Realisation of two « dual sensors » floats prototypes for nitrate and irradiance

Ref.: D4.1_V0.1

Date: 11/01/2021

Euro-Argo Research Infrastructure Sustainability and Enhancement Project (EA RISE Project) - 824131

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement no 824131.

Call INFRADEV-03-2018-2019: Individual support to ESFRI and other world-class research infrastructures

Document Reference

Project	Euro-Argo RISE - 824131
Deliverable number	D4.1
Deliverable title	Realisation of two “ dual sensors” floats prototypes for nitrate and irradiance
Description	Realisation of two “ dual sensors” floats prototypes for nitrate and irradiance
Work Package number	WP4
Work Package title	Extension to biogeochemical parameters
Lead Institute	SU
Lead authors	Edouard Leymarie, Antoine Poteau
Contributors	Fabrizio d’Ortenzio, Hervé Claustre
Submission date	12/01/2021
Due date	[M24] 31st December 2020
Comments	
Accepted by	Fabrizio D’Ortenzio

Document History

Version	Issue Date	Author	Comments
0.1	11/01/2021	E. Leymarie	Initial Version

EXECUTIVE SUMMARY

Two "dual-sensor" float prototypes were built and tested as part of the Euro-Argo RISE project.

A first prototype, consisting of two Nitrate sensors (SUNA from SeaBird and OPUS from TriOS), was assembled and tested at sea in July and November 2019. 23 profiles were carried out in the Mediterranean Sea with concomitant measurements of the two sensors. These results were compared to the CANYON-MED model. The results obtained with the OPUS were considered unsatisfactory at this stage of the project with regard to precision and accuracy requirements for nitrate, as defined by the BGC Argo planning group. Given the high-power consumption of the sensor, it was decided in agreement with the partners that the OPUS sensor would not be used during the operational deployments in the Baltic Sea. But a float equipped with the SUNA nitrate sensor will be delivered and used in the Baltic Sea in accordance with the objectives of the project.

A second prototype, consisting of two Irradiance sensors (OCR from SeaBird and RAMSES from TriOS), was assembled and delivered to LOV at the end of November 2020. The Ramses sensor has been specially modified for float applications by increasing its maximum depth from 300 to 1,000m. The software integration has been fully realized on the new profiler Provor CTS5. Technological tests carried out on a bench, and with the final profiler, demonstrate the good performance of the prototype, which will be used in the Baltic Sea in accordance with the project objectives.

TABLE OF CONTENT

LIST OF ACRONYMS

Chla	Chlorophyll a
BGC	BioGeoChemical
PAR	Photosynthetically Available Radiation
PACE	Plankton, Aerosol, Cloud, ocean Ecosystem
SUNA	Integrated *Sea-Bird,Inc.* Nitrate Sensor
ISUS	OEM *Sea-Bird,Inc.* Nitrate Sensor
RAMSES	Hyperspectral *TriOS GmbH* irradiance sensor
RS232/RS485	Serial communication Standards
OCR	Ocean Color Radiometer
OPUS	Integrated *TriOS GmbH* Nitrate Sensor
Sea-Bird, Inc.	Sea-Bird, Inc. 13431 NE 20th St, Bellevue, WA, 98005 USA
NKE Instrumentations	NKE Instrumentations Rue Gutenberg, ZI de Kerandré, 56700 Hennebont, France
TriOS GmbH	TriOS GmbH Bürgermeister-Brötje-Str. 25, 26180 Rastede, Germany

1 Rationales

1.1 Scientific context

In the context of the emerging BGC-Argo program, six variables have been determined as essential variables that should be systematically measured (Roemmich et al., 2019; Claustre et al., 2020). These variables are: chlorophyll a, suspended particles, oxygen, nitrate, pH, and downwelling irradiance. Since 2018, only the NKE Instrumentations PROVOR technology is able to carry the six-sensor suite allowing to measure the 6 core BGC-Argo variables. In early 2021, the three other float companies, all from the US, are either only recently proposing this 6 variables product (Teledyne) or are still in the development phase (Seabird, MRV)

Out of the 6 variables, nitrate concentration is presently the most expensive to be measured because of the price of the SUNA sensor which is the principal available sensor on BGC-Argo floats. In this sense, the long-term sustainability and the cost-effectiveness of the BGC-Argo float array is of main concern. Additionally, the optical measurement of nitrate is presently possible through sensors provided by only one manufacturer (Sea-Bird, Inc.). It is then mandatory to explore if a less-expensive sensor may represent an alternative and viable option for measuring the same variables, with the same accuracy, on a float which is a very demanding platform. There are additional “of the shelf” nitrate sensors provided recently by other manufacturers. These sensors are potentially less expensive, and we need to test them to explore the feasibility and potential benefits of implementing them in a more systematic way.

Radiometry is routinely measured at three wavelengths (380, 412, 490 nm). The choice of these wavelengths has been done to catch the imprint of the main optically-significant substances in open ocean waters, mainly the Chla and associated pigments (absorption peak around 490 nm) and the non-algal particles and colored dissolved organic matter, whose absorption exponentially decreases from the UV to longer wavelengths. Additionally, a sensor measuring Photosynthetically Available Radiation (PAR) allows the integrated downward irradiance between 400 and 700 nm to be systematically monitored in complement to the three selected wavelengths. At the first order, these measurements provide an assessment of the bio-optical status of open ocean waters (Organelli et al., 2017). However, they lack spectral resolution to (1) better resolve and quantify the optically significant substances and (2) refine the inversion of these optical measurements for the assessment of additional biological parameters (i.e. phytoplankton communities). Refining the spectral resolution of the measurement appears thus to be a critical improvement in Argo technology, especially at a time when satellite ocean color sensors with hyperspectral resolution will be soon launched (e.g. PACE mission of NASA) and will require comparable hyperspectral capabilities at sea for in-situ comparison.

1.2 Technological contents

1.2.1 Nitrate Sensors

Currently, all nitrate sensors on the BGC-Argo fleet are provided by a unique manufacturer: *Sea-Bird,Inc.* Two models from this company are available. A stand-alone sensor named SUNA-Deep, which represents the majority of the deployed sensors, and a more integrated solution named ISUS. These sensors measure the spectral absorption of the medium in the near UV domain and use the specific absorption of nitrate in the UV band to determine its concentration. These types of sensors are recent (less than 20 years) and still not very common over the worldwide market. A European company named *TriOS GmbH* is the other company which proposes a similar sensor based on absorption in UV. The proposed sensor named OPUS is very similar in terms of size and characteristics but for a much lower price. For the Euro-Argo RISE project, we wanted to compare the historical SUNA sensor used as a reference sensor for the BGC-Argo fleet with the OPUS sensor. If the performance of the

OPUS on a float would be proven to be equivalent or superior to that of the SUNA, it would represent a very interesting and cost-effective alternative, facilitating the financial sustainability of the BGC Euro-Argo network.

	Deep SUNA V2 (SeaBird)	OPUS (Trios)
Light source	UV deuterium lamp	Xenon flash lamp
Detector spectral range	190nm to 370nm	200nm to 360nm
Size	Φ6.3 * 55 cm	Φ4.8 * 47 cm
Power (lamp)	7.5 W	< 8 W
Optical path	5, 10mm	0.3, 1, 2, 5, 10, 20, 50mm
Max Depth	2000 m	6000 m
Telemetry	RS232	RS232 , RS485
Weight in water	0.4 kg	0.5 kg (Titanium), 1.5 kg (steel)

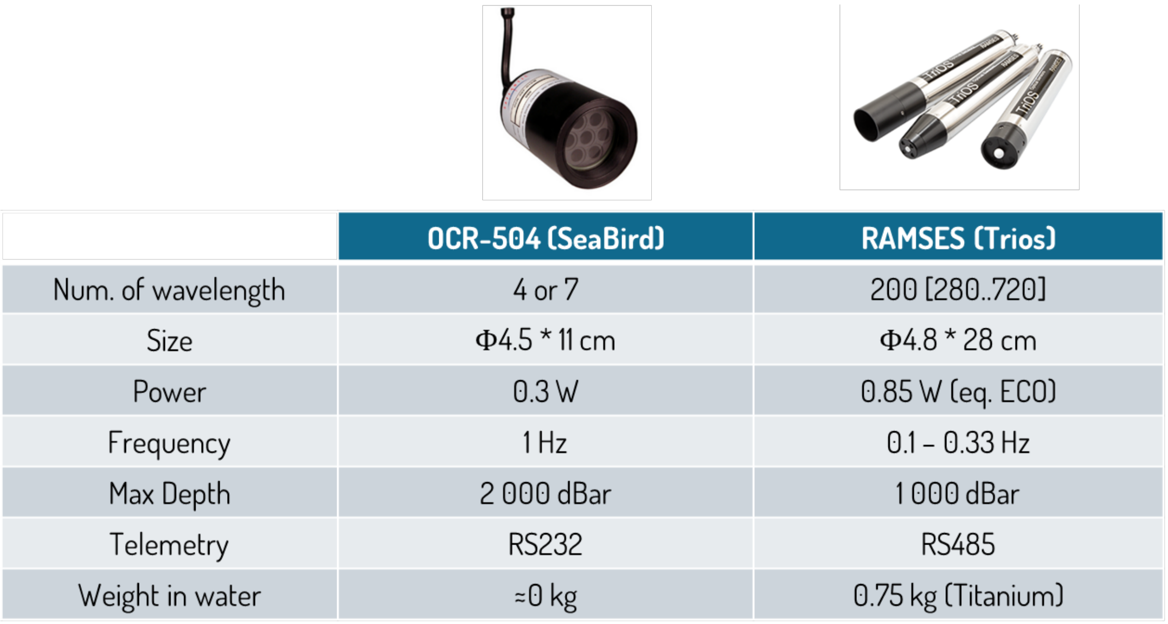
Figure 1: Comparison of some technical specifications between SUNA and OPUS Nitrate sensors

1.2.2 Irradiance Sensors

On the BGC-Argo fleet, the irradiance sensors (named OCR) are also manufactured by the same company: *Sea-Bird, Inc.* But, compared to nitrate sensors, radiometric sensors are more common and several companies may provide such sensors.

For the Euro-Argo RISE project, we have selected the hyperspectral irradiance sensor (RAMSES) from *TriOS GmbH* company. This sensor provides increased measurement capabilities (Hyperspectral vs 4 wavelength) for a similar price. This sensor has already a long history and is known to be robust. A deep version (2000 meter) is currently under development within *TriOS GmbH* company.

The RAMSES sensor provides RS485 telemetry capabilities and requires a power three times higher than the OCR sensor. But the main challenge will be to manage the increased (50 times) data flow from an hyperspectral sensor with respect to a simple multispectral sensor.



	OCR-504 (SeaBird)	RAMSES (Trios)
Num. of wavelength	4 or 7	200 [280..720]
Size	Φ4.5 * 11 cm	Φ4.8 * 28 cm
Power	0.3 W	0.85 W (eq. ECO)
Frequency	1 Hz	0.1 – 0.33 Hz
Max Depth	2 000 dBar	1 000 dBar
Telemetry	RS232	RS485
Weight in water	≈0 kg	0.75 kg (Titanium)

Figure 2: Comparison between OCR-504 and RAMSES irradiance sensors

1.3 Specifications and requirements for data accuracy/precision and sensor/model resolution

1.3.1 Nitrate Sensors

Nitrate concentration is required with an Accuracy/Precision of 1 µmol.kg^{-1} / 0.1µmol.kg^{-1} (Biogeochemical-Argo Planning Group, 2016). Power consumption must be comparable to previous integration.

1.3.2 Irradiance Sensor

Irradiance measurements are required with an Accuracy/Precision of 5.10^{-3} µW.cm^{-2}.nm^{-1} / 2.5.10^{-3} µW.cm^{-2}.nm^{-1} (Biogeochemical-Argo Planning Group, 2016). Power consumption must be comparable to other BGC sensors but could be a little bit higher than the consumption of the OCR504 sensor if new scientific benefits are provided by the enhanced spectral resolution. The acquisition frequency of the sensor must allow the acquisition of a minimum of 2 points per meter (frequency > 0.2 Hz).

2 Dual prototypes

2.1 Dual Nitrate prototype (OPUS)

2.1.1 Sensors test

Laboratory comparisons were carried out, between the SUNA (Seabird) and the OPUS (TriOS), to characterize performance in terms of power consumption and reactivity. The SUNA was configured to measure the absorption spectrum with a dark correction. The nitrate concentration value was derived from the spectrum (column: "Deep SUNA V2"). Three different configurations of the OPUS were tested:

- configuration 1: the raw absorption spectrum was measured (column: OPUS Raw Light),
- configuration 2: The absorption spectrum with a dark correction was measured (column: OPUS Absorption)
- configuration 3: the nitrate value from the spectrum was additionally computed (column: OPUS Analysis).

From these first tests, the SUNA appears more efficient in terms of measurement time (3 s) versus the third configuration of OPUS (18 s) to get the same data retrieval quality. As a result, the energy consumption, at first order proportional to the duration of the measurement, is 5 times higher for the OPUS than for the SUNA when NO3 is calculated by the sensor. Note that this laboratory test was not intended to compare the quality of the measurements.

	Deep SUNA V2	OPUS Raw Light	OPUS Absorption	OPUS Analysis
Min Sampling Period	3 s	7 s	14 s	18 s
Dark Correction	Yes	No	Yes	Yes
Nitrate Process	Yes	No	No	Yes
Energy (Vs SUNA)	x 1	x 2	x 4	x 5

Figure 3: The various laboratory configurations of the OPUS for the comparison with the SUNA sensor

2.1.2 Sensor integration

The in-situ comparison tests have been conducted to verify the quality of OPUS data (accuracy and precision) compared to the already implemented SUNA. These tests have been conducted with a "light" integration (i.e. only connection and software integration) on the so-called CTS5-Payload NKE provor float.

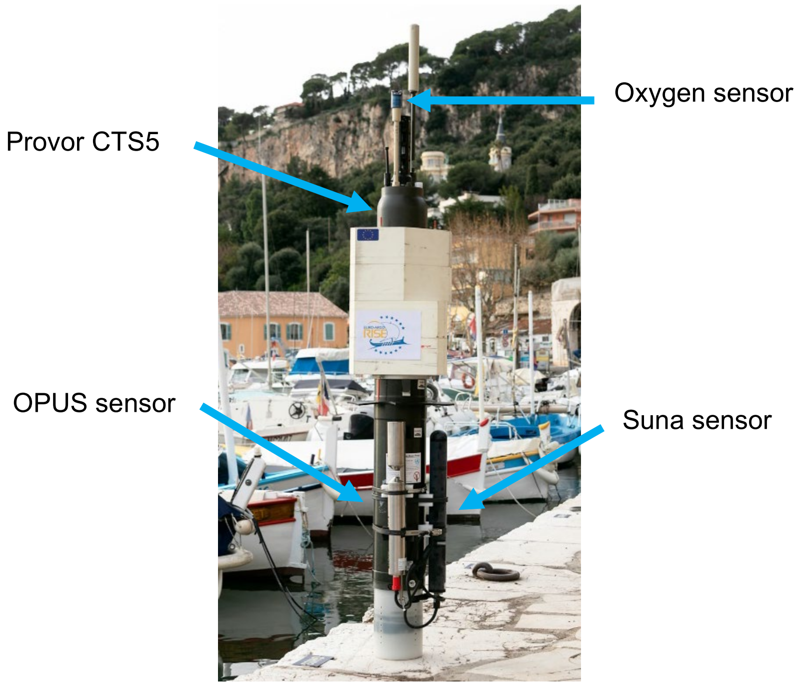


Figure 4: Dual sensor Float prototype with the OPUS and SUNA sensors

The tests have been carried out off the Villefranche bay from the 1st to 8th of July 2019 and then from the 20th to the 25th of November 2019. In total 23 ascent and descent profiles from 1000m to the surface were made during both 2 tests. The test float was also equipped with an oxygen aanderaa optode sensor. The optode sensor mounted on a 30 cm mast can be accurately calibrated at each float surfacing with respect to atmospheric O2 (Bittig et al., 2015). Such measurements together with P, T, S from the float CTD and the geolocation serve as input to the so-called CANYON-MED neural network (Fourrier et al., 2020) which retrieves the NO3 concentration with an accuracy of 0.73 umol.kg^{-1}.

The data were visualized in real-time for salinity, temperature, NO3 OPUS (raw signal), and optode (raw signal). The SUNA data were internally logged in the sensor, and downloaded once the float was recovered (figure 5)

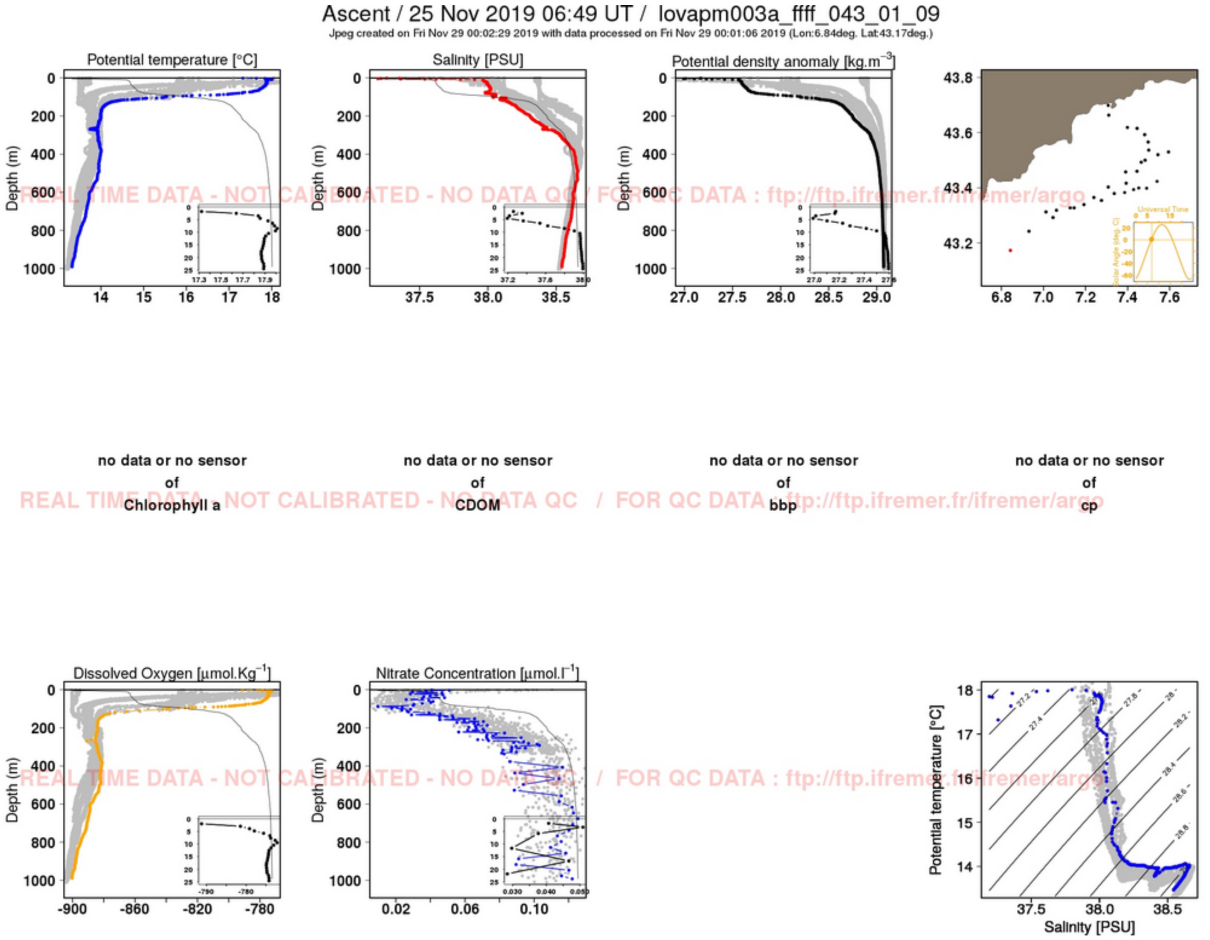


Figure 5: Example of this profile from November 25, 2019. Float test equipped with SUNA and oxygen aanderaa optode sensor.

2.1.3 Data processing

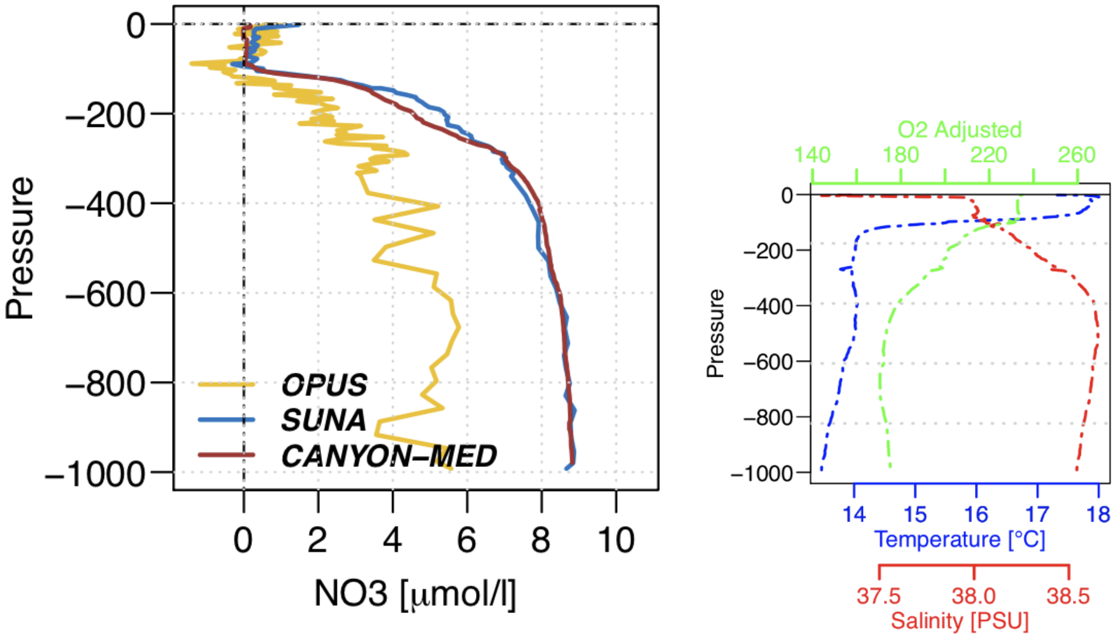


Figure 6: The comparison of the NO3 retrieval by the two sensors and through the neural network Canyon-Med method (left panel) for November 25, 2019. At this period, the surface waters are still stratified (right panel)

The reprocessing of the Nitrate Value of the SUNA (blue line) was made following the standard Argo protocol https://archimer.ifremer.fr/doc/00350/46121/. Nitrate was also calculated by using CANYON-MED (red line, left panel). CANYON-MED used as input oxygen data. The oxygen data were adjusted by using the World Ocean Atlas following the method developed by Takeshita et al, 2013 (green line, right panel). The OPUS was processed using the software made available by *TriOS* at that time. Because data did not appear of the expected quality they were subsequently sent to the *TriOS* for a reprocessing with the latest version of their OPUS software (dark orange line, left panel). All sensor profiles were offseted to a zero value at the surface which correspond to the expected NO3 concentration at this period with still stratification.

From the analysis of the NO3 profiles with different sensor and methods, it presently appears that OPUS measurements are noisier than their SUNA counterparts and that they failed in reporting concentration > 8 uM kg^{-1} at depth that are expected in the Ligurian Basin at those depths.

These results agree with initial analyses (grey literature: Pellerin *et al.,* 2013; Snazelle *et al.,* 2015), which have shown that OPUS could possibly not match the required accuracy on NO3 estimation. This essentially results from the use of a Xenon Lamp on OPUS (deuterium lamp on SUNA) whose outputs require some attenuation at the expense of precision.

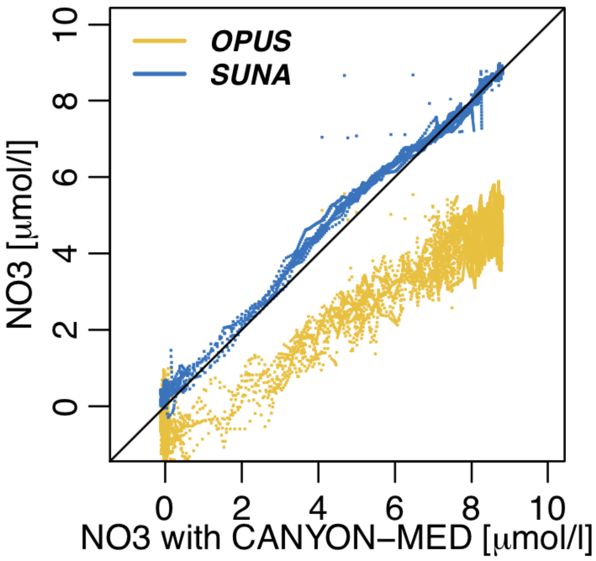


Figure 7: OPUS and SUNA nitrate concentration versus CANYON-MED output. Data from all 23 ascent and descent profiles.

2.1.4 Conclusion and operational float

The present comparison both in terms of energy consumption as well as of accuracy and precision of the NO3 retrieval reveal that the OPUS sensor has not yet the required maturity for being implemented for an operational deployment, especially in open ocean with oligotrophic conditions. The comparison of both sensors and the evaluation of the discrepancies have to be further continued[1] but are out of scope of the present task which has to rely “on the shelf”, ready to be implemented.

The operational float, a CTS5-USEA Provor float equipped with the nitrate sensor SUNA, an *aanderaa optode* sensor, an ECO sensor *(chl_a, bbp, cdom)* and OCR (Irradiance and PAR) is ready for deployment in the Baltic Sea in collaboration with our Finish colleagues.

---

[1] Further work on OPUS will be performed by a German Institute (IOW), but is not carried out under the framework of Euro-Argo RISE project.

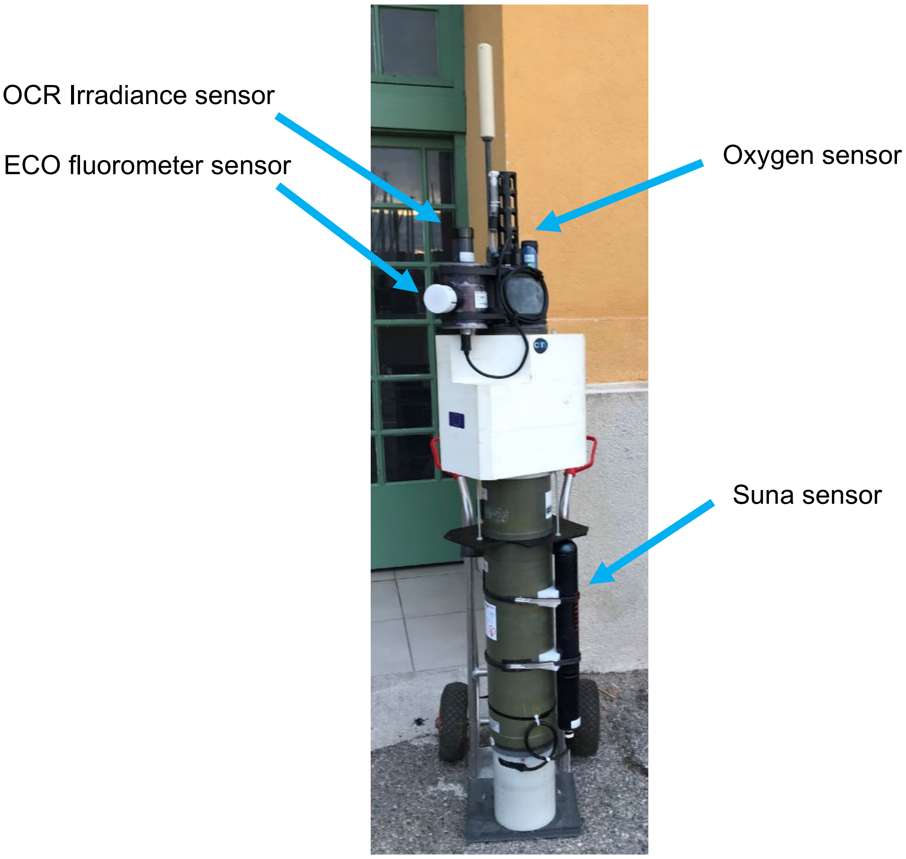


Figure 8: Final product of the CTS5 equipped with Nitrate sensor (SUNA).

2.2 Dual Irradiance Prototype (RAMSES)

2.2.1 Sensor Test

The Ramses sensor is a Hyperspectral radiometric sensor from the manufacturer *TriOS GmbH* known for the quality of its measurement and its reliability. Here we worked on the new version of this sensor, called G2, which has a new software interface and allows to go down to 1,000m depth. A 2,000m version is currently being developed by *TriOS*. Initial tests were carried out in the laboratory in order to determine the possible acquisition frequencies and the associated electrical consumption. It appeared that the first acquisition was always longer, thus using more energy, in order to determine the integration time. Depending on the measurement frequency, it may then be more interesting to keep the sensor on rather than off.

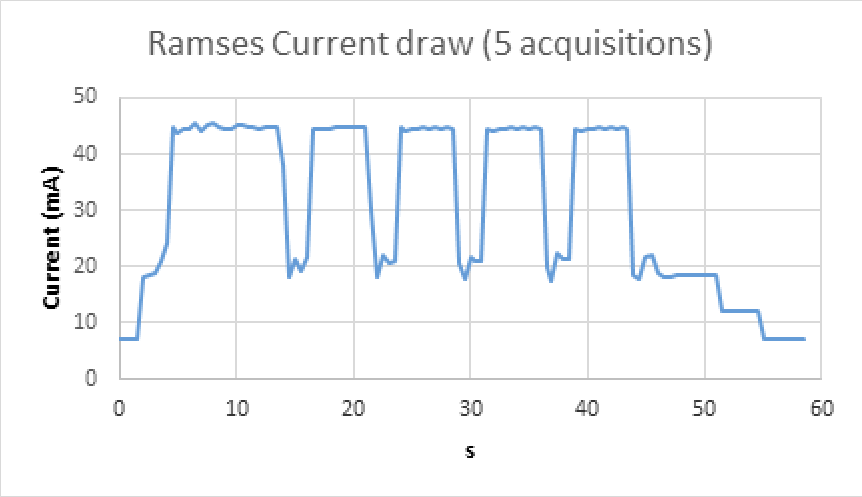


Figure 9: Measurement of the current consumed by the Ramses sensor and acquisition timing

The typical shorter measurement period is 2s + Integration Time. A measurement period of 3 to 5s, corresponding to a vertical resolution on a profiler of 30 to 50cm, is therefore possible and satisfactory for BGC-Argo applications.

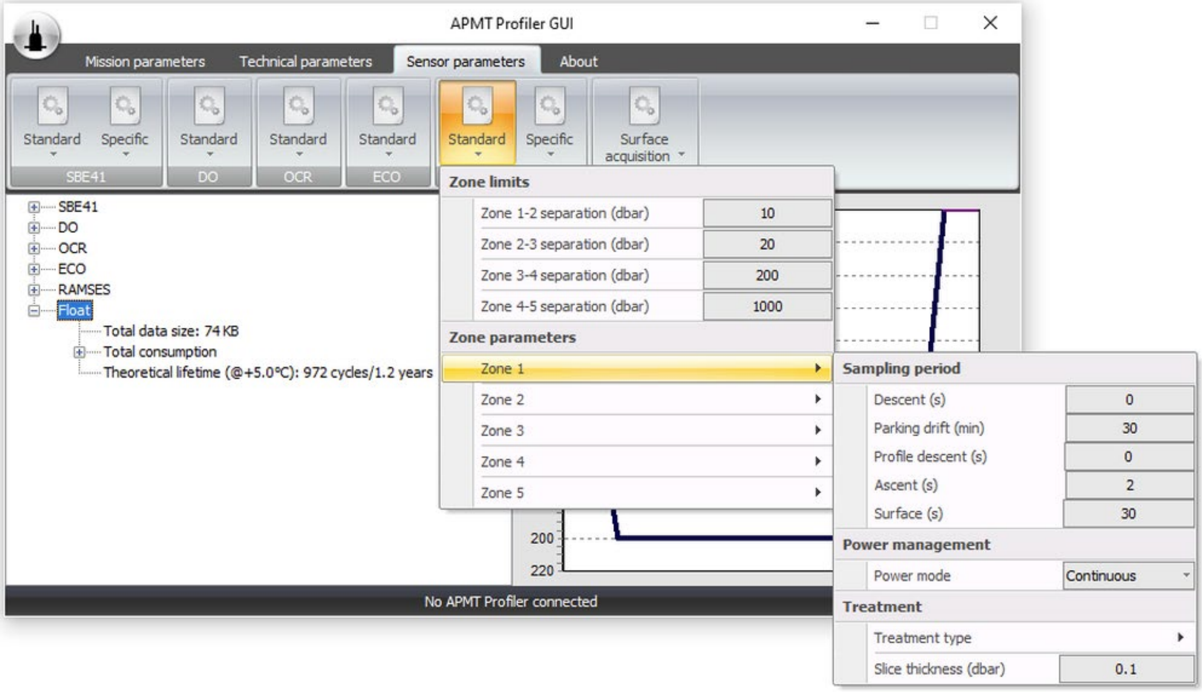
After the power consumption and acquisition frequency of the sensor, the amount of data produced by the hyperspectral sensor was another expected difficulty. For that, the sensor driver on the PROVOR float will allow to choose, remotely, the area of interest to be transmitted (wavelength range) as well as the spectral resolution (binning of 1, 2 or 4 pixels). The data format was also chosen, in collaboration with NKE, in order to be as compact as possible.

RAMSES	Size (octets)	Range	Resolution
Time	4	Unix Epoch	1 sec
CTD Pressure	2	-100 à +2500 dbar	0,1 dbar
Integration Time	2	0 à +65535	1
Pre- Pressure	2	-100 à +2500 dbar	0,05 dbar
Post- Pressure	2	-100 à +2500 dbar	0,05 dbar
Pre-inclination	2	0 à +360°	0,01°
Post-inclination	2	0 à +360°	0,01°
Dark Signal	2	0 à +65535	1
Channel Number : N	1	1 à +245	1
Value 1	2	0 à +65535	1
…	(N-2)*2	0 à +65535	1
Value N	2	0 à +65535	1
Total (octets)	19 + N		

Figure 10: Encoding format for Ramses measurements transmitted by the float (Source NKE)

With these inputs, we can estimate that a typical radiometric profile, of 115 wavelengths, with a vertical resolution of 2m between 250 and 50 dbars, then 1m up to 25 dbars and finally 50cm to the surface will represent a data volume of 36 kB and an energy consumption of 0.65 kJ. The latter represents 14% of the energy consumption of the CTD sensor on a 2000m profile and can therefore be considered acceptable given the amount of information generated by the Ramses sensor.

A new version of the nke float Firmware (version 1.08.004), integrating the Ramses sensor, was delivered to the LOV at the beginning of October 2020. This firmware is associated with a new version of the float programming GUI. This interface allows to set the spectral range and resolution as well as the acquisition frequency of the RAMSES. An energy and data budget evaluation are carried out by the graphical interface.



- SBE41
- DO
- OCR
- ECO
- RAMSES
- Float
  - Total data size: 74 KB
  - Total consumption
  - Theoretical lifetime (@+5.0°C): 972 cycles/1.2 years

Zone limits

Zone 1-2 separation (dbar)	10
Zone 2-3 separation (dbar)	20
Zone 3-4 separation (dbar)	200
Zone 4-5 separation (dbar)	1000

Zone parameters

- Zone 1
- Zone 2
- Zone 3
- Zone 4
- Zone 5

Sampling period

Descent (s)	0
Parking drift (min)	30
Profile descent (s)	0
Ascent (s)	2
Surface (s)	30

Power management

Power mode	Continuous

Treatment

Treatment type	
Slice thickness (dbar)	0.1

No APMT Profiler connected

Figure 11: APMT GUI with RAMSES interface opened

2.2.2 RAMSES float firmware validation

The LOV has a float simulation bench for testing new firmware on real hardware. Float navigation as well as data transmission are also simulated. A RAMSES sensor has been connected to the bench and 76 virtual profiles, over 48 days, have been realized with remote modification of the spectral interval and resolution as well as the acquisition frequency. No errors were detected, which validates the new firmware as well as the data transmission and decoding chain.

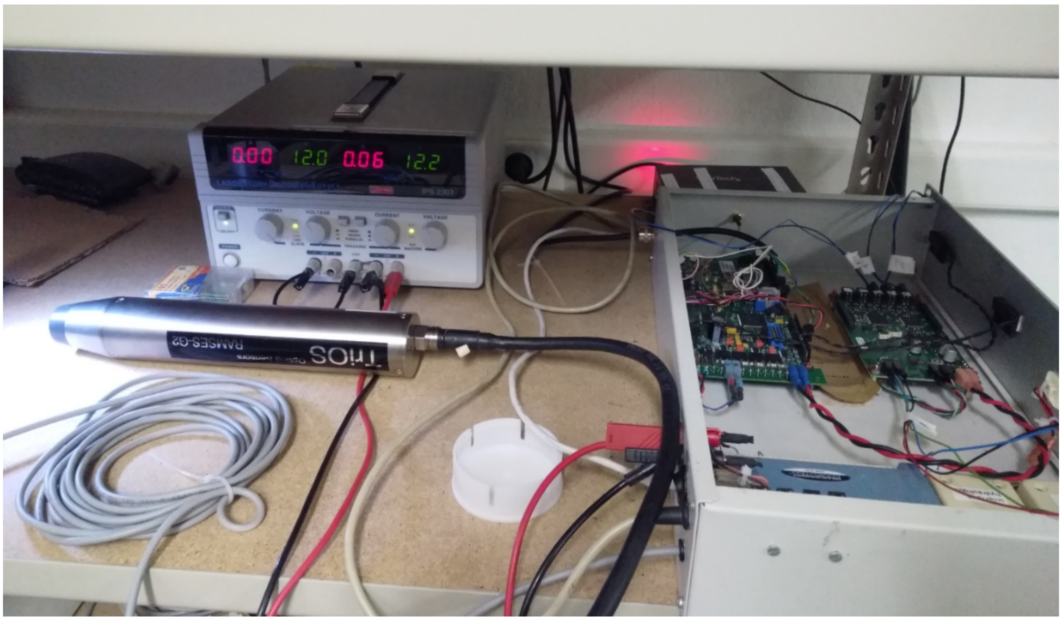


Figure 12: Float simulation bench (real electronics and firmwares) at LOV connected to a RAMSES sensor (illuminated)

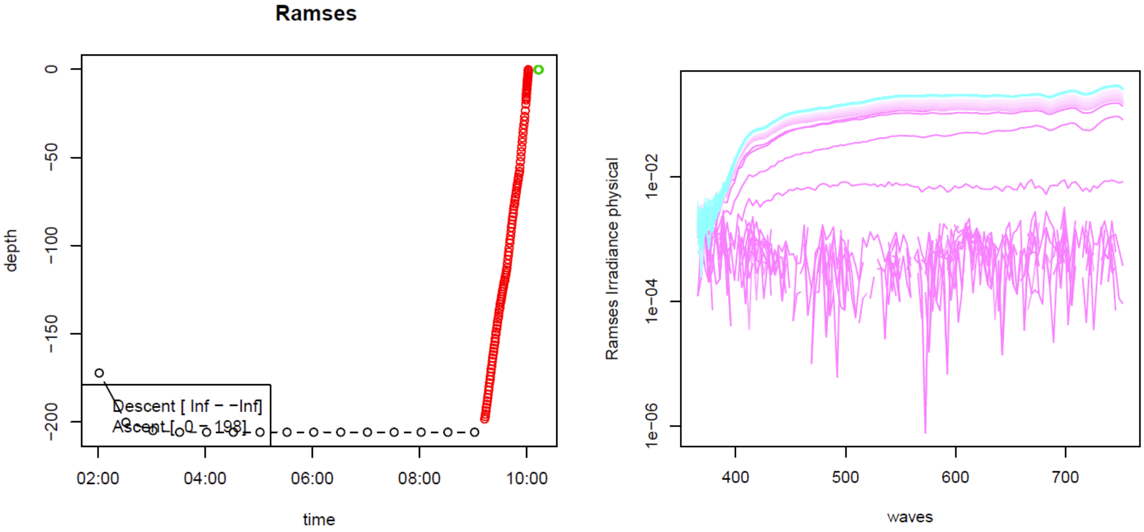


Figure 13: Virtual profile cycle: 64, pattern: 1, date: 2020−12−03 10:01:53 in natural weak ambient light. Left: Depth of acquisition, Right: Irradiance spectra.

During bench tests where the sensor is exposed to low ambient irradiance, the integration time is automatically set to its maximum value of 4s. However, the acquisition period remains high with a maximum of 13 acquisitions in 92s (7.1 s per acquisition) in the example of the virtual profile number 64 (Fig 13). This frequency could possibly be higher at sea, close to the surface, if the irradiance allows shorter integration times. Tests were carried out by artificially illuminating the sensor. At an irradiance level of 20 µW/cm2/nm, an integration time of 32 ms and an effective acquisition period of 3.1s were reached, which allows a resolution of about 3 acquisitions per meter close to the surface.

2.2.3 Dual Irradiance sensors prototype

The dual irradiance float prototype was delivered at the end of November by nke with a RAMSES sensor and an OCR sensor. This profiler is also equipped with an EcoPuck fluorometer and an *Aanderaa* optode. This profiler is ballasted and ready to use. A one-day sea test is planned off Villefranche at the end of December or early January depending on weather conditions.

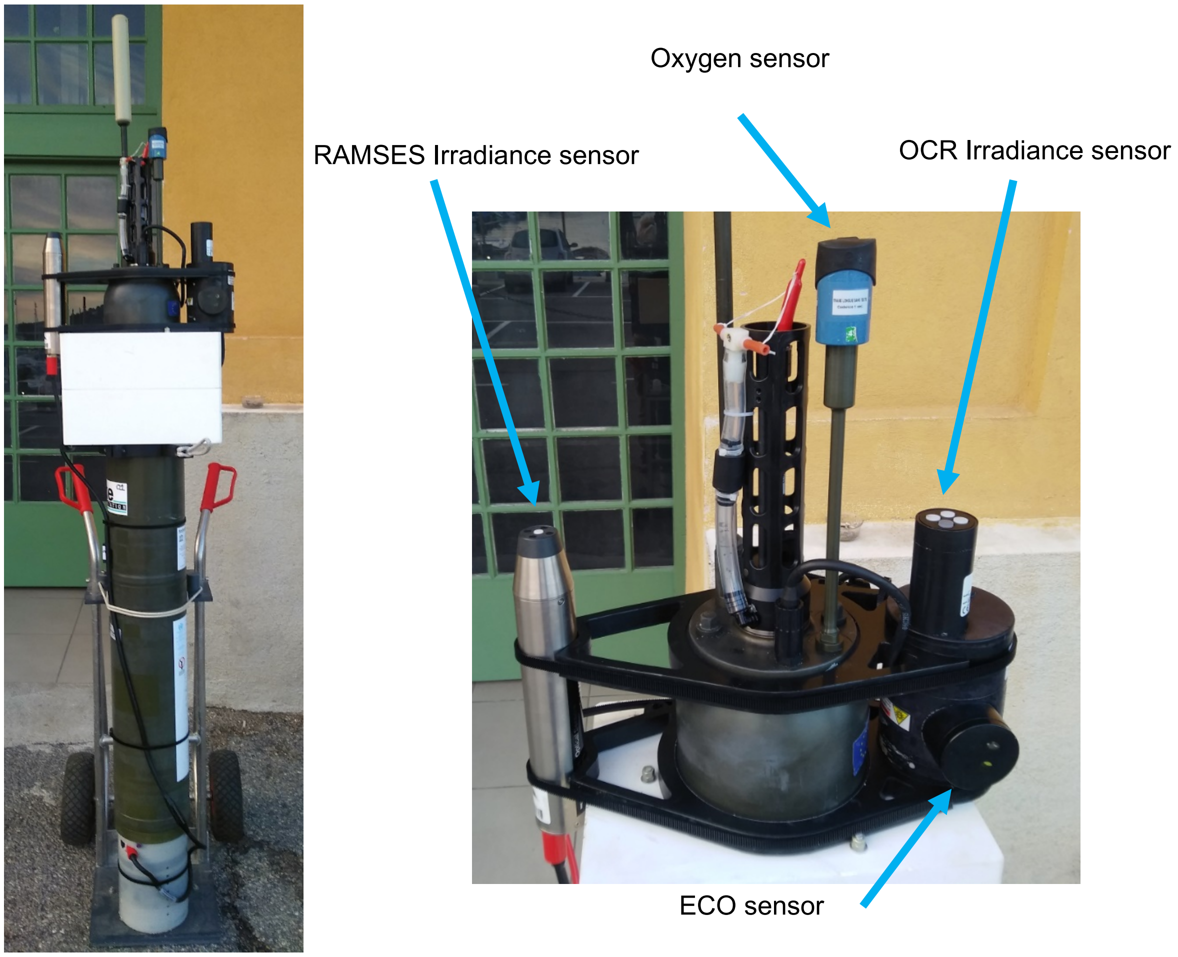


Figure 14: Dual Irradiance float including in addition ECO and Oxygen sensors

However, a first test was carried out by making atmospheric measurements at the LOV parking lot using the profiler as a datalogger. This simple experiment allows a first comparison of the two sensors (Fig 15.) and confirms that a RAMSES acquisition at a frequency of 0.3 Hz is possible, which is above our requirement of 0.2 Hz.

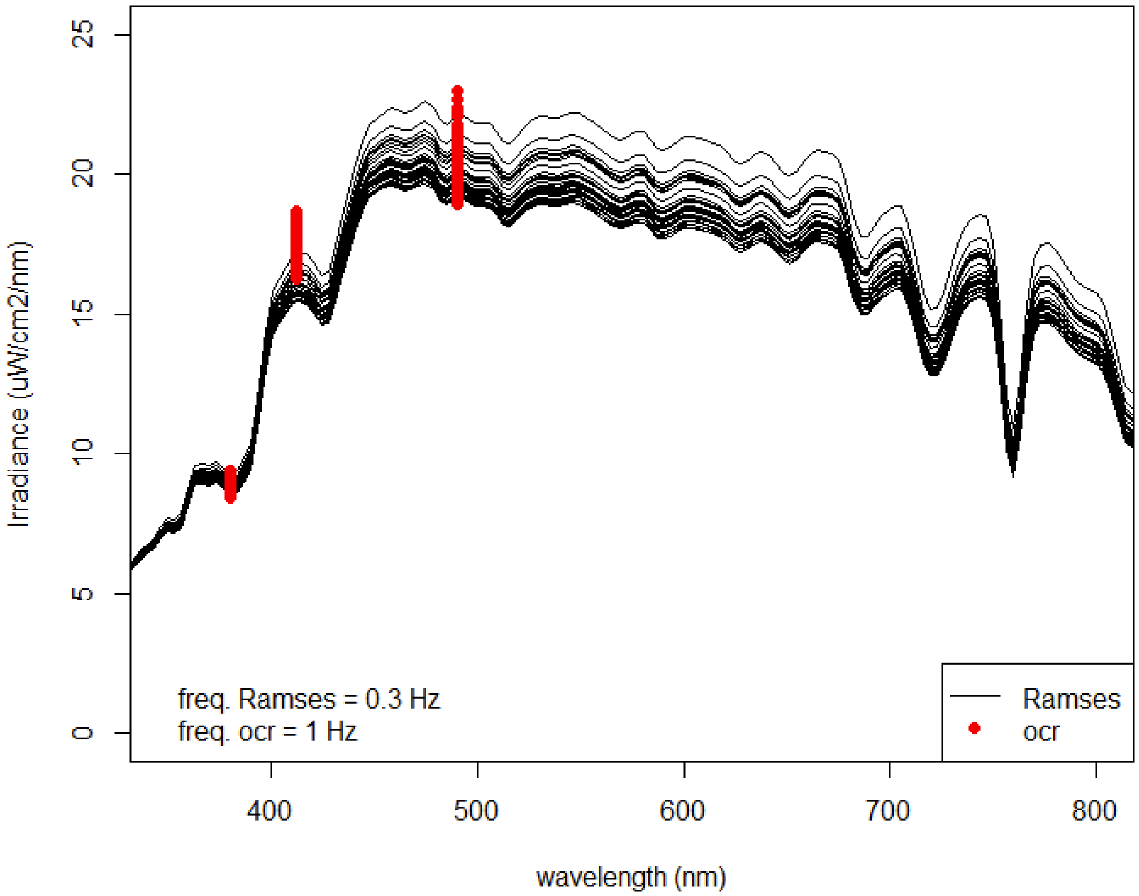


Figure 15: Dual irradiance acquisition in air with the prototype during 120s. Outdoor cloudy low light condition.

3 Baltic deployments planning

Several meetings (visioconference) were held with our FMI partner to plan future deployments. The performance of the prototypes as well as the constraints of the Baltic Sea deployments were discussed as well as the scientific objectives of these deployments. These early contacts should allow the deployments to proceed smoothly.

Both floats will be sent to FMI partners by January 2020 for deployment in the Baltic Sea in late spring. A quality control procedure for hyperspectral data is already under study at LOV as part of the CNES-funded ProVal project. LOV staff will visit the FMI, subject to health conditions, to train our partner in these new technologies. If travel is not possible, video and videoconference training will be organized.

4 Reference documents

Biogeochemical-Argo Planning Group (2016). The scientific rationale, design and implementation plan for a Biogeochemical-Argo float array. doi:10.13155/46601.

Bittig, H. C., Steinhoff, T., Claustre, H., Fiedler, B., Williams, N. L., Sauzède, R., et al. (2018). An Alternative to Static Climatologies: Robust Estimation of Open Ocean CO2 Variables and Nutrient Concentrations From T, S, and O2 Data Using Bayesian Neural Networks. *Front. Mar. Sci.* 5. doi:10.3389/fmars.2018.00328.

Bittig, H. C., and A. Körtzinger (2015), Tackling Oxygen Optode Drift: Near-Surface and In-Air Oxygen Optode Measurements on a Float Provide an Accurate in Situ Reference, *Journal of Atmospheric and Oceanic Technology*, *32*(8), 1536-1543, doi:10.1175/jtech-d-14-00162.1.

Claustre, H., K. S. Johnson, and Y. Takeshita (2020), Observing the Global Ocean with Biogeochemical-Argo, *Annual Review of Marine Science*, *12*, 23-48, doi:10.1146/annurev-marine-010419-010956.

Fourrier, M., L. Coppola, H. Claustre, F. D'Ortenzio, R. Sauzède, and J. P. Gattuso (2020), A regional neural network approach to estimate water-column nutrient concentrations and carbonate system variables in the Mediterranean Sea: CANYON-MED, *Frontiers in Marine Science*, doi:10.3389/fmars.2020.00620.

Organelli, E., Claustre, H., Bricaud, A., Barbieux, M., Uitz, J., D'Ortenzio, F., et al. (2017). Bio-optical anomalies in the world's oceans: An investigation on the diffuse attenuation coefficients for downward irradiance derived from Biogeochemical Argo float measurements. *J. Geophys. Res.-Oceans* 122, 3543–3564. doi:10.1002/2016JC012629.

Pellerin, B.A., Bergamaschi, B.A., Downing, B.D., Saraceno, J.F., Garrett, J.A., and Olsen, L.D., 2013, Optical techniques for the determination of nitrate in environmental waters: Guidelines for instrument selection, operation, deployment, maintenance, quality assurance, and data reporting: U.S. Geological Survey Techniques and Methods 1–D5, 37 p. https://doi.org/10.3133/tm1D5

Roemmich, D., et al. (2019), On the Future of Argo: A Global, Full-Depth, Multi-Disciplinary Array, Frontiers in Marine Science, 6, doi:10.3389/fmars.2019.00439.

Snazelle, T.T., 2015, Results from laboratory and field testing of nitrate measuring spectrophotometers:
U.S. Geological Survey Open-File Report 2015–1065, 35 p., https://doi.org/10.3133/ofr20151065