Report on operational deployments of the two prototypes with N03 and Irradiance

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EXECUTIVE SUMMARY

Prototypes with RAMSES (irradiance) and OPUS (nitrate) sensors were deployed and tested in the Mediterranean and Baltic Sea. Tests demonstrated that the RAMSES sensor (from TriOS manufacturer) is applicable for both areas. Advantages compared to OCR (from Sea Bird Scientific manufacturer) are the hyperspectral data with higher sensitivity. The downsides in comparison with OCR are higher energy consumption and lower vertical resolutions, which however are still reasonable and in line with the BGC-Argo recommendations.

Initial nitrate sensor comparisons in the Mediterranean between SUNA (from Sea Bird Scientific manufacturer) and OPUS (from TriOS manufacturer) indicated SUNA to be more suitable for continuing in the Euro-Argo RISE experiments. Despite the float deployment in the Baltic Sea failing, further data from Germany experiments helped to progress on the analysis of the OPUS sensor.

The tests with SUNA and OPUS sensors in the framework of DArgo 2025 indicated SUNA to be more energy conservative and less noisy. There is however potential as a more economical option for missions in the OPUS sensor with proper calibration and further work on data quality.

TABLE OF CONTENT

1 Introduction

The prototypes developed earlier and documented within deliverable 4.1 (Leymarie et al, 2021) were developed and tested in the Mediterranean Sea (technological tests). After this first evaluation step, operational deployments were carried out in the Baltic Sea for further evaluating the performance in various conditions. Baltic Sea was chosen as the second test area, as it has strong variability in conditions. The water has much lower salinity, but still strong haloclines, and varying temperature profiles. The area is rather confined, so possibilities for recovery are also good.

Two prototypes were deployed, one with RAMSES sensor in the Baltic Proper, Gotland deep, and the other with SUNA sensor in the Gulf of Bothnia, Bothnian Sea.

In addition to the test performed in the Baltic Sea, we will describe the results of earlier Mediterranean experiment, deployed after the writing of the deliverable 4.1. For nitrate sensors, we also describe complementary experiments performed in the DArgo-2025 project.

2 Experiments and results conducted in the Mediterranean Sea

As planned in the project, prototypes were tested in the Mediterranean Sea before operational deployments in the Baltic. This section details and recalls the analysis of the dual sensor prototypes deployed in 2021.

2.1 Prototype with RAMSES sensor

A dual sensor prototype (RAMSES + OCR) was deployed off Villefranche sur Mer from 26/02/2021 to 23/06/2021 producing 74 profiles. Trajectory is shown in Figure 1.

The deployment was very successful and demonstrated the great capabilities of this instrument. In particular :

- Hyperspectral radiometric measurement usable from 320 nm to almost 800nm (Figure 2)
- Unexpectedly a higher sensitivity compared to the OCR sensor (Figure 3)
- A sensor that is fast enough to provide metre to sub-meter resolution close to the surface (as requested by the Argo radiometry working group (ADMT-23).
- Energy consumption and data transmission are still manageable

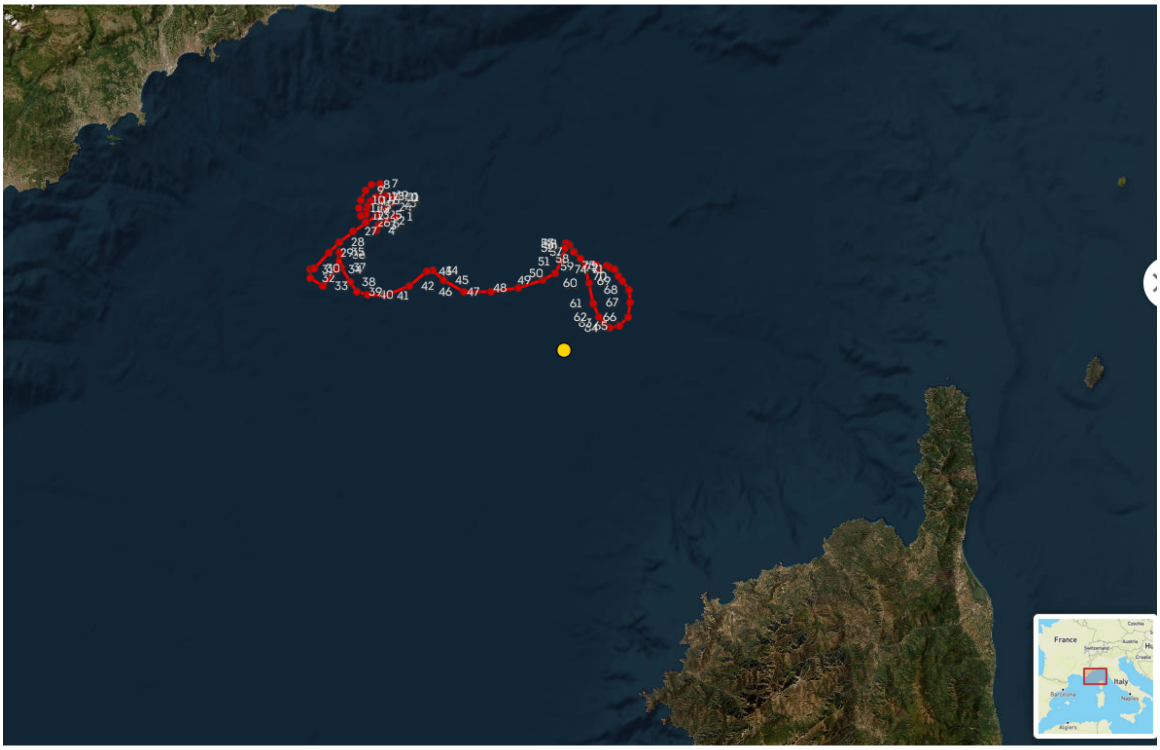

Figure 1:Trajectory of the Mediterranean prototype test, mission WMO 6903124

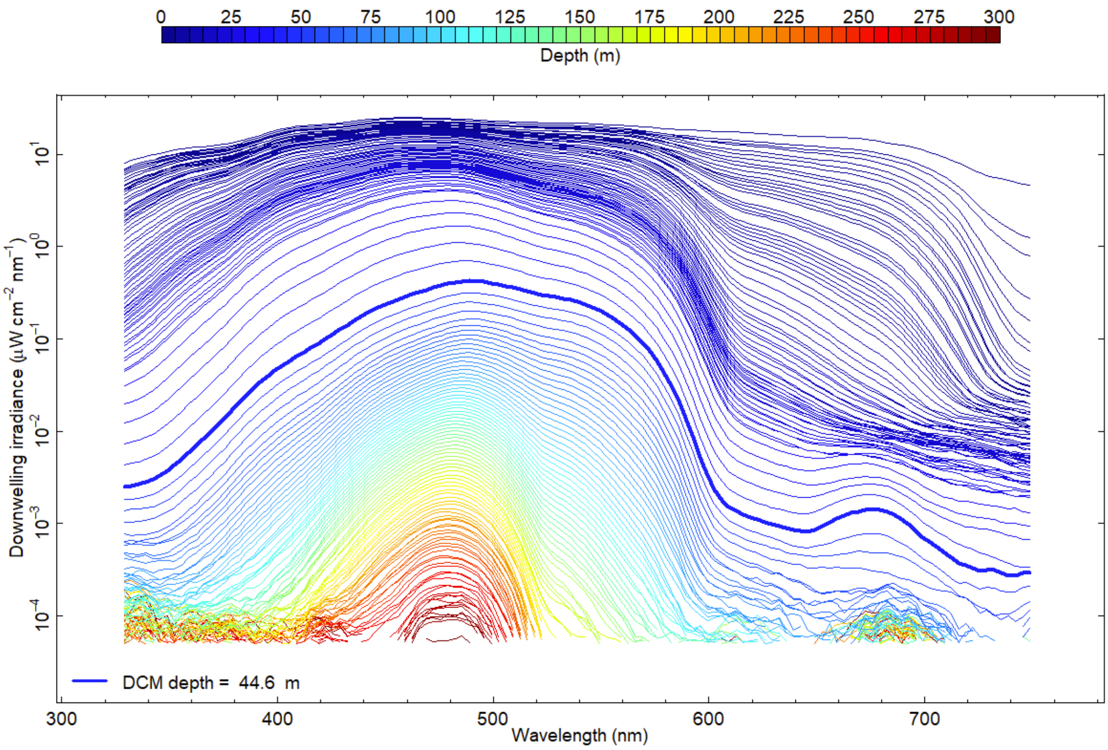

Figure 2: Example of hyperspectral measurements obtained in the Mediterranean Sea on 2021-06-02. The natural fluorescence of Chla induced by sunlight is visible at 680 nm and at 44.6 m depth.

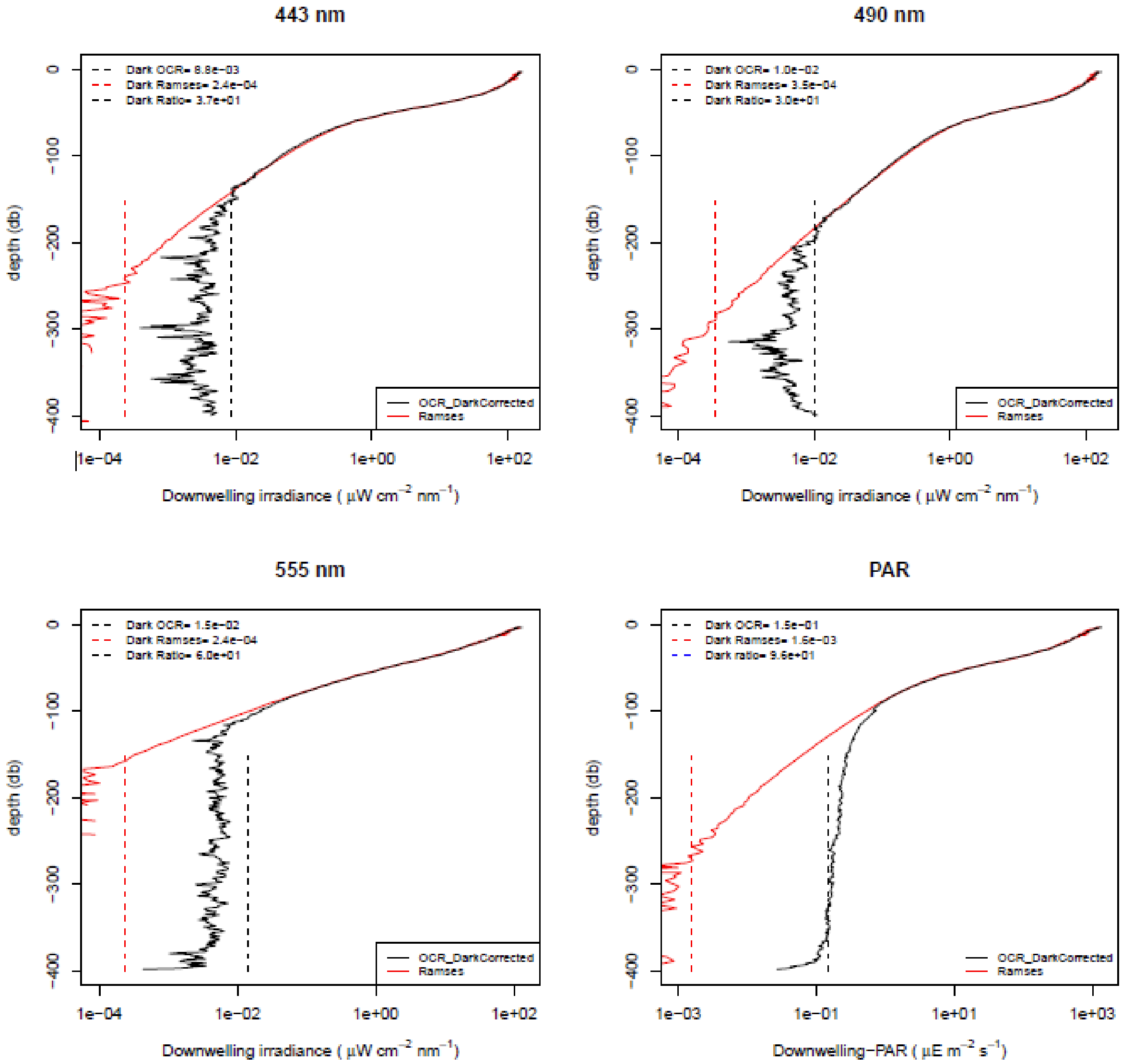

FIgure 3: Example of comparison between RAMSES (red curve) and OCR (black curve) irradiance profiles in the Mediterranean Sea on 2021-06-12

The RAMSES sensor appears to be much more sensitive than the OCR sensor with a detection limit typically 40 times lower on average. The OCR sensor consumes more in this test than usual because we have carried out a continuous acquisition on the 400-100m range, with an averaging by 1db slice, to try to increase the sensitivity of the measurement by the OCR. The differences are listed in table 1.

TriOS RAMSES			**SBE OCR**		
Sampling Settings			Sampling Settings		
Depth Zone	period	Practical Vertical resolution	Depth Zone	period	Practical Vertical resolution
450 - 300 db	50 s	5 m			
300 - 30 db	30 s	3 m	400 - 100	2 s	1 m (mean 1m)
30 - 10 db	10 s	1 m	100 - 10	10 s	1 m
10 - 0 db	full	0.35 m	10 - 0	2s	0.2 m
+ parking and surface data			+ parking and surface data		
Spectral resolution : 136 wavelengths [315 – 765]			**Spectral resolution** : 4 wavelengths		
Results			**Results**		
Data : 60 kB / Profil			Data : 17 kB / Profil		
Energy : 55 mA.h / profile (9%)			Energy : 28 mA.h / profile (5%)		

Table 1: describing the acquisition strategy used in the Mediterranean Sea with the resulting energy consumed by each sensor and the volume of data generated.

2.2 Prototype with OPUS sensor

The Mediterranean experiments led with a dual sensor SUNA/OPUS prototype are further described in Deliverable 4.1 (Leymarie et al 2021). They confirmed SUNA to be ready for use in the Baltic Sea, while OPUS still needed further developments.

3 Experiments conducted in the Baltic Sea

3.1 Prototype with RAMSES sensor

3.1.1 Euro-Argo RISE prototype

The prototype was deployed on board r/v Aranda on 19/05/2021 at 57.34 °N 20.05 °E (Figure 4), and recovered by r/v Aranda on 07/04/2022. During its mission (WMO 6903706) it measured 86 cycles in total. After recovery no biofouling was detectable on the instrument (Figure 6).

The route can be seen in Figure 5 and https://fleetmonitoring.euro-argo.eu/float/6903706

Figure 4: Deployment of the Provor float prototype with RAMSES Sensor. (Image: Tuomas Kärnä, FMI)

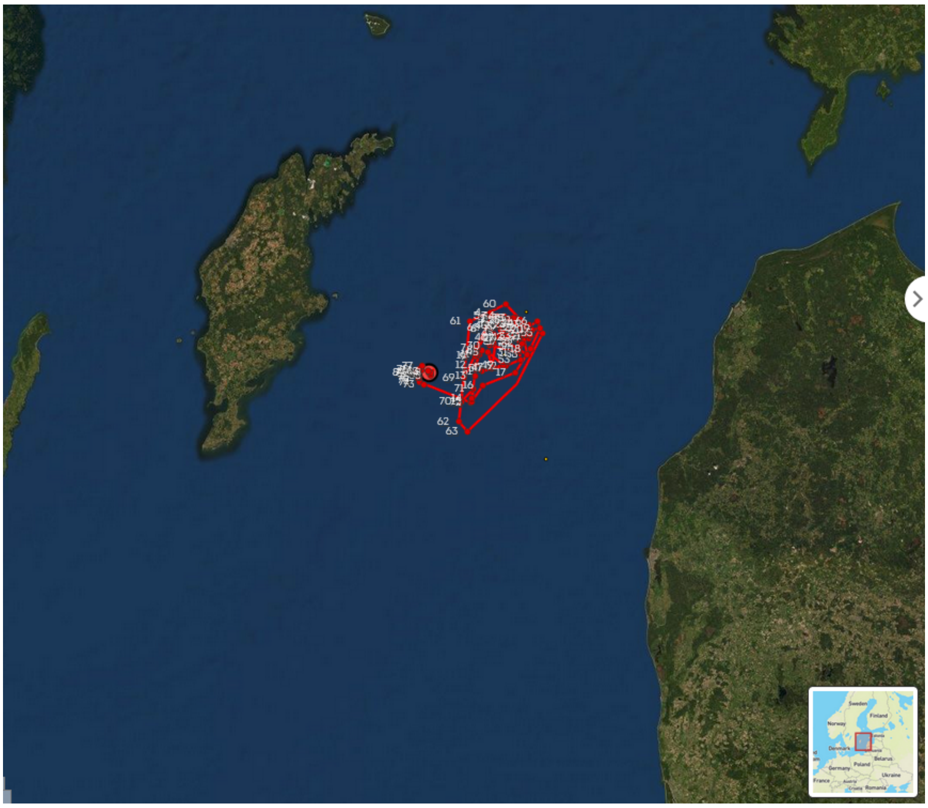

Figure 5: The route of the RAMSES prototype (WMO 6903706) from deployment to recovery

Figure 6: The RAMSES prototype (WMO 6903706) right after recovery onboard Aranda. No signs of biofouling were detectable.

It is important to note that the RAMSES prototype has a 1,000 m deep version of the sensor, which is no longer available since the end of 2021. It is now replaced by a 2,000 m version, ready to be implemented in the BGC-Argo floats. As such, there are no longer limits to the typical operation depth.

3.1.2 Other RAMSES sensors in Baltic Sea

Additional experiments were carried out at European level with Teledyne's APEX floats fitted with RAMSES sensors. Deployments from the DArgo-2025 project by the team of Dr. Oliver Zielinski from the University of Oldenburg (ICBM) are listed in table 2.

WMO Number	Area	Status	Deploy Time	Deploy Coordinates
7900564	Baltic Sea	Maintenance	x	x
7900586	Baltic Sea	Recovered	25.03.2021 - 19.04.2022	57°19'22.3"N 20°03'19.4"E
7900587	Baltic Sea	Recovered	25.03.2021 - 01.06.2022	57°17'54.0"N 20°11'38.7"E

Table 2: Other Baltic Sea missions with RAMSES sensors

3.2 Prototype with SUNA sensor

3.2.1 Euro-Argo RISE prototype

The prototype was deployed on board r/v Aranda on 21/05/2021 at 61.40° N, 20.19° E. Unlike the other prototype, this one started descent rather quickly right after deployment (Figure 7). Unfortunately this float experienced immediate problems in surfacing. The float managed to surface a few times and connect to the server, but not enough to relay its location. After a few attempts on the surface we lost contact with the prototype completely.

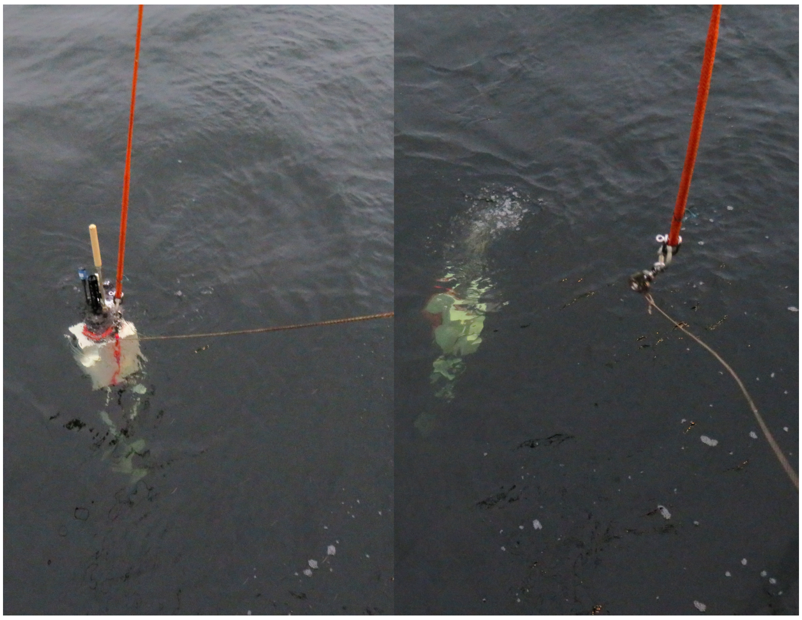

Figure 7: The float right before (left) and right after (right) release of the deployment rope. The float started descending immediately after release. (Image FMI)

3.2.2 Other SUNA/OPUS sensors in Baltic Sea

IOW from Germany has also deployed two Argo floats with SUNA and OPUS sensors in the Baltic Sea, Gotland Deep at the beginning of 2021 and one more in March 2022. These are Provor type floats WMO 6904117 and WMO 6904116 with approx 200 profiles each. An additional Provor float with SUNA sensor, WMO 6904226, has measured 60 profiles, latest mid July, 2022. The routes of these floats can be seen in Figure 8.

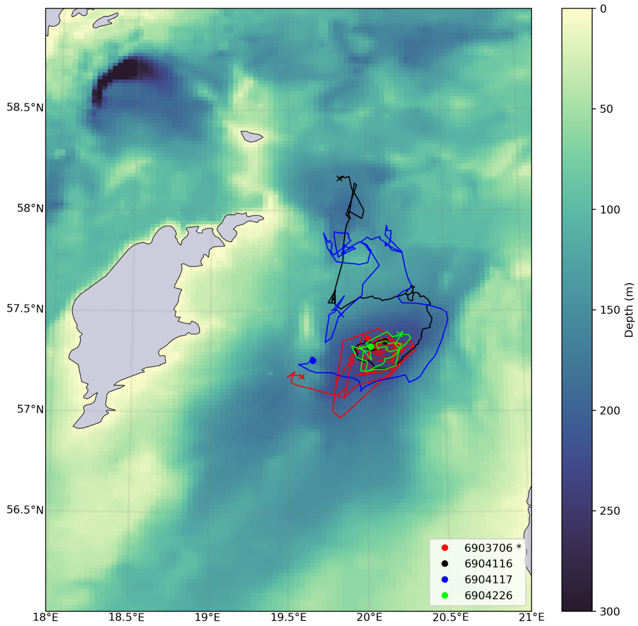

Figure 8: Routes of the Euro-Argo RISE RAMSES prototype (red), and IOW's floats with SUNA sensors

4 Results from the Baltic Sea experiments

We present here the general performance of the tested sensors, concentrating on analysis needed to provide recommendations for their use by the BGC Community.

4.1 Prototype with RAMSES sensor

During the deployment we performed a CTD cast as well as oxygen measurements, in order to compare with the floats initial operation. Comparison is shown on Figure 9, and indicated the float was behaving as expected. The CTD and oxygen profiles produced by the Argo float prototype with RAMSES sensor were also compared to measurements recorded by another float (WMO 6903708, equipped with a RAMSES sensor) transiting in the same area at the same period as well as to high resolution CTD profiles extracted from the ICES oceanographic database. Overall, the magnitude and the shape of the profiles for the different parameters (temperature, salinity and oxygen concentration) were consistent.

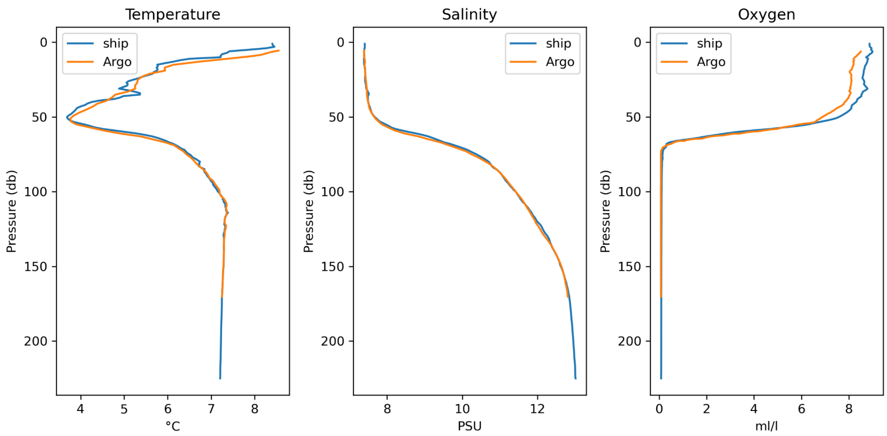

Figure 9: Comparison between the first profile from the float and CTD cast done during deployment. The float profile was made about 6 hours later compared to the CTD cast

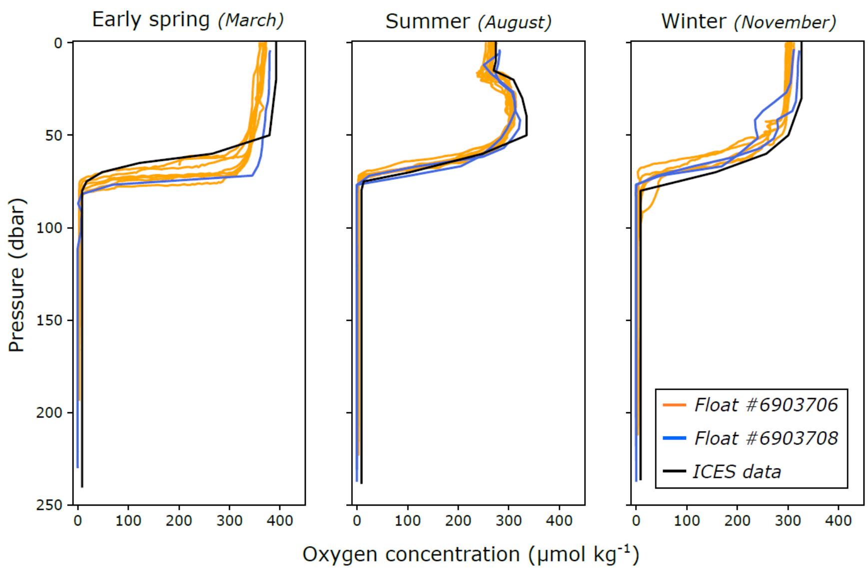

Figure 10: comparison of the prototype float’s oxygen with ICES data and another float. In general the float worked nominally.

As example, a comparison with the oxygen on figure 10, the prototype is able to record similar small-scale features and their seasonal variations, such as subsurface oxygen minima and/or maxima, as earlier floats in the area. We observed some small differences between sensors, for example in the position of the oxycline during wintertime, or a small lag between surface oxygen concentrations. This is likely because these profiles represent only a snapshot in time and space and were not produced from the exact same position and exact same day.

RAMSES sensor itself performed in the Baltic Sea in a similar manner than in the experiments in the Mediterranean Sea. An example of a radiometric spectra recorded is shown on Figure 11. The data between RAMSES and OCR are in good agreement with always a higher sensitivity for RAMSES. The intercomparison of these two can be seen in Figure 12. Further details in power consumption and data volumes between each sensor area listed in Table 3.

The concurrent work of the ICBM with RAMSES sensors demonstrated that RAMSES is now applicable for at least two Argo platforms, APEX and Provor floats.

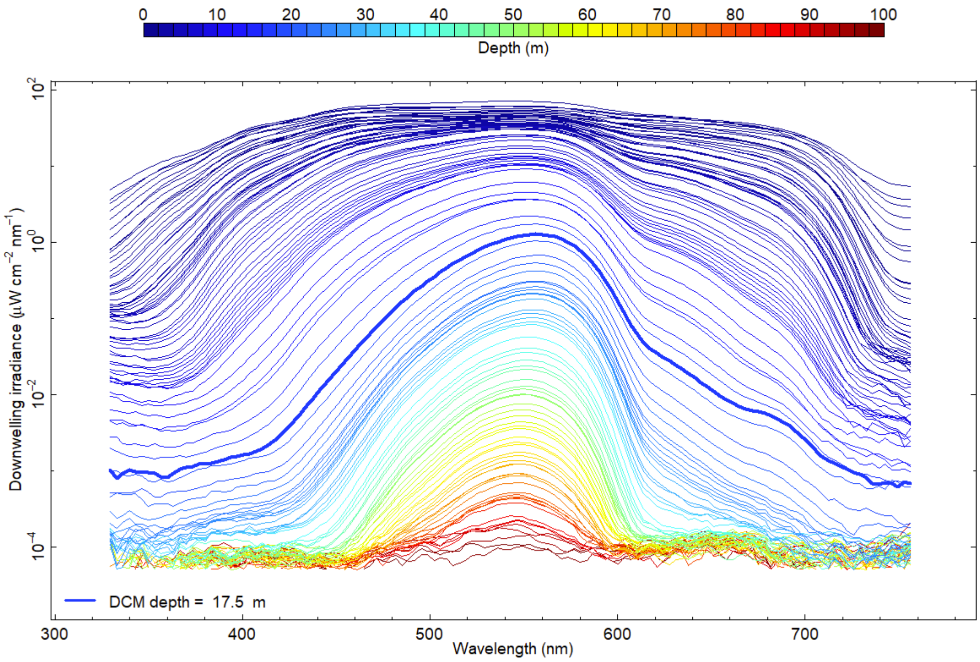

Figure 11: Example of radiometric spectra for the profile 28 (02/08/2021)

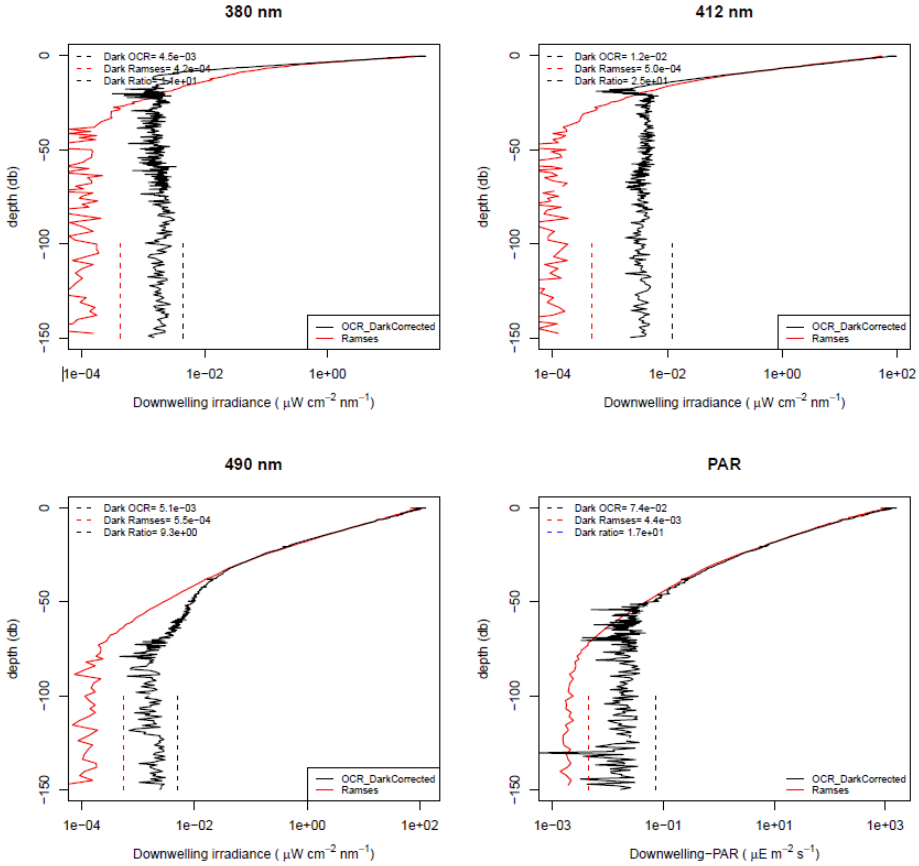

Figure 12: Intercomparison with the classical OCR sensor (black curve) on the same profile

TriOS RAMSES			**SBE OCR**		
Sampling Settings			Sampling Settings		
Depth Zone	period	Practical Vertical resolution	Depth Zone	period	Practical Vertical resolution
150 - 30 db	30 s	3 m			
30 - 10 db	10 s	1 m	150 - 10	10 s	1 m
10 - 0 db	full	0.35 m	10 - 0	2s	0.2 m
+ parking and surface data			+ parking and surface data		
Spectral resolution : 136 wavelengths [315 – 775]			**Spectral resolution** : 4 wavelengths		
Results			**Results**		
Data : 57 kB / Profil			Data : 15 kB / Profil		
Energy : 62 mA.h / profile (10 %)			Energy : 11 mA.h / profile (2%)		

Table 3: The acquisition strategy used in the Baltic Sea with the resulting energy consumed by each sensor and the volume of data generated.

The RAMSES consumes a little bit more energy in this deployment, even if the acquisition starts at 150m instead of 400m, probably because of the lower light penetration which results in longer integration times. The OCR sensor consumes much less than in the Mediterranean test because we have eliminated the acquisition at depth with the average of 1m.

Note : as comparison ECO-flbb fluorescence sensor (an optical sensor from SeaBird available for measurements of backscattering) consumes 80 mA.h and generates 6 kB of data per profile pointing out that the main difficulty with the RAMSES sensor is not the energy consumption but the volume of data to be transmitted.

4.2 Prototype with OPUS sensor

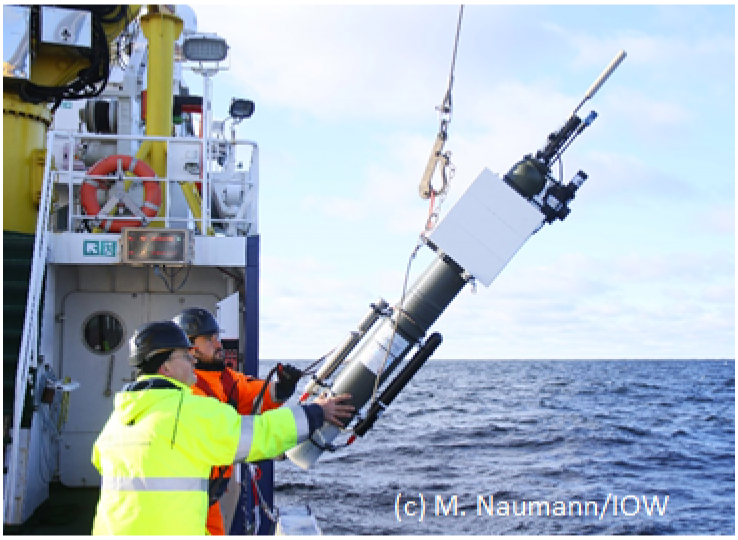

Figure: 13: Deployment of a double Nitrate float in the Baltic by IOW

In parallel to the Euro-Argo RISE project, the IOW also worked on a double nitrate prototype as part of the DArgo-2025 project. Photo of deployment can be seen in Figure: 13. Specific work was carried out on the sampling strategy and especially on the post-processing of the data.

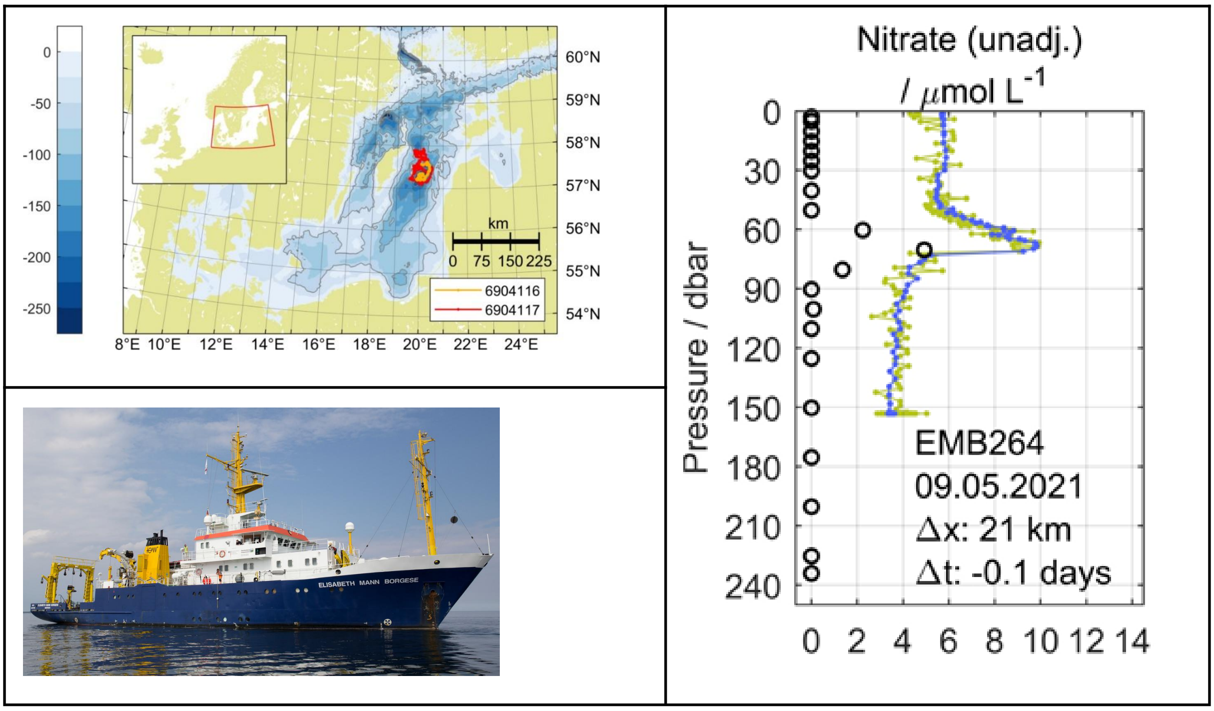

Figure 14: Intercomparison between nitrate measurements obtained from SUNA, OPUS and bottle measurements. The in-situ optical measurements (SUNA and OPUS) were not readjusted to zero.

Thanks to the work on the sampling optimisation, the consumption of the OPUS is better controlled and only exceeds that of the SUNA by 20%, which becomes acceptable.

Illustration of the route of the prototype, and comparison between the sensors can be seen in Figure 14. As can be seen, the OPUS data are still significantly noisier than the SUNA data but no similar bias than in Mediterranean Sea is observed in this optimised setup.

5 Conclusions

RAMSES sensor works very well and provides hyperspectral data with better sensitivity. The sensor generates four times more data at full spectral resolution than the OCR sensor, but it also requires five times more energy. Despite this, the higher radiometric qualities of RAMSES (higher sensitivity and spectral resolution) justify its increased energy consumption and the cost associated with the transmission of additional data. With regard to energy consumption, it should be noted that the RAMSES is compared to the OCR sensor, which is particularly low in energy consumption. In comparison with the ECO-flbb fluorescence sensor (SeaBird), the power consumption of the RAMSES becomes comparable, and is thus acceptable for the BGC community.

The RAMSES sensor is available for both Provor and APEX Argo-floats, successfully applied in both, which further indicates its availability and maturity.

Initial comparisons of nitrate sensors in the Mediterranean Sea between SUNA and OPUS indicated that OPUS may not yet be ready to continue in the Euro-Argo RISE experiments. The float deployment of SUNA in the Baltic Sea failed, so we have analysed data from other sources to further assess its performance.

The tests conducted within the framework of DArgo-2025 showed that SUNA is still more energy-efficient and produces less noise than the OPUS sensor. However, there is potential for the OPUS sensor to be a more economical option with proper calibration and further work on data quality in co-operation with TriOS, with the added advantage of being a European sensor and allowing for supplier diversification.

Further developments

As a result of the very good performance of the RAMSES sensor, RAMSES were implemented on 10 BGC-floats of the ERC REFINE (Robots Explore plankton-driven Fluxes in the marine twIlight zoNE, PI H. Claustre) in an improved configuration with two RAMSES sensors per profiler allowing the measurement of downwelling irradiance (Ed) and upwelling radiance (Lu) (Figure 15).

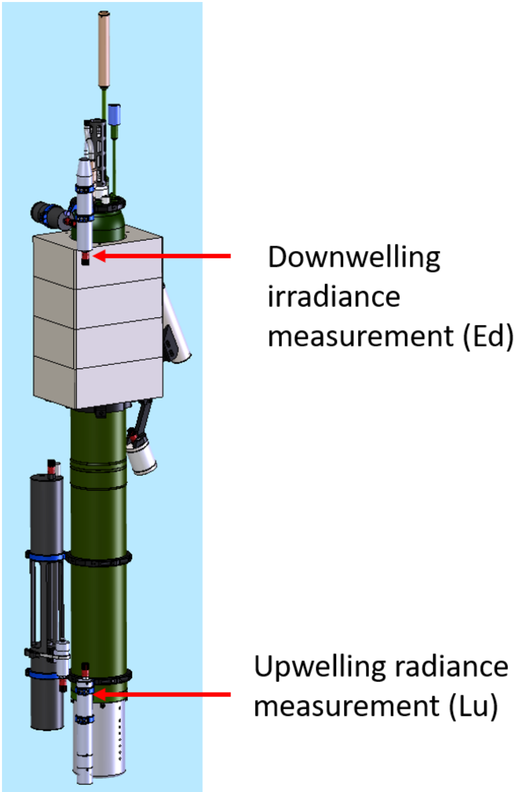

Figure 15: Profiler float with a double RAMSES sensor configuration (copyright E. Leymarie)

Additionally, space agencies have shown interest in using these hyperspectral floats for the calibration and validation work of ocean colour products, which would be an important application for the data. The French space agency (CNES) will finance the supply of 4 profilers per year equipped with two RAMSES allowing Ed and Lu measurements.

Acknowledgements:

We thank Henry Bitting for the discussions and work on IOW's deployments with the floats with SUNA and OPUS sensors in the Baltic Sea, which helped to expand this report.

References:

ADMT-23 Argo Data Management Meeting, December 5-9. 2022, report will be available at:, https://cpaess.ucar.edu/meetings/admt-23-argo-data-management

Leymarie, Edouard,. Poteau, Antone,. d'Ortenzio, Fabrizio,. Claustre, Hervé, 2021, Realisation of two " dual sensors" floats prototypes for nitrate and irradiance, Euro-Argo RISE Deliverable D4.1 10.5281/zenodo.6669025