People, science and instruments

of the

BioSWOT-Med campaign

People, science and instruments.
The BioSWOT-Med campaign

Bio*logical applications of the satellite* ***S****urface* ***W****ater and*
O*cean* ***T****opography in the* ***Med****iterranean*

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Table of contents

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Foreword

We created this little book to give an overview of the scientific richness of an oceanographic campaign and to preserve the memory of the passion and dedication of the participants of the BioSWOT-Med project.

Here you can learn about the people, the science, and the instruments that made the BioSWOT-Med campaign in April – May 2023. In the first three sections we collected three series of interviews carried out to cruise participants before the start of the campaign ("The research themes", "The instruments of oceanographers", "The new wave of oceanographers"). In the last section we reported stories and anecdotes shared by the researchers while at sea ("Dispatches from sea").

We hope you enjoy the reading and become fascinated by state of the art research on ocean fine scales.

Andrea and Tosca

Introduction

A successful campaign under SWOT swath in the Mediterranean Sea

The BioSWOT-Med campaign (10.17600/18002392) took place from 20 April to 14 May 2023 aboard the R/V L'Atalante in an area about 100 km north-east of Menorca Island (Spain), in the Northwestern Mediterranean Sea*, along one of the swaths of the SWOT satellite launched just a few months before, in December 2022.

Just at the beginning of the cruise, a very welcomed surprise was the availability of preliminary, near real-time images of sea surface height from the SWOT satellite. At the time, SWOT was in its "fast-sampling phase" with a one-day repeat orbit on selected sites on Earth, among which the BioSWOT-Med study area. SWOT images of sea surface height, produced by the SWOT Project (CNES, NASA, and JPL), have revolutionized the sampling strategy of the BioSWOT-Med campaign, allowing researchers to pinpoint the position and shape of fronts and vortices with an unprecedented precision of only few km.

The BioSWOT-Med campaign also had the luck of several cloud-free days just before the cruise, which allowed it to use a sequence of several high-resolution maps of surface chlorophyll from the OLCI-Sentinel 3 sensor. Combined with land-based satellite analysis carried

* https://doi.org/10.17600/18002392

out with the "SPASSO" toolbox developed in the framework of the SWOT-AdAC consortium, SWOT and Sentinel-3 were precious tools for mapping the physical and biological seascape of the study region.

Aboard the R/V L'Atalante, researchers thus headed to a persistent front between modified Atlantic waters of different ages about 100 km north-east of Menorca, spending three weeks there and explored the fine-scale ocean dynamics and their impact on plankton diversity. Although ideal for addressing the scientific questions of the BioSWOT-Med researchers, this region was challenging in terms of navigation. Strong northerly winds, Tramontane and Mistral, contribute to the transformation of local water masses, but at the same time may create challenging conditions for shipboard operations.

Altogether, the researchers were able to carry out all the vertical profiles envisaged, and even more than expected casts for CTD-rosette, and for FFADCP and VMP (respectively, vertical velocities and turbulence).

A large number of plankton nets' casts was performed and plankton was also studied in mesocosms experiments (Waipapa Taumata Rau University of Auckland).

The BioSWOT-Med experiment also took advantage of instrumented autonomous plat- forms, which provided simultaneous observations at different locations, in addition to those carried out by the ship, and even during storms. Several gliders were successfully deployed and recovered: two gliders of MIO (France), one of MOOSE (France), one of the University of Bergen (Norway) as well as SCRIPPS's Zooglider (California, USA). The latter was recovered south of Menorca where it was blocked by very strong currents and was redeployed to the main study area, where it was recovered at the end of the cruise.

Six ARGO profiling floats by OGS (Italy) and LEFE-GMMC (France) were deployed. These instruments continued drifting in the study area after the end of the cruise and provided very useful insights of the evolution of post-cruise conditions.

To validate the observations of the newly-launched SWOT satellite and for studying the details of the ocean currents, a large number of surface drifters was released: 10 SVPs and 10 CODEs (OGS, Italy), 20 CARTHE (ISMAR-CNR, Italy), 15 eOdyn (SWOT-AdAC international consortium), two Spotter (LOPS, France) and 8 additional SVPs from SCRIPPS Inst. (California, USA). A prototype surface drifter equipped with a set of biogeochemical sensors (ISMAR-CNR, Italy) was also deployed and recovered before leaving the study area.

One of BioSWOT-Med's prototype systems designed for measuring vertical velocities, the Vertical Velocity Profiler (VVP), unfortunately went lost during the first station, probably due to a malfunction of the instrument and/or the positioning system. The MIO scientific team therefore improved the second prototype unit, which successfully performed many vertical profiles.

The Moving Vessel Profiler (MVP) (GENAVIR and MIO, France) performed more than 1400 high-resolution multiparameter profiles.

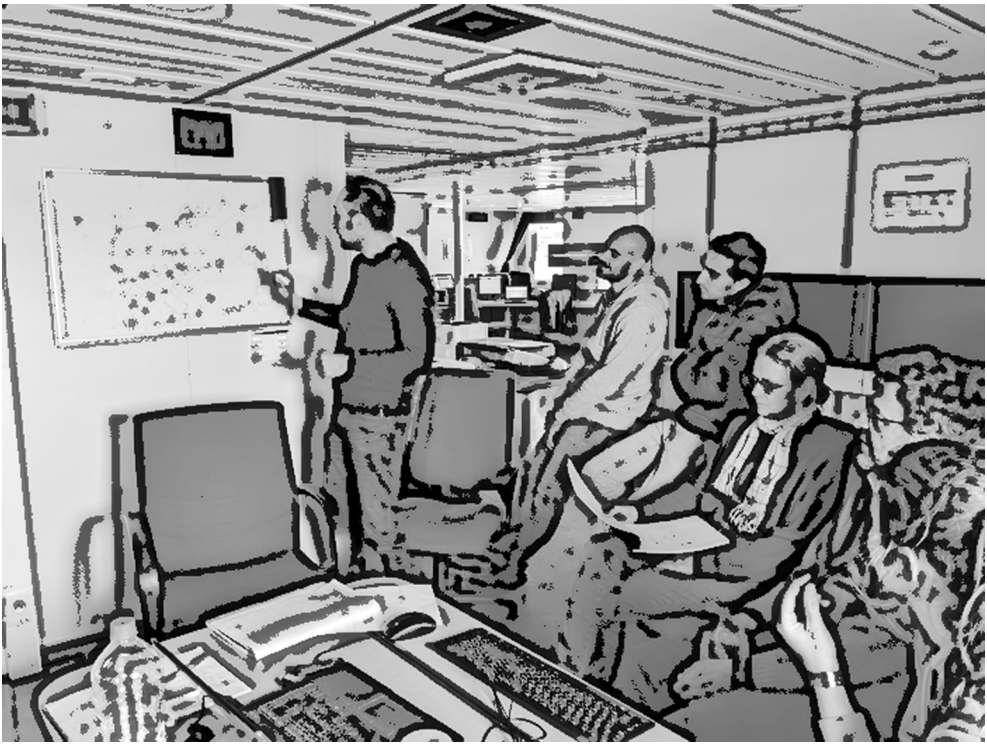
All the pumped water samples worked well, thanks also to the help and technical support provided by the crew of the R/V L'Atalante, who significantly improved the scientific equipment with parts manufactured on board!

Cytometer and spectrometer acquisitions on the thermosalinograph water inlet also worked perfectly and the ADCP and single-beam sounder acquisitions were fully satisfactory. More than 500000 liters of seawater were sampled and analyzed for their biogeochemical properties.

In conclusion, the scientists benefited from a well-equipped and performing research vessel and after four weeks of navigation, the R/V L'Atalante returned to his port of origin at La Seyne-sur-Mer, after a successful campaign and with the full satisfaction of the scientific team. The Captain of the R/V L'Atalante, Gilles Ferrand, and his competent, enthusiastic, and accommodating crew, deserve the thanks of the scientific team for their work, which allowed a great campaign!

A.M. Doglioli, G. Grégori and F. d'Ovidio

THE RESEARCH THEMES



Andrea at work on the R/V L'Atalante.

Massimo, Sven, and Andrea about to launch a drifter.

1. Investigating the fascinating biodiversity of the plankton in the turbulent ocean

Andrea Doglioli

Andrea is an Associate Professor in Physical Oceanography at Aix-Marseille University. His research at MIO focuses on the oceanic circulation, and in particular on oceanic eddies, filaments, and turbulence and their impact on the dispersion of nutrients, marine organisms, sediments, and pollutants. For his research, Andrea deals with both numerical modeling and field measurements at sea, with a preference for Lagrangian methods.
Andrea is the BioSWOT-Med's Chief Scientist. In this interview he explains the objectives of the campaign and how he and his collaborators will try to disentangle "the plankton paradox" in the Mediterranean Sea by investigating fine scales. Results from the campaign will provide insights on the physical-biological coupling relevant for most of the global ocean.

• What are the main research questions of the BioSWOT-Med campaign?

I could summarize by saying that the goal of the BioSWOT-Med campaign is to try to solve "the plankton paradox". In ecology there is a principle that says that when resources are scarce, living organisms compete among each other to access them, and only a few individuals - the most adapted ones - survive. In reality, when we study the microscopic organisms that belong in the marine plankton we realize that, despite the very low availability of nutrients, there is an enormous biodiversity. This leads to the plankton paradox! We hypothesize that

this rich biodiversity is possible thanks to the continuous mixing of movements generated by the currents on the surface of the ocean. For this reason, during the BioSWOT-Med campaign we will measure the horizontal movements separating different plankton communities, the vertical nutrient fluxes and the zooplankton grazing on phytoplankton, and. We will acquire data that will allow us to study what happens at fine scales.

• The ocean region around the Balearic Islands is one of the places where there will be a SWOT crossover. In the past you have already made other oceanographic campaigns in this region. How is this region characterized and why is it interesting to study physical-biological coupling here?

The oceanic region around the Balearic Island is particularly interesting because it is characterized by the presence of different types of surface water, the one recently coming from the Atlantic by the Gibraltar strait and the water resident by several years in the Mediterranean Sea. In the past we have already observed that these different types of water are populated by different plankton communities, separated by ephemeral currents. Seeking to understand the mechanisms underlying these previous observations is the aim of this new campaign. Since oligotrophic (i.e. poor in nutrients) and moderately energetic regions are representative of a very large part of the world ocean, our results may have Wide-ranging significance when extrapolated to the global ocean.

• During the campaign you will investigate ocean processes at the submesoscale. Can you explain what a submesoscale is?

The term "scale" is used to represent the size in space and the duration in time of a dynamical phenomenon. For example, the Gulf Stream is a "large" scale current: it crosses the entire Atlantic Basin and it is permanent; the big vortices generated by the Gulf Stream are called "mesoscale" eddies since they have a radius of about 100 km

and can live several months or few years; zooming a little bit more, it is possible to observes also small and ephemeral vortices or current filaments between the rings, these features characterize the oceanic "submesoscale". Finally, with the term "fine scale" we put together meso and submesoscale.

• The BioSWOT-Med campaign will follow an adaptive sampling strategy. What does it mean?

Since the submesoscale features are small and ephemeral, to sample waters inside them you need to use the satellite images of the ocean surface to identify them in your study area. Then, we design the research vessel route to meet them: this is what we call an adaptive sampling strategy.

• During the campaign there will be times in which you will let the boat drift at sea with currents. Can you explain how you do so and why?

Yes, this technique is called Lagrangian sampling, from the XVIII century mathematician Joseph-Louis Lagrange, who suggested sampling the ocean currents following their movement and using drifting objects. Then, we will deploy drifting buoys that we can follow thanks to satellite positioning. The interesting thing is that in this way we can obtain a time series of, for example, plankton concentration in a target water mass not affected by the transport of the current itself and then we can focus on the processes affecting their concentration, such as the nutrients fluxes or the zooplankton grazing.

• Why do you repeat the same sampling strategy three times?

Because we need to observe temporal variation, increase the precision of our estimates, and test the reproducibility of our measurement.

• Life onboard a research vessel needs to be organized. What will be your daily rhythms and the organization of research activities?

Indeed, to work efficiently during an oceanographic cruise we will need to be well organized! The people in charge of the adaptive and Lagrangian strategy will have daily meetings between them to study the satellite images, the position of the buoys and also daily meetings with the ship crew to define the route. During the sampling stations, precise protocols are respected to exploit at best the water sample coming from the ocean depths. Moreover, being BioSWOT-Med a multidisciplinary cruise, we will also organize onboard seminars to share the preliminary results obtained by the specialists of each discipline, as physics, chemistry and biology.

• This BioSWOT-Med campaign is a collaboration among different institutions, both in France and internationally. Which are they?

Yes, indeed. BioSWOT-Med is an interdisciplinary and international campaign! The researchers that will take part to the BioSWOT-Med cruise are affiliated to Université d'Aix-Marseille, CNRS, Sorbonne Université, Musée National d'Histoire Naturelle (France), CNR and OGS (Italy), Thünen Institute (Germany), University of Arizona (Arizona, USA) and University of Auckland (New Zealand).

Moreover, we collaborate with colleagues from SHOM, CEA, IFREMER, ULCO, Université Gustave Eiffel (France), CSIC (Spain), SZN (Italy), University of Bergen (Norway), UCSD and MBARI (California, USA), NWRA (Washington DC, USA) and University of Washington (Washington, USA). This sums up to more than 50 people involved in BioSWOT-Med, all working for important oceanography laboratories such as MIO and LOCEAN (France), ISMAR (Italy), IMEDEA and SOCIB (Spain), SCRIPPS (California, USA).

Gérald at work on the R/V L'Atalante.

2. Seeking to uncover the drivers of plankton diversity and distribution in the Mediterranean Sea

Gérald Grégori

Gérald is a researcher at CNRS working at MIO. His research focuses on marine planktonic microbes and their relationships with the ecosystem and biogeochemistry. To do so, he studies the factors that influence their abundance and distribution along the water column, in various locations such as coastal or open ocean. The originality of this research is to use single-cell analysis to study them, both in situ and in the laboratory, with a particular focus on flow cytometry.
Gérald is BioSWOT-Med's Co-Chief Scientist in charge of Biology. Here he describes the sampling strategy of the campaign and how it will allow gathering data to investigate the drivers of plankton diversity and distribution in the Mediterranean Sea by studying fine-scale features such as filaments or small eddies. Even if these structures are weak and short-lived (fed days) they can indeed strongly influence the microbial community.

• What are the main research themes that will be addressed during the campaign?

The themes that will be addressed during the campaign aim at unveiling the drivers of plankton diversity and distribution in the Western Mediterranean Sea. Why here? Because this region combines high plankton diversity, low nutrient concentration, and weak ocean circulation. We suspect that fine-scale features such as filaments or small eddies, even if they are weak and short-lived (few days), can strongly influence the microbial community.

During the BioSWOT-Med campaign we plan to follow the temporal evolution of these fine-scale structures over the western Mediterranean crossover generated by the tracks of the new SWOT satellite which is equipped with new-generation instruments. Among these, the new Ka-band Radar Interferometer (KaRIn) will measure the sea level at an unprecedented resolution and will help us to better identify, define and describe the small-scale features met in situ. During the BioSWOT-Med campaign, we aim at characterizing the physical-biogeochemical coupling in these fine-scale structures thanks to an adaptive Lagrangian sampling strategy. To perform this Lagrangian strategy we will use the software SPASSO (Software Package for an Adaptive Satellite-based Sampling for Oceanographic cruises) developed in our group and applied in several research cruises. The physical information collected thanks to a panel of instruments (from drifters and CTDs, Moving Vessel Profiler MVP, satellite, and numerical models) will be combined to create a huge biological dataset collected by a multi-sensor characterization of the planktonic community. We will combine flow cytometry analyses, imaging, and advanced molecular (meta-transcriptomics, metagenomics and meta-barcoding) techniques, with the use of autonomous and robotic platforms deployed in situ or in the laboratory. The goal is to have the more complete picture of the distribution and dynamics of the various compartments of the first levels of the trophic network, and to define the relationships between them and with the hydrological (nutrients, temperature, salinity) and physical (horizontal currents, vertical velocities, ...) parameters.

• In the BioSWOT-Med campaign you are in charge of microbiology. Can you explain what microbiology is and why it is important to study it?

In a small spoonful of sea water, millions, even hundreds of millions, of organisms are present: viruses, archaea, bacteria, eukaryotes. Are they dangerous? No! All these organisms are natural hosts of sea

water. They are even essential to the plankton machinery. Without this machinery, we would not eat fish, water infected with organic waste would be unfit for swimming and, moreover, man would probably not exist. Phytoplankton organisms are microscopic, invisible, apparently insignificant. And yet, plant plankton are capable of transforming the invisible (dissolved carbon dioxide or CO_2), the mineral (nutrient salts - nitrates, phosphates, silicates) and the immaterial (light) into organic matter. Like terrestrial plants, plant plankton are at the origin of a miracle: creating life, organic matter, from inert mineral matter thanks to the energy provided by the sun. This process is called photosynthesis. Organisms capable of making organic matter from mineral matter and energy are called autotrophs.

Phytoplankton are at the base of the marine food web. It is a very complex network that starts with phytoplankton, then passes through zooplankton (consumers of phytoplankton and small carnivores), and extends to top predators (such as fishes, dolphins, ... and humans). It is estimated that it takes one ton of phytoplankton to obtain 100 g of fish flesh. Phytoplankton cells can also precipitate to the bottom of the sea after their death and be incorporated into the sediments, trapping the carbon they contain over geological time. Did you know that they are one of the sources of oil? Finally, they can also be 'recycled' in the water column by bacteria. Phytoplankton organisms are tiny and their biomass (mass of living matter) does not exceed 2 % of the planet's plant biomass (sea and land combined). But they are responsible for almost half of the primary production of our planet. Indeed, half of the oxygen we breathe comes from the phytoplankton. Without the presence of phytoplankton in the oceans, the atmospheric CO_2 content would be of the order of 600 ppm (parts per million) instead of the current 400 ppm, which would be equivalent to an additional increase in the average temperature of our planet of 1°C.

Phytoplankton is not the only compartment of the plankton. Heterotrophic prokaryotes, more commonly known as bacteria and ar-

chaea, represent the largest source of biodiversity still unknown on the planet. These tiny cells do not have a nucleus, unlike the so-called eukaryotic cells. Most of these bacteria, and all archaea, are heterotrophs: they do not photosynthesize and (like us) need organic matter for food. It is often dead organic matter, dissolved or particulate, that they degrade and recycle. Bacteria and archaea are therefore the indispensable 'garbage collectors' of plankton.

Not all bacteria are heterotrophic. One group of photosynthetic bacteria plays a consider- able role in phytoplankton: the cyanobacteria (or 'blue-green algae'). Some cyanobacteria are able to fix molecular nitrogen (N2), the gas that makes up most of the air we breathe, thus compensating for the lack of nutrient salts. Others simply photosynthesize, such as Prochlorococcus and Synechococcus; they are very small (0.2 to 2 μm in diameter) but extraordinarily numerous: up to 100,000/milliliter.

There are also particles in the plankton that are much smaller than bacteria and archaea: viruses (0.02 to 0.2 μm). They are also much more numerous: up to 100 million viruses per milliliter of seawater! We have seen that, in the world ocean, the weight of viruses represents that of 75 000 blue whales (Le Tropézien, N° 107 - 2019). Like all viruses, they need a host to survive (bacteria, phytoplankton, etc.), a host whose proliferation they prevent. These are the viruses that come to an end, in particular, of the proliferation of dinoflagellates, unicellular organisms sometimes toxic. Plankton, with its largely microscopic and invisible, but innumerable organisms (hundreds of millions in a spoonful of sea water), is indeed the fabulous machinery on which our planet depends: the oxygen we breathe, the fish we eat, the oil we use (excessively!) and even the control of the climate, depend in large part on plankton. This awareness is quite recent. Plankton still holds many surprises in marine ecology and in the functioning of marine ecosystems, especially in the context of global change.

Margot and Francesco on the R/V L'Atalante.

Francesco and Massimo ready to launch an SVP drifter under the moonlight.

3. SWOT and the study of fine scales

Francesco d'Ovidio

Francesco is a senior researcher at CNRS working at LOCEAN-IPSL. His research focuses on Physical Oceanography, and in particular on oceanic fine scales. Francesco is the coordinator of the SWOT Adopt-A-Crossover (AdAC) Consortium, an initiative of the SWOT Science Team that assists oceanographic in situ experiments relying on SWOT and assures that SWOT data are interpreted and exploited in the best possible way. In the BioSWOT-Med campaign, Francesco coordinates the Langrangian and adaptive sampling strategy. Here, he explains how the new SWOT data will improve our understanding of fine scales.

Conceived as a major new tool for climate studies, the Surface Water and Ocean Topography (SWOT) satellite mission launched December 16th 2022. SWOT sea surface height measurements can help retrieve the dynamics of the upper ocean at an unprecedented O(10km) resolution. SWOT surface maps have a resolution roughly one order of magnitude finer than what is available with conventional satellite altimetry. This improvement in resolution is groundbreaking for several key ocean questions, including the energy budget, the connection between surface and internal dynamics, biogeochemistry and biodiversity, and the dynamics at the ice margin.

The spatial scales resolved by SWOT (down to 7-20 km depending on sea state) have relatively short lifetimes (days to weeks) but crucially affect ocean physics and ecology up to the climate scale, due to the strong gradients created by their energetic dynamics. These gra-

dients are associated with strong vertical transport of energy, matter and nutrients, connecting the ocean's upper layer to its interior. The horizontal and vertical dynamics of fine-scale processes modulate the energy cascade – i.e. the transfer of energy from large to small spatial scales – as well as ice-sea and air-sea interactions. The range of temporal scales associated with these horizontal and vertical fine scales is the same as the one observed in many important biogeochemical and ecological processes, including phytoplankton demography and competition, and the duration of foraging trips for many marine top predators. This temporal resonance is one of the reasons behind the fine-scale variability appearing in many features of marine ecosystems and their services, including the spatiotemporal patterns in biogeochemical cycles, biodiversity, and even in the foraging strategies of the megafauna.

On the modeling side, in the past few decades great progress has been made in characterizing this regime but a troubling gap has formed between models and observations. Field campaigns can target individual features, but they represent a tiny fraction of the possible ocean conditions. Moreover, most in situ studies are biased by choice of the stronger and longer-lived fine scales, which are the only ones that can be reliably tracked today with remote sensing tools. SWOT is expected to yield a major contribution to this gap between models and observations, providing synoptic images of fine-scale features over large portions of the ocean surface and greatly enhancing in situ sampling strategies.

SWOT observations will shed new light on the way in which fine scales are associated with the conversion of potential energy to kinetic energy and eventually down to dissipation. As recently recognised by the CLIVAR Ocean Modeling Developing Panel, precise spatial and temporal representation of fine-scale processes is needed for a correct estimation of the ocean energy budget and for designing optimal parameterizations for high resolution, as well as climate resolving, nu-

merical models. For example, the intensity of fine-scale density gradients.

In terms of biogeochemistry and marine ecology, SWOT is expected first of all to help to constrain observation-based methods to estimate ocean vertical velocities and associated fluxes of nutrient and organic matter. Direct determinations of vertical velocity remain in general technologically out of reach, and possible only in particular situations of very strong frontal systems. In order to circumvent this problem, several indirect methods have been proposed, based on the derivation of vertical velocities from other observations. SWOT does not directly observe vertical velocities, but the combination of SWOT observations with in situ data is expected to improve indirect methods, which in turn will provide accurate estimations of vertical fluxes in a much broader range of conditions than today. A more precise estimation of horizontal velocities will also open the way to accurate estimations of the redistribution patterns of surface water masses and in general to Lagrangian applications, permitting to explore the role of mesoscale stirring in creating biodiversity hotspots and in constraining the behavior of marine organisms all along the trophic chain.

Anthony onboard the R/V L'Atalante.

MIO and University of Bergen's gliders on deck of the R/V L'Atalante.

4. Studying how ocean dynamics impact heat distribution and its evolution with climate change in the Mediterranean Sea

Anthony Bosse

Anthony is a researcher at MIO affiliated to Aix-Marseille University. He is an oceanographer with a background in physics, which led him to combine the two disciplines to analyze observations carried out from research vessels or collected by autonomous platforms. The main focus of his research is to understand how the ocean dynamics from mesoscale (eddies and fronts of 10-50km) to dissipation scale (millimeter scale turbulence) impact the distribution of heat and its evolution with climate change, as well as the impact those processes can have on the development of phytoplankton. His research focuses on the two regions: the Mediterranean Sea and the Nordic Seas.
Anthony is the leader of WP2 Physical Processes in the BioSWOT-Med campaign. Here, he describes the different physical processes that will be studied during the campaign as well as the different sampling platforms that will be used with the goal to understand ocean dynamics from mesoscale (eddies and fronts of 10-50km) to dissipation scale (millimeter scale turbulence) impact the distribution of heat and its evolution with climate change, as well as the impact those processes can have on the development of phytoplankton.

• In the BioSWOT-Med campaign you are the leader of WP 2 on physical processes and will coordinate the work of other 8 people. What are the main contributions of your team to the campaign?

The BioSWOT-Med cruise is an ambitious research cruise with a strong multidisciplinary approach to study the physics/biology cou-

pling in the context of the SWOT CalVal. In this context, the WP2 dedicated to the physical processes will have the important task to describe the different aspects of the physical context driving the distribution and fluxes of biogeochemical tracers (such as nutrients) and plankton. To do so, a strong team of researchers in WP2 will use Lagrangian surface drifters, shipborne current meters and underway temperature and salinity sensor, as well as underwater gliders, to characterize flows at submesoscale (typically 1-10km) and at high resolution, assess vertical velocities using a vertical velocity profiler and free-fall current profiler, and finally characterize the level of turbulence using dedicated sensors.

• What do you refer to when you speak about "flow"?

Flow is a generic term in oceanography referring to streams of water with significant velocities (typically of 0.1 to 1 m/s). They are similar to oceanic rivers transporting waters of specific physical (temperature and salinity) and biogeochemical properties (nutrients, oxygen, carbon,...). The only difference is that the scale of these rivers is much larger, and the volume transport of a single one of these is about 10 larger than the Amazon.

• What are the "vertical velocities"?

Vertical velocities refer to vertical movements in the oceans. Those are ubiquitous, but usually much smaller in magnitude than horizontal ones: of the order of mm/s, or even smaller, but yet, they are crucial to sustain biological activity and carbon sequestration, as vertical velocities bring nutrients upward to the sunlit layer where they can be consumed to sustain primary production, and carry fresh organic matter to great depths where they will die and eventually fill layers of sediments with carbon.

• What is "turbulence"?

Energy is injected into the Ocean at large scale by winds for instance, and atmospheric forcing. Once a water parcel is set in motion,

a large amount of energy is transported over large distances while being slowly dissipated. This dissipation involves turbulent motions at scale of a few millimeters. Turbulence describes the chaotic tri-dimensional movements of waters at those scales where kinetic energy is converted into heat by the friction of water. We (oceanographers) like to compute the rate of energy dissipation, because it affects vertical fluxes of heat or tracers, and oceanic circulation as a whole. To put it in simple words, turbulence is like the movements created in a cup with a spoon when stirring milk with tea, and the energy dissipation rate controls how fast the homogeneous process happens.

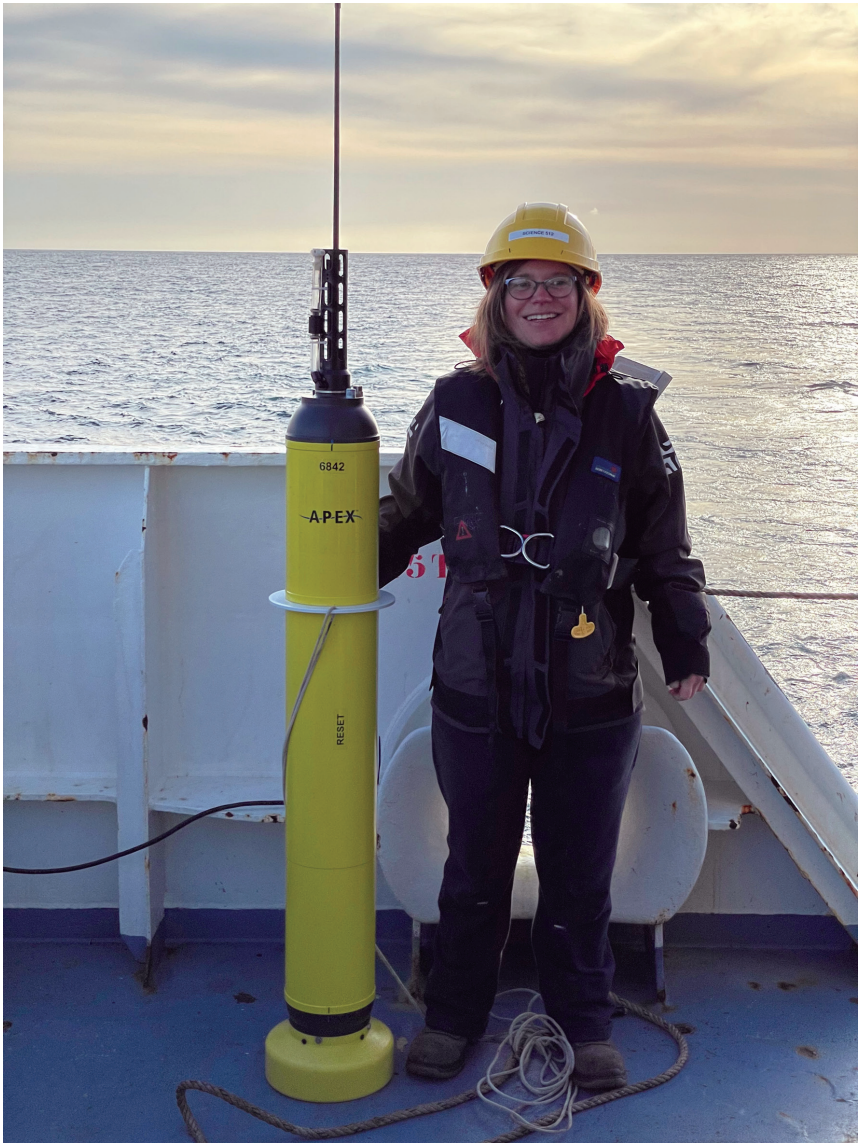
• To study these processes, you will use both instruments that are aboard the R/V L'Atalante, as well as deploy instruments in the water. What instruments will you use to measure these processes?

As said before, we will use a broad range of instruments. In collaboration with Italian partners from Italy (CNR-ISMAR and OGS), we will deploy Lagrangian drifters, which record their position in real-time and drift with surface currents, as well as subsurface Argo profiling floats, which drift at depth and every day sink to 2000m and profile the water column measuring temperature and salinity. Some of these floats will even be able to measure vertical profiles of nutrients, oxygen and chlorophyll-a fluorescence. From the ship, we will have three instruments onboard recording currents under the hull down to 1000m. We will tow the MVP (Moving Vessel Profiler) behind the ship while transiting in order to get high resolution properties of the water column from the surface down to 400m. On station, we will deploy classic CTD instruments to measure temperature, salinity, horizontal currents and collect water samples. What is more interesting is the deployment of two new instruments developed at the Mediterranean Institute of Oceanography (MIO) able to track vertical velocities (VVP and FF-ADCP) using two different techniques, as well as a turbulence profiler in order to quantify its impact on vertical fluxes (of nutrients for instance). BioSWOT-Med is an international campaign

with several partners and together with your colleagues from Norway and the USA you will be deploying 4 gliders.

• What is a glider and how does it work?

Indeed, last but not least, during the cruise we will be using several autonomous platforms called «gliders». They are long-range autonomous underwater vehicles that can stay in the water for several months while profiling from the surface to a depth and carrying low-power sensors. They dive and climb by modifying their volume using an oil bladder and are equipped with wings that convert their vertical motion into horizontal transla- tion. During the BioSWOT-Med cruise, we will deploy two gliders piloted by the French team at MIO, one glider equipped with a turbulence sensor will be piloted by Norwegian partner (University of Bergen) and another one piloted by American partner (SCRIPPS) carrying acoustic and optic sensors to look at zooplankton. In addition, Spanish colleagues from SOCIB will also deploy 2 gliders in the region as part of another cruise (FastSWOT). So, it is going to be a challenge to coordinate all these platforms to work together, but it is a very exciting time and the data set collected will allow some groundbreaking discoveries.



Maristella and a profiling float.

5. The Lagrangian experiments

Maristella Berta

Maristella is a researcher in physical oceanography at CNR-ISMAR in Lerici, La Spezia, Italy. In the BioSWOT-Med campaign she is in charge of Lagrangian instruments coordination. Here, she describes what drifters and floats are, what information can be gathered from them, and how real-time data can help inform the adaptive sampling strategy of BioSWOT-Med.

• What are your research interests besides BioSWOT-Med?

I am a physical oceanographer and I focus on the dynamics of sea currents by analysing observations from field samplings (buoys and sensors at sea), remote platforms (such as satellites and radars) and ocean model outputs. I'm interested in the combination of independent and complementary observation platforms that is essential to get the overall picture of the ocean processes playing at different scales at the same time. Multidisciplinarity is also a key aspect of the multiplatform approach, since it allows us to investigate the interaction between the physical and biogeochemical components of the ocean. Among the physical processes characterizing the upper layer of the ocean I investigate how marine currents drive the dispersion of tracers and passive particles (such as pollutants like oil or plastic, and biological tracers as microalgae or fish larvae), and the transport of these particles in the vertical (from surface to depth, and vice versa). Understanding these processes can provide guidance for practical applications such as marine accident response or management of marine protected areas.

• In the BioSWOT-Med campaign you are in charge of Lagrangian instruments coordination. What does lagrangian mean?

Lagrangian instruments are devices that measure seawater properties as they drift with sea currents. This category of instruments differs from the Eulerian ones which observe sea water properties from a fixed-point, such as a device moored to the sea floor. Lagrangian devices need to be equipped with a GPS (Global Position System) tracker and satellite communication in order to retrieve measurements and correspondent location at regular times.

Drifters are Lagrangian buoys usually equipped with drogues, that make them "sail" at a specific depth: CODE and CARTHE drifters follow surface currents within the first meter, while SVP design includes a drogue centered at 15m depth to be representative of the dynamics of that water layer. Other drifters, such as the spotters, are designed to float at the air-sea interface and do not have any drogue.

Floats instruments, on the other hand, are pseudo-Lagrangian in the sense that they are not totally passive to sea currents since they drift at a specific depth and periodically perform vertical cycles measuring water properties from depth to the surface, where they also transmit position and data just recorded. In BioSWOT-Med we will have 30 CARTHE plus CODE drifters, 20 SVPs, 2 spotters, and 6 floats.

• What type of sensors are present on the drifters and floats and how do you use the information gathered from these instruments?

Aside from the basic drifter setup (simply the GPS tracker, as for CODE and CARTHE), the other drifter types involved in the experiment are equipped with additional sensors to measure essential ocean variables such as sea water temperature (for the SVPs), waves (for spotters) or biogeochemical properties of the water (in the SVP-BGC prototype). All (six) floats have pressure, temperature and conductivity (for salinity) sensors, four of them have an additional oxygen sensor, while the other two have biogeochemical sensors as well.

In Lagrangian datasets we look at individual drifter trajectories, but more importantly to the relative displacement among drifters

within a cluster. This analysis can indicate converging or diverging water masses in the upper sea layer, where intense vertical currents tend to develop and, in turn, enhance the water properties exchange from surface to depth. Combining drifter trajectories with water column sampling from floats can contribute to characterize sea properties in correspondence of intense water mixing spots that can be associated with high biological productivity.

• While on board, you will analyze in real time the data collected by the Lagrangian instrument. How can this help the sampling strategy of the campaign?

During BioSWOT-Med we will target specific small scale (order of 10km) circulation features, such as vortices or fronts (the interface between two different water masses) identified within the SWOT satellite swaths. The satellite observations will guide the choice of the field of activity that we will start exploring with some water samplings and drifters' deployment. Through a first real-time processing, the Lagrangian component (drifters) will contribute to assess and sharpen the target identified by SWOT images and it will provide guidance for the deployment of other instruments at sea able to resolve finer scale processes. In a second phase, the analysis of drifter data can be used to quantify surface divergence and convergence and to provide an estimate for vertical currents magnitude in the targeted feature. The analysis of floats together with the other high-resolution observations will contribute to characterize the variability of the biophysical properties in the targeted feature.

Elvira and colleagues working at the pumping system.

6. High frequency and precision to study nutrient concentration

Elvira Pulido

Elvira is a marine biogeochemist at CNRS working at MIO. She studies nutrient cycling at the surface of the ocean and she is particularly interested in the oligotrophic ocean, where nutrient scarcity limits biological activity and carbon export. Currently, she uses high-sensitive techniques to measure phosphate concentration at the surface of the ocean to gain further insights on the phosphorus cycle, particularly concerning the mechanisms involved in phosphate supply to the euphotic zone and the bioavailability of the organic phosphorus pool. In BioSWOT-Med she's the leader of WP3 dedicated to nutrients in the ocean.

• In the BioSWOT-Med campaign you are in charge of WP3 dedicated to nutrients in the ocean. What are the chemical substances that you will be measuring? Why is it important to measure them in the ocean?

The availability of nutrients may ultimately control biological activity and diversity. This is particularly true in nutrient-depleted oceanic regions like the Mediterranean Sea. One of the main objectives of the BioSWOT-Med cruise is to explore how and to which extent fine-scale ocean dynamics impact nutrient distribution and fluxes. The study of nutrient dynamics during the BioSWOT-Med cruise faces two challenges: first, the study area is characterized by very low nutrient concentrations, and second, fine-scale oceanic circulation shall provoke small (i.e. nanomolar) and rapid changes in nutrient concen-

tration. Both challenges will be undertaken by conducting nutrient measurements (nitrate, nitrite, and phosphate) at both high frequency and precision.

• The Mediterranean Sea is called "oligotrophic". What does it mean? What are the differences with other seas and regions of the global ocean?

The term oligotrophic comes from the Greek *oligos*, meaning 'small' or 'few' and *trophe*, meaning nutrition. The oligotrophic marine regions are thus characterized by low nutrient concentration and low biological productivity due to a more or less pronounced thermal stratification which delimits a warm surface mixed layer. They cover up to 60 % of the global ocean including regions like the Mediterranean Sea and the large subtropical gyres in the Atlantic and Pacific Oceans, and play a key role in the regulation of climate by sustaining one third of total marine carbon fixation. In addition, oligotrophic regions are currently expanding due to increase in sea surface temperature and stratification. Studying the functioning of these regions is thus crucial to understand the current and future role of the ocean in climate regulation.

Magali aboard the R/V L'Atalante.

7. The Omics

Magali Lescot

Magali is a research engineer at CNRS working at MIO. Her research focuses on the evolution of plankton genome and the adaptation of plankton to their environment. In the BioSWOT-Med campaign she's in charge of the Working Group on Genomics. She will collect samples to study the microbial community (viruses, bacteria, protists) to evaluate the patchiness of these plankton functional types and taxa and to monitor the short term biogeochemical functional responses of the microbiome to the physical environment.

• In the BioSWOT-Med campaign you will collect samples to study the microbial community (viruses, bacteria, protists). What are the different hypotheses to explain their distribution and patchiness?

The distribution / patchiness of the microbial (plankton) community is driven by the environmental parameters and the ocean physics. In the BioSWOT-Med campaign, we will test two hypotheses. The first hypothesis is the "fluid dynamical niches hypothesis" – Horizontal stirring can create a patchwork of water masses of different origin, in which contrasting phytoplankton communities can develop. Contact regions where many of these "fluid dynamical niches" are stirred together and eventually mix will turn into diversity hotspots.

The second one is the "biotic (top-down) hypothesis" – According to this hypothesis, the formation or dissipation of vertical thin layers of phytoplankton during stratification or mixing can markedly

alter phytoplankton concentrations, encounter rates with grazers, and grazing losses, hence modulating community structure, diversity, and ultimately their biogeochemical functions.

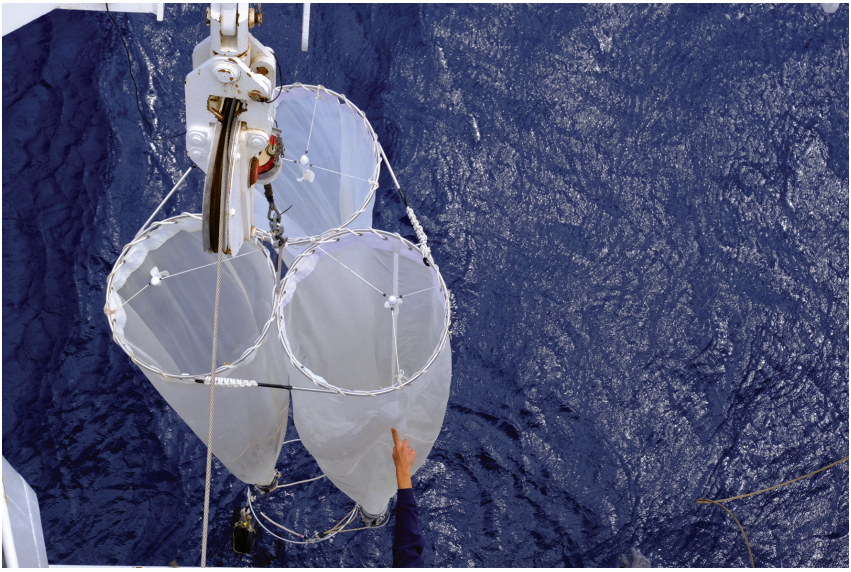
• You will be using a series of techniques called "omics"? What are they?

The "Omics" correspond to the disciplines such as genomics, metabolomics, proteomics, metagenomics or transcriptomics to study the molecules (such as the genes for genomics, transcripts for transcriptomics) for a cell, an organism or an ecosystem.

For example, the metabarcoding (amplification of gene markers, genomics) allows to decipher diversity in the microbial community by identifying multiple taxa simultaneously in a sample using DNA sequencing.

The sequencing of the microorganism expressed genes (transcriptome) will instead inform about the gene function and to what the microorganisms do at the moment we sampled them.

François and the zoonet.



The zoonet lowered into the sea.

8. Exploring the links between fine-scale structures and zooplankton dispersal

François Carlotti

Biological oceanographer with strong interests in the structure and functioning of pelagic marine ecosystems and their responses to climate forcing and anthropogenic impacts, Francois is research director at CNRS, working at MIO. In the BioSWOT-Med campaign François is the coordinator of WP4 "From zooplankton to higher trophic levels". Here he describes the research objectives and the hypothesis under test to explain the distribution of different zooplankton groups in different water masses.

• What are your research interests besides BioSWOT-Med?

I am a biological oceanographer with strong interests in the structure and functioning of pelagic marine ecosystems, and their responses to climate forcing and anthropogenic impacts. My research focuses on zooplankton, which play a pivotal role in all pelagic food webs, and extends to adjacent trophic levels through research on bottom-up and top-down forcing processes. My main approaches are observation with different types of analyses of collected samples (zooplankton imaging, diversity, size structure, physiological processes) and in situ sensor data, and mathematical modelling. My main interests are (1) the importance of couplings between hydrodynamic processes, their biogeochemical functioning and the behaviour of organisms in the variability of zooplankton distributions; (2) the contribution of zooplankton in trophic and biogeochemical fluxes within ecosystems.

This corresponds to the research lines of the international programme Future Oceans - IMBeR. My research is carried out from the polar regions to the tropics and the Mediterranean, and from the open sea to the coastal domain. Over the last ten years, I have participated in the main biogeochemical campaigns in the Mediterranean as part of the MISTRALS-MERMEX programme.

• In the BioSWOT-Med cruise you are the coordinator of WP 4 that studies the trophic network from zooplankton to upper trophic levels. You have several research objectives; can you tell us about them?

Our WP 4 is entitled "From zooplankton to higher trophic levels". Our overall goal in BioSWOT-Med is to understand how fine-scale oceanic structures may affect the patchiness from metazoan organisms from the smallest (zooplankton) to the largest (cetaceans). In practice, we mainly focus on the first trophic levels (zooplankton and their planktivorous predators), but also note opportunistically if larger animals (cetaceans, basking sharks,...) are present around. This overall goal can be broken down into different scientific objectives:

• To characterize mesozooplankton and macrozooplankton/micronekton distributions in both horizontal and vertical dimensions (from meso to fine scales);

• To define structural and functional variations of zooplanktonic communities in water masses and within the frontal region;

• To estimate the impact of grazing of mesozooplankton on the phytoplankton community;

• To estimate mesozooplankton contribution in carbon fluxes.

• In the BioSWOT-Med cruise you will take samples at different depths, at day and night. Why?

All of these metazoan organisms can move through the water column, and all of them over large distances relative to their size. Even

zooplanktonic organisms (initially thought to be unable to escape from currents) have very strong vertical swimming capacities, especially as they migrate vertically between day and night. The main reason for this is that many of them descend during the day to the deep ocean (down to hundreds of meters) where it is darker to escape visual predators, but rise to the surface at night to feed on the phytoplankton and associated microorganisms that have grown there in the light during the day. This process is called diel vertical migration and is the largest animal migration on Earth. We will therefore try to understand how the mesoscale surface structures can impact or modulate these migrations, if they induce differences in the migration process depending on the species. In addition to observations of changes in zooplankton distribution between day and night, we will measure the actual grazing of zooplankton between day and night and try to quantify the additional impact of migrating zooplankton on the phytoplankton stock and the associated microbial community at night through large mesocosm experiments.

• One of your research hypotheses is that different groups of zooplankton species will be found in different water masses. Can you explain this?

Zooplanktonic organisms have very diverse diets. Even among copepods, a dominant crustacean group among zooplankton, there are herbivores, omnivores and carnivores. Copepods are selective feeders and thus the distribution, size, behaviour and biochemical quality of their prey (including phytoplankton and smaller zooplankton) will condition the selective process. As the nature and distribution of prey are themselves conditioned by the fine oceanic structures, it is expected that the zooplanktonic assemblages in these structures will be affected as well.

• What is the hypothesis that could explain how fine-scale structures impact zooplankton distribution?

Since the 1990s (GLOBEC International Program), observations have been accumulating showing that zooplankton develop particularly well in mesoscale structures. New physical and biological instrumentations (platforms and sensors) allow nowadays to explore this topic at scale smaller than the mesoscale. The observations made during the BioSWOT-Med campaign, in particular those from the Zooglider, will make it possible to confirm the links between fine-scale structures and zooplankton patchiness. The hypothesis that we want to test in connection with WP3 (Biogeochemistry and microbial dynamics) and WP5 (Plankton genomics) is that the structure of autotrophic and microbial communities stimulated by a fine-scale physical structure is reflected at the level of zooplankton consumers. Thus, the mosaic of physical structures corresponds to a mosaic of each of the first trophic levels.

Cédric studies how fine scales impact the distribution of marine top predators.

9.Fine scales and marine top predators

Cédric Cotté

Cédric Cotté is a researcher of the MNHN at the lab LOCEAN. His research focuses on the ecology of mid-trophic organisms (crustaceans, fish and gelatinous organisms) and how the physical environment structures prey-predator interactions with top predators (seabirds, marine mam- mals). In BioSWOT-Med, Cédric is in charge of monitoring marine top predators. Here he explains how mesoscale features structure the foraging of top predators by generating favorable areas where preys are aggregated.

• What marine predators do you expect to find south of the Balearic Islands and how do you study them?

We expect to meet cetaceans (whales and dolphins), seabirds, tuna, turtles. During the BioSWOT-Med cruise, we will use the visual observations to study them. Other studies are using biologging, i.e. electronic devices fitted on animals to track their trajectory and behaviour. Passive acoustic can also be used to detect acoustically active species.

• Why is it important to study marine top predators? Are some of these species endangered? and if yes, are there any measures to protect them?

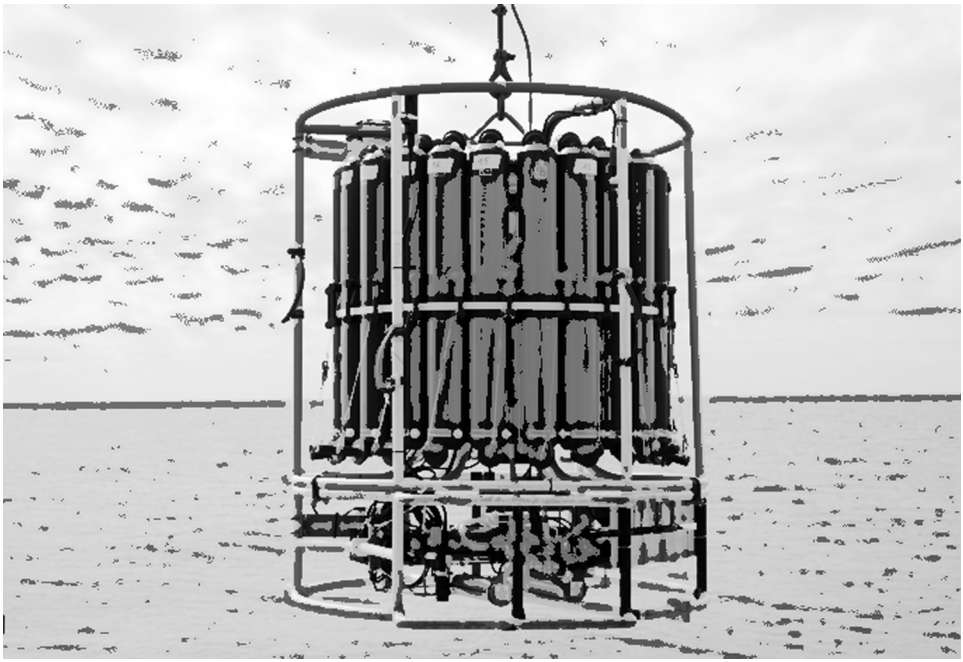
The monitoring of populations is important to study the possible trends of abundance in time. Some species are threatened at different levels by shipping strike (large whales), bycatch (dolphins and turtles), pollution (e.g., noise increase), and climate change. Marine reserves

and Marine Protected Areas could be a good tool to protect them according to the behaviour and the life cycle of these predators.

• What existing hypotheses are there to explain the distribution and abundance of these species in the Mediterranean Sea?

At mesoscale, the eddies and frontal features are structuring the foraging of top predators by generating favourable areas aggregating the prey. Measuring fine-scale features from space and from the cruise and observing predators is a unique opportunity to validate this hypothesis during BioSWOT-Med.

THE INSTRUMENTS OF OCEANOGRAPHERS



Louise produces the daily bulletin to inform BioSWOT-Med adaptive sampling strategy.

10. The daily bulletin

Louise Rousselet

Louise is a research engineer employed by LOCEAN and financed by CNES. She is the SWOT AdAC science officer. During BioSWOT-Med she is in charge of producing the daily bulletin that informs the BioSWOT-Med adaptive sampling strategy.

• What are your research interests besides SWOT AdAC campaigns?

My research focuses on the influence of small-scale features (eddies, fronts and filaments) on the 3D distribution of elements (tracers, nutrients and phytoplankton communities) in the ocean. Fine-scale circulation shapes the horizontal distribution of these elements through transport and stirring processes.

They can also create favorable conditions for phytoplankton bloom to occur by bringing together limiting nutrients either through horizontal or vertical transport. Therefore, they have a strong impact on the biological growth, primary production and thus global biogeochemical cycle.

Several field studies already observed instances of these influences but many questions remain: Are these influences similar in oligotrophic vs nutrient-rich regions? Can we quantify these influences? What is the global variability of fine scale features? How are biogeochemical fluxes impacted by fine scales? All these questions are part of my current research field and can be assessed in the framework of SWOT mission and SWOT-AdAC consortium.

• You are the SWOT AdAC science officer and in the BioSWOT-Med campaign you are in charge of the software SPASSO and of the Lagrangian and adaptive sampling strategy. What is the software SPASSO and how do you use it?

The BIOSWOT-Med campaign aims at targeting a fine-scale front separating water masses with contrasting conditions, especially in terms of biological activity (i.e. productive vs. poor water masses identified using Chlorophyll-a concentration). However due to their small scale and ephemeral characteristics, it is a real challenge to sample such features like fronts. The software package SPASSO has been developed to overcome this issue. SPASSO provides maps of dynamical and biogeochemical structures such as fronts, eddies, filaments, in addition to chlorophyll and SST, based on near-real-time acquisition of satellite sensors. The fine-scale features are detected by Lagrangian diagnostics computed from numerical particle trajectories advected with daily near-real-time surface currents derived from altimetry. All these maps are generated automatically every day and sent to the BioSWOT-Med team to analyze them in order to determine the best sampling site.

• What other software and analysis will you perform to provide information for the cruise?

I re-wrote and developed a Lagrangian software allowing for advecting numerical particles within any 2D current field. The Lagrangian software computes some Eulerian diagnostics such as Kinetic energy or Okubo-Weiss parameter but also series of diagnostics from the particle trajectories: a) Lyapunov exponents to detect fronts; b) longitude/latitude advection fields to identify water masses origin; c) retention parameter to detect trapping eddies; d) tracer advection fields (SST, SSS or Chlorophyll); e) water masses age since last contact with a topographic feature. This tool is included in the SPASSO software but can be used with any current data. It will be surely used during the cruise to compare with drifters/float trajectories and predict water masses motion.

• Sampling activities during the SWOT AdAC campaigns will be carried out day and night. You will not be on board, but you

will be in contact with them and will provide them with a daily bulletin. What is inside the bulletin?

The daily bulletin includes all maps computed by SPASSO software. In particular, SPASSO uses standard Copernicus satellite-derived data for surface currents, SST and Chlorophyll but also a bunch of innovative and high-resolution satellite-derived data for surface currents, SST and chlorophyll produced by CLS, with support from CNES, for SWOT-AdAC campaigns. These latter data are very useful because they minimize cloud coverage. Maps of Eulerian and Lagrangian diagnostics described earlier are also included. Some useful information such as SWOT passing time over the sampling area are also inserted in the bulletin. Every day I will analyze these maps and write down my sampling strategy suggestions to the on-board team.

• You have developed a tool to optimize the route of the ship. Can you explain how it works?

Indeed, the LATEXtools toolbox includes several tools to simulate the vessel route, compute sailing time and provide waypoint coordinates. When analyzing SPASSO maps, the on-board team might decide to sample in the middle of a chlorophyll patch and perform back and forth transect to cross a front detected by Lyapunov exponents. To easily get the precise coordinates of the projected waypoints the LATEXtools toolbox retrieves SPASSO maps, superimposes variables of interest and allows the user to click on the map to choose manually the target points while visualizing the satellite-derived data. When the user is done, LATEXtools provides a file, including longitude/latitude of the waypoints and the sailing time, that can be given to the vessel captain to prepare following operations. This tool is very useful especially in the context of adaptive sampling strategy. The tool also allows for plotting some near-real-time in situ data collected on-board such as currents from ADCP, surface temperature and salinity from TSG or surface phytoplankton group abundances from flow-cytometry. Comparing satellite and in situ data validates the use of satellite data and also improves features detection.

Massimo during a night shift aboard the R/V L'Atalante.

11. Surface drifters and floats

Massimo Pacciaroni

Massimo is a research engineer working at OGS, in Italy. In the BioSWOT-Med cruise he was in charge of WP Physical processes, and in particular in charge of drifters and floats deployment. He describes what the differences are between the two and what physical processes they can study.

• What are your research interests besides BioSWOT-Med?

My research interests focus on water properties measurements using floats and drifters, with a particular interest on floats programming and their data analysis.

• In the BioSWOT-Med campaign you will be in charge of drifters and floats deployment. What is the difference between floats and the drifters? How do they work and what sensor do they carry?

By using floats we measure water column temperature, salinity and dissolved oxygen starting from 2000 m depth going up to the surface. An inflatable external bladder allows the float to ascend and descend. When at surface the Iridium transmission starts in order to transmit all the data. Floats are equipped with a CTD, and depending on the model they carry an oxygen probe, radiometer, fluorometer, spectrophotometer (nitrates in our case).

With the drifters we observe the water velocity near the surface and, depending on the drifter type (the design can vary), a few more parameters are registered.

• What physical processes can they study?

Seawater velocity and mixing, heat content and exchange, fronts, tides. In general, there are a great number of processes that can be observed with floats and drifters.

Anne analysing physical data aboard the R/V L'Atalante.

12. The ADCP current meter

Anne Petrenko

Anne is an Associate Professor at Aix-Marseille University, working at MIO. She's a physical oceanographer with interdisciplinary competences and interests. In the BioSWOT-Med campaign Anne is in charge of analysis of hull mounted ADCP and of deployment of L-ADCP and FF-ADCP. Here, she describes how these instruments work and what are the differences among them.

• What are your research interests besides BioSWOT-Med?

Science-wise, for a while I have concentrated my research on coastal circulation, coast-offshore gradients, using multidisciplinary approaches: in situ data, modeling outputs, satellite. Apart from currents, the data include classical temperature, salinity, depth but also all kinds of optical data providing information on phytoplankton and particles present in the water column. I generally measure currents with ADCPs as described below.

Lately, with our PhD student Caroline Comby, and colleagues Stephanie Barrillon and Jean-Luc Fuda and others, we have focused on the challenge to estimate vertical velocities. We're doing it either theoretically (with equations) or by measurements. In the latter case, we have two types of approaches: either using a flight model as in the case of VVP (see Jean-Luc Fuda site), or with 5-beam ADCPs (ADCPs with a special vertical beam). We have been doing these measurements in low energy regions (with relatively small vertical velocities) to challenge our results and are also aiming at measuring these velocities in

areas with stronger ascending or descending velocities. The aim afterwards is to connect the results with biology, and in the future HOPE-VV program (starting at the end of 2023) to connect it with carbon export due to trichodesmium in the South Pacific.

Aside from science, I love swimming, walking/hiking, singing, reading, doing yoga and teach- ing hatha yoga. Teaching yoga is completely different from teaching science but, in both cases, it is great to either sow seeds or, even better, see "plants" growing. I really enjoy teaching, and love to see people/students understand new concepts. Maybe it is linked to the fact that I bloom on learning new things myself. I am very curious, enthusiastic at discovering new ways of thinking. I suppose that's why I am a scientist. I am never bored at work.

• In the BioSWOT-Med campaign, among other things, you will be in charge of analysis of hull mounted ADCP and of deployment of L-ADCP and FF-ADCP. What are they and how do they work?

An acoustic Doppler current profiler (ADCP) is an instrument used to measure water current velocities over a depth range using the Doppler effect of sound waves, scattered back from particles within the water column. If a sound is emitted and there is a receiver, the Doppler effect consists in having the sound pitch getting higher (lower) when the distance transmit- ter/receiver shortens (lengthens). The quicker the distance changes, the quicker the soundpitch changes. Reversely, if we measure the pitch drift from its initial value, we can evaluate the relative displacement between the transmitter and the receiver. That is what we are using with ADCPs with the hypothesis that the particles -on which the sound backscatters- are drifting passively with the ocean currents. Hence the velocities, measured by the frequency shift of the backscattered sound waves, are taken to be oceanic velocities.

These ADCP can be put at a fixed point (for example on a mooring or oceanic fixed structure), in the hull of a vessel (hereafter called VM-ADCP as vessel-mounted ADCP), attached to a CTD rosette (called L-ADCP for lowered ADCP) or to a free-falling cage (hence called FF-ADCP).

Stéphanie on the deck of R/V L'Atalante.

13. The FF-ADCP and CTD

Stéphanie Barrillon

Stéphanie is a CNRS researcher working MIO. Her research focuses on the investigation of the oceanic vertical velocities and their impact. During the BioSWOT-Med campaign she is in charge, among others, to deploy and analyze data from the ADCP and CTD, two classical instruments for measuring oceanic physical characteristics. Here she explains what they are and how they work.

• What are your research interests?

I'm interested in understanding the oceanic vertical velocities and their impact. These vertical velocities are present everywhere in the ocean but still largely undetermined. Their in situ measurement is very challenging, in particular because of their low intensities. How to measure them in situ and with which precision? How do they structure the ocean vertical dynamics? What IS their impact on nutrients' transport upward the surface and on the carbon sequestration to the bottom of the ocean? The BioSWOT-Med cruise will certainly bring some building blocks towards the answers to these questions.

• The FF-ADCP was developed at MIO. What is the difference with other existing ADCP?

The ADCP (Acoustic Doppler Current Profiler) is a classical instrument for measuring oceanic currents using acoustic beams and the Doppler effect. ADCPs are usually used for the horizontal components' measurements, but we are now exploiting them for the vertical

component. In particular, the new generation ADCPs can have an additional vertical beam dedicated to this component.

ADCPs are either fixed on the bottom of the ship or deployed with a package attached to the ship, their measurements are thus largely influenced by the ship movement. The idea of the FF-ADCP (ADCP in Free Fall) is to decouple the ADCP from the vertical movement of the ship: attached to the ship by a loose rope, the FF-ADCP falls freely, independently from the ship movements. Thanks to this decoupling, and using the vertical beam of the new generation ADCPs, the measurement of the vertical velocities reaches a precision of a few mm/s.

• In the BioSWOT-Med campaign, among other things, you will be in charge of the CTD. Can you explain what it is?

The CTD (Conductivity, Temperature, Depth) probe is yet another classical instrument in oceanography that measures pressure, conductivity and temperature of the water. It is usually fixed on a vertical moving package electrically connected to the ship. This package contains a lot of other instruments to measure physics and biological observables through the water column, as well as Niskin bottles to sample water at different depths. A lot of profiles will be performed using this package during the BioSWOT-Med cruise.

Zooglider with Jeff Sherman (left), Mark Ohman (center), and Sven Gastauer (right) at the Scripps Institution of Oceanography before the start of the BioSWOT-Med cruise.

14. Everything about Zooglider

Sven Gastauer

Sven is a senior acoustic scientist at the Thünen Institute for Sea Fisheries, Germany, and holds a visiting scholar position at the Scripps Institution of Oceanography (University of California San Diego), USA.
In the BioSWOT-Med campaign, Sven is in charge of Zooglider, a specialized glider aiming at furthering our understanding of mesozooplankton. Here, he describes the functioning of Zooglider, the different instruments mounted on it, and the large range of data that can be gathered.

• What are your research interests besides BioSWOT-Med?

My main research interests are in the field of hydroacoustics, as a tool to better understand ecological and biological processes. This often requires coupling of hydroacoustics with auxiliary data sources, such as biological samples, optics and physical measurements. This requires me to constantly further my understanding of acoustic signals, which resulted in a strong interest in acoustic scattering models.

• What is the zooplankton glider?

Zooglider is a specialised glider, aiming at furthering our understanding of mesozooplankton. Many zooplankton species are fragile or gelatinous animals, difficult to sample or observe with traditional methods, such as nets. Zooglider is designed to be as stealthy as possible under water, causing as little turbulence as possible in order to not disturb the marine organisms in their natural behaviour.

Zooglider is typically deployed by two or three people. Once released in the water it is autonomous. Zooglider does not have an engine or external moving parts. As a glider, it is equipped with a small oil bladder. An integrated pump will pump oil from or into this bladder, causing a small change in total density of the glider, resulting in a downwards or upwards force. The presence of wings creates lift, allowing the glider to swim upwards or downwards in the water column at an angle, and thus moving over the seafloor. A typical dive would be down to 400 m of depth and last approximately 3 hours. When Zooglider reaches the surface, it raises one of its wings into the air to establish a satellite link to shore. This is how it communicates us that everything is ok and it sends us a summary of what it has observed on its last dive.

• How do you operate Zooglider?

Based on the latest position from Zooglider, we combine information from satellites about features we might want to sample with the later report we receive from Zooglider, to decide if we want it to continue its pre-programmed path, or if we want to give it a new destination. This routing process is revised constantly during a mission. In the case of BioSWOT-Med, I will closely monitor the received information and negotiate the next waypoint with Prof. Mark Ohman from the Scripps Institution of Oceanography. Once we agree on our next destination, Dr. Jeff Sherman from the Scripps Institute Development Group will send the commands to Zooglider through a satellite link.

• What data do you acquire with Zooglider?

During the descent, Zooglider is in a passive mode and only records ambient sounds of the sea with a hydrophone. During the ascent, Zooglider collects CTD information - Temperature, Salinity and chlorophyll fluorescence (as a proxy for phytoplankton concentration), allowing us to gain detailed insights about the physical environment in which Zooglider is operating. But the ocean is not only physics and

we also want to understand the drifting planktonic organisms near the base of the ocean food web. Therefore, we have equipped Zooglider with a specialised optical system we call the Zoocam. Zoocam is a shadowgraph imaging system, which as the name suggests, records the shadows of anything Zooglider crosses on its journeys. A red LED beam (bundled and parallelised to remove any spatial distortion) is projected across a sampling tunnel of about 250 mL, attached to the font of the glider. Anything that passes through this light beam will cast a shadow that is then recorded by the camera.

This allows us to quantitatively record dense organisms, like small crustaceans, as well as translucent gelatinous organisms, like medusae, siphonophores or marine snow. With ambient light being so sparse at depths greater than a few meters, many organisms don't rely on their optical senses alone but use sound as a way of communicating and sensing the environment. Zooglider is also equipped with a dual frequency active acoustic system we call Zonar. Zonar sends out acoustic waves at 200 and 1000 kHz and then waits for the signal to come back. A soundwave travels much faster underwater than in the air. On its path through the water column, any object or organism it encounters will send back a part of the acoustic energy to its source. In very general terms, the signal received at higher frequencies will be more dominated by smaller organisms and the signal at lower frequencies will be more dominated by larger organisms. This is a technique very similar to what dolphins use to find prey, friends and how they avoid potential obstacles. The latter inspired us to also build a seafloor detection algorithm into Zooglider, which allows it to sense the presence of the seafloor and automatically adjust its trajectory, should it get too close. Through a combination of acoustic scattering models, information received from zonar and the zoocam, we can separate the acoustic signal into organisms of different size classes or taxonomic groups. Coupled with observations of the physical environment and the zoocam images, this allows us to detect changes in density or composition of the mesozooplankton communities.

• How do you use the hydrophone on a Zooglider to listen to marine mammal and fish calls?

Many marine organisms are very vocal; they communicate using sound. A hydrophone is an underwater microphone, which allows us to listen in into the chitchat of sound producing animals, such as marine mammals or fish. It is well-known that whales have different songs or types of calls they use to communicate. We can for example distinguish different baleen whale species by the calls they produce and often we can even understand if they are performing social, feeding or mating calls. Not so well known is the fact that many fish are also rather vocal. Admittedly, the sound of a fish chorus is not quite as melodic or relaxing as the sound of a humpback whale might be, and more accurately described as grunting. Nonetheless these sounds can provide us with insights on the behaviour of fish.

While marine mammals produce sounds using mechanisms similar to ours, fish mainly produce sound through sonic muscles on or near their swim bladder, by rubbing together skeletal components or in a more passive fashion, through abrupt changes in swimming directivity or speed. On Zooglider we recently added an Acousonde, a kind of highly portable hydrophone. We have pre-programmed the hydrophone such that is starts recording when the glider reaches a certain depth and stops when Zooglider begins the ascent. We use the descent for our listening session, because this is the time Zooglider is the quietest, with no other instrument noise. After the voyage we can then listen into all the conversations that Zooglider recorded on its mission.

Véronique working at the optical microscope onboard the R/V L'Atalante.

15. How to study phytoplankton diversity?

Véronique Cornet

Véronique is a research engineer at CNRS working at MIO. During her career she has participated in 10 oceanographic campaigns from the Southern Ocean (Kerguelen Islands - Macquarie Island), Pacific (New Caledonia - Polynesia, Solomon Islands) Mediterranean Sea, and one ice camp in the Arctic.
Specialist of microphytoplankton and their role in the biological carbon pump, here she describes what phytoplankton are, how to collect them in the sea using the phytonet and Niskin bottles and how to analyze their diversity using the PlanktoScope, the optical microscope and the scanning electron microscope (SEM).

• First of all, what is phytoplankton?

The name comes from the Greek words *phyto*, meaning "plant," and *planktos*, meaning "wanderer" or "drifting." Phytoplankton are the autotrophic component of the planktonic community and are a key component of ocean and freshwater ecosystems. They are responsible for more than half of the global primary production of the oceans and for the export of anthropogenic carbon to the deep ocean. Knowing and understanding how phytoplankton function is essential in the context of current climate change.

• What will you study about phytoplankton during the cruise?

During the BioSWOT-Med cruise, we will be looking for information on the share of diatoms in the spring bloom and the possible contribution of nanoplankton-sized diatoms. During the campaign

we will have the opportunity to carry out in parallel a certain number of cytometry and molecular biology samples to analyze them in microscopy. This will allow us to compare the data obtained by these different approaches.

• How are phytoplankton samples collected and how are they preserved before analysis?

During the BioSWOT-Med campaign we will use two sampling techniques: The first one by using a plankton net or phytonet, with a mesh size of 20 microns: a vertical line is drawn between 200 meters from the bottom and the surface; a sub-sample of this net is observed immediately and 2 sub-samples are fixed; 1 in acid lugol and 1 in neutral formalin and kept in a cool, dark place. The second one by sampling with Niskin bottles. The depths studied will be 200 m - the "DCM" (variable depth) - and the surface. These samples will be fixed with acid lugol and neutral formalin.

• How do you analyze the samples and how do you study phytoplankton diversity?

A subsample of the phytonet will be observed live under the microscope in order to evaluate the community structure and to acquire good quality images to feed our image databases. This sample will also be analyzed using a PlanktoScope. The PlanktoScope is a benchtop device that allows us to acquire semi-continuous images of the plankton present in our sample. Compared to the microscope, this device allows us to quickly acquire a large number of images representative of the diversity of our sample; we will then use an automatic image recognition software to sort and classify them by major taxonomic groups.

Another unfixed sub-sample will be filtered for observation with a scanning electron mi- croscope (SEM) in the laboratory. This technique allows magnifying the image up to 175 000 times (a "classical" microscope magnifies up to 1000 times), which allows us a very fine

taxonomic identification, especially for nano diatoms that are difficult to recognize with optical microscopy.

The fixed samples will be studied in the laboratory with an optical microscope: identifi- cation, counting and measurement of the biovolume of phytoplanktonic cells. Biovolume measurements allow us to evaluate the carbon biomass of the cells. By combining counting, identification and measurement we have access to the community structure not only in terms of abundance but also to the contribution of species or functional groups in terms of biomass.

Alice setting up the zooplankton grazing experiment.

16. How to measure zooplankton grazing

Alice Della Penna

Alice is a biological oceanographer currently working as Lecturer at the Waipapa Taumata Rau University of Auckland, in New Zealand. Her research interests focus on how oceanic currents affect marine life from microbes to large animals such as sharks, seabirds, and marine mammals. In BioSWOT-Med Alice is in charge of studying zooplankton grazing. She explains what it is, why it is important to measure it, and she describes a new "exclusion experiment" that will be carried out during the campaign.

• First of all, what is zooplankton grazing?

Zooplankton grazing is the process by which zooplankton (an extremely diverse group of floating animals that can be microscopic or as large as jellyfish) feed on phytoplankton(floating microalgae). One of the aspects I've been growing more and more interested in is not just how currents affect the distribution of marine organisms themselves, but how features such as eddies, meanders, and fronts can impact the relationships between organisms (for example grazing and predation).

• Why is it important to measure it?

Phytoplankton play a key role in marine ecosystems and in biogeochemical cycles. However, their role is heavily modulated by their fate. For example, if phytoplankton is grazed by zooplankton that migrate in the water column, the carbon that constitutes that phytoplankton will be transported away from the ocean surface, and it will be 'export-

ed' to the deep ocean. This is an important component of the carbon cycle, but it is very hard to quantify, and it is especially difficult to assess how it varies in space and time. Furthermore, it is a mechanism that as far as I know is not well represented in climate models.

• How do you measure zooplankton grazing?

There are multiple methods to measure zooplankton grazing which are focused on different types of zooplankton of different sizes. My goal for the BioSWOT-Med campaign is to try a new method to estimate the grazing of vertically migrating zooplankton on phytoplankton living in the epipelagic (the upper layer of the ocean that receives sunlight during the day).

• During the BioSWOT-Med campaign you will be carrying out an "exclusion experiment". What is it?

The key idea is to have two mesocosms (two very large aquaria onboard of the R/V L'Atalante) and monitor how the planktonic community they contain changes in time during the night. The 'day mesocosm' will contain the phytoplankton and zooplankton that lives all the time in the epipelagic ocean, the other one, the 'night mesocosm' will contain organisms that live in the epipelagic during the day and the zooplankton that migrates to the epipelagic as the sun sets from the deep ocean. Therefore, the migrating animals whose grazing we want to estimate are excluded from the 'day mesocosm' but not from the 'night mesocosm'. We will then monitor these two mesocosms during the night and study the differences we obtain between the two. Because we expect everything else to be the same for the two mesocosms (e.g., the physiological cycles of phytoplankton, the digestion of zooplankton, which is impacted by sunlight, etc.) we anticipate that the differences between the phytoplankton abundance and size in the two mesocosms will be the result of the grazing from the migrating zooplankton.

Loïc is in charge of zooplankton sampling during BioSWOT-Med.

17. How to study zooplankton diversity?

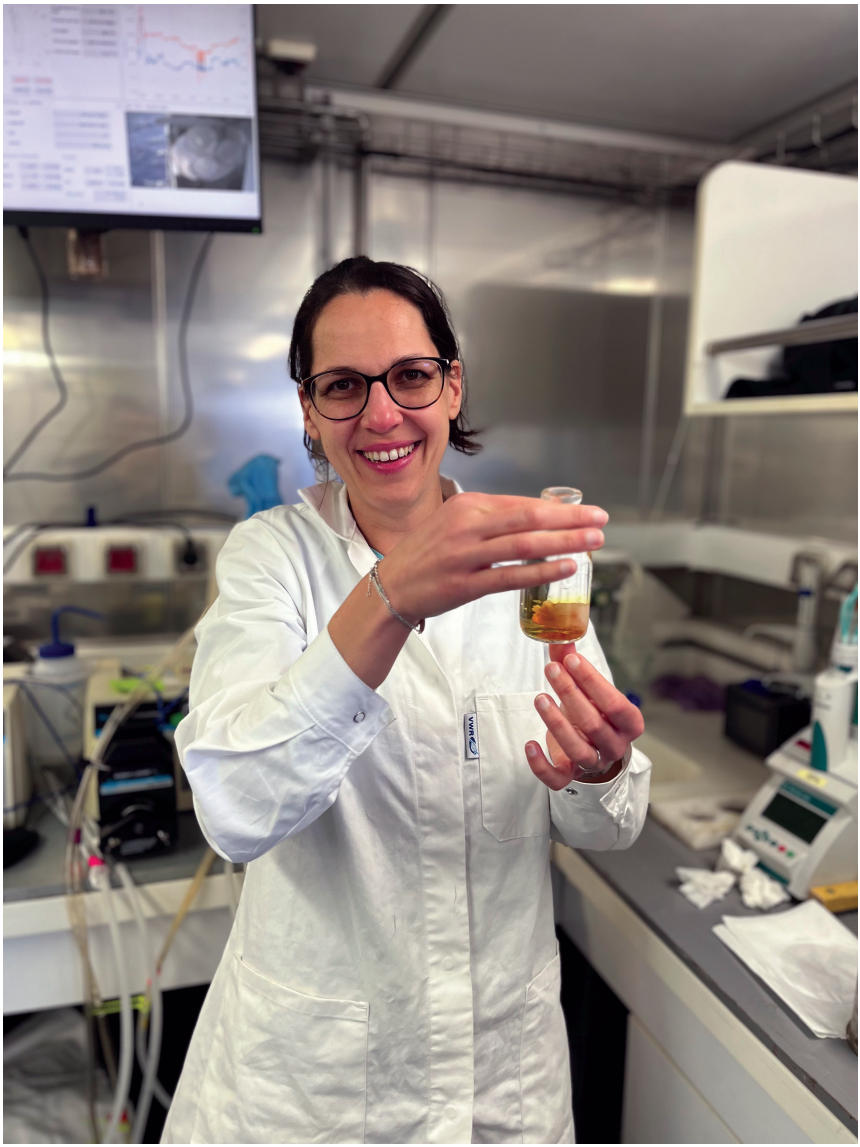
Loïc Guillox

Loïc is a Study Engineer at CNRS working at MIO. In the BioSWOT-Med cruise Loic is in charge of zooplankton sampling. Here he explains the different analyses that will be carried out later on back in the lab to assess zooplankton diversity.

• What instruments do you use to sample and study zooplankton diversity?

I will use nets of different mesh sizes in order to sample different size ranges of zooplankton. Back to the lab, these samples will be analysed in various ways.

First, thanks to zooplankton expertise a taxonomic identification and enumeration will be carried out using the stereomicroscopy. Second, through digital imaging using the ZooScan, a device that makes digital images of zooplankton samples and can process samples in a fast and semi-automatic way. All the images taken with the ZooScan will be stored on the MIO server for subsequent analyses. Finally, through isotopic analyses that will allow us to assess the zooplankton diets.



Laure analyzing a freshly collected sample.

18. Measuring oxygen and community production

Laure Chirurgien

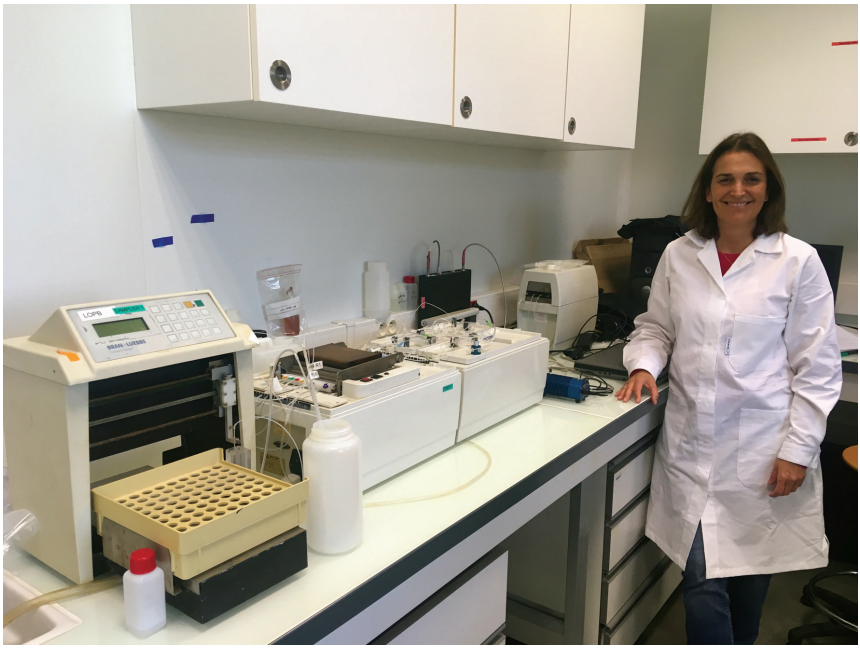
Laure is an instrumentation and experimental technical engineer at MIO. During BioSWOT-Med she is in charge of measuring oxygen dissolved in seawater and community production. Here she describes the different instruments she uses, some of which especially developed at MIO.

• What are your research interests besides BioSWOT-Med?

I develop experimental devices and set ups. In the last few years, I have mainly worked with Dominique Lefèvre, on the development of calibration baths for dissolved oxygen sensors.

• In the BioSWOT-Med cruise you are responsible for measuring oxygen. What instruments do you use and how do they work?

On the CTD, there is a dissolved oxygen sensor that needs to be corrected for potential drift and exactitude errors. Therefore, every day, I will take samples from the CTD at different depths and measure the oxygen concentration at these depths using the chemical reference methodology: the Winkler method. With these reference values we are able to correct the calibration parameters of the sensor to provide the community with more accurate values. To make this measurement I use a one-wavelength spectrophotometer, called Endpoint, which we developed in collaboration with the Marseille Particle Physics Centre (CPPM) and the Technical Division of the National Institute of Sciences of the Universe (DT INSU).



Sandra at MIO with the instruments used on land to analyze the samples collected during the cruise.

19. Measuring nutrients

Sandra Nunige

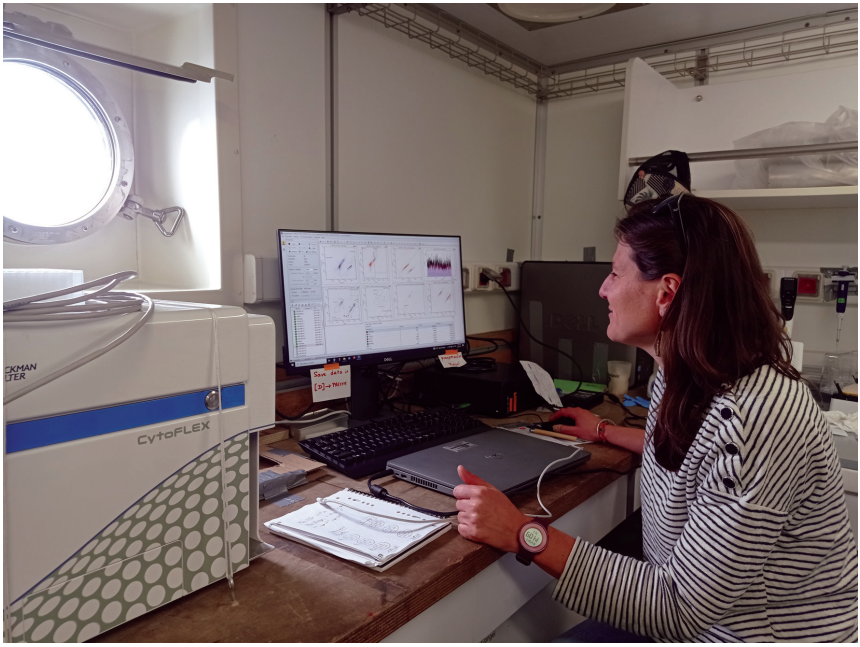
Sandra is a chemical engineer at CNRS working at MIO, expert in nutrient salt measurements. In BioSWOT-Med she is in charge of measuring nutrients concentrations. Here she describes the different analyses she will carry out during the BioSWOT-Med cruise.

• What are your research interests in the BioSWOT-Med campaign?

I am involved in the BioSWOT-Med project for the determination of nutrients that allow the growth of phytoplankton in seawater. This project is of particular interest to me because it will allow me to sample near eddies and to make the link with the images obtained by the SWOT satellite. The time of year corresponds to the spring bloom of phytoplankton with low nutrient con- centrations. To carry out these measurements, it will be interesting to use the automated nanomolar phosphate measurement technique recently developed in the laboratory at MIO.

• You are responsible for measuring nutrients. What instruments do you use to measure them?

As a specialist in nutrient salt measurements, I will perform measurements of nitrate, nitrite, phosphate, silicate, ammonium, and determine the nitrogen and phosphorus content of particulate and dissolved organic matter. Samples will be collected on rosette CTDs or by the pumping system and then analyzed directly with an auto-analyzer. Samples will also be taken for more sensitive measurements of phosphates at nanomolar concentrations using the Liquid Waveguide Capillary Cell protocol.



Morgane while analysing samples with the cytometer aboard the R/V L'Atalante.

20. The flow cytometer

Morgane Didry

Morgane is a technician at University Aix-Marseille working at MIO on the PRECYM cytometry platform. In BioSWOT-Med she is in charge of flow cytometry. Here she explains how flow cytometry works and what information it can provide about different assemblages of phytoplankton.

• What are your research interests besides BioSWOT-Med?

I study marine microbiology and more precisely the distribution of different assemblages of phytoplankton, bacteria and viruses. I can be asked to work on local projects of researchers (as it is the case with this campaign), but also for external providers and thus analyze very different samples coming from all over the world.

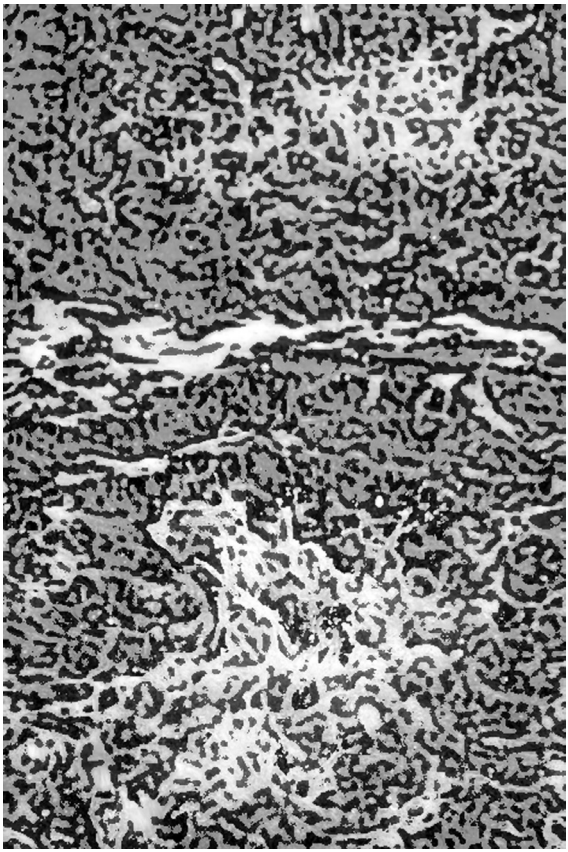
• In the BioSWOT-Med cruise you will be responsible for flow cytometry. What is a flow cytometer and how does it work?

Flow cytometry allows to count and analyze suspended particles individually and at very high throughput. These particles are carried by a sheath liquid which aligns them, separates them and leads them to a light source (laser). Different parameters are then measured, allowing us to classify the cells according to their optical properties of light scattering and fluorescence, which then gives us information on their size, their structure, and their physiological state.

• Will you take part in the day/night shifts?

Yes, we will take turns with Gérald Grégori for the cytometry. During the three days on station, we will take water samples from Niskin bottles and fix the samples. Then we will take advantage of the three days of mapping and repositioning of the boat to analyze at least part of the samples (phytoplankton analysis). The rest (bacteria, viruses and heterotrophic nanoflagellates) will be analyzed in the lab upon our return.

THE NEW WAVE OF OCEANOGRAPHERS



Robin learning from Jean-Luc how to check the good functioning of a glider.

21. How internal-mesoscale waves impact the energy cascade

Robin Rolland

Robin completed his bachelor's degree in Biology and his Master's degree in Marine Sciences at Aix-Marseille University. He is currently a PhD student at Sorbonne University at LOCEAN. For his PhD in physical oceanography he focuses on internal wave-mesoscale interactions and their impact on the energy cascade.

• What is your field of research and how did you choose it?

I am interested in internal wave-mesoscale interactions and their impact on the energy cascade. That is, how these interactions modulate energy transfer between currents of different spatial scales. I am studying this around the Sicilian Channel which has many topographic and bathymetric constraints. It is also one of the few areas in the Mediterranean Sea where there is a significant tide.

I will also be interested in this question in the Algerian basin, where I will participate in the BioSWOT-Med campaign to measure turbulence at (deci)metric scales.

This subject was proposed to me by my Master 2 supervisor Francesco d'Ovidio, coordinator of the SWOT AdAC consortium, together with Pascale Bouruet-Aubertot and Yannis Cuypers, both specialists in internal waves. The internship went well and the subject interested me because it dealt with fine scales, although I knew little about internal waves at that time. So I chose to defend this subject at the doctoral

school. I'm very happy with this choice because I was able to discover a whole new exciting part of physical oceanography.

• What is the link between your research field and SWOT?

SWOT will allow us to observe ocean currents that have a spatial scale of a few tens of kilometers or even a few kilometers. At these scales, the signal from internal waves (tidal waves in particular) is significant and mixes with that of the balanced (geostrophic) dynamics of the ocean, which can already be observed by satellite today.

The internal wave-mesoscale interactions I am interested in occur at scales that SWOT will be able to observe. We hope to take advantage of these data as well as the BioSWOT-Med data to learn more about these interactions, and to compare model data with satellite and in situ observations.

More generally, current knowledge of currents at the scales that SWOT will observe is largely model-based, but there are few observations to validate this knowledge. SWOT will partially fill this gap. For the energy exchange issues I am interested in, these observations will be of great help!

• What excites you about SWOT and the BioSWOT-Med campaign? How will you contribute to the campaign?

First, it is the breakthrough that SWOT will enable in the observation of ocean surface currents and the technological feat that makes it possible. Second, it's the number of projects and research topics that SWOT has helped stimulate years before its launch. There is a real buzz in the community that is very exciting as a young researcher.

As far as the campaign is concerned, it is a unique opportunity to be able to cross-reference campaign data with satellite data at high spatial and temporal resolutions (1-2 satellite passes per day). The SWOT data will be valuable for the interpretation of the data collected in situ, to give a broader view of the surface dynamics of the sampled area. More generally, a campaign is always a unique experience!

During the BioSWOT-Med campaign, I will be in charge of turbulence measurements at (deci)metric scales using a Vertical Microstructure Profiler. The analysis of the campaign data and SWOT data will be an integral part of my thesis.

• What are your plans after the campaign?

The analysis of the campaign data first. I also have other projects underway, including Lagrangian analyses in the Sicilian Channel. Currently, I am finalizing a first paper that I hope to submit before the start of the campaign.

Concerning the post thesis, I don't know yet. For the moment, I would like to continue in research but I do not close any doors.

Laurina (first from right) takes a selfie with the team
excited to receive a rosette sampler filled with deep seawater.

22. Nature functions "as a whole"

Laurina Oms

Laurina is a PhD student in physical oceanography at MIO, Aix-Marseille University. For her PhD Laurina investigates the distribution of phytoplankton in the ocean by studying both ecological processes and physical structures at fine scales.

• What is your research field and how did you choose it?

I chose to study oceanography because it is a multidisciplinary field that allows the study of natural processes, taking into account that they all work in synergy. The study of the ocean is the study of a fluid in motion where the skills of physicists, chemists, biologists are all required to advance. I therefore chose oceanography because it allows us to better understand that nature functions as a whole.

• How does your research relate to SWOT?

I study the link between physics and biology at fine oceanic scales. For this purpose, different approaches are used and complement each other.

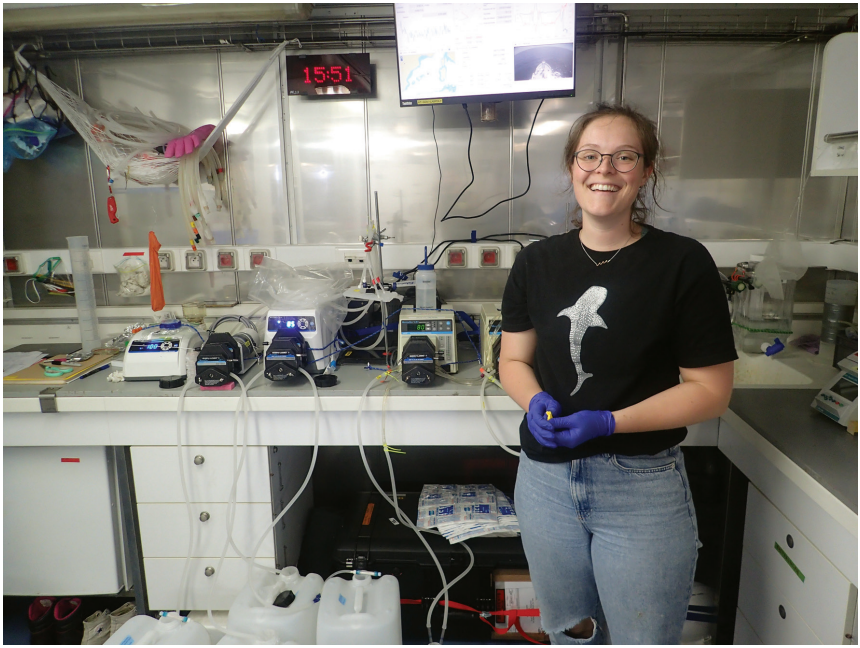
First of all, I have a modeling approach where I numerically simulate the physical and biological processes of interest, but also an in situ approach where we collect our data directly at sea. For this second approach, we use satellite observations that allow us to have a general view of our study area and to target the physical and biological structures that we want to study. SWOT will thus bring us a high-resolution observation of the ocean surface.

• What excites you about SWOT and the SWOT-AdAC campaign you will be participating in? How will you contribute to the campaign?

I am very curious to see how SWOT high resolution data from the surface of the ocean can improve both the general knowledge of the physical dynamics of the ocean, and help me in answering my own scientific questions, namely: the peculiarities of fine-scale physical structures and their role on the distribution of phytoplankton communities. For this question, during the BIOSWOT-Med campaign I will use flow cytometry to measure the abundances of the different populations of phytoplankton present in the region, and to report these results on maps indicating the abundance points and some physical features such as the direction and speed of the currents.

• What are your plans after the campaign?

After the campaign I will analyze the physical and biological data *in situ*, and from that feed my numerical model. The idea is to understand the common history of water masses and organisms during the cruise and to extend these results to define more generally the fine-scale features in the ocean.



Emily in the lab aboard the R/V L'Atalante.

23. How is phosphorus used by phytoplankton?

Emily Wagonner

Emily is a 3rd year PhD Candidate in Solange Duhamel's lab at the University of Arizona, Molecular and Cellular Biology Department. For her PhD in biological oceanography, she focuses on understanding the various forms of phosphorus that phytoplankton can use and the enzymes that help support this.

• What are your research interests besides BioSWOT-Med?

I've always been drawn to the ocean, spending summers at the coast as a kid. I met Dr. Solange Duhamel onboard the R/V Endeavor in 2018 and since then, I've been enamored by phytoplankton and how they survive in regions with little to no phosphorus for growth. My PhD work focuses on understanding the various forms of phosphorus that phytoplankton can use and the enzymes that help support this.

• In the BioSWOT-Med cruise you will be responsible for measuring polyphosphates and organophosphates esters. What are they and why is it important to measure them?

Phosphorus is essential for cells to function and grow. In the Mediterranean Sea, where phosphate is a limiting nutrient, polyphosphates can be used as an alternative source of phosphorus for phytoplankton. Emerging pollutants, such as organophosphate esters, are present in the Mediterranean Sea and may also play a role in the phytoplankton community.

• What instruments do you use to measure them? How do they work?

On R/V L'Atalante, we will filter seawater for both polyphosphates and organophosphate esters, store the samples, and analyze everything back in the lab.

For polyphosphates, this includes collecting phytoplankton on a filter and measuring polyphosphate by either mass spectrometry (identifying polyphosphate by the compound mass/charge ratio), or staining with a fluorescent dye. We can also look at the polyphosphate specific to phytoplankton groups by first sorting the cells.

Organophosphate esters are collected by passing seawater through a column that retains the compounds. In the lab we can transfer the compounds to a vial which is then analyzed by coupled gas-chromatography mass spectrometry. The sample is vaporized and each compound "breaks apart." The way each compound separates is consistent and we can use that pattern to identify which compound we're looking at and the quantity.

Caroline is responsible for the acquisition
and analysis of vertical velocity measurements.

24. Measuring vertical velocity as part of fine-scale dynamics

Caroline Comby

Caroline is a PhD student studying ocean dynamics through the observation of fine scales at MIO, Aix-Marseille University. She started her studies at the University of Perpignan Via Domitia (UPVD) and then joined Aix-Marseille University during her last year of undergraduate studies. Her PhD advisors are Stéphanie Barrillon and Anne Petrenko. For her PhD she focuses on the issue of vertical velocity measurements in the context of fine-scale dynamics.

• What is your field of research and how did you choose it?

My research field is the study of ocean dynamics through the observation of fine-scale processes. More specifically, my thesis work consists in solving the question of measuring vertical oceanic velocities in fine-scale processes by combining instrumental development, experiments at sea, the analysis of in situ data and modeling.

I choose this field of study as a continuation of my training as a physical oceanographer, motivated by my passion for field work and the challenge of developing new in situ measurement techniques. It was important for me to maintain a balance in my research between the theory of physical oceanic processes and the reality of the field.

• What is the link between your research area and SWOT?

The new SWOT satellite provides a very high-resolution view of the dynamics of surface currents, and such a resolution will allow us

to characterize the vertical transport. My research work on direct in situ measurements of the vertical component of currents will complement the surface synoptic view provided by SWOT by adding localized observations at specific points in the ocean from the surface to the depths.

The application of my work during the BIOSWOT-Med campaign will allow me to collect a lot of data in order to be able, at first, to make an inter-comparison with the surface estimates from the satellite. The final objective is to obtain a 3D understanding of the ocean dynamics supporting vertical exchanges.

• What excites you about SWOT and the BioSWOT-Med campaign? How will you contribute to it?

What I find exciting is the international dimension offered by the SWOT orbit, with the gathering of many oceanographic researchers carrying out joint missions almost simultaneously on different parts of the ocean and seas of the world. Moreover, the BIOSWOT-Med campaign emphasizes interdisciplinarity and will couple the study of physical processes with biological processes. I find it very interesting not to stop at understanding the dynamic processes from a purely physical point of view, but to consider the fine-scale circulation as a driver of planktonic biodiversity.

During the BIOSWOT-Med campaign, I will be responsible for the acquisition and analysis of vertical velocity measurements, which requires the use of several different sampling techniques and measuring instruments. More broadly, I will also participate in the acquisition of other current data. The analyses will be done in real time and will allow us to intervene in the sampling strategy by adapting the navigation plan of the mission if necessary.

• What are your plans after the campaign?

Immediately after the cruise, I will pool all the current data that was collected during BioSWOT-Med, in order to provide a global analysis

of the hydrodynamic context of the mission. It turns out that this will represent the culmination of my research work since this campaign comes in my last year of PhD. My biggest project will be to transcribe the evolution and the conclusions of my work in the form of a thesis manuscript.

Laura during a night shift aboard the R/V L'Atalante.

25. How phosphorus and nitrogen are distributed in the water column

Laura Giraud

Laura is currently doing a Master's 2 internship at the MIO, Aix-Marseille University, where she completed a degree in physics-biogeochemistry. Prior to that, she got a Master's 1 degree in geosciences from the École Normal Supérieur and a bachelor's degree in Earth Sciences from the University of Tours. For her Master Laura studies marine biogeochemistry in the Mediterranean Sea.

• What is your field of research and how did you choose it?

I'm currently working in marine biogeochemistry with Elvira Pulido and Thierry Moutin on Phosphorus and Nitrogen in the oligotrophic ocean, and more specifically in the Mediterranean Sea. I try to understand how phosphorus and nitrogen are distributed spatially and within the water column. I've always been fascinated by biogeochemical cycles, ever since my degree at Tours. I first became interested in Carbon, then I discovered the importance of Phosphorus and Nitrogen for phytoplankton in the oligotrophic ocean (60% of the ocean surface). What interested me in working in biogeochemistry is to be able to do chemistry while still being able to work on ocean physics.

• How is your field of research related to SWOT?

Working on the horizontal and vertical distribution of phosphorus and nitrogen, the impact of fine-scale structures on this distribution and on the fluxes of phosphorus and nitrogen to the surface is of

importance, as these structures are ubiquitous in the ocean. SWOT provides access to very fine-scale altimetry and surface velocity data. As a result, these structures are easier to detect using satellite measurements. This will enable us to precisely target a frontal structure in order to sample on either side of it as part of our biogeochemical studies.

• What excites you about SWOT and the BioSWOT-Med campaign in which you'll participate? How will you contribute to the campaign?

What excites me about SWOT is the resolution of the maps it makes available to us thanks to its measurements from space. Being able to work on satellite maps with such precision is very exciting. During BioSWOT-Med I'll help to measure high-resolution dissolved phosphate and nitrogen, as well as the activity of an enzyme (phosphatase) in water samples taken at the surface and in the water column on both sides, as well as on the front.

• What are your plans after the campaign?

After the campaign, the idea is to continue the analyses on the samples we have taken and frozen. We also want to measure organic phosphorus and nitrogen at high resolution, as well as taking measurements of phosphorus and nitrogen in particulate matter. In this way, we want to study the nitrogen and phosphorus profiles on either side of the structure and try to quantify the fluxes of these elements to the surface due to physics and biology.

Margot is involved with physical measurements
during the BioSWOT-MED campaign.

26. The synergy of different types of data provides a better understanding of fine-scale surface ocean dynamics

Margot Demol

Margot is a PhD student at the Physical and Space Oceanography Laboratory (LOPS) in Plouzané, France. For her PhD she investigates ocean circulation and surface dynamics at fine scales.

• What is your research field and how did you choose it?

I study the physics of the ocean, and more specifically the circulation and surface dynamics at fine scale (i.e. processes with spatial extent less than 100 km and temporal scales less than one month such as eddies, fronts or internal wave signatures). Already passionate about physics, I chose this discipline because I was attracted by the ocean, where I grew up. Many of the physical processes that occur in the ocean are still relatively unknown and observations are limited, so it is a fantastic field of research.

• What is the link between your research field and SWOT?

One way of observing surface ocean circulation and dynamics is by measuring sea level changes with satellite altimetry. The SWOT satellite is equipped with a brand-new generation KaRIn (Ka-band Radar Interferometer) that will provide us with these sea level measurements with unprecedented coverage, accuracy and spatial resolution, allowing us to observe fine-scale surface processes.

• What excites you about SWOT and the BioSWOT-MED campaign in which you will be participating?

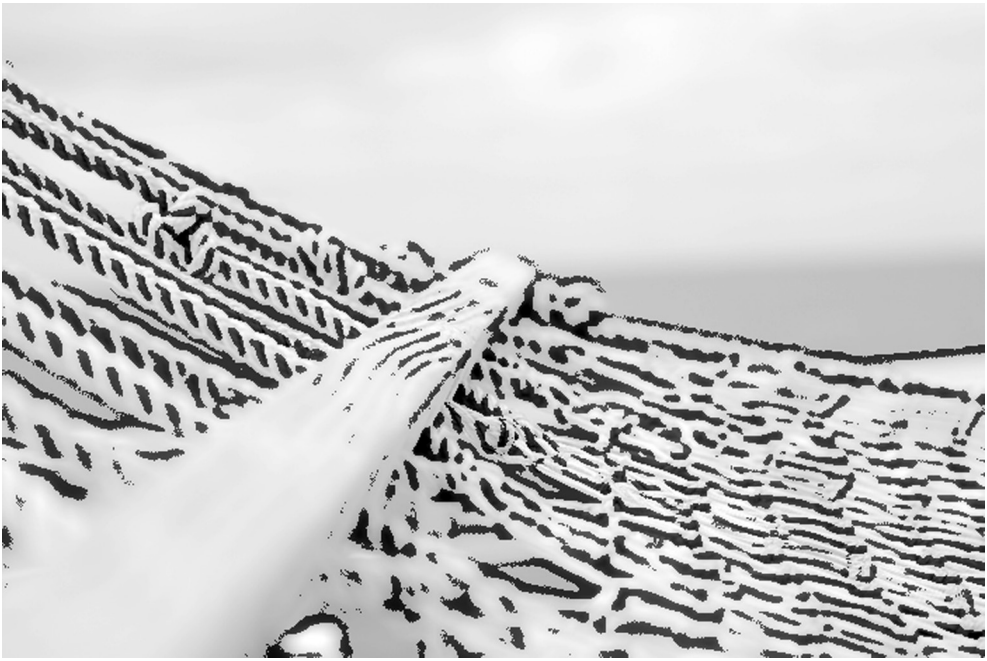
SWOT is expected to revolutionize our observation of the ocean by perhaps finally allowing us to observe sub-mesoscale processes through altimetry. During the first months of its orbit, the satellite will pass over the Mediterranean Sea every day and then every 20 days, which is also a great opportunity to observe rapid temporal variability. Different types of measurements – altimetry, drifting buoys, moorings, salinity/temperature profiles – condensed during this period in the BioSWOT-MED campaign and other campaigns constitute a very complete set of observations, giving hope for great analyses and discoveries.

My job on board will be to help with the design and implementation of the deployment of drifting buoys (small buoys that follow the currents and whose displacement is tracked by GPS) under the satellite swaths.

• What are your plans after the campaign?

I will continue my thesis and study how the synergy of the different data from this campaign (and hopefully from other SWOT AdAC campaigns) allows us to define and better understand the fine-scale surface ocean dynamics. I will also contribute to the Calibration/Validation of the SWOT data by comparing them with other *in situ* data sources.

DISPATCHES FROM SEA



20.04.2023: Start of the BioSWOT-Med cruise

The R/V L'Atalante is fully loaded at the port of La Seyne-Sur-Mer and the BioSWOT-Med campaign can start!

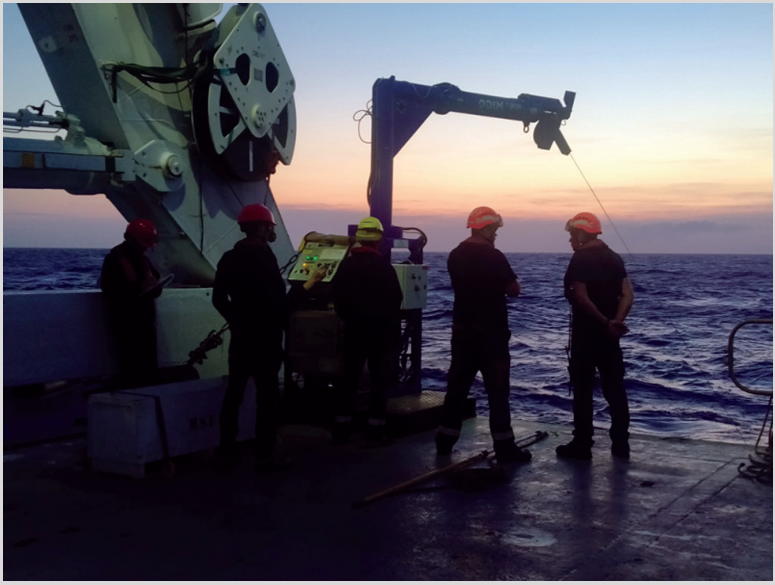
21.04.2023: Training with the sea survival suite

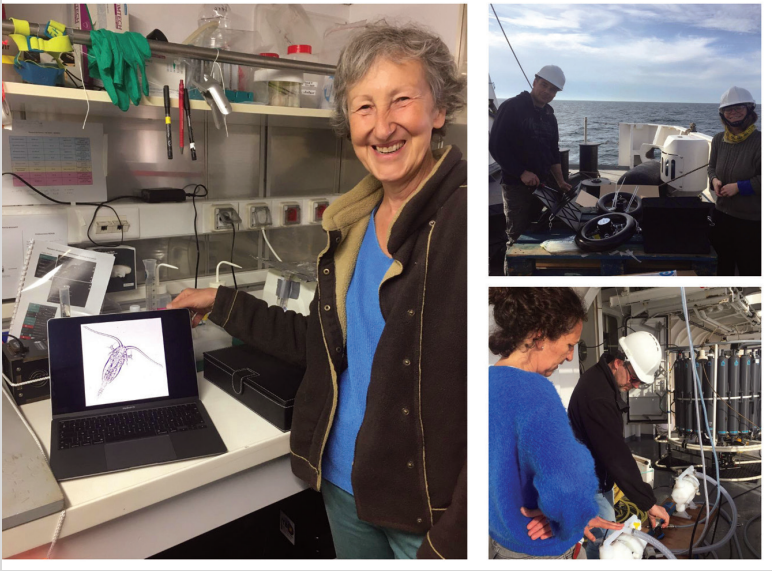
In case of an urgent evacuation from a vessel while at sea, survival rates are highly increased if you manage to wear a sea survival suit in less than 2 minutes. Here, Francesco d'Ovidio successfully managed to do so!

21.04.2023: Starting to acquire data

The R/V L'Atalante is finally fully loaded and the BioSWOT-Med campaign can start!

«At 12:54 (Local) we finally left harbor and At 21:48 (Local) position 42° 4542' N - 4°49.72' E we started to acquire data ADCP+MVP+TSG+CYTOMETRY. The plan is to continue until 7:00 local time when we will deploy the first glider, perform a first CTD cast and then test the pumping system» said Andrea Doglioli.





22.04.2023: Setting up the instruments

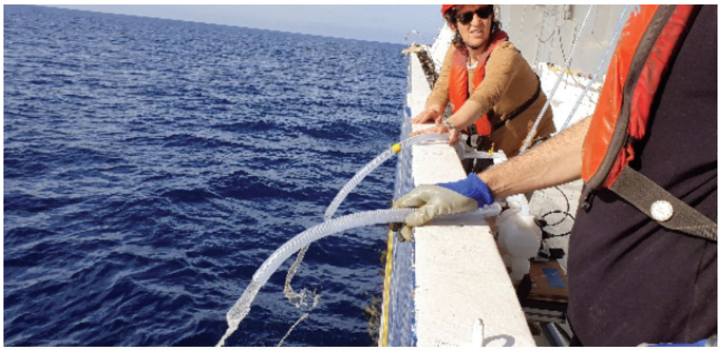
Veronique Cornet shows an image of a Calanoid (small crustacean belonging to the family of calanoid copepods commonly found as zooplankton) that she took with the Planktoscope (left); Massimo Pacciaroni and Maristella Berta are preparing the drifters (right, top); Elvira Pulido and Gérald Gregori control the pump (right, bottom).

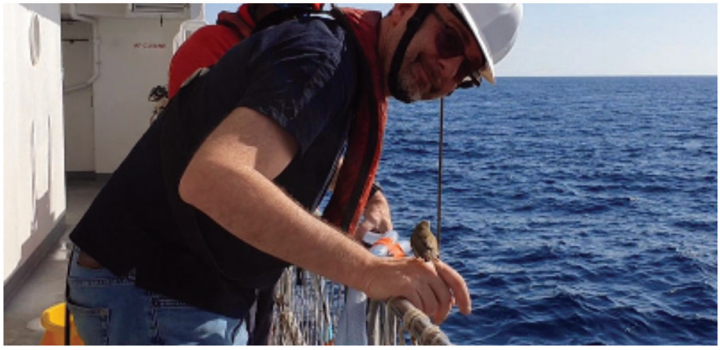
22.04.2023: Deployment of the sea glider

«This morning we deployed the CNRS seaglider for the 'Service d'Observation National MOOSE' (long term observatory of the North-Western Mediterranean Sea). This glider is going to sample from 0 to 1000m, temperature, salinity, oxygen and chlorophyll-a between Marseille and Menorca until August. It will allow us to follow the end of the spring bloom and the transition to summer conditions. Its trajectory will stay under the SWOT swath during the CalVal and will bring important complementary data to the BioSWOT-Med campaign!» said Anthony Bosse, leader of WP2 Physical Processes in the BioSWOT-Med campaign.

24.04.2023: Successful test of the new pumping system

«We have greatly improved the previous system and instead of just one pipe, water now comes on board from two different depths at the same time allowing for better analysis. Everything is ready for the first station scheduled for tomorrow morning (Tuesday 25/04). Even a little bird came to the middle of the sea to check how good the work done was!» Says the BioSWOT-Med crew.





24.04.2023: Glider deployment

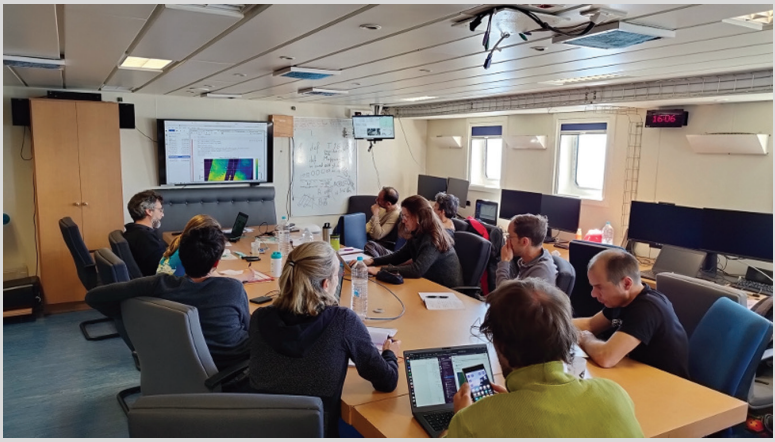
The glider was successfully deployed today by Jean Luc Fuda and the R/V L'Atalante's crew from a dinghy in perfect sea conditions!

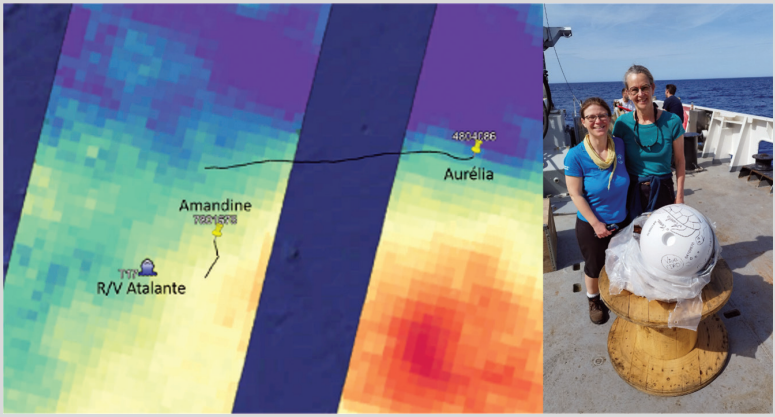
26.04.2023: Plankton net and rainbow

«Today we found a great wealth of planktonic organisms and hope to understand why right here!» Researchers are bringing the plankton net onboard after it was towed in sea water and collected plankton samples. The plankton net is made of very fine mesh, with holes large enough to allow water to pass through but small enough so that plankton cannot pass through.

27.04.2023: The adaptive sampling strategy

Meeting for the adaptive sampling strategy of the BioSWOT-Med campaign: researchers analyze real-time satellite images in order to detect the position of fine-scale structures and adapt the locations and the sampling strategy according to the origin, the shape and the evolution of these structures. Decisions are taken with the crew so to optimize the efficiency of the campaign.





28.04.2023: Drifting in a fine-scale world

Two of the Lagrangian drifting buoys are happily traveling along an oceanic front in the BioSWOT-Med study area. They are very useful to the scientists to know where the currents are going and to detect the front. Maristella Berta is in charge of the deployment and real-time follow up and analysis of their trajectories. See the beautiful map of SWOT data with the positions of the R/V L'Atalante, the trajectories of the 2 buoys and... the enthusiasm of researchers (Maristella Berta and Anne Petrenko, who drew the turtle on the Aurelia buoy) to track them !

29.04.2023: Zooplankton busters

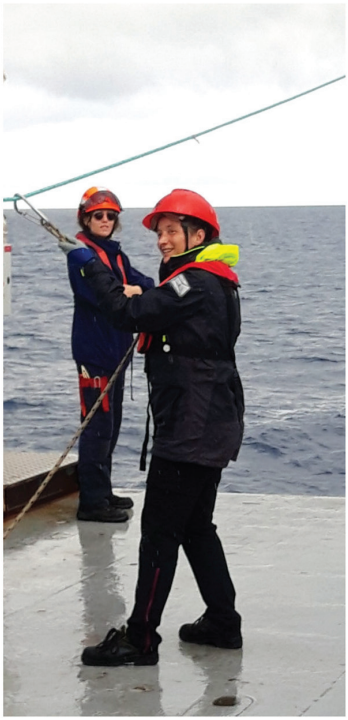
The net is ready to be deployed to capture zooplankton, small animals that are a key to the functioning of marine food webs.

30.04.2023: Recovery of a sick glider

One of the four gliders (autonomous, remotely controlled underwater instruments) on the mission emitted an emergency signal during the night of 28-29 April. A water leakage was detected and it was therefore urgent to recover it the next morning. The rescue of the glider, led by Jean-Luc Fuda and the crew, was a success. The glider is now on board and will not be redeployed for the rest of the campaign. At this stage, the other three gliders are continuing their acquisitions. Stay tuned!

02.05.2023: Escaping the storm

After a complete cycle of sampling covering the contrasted fine-scale areas, the weather forecasts reported on board by Robin Rolland indicated strong winds coming at sea from la Tramontane. This meteorological event prevents any operations, so the sampling strategy team (including Margot Demol planning the new route) decided to move and find another area where it would be possible to work. The South Balearic islands area was found to be a good place to confirm the measurements we conducted in the previous southern area. We will be back soon in the targeted BioSWOT-Med region to continue the high-resolution sampling as the weather forecasts looks better!



03.05.2023: Zooglider recovery

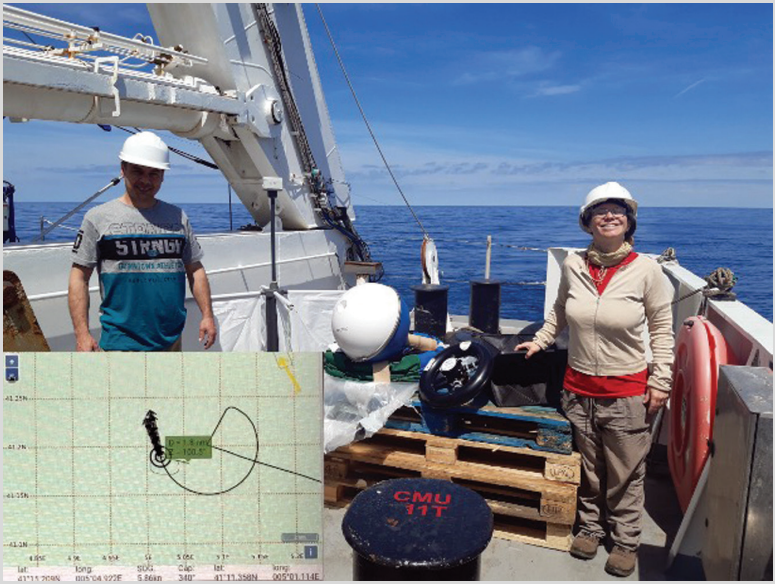
While seeking shelter from the winds, we used the opportunity to recover Zooglider. While gliders can operate in any conditions - sunshine or storm, day or night - they can struggle with strong currents. At this point Zooglider struggled against the strong currents from the North, coming around Minorca. The weather has improved and we are heading to the next station in the BioSWOT-Med area.

05.05.2023: Recovering the VVP

The Vertical Velocity Profiler (VVP) used in BioSWOT-Med is a prototype especially developed at MIO for this campaign. While its deployment from the ship is relatively simple, its recovery requires much more work, including the launching of the zodiac. Yesterday's recovery is an example of the difficulties that can be encountered by oceanographers when using drifting autonomous instruments. Indeed, many hours passed without any possibility of locating the VVP by GPS. It was only at sunset that the light system embedded on the device enabled us to locate it and to carry out the recovery, with our great relief!

06.05.2023: Launching drifters

From left to right: Massimo Pacciaroni (OGS), Maristella Berta (ISMAR-CNR) and Andrea Doglioli (MIO) ready to launch an artistic drifter.

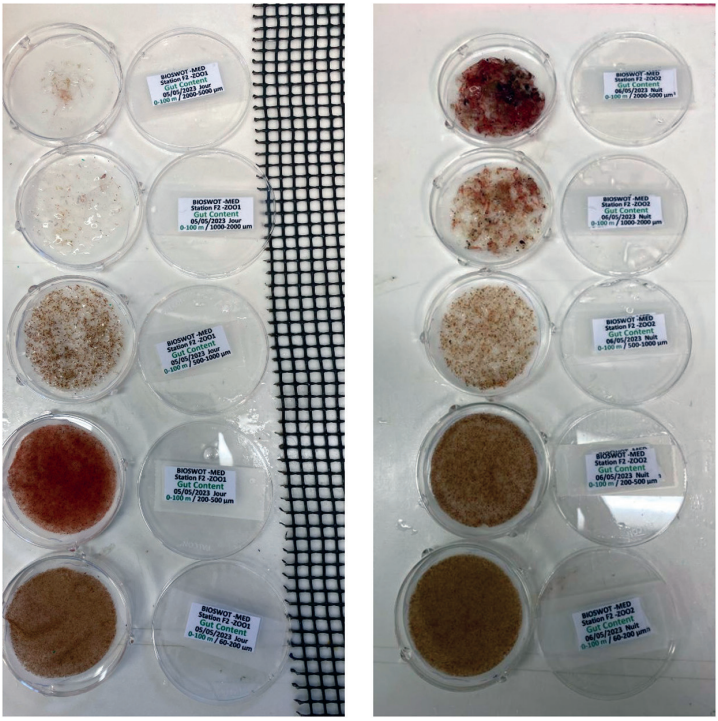


07.05.2023: The circle of drift

«Ocean currents are highly variable in space and time and are characterized by intense vertical velocities, especially nearby fronts (i.e. at the interface between two water masses with very different origin and physical and biogeochemical properties). To study ocean currents we can use drifters: gps tracked buoys that move passively with surface currents, put in evidence the main sea circulation features, allow to quantify dispersion processes, and to estimate vertical velocities in the upper sea layer. This afternoon we deployed a cluster of drifters at different depths (1 m and 15 m) in a circular configuration (see the screenshot of the navigation station) across the front to study how they get transported by currents. We observed very intense surface currents along the front and we plan to estimate vertical velocities related to the interaction between denser and lighter water masses, as background for the interpretation of the biological samples collected during the cruise» say Maristella Berta, Cédric Cotté and Francesco d'Ovidio.

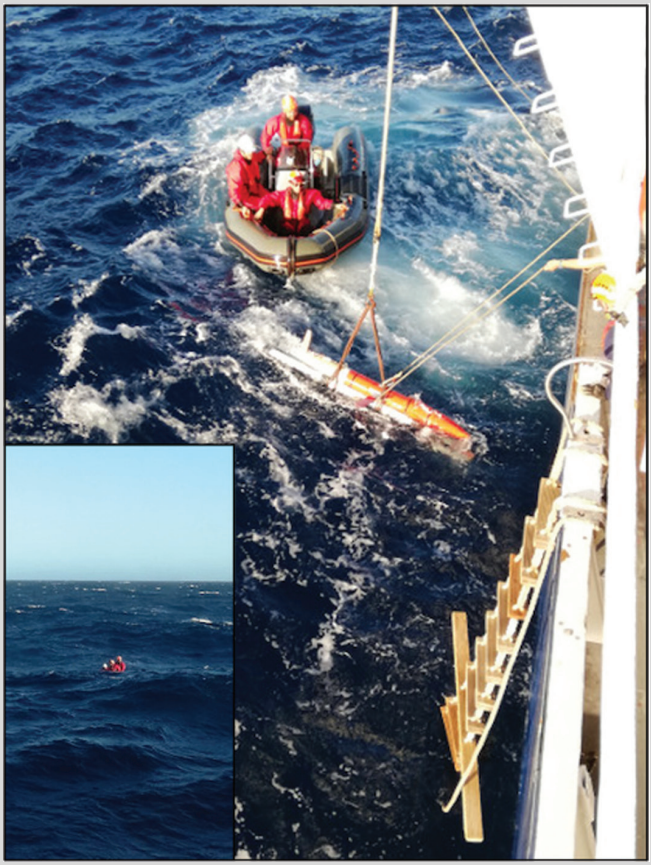
07/05/2023 – Zooplankton day and night

Size class fractionation of plankton from "zooplankton" nets at station F2 during day (left) and night (right). Day: Fraction 200-500 um dominated by copepod crustaceans (dark pink color) then transition to gelatinous zooplankton in the higher size classes. Fraction 60-200 um: mixture of small crustaceans - microphytoplankton. Night: The community appears very different, especially in the large size classes dominated by crustaceans (mainly euphausiids).



08.05.2023: Glider in the storm

«Today we recovered the glider (an autonomous underwater unmanned vehicle) in pretty rough conditions with 2.5 m high waves. As you can see in the picture, the zodiac could completely disappear behind the waves, with only the heads of the recovering team popping out. The ship was positioning itself in order to shelter the zodiac so that it could approach the boat. Then, as seen in the second picture, the glider was lifted up on the deck, followed by the recovering team. The team, the instrument, and the zodiac are all back safely onboard, looking forward to more auspicious sea conditions.»



11.05.2023: Chilling in the lab

Today Emily Waggoner is working in the cold lab, processing her samples to measure organophosphate esters: «There's a range of 20+ compounds, used as plasticizers and flame retardants, that are now showing up in the Mediterranean Sea. As an emerging field, we know very little about how these compounds are distributed and interact with the microbial community. I'm collecting samples to understand their vertical distribution, across the two water masses, and over time. In each sample, I'll measure the concentration of individual compounds in the seawater and within phytoplankton cells.» Once Emily has collected seawater, she heads to the lab, where she passes each sample through a solid phase extraction column that retains all the organophosphate esters (bottom right picture: the yellow material is where all the compounds are retained). The columns will travel back to the University of Arizona with Emily, where she will complete her analysis.

12.05.2023: Like a rainbow

Laure Chirurgien is processing samples taken while underway and with Niskin bottles in this home-made system to study O_2-based net community production versus controlled-light during 24 hours incubation.

14.05.2023: A successful campaign under SWOT swath

The BioSWOT-Med campaign ended on Sunday 14th May after four weeks of navigation sampling an area characterized by a persistent front between modified Atlantic waters of different ages about 100 km north-est of Menorca Island (Spain) under one of SWOT swaths. The BioSWOT-Med scientific team is fully satisfied by the data that were acquired and thanks the Captain and the crew of the R/V L'Atalante which allowed a great campaign despite challenging weather conditions.

Acknowledgments

The chief scientists, the principal investigators and the scientific teams involved in the BioSWOT-Med cruise are grateful to the French Oceanographic Fleet for having supported it. We thank the captain Gilles Ferrand as well as the crew of the R/V L'Atalante for their help, their enthusiasm, and their precious collaboration, together with Ifremer and Genavir people helping in the cruise preparation, in particular, Aurélie Feld and Erwan Nedelec.

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BIOSWOT MED