

New technology improves our understanding of changes in the marine environment

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Abstract: Existing European observation tools and services have the potential to take advantage of cutting-edge technologies to obtain a wide range of data at a much higher spatial resolution and temporal regularity and duration. The EU-funded NAUTILOS project will develop a new generation of sensors and samplers for physical, chemical, and biological essential ocean variables in addition to micro- and nano-plastics. The project will improve our understanding of environmental variations and anthropogenic impacts connected with aquaculture, fisheries, and marine litter. The project will integrate recently advanced marine technologies into different observing platforms and deploy them through innovative and cost-effective methods in a wide range of key environmental settings and EU policy-related applications. The project aims to complement and expand existing European observation instruments and services and further enable and democratise the monitoring of the marine environment for both traditional and non-traditional data users.

Keywords: ocean observations, sensors, samplers, fisheries, ocean modelling, data management

1. INTRODUCTION

The H2020 NAUTILOS project aims to fill in existing marine observation and modelling gaps, through the development of new technologies and their deployment onto different observing platforms promoting innovative and cost-effective methods in a wide range of crucial environmental settings and EU policy-related applications.

NAUTILOS will develop a new generation of cost-effective sensors and samplers for physical (salinity, temperature), chemical (inorganic carbon, nutrients, oxygen), and biological (phytoplankton, zooplankton, marine mammals) essential ocean variables in addition to micro-/nano-plastics. Newly developed technologies will be integrated with different observing platforms (e.g., platforms of opportunity such as commercial vessels, aquaculture plants, fixed stations, animal routes, AUVs etc.) and deployed through novel approaches in a broad range of key environmental settings (e.g., from shore to deep-sea deployments) and EU policy-relevant applications. The impact of the project will be assessed through numerical models. Data products will be made FAIR available to further European and international Ocean Data integrators. Synergies with relevant initiatives, Citizen Science campaigns and capacity building courses will be also organised to reach all relevant stakeholders and users.

2. MATERIALS

2.1 Newly developed technologies and monitored variables

Two work packages are dedicated to developing instruments for biogeochemical and biological observations and for physical, chemical, and microplastics observations, respectively. In sum, there are thirteen types of sensors and samplers from these two work packages, and they are related to 21 Essential Ocean Variables and 9 Marine Strategy Framework Directive descriptors (Fig. 1). The first part of developments will include sensors and samplers such as dissolved oxygen (DO) and fluorometric sensors based on optical technologies (fluorescence decay measurement), hyperspectral and downward-facing laser-induced fluorescence imagers, passive acoustic sensors, active multi-frequency bioacoustics water column profiling sensors, and phytoplankton and other suspended matter samplers.

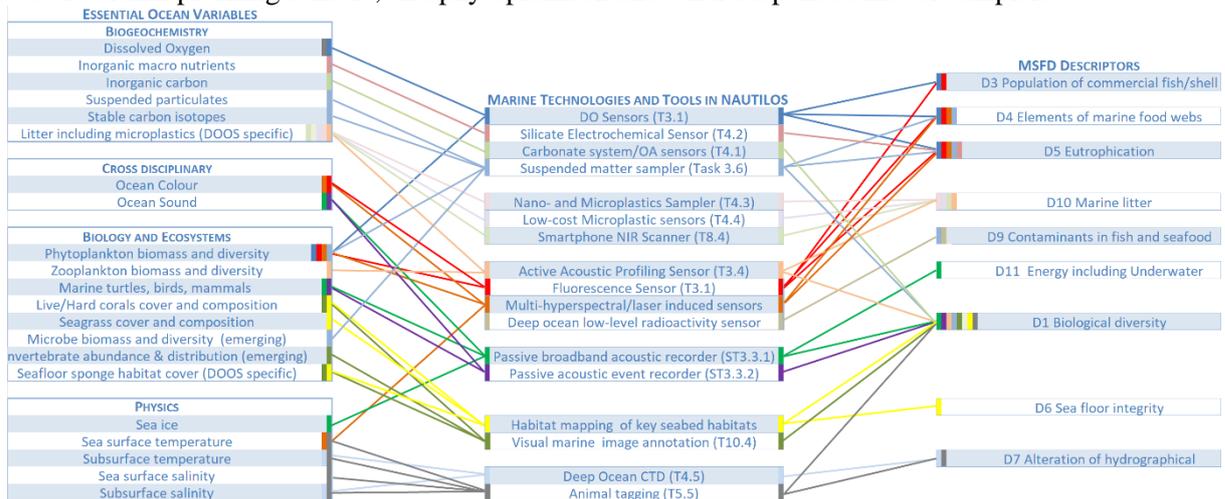


Fig. 1. NAUTILOS technologies covering EOVs and MSFD descriptors.

The second part of the developments will involve cost-effective sensing technologies in response to marine chemistry and deep-sea physics measurement needs. Ocean carbonate/acidification system sensors, electrochemical sensors measuring silicates in the water column, deep ocean CTDs based on MEMs technology, samplers for micro- and nano-plastics, and a novel LIBS-based microplastics sensor will be developed. Through these developments, we will target the variables: CO₂, pH, silicate, microplastics in seawater, conductivity, temperature and depth, and marine radioactivity.

2.2 Observational platforms and Integration

A truly diverse set of vehicles and platforms are envisaged for integrating the different sensors developed in NAUTILOS to enable the testing and demonstration of the sensors as well as the collection of data in representative situations to prove the concept and feed the data models in preparation for wider use beyond the project.

Besides, an innovative exercise is planned where multi-platform and vehicle cooperation, between an Autonomous Surface Vehicle (ASV), Lander platform and an Autonomous Underwater Vehicle (AUV) will operate as a type of network. This exercise will make use of marine communication solutions to simulate situations where automation could be a future benefit for data collection and marine monitoring. Given the exponential increase in the need for in-situ data for broader and higher quality models, automation can be a key enabler to achieve this cost-effectively. Therefore, an enhanced UW communication network will be established to allow an increased data exchange capability between sensors and sea platforms. It will be based on two modem links (acoustic and optical) of a new conception to be installed on AUV, ASV and Lander.

In terms of moveable vehicles and platforms, the project will use a UUV and its characteristics, the fluorometric and DO sensors will be integrated into an existing AUV platform (a modified AUV U_Tracker®) as well as the passive broadband acoustic recording sensor for noise monitoring. Similarly, on the ASV the same passive acoustic recording sensor will be installed with the addition of a passive acoustic event recorder as well as a carbonate system/ocean acidification sensor and a nano- and micro-plastics sampler in addition to other standard equipment of the vehicle. Finally, an Unmanned

Aerial Vehicle (UAV) will be installed with a downward-looking hyper/multispectral camera and flight-tested in Portugal in preparation for further demonstrations.

In terms of sensor integration onto ships of opportunity, there are two main approaches covered, the integration of sensors and samplers on fishing vessels and FerryBox. Ships of opportunity will perform in-field validations of DO and fluorescence sensors in cruises in the Adriatic Sea in conjunction with traditional oceanographic tools and samples of water to allow comparison with traditional methodologies. This activity will lead to integrating these sensors on the Fishery and Oceanography Observing System (FOOS) device for testing during an experimental fishing cruise. Concerning the FerryBoxes activity, a variety of different sensors will be integrated on ships for later use in aquaculture and coastal and shelf-sea-related demonstration activities.

Further integrations of sensors will be performed on floats, buoys and landers to additionally cover a variety of available marine platforms that can also be tested and used for demonstrations to materialise the final objectives. Silicate sensors will be integrated into a new generation of profiling float CTS5 with a careful balance of energy, power consumption, hardware and software packages. The integration of sensors in buoys located at the Cretan Sea (POSEIDON HCB observatory and M3A open sea site (Petihakis *et al.*, 2018)) and in the South Tyrrhenian Sea, will be performed to achieve different locations and depths of water for analysing the performance of the sensors. Finally, the Lander platform will be used to integrate and test the active acoustic profiling and deep ocean low-level radioactivity sensors, as well as the deep ocean CTD and oxygen sensor package at various sites for demonstration activities.

With regards to the animal-borne instruments activity, a collaborative effort to investigate the use of DO sensors in two different animal tagging systems to help better understand the animals, their habitats and the marine ecosystem in general, via their uniquely valuable in-situ data returned from the oceans. The first type of system is specially designed to be towed by forward-moving species in a non-invasive and low drag manner.

3. METHODS

3.1 Data Management and sharing

NAUTILOS aims to provide freely accessible marine data by allowing and enabling data flow towards existing globally accepted infrastructures and integrators (e.g., CMEMS, EMODnet, SDC – SeaDataCloud – SeaDataNet, etc.). An essential aspect of data management will be processing the acquired environmental data to a format that meets widely accepted data standards such as MEDIN discovery metadata standard, INSPIRE data specification, etc.

The project will be acting as the integrator by connecting different data sources so that ocean data can be used, reused, stored and integrated. The interoperability necessary to coordinate the scattered data management of ocean observing systems will be achieved through standardisation of formats, distribution protocols and metadata. A minimum number of metadata elements will be applied, to provide users with information identifying a collection of files as a thematic/coherent dataset. It will support the search through that collection using keywords and spatio-temporal coordinates and will provide information on or links to the processing history of the observations (i.e., source, version, quality assessment and control, sensors).

To facilitate the data harmonisation and to operate as an integrator and data translator for facilitating data use and interoperability, the project data management will adopt ERDDAP as the core solution for data management. The goal is to make it easier for users to access the project scientific data, as well as provide Thematic Data Assembly Centres (TACs) with a machine-to-machine interface to find, access, use and reuse the newly collected and high valuable NAUTILOS data.

3.2 Data Modelling

The new ocean observations made possible by NAUTILOS are expected to significantly improve model performance through data assimilation. To evaluate this outcome, simulation experiments will be performed in three distinct geographic areas using different modelling approaches: in the Mediterranean basin, a coupled hydrodynamic, biogeochemical and carbonate model with a 5 km mesh resolution will be used (Tsiaras *et al.*, 2017). The hydrodynamic model is based on the Princeton Ocean Model (POM), while the biogeochemical model is based on European Regional Seas Ecosystem Model (ERSEM) and is equipped also with a carbonate chemistry module (Blackford and Gilbert, 2007). Additionally, a

Lagrangian Individual-Based Model (IBM), coupled with the hydrodynamic model, will be used to simulate the distributions of floating plastics, originating from major source inputs. In the SW Iberia Coast, the high-resolution SOMA operational model with a 1 km mesh resolution will be used. The hydrodynamic system is based on the MOHID model and uses a generic vertical coordinate approach (Janeiro *et al.*, 2017). In the Hardangerfjord, Norway, the ROHO800 modelling system, which is based on the ROMS model for the hydrodynamics and in the ERSEM model for the biogeochemical processes and adapted to Nordic plankton species will be used. A methodology based on the Observing System Simulation Experiments (OSSE) concept will be explored to evaluate the impact produced by new sensors and observation strategies defined in NAUTILOS. Additionally, results will be useful to define optimal observation strategies in terms of types of ocean variables and observation distribution both in time and in space.

4. TESTING AND DEMONSTRATION

4.1 Laboratory calibration and field validation

Sensors and samplers developed within NAUTILOS (described in section 2.2) will be calibrated and validated to demonstrate their functionality in end-user specific environments for eventual use in field demonstration activities described in section 4.2.

The controlled laboratory calibration and validation activities will utilize certified reference materials, measurements by reference instruments, and other calibration techniques to provide metrics that can be used to characterize sensor/sampler performance including, for instance, accuracy, precision, and range of the target measurements. When appropriate, tests will also control the impact of temperature, pressure, and salinity variability on sensor performance. For some instruments, including some samplers and above water sensors, large test tanks (>800 m³) will be used for calibration and validation by manipulating the test tanks with model particles and/or organisms. Data generated during the calibration and validation experiments will be collected for evaluating the expected performance (and limitations) of a given instrument under controlled environments. This will be used to inform field demonstration activities as well as to serve as a baseline for comparison with post-field demonstration campaign sensor/sampler assessments of reliability and repeatability.

The controlled scenario testing of platforms and sensors, joint operations of multiple platforms with integrated sensors and existing observatories, will be carried out in several deployment sites. Sensors/platforms integration and deployment will be tested under different environmental scenarios to offer valuable technical information and feedback since each sensor/platform will be operated close to their environmental parameter threshold condition. Moreover, joint operations will be organized between lander, ASV and buoys with novel equipment such as acoustic sensors, sonar and cameras being used for key seabed habitat mapping. Cross-evaluation will be conducted by a comparable assessment performed by divers. A controlled scenario will be carried out in a station in Capo Tirone, in the South Tyrrhenian Sea integrating three data collecting systems (AUV, boat and a buoy). Verification and preparatory flights with the UAV platform and integrated sensors to be carried out in Portugal.

4.2 On-field Demonstration activities

Especially within the last 2 years of the project, demonstration activities involving the use of the sensors and samplers developed within NAUTILOS, will be carried out in several European regions. Demonstrations will also aim to develop new multidisciplinary and more comprehensive observational approaches involving the use of a wide range of conventional and non-conventional platforms and exploiting innovative and cost-effective methods to monitor key environmental settings and provide data for EU policy-related applications. Deployments and operations of the system will take place from shallow coastal waters to open and deep-sea sites, providing complete datasets for studying the marine ecosystem functions and advanced data products and tools. To improve the emerging approach of “Fisheries Observing Systems” (Van Vranken *et al.*, 2020), in the Adriatic Sea and the Bay of Biscay, the use of new generation specific sensors for key environmental variables related to fishery resources and specifically designed to be mounted on commercial fishing vessels will be demonstrated. A novel integrated “Aquaculture Observing System” approach will be trailed in coastal regions of Norway and Greece, based on sensors deployment within mariculture and fish farm plants but also FerryBoxes and

fishery research vessels operating in the areas. The data stream from underway sensor operations will be used to enable real-time event detection with an adaptive machine learning approach. New acoustic marine mammals monitoring systems will be deployed with the help of commercial fishermen in the Swedish Sound/Kullaberg/Lysekil waters and additional demonstrations will be carried out in the Portofino MPA cetaceans' sanctuary.

A network of FerryBoxes infrastructures operating in Coastal Norway, the Gulf of Finland and the Aegean Sea, covering a wide range of environmental parameters will be available for the demonstration of the sensors through the project and will also be used in combination unmanned aerial vehicles (UAVs) to apply data stream mining and concept change detection, leading towards automated, AI-based event- and anomaly-detection and comparisons with satellite data (phytoplankton bloom measurements/detection and other ocean colour related variables).

To demonstrate novel approaches to observe the ocean with multiple platforms combined operations and new technologies for augmented observatories, landers and autonomous vehicles equipped with the developed sensors will be deployed and tested in the POSEIDON integrated ocean observing infrastructure at the eastern Mediterranean (Perivoliotis *et al.*, 2017). To enhance the monitoring of the oceans in regions undergoing deoxygenation, a new generation of silicate sensors will be implemented onto ARGO profiling floats and demonstrated in the Mediterranean Sea.

To help better understand the animals' ecology, their habitats and the marine ecosystem in general, new animal-borne instruments (e.g., new DO sensors included in non-invasive animal tagging systems) will be demonstrated on sharks and manta rays in the Archipelago of the Azores and also outside of Europe on elephant seals in the Valdes Peninsula, Argentina. Hence, data collected in distinct regions will be shared with the wider community, such as via AniBOS.

Some of the products developed such as microplastics sensors and samplers and other tools and approaches, will also be demonstrated and applied in the context of Citizen Science Campaigns involving tourists, divers, volunteers, high school students etc.

5. CONCLUSIONS

5.1 Communication, dissemination and exploitation activities

Dissemination and communication activities focused on increasing the visibility of the project and its opportunities to science and industry will expand the reach and impact of the project in developing cross-disciplinary interactions.

NAUTILOS Project aims to establish synergies and collaborations for the European Strategy for Plastics in a Circular Economy (ESPCE) with current and past projects, initiatives, networks and relevant stakeholders. The ESPCE is one of the main blocks of the European Green Deal agenda and will also contribute to the Sustainable Development Goals (SDGs) of the 2030 EU Agenda. A series of Citizen Science activities planned in different countries will raise awareness and offer knowledge to society members willing to act as citizen scientists and participate actively in the monitoring and elimination of plastics. Field campaigns for the collection and identification of micro- and macro-plastics using traditional (e.g., sieving, filtering, density separation) and innovative methods (e.g., smartphone NIR scanner) will be organised. The Citizen Science data will be uploaded in graphical maps indicating locations and respective quantities of plastic litter data. Furthermore, the microplastic sensors and samplers that will be developed during the project will be presented during school campaigns and will also be the subject of Capacity Building Learning Labs focusing on early-career scientists and marine technicians. Concerning the exploitation strategy, the Key Exploitable Results (KERs) identified for the project will be closely monitored and incentivized with the support of the exploitation plan and the 10-year open access marine instrumentation roadmap to be developed during the project. Also, environmental and socio-economic impact assessments will help ensure sustainable and socially conscious development of the project activities.

5.2 Conclusion

The project will improve our understanding of environmental fluctuations and anthropogenic impacts connected with aquaculture, fisheries and marine litter. This will also complement and contribute to expanding European observation tools and services to obtain data collection at a much higher spatial

resolution, temporal regularity and length than currently available at the European scale, and further democratise the marine environment's monitoring to both traditional and non-traditional data users.

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