- The second reason to introduce double board architecture is to secure the integration of new sensors. With a unique board, the integration of a new sensor requires to modify the unique software which also drives the float. This makes possible unwanted side effects on vital functions. The two board architecture is therefore a way to increase system capacities, to protect float vital functions and allows easier and safer implementation of new sensors.

The Science Board architecture was designed by IFREMER and the board was developed by the ASICA Company, thanks to funding from IFREMER, to be implemented on both PROVOR and ARVOR-CM (Coastal Multisensors) floats. The Science Board uses the same 8 bit low-power micro-controller as the I535, with 128/256 Kbytes of code memory, 64Kbytes of RAM, 8Mbytes of data memory, six extended serial ports and a 12 bit height channels analog to digital converter. One major improvement is the implementation of switchable supply regulators, which allows various sensor connections with a dedicated switchable power supply. A communication protocol between the two boards ensures the separation of tasks: the acquisition board samples the sensors, computes the data and sends packets of data to the navigation board. The navigation board ensures the link with satellite network (see hereafter) to send data packets onshore without knowledge of their content. The acquisition board is now industrialized and directly provided by NKE, which also developed the embedded software.

In order to manage the new double board architecture, two new software programs were developed by NKE according to IFREMER and LOV specifications. The first one embedded on the navigation board provides enhanced functionalities and flexibilities to manage navigation cycles of the ProvBioII. For example, on a previous version (ProvBioB floats), only mono or a tri-profiles cycles were available (i.e. one or three profiles per cycle). On the ProvBioII, up to ten profiles per cycle can be realized to study diurnal cycles or other time-dependent processes. Additionally, for each profile, different starting depths, schedules for surfacing and communication options could be indicated (figure 1). Moreover, any configuration could be modified through the Iridium downward link, and a “mission end” command could be sent to allow float recovery.

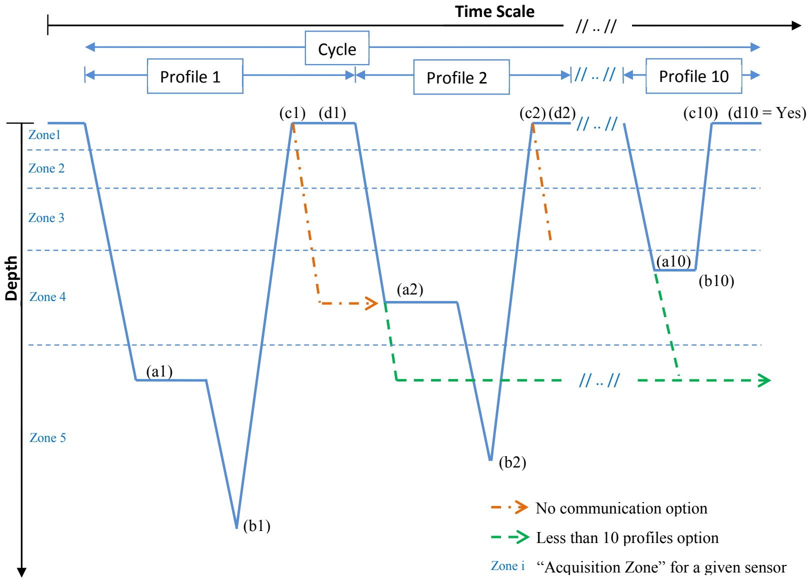

Figure 1: Navigation options of ProvBioII float: from 1 to 10 profiles could be programmed per cycle. For each profile, it is possible to define: (a) parking depth, (b) starting profile depth, (c) time schedule for surface (over several days), (d) Positioning and communication option (Yes or No). Five “Acquisition Zones” could be defined for each sensor within which acquisition parameters could be personalized.

The second new software, installed on the acquisition board, allows a very precise definition of sensors sampling strategy during profiling phases. For each sensor, five depth intervals (i.e. zones) could be created within which it will be possible to personalize the acquisition mode and the depth resolution. For each zone, a given sensor could be off, in pulse mode (i.e. powered on and off for each acquisition) or in continuous mode (Figure 2). Pulse mode, which is primarily used to save energy, could automatically switch to continuous mode (and vice versa) depending on the requested depth resolution and the warm-up time of the sensor. For each zone, raw data are generally averaged to obtain the required resolution by subsampling data within defined depth slices (down to 1m width). In each depth slice, data could be averaged, but median and standard deviation could be also optionally calculated within the slices. Standard deviation can be useful to characterize the quality of the data but also provides valuable information like the presence of aggregates, which can be associated to pulses on backscattering data for example. However, raw data (raw mode) could be optionally stored, and then transmitted to shore, providing resolution up to 0.2m (this very high resolution is currently limited by the CTD sampling rate).

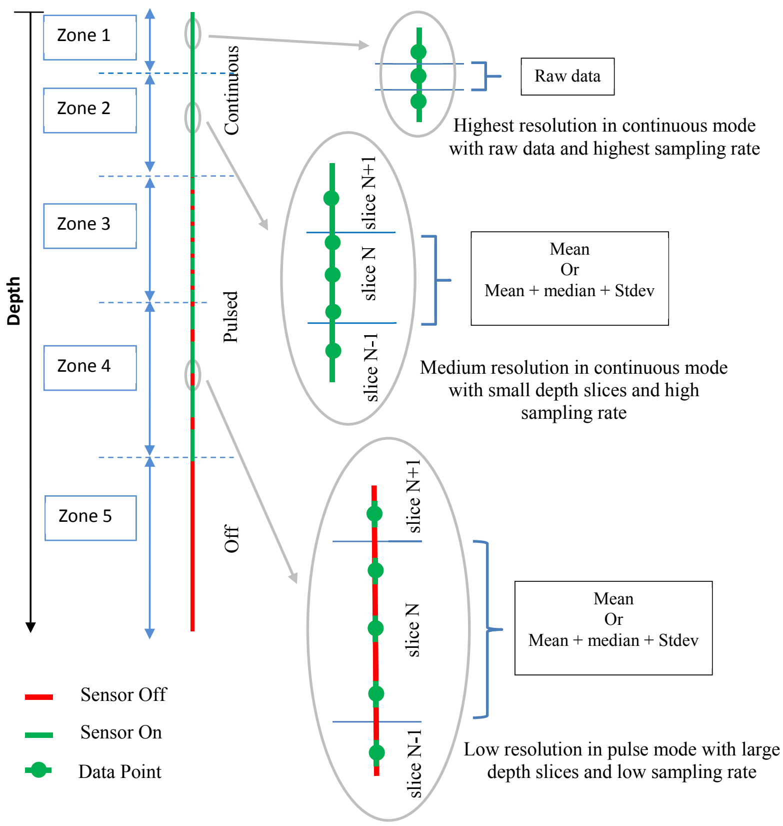

Figure 2: Sensor powering and data acquisition options along a profile. The ProvBioII float allows balancing power consumption and data resolution by controlling the sensor power supply, the sampling rate and the thickness of slices within which data will be processed. These parameters could be defined independently for each sensor for five depth intervals (Zones). In addition, within each zone, different sampling rates for descent, parking or ascent phases could be defined. This allows to have for example no (or low resolution) acquisition during the descent and the requested acquisition during the ascent of the float.

The large amount of data generated by the ProvBioII float required an enhancement of the data telemetry. The previous version (i.e. ProvBio float) used Iridium Short Burst Data (SBD) packets, which was easy to use and well-adapted to small amounts of data. SBD is however too expensive, when data amount increases. The ProvBioII float was then equipped with an Iridium Router based Unrestricted Digital Interworking Connectivity Solution (RUDICS) system, although SBD telemetry is still available. Less expensive than SDB for large amounts of data, the RUDICS system allows a direct connection of a large number of floats on a given server. The RUDICS configuration of the ProvBioII float allows transmitting typically between 50 kBytes to 150 kBytes of data per cycle at an average speed of around 3 kBytes/min. This speed is currently mostly determined by the capacity of the navigation board in charge of the communication. In this configuration, the RUDICS telemetry is six times less expensive than the cost per kBytes obtained by using SBD on ProvBioB floats. The RUDICS application on the ProvBioII float was developed by NKE, while the server application was directly based on the initial development of Dana Swift (Univ. Washington). The server was set up by the LOV in a secured data center to minimize the risk of a failure. However, if the float is not able to join the server, a redial procedure could be used to wait the re-establishment of the link.

Additional battery and connectors

The last point regarding the new ProvBioII float concerns energy. An additional 60% of battery has been added to the float, to meet the requirement of 250 cycles with the full sensor configuration of the remOcean project (see below). In order to compensate for the negative buoyancy of sensors and the weight of the extra battery, three 4.3 dm3 syntactic foams have been added to the float. In order to connect all the sensors, the ProvBioII float has on the upper end cap, close to the CTD sensor, one hole to connect an Aanderra oxygen optode and one hole to receive a Subconn 8 pin connector. This connector is sufficient to separately power and receive data from 3 sensors through a one-way serial communication. An optional second Subconn 8 pins connector can be added on the lower end cap to connect a nitrate sensor (SUNA) for example.

Examples of sensor configurations: remOcean and NAOS projects

In addition to the effort on development of the ProvBioII float, remOcean and NAOS projects also include developments and integration of new sensors. These integrations could be seen as an example of the capacity of the ProvBioII float to integrate new sensors.

In the framework of the remOcean project, two new optical packages were developed by Satlantic to be specifically implemented on profiling floats: the remA and remB combo sensors. The remA sensor is composed by one downwelling irradiance sensor (OCR 504: 380, 410 and 490nm + PAR) and one ECO3 sensor (Chlorophyll-a fluorescence, Colored Dissolved Organic Matter and particle backscattering coefficients at 700nm). Compared to the ProvBioB configuration, the remA sensor includes a downwelling Photosynthetic Active Radiation (PAR) sensor. However, the main difference with ProvBioB version is that the two sensors (Irradiance and ECO3) can be powered separately, allowing different sampling strategies (i.e. ECO3 all along the profile, irradiance sensors only close to the surface, typically above 250m, where signal is detectable). The remB sensor is the remA sensor plus a Wetlabs transmissiometer (C-Rover) at 650nm, which could also be used independently of the irradiance and ECO3 sensors. Both remA and remB systems were implemented on ProvBioII float.

Significant effort was also performed to improve the measurement of nitrates, mainly based on the know-how acquired during the ProNuts project. Compared to the ProNuts float, a new version of the SUNA nutrient concentration sensor was successfully implemented on ProvBioII: the Deep SUNA. This sensor, still from the Satlantic Company, has the same optical scheme as the SUNA used on the ProNuts float (i.e. measurement of UV absorption spectrum and derivation of nitrate concentrations by optical fitting, Johnson et al. 2002). Differences between the two SUNA versions are on the way to sample and process data. While the first SUNA works on a continuous scheme, like all other sensors, the deep SUNA takes a sample only on a direct request from the float. This sampling mode, which saves energy and provides a more repeatable warm-up for the lamp, requires a two-way link with the float. The latter then drives the acquisition of the sensor by sending a specific command. The float sends also to the deep SUNA temperature and salinity data, which are used for a real-time correction of the temperature and bromide effects on the nitrate concentration estimates (Sakamoto et al. 2009). This option, which was not available on the ProNuts floats, is considered crucial to obtain accurate nitrate concentration data. The ProvBioII float allows two options to transmit SUNA data, which can be remotely selected after deployment. In a first option, for each sample, a reduced spectrum (up to 45 wavelengths) of the measured UV absorption spectrum is transmitted. From this transmitted spectrum, nitrate concentrations could be reprocessed on land by using the current algorithm (i.e. Sakamoto et al. 2009) or reprocessed in the future by using new algorithm. In a second option, only the nitrate concentrations computed internally in real-time by the SUNA are transmitted. With this second option, the amount of data transmitted, and then the cost, is reduced, although only a basic reprocessing of data is allowed. The first option is presently selected on the deployed remOcean and NAOS floats (see below), specifically to optimize and verify the algorithms to estimate the nitrate concentration. In addition to the integration by LOV of these sensors (OCR, ECO3, C-Rover and Deep SUNA), Wetlabs FLNTU (Chla fluorescence and turbidity) and Aanderaa optode were also interfaced with the ProvBioII float.

Consequently, the ProvBioII float is presently the only float able to carry together: the SeaBird CTD, a Satlantic OCR504, a WetLabs ECO3, FLNTU, C-rover, an Aanderaa oxygen optode and a SUNA nitrate concentration sensor. Any combinations including one or several of these sensors are also possible without any modification of the software (Figure 3). The only requirements are the adaptation of the float buoyancy as well as the change of the parameter file of the float.

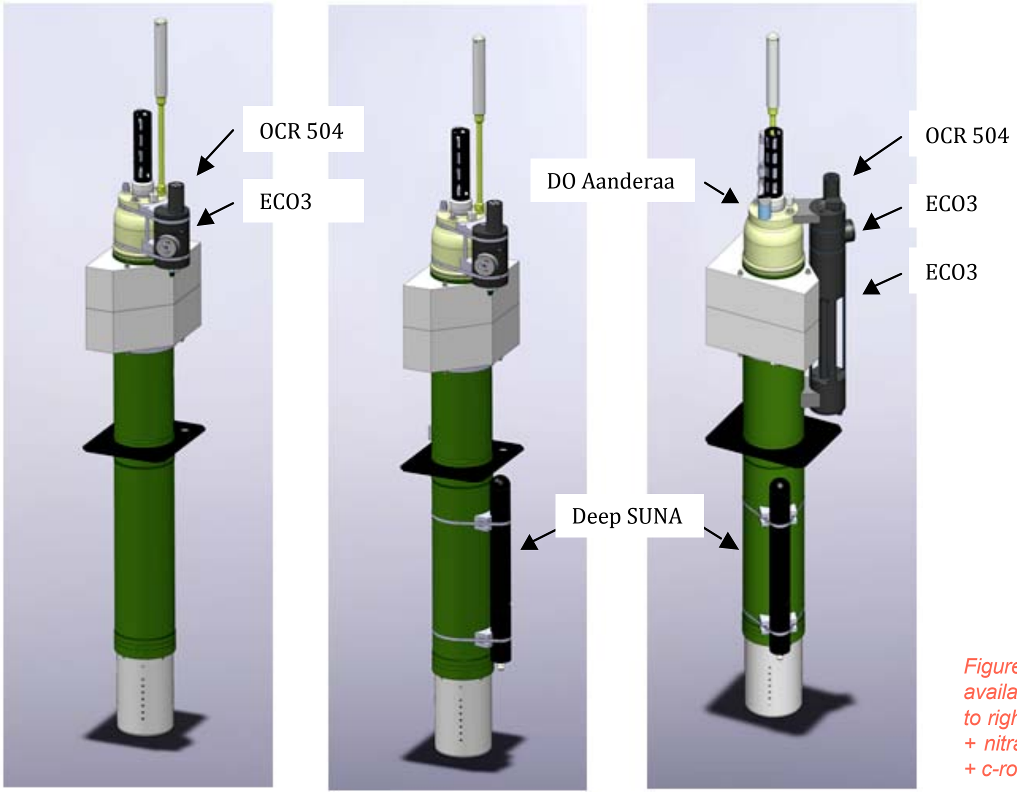

Figure 3 : Examples of sensor configuration available on the new ProvBioII float. From left to right: 1) RemA (OCR504 + Eco3), 2) RemA + nitrate (SUNA), 3) RemB (OCR504 + Eco3 + c-rover) + nitrate (SUNA) + DO (Aanderaa).

First deployments

After a validation phase (by NKE in a submerged quarry near Lorient and by the LOV off the coast of Villefranche), more than twenty ProvBioII floats have been deployed in the framework of the remOcean project in both north and south Atlantic subtropical gyres, Island and Labrador seas. Seven ProvBioII floats have been also deployed in the Mediterranean Sea, in the framework of the NAOS project. Other international groups (Sandy Thomalla from the Southern Ocean Carbon and Climate Observatory) have also purchased and deployed three floats. After these deployments, some technical problems on sensors and on RUDICS telemetry were identified and fixed.

Overall, the first results from new ProvBioII floats are very encouraging. High quality data are daily collected and delivered in real-time through a web interface. All sensor configurations were tested: from the simple RemA configuration to the complete RemB + Optode + SUNA. A large number of missions were already tested, including mono-profile missions (i.e. one profile per cycle) with various time intervals (from one to 10 days), as well as quadri-profile mission. Data are already available at www.oao.obs-vlfr.fr/carto/index.html.

Regarding depth resolution of data acquisition, radiometric and fluorescence data were acquired at a resolution of 0.2m in the upper layer (above 10m) to increase the data quality. Real improvement was also achieved for the nitrate concentration measurement. While this acquisition was subject to a drift within the ProNuts project, data from the new deep SUNA are much more stable in time (Figure 4).

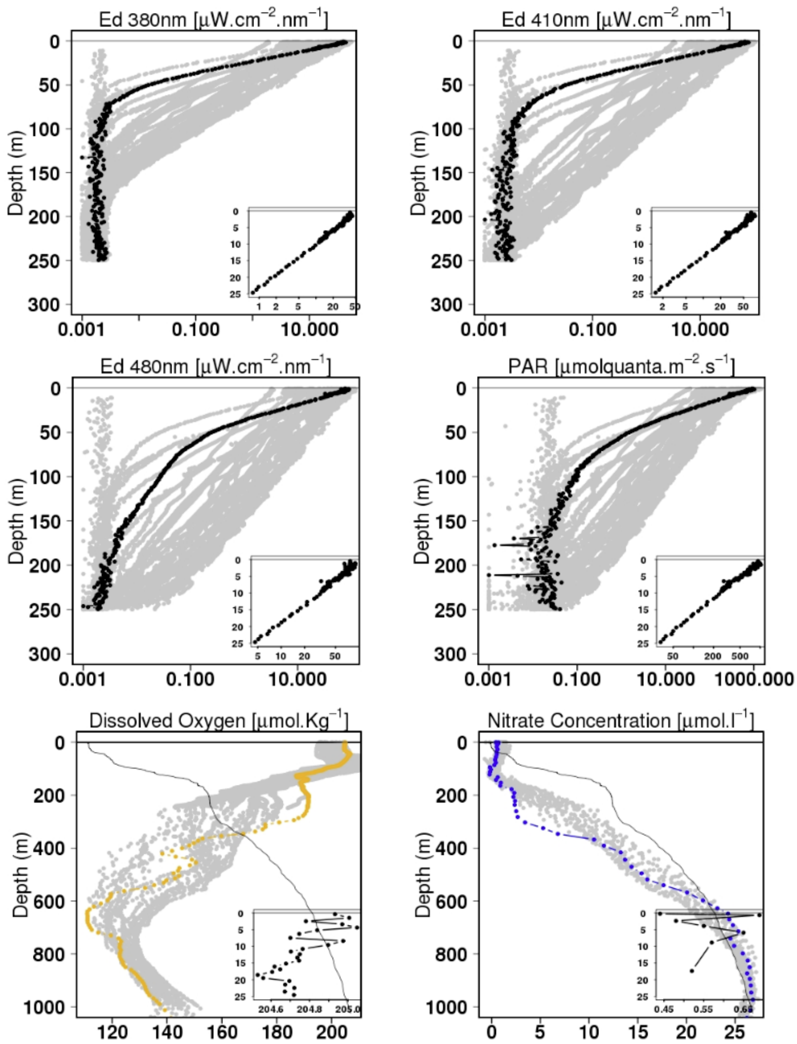

Figure 4: Examples of collected data. All data are visible through the link www.oao.obs-vlfr.fr/carto/index.html. High depth resolution (0.2m) is used for radiometric data. Very good stability of nitrate measurements is also achieved. Radiometric data from lovbio035b (wmo6901511), oxygen and nitrate from lovbio009b (wmo6901472).

Conclusion

The collaboration between LOV, NKE and Ifremer, and the opportunity offered by the remOcean and NAOS projects, lead to the development of a new float with extended functionalities. The new ProvBioII is currently the only available float offering the maximum of capacity and flexibility on the mission scheme as well as on the sensor configuration. The extra on-board battery and the Iridium RUDICS telemetry allow long term missions, even with the full sensor configuration and a large amount of data per cycle. Having a large panel of biogeochemical sensors on the same float opens new opportunities to deeply understand natural cycles and cost reduction could be also expected by sharing expenses like the float itself. After first deployments, this float is already planned to be used within French and European programs like remOcean, NAOS, E-AIMS and Euro-Argo, as well as in non-European projects. We are confident that the ProvBioII float will be an invaluable tool to increase our knowledge of oceans.
The same collaboration is already preparing the next step through a new float which will provide new functionalities for demanding sensors like imaging or acoustic and new mission flexibilities for challenging areas like arctic. This float is already in validation process and will be launched at sea for 2014.

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Programs:

NAOS: Novel Argo Ocean observing System (www.naos-equipex.fr).
remOcean: remotely-sensed biogeochemical cycles in the Ocean (www.oao.obs-vlfr.fr).
CARBOOCEAN: Marine carbon sources and sinks assessment (www.carboocean.org)

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