Project Information	
Project full title	EuroSea: Improving and Integrating European Ocean Observing and Forecasting Systems for Sustainable use of the Oceans
Project acronym	**EuroSea**
Grant agreement number	862626
Project start date and duration	1 November 2019, 50 months
Project website	https://www.eurosea.eu

Deliverable information	
Deliverable number	3.5
Deliverable title	ASV-Network structure and roadmap
Description	Report on ASV-Network structure and roadmap
Work Package number	3
Work Package title	Network Integration and Improvement
Lead beneficiary	PLOCAN
Lead authors	Andres Cianca and Carlos Barrera (PLOCAN)
Contributors	Joao Borges de Sousa (UPORTO), James Burris (NOC), Christoph Waldmann (UBREMEN)
Due date	31.10.2021
Submission date	23.11.2021
Comments	

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 862626.

https://doi.org/10.3289/eurosea_d3.5

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Executive summary

In-situ observations provide key information about the Ocean environment – its physical, biogeochemical, geological and ecological characteristics. To ensure the long-term stability of ocean information, the totality of the underlying in-situ ocean-observing system, comprising networks of different observing platforms and sensors, needs to be recognized as a critical global infrastructure.

Currently, there are numerous programmes, projects and initiatives working to develop and implement effective ocean observing capacities, operating at different geographical scales (local, national, regional, pan-European and international) and different timescales (real-time, daily, monthly, annually, etc). These capabilities are, by their nature, highly fragmented and complex. While there is some coordination at global level, for example under the auspices of GOOS and the OCG, a strengthening in coordination at regional scale is necessary to ensure that the right observations are made and that they are made on a systematic and sustained basis. An overarching strategy across all measurement platforms is required to ensure that best use is made of limited resources in Member States and at European level. The European Ocean Observing System (EOOS) links the currently disparate components of the observing system in Europe and will promote novel technology and infrastructure development, standardization, open access to data, and capacity building.

Autonomous and uncrewed systems have significantly improved and evolved in the last decades to provide a key platform for several sectors and domains, including ocean observing systems. Transition from research concept to commercial product and related services has not always been easy due to technology, business and policy framework constraints. Autonomous Surface Vehicles (ASV) development and implementation illustrates this evolution. Starting as small custom-prototypes operating near shore for survey and research applications, ASV have evolved into more complex and capable platforms that are now able to operate in highly demanding scenarios and the open-ocean for long periods in routine-fully-autonomous mode. This progress has paved the way for small and large-scale autonomous ships (MASS) to be used as an ultimate step in maritime autonomy.

Within the framework of in-situ ocean-observing technologies acting as recognized international network in support to global observing strategies, this initiative is aiming to engage key actors from the “triple-helix” perspective representing developers, industry, research, end-users and regulatory bodies to provide an overview on current trends in ASV technology, while seeking a baseline understanding of the sector from lessons learned and current status at technical, operational, data management and policy/regulatory levels to be used as the basis for a ASV Network implementation.

Technology developments enabling ASV include a multidisciplinary set of cutting-edge sensors and systems for measuring, sampling, guidance, navigation, control, telemetry, propulsion, path planning, as well as specific tools for oversight of operations and situational awareness, including key applications of machine/deep learning and artificial intelligence techniques. ASV capabilities and applications presently include a wide range of operations and services that address specific needs from marine and maritime sectors, highlighting ocean observing in both coastal and open-ocean areas, as well as providing unique features like monitoring at the same time Essential Climate and Ocean Variables in support to WMO and GOOS respectively or acting as gateway to link in real time underwater observations with satellite platforms.

The EU-funded EuroSea project provides a unique framework opportunity to define the basis and implement a recognized useful ASV Network in support to international ocean-observing initiatives such as GOOS or EOOS from a synergetic approach with already existing ocean-observing networks (moorings, floats, gliders, radars, FerryBox, tide-gauges, etc.).

1. Ocean Observing: Why a need?

The ocean is a key component of the Global Earth System influencing the global/regional climate, weather, ecosystems, living resources and biodiversity. The ocean plays a key role in many human activities such coastal protection, tourism, search and rescue, defense and security, shipping, aquaculture and fisheries, offshore industry, and marine renewable energy, among others. Ocean observation enables us to better understand ocean functions and meet societal needs related to these activities. The Intergovernmental Oceanographic Commission (IOC of UNESCO) developed the Global Ocean Observing System (GOOS) more than two decades ago to coordinate different national efforts in terms of sustained ocean observations throughout the world and to maximize the societal benefits of ocean observations. GOOS was established in 1991 by the Member States of the Intergovernmental Oceanographic Commission (IOC) of the United Nations Educational, Scientific and Cultural Organization (UNESCO), with the World Meteorological Organization (WMO), UN Environment, and the International Science Council (ISC) later joining as sponsors. Over the past quarter-century, the GOOS community and partners have worked in a good progress coordinating global ocean climate observing and information products and in supporting observations for operational forecast systems. More recently, GOOS has had a growing focus on an integrated global observing system including a wider range of data types and serving a broader range of users, consisted with the Framework of Ocean Observing. In 2012, the IOC General Assembly unanimously endorsed all the FOO recommendations. A new GOOS Steering Committee was established to replace the IOC Intergovernmental Committee on GOOS and its supporting GOOS Scientific Steering Committee. Three new recommended expert panels were formed, and the GRA Council was reinvigorated.

The resulting Framework for Ocean Observing has been widely endorsed by the ocean observing community and adopted formally by GOOS as a guiding document. In addition to its extensive recommendations on the design of an enhanced ocean observing system, the FOO made two recommendations on governance: (1) To simplify and strengthen the high-level governance of GOOS, establish a single, expertise-based Steering Committee reporting directly to the IOC officers and members; and (2) Establish two new GOOS Panels – for Biogeochemistry, and for Biology and Ecosystems, to complement the existing Observations of Ocean Physics and Climate Panel. (Tanhua et al., 2019)

The FOO argues that it is essential that governance of the global ocean observing system reflects the needs and contributions of both the broad ocean observing system community (scientists, institutions, observing system managers) and the IOC member states who should represent their national and collectively the international community's interests and users of ocean information. The FOO provides a structure that allows ocean observing providers and users to engage in the system at various points. It traces the path from Inputs (e.g., essential ocean variables) to Processes (observations and maintenance), to Outputs (data and products). It has helped form an understanding of the elements of the system as a whole and has facilitated the activities of GOOS in many areas. (Miloslavich et al., 2018)

The common language and system design principles introduced by the FOO are: (1) Essential Ocean Variables (EOVs); (2) Requirements; (3) Observing system elements; (4) Data management and information products;

(5) Readiness levels for requirements, observations, and data/information; (6) Incorporation of both coastal and open ocean observations; (7) Feedback loops addressing science challenges and social needs.

In the last two decades, discussions on GOOS highlighted the tremendous potential value for physical, biogeochemical, and biological observations, particularly in the transition between the open-ocean and the coastal environment, which is a key area for societal issues, economical applications and at the same time is a prime area for autonomous technologies' observations. (Lindstrom et al., 2012)

Figure 1. Schematic overview of the ocean observing system based on autonomous in-situ platforms retrieved from ATLANTOS project website.

In-situ observations provide key information about the ocean environment – its physical, biogeochemical, geological and ecological characteristics (Figure 1). They are essential to monitor critical aspects of the state, change, and variability of the subsurface Ocean, which comprises 97% by volume of the global biosphere, takes up and redistributes 93% of excess heat in the Earth system, and absorbs over 25% of all human-produced carbon emissions. (Lubchenco and Gaines, 2019)

To ensure the long-term stability of ocean information, the totality of the underlying in situ ocean-observing system, comprising networks of different observing platforms and sensors, needs to be recognized as a critical global infrastructure. This mostly publicly funded infrastructure generates openly accessible data as a global public good from which specific information products and knowledge are created to deliver direct and indirect benefits to society as a whole by informing public policy, governance and business decisions. Such infrastructure needs a strong mandate, including a legal basis to secure binding commitments in a sustained way and in accordance with international standards, including an appropriate data policy for open access and sharing of data. National observing systems and roadmaps should be better aligned and deeper cooperation with regional governing bodies is needed. The required growth of the system urgently needs to be matched with more innovative, holistic and integrative thinking about how to sustainably finance and coordinate these observations.

Autonomous platforms are making measurements over a wide array of spatial and temporal periods is a more efficient and sustainable way than traditional ship-based technologies. Observations range from large-scale processes to small-scale variabilities in salinity, temperature, nitrate, pressure, oxygen, biomass; and many other parameters, depending on the needs of the user. Autonomous technologies for ocean observations in use today include aerial, surface, and subsurface vehicles, satellites, buoys, subsea moorings, and bottom nodes. Observation systems can use any or all of these elements. True autonomy is still unavailable; all these observation systems still require a significant deal of human interaction and support. The largest platforms now support payloads that many years ago would have required manned research vessels. These platforms are still quite expensive and complex. Conversely, systems of numerous, small, and inexpensive observing platforms can increase spatio-temporal coverage, but only for a limited number of ocean variables because small size and limited power implies a limited scientific payload.

Sustained, long-term global in-situ Ocean observations are required to support climate and environmental policies, i.e. the European Green Deal, and policies aiming to reach net zero carbon, achieve a sustainable blue economy, protect nature, and reverse the degradation of ecosystems. They are crucial for discovering unexplored parts of the ocean, and to better observe, monitor and predict the physics, chemistry, biology and geology of the ocean from global to coastal scales. This is needed to better understand and predict climate change and its impacts on global Ocean ecosystems, increase resilience, develop sound mitigation and adaptation strategies to natural and man-made hazard impacts, and better protect marine ecosystems, among many other uses. These benefits are linked to the need to protect biodiversity, ensure a healthy ocean and allow a sustainable use of marine resources, which rely on biological observations and need further efforts to be fully integrated into the global ocean-observing system. They generate baseline knowledge informing ocean governance, ocean economic opportunities, and sustainable development. In-situ Ocean observations are also pivotal to improve weather predictions, predict extreme events such as Harmful Algal Blooms, and inform tsunami warning systems, among many others. (European Marine Board, 2021)

Globally, meteorological services are driven by a primary purpose: to deliver weather forecasts to protect lives, property and livelihoods. A report on the value of surface-based meteorological observations (including at the sea surface) makes the case for the development of the Global Basic Observing Network, indicating that this could generate more than USD $5 billion annually, with a benefit-to-cost ratio of 25. As weather and climate predictions extend further into the future, sub-surface Ocean observations will be increasingly necessary. National weather prediction services are coupling atmospheric models to Ocean models – because heat energy that fuels weather systems is stored in the subsurface. The impact of ocean observations on future weather predictions will therefore require close partnering with meteorological services. (Fujii et al., 2019)

Operational oceanography systems such as the Copernicus Marine Environmental Monitoring Service (CMEMS) integrate in-situ and satellite observations with model predictions to provide a wide range of Ocean services with large socioeconomic impacts such as for maritime transport, fisheries and aquaculture, oil and gas, and marine renewable energy.

Although the benefits of ocean-observing are difficult to comprehensively identify and value, a high benefit-to-cost ratio for investing in ocean-observing has been described in several case studies. However, more work needs to be done to value the social, economic and environmental benefits of ocean-observing, as many of the societal benefits are also associated with improved science and therefore do not have a readily measurable economic value. It is indisputable that it is necessary to invest in in-situ observations and satellite constellations to have reliable systems to enable ocean predictions.

Rapid technological innovations that have reached certain maturity and reliability have made systematic, sustained ocean measurements possible that would not have been achievable two decades ago. However, the institutional and funding landscape are yet to catch up with the technological innovations that have made sustained ocean-observing possible. Each country has its own national landscape of institutions responsible for ocean observations: meteorological agencies, ocean agencies, the navy, national research agencies, research councils, environmental agencies, national laboratories and academic institutions all play a role. This situation has led to fragility, in particular on the product side of the ocean-observing value chain. More coherent governance, a better-defined core mission, together with a more strategic approach to evolve the observing system would enable more sustained funding to continually observe the ocean in a smarter and sustainable way.

2. Autonomous Surface Vehicles Technology: An Overview

2.1. Introduction

All manner of “water-going” platforms have been by far the first sophisticated machines developed by humans. As a key element of exploration, commerce and war, ships have always involved engineering solutions to difficult problems and talented humans to build and operate them. For thousands of years sailors have placed their trust, and their lives, in constructions of wood, then steel, in the face of a challenging ocean. It could be said that the age of “autonomy” has been slow to come to ships. But this is changing. Nowadays there are many small and medium-size unmanned boats in routine-use paving the way toward fully autonomous vessels as ultimate step in this sector.

Many institutions, universities and companies have begun developing Autonomous Surface Vehicles (ASV) aiming to cover a wide range of applications and services, evolving rapidly (Figure 2). With growing worldwide interest in commercial, scientific, and military issues associated with both open-ocean and shallow waters, there has been a corresponding growth in demand for the development of more complex ASV with advanced guidance, navigation, and control (GNC) functionalities. The development of fully-autonomous ASV is underway aiming to minimize both human control needs and the effects to the effective and reliable operation from human errors. (Campbell et al., 2012)

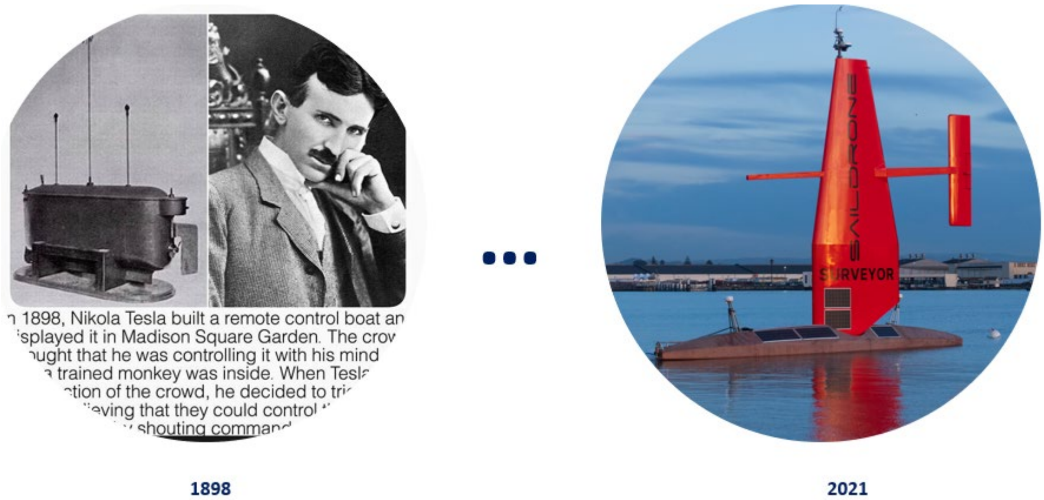

Figure 2. On the left, the first prototype of ASV developed by Nikola Tesla in 1898. On the right, a current ASV manufactured by Saildrone company.

ASV are defined as unmanned vehicles which perform tasks in a wide range of environments without any human intervention with highly nonlinear dynamics. Further improvements on ASV technology are expected to bring tremendous benefits, such a lower development and operation cost, improved staff safety, extended operational range and precision, greater autonomy, as well as increased flexibility in sophisticated environments and dangerous missions (Roberts et al., 2006; Bertram, 2008; Breivik, 2010). With the inclusion of a more robust, commercially available and affordable navigation equipment (GPS, IMU, etc.), wireless telemetry systems, "blue" power sources and trending intelligent-analytics technologies such artificial Intelligence, machine/deep learning, etc. (Nilsson, 1982; Michalski et al., 1983; Marichal et al., 2001; Matia et al., 2014), the applications range for ASV has significantly increased and improved in key domains and sectors such as scientific research, environmental missions, ocean exploration, military uses and other applications (transportation, communication relays, refuelling, unmanned aerial or unmanned underwater vehicles platform, etc.) (Marichal et al., 2016; Barrera, 2019). (Table 1)

Table 1. USV development from 1985 to date (Liu et al., 2016)

Country	Year	USV Name	Research Purpose & Major Achievements
USA	1993	ARTEMIS (Vaneck et al., 1996)	1) Systems test; 2) Bathymetry sampling
	1996	ACES (Manley, 1997)	1) Oceanographic data collection
	1998	SCOUT (Goudey et al., 1998)	1) Cooperative control; 2) Testbed
	1990*s*	Roboski (Bremer et al., 2007)	1) Surveillance; 2) Target drones
	1990*s*	Owls USVs (Motwani, 2012)	1) Harbor and ship security
	2000	AutoCat (Manley et al., 2000)	1) Survey of shipwreck
	2001	Spartan Scout (Motwani, 2012)	1) Port surveillance; 2) Force protection
	2003	USSV-HTF (Motwani, 2012)	1) Towing various sensors and effectors
	2005	WASP (Mahacek, 2005)	1) Stability test; 2) Bathymetric mapping
	2005	Seadoo Challenger 2000 (Ebken et al., 2005)	1) Collision avoidance; 2) Autonomous recovery
	2005	HUSCy (Curcio et al., 2005)	1) Hydrographic survey
	2008	Wave Glider (Bingham et al., 2012)	1) Data collection
	2008	Nereus (Beck et al., 2009)	1) Stability test; 2) Bathymetric mapping
	2009	SeaWASP (Furfaro et al., 2009)	1) Environmental monitoring; 2) Testbed
	2010	Piranha (Yang et al., 2011)	1) Reconnaissance
	2011	MUSCL (Bertram, 2008)	1) Surveillance and reconnaissance
UK	1990*s*	MIMIR (Roberts & Sutton, 2006)	1) Shallow water search and survey
	2000*s*	C-series USVs (Anonymous, 2014a)	1) Assets security; 2) Environmental monitoring; 3) Mining
	2000*s*	FENRIR (Roberts & Sutton, 2006)	1) Relay between UUV and control center
	2000*s*	Sentry (Murray, 2008)	1) Harbor and shore survey and protection
	2003	SWIMS (Roberts & Sutton, 2006)	1) Mine sweeping
	2003	SeaFox (Yakimenko & Kragelund, 2011)	1) Maritime security operations
	2004	Springer (Naeem et al., 2008b)	1) Environment monitoring; 2) Test platform
	2008	Blackfish (Sonnenburg, 2012)	1) Harbor protection and patrol
Canada	1983	DOLPHIN (Curcio et al., 2005)	1) Bathymetric mapping
	2000*s*	Barracuda (Bertram, 2008)	1) As sea-surface target system
	2000*s*	Hammerhead (Bertram, 2008)	1) Simulating a multi-vehicle swarm threat
Italy	2004	SESAMO (Caccia et al., 2005)	1) Environmental sampling
	2005	Charlie (Caccia et al., 2007)	1) Environmental sampling and survey
	2007	ALANIS (Bibuli et al., 2012)	1) Environmental sampling and survey
	2008	U-Ranger (Motwani, 2012)	1) Mine sweeping; 2) Harbor protection
Portugal	2000	CARAVELA (Pascoal et al., 2006)	1) Oceanographic sampling; 2) Testbed
	2004	DELFIM (Alves et al., 2006) and DELFIMX (Gomes et al., 2006)	1) Oceanographic sampling; 2) Communication with UUVs
	2006	ROAZ I & II (Martins et al., 2007a)	1) Search and rescue
	2006	Swordfish (Ferreira et al., 2007)	1) Environmental survey
Norway	2008	Kaasbøll (Breivik et al., 2008)	1) Navigation and control systems test
	2008	Viknes (Breivik, 2010)	1) Multi-purpose system tests
	2000*s*	Mariner (Breivik, 2010)	1) Environmental surveillance and sampling
Israel	2003	Protector (Breivik et al., 2008)	1) Reconnaissance; 2) Counter-mine
	2005	Seastar (Yang et al., 2011)	1) Port, coastal survey; 2) Reconnaissance
	2005	Stingray (Bertram, 2008)	1) Homeland security and coastguard
	2007	Silver Marlin (Bertram, 2008)	1) Surveillance and reconnaissance
Germany	1998	MESSIN (Majohr & Buch, 2006)	1) Water ecological study
France	2005	Basil (Bertram, 2008)	1) Offshore pipelines survey
	2005	MiniVAMP (Bertram, 2008)	1) Remote survey of offshore pipelines
	2007	Inspector (Yang et al., 2011)	1) Surveillance and reconnaissance
Sweden	2002	Piraya (Yang et al., 2011)	1) Cooperative control
Singapore	2010	Venus (Bertram, 2008)	1) Multi-tasks test
China	2008	Tianxiang One (Yan et al., 2010)	1) Meteorological survey
	2010	USV-ZhengHe (Yang et al., 2011)	1) Inshore marine data collection
Japan	2000	Kan-Chan (Desa et al., 2007)	1) Study of global warming
	2004	UMV series (Bertram, 2008)	1) Ocean and atmosphere exploration
India	2006	ROSS (Desa et al., 2007)	1) Oceanographic sampling

An ASV is, by definition, an unmanned vessel that operates on the sea surface without real-time input or control from human operators (Bratić et al., 2019). This platform can be equipped with many of the same sensors as an AUV. Pre-planned mission paths, often following a 'lawn-mowing' pattern, are transmitted to the ASV and, once it is in the water, the AUV will navigate to the first monitoring location, conduct the entire mission, and then return to its starting point. The ASV is always at the surface, therefore, it can constantly maintain a GPS fix, eliminating the need for dead-reckoning navigation as used by AUVs. ASVs can range from small platforms that carry only one sensor, to large vessels greater than 10 m in length that carry comprehensive sensor suites. Differences in propulsion, as with AUVs, are also seen in different types of ASVs. Some ASVs are propelled solely by wind like a sailboat, some use rechargeable batteries, while others are propelled using fuel.

2.2. ASV Technology: Main Developments and Milestones

Through the last two decades, several ASV developments have been undertaken through public and private initiatives with diverse scope and purpose (Manley, 2008; Motwani, 2012; Verfuss et al., 2019). After clearly experimental first steps with limited capabilities in terms autonomy, endurance, payload, power outputs, etc., in recent years significant progress has been made in all ASV subsystem components (hull and structural elements, propulsion and power system, GNC, telemetry, payloads, data management and ground station), enabling ASV a leading commercial technology solution in several applications and services (some on a routine basis) beyond the military and research (Fossen, 1994; Caccia, 2006).

The initial reference on the path to autonomous ships is technical (Lambert et al., 2007; Fossen, 2011; Bibuli et al., 2012). The core technologies that enable unmanned vessels have come about largely due to developments in other fields (Bremer et al., 2007; Ferreira et al., 2007; Martins et al., 2007; Cruz et al., 2008). Improved ASV capabilities allow to undertake missions both in coastal and open-ocean areas for long periods of time due to a more efficient power and propulsion systems based in some cases on renewable energy sources (solar, wind, waves). State-of-the-art broadband telemetry systems enable remote real-time operation and decision-making by the operator. In parallel with the mechanical and electronic system architecture improvements for ASVs, software advanced rapidly as well, with special focus on autonomous navigation methods and techniques in compliance and contribution to ocean digitalization and e-navigation framework initiatives.

While small ASV developments are usually deployed within sight of the operator there are many others that go further (Figure 3). Considering hull dimension and propulsion system as classification factors, several flag-ship developments have been released in the last decade, highlighting Sailbuoy (Offshore Sensing, Norway) tested as pre-commercial solution at PLOCAN open-ocean observatory in 2012 (Fer and Peddie, 2012); Wave Glider (Liquid Robotics, USA) robust enough to complete a crossing of the Pacific Ocean from California to Australia (Hine et al., 2009; Daniel et al., 2011); AutoNaut (Autonaut-Seiche, UK) performed trials at PLOCAN test-site waters for marine mammal monitoring (Johnston and Poole, 2017); C.-Enduro (L3 Harris, UK); the Saildrone (Saildrone, USA) able to perform long-range missions such circumnavigate the Antarctica and ATL2MED (Zhang et al. 2019; ATL2MED-ICOS Saildrone Mission, 2019); DriX (iXblue, France) with specific applications on routine off-shore survey-services for industry (iXblue-DriX USV, 2018); Mayflower (MARS, 2015) expecting to sail between Plymouth-Cape Cod (MA, USA); Sphyrna (SeaProven, France) that focusses on passive acoustic monitoring applications (SEAPROVEN, 2015); XO-450 (Xocean, UK) mainly addressed for energy and seabed mapping commercial survey services (XOCEAN XO-450, 2018); SeaTrac (USA) and SeaSats (USA); S10-submaran (Ocean Aero, USA) as hybrid concept able to both sail the ocean surface and glide the water-column as underwater vehicle (OCEAN AERO S-10, 2015); GPASEABOTS (GPA, Spain); etc. among other existing ASV technologies.

Figure 3. Several ASV technologies already available for using in science and industry services.

All of them are fully or partially powered by endless ocean-energy sources. In parallel, half-way to autonomous ship concept, developments such Sea-KIT and Ocean Infinity have also been released for specific seabed-mapping and survey-services in industry applications at ocean-basin level worldwide. These developments, many of them already commercial, demonstrated that specialty ASV could withstand the harsh ocean environment for extended periods and their software and systems were reliable enough for extended voyages and missions.

The current global trend on autonomy developments in mobility seems to be widely yet accepted by the maritime community, primarily due to budgetary issues. Up to date, autonomous and remotely operated platforms at sea have been mainly used as carriers of sensors and other measuring devices mainly addressed to oceanography, hydrography and off-shore applications in near-shore, controlled test-site areas or outside shipping routes. However, nowadays we are facing a step further towards a new paradigm associated with cyber-physical systems, big data and autonomy as part of Shipping 4.0 and Digital Ocean international trends and strategies (Figure 4). Efforts in transport cost reduction, the global need of minimize emissions and the demand for improving safety at sea are three base reasons on why autonomous shipping is under consideration and early stages of implementation (Burmeister et al., 2014; Remote and Autonomous Ships-The Next Steps, 2016; Rødseth, 2017; Munim, 2019).

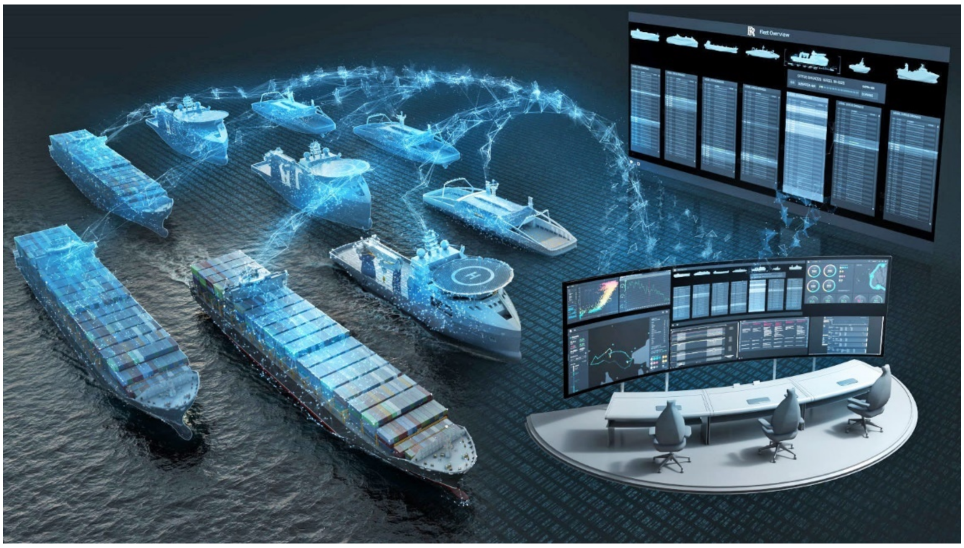

Figure 4. A schematic view for the new ASV developments associated with the cyber-physical systems and the big data.

Under these premises, the development and future implementation of vessels as MASS (Maritime Autonomous Surface Ship) by IMO will represent an inflexion point for the paradigm shift in the industry and maritime shipping system as a whole (Poikonen et al., 2016; Wróbel et al., 2017; Kim et al., 2020; Wright, 2020). Therefore, for a successful and smooth settlement of MASS as well as the relevant infrastructures in the maritime sector, key aspects related to autonomous shipping and their impact on technology, regulation and societal aspects should be envisaged (Autonomous and Remotely Operated Ships, 2020; Gu et al., 2020; Guidelines for Autonomous Shipping, 2021).

From the purely technology perspective, ships should be built with enhanced control capabilities, broadband telemetry, graphic interfaces, complex sensor payloads, etc. to be operated by means of remote land-based or off-shore services (Komianos, 2018). However, the technology replacing manning needs to re-shape the crew in terms of safety, efficiency and environmental protection. On the industry side, MASS is expected to change shipbuilding and equipment, as well as shipping protocols and port infrastructures. Industries related to high specialized technology base sectors such autonomy and automation, unmanned operations, big data, artificial intelligence, machine learning, enterprise-grade connectivity and analytics will be essential.

Therefore, despite the rapid development of science and technology in the ocean industry, ASV indisputably need to be subject to the international regulations necessary for the vessels to operate safely across nations and even the seabed areas beyond national jurisdiction. Although some regulatory aspects of manned vessels may be compatible with unmanned vessels, such as certain clauses of the International Safety Management (ISM) Code, there is a need for specific international regulations considering the characteristics of unmanned vessels as well. While technology and market push are required for any innovation to take hold, regulation aspects become a major consideration. This is especially right in the case of ASV developments, where certain key developments can be noted as advancing the field.

During the period of roughly 2000-2010 early work on software and algorithms to enable unmanned vessels to adhere to the COLREGs (Convention on the International Regulations for Preventing Collisions at Sea) began including the launch of the ASTM Committee, designed to develop technical standards for unmanned maritime vehicles, including a sub-committee for regulatory issues. This catalysed further policy developments. The Association for Unmanned Systems International (AUVSI) began to engage the issue through their Maritime Advocacy Committee in 2011. A particular focus was informing and engaging the U.S. Navigation Safety Advisory Council (NAVSAC). This body informs the U.S. Coast Guard, the relevant regulator for U.S. Waters. Through a series of meetings this work eventually resulted, in late 2012, in a resolution offering advice on both technology solutions, such as use of the automated identification system (AIS) and policy steps, such as amendments to certain COLREGs (Karlis, 2018).

The UK's industry group, Maritime UK, launched an effort to develop voluntary best practices for unmanned vessels, though they referred to them as maritime autonomous systems (MAS). The first version of the UK Industry Code of Practice focused mainly on technical aspects such as design and construction of MAS. The UK Maritime Autonomous Systems Regulatory Working Group (MASRWG) released this first document in 2017. While the guidance in the first version of the code was for design, construction, and operation, it was heavily focused on design and manufacture. Seeing significant growth in the autonomous systems the MASRWG updated the Code of Practice to increase focus on the ASV operations, with firstly guidance on skills, training and platform's registration (First Unmanned Vessel Joins UK Ship Register, 2019; Maritime Autonomous Surface Ship UK Code of Practice, 2020).

A multidisciplinary group of Spanish research centres, companies and public agencies, under the coordination of DGMM (General Directorate of Marine Merchant) are joining forces since late 2020 in order to setup a working group on autonomous maritime navigation, aiming to setup the right national framework to develop and operate ASV and autonomous ships that currently are under development becoming PLOCAN an active partner providing both test-site capabilities and owner of the first autonomous boat flagged in Spain.

3. The meaning of Ocean Observing Network

Several organisations and initiatives (EuroGOOS, EOOS, OCG, ERICs etc.) at international level are promoting and attempting to sustain ocean observing networks somehow through different initiatives, approaches, and level of commitment from their members (working groups, task teams, etc.) In this context, key references could be ARGO, EMSO, Ocean-Gliders, OceanSites, EuroGOOS, among others.

The GOOS Observations Coordination Group (OCG) coordinates across the major, sustained, global oceanographic and marine meteorological observing networks. The requirements for ocean observations are expanding and new technologies, variables, platforms, and networks are being developed, deployed and measured (Figure 5). Observing networks need sufficient maturity and scale to engage with OCG and the coordination towards supporting GOOS and GCOS (OCG-Observations Coordination Group, 2018).

Networks may not fulfil all attributes; however, these can act as a roadmap to help guide development towards achieving the elements that OCG has understood make networks of global scale effective, productive, engaged and responsive members of the GOOS.

Within OCG, one of the funding coordination groups is the Data Buoy Cooperation Panel (DBCP) that presently coordinates the network of over 1,250 drifting buoys and around 400 moored buoys all collecting so called "metocean" data and in real time. DBCP also includes an ASV pilot activity "Evaluation of Unmanned Surface Vehicles" (https://www.ocean-ops.org/dbcp/overview/evaluation_usv.html). The primary interest of the DBCP community is on the potential of Autonomous Surface Vehicle (ASV) platforms for collecting meteorological and oceanographic data from the oceans. It will be a key activity of the EuroSea task 3.5 to closely coordinate with DBCP for joint operations.

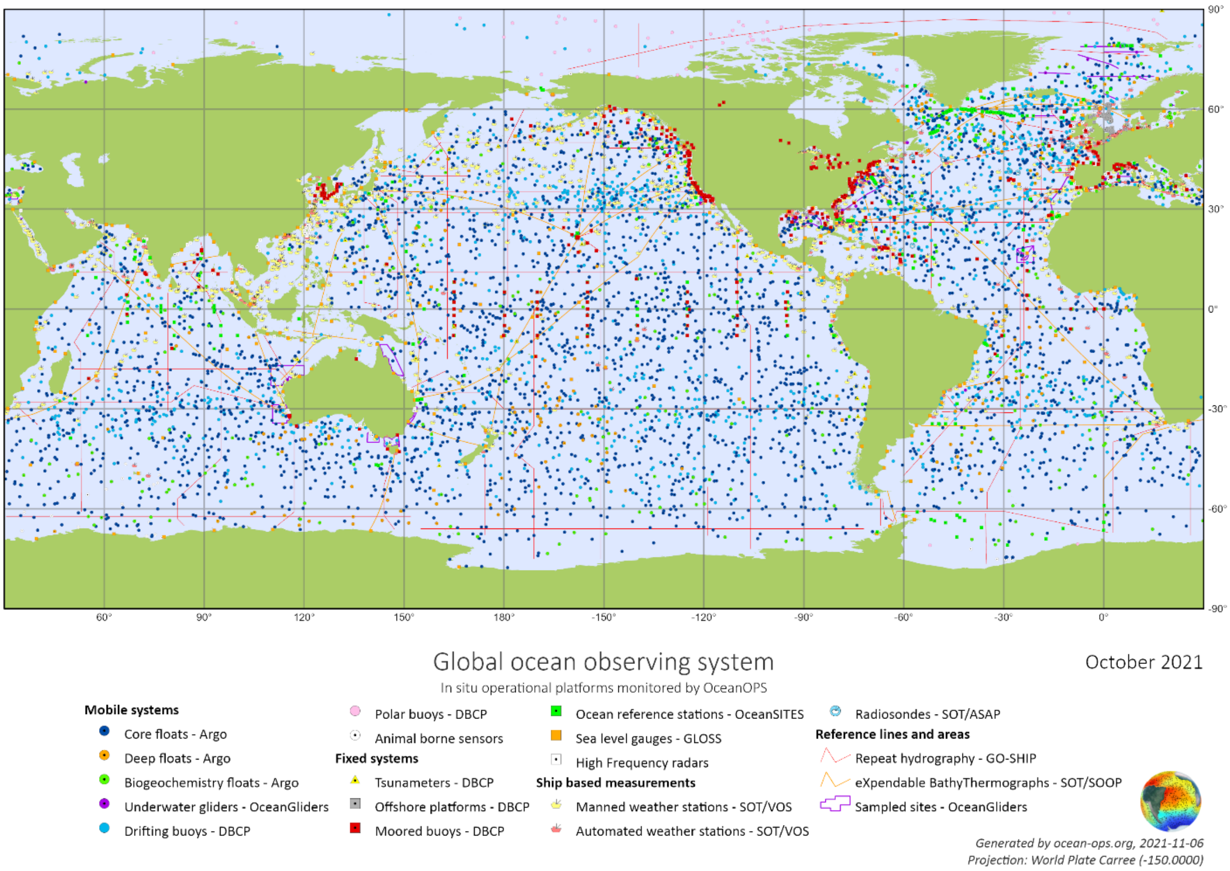

Figure 5. A global view of the observational coverage from the different ocean-observing platforms at OceanOPS portal.

3.1. Network Attributes

Some of the main attributes of a network framework provided by OCG in the GOOS Report N.266:

- Global in scale (greater than regional and, as far as possible, intention to be global)
- Sustained over multiple years, beyond the timespan of single research projects
- Coordinates a community of best practice and governance, i.e. a means of developing multi-year strategy, implementation standards and development plans
- Data are free, open and available in a timely manner, i.e. a data management infrastructure that delivers interoperable/inter-comparable data in real-time, or with minimal delay, through internationally recognised data centres or services
- Contributes to meeting requirements for one or more Essential Ocean Variables or Essential Climate Variables
- Defined observation mission/s and implementation targets, such that a role in the GOOS is defined and progress towards targets can be supported

- Agreed to develop, update and follow best practices to ensure consistent delivery of observational data (from deployment to delayed mode quality control). These best practices should be documented, utilised by members and consist with other OCG networks
- At least development stage 'Pilot' in technological readiness level in all aspects of the Framework for Ocean Observing and WIGOS Observing System Network Design Principles, with a roadmap towards maturing

3.2. Benefits for Networks

OCG coordination supports cross-network observing planning towards global integrated requirements, builds on synergies, supports technology and best practice transfer, provides visibility to the global network, a common voice and supports network development towards common objectives. Benefits include:

- Visibility as part of the integral global observing system i.e. OceanOPS Report Card.
- Support for sustainability through demonstrated global role.
- Technical support and coordination for network monitoring, reporting and deployment coordination through OceanOPS as a global service.
- Support in areas of coordination, including standards and best practices, new technology adoption, deployment opportunities, open data availability, network development, etc.
- Opportunity to provide feedback into GOOS/GCOS development and representation at the global level with IOC, WMO, GOOS, GCOS for issues of relevance, i.e. EEZ, etc.
- Support for Capacity building activities?? (via IOC or OBP).
- Integration into WIGOS (optional).

3.3. Commitment

Main derived commitments for a globally accepted observation coordination network:

- Participation in GOOS OCG annual meetings, quarterly calls and actively contributing to and supporting the implementation of the OCG proposed cross-network activities
- Provision of network metadata information to OceanOPS and of routine updates on the status and evolution of the network, i.e. for the Ocean Observing System Report Card.
- Support the monitoring of the overall system status, progress, data flow, and development through OceanOPS (depending on financial contributions)
- Coordinate with and support the activities of other networks

3.4. Process to become a partner network

Main steps or stages that define the procedure:

- It will be a key activity of the EuroSea task 3.5 to closely coordinate with DBCP for joint operations. DBCP is already an OCG network and all integration of ASV could theoretically be processed through DBCP.
- If it can be demonstrated that ASV cannot be sufficiently accommodated by DBCP as a subproject the ASV community may wish to establish its own network. The network then would need to outline its status, a justification why DBCP is not the "home of choice" and its project and implementation plan. This plan shall be brought to the attention of OCG directly via the secretariat or IOC/UNESCO GOOS Program through the global working groups i.e. GOOS Panels and GRAs, WMO or GCOS, or may approach directly GOOS.

- A "review" by OCG is undertaken to assess that the network meets sufficient criteria and an operation within DBCP is not feasible. Networks who do not meet all criteria but have plans to address deficiencies can be provisionally designated an 'emerging' OCG network and recommendations for network improvements will be given by the OCG.
- Formal acceptance of emerging networks is reviewed/approved by OCG
- Progress of emerging networks is reviewed annually until such time the network is fully accepted and/or the OCG determines the network is not making progress and removed from consideration.

4. ASV Network contributions to EOOS Strategy

International coordination takes place through the Global Ocean Observing System (GOOS). However, the existing coordination at the global level needs to be supported by clear regional, national and local arrangements, with connections between those coordination structures based on common methods and practices to ensure compatibility and interoperability across scales. Today, GOOS is organised around globally coordinated regional observing systems, and a heterogeneous set of regional alliances established around regional groupings of nations (GRAs) with common interests, such as EuroGOOS for Europe.

Currently, there are numerous programmes, projects and initiatives working to develop and implement effective ocean observing capacities, operating at different geographical scales (local, national, regional, pan-European and international) and different timescales (real-time, daily, monthly, annually, etc). These capabilities are, by their nature, highly fragmented and complex. While there is some coordination at global level, for example under the auspices of GOOS and OCG, a strengthening in coordination at regional scale is necessary to ensure that the right observations are made and that they are made on a systematic and sustained basis. An overarching strategy across all measurement platforms is required to ensure that best use is made of limited resources in Member States and at European level.

EOOS is a coordinating framework designed to align and integrate Europe's ocean-observing capacity, promote a systematic and collaborative approach to collecting information on the state and variability of our seas, and underpin sustainable management of the marine environment and its resources. Specifically, what EOOS does is:

- Align and connect existing initiatives to ensure efficiency and value for money.
- Identify gaps in the European observing capacity and foster initiatives to fill those gaps.
- Promote observing capacities which can benefit multiple sectors including research, policy, management and industry.
- Ensure that European ocean observing is integrated into the global observation system(s) by providing a focal point for interaction with international programmes and partner initiatives outside of Europe.

EOOS can help add value to existing observing efforts, empowering those who are already working to advance ocean observing in Europe, and catalysing new initiatives in a strategic way, targeting identified gaps and communicating progress to a wide range of stakeholders. EOOS will act as a framework to bring the community together to set priorities and act as a single, well-organized voice for Europe, as well as facilitating the exchange of best practice and capacity within Europe.

EuroGOOS Task Teams are operational networks of observing platforms. They promote scientific synergy and technological collaboration among European ocean observing infrastructures. Task Team members exchange open-source tools, collaborate in areas of common interest, and jointly make European data available to the EuroGOOS ROOS regional data portals, which in turn are feeding data to EMODnet and Copernicus Marine Service (CMEMS).

The following Task Teams are currently coordinated by EuroGOOS: FerryBox; Tide gauges; Gliders; HF radars; floats (Euro-Argo); Fixed platforms.

Task Teams are important operational components of the EOOS framework setting out a vision and coordination mechanisms for a truly integrated ocean observing in Europe, for the benefit of society, Science and innovation. Task Teams work to:

- Coordinate the existing efforts of the individual observation communities.
- Provide an up-to-date picture of the reporting platforms in Europe.
- Facilitate development of common operational data procedures and services (incl. data quality control and data management).
- Foster scientific and technological development, joint programmes and concerted actions, enhancing the European marine infrastructure capacity.

In compliance with the organizational and functional structure already implemented for the set of the main ocean-observation networks, it is intended to establish the new ASV Network, considering at the same time the particularities and specific capabilities of this technology aiming to contribute synergistically to cover current gaps.

5. First EuroSea ASV Workshop: Brief summary

5.1. Workshop Motivation

ASV-Network definition and roadmap addressed to cover current and future user's needs, including access to infrastructures, community roadmap monitoring, promoting knowledge exchange, enhancement, and partnership worldwide with the establishment of an ASV User Group. Improvements on Standard Operating Procedures (SOP) for derived Best Practices (BP) implementation on operational protocols, data management, knowledge transfer, risk assessment, legislation, etc. to properly improve the ASV technology, contributing to the EOOS implementation plan.

Two workshops (WS) have been planned within the framework of EuroSea aiming at ASV technology status, applications, synergies, challenges, opportunities, member engagement, Best Practices and roadmap definition and implementation.

5.2. Workshop Attendees and Agenda

The first WS was held online (5th and 6th October 2021) despite efforts -including two postponements- in order to be able to carry it out in person. Despite difficulties, the 1st WS was successful and very fruitful in terms of engagement from potential members of the ASV network from industry, academia, science community, agencies and policy framework from worldwide (Figure 6). In terms of convening capacity, considering that the WS registration was only under invitation, 117 people were finally registered, of which 24 were speakers.

Figure 6. Dissemination call for the 1st ASV workshop held on October 2021.

The two days WS agenda (Figure 7) were divided in 4 thematic sessions: (1) Technology status and overview, (2) Applications and Operations, (3) Regulatory Framework and (4) Best Practices and Roadmap definition.

Day 1

2:00 PM	Welcome + Workshop goals	Carlos Barrera (PLOCAN)
2:10 PM	EuroSea Project Overview	George Petihakis (HCMR)
Session 1 - ASV Technology		
2:20 PM	Offshore Sensing	David Peddie
2:30 PM	AutoNaut	Sarah Haesman
2:40 PM	GPASeabots	Pau Guasch/Adria Fradera/Daniel Sanchez
2:50 PM	iXblue	Guillaume Eudeline
3:00 PM	UTEK	Cesar Martinez
3:10 PM	SeaSats	Mike Flanigan / Declan Kerwin
3:20 PM	Saildrone	Andy Ziegwied
3:30 PM	Panel Discussion	All attendees
3:45 PM	Break	
Session 2 - ASV Applications /Operations		
4:00 PM	UEA	Karen Heywood
4:10 PM	GEOMAR	Bjorn Fiedler
4:20 PM	XOCEAN Ltd.	Michael Huskilson
4:30 PM	Tidewise	Rafael Coelho / Sylvain Joyeux
4:40 PM	Ocean Infinity	Ramsay Lind
4:50 PM	Saildrone	Andy Ziegwied
5:00 PM	NOAA	Christian Meinig
5:10 PM	MARUM	Christoph Waldmann / Sebastian Meckel
5:20 PM	SEAPROVEN	Antoine Thebaud
5:30 PM	Panel Discussion	All Attendees
5:50 PM	Wrap up and closure	Carlos Barrera

Day 2

2:00 PM	Welcome + Session goals	Carlos Barrera (PLOCAN)
2:05 PM	EOOS Overview	Inga Lips (EuroGOOS)
Session 3 - ASV Regulatory Framework		
2:20 PM	National Oceanography Center	Roland Rogers
2:40 PM	DGMM / MITMA	Hernan del Frade
3:00 PM	XOCEAN Ltd.	Michael Huskilson
3:15 PM	NOAA	Chris Meinig
3:30 PM	LSTS FEUP	Joao Tasso / Sergio Ferreira
3:40 PM	Panel Discussion	All attendees
3:50 PM	Break	
Session 4 - Best Practices and ASV Network Roadmap Definition		
4:00 PM	Ocean Best Practices (OBPS)	Jay Pearlman /Johannes Karstensen
4:20 PM	EMODNet	Patrick Gorringe
4:40 PM	iXblue	Guillaume Eudeline (TBC)
4:50 PM	NOAA	Andy Chiodi
5:00 PM	MARUM	Christoph Waldmann
5:20 PM	Panel Discussion	All Attendees
5:40 PM	Next steps - AOB	Andres Cianca
5:50 PM	Wrap up and closure	Carlos Barrera

Figure 7. Agenda and speakers list of the 1st ASV workshop for Day 1 and Day 2.

Some highlights (from Figure 8 to Figure 30) from presentations are as follows:

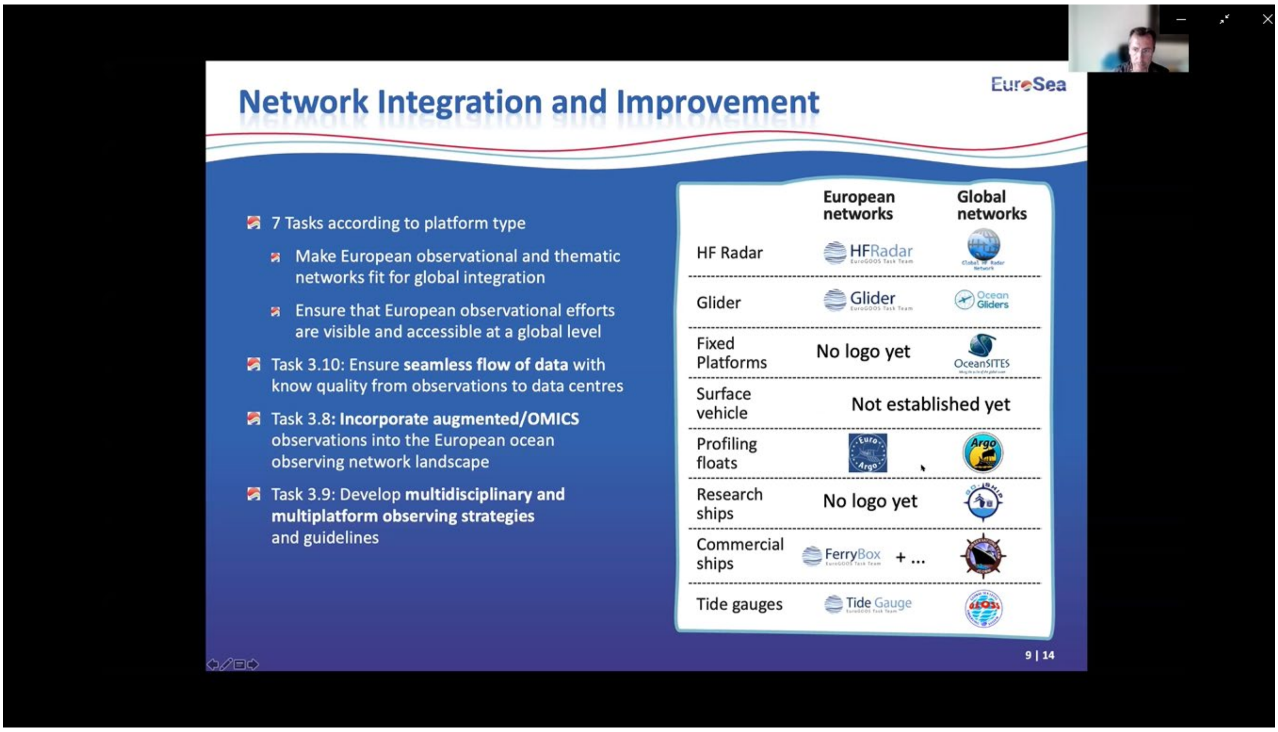

Figure 8. Overview and status of main EU and Global Observing Networks.

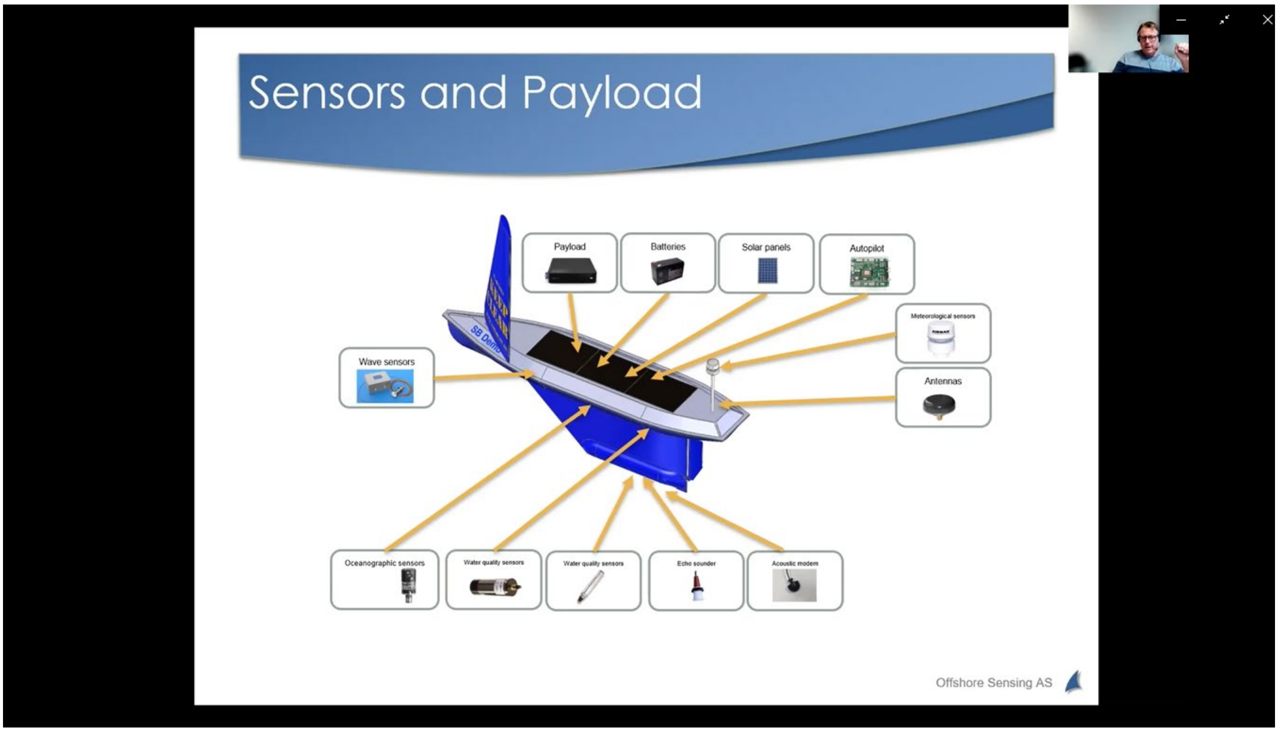

Figure 9. Sailbuoy ASV technology architecture developed by Offshore Sensing company.

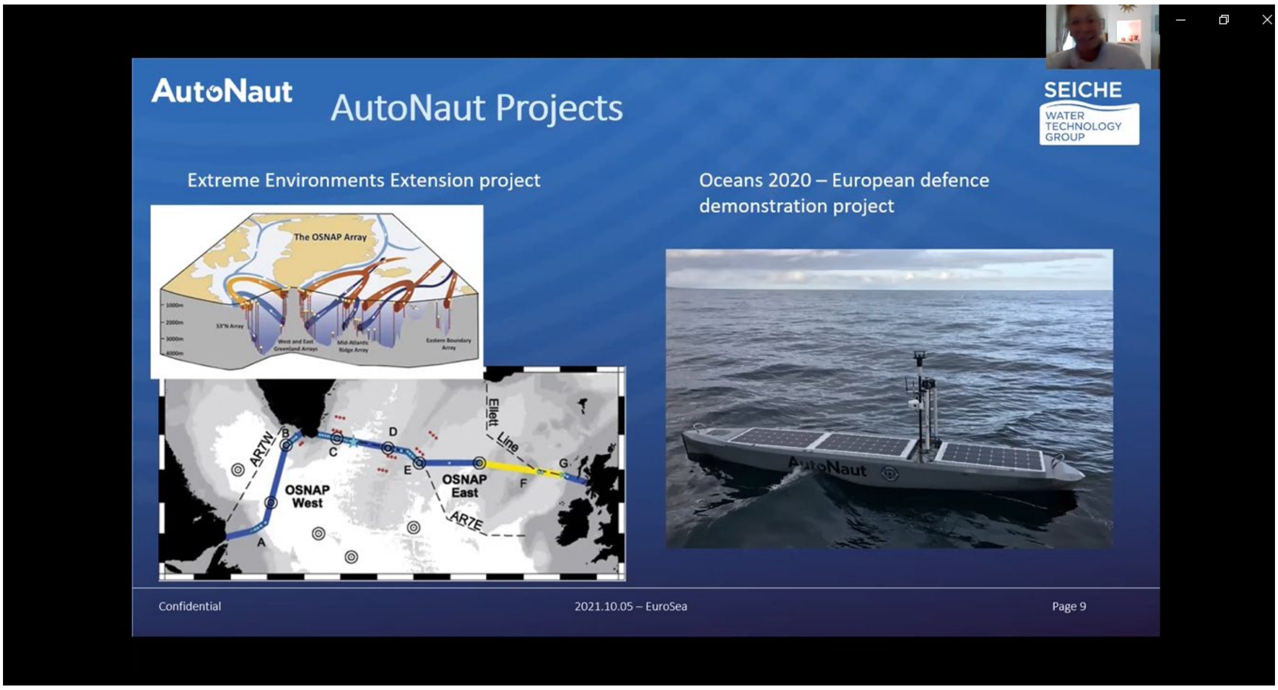

Figure 10. Example of AutoNaut ASV capabilities in terms of mission performance.

Figure 11. SEASAT ASV technology features overview.

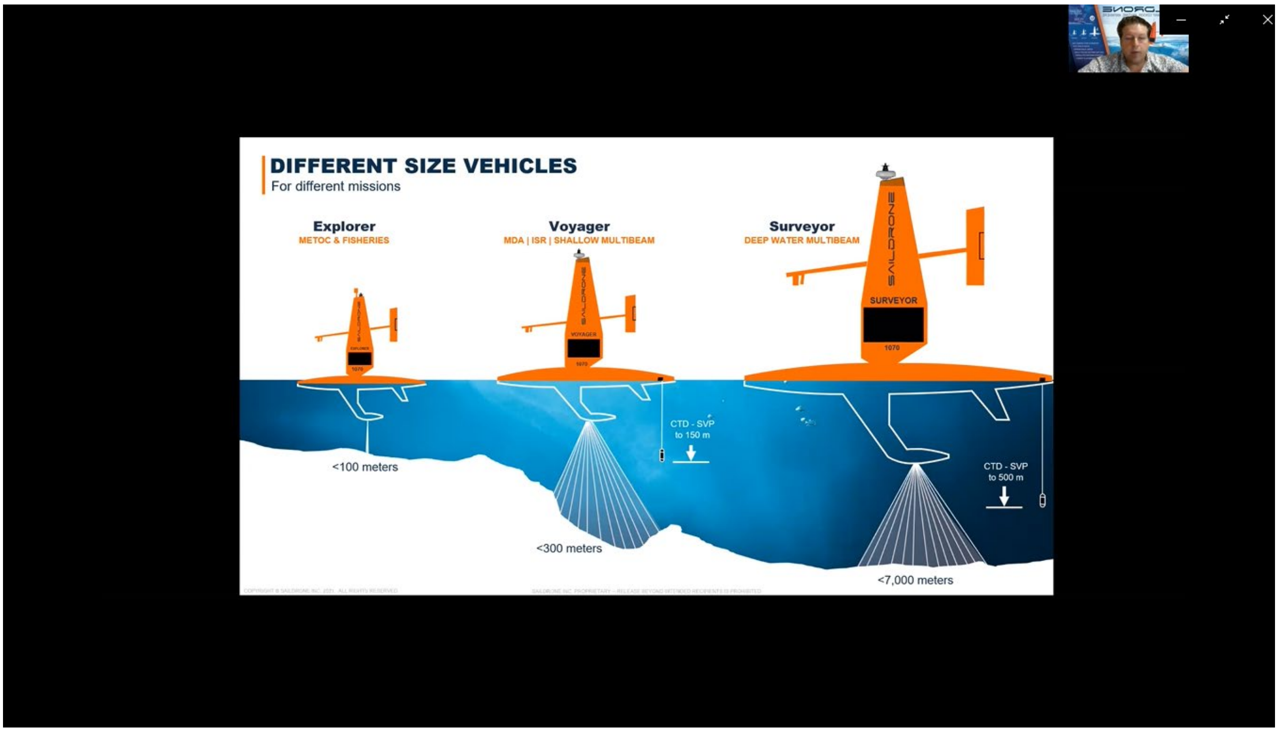

Figure 12. Saildrone ASV technology models overview

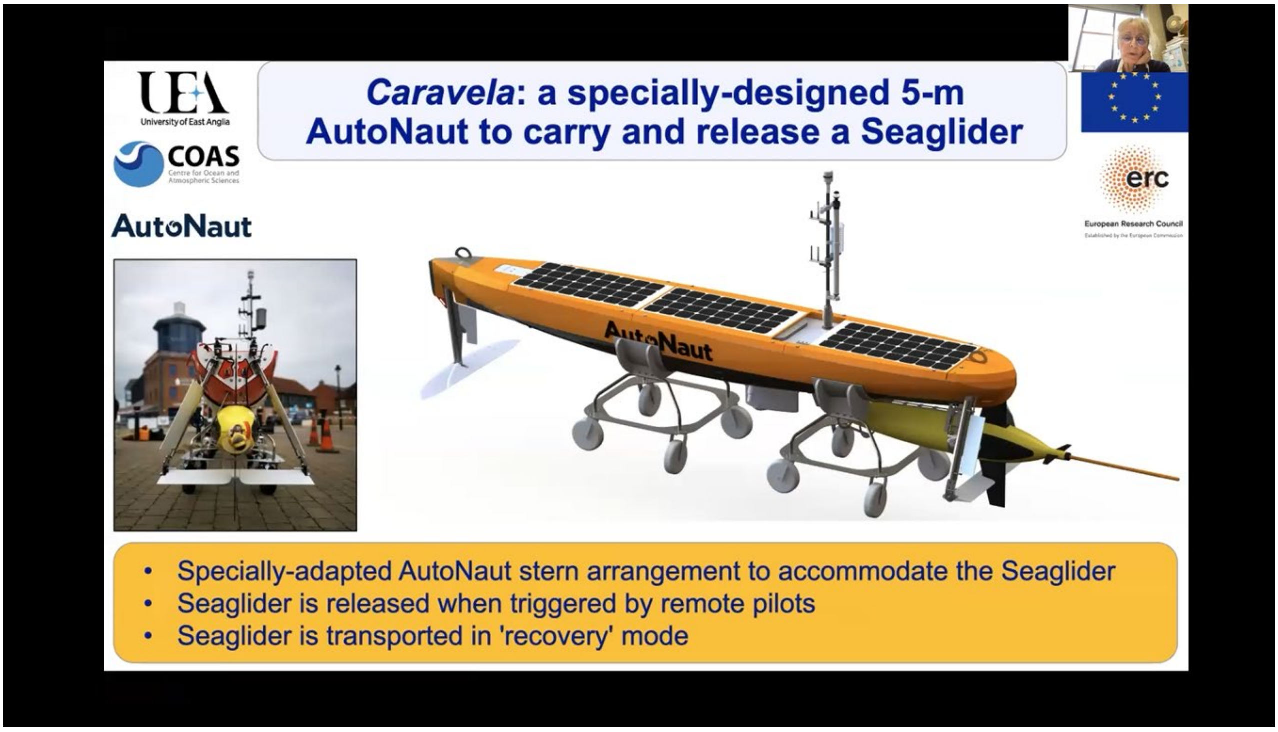

Figure 13. Caravela – A synergistic project between ASV and underwater glider technologies conducted by UEA.

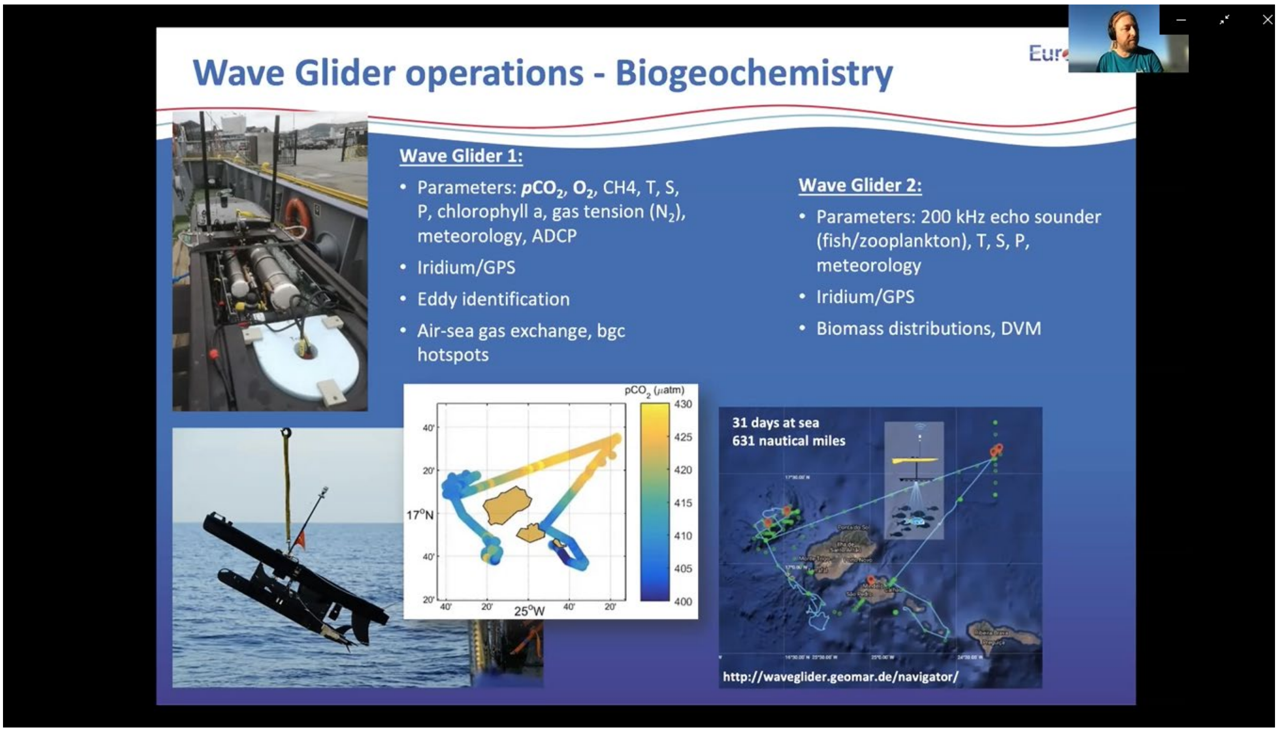

Figure 14. ASV experiment by GEOMAR using Waveglider ASV technologies.

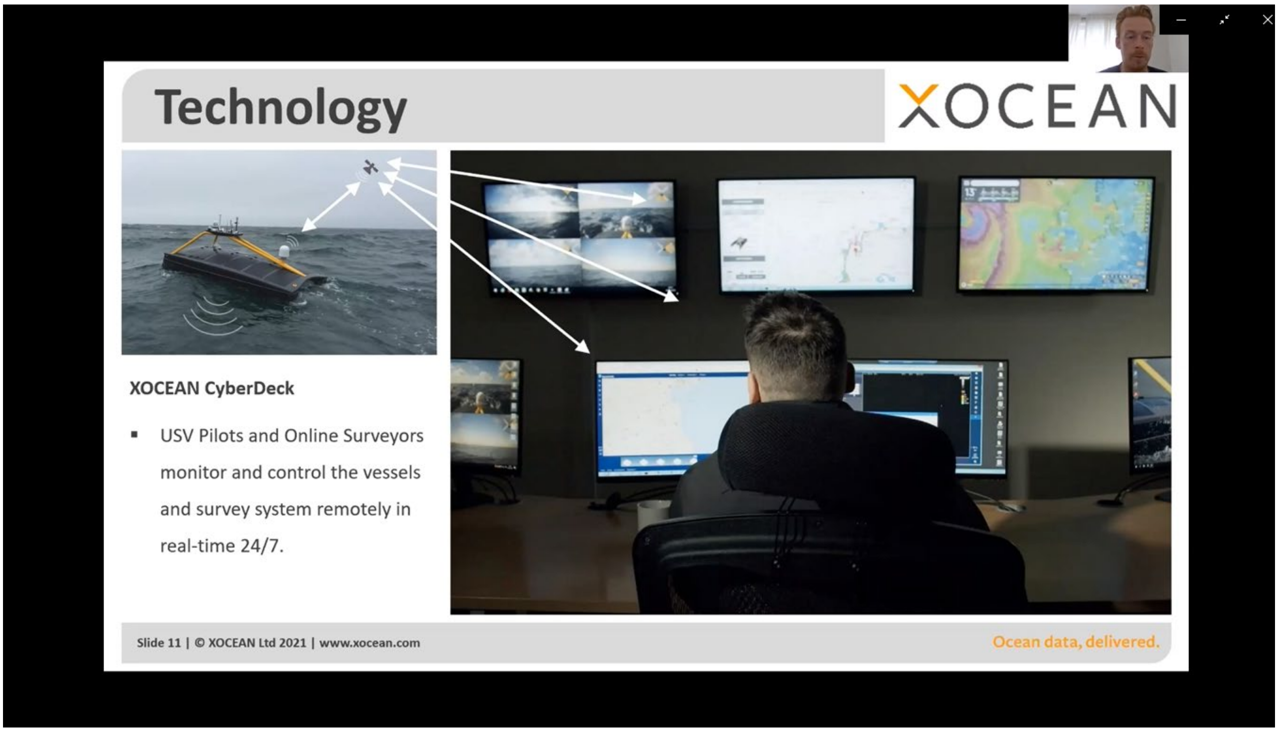

Figure 15. Remote Control Centre of XOCEAN for ASV operations

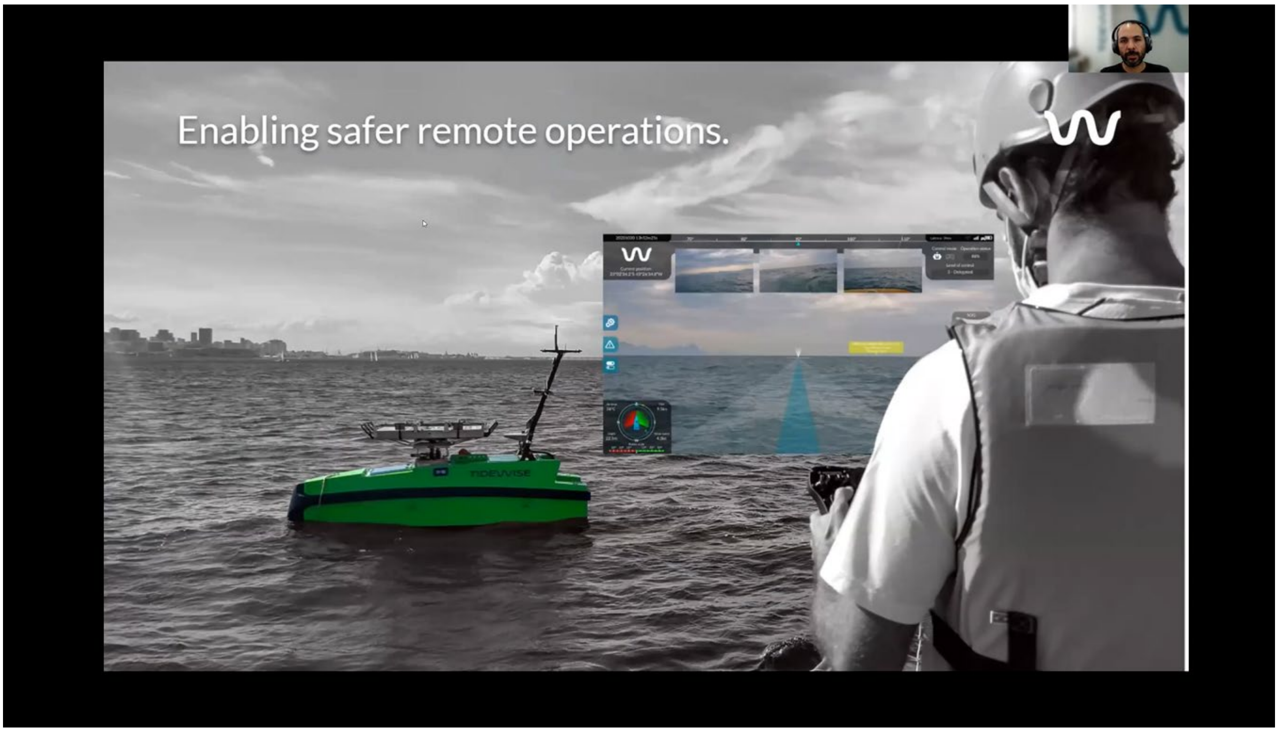

Figure 16. TIDEWISE as service provider using ASV technologies for a safer sea operations.

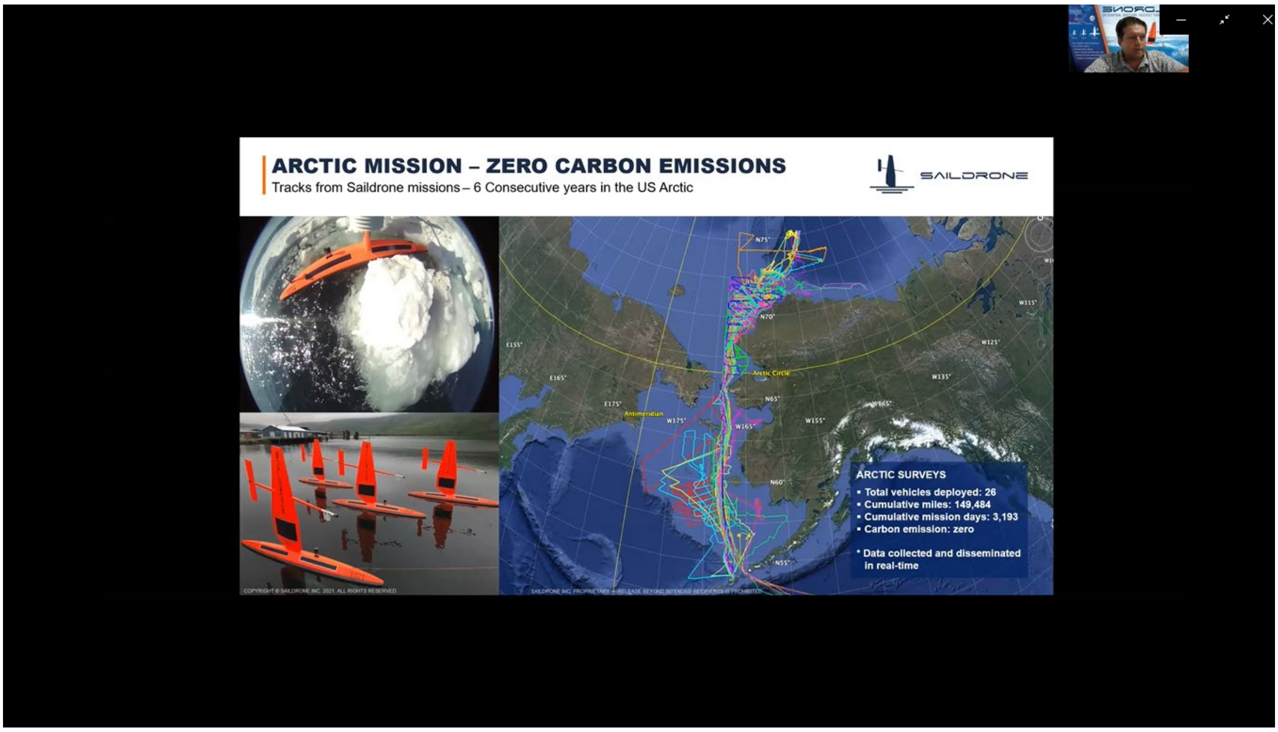

Figure 17. Long endurance Saildrone ASV mission performed in the Artic region.

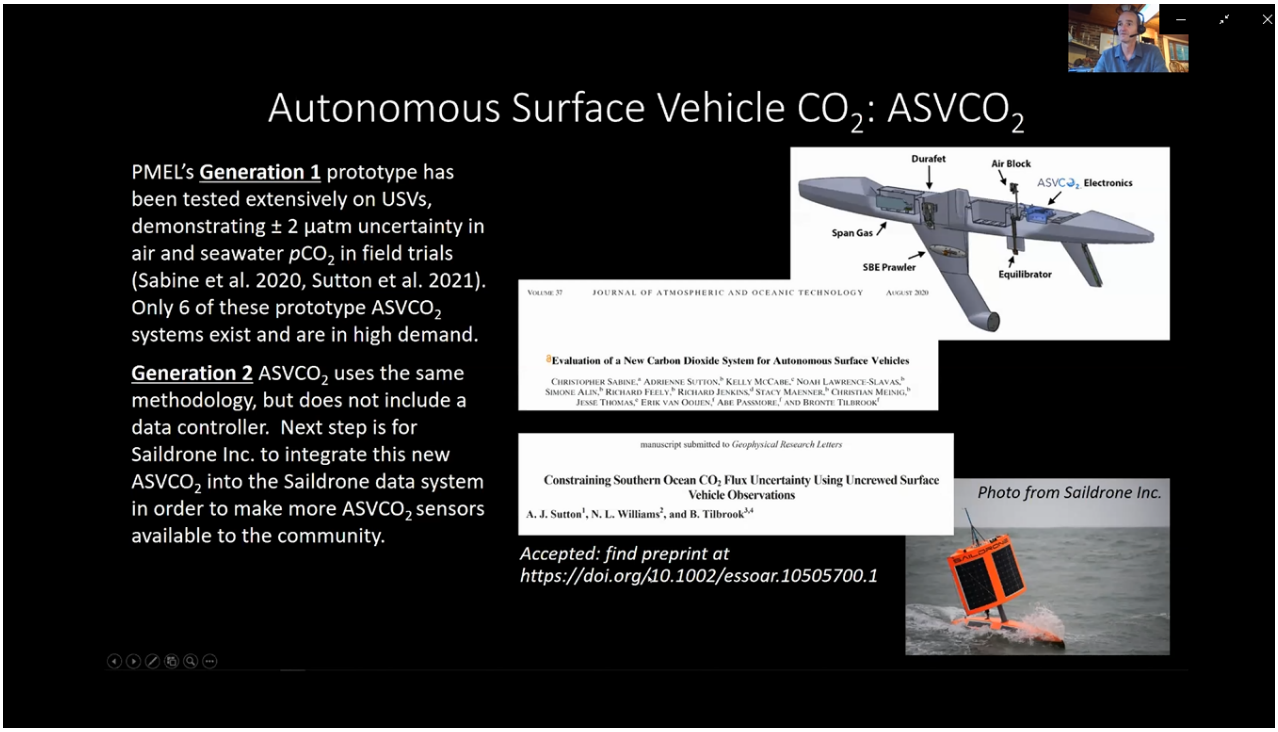

Figure 18. Evolution of the Saildrone ASV technology for CO2 measurements by NOAA.

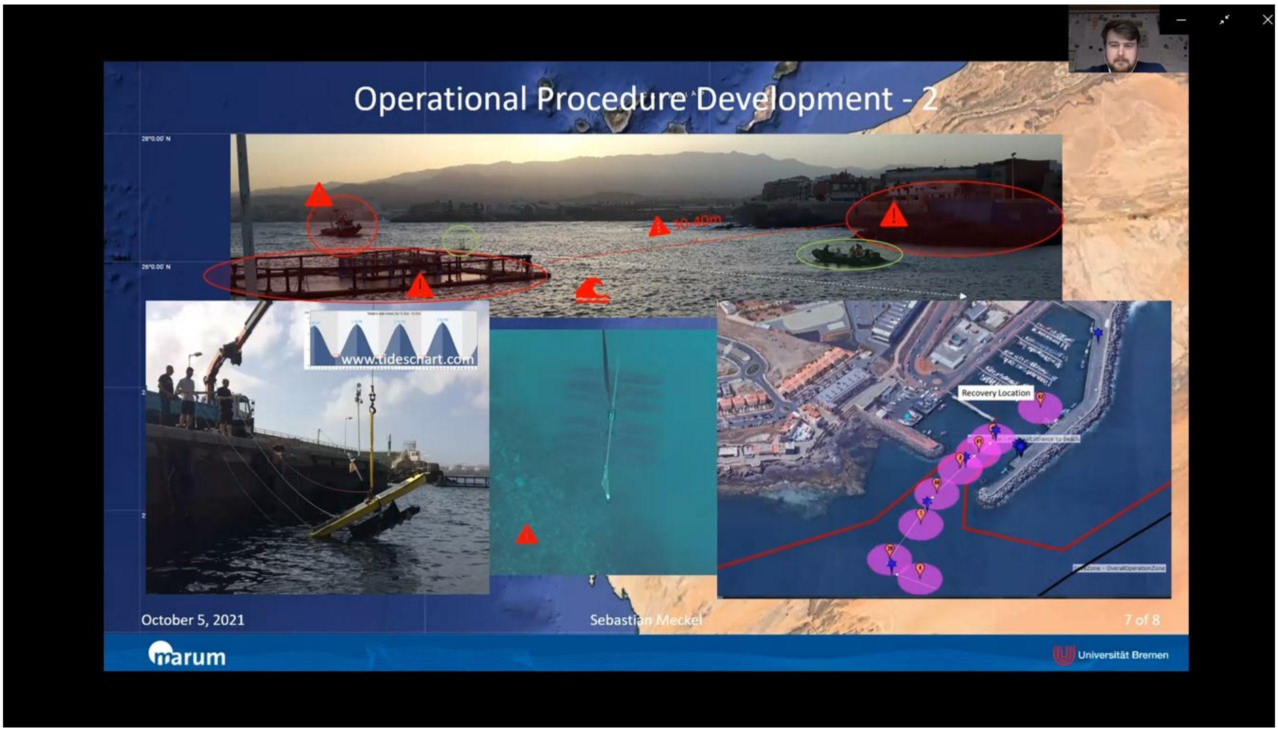

Figure 19. Example of operational procedure for a Waveglider deployment conducted by MARUM.

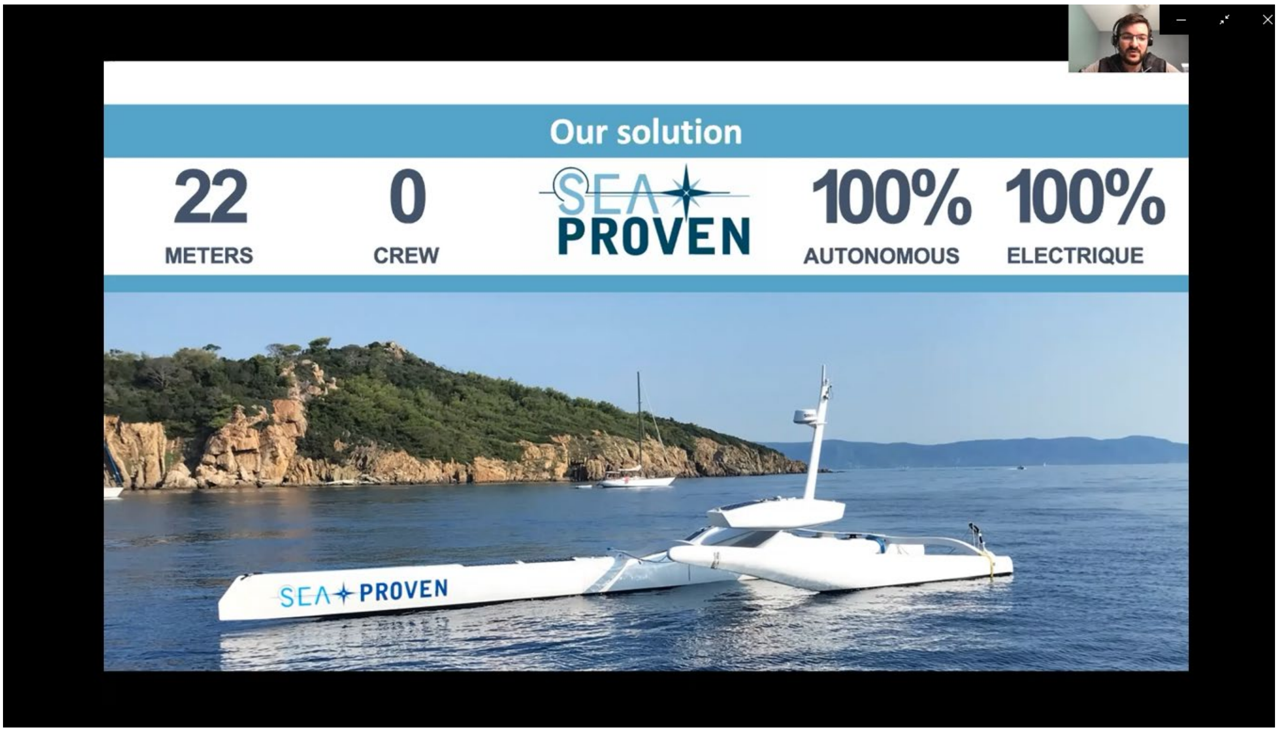

Figure 20. SeaProven: example of large and very capable ASV technology for ocean-observing.

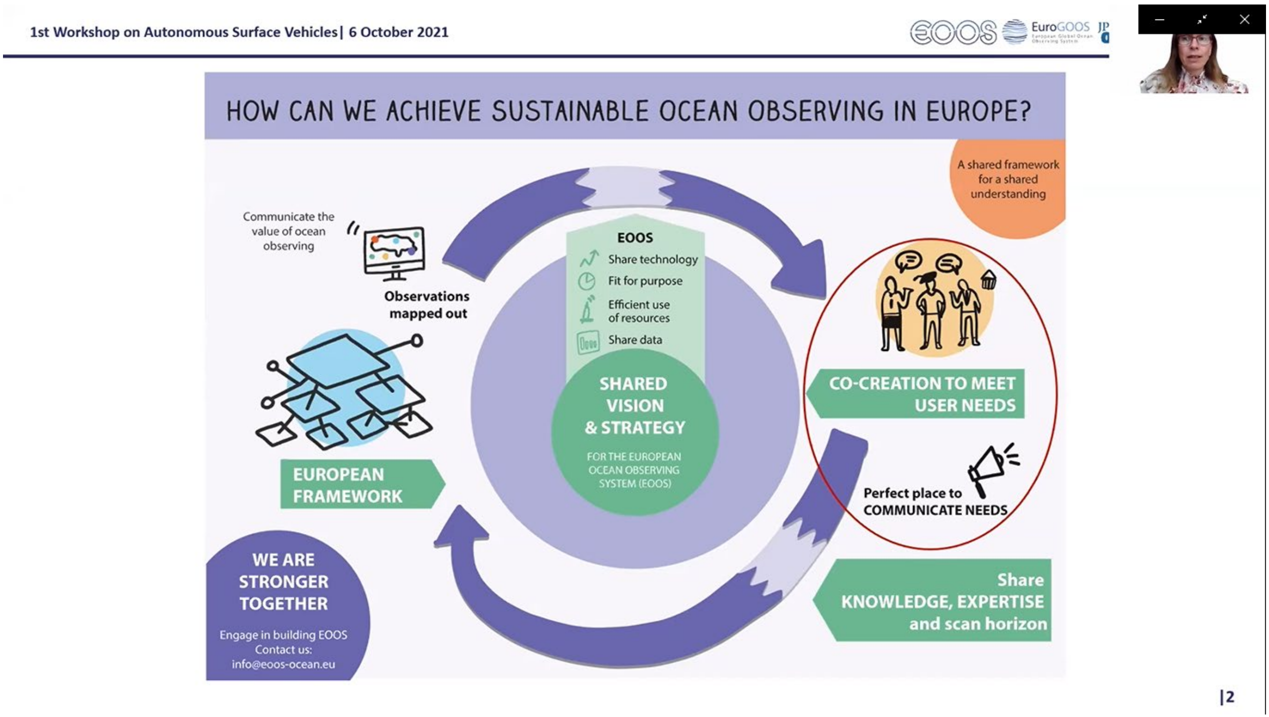

Figure 21. Overview on the European Ocean Observing System approach (EuroGOOS).

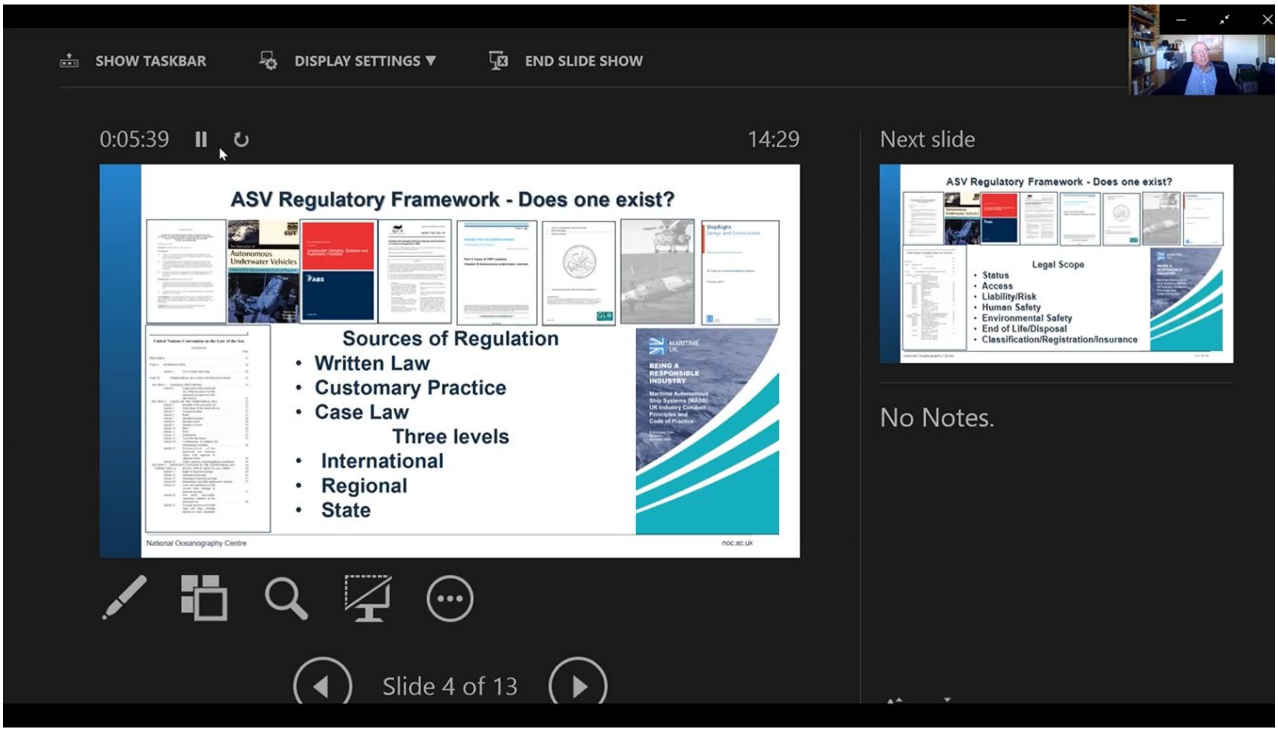

Figure 22. Status of the regulatory framework for ASV in UK.

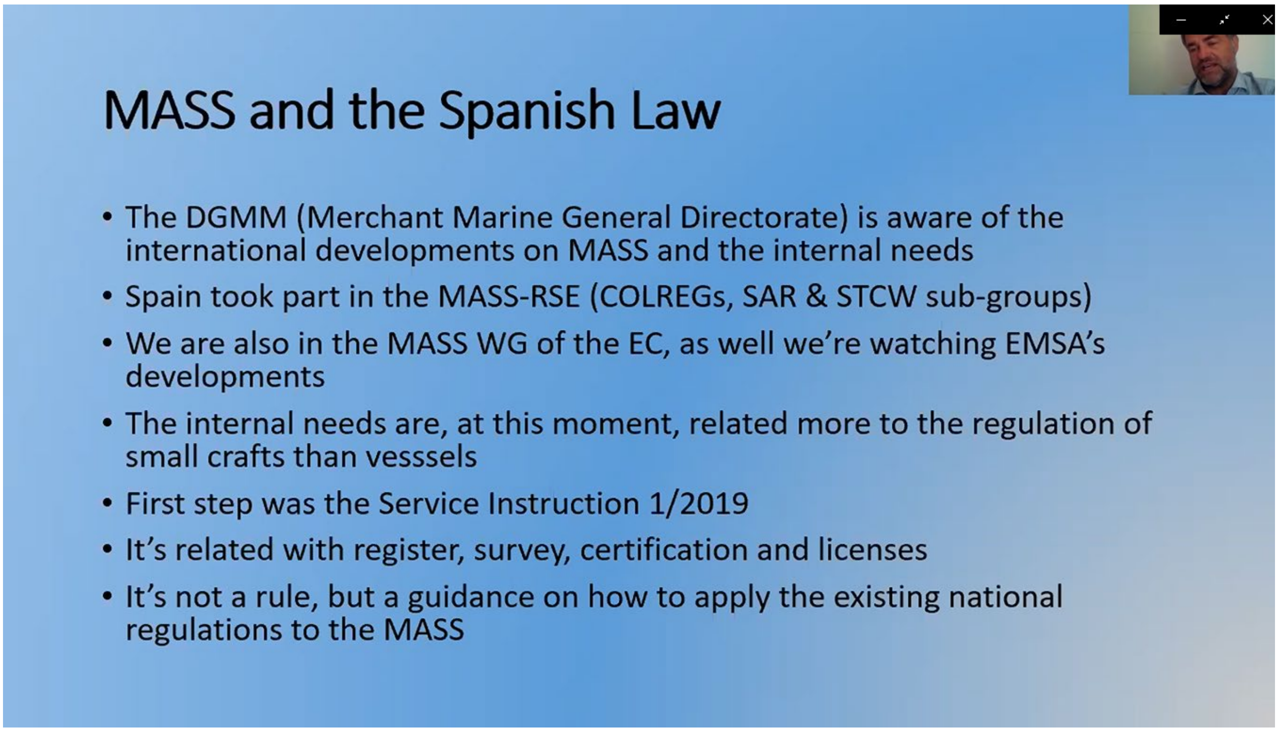

Figure 23. Regulatory framework status of MASS and ASV in Spain, lead by DGMM.

Figure 24. Study case conducted by XOCEAN in Canada waters as contribution to Regulatory framework session.

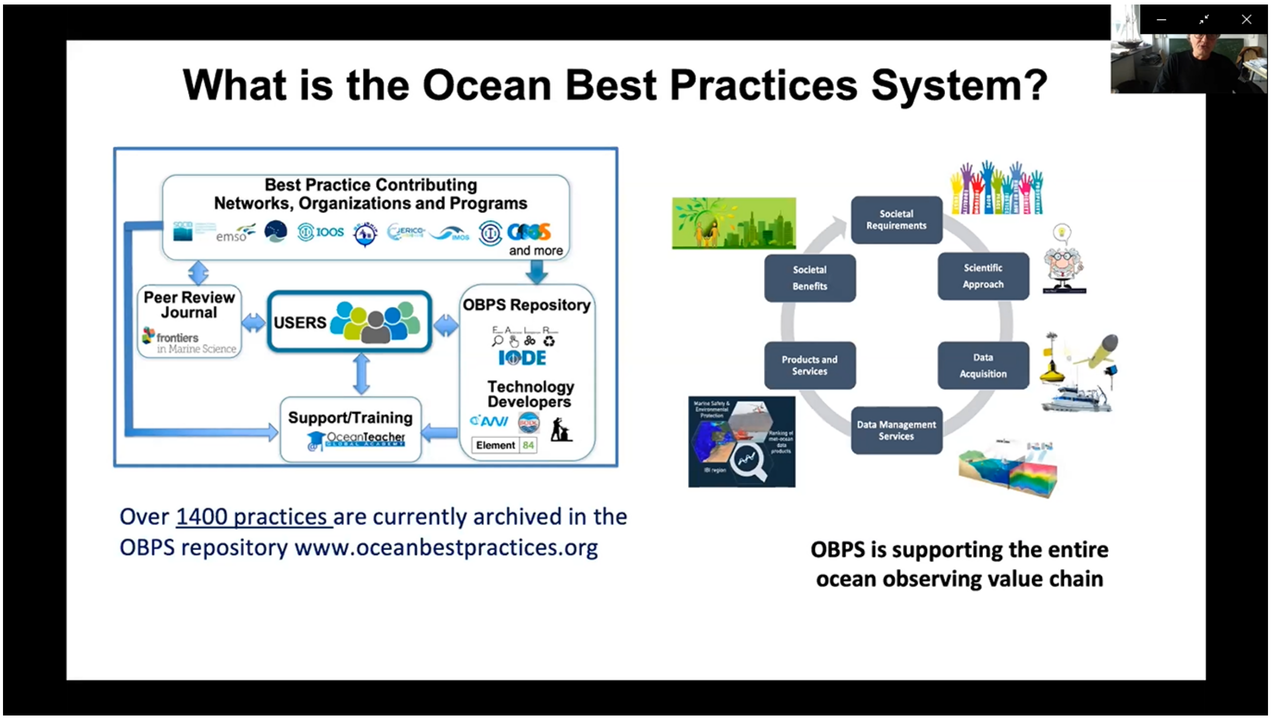

Figure 25. Ocean Best Practices System structure overview.

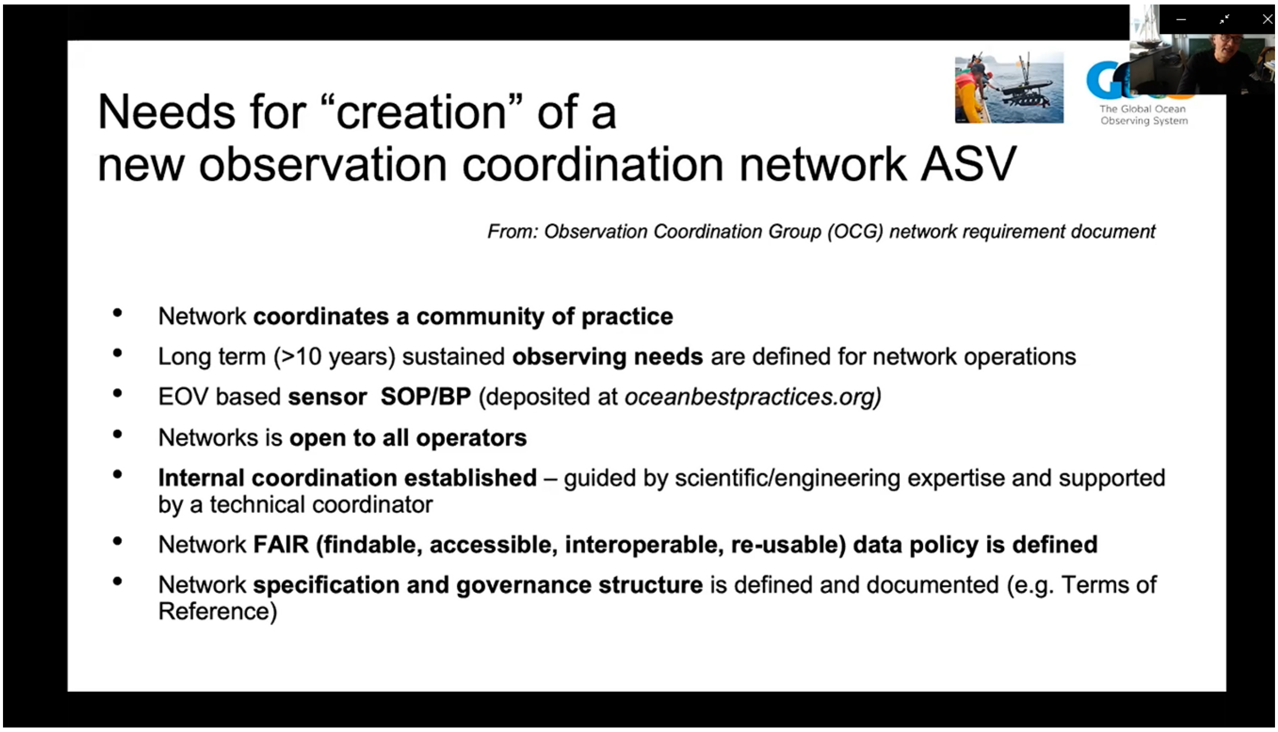

Figure 26. List of main needs to create and implement a new observation coordination network for ASV technologies based on OCG approach.

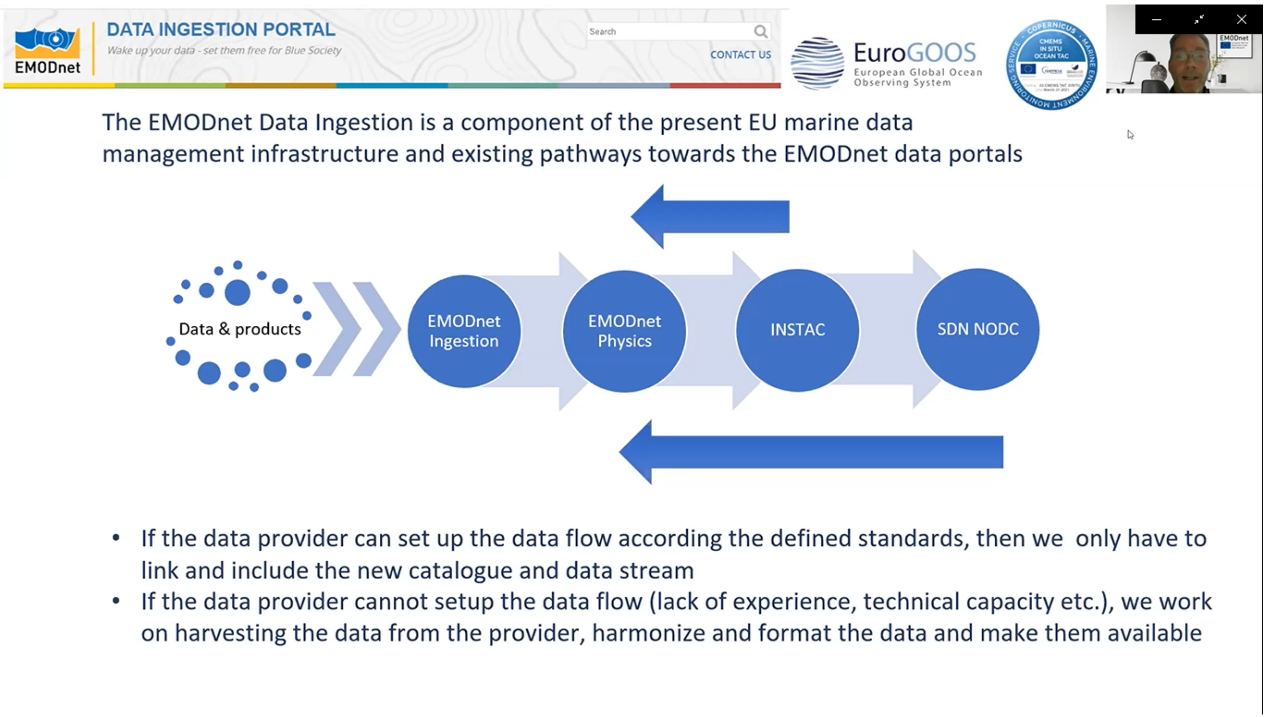

Figure 27. EMODNet data ingestion structure as part of the EU marine data management infrastructure.

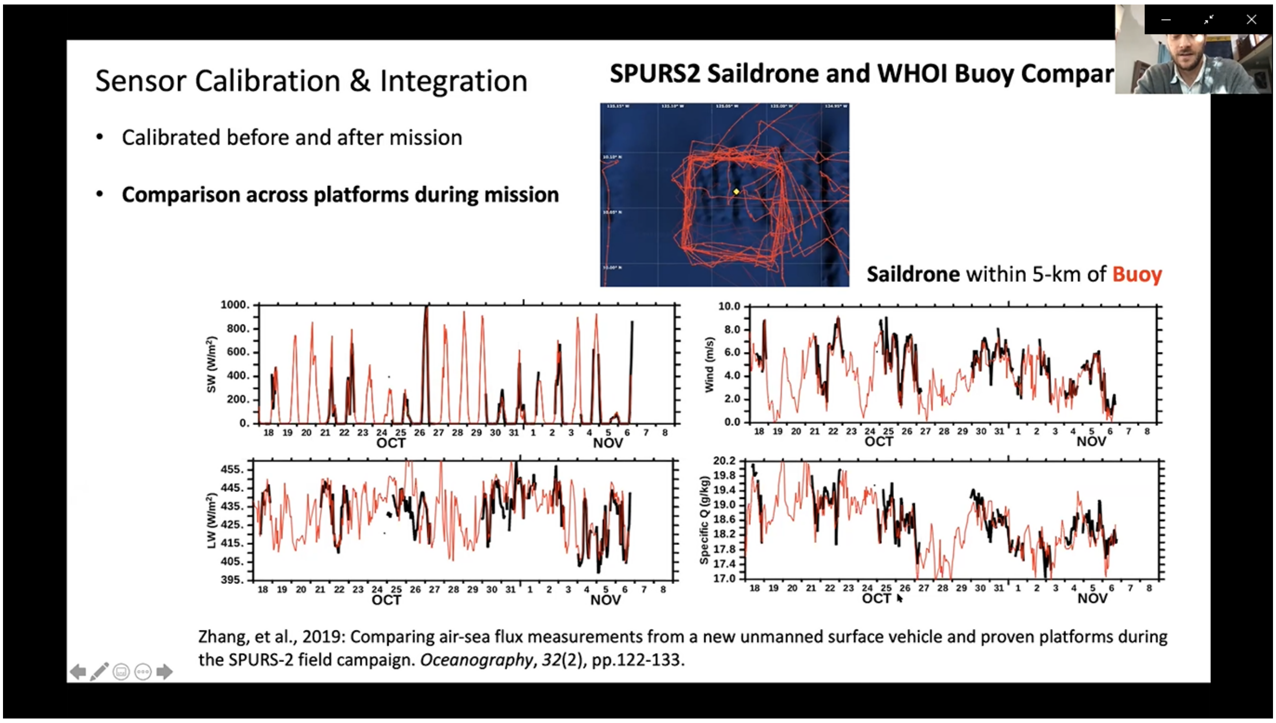

Figure 28. SPURS-2 best practices related to sensor calibration and integration between ASV Saildrone and moored buoy conducted by NOAA.

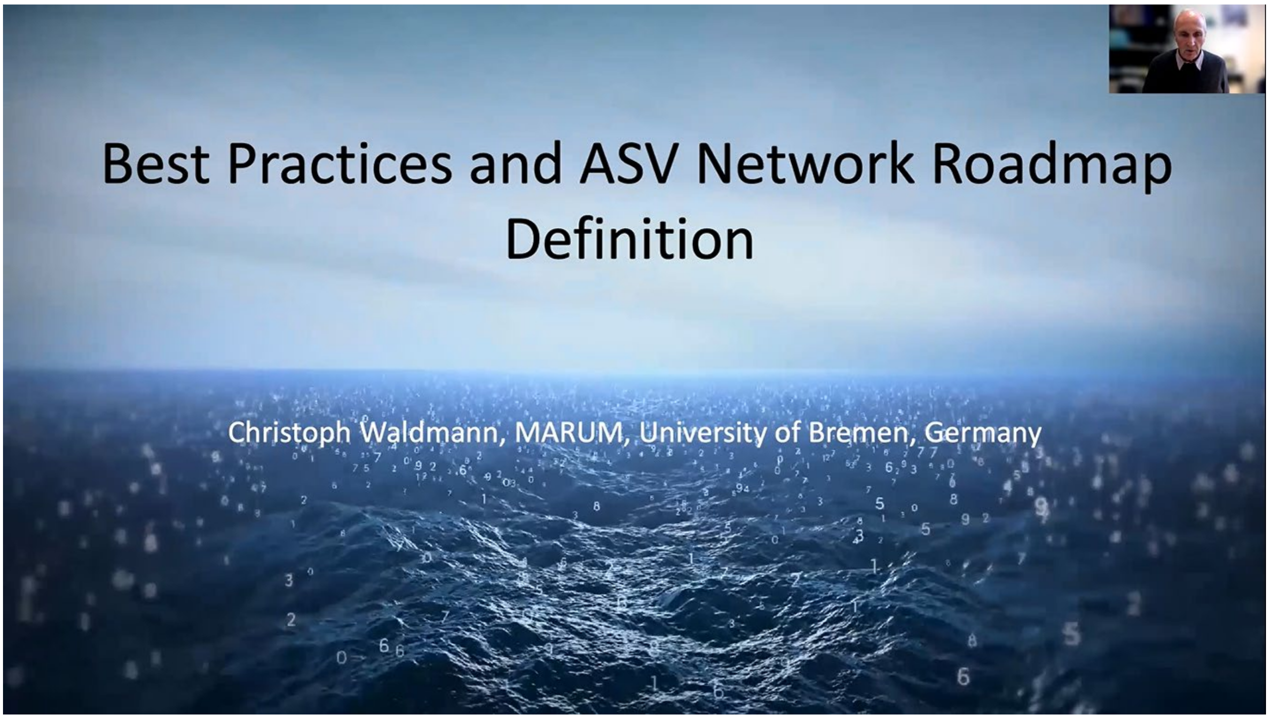

Figure 29. Overview on ASV Best Practices and Network Roadmap definition by MARUM.

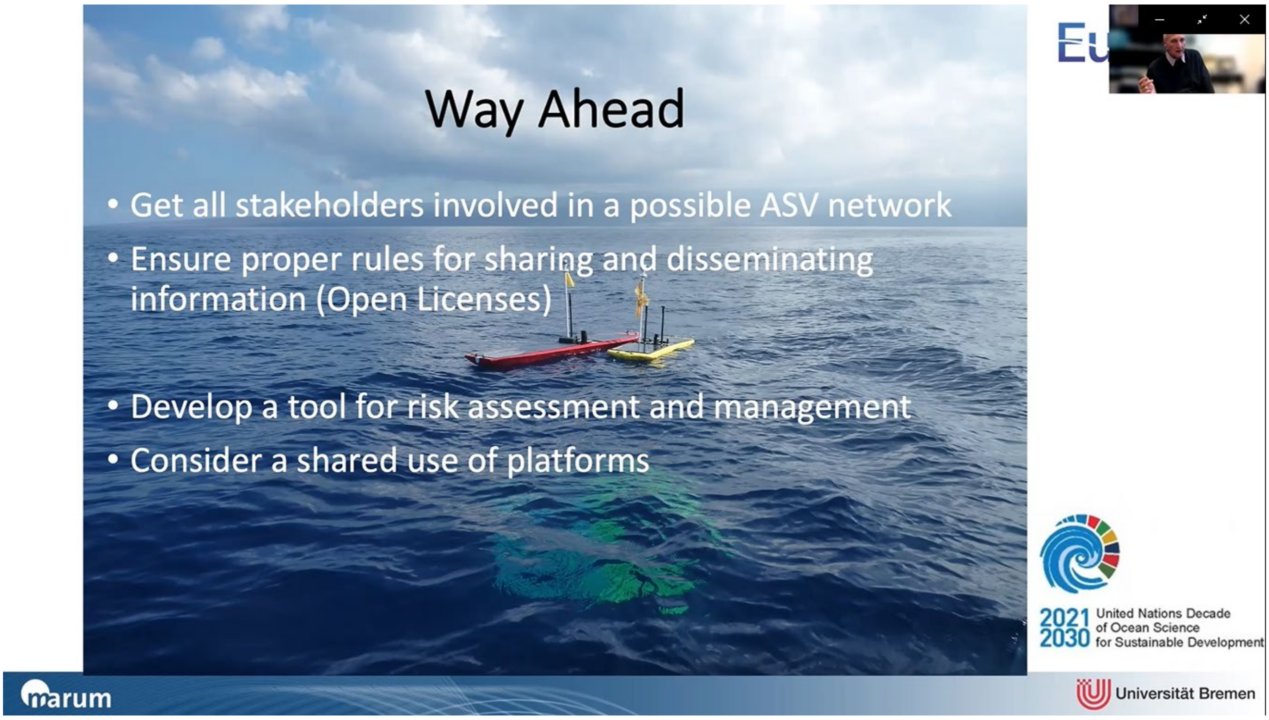

Figure 30. Key recommendations to implement an ASV Network.

5.3. Workshop's main preliminary outcomes

Preliminary but at the same time very helpful and promising outcomes derived from the 1st ASV workshop are listed below:

- Great level of interest, attendance and contribution from current key ASV-community members representing the "triple-helix" perspective (industry, academia/science and agencies). Some other key members unable to attend by committed for
- The ASV technology is already well developed and mature (TRL 8-9) in many cases.
- Huge technological and operational capabilities to cover in a synergistic way current ocean-observing gaps, being two of the main ones (1) to be able to monitor essential climate variables (ECV) and essential ocean variables (EOV) at the same time on an unprecedented space-time scale, and (2) act as gateway to link in real-time underwater observations with satellite platforms.
- Several helpful synergies already identified (and tested) with other ocean-observing platforms (fixed and mobile).
- Wide range of applications/services for several Blue Growth sectors on ocean-observing, survey, intervention, border security, etc. some of them already implemented in routine mode.
- Several technologies already as commercial product (important difference from other ocean-observing technologies).
- Risk assessment and management system is key.
- Clear lack at network level (main motivation to undertake this initiative under EuroSea project) from key aspects like technical -platforms and subsystems components-, coordinated operations/missions, data/metadata, legal framework (links with IMO/MASS strategy), best practices and standards, etc.

6. ASV Network: The way ahead

ASV technology is already present in various areas of the main seas and ocean, to carry out a large variety of measurements of physical and biogeochemical variables. The ASV-Network aims at integrating and leveraging the efforts of the ASV community becoming this activity an important building block towards an integrated end-to-end International/European Ocean Observing System, EOOS. Through their unique sampling capabilities, ASV enhance the panel of observing systems and contribute to the design of the EOOS. Sustained ASV observations link the open-ocean to the shore with physical, chemical, and biological observations in a synergistic way with other platform, such as floats, moorings, drifters etc. They contribute to fulfill the establishment of an operational service for ecosystem-based management and boost the improvement of modelling and forecasting of the ocean.

The ASV Network aims at boosting scientific collaboration and information resources to address the following priorities:

- International cooperation
- Sustained observation, operational oceanography and scientific research
- Technology development and relationship with industries
- Data management
- Support to EU/international policies and research Infrastructures (RIs)

In terms of aim and objectives, the below are the envisaged so far:

1. Act on behalf of the global ASV community.
2. Further develop the ASV network, coordinate and assist in the standardization and sharing of best practices for ASV operations and applications and harmonization of data and metadata.
3. Ensure data availability for the Copernicus Marine Environment Monitoring Service (CMEMS), WMO, EMODnet data portals and other data aggregators and appropriate users via the Global Data Assembly Centre (GDAC) for ASV data.
4. Set up a framework for:
   - Promoting ASV applications and operational oceanography services through liaison between industry, operators, users, advocacy, and provision of expert advice.
   - Sharing success stories and difficulties.
   - Maintaining and sharing reference material on ASV-related technologies (sensors, protocols, readiness levels and specifications, data management standards and quality control).
   - Providing and exchanging source tools (data analysis, applications…).
   - Promoting scientific synergies for key questions.
   - Filling gaps and looking for complementary with other ocean-observing technologies
   - Promotion of joint proposals.
5. Contribute to the development of the GOOS, initially focused on the EOOS for the coastal area and the open ocean.
6. To enhance the number of EOVs and ECVs measurements.
7. To provide recommendations on metadata, data structure, format and dissemination (interoperability of datasets) and Quality Control procedures.

The ASV Network should be composed by a Chair and can have one or two Co-chairs, and members. The mandate, role and responsibilities of potential co-chairs are the same as for the Chair. Chair and Co-chair are responsible for: (1) Oversight of the ASV Network management; (2) Alignment of the "Task Team Work" (if any) with its terms of reference and with the ASV; (3) Developing the task team (if any) yearly implementation plan in line with the above; (4) The organization of regular meeting with ASV Network members (i.e. once a year); (5) Represent the working group at external meetings.

Members are selected based on a call for nominations to the ASV network members and an external call or expression of interest among experts at international level. Members are selected by the Chair and the ASV Network, keeping in mind the spread and representativeness in expertise, geographical representation and the gender balance of the group. Membership is reconsidered by the Chair and the ASV Network on a regular basis and can be terminated if the member does not fulfill the below responsibilities. Members' responsibilities are to: (1) Be a committed advocate for ASV Network goals and objectives; (2) Understand strategic implications and outcomes of the ASV Network; (3) Provide guidance for ASV Network goals and objectives; (4) Participate to the working group activities; (5) Monitor and review ASV Network activities, orally or in writing, in a timely manner; (6) Represent the activity at external meetings, upon agreement with the chair; (7) Attend working group meetings; (8) Follow-up on the developments related to the working group's activities, to ensure the working group's work is timely and topical.

Terms of reference (ToR) for the ASV Network should be defined for approval by the ASV community. Once approved, the ASV Network chair will launch a call for member nominations and the working group is formally established according to these ToR. A kick-off meeting should be organized with all the members to develop the first annual implementation plan. ASV Network chair oversees the communication related to the working group activities. To this end, the working group implementation plan should be cognizant of general strategy at upper level (board, steering committee -SC- or similar).

The ASV Network should run according to its ToR and annual implementation plans. The ASV Network will report to upper level its activities to be reviewed and approved at General Assembly meetings (minimum in a year basis, desirable every six month).

At the kick-off meeting, the members and the chair(s) brainstorm on the target audience for the ASV Network outputs and the main communication messages. This brainstorming is prepared with support of the SC to align the plans with other strategic initiatives on Ocean Observing at international level. The group also establishes the expected/desired impact of its activities on the target audience.

6.1. Future specific actions

- Based on the success derived from the 1st ASV workshop conducted, the following specific actions are envisaged within the framework of EuroSea (and hopefully beyond) to accordingly setup and implement the ASV Network as one network component more aligned with the main international ocean observing strategies:
- Keep the promotion of the initiative to engage new potential members in the upcoming months. Part of this strategy is the session "*Uncrewed Surface Vehicles (ASVs). Technology Trends and Improvements on Observing Applications for the Ocean Decade*" (https://www.aslo.org/osm2022/scientific-sessions/#ot) already included in the science/technical program of the Ocean Sciences Conference 2022, to be held virtually from February 27th to March 4th. In parallel, dedicated additional meetings as side-event within the framework of scientific and/or workshops, conferences, trade shows, etc. are planned at least once a year.
- Define possible synergistic cooperation frameworks with initiatives already ongoing and implemented, such organizations, initiatives and projects (i.e. EuroGOOS, OceanGliders, GROOM II, EUmarineRobots, TechOceans, etc.).
- Define a business model and a cooperation framework within "triple-helix" (industry, academia and agencies) approach in matters of technological development, applications and related services.
- Organize and conduct the 2nd ASV workshop (expected in Spring 2023) within the framework of EuroSea, in line with the defined objectives, being the main one to setup and approve the bases to implement (2024) the ASV network under a common framework of action approved by all the parties finally involved.

Acknowledgements

The authors of this document thank all members from industry, academia, government agencies, NGO and stakeholders who have shown interest and contributed to all the actions undertaken to date within the initiative to define and implement an international ASV Network. Your trust and willingness are very much appreciated and encouraging for the way ahead.

A special mention of acknowledge is for the WP3 leaders for their support and understanding despite difficulties that occurred during these last project months. Sometimes things do not go as expected, but in this case what is undoubtedly is the interest and enthusiasm with which the four lead partners in charge of

task 3.7 face the opportunity that EuroSea offers to implement a new ocean-observing network based on ASV technology in benefit to EOOS and GOOS, among other ocean-observing initiatives.

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