JERICO-S3 DELIVERABLE

Joint European Research Infrastructure for Coastal Observatories
Science, Services, Sustainability

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EXECUTIVE SUMMARY

JERICO science strategy emphasises the importance of integrated observation as a fundamental requisite for the understanding of coastal complex processes. During JERICO-S3 the implementation of integrated observation has focused on the integration and harmonisation of coastal observatories across various European coastal regions, encompassing different aspects, from regional collaboration and technological innovation to the development of scientific data products and experimentation. The progress in the implementation of integrated observations is summarised and analysed in this deliverable, showcasing the added value of a research infrastructure capable of measuring complex ecosystem processes within coastal waters, and to address a wide range of scientific questions in agreement with the JERICO Science Strategy.

1.INTRODUCTION

1.1.Main aim of this document

JERICO-S3 is aiming at setting up a sustained pan-European integrated research infrastructure dedicated to the observation of coastal marine systems, which is lacking in the landscape of European observing initiatives, currently focusing on the open ocean and continental systems. The main purpose of such an infrastructure is to enable a sound understanding of the responses of coastal marine systems to natural and anthropogenic drivers, and to respond to the crucial need of developing coordinated observations of coastal marine systems.

JERICO-S3 WP1 main aim is twofold: (1) refining the JERICO science strategy based on *JERICO-S3* achievements, and (2) establishing a long-term vision for the observation of European coastal Marine systems.

The main worklines of **WP1 have been:**

- To **define the science strategy** and to converge into a common general scientific framework structured in **consolidated KSCs and SSCs** and a list of specific RA to be updated during the project.
- To analyse the **early scientific monitoring strategies** put in place within *JERICO- S3*, both from the point of view of experimentation (PSS, WP4) and of networking towards a coordinated pan-European dedicated research infrastructure (IRS, WP3) and including interfacing with other observing initiatives (WP2).
- To provide **early recommendations** on the nature and the implementation of innovative technologies to be developed within *JERICO-S3*.
- To **refine the concept of JERICO regions**, considering regional specificities and the European vision, which will be central to the implementation of the future infrastructure.
- To contribute to JERICO-S3 implementation, ensuring **coherence between a science strategy based on theoretical grounds and the outcomes of practical experimentations** through research actions.

Early strategic elements were provided in D1.1, while D1.2 focused on the evaluation of the JERICO-S3 regional approach (i.e. how scientific and societal challenges were addressed by regions, gaps and collaboration between regions). D1.4 is working on the establishment of a long-term vision for the observation of European coastal Marine systems.

In this context, the main objective of deliverable D1.3 is to provide a **synthesis of JERICO-S3 implementation in terms of multidisciplinary integrated observations and innovative monitoring, in line with WP1 recommendations and including regions activities (WP3 and WP4) and development and demonstration of JERICO-S3 innovative technologies (WP7, WP5, TA)**.

Integration is a bedrock for the whole JERICO science strategy. It is achieved in a regional dimension, but also from the point of view of technological innovation and experimentation. D1.3 is a synthetic document on what are the progress observed in this direction, mostly in the context of D1.1 and the contribution of the implementations of integrated observations to the JERICO-S3 science strategy and the unfragmented endorsement of KSCs and SSCs. Strategy elements for further integration will be discussed in D1.5. Further technical recommendations towards integration will be provided in D5.7.

In the coastal ocean, integrated observations are a fundamental requisite for the understanding of coastal complex processes, which overlap, acting at different time and spatial scales. In addition to the integration of multiple scales, the integration of coastal distributed marine observations into one research infrastructure is also required to be able to tackle scientific questions which need a broader perspective, only achievable at pan-European scales. Integration of observations also must ensure that data are standardised and freely provided to end-users, such as marine scientists or other stakeholders, following the principles of FAIR data and marine services. Moreover, from a technical point of view, integration implies to be able to implement and provide access to an infrastructure composed of science-driven platforms and sensor systems that measure physical, chemical, and biological properties and processes in coastal waters from the open ocean to land-sea interfaces. With this in mind, in this deliverable, **the progress towards integrated observations is analysed from a broad perspective, spanning integration of data, methodologies, and platforms, and including collaboration beyond JERICO-S3 and other research infrastructures.**

1.2. JERICO-S3 mechanisms for the implementation of multidisciplinary and integrated observations

JERICO observing platforms are distributed over many European coastal regions (Figure 1). **The regional dimension is essential to ensure the integration**, harmonization, and effective operation of coastal observatories, contributing to a comprehensive and pan-European effort in monitoring and understanding coastal seas. In JERICO-S3 the regional dimension was tackled through different WP, but mostly concentrated in WP3 and WP4. WP3 was focused on the capacity development of the so-called Integrated Regional Sites (IRSs) distributed among 5 regions, with the main aim to progress in organizing, harmonizing, and integrating existing coastal activities within the regions and between regions. WP4 focused on the Pilot Super Sites (PSSs), distributed among 4 regions, with the main aim to demonstrate the added value of integrated, state of the art, multidisciplinary and multiplatform observation capabilities. PSSs have different regional extensions, but in general they are a well-defined and coordinated set of integrated multiplatform observations within the region, demonstrating a subset of regional observation capacity. PSSs have also progressed in tasks concerning organization, harmonization, and integration of coastal activities within the region and between regions.

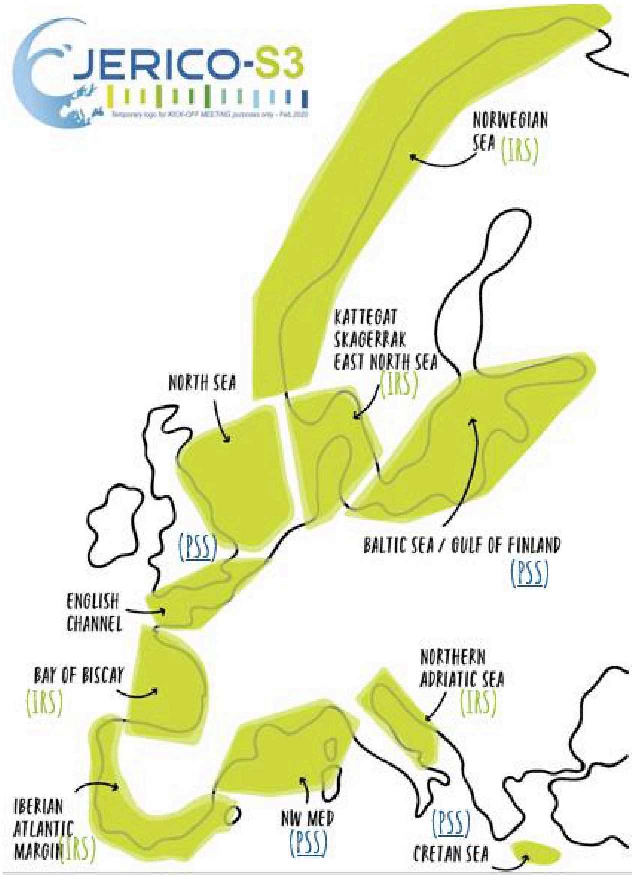

Figure 1. Map showing the geographical locations of the Pilot Super Sites and Integrated Regional Sites questioned within JERICO-S3.

Therefore, IRSs and PSSs are **pivotal for integrating and harmonizing coastal observatories across Europe, with the emphasis is of contributing in an integrated way to the overarching JERICO-S3 Science Strategy at the same time they address specific regional challenges**. They also contribute to standardizing data collection methods, deploying innovative technologies at the regional level, and engaging diverse stakeholders, including researchers and policymakers. Both IRSs and PSS actions are oriented to the promotion of the use of their data and products in interaction with other Ris and in support to EU directives.

Transnational and cross-regional integration is also promoted to ensure the upscale of regional activities to wider areas and for the joint identification of observational gaps. Furthermore, IRSs and PSSs play an important role for the identification and future engagement of key regional actors not currently involved in JERICO-S3, which is fundamental to enable responses to complex scientific questions requiring integration of data, disciplines, and additional expertise. Finally regional activities also enable an integrated vision of coastal marine ecosystems which are important for stakeholders and various end-users (e.g. MPAs, education...).

In addition to these activities, the **series of demonstration actions undertaken by the PSS addresses various issues related to ocean and coastal dynamics, ecosystem health, and multidisciplinary interactions**, focusing on specific challenges and research objectives within each region but contributing to a broader understanding of marine and coastal ecosystems.

Concerning technological innovation, several **WP7 demonstration activities showcase specific advances in the implementation of new solutions for ocean observation.** During JERICO-S3 three main technical developments have showcased the impact of innovation on the enhancement of integrated ocean observation:

(i) **The Plankton dynamic Sensor Package - PSP**, which was developed taking the EGIM, EMSO Generic Instrument Module as a starting point, and adding a set of new biologically related sensors (zooplankton and nitrate), a processing unit to automatically adapt the sampling strategy as a function of observations and a standardised data flow of real-time data.

(ii) **The Autonomous Coastal Observing Benthic Station - ACOBS**, which integrates simultaneously acquired data on: bottom seawater characteristics, diffusive and total oxygen fluxes at the sediment-water interface, and benthic activity at the sediment-water interface as well as in the upper sediment column.

(iii) **The Water-Sample filtering and Preservation device - WASP**, which allows the integrated real-time observation of seawater hydrographic characteristics, chlorophyll a fluorescence, coloured dissolved organic matter fluorescence, and turbidity, with a solution that allows to filter seawater for the collection of phytoplankton for environmental DNA (eDNA) and metabarcoding.

While of different nature (EGIM/ACOBS closer in terms of scientific drivers while WASP was mostly driven by the needs of technological innovation on a specific technique, see technical specifications in D7.4 and D7.7) these three examples provide a complementary and sound step towards integration.

In addition, to the development of technology for data acquisition, JERICO Coastal Ocean Resource Environment (JERICO-CORE) was developed in WP7 (task 7.5) as the unified central hub of JERICO (https://www.jerico-ri.eu/va-services/jerico-core/) to discover, access, manage and interact with JERICO-RI resources including services, datasets, software, best practices, manuals, publications, organisations, projects, observatories, equipment, data servers, e-libraries, support, training and similar assets. Four Data-to-Products Thematic Services (D2PTS) waere developed within JERICO-S3 as demonstrators of JERICO-CORE capabilities, and among them the following two deserve attention, since they also contribute to the needed integration of multidisciplinary data:

(i) **Estimation of sea water masses types and transport monitoring from Gliders D2PTS**, which allows to integrate data on seawater hydrographic and hydrodynamic characteristics (including water mass transports) and biogeochemical (BGC) data from glider measurements (chlorophyll-*a* concentration, oxygen concentration and saturation, and turbidity).
(ii) **Biogeochemical (BGC) state of coastal areas D2PTS**, which combines near-real-time (NRT) observations on the Gulf of Finland (GoF) providing regional, combined multiplatform physical, biological and chemical observations.

Finally, another component of JERICO-S3 that contributed to the implementation of integrated observations was the Transnational Access (TA, WP8). TA is a program that provides scientists and researchers with the opportunity to access and utilise JERICO state-of-the-art coastal observatories and related facilities across Europe. This access to the JERICO infrastructure enables additional experimental actions, data collection, and carry out of studies in diverse coastal settings. The focus of TA experimentation projects during JERICO-S3 was broad, encompassing technological testing, validation, and intercalibration efforts. However, a significant number of TA projects aimed at advancing our comprehension of marine coastal ecosystems, while enhancing monitoring and prediction capabilities. These projects often involved the integration of various platforms or the use of integrated sensors, such as in glider experiments. By incorporating diverse methodologies and innovative approaches, these initiatives contributed significantly to the advancement of integration and the development of more effective monitoring and predictive tools.

1.3. Assessment of the implementation of multidisciplinary and integrated observations

The assessment of the implementation of multidisciplinary and integrated observations, as detailed in section 2.2, is taking account several key aspects for each of the selected technical or methodological actions. First, a concise overview of the nature of the actions, is provided, along with a short explanation on how they contribute to the JERICO-RI science strategy, encompassing its Key Scientific Challenges (KSCs) and Strategic Scientific Challenges (SSCs). Other considered aspects are the extent and nature of integration, spanning data, methodologies, and platforms, including collaboration beyond JERICO-S3 and other research infrastructures. Emphasis is placed on multidisciplinarity, degree of innovation, added value and impacts of the actions, whether local, regional, or within specific scientific or technological domains, with a spotlight on replicability (especially in the case of demonstration only showcasing local impacts). An illustrative figure is provided in some cases, complementing but not duplicating the detailed descriptions available in related deliverables. Links to these deliverables are provided for reference.

2. IRSs and PSSs as main actors for multidisciplinary integrated observations

As mentioned in section 2.2, IRSs and PSSs were designed in JERICO-S3 to integrate, harmonise, coordinate, and demonstrate integrated multiplatform observations. These activities varied in terms of spatial extent with some occurring within regions, cross-regionally, and at times transnationally. The primary goals of IRSs (Networking Activity) were related to development of regional networks in terms of coordination, integration, harmonisation, governance, and business case - the building blocks required for future coastal trans-national observing nodes. The primary goals of PSSs (Joint Research Activity) were related to demonstrating integrated, state-of-the-art multidisciplinary and multiplatform observation capabilities through the implementation of the concept of transnational Supersites focused on scientific research questions and objectives that were carried in certain JERICO-S3 regions. Together, IRSs and PSSs collaborated to increase the feasibility of establishment and operation of regional observing nodes as well as the scientific and technical implementation aspects that are required. In this section, several examples from IRSs to how integrated activities in terms of networking and joint research activities are described, both of which are crucial for developing a functioning and effective European coastal observing research infrastructure. Then, an analysis of PSSs contribution, focusing on PSSs experimentation activities is provided. Reference documents for this section were D1.1, D1.2, D3.2, D3.3, D3.4, D3.5, and D4.4.

2.1.Inter and cross-regional integration in IRSs

Various integration activities took place in individual IRSs, across IRSs, and sometimes between IRSs and PSSs. Throughout the project period, IRS activities have been focused on regional coordination and integration of coastal observing efforts that include activities related to regional integration, interoperability/harmonisation, business case, and organisation. These activities are reported in detail in D3.5: "Final report on integration within and between IRSs" with examples of integration and coordination within IRSs and across regions that include automated plankton imaging developments across IRSs and PSSs, data integration from specific platforms/regions, cooperation and knowledge exchange on glider platforms, improvements on carbonate system observations, harmonising fluorescence sensor data across regions, building trans-boundary capacity on coastal risks, building cross-border collaborations in various regions, and collaboration and integration with other research infrastructures. While significant progress was made during the project period, several challenges were identified related to formal organisational structure and the business case strategies.

Three specific examples of inter- and cross-regional integration are presented here to demonstrate progress that has been made since the beginning of the project when regional coordination and integration were occurring on an ad-hoc basis. Example one is from the Kattegat-Skagerrak-Eastern North Sea (KASKEN) IRS where harmonisation activities, which are critical for JERICO-S3's Science Strategy and specific regional challenges, related to biological and carbonate system observations have been carried out together with other regions. Example two is from the Iberian Atlantic Margin (IAM) IRS where integration activities related to transnational collaboration promoted coordinated regional activities and identification of observational gaps. Example three is from the Bay of Biscay (BoB) IRS where interaction and engagements with key regional actors, research infrastructures, and initiatives were carried out which is important for JERICO-S3 to be able to respond to complex scientific questions that require additional data and expertise.

2.1.1. The harmonization work on automated plankton observations across Europe

Phytoplankton are the dominating primary producers in the global ocean, and they also dominate in coastal waters. They form the base of the marine food web. This is reflected in that phytoplankton biomass, diversity and primary production are part of the Essential Ocean Variables. Some phytoplankton are harmful and cause problems for fisheries, aquaculture, human health etc. Phytoplankton analysis has traditionally been performed using a microscope after collecting water samples in the field. This is a slow and time-consuming process. Automated analysis is essential to produce near real time data and to increase sampling frequency. In the previous JERICO projects (JERICO and JERICO-NEXT) the work on applying automated methods commenced. Workshops were arranged in Sweden and in France. In JERICO-NEXT SMHI deployed an Imaging Flow CytoBot at a mussel farm on the Swedish Skagerrak coast. CNRS/ULCO used the CytoSense in the English Channel. Other Cytosense instruments were used in the North Sea and in the Mediterranean. SMHI, SYKE and CNRS/ULCO used the Cytosense and the UVP5 during a cruise in the Baltic Sea and the Kattegat Skagerrak. The use of automated plankton imaging instruments has become widespread and is used by several JERICO partners. An example of the SMHI system is illustrated in Figure 2. Today there are approximately 15 Imaging Flow Cytobot's in Europe and a European IFCB user network is in operation (Figure 3). AI-assisted automated analysis of the millions of plankton images produced by the instruments is working well but is also in rapid development. In August 2022 an international workshop on automated plankton observations was arranged in Fiskebäckskil, Sweden. JERICO contributed to the workshop (presentations are available at https://www.globalhab.info). In JERICO-S3 the work on automated plankton analysis using the imaging approach has been carried out in several IRSs and PSSs, this is described in more detail in D3.5 where several use cases are included.

Data flows for automated plankton analyses have been set up, the general data flow for image-based data is shown in Fig. y. An important step during the data integration for automated plankton data is to create a training data set for supervised machine learning (AI-assisted image analysis) by manual identification of planktonic organisms. Annotated images are shared using repository links at the Nordic Microalgae website www.nordicmicroalgae.org to facilitate training of automated AI-assisted image classifiers, which are then used to analyse the main data set. The data output is species composition, cell abundance and biomass. Results can be used in near real time, e.g. for Harmful Algal Bloom (HAB) early warnings. The last steps are to send quality-controlled data from a National Oceanographic Data Centre (NODC), or by the data provider, to the international data repositories OBIS/EMODnet and GBIF using the Darwin Core data standard. Both human verified image data and AI-classified data can be delivered to the data repositories. IFCB data are further integrated into the Digital Twin Ocean (DTO) through EMODnet and the DTO-BioFlow project.

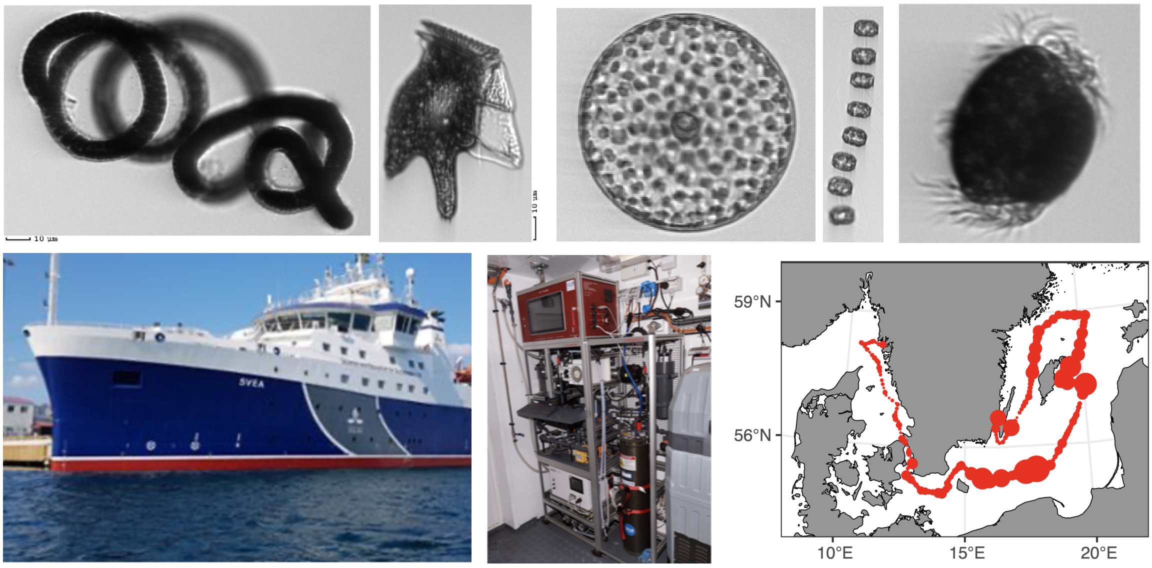

Figure 2. Top: Examples of phytoplankton images from the Imaging Flow Cytobot on R/V Svea. Bottom: R/V Svea and the Ferrybox system with IFCB. The map illustrates the distribution and biovolume (~biomass) of the toxin producing cyanobacteria Nodularia spumigena in July 2023. Preliminary data from IFCB on R/V Svea.

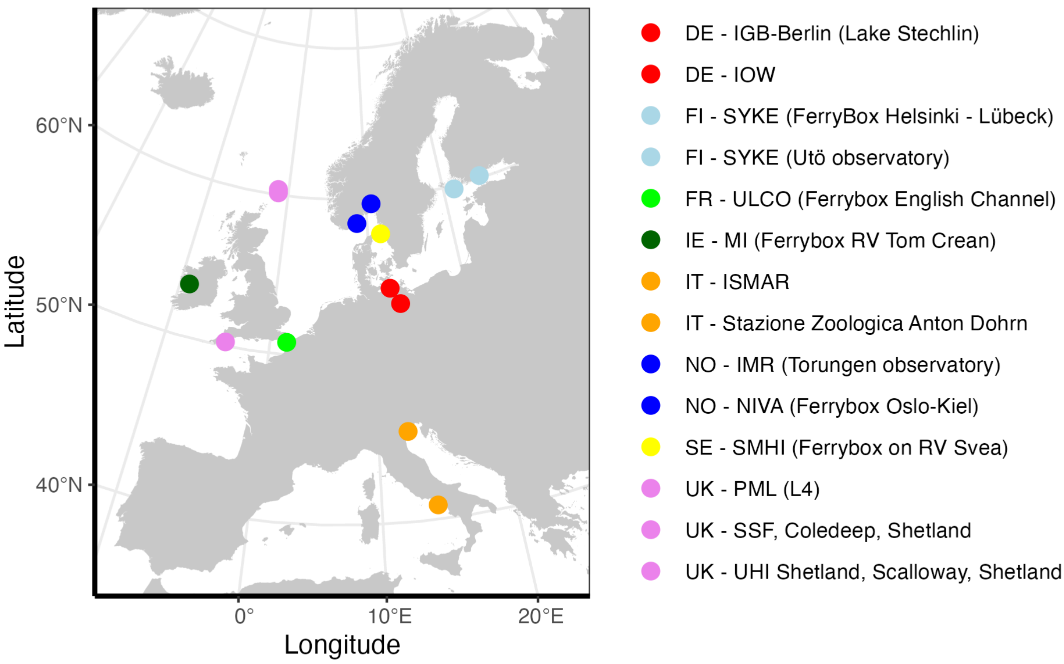

Figure 3. Approximate locations of Imaging Flow Cytobots in Europe and names of institutes operating the instruments (May 2024).

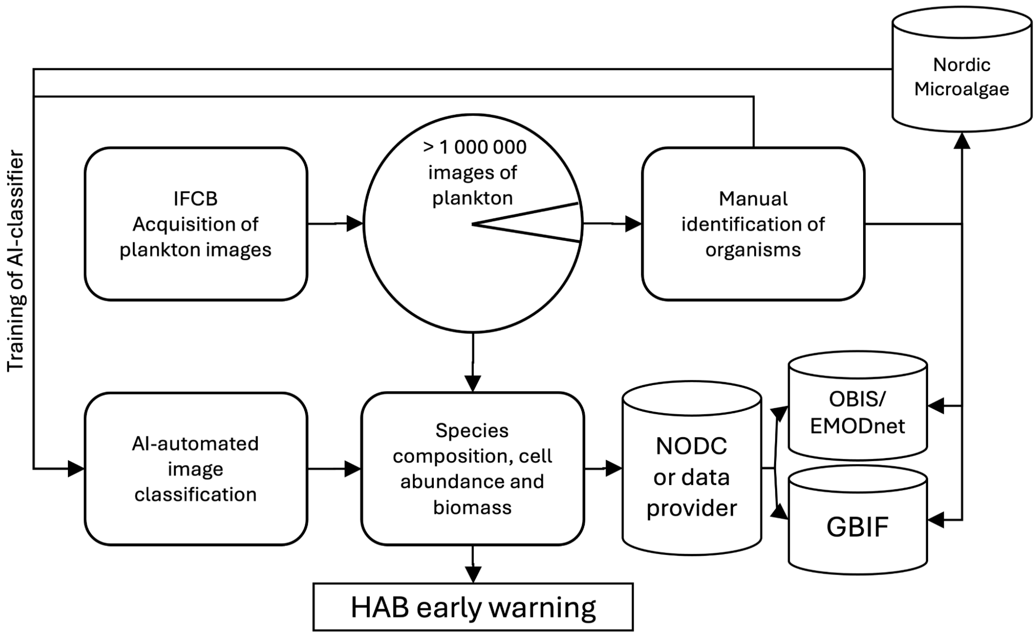

Figure 4. The figure illustrates the most important steps in the data flow from images of plankton acquired using the Imaging Flow Cytobot (IFCB).

At present (June 2024) the work on implementing new AI-approaches for automated image-based plankton analysis is ongoing and not fully standardised. Standardisation is ongoing through the European IFCB user network and through production of a best practices document in the EuroGOOS Biological Observations Working Group (BIOWG). The previous and ongoing work in JERICO form important contributions. Standardisations are likely best carried out at the regional level where the phytoplankton communities are similar. This means that training sets of annotated images from the Baltic, the North Sea, the Bay of Biscay, the Mediterranean etc. are best shared and used in the respective regions. But the software tools can be pan-European.

2.1.2. Answering to Coastal Ocean challenges in the Iberian Atlantic Margin: the importance of integration of observations and articulation of efforts

The Iberian Atlantic Margin comprises a broad coastal ocean area that extends over the continental coast of Portugal and Spain along the Southwest and West Iberian Peninsula to the Atlantic area of the Canary Islands. It is an area well exposed to a broad range of forcing agents and influences, namely those promoted by the highly energetic North Atlantic conditions, by the Mediterranean outflow through the Gibraltar Strait or by the transport of southward waters masses along the NW African slope. The Iberian Atlantic Margin IRS gathers 3 institutions – Instituto Hidrográfico, in Portugal, and Puertos del Estado and PLOCAN in Spain - that are key actors in the observation of the coastal ocean, maintaining real-time monitoring infrastructures that include multiparametric buoys, wave buoys, HF radar stations and coastal tide gauge stations and gliders (Figure 5). The MONIZEE infrastructure maintained by Instituto Hidrográfico extends over the complete continental margin of Portugal, with some capacities installed also in the Azores and Madeira Archipelagos. In Spain, data from PdE observing platforms are integrated in near-real time at the PdE PORTUS visualisation, extending over the complete Spanish continental margin and the Balearic and Canary Islands Archipelagos, while PLOCAN integrates observation capacities installed over the Canary Islands Archipelago and a pool of gliders that operate in the broader Atlantic domain.

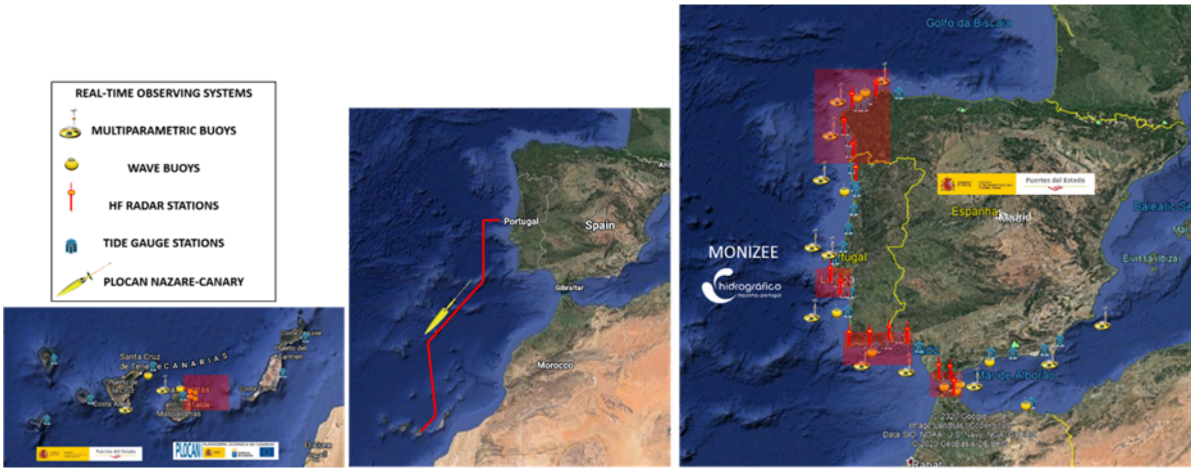

Figure 5. The real-time observing platforms that contribute to the Iberian Atlantic Margin IRS

The interaction between these three partners inside the IAM IRS was developed along two main axes. The first axis aimed to explore the potential of integration of the coastal ocean observations collected by the different systems operated by IH, PdE and PLOCAN. Two types of processes are explored, focussing specific time periods during which a comprehensive set of observations is available to explore those processes. Transboundary transport and connectivity processes explore the different ways in which the continental margin, acting as a waveguide, can propagate the coastal ocean response to disturbances through long distances, affecting a large part of the integrated regional site and beyond (Figure 6). The extreme events study explores how energetic events impacting the Iberian Atlantic Margin are expressed in the different parts of the larger regional domain.

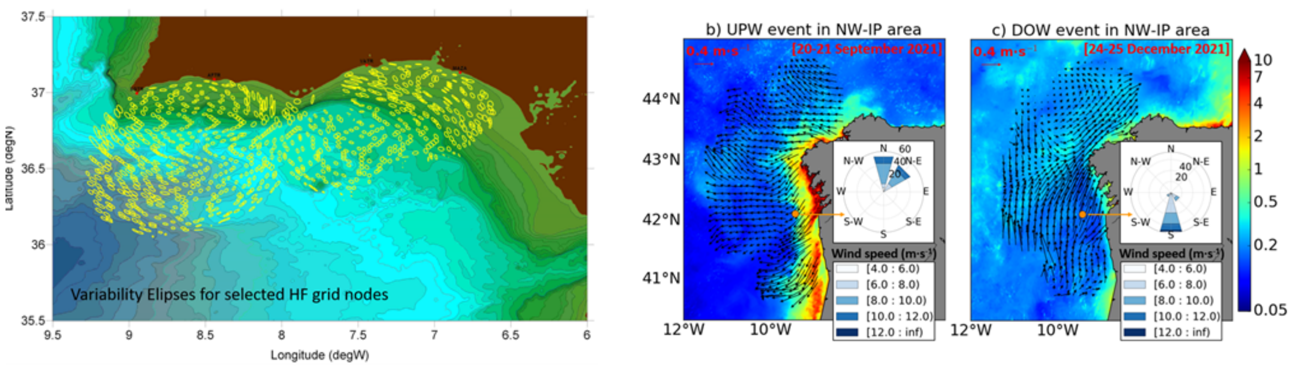

Figure 6. (Right panel) Surface current variability ellipses in the southern Iberian area from HF radar measurements collected during in March 2020 (Vitorino & Lima, 2023); (Left panel) integrated analysis of upwelling and downwelling conditions in the NW Iberian area, combining

HF radar measurements, multiparametric buoy measurements and remote sensing (Lorente et al., 2023).

Besides its intrinsic scientific interest, the work developed in this first axis also provided the opportunity to discuss potential services related with coastal ocean observations exploration and integration. Some of the ideas derived from this discussion are presently being implemented by IH as part of a Virtual Lab in development as part of the Blue Cloud 2026 project. This Virtual Lab aims specifically to open to users the access to tools from which users can explore and integrate coastal ocean data (in particular the observations collected by JERICO-RI) and other complementary datasets.

Answering to the different coastal ocean challenges also ask for an articulated approach in which the effort of the different national institutions can be combined to improve the observation of the coastal ocean areas and associated forcing and to fill the existent gaps. This articulation of efforts corresponds to the second axis of development of the IAM IRS. As one example of this articulation, we can refer to the close communication between IH (Portugal) and PdE (Spain) in the operation of the HF radar capacities installed in the transboundary areas between the two countries (in the NW and SW Iberian coasts). These capacities were installed through several projects in which both institutions participate as partners and the management of the capacities is the object of a continued discussion.

A second example of the articulation of efforts to fill the gaps in the coastal ocean observations in the IAM IRS is the collaboration between IH and PLOCAN to insure the maintenance of a glider line between the W Portuguese coast and the Canary Islands. This collaboration is, until now, based on the glider capacities of PLOCAN and the ship opportunities provided by IH on the Portuguese coast. The data collected are providing important information about the way in which the Northeast Atlantic circulation is forcing the W Iberian coastal ocean, namely a poleward slope current (Figure 7). The collaboration is also promoting an important transfer of knowledge in glider operation, allowing IH to start gaining the know-how required to operate this kind of vehicle. The collaboration profited from the opportunities provided by the JERICO-S3 TA program (through the CBONDEX TA project) and is now entering in a next phase, with the acquisition and start of operation of the first two gliders of IH, which will in the future will used in articulation with the PLOCAN gliders.

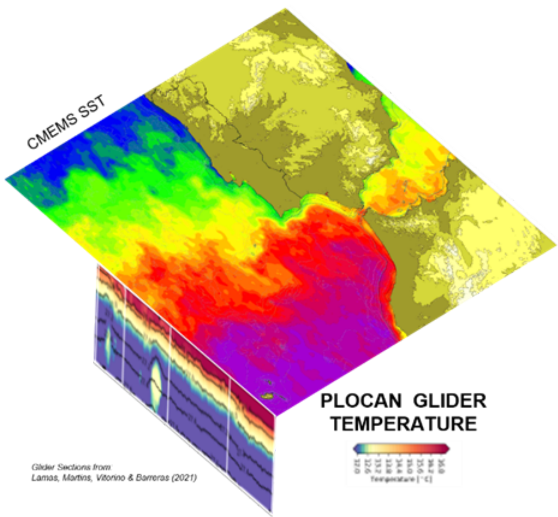

Figure 7. Collaboration between IH and PLOCAN in the maintenance of a long glider section, providing key observations on the Northeastern Atlantic influence on the W Iberian coastal ocean.

2.1.3. Understanding and Collaborating for Coastal Observation in the Bay of Biscay

The Bay of Biscay, characterized by intricated bathy-topographical features and significant physical forcings, and other aspects such as important fisheries, aquaculture facilities and the. fragility of the coastline, is a focal point for research. Two key infrastructures, ILICO in France and EuskOOS in Spain, with significant activities in coastal ocean observation and prediction, are part of JERICO Bay of Biscay IRS. Additional stakeholders include research platforms, universities, and water agencies in both countries. Cross-boundary collaborations, like the Ireland-Biscay-Iberia Regional Operational Oceanographic System (IBI-ROOS) and the Basque Coast Scientific Interest Grouping, facilitate regional cooperation. Notably, the KOSTA RISK LabCom, a joint venture between French and Spanish institutions, focuses on coastal risk management.

Efforts were needed to map coastal observation infrastructures in the Bay of Biscay for future integration into a pan-European infrastructure. To this end, in December 2020, the IRS team organised a meeting with the main actors in the Bay of Biscay (external to JERICO) to work collaboratively in the RI mapping for this region (Figure 7Figure 8).

Figure 8. Images of the IRS Bay of Biscay workshop held In Irun (Spain) on the 30 Nov 2021 - 1 Dec 2021, which outcomes are presented in D3.2.

This workshop constituted a first key step for the organization in the Bay of Biscay (and our own organizations) of the future European infrastructure. The targeted audience for this workshop were the representatives of organisations that were major contributors to the observation of the coastal component of the Bay of Biscay, including the Bordeaux University, OFB – PNMSA, Museum National d'Histoire Naturelle, IEO – Centro oceanográfico de Gijón, U Bordeaux OASU, BIMEP, Centre Rivages Pro Tech of SUEZ, PIE UPU /EHU, ILICO, IBIROOS and KOSTARISK.

The workshop on coastal observation in the Bay of Biscay allowed progress in the elaboration of a comprehensive inventory of observing infrastructures in the Bay, user identification, and emphasised the need of improving the monitoring of key variables beyond physics and biogeochemistry. This action was key to address gaps, enhance integration, and advance coastal observation efforts in the Bay of Biscay.

2.2.Experimentation in PSSs

In this section, we rely on D4.4 as the main reference document. D4.4 provides a thorough overview of PSS activities, emphasizing collaboration between work packages and offering a synthesis of PSS implementation, success stories and remaining gaps. Additionally, it presents topical syntheses on experimentation/collaboration on key issues like the carbonate system, phytoplankton dynamics, and best practices, highlighting the progress done during JERICO-S3. The **series of demonstration actions undertaken by the PSS addresses various issues related to ocean and coastal dynamics, ecosystem health, and multidisciplinary interactions**, focusing on specific challenges and research objectives within each region but contributing to a broader understanding of marine and coastal systems. All PSS actions were transnational, and observations were implemented by using practical real-world studies such as coordinated multiplatform observations, methods of harmonisation or connection with end-users.

The key demonstration actions tackled by JERICO-S3 PSS which contributed to the implementation of integrated observations are summarised in the following table and grouped following their relation to the different KSC and SSCs (Table 1). The regions involved and the different levels of integration at different levels are also detailed. Three specific examples which showcase progress beyond the state of the art, interactions with other RIs and transnational approaches, are detailed further in the following subsections.

Table 1. Summary of experimentation actions showcasing progress towards the implementation of integrated ocean observations: regions involved, relation to JERICO Science Strategy and type of integration considering different items (integration of data, data-models, methods, sensors, platforms, approaches, disciplines, regions, RIs). In bold, the examples highlighted further down. The number of the specific action in each region is given after the symbol #, as they are referred in D4.4.

Actions main topic	Involved regions	Relation to KSC/ SSC	Type of Integration
Integrated biological observations for Eutrophication Status Assessments, Ocean Colour applications, modelling and uptake of new technologies	GoF (#1, #3, #4 & #7) NW-MED (#4) NSEA & CHANNEL #3, (#4), CRETAN (#2, #5)	KSC1 (ecosystem biogeochemistry), KSC2 (impacts of rare and extreme events), KSC3 (anthropogenic impacts)	data, platforms, methods, disciplines, data-models,
Mapping the deep-water oxygen conditions	GoF(#5)	KSC1(ecosystem biogeochemistry)	data, platforms
Extreme events affecting phytoplankton	GoF (#8) NW-MED (#3) CRETAN(#3)	KSC2 (Impacts of rare and extreme events)	platforms, disciplines, regions, RIs

Reconstruction of the 3D coastal dynamics	NW-MED (#1)	KSC1(ecosystem biogeochemistry connectivity and transport)	data-models, platforms, disciplines
Impacts of river discharge to coastal ecosystems	NW-MED (#2) NSEA & CHANNEL (#2)	KSC1(ecosystem biogeochemistry connectivity and transport) KSC3(anthropogenic impacts)	data, methods, platforms, disciplines, RIs
Harmonized observations of regional C fluxes, plankton biomass, diversity, and productivity dynamics	NSEA & CHANNEL (#3)	KSC1(ecosystem biogeochemistry)	data, platforms, methods
Intercomparison of phytoplankton distribution using data integration	CHANNEL(#5)	KSC1(ecosystem biogeochemistry)	data, data-models, platforms
Solubility and biological pumps	CRETAN (#1)	KSC1 (Carbon budget and CO2 system)	data, sensors, methods
Improved approximations of Primary Production	CRETAN (#2)	KSC1(ecosystem biogeochemistry)	data-model, platforms
Upscale regional data to a wider scale	CRETAN (#4)	KSC1 (Carbon budget and CO2 system)	data-model
New sampling strategies, new technologies, best practices	CRETAN (#5)	KSC1(ecosystem biogeochemistry)	data, data-model, methods

2.2.1. Integrated biological observations for Eutrophication Status Assessments, Ocean Colour applications, modelling, and uptake of new technologies.

The first example to be highlighted is constituted by the different actions towards integration of biological observations and their use for the monitoring and forecasting of eutrophication and phytoplankton blooms. The activities undertaken spanned from the harmonisation of observations (methods, sensors) and use of new methods to the use of multiplatform data, integration with satellite products and modelling. Activities took place in all PSS regions and links were established towards the activities of WP7 through the development of a D2PTS (see section 4.2). The activities showcase integration at the level of data, platforms, disciplines, data-model and methods.

Activities focused on:

- Improving harmonisation and comparability of the biological observing methods in the water column within PSSs, including other actors within the region, as well as between PSS and IRS (**PSS GoF#1**)
- Strengthened the regional dialogue in GoF with Ocean Color EO community and took regionally important steps ahead in using such data by describing relationships between various optical proxies for phytoplankton and CDOM (**PSS GoF #3)**

- Develop an automated routine for near real time recognition of cyanobacteria biomass and species structure was created using imaging methods and artificial intelligence-based classification (**PSS GoF #4)**
- Develop a novel forecasting system using synthesis of multiplatform data as an initial estimate of cyanobacteria bloom status, with the end aim to create an expert tool to better estimate the current situation on existing data, and the development of the bloom situation (**PSS GoF #7)**
- Development of a biogeochemical (BGC) product, based on the multi-platform approach, combining in situ data, a regional 3D model, and a neural network for CO_2 fluxes. **(PSS NW MED #4)**
- Sharing and developing of Best Practices for plankton imagery and fluorometry, and contributing to regional harmonisation of methods (**PSS NSEA & CHANNEL #3)**
- Developing and demonstrating new products on impacts of eutrophication for regional ecosystem assessments and reporting **(PSS NSEA & CHANNEL #4)**
- Improving estimation of primary production using modelling and testing new in situ technologies **(PSS Cretan #2, #5)**

In the case of the Gulf of Finland, harmonising biological observations across transnational platforms has been a key priority, advancing comparability and usability of results. These activities also included participants from other PSSs and IRSs, as well as observing communities outside JERICO. Several data collection surveys were conducted, providing additional data for ecosystem assessment, modelling and EO products validation, and revealing annual climatologies and long-term trends of Chla concentrations (suggesting persistent eutrophication). Improved streamline of in-situ observations with EO data was achieved through the development of a web service where FerryBox results can be overlayed with EO data (TARKKA service). As detailed in the previous section, developments of phytoplankton imaging with a tuned Convolutional Neural Network (CNN) classifier resulted in operational near real time data flow for research and public services. The results were used in operational weekly algae reviews in the Gulf of Finland and widely disseminated (swell portal, see Kraft et al (2022). Weekly algae review, launched by SYKE in summer, used the data sources described above, to inform the public and authorities on nuisance algae blooms (see SYKE Baltic Sea portal, which is also part of a D2PTS example, and SYKE website). In addition, a modelling system was designed to help in creating short term forecasts for cyanobacteria situation development. The system is based on synthesis of available data from satellites, FerryBox measurements and potentially other sources. As such the result of the system is given as an approximation of the cyanobacterial state, as well as a reliability field, giving an estimate on the uncertainty of the given area. Next steps in this development would use the generated fields as initial state for drift model, OpenDrift along with forecasts from NEMO circulation model, to estimate the algae situation 1-5 days forward.

In the NW Med, BGC products were developed based on a neural network and a regional model and supported by sustained in situ observations (Argo floats, gliders, coastal buoys and research vessels) of physical and BGC variables (T, S, O_2, pH, pCO_2, TA, TC, nutrients). A new module in the 3D coupled physical-biogeochemical-chemical model SYMPHONIE ECO3M-S was developed to simulate the DIC budget and estimate the air-sea CO_2 fluxes in the NW Mediterranean Sea (Ulses et al., 2022). The model underlined the key role of the coastal zone near the Rhone River as a CO_2 sink on the annual CO_2 budget. Moreover, a new neural network (NN) has been trained and validated for the MedSea NW (CANYON-MED; Fourrier et al., 2020, 2022) to provide synthetic data on the carbonate system and nutrients. The NN was used to reconstruct pH measurements in some coastal water stations, being able to fill the gaps to predict CO_2 variables in these areas, sensitive to climate change and anthropogenic pressure.

In the NSEA & CHANNEL knowledge transfer on phytoplankton observations was carried out by conducting several joint cruises and in situ measuring campaigns (including The Plankton dynamic Sensor Package (PSP)described in 4.1.1), and by series of workshops. Development of procedures to overlay monitoring data (SRN, REPHY, and REPHYTOX) with existing datasets was done, contributing to filling OSPAR data gaps an improve quality control and calibration to make data useful for OSPAR and the MSFD. Combining model results and OC products (Chl-a), Ifremer was able to define nutrient reduction scenarios for several rivers for the French part of the CHANNEL PSS. Other significant achievements in this area were related to (i) the tests of the reliability of satellite and modelling-derived products integration in the eutrophication assessment procedure directly (as data to be process) or indirectly (as high-resolution data to support assessment based on low resolution data) and (ii) the development and test of various monitoring scenarios together with their impact on eutrophication assessments. All these results and expertise were combined with other contributions from the OSPAR and MSFD communities, from local to EU levels, contributing to the possibility of proposing a complete and quantitative eutrophication assessment in the Channel area.

In the Cretan Sea, improvements in modelling of primary production were done, by updating models for light attenuation, nutrient assimilation, and carbon-to-chlorophyll ratio, and testing the outcomes with Ocean Colour and observation data. Jointly with other PSSs and sensor manufacturers, series of tests with new sensors were conducted. LabSTAF fluorometer (Chelsea Technologies) was noted sensitive enough to detect reliably photosynthetic variables even in the ultraoligotrophic conditions of Cretan Sea, which has not been possible with previous models of primary productivity fluorometers. Part of the tests were done in conjunction with mesocosms experiments (next section).

2.2.2. Extreme events affecting phytoplankton.

In the demonstration activities conducted on the issue of extreme events affecting phytoplankton, the main aspects to be highlighted are the strong iteration and coordination between three JERICO PSSs but also with other RIs, since for all three regions there were specific mesocosm experiments in collaboration with AQUACOSM–RI. Collaborations and exchanges of knowledge were successfully established regarding the responses of phytoplankton communities to extreme events between the NW-MED, GoF and CRETAN PSSs producing the scientific added-value to highlight the consequences of global change in the marine system.

The mesocosm activities undertaken were accompanied with different in-situ and satellite data analyses. The areas concerned were the Gulf of Finland, the NW Mediterranean and the Cretan Sea and different links were established towards the activities of TA WP8, since three Transnational Access projects were funded, providing the access to the mesocosm experiment. All the projects were linked to AQUACOSM-plus partners, and they included altogether 13 visitors.

The activities on the characterization of the effect of extreme events on phytoplankton showcased integration at the level of platforms, regions, RIs and disciplines, and focused on:

- The effect of heatwave on the Gulf of Finland plankton ecosystem **(GoF PSS#8)**
- The effects of terrestrial dissolved organic matter input and temperature increase on phytoplankton community responses **(NW-MED PSS # 3)**
- Optimization of phytoplankton monitoring methods and the effect of extreme rain events **(CRETAN PSS #3)**

In the Gulf of Finland, the mesocosm experiment was conducted in Syke indoor mesocosm in 2022, based on temperature anomalies observed from a FerryBox transect between Helsinki (FI) and Travemunde (DE) (Elovaara et al 2021). Experiment included three TA projects. Project AQUA-Action 1 by IGB (Leibniz Institute of Freshwater Ecology and Inland Fisheries, led by Dr. Stella Berger) studied how the Baltic Sea plankton community responded to extreme events such as sudden shifts in temperature and to share knowledge and harmonised competences for plankton imaging technologies. Project OBS-EXP-Bridge by CNRS-MARBEC (Marine Biodiversity, Exploitation and Conservation, CNRS – Université de Montpellier, led by Dr. Francesca Vidussi) focused on the i) study of the metabolic and structural responses of plankton communities of the Baltic Sea to a simulates heatwave using high-frequency sensors; ii) the comparison of the high-frequency data obtained with those acquired by host SYKE laboratory; and iii) the comparison of the responses of the Baltic Sea communities to heat wave obtained with those obtained previously in the NW-Med Sea during in situ mesocosm experimentations. Project BalHObEx by HCMR (Hellenic Centre for Marine Research, led by Iordanis Magiopoulos) investigated the effects of extreme heat waves on the marine plankton food web via a mesocosm experiment and compared and combined them with findings in the natural environment using measurements from FerryBox transect.

In NW Med, a large mesocosm experimentation was performed in May 2021 to investigate marine plankton community responses to terrestrial dissolved organic matter input. This experiment was combined with a parallel microcosm experiment to also study the effect of water temperature increases in the framework of the French ANR national project. Using AQUACOSM-plus TA funds, Dr. Carolina Cantoni (CNR) from the JERICO-S3 consortium participated in the experiment to study the effect of extreme events on phytoplankton by monitoring alkalinity and pH. In this way, a synergy between JERICO-S3 observing community and AQUACOSM-plus mesocosm experimenting community was established.

In the Cretan Sea, a mesocosm experiment studied the effect of episodic introduction of airborne microbes into the marine ecosystem. The aim was to establish new sampling strategies and best practices. The experimental plan was agreed within partnership (including industry partner Chelsea Technologies Ltd), and AQUACOSM-plus. In addition, the effect of extreme rain events on phytoplankton was studied using two additional multiplatform experiments using in situ and satellite data.

2.2.3. Impacts of river discharge to coastal ecosystems

A final example includes specific activities to characterise and study the impact of river exchanges on coastal ecosystems. The activities undertaken spanned from the use of methods for the improvement of river data to a specific multiplatform field campaign to study river ocean interactions. The areas concerned were the NW Mediterranean and the North Sea and Channel and showcased integration at the level of data, platforms, disciplines, and methods.

Activities focused on:

- A field campaign in front of the Ebro River with operational platforms to study the impact of river inputs on coastal ecosystems **(PSS NW-MED #2)**
- Methodological developments for harmonised data for riverine input including both discharge and water quality measurements **(NSEA and CHANNEL PSS #2)**

The main input for the action in the NW Med was the completion of a joint campaign in September 2021 in front of the Ebro River. This campaign was dedicated as a demonstration action using operational services (buoys, satellites, glider, boat) to study the impacts of river discharge to coastal ecosystems and acquire glider ADCP data to validate/compare with HF Radar data. HF Radar measurement highlighted the high frequency spatio-temporal variability of surface currents including inertial currents which can play an important role in the coastal area in mixing processes and resuspension of sediment in the coastal area. The action demonstrated the potential of combining glider and HF Radar to monitor the coastal dynamics.

In the North Sea and Channel, the activities consisted on the testing and developing of gap filling methods to fill gaps in data and inferring high temporal resolution water quality measurements (nitrate loads in the Elbe and Seine rivers). It is worth highlighting that these methods were tested on large rivers with high frequency monitoring. To go further, these methods should be applied on medium and small rivers with less frequent monitoring. Further collaboration among JERICO and DANUBIUS RIs were highlighted as key for enabling the testing of methods on a larger variety of river-sea systems and providing better, more generalizable, conclusions and a more robust dataset.

3.Integrated observation through technical innovation

3.1.New technical solutions for ocean observation

The main reference documents for this section are the deliverables from WP7, D7.3, D7.4 D7.7 and D7.9 (which was in development while we wrote the present section). In this subsection we provide a short description of three main developments which have the commonality of providing advanced technical solutions for integrated ocean observation.

3.1.1. The Plankton dynamic Sensor Package (PSP)

The Plankton dynamics Sensor Package (PSP) was built on the EGIM technology that was developed by the EMSO Community in the EMSODev project, which led to the design of the so-called cEGIM or coastal EGIM (Figure 9). The new module was initially designed by and for the JERICO community to facilitate and enhance the observation of coastal parameters (water column) in an interoperable manner. A prototype was developed to showcase its concept through a demonstration at Luc-sur-Mer, within the English Channel Pilot Super Site. Equipped with four sensors (NKE MP6, BBE Moldaenke Fluoroprobe, Hydroptic/LOV UVP6, and SATLANTIC ISUS) provided by JERICO-S3 partners, the prototype is designed to be deployed on the seabed. Demonstration phase was completed in 2023, the results of which are being documented in the upcoming Deliverable D7.9 and a related journal article is in preparation.

The coastal EGIM, when equipped with the related sensors, can contribute to the in situ data requirements of the following KSC (SSCs) : KSC#1 “Assessing changes under the combined influence of global and local drivers” (all SSCs), KSC#2 “Assessing impacts of extreme events” (all SCCs), KSC3 “Unravelling and predicting the impacts of natural and anthropogenic changes” (Resolving climate change and anthropogenic impacts).

The module is controlled by a single communication and power unit called COSTOF2, designed by Ifremer, it is designed to be transposable to other JERICO-RI sites and constitutes a platform that is then meant to be replicable and provide a common base for all sites. Data provision can also be standardised through the use of OGC open standards in the case when real-time communication is available at the site (e.g. via cable or acoustic modem connectivity).

By design and thanks to years of development the module can serve several scientific and societal needs. A list of drivers is available for more than twenty commercially available scientific-grade sensors that cover physics, chemistry, and biology. On request, new drivers can be developed, and the aim of future developments is to open further the platform hardware so users can develop their own drivers.

The innovation brought by Jerico-S3 lies in the addition of new biologically related sensors (zooplankton and nitrate), the addition of a processing unit that brings self-awareness to the module and can automatically adapt the sampling strategy as a function of observations (e.g. activate sensors, modify sampling rate), and the provision of a standardised data flow of real-time data.

Because of limited project resources only one prototype was designed and developed, for a case study that could show new perspectives and contrast with former work in EMSODev, add real value and impact. A broad consultation process involving the JERICO-S3 scientific and technical community led to two key choices, mainly led by impact and feasibility. Coastal plankton dynamics was chosen as the main scientific driver and the English Channel Pilot Super-Site as demonstration site.

The technology proved efficient at detecting algal bloom and enabling automation, with rich synchronised ancillary data. The technology can be replicated in other regions of similar characteristics (i.e. estuarine waters with recurrent algal blooms). Further, the COSTOF2 can be replicated with different sensor packages for other applications, thus enabling replicability at other sites, in other environmental conditions, and thus addressing other challenges. As summarised in Deliverable D7.3, the main benefits of the cEGIM technological innovation mainly lie in the use of its core electronic unit, which brings:

- A high TRL and high reliability solution for interfacing sensors and communication systems,

● Versatility as it can operate in a variety of coastal environments: underwater (benthic or water column), at the sea surface (buoys) or on jetties, pontoons etc, either autonomously or linked to an energy/communication link,

● Access to a wide library of existing sensor drivers, inherited from coastal and open ocean applications,

● Openness: easy integration of new sensors and functions, that will in turn benefit the whole cEGIM user community,

● Possibility of adaptive sampling based on innovative data science algorithms,

● Technical convergence with EMSO Generic Instrument Module,

● Interoperability.

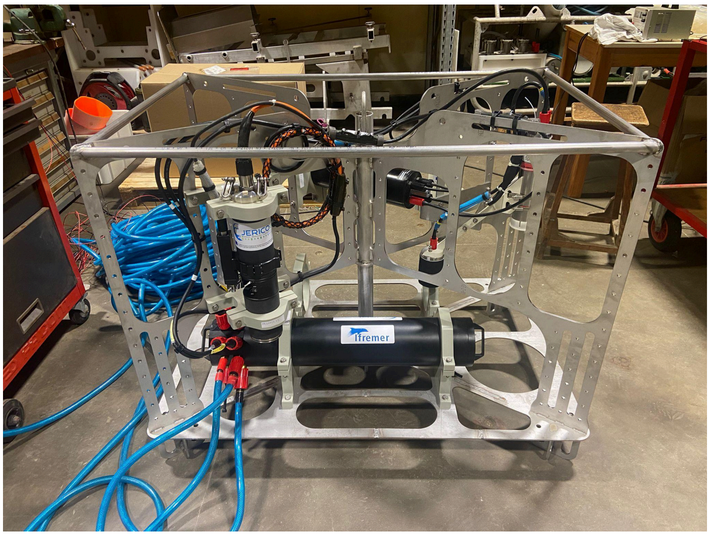

Figure 9. cEGIM before deployment in cabled mode at Sainte Anne du Portzic (source: Ifremer)

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3.1.2. The Autonomous Coastal Observing Benthic Station - ACOBS

ACOBS is aiming at assessing the relationships between spatio-temporal changes in the intensity of mineralization processes taking place at the sediment-water interface and those of potential controlling factors such as bottom seawater characteristics (e.g. temperature, oxygen concentration…) and benthic macrofauna activity including sediment reworking (Figure 10). ACOBS is therefore designed to simultaneously acquire physical, chemical, biogeochemical and biological data sets with the overall aim to unravel the functional links between these different types of parameters. By doing so, ACOBS is contributing to the integrative multidisciplinary approach put forward by JERICO-RI for the integrative observation of the European Coastal Ocean (see D1.1).

ACOBS is partly based on the integration of technological developments achieved within previous JERICO projects (i.e., measurements of diffusive and total oxygen fluxes, assessment of macrobenthic activity and bioturbation). It also includes new technological developments regarding: (1) the measurements of total oxygen fluxes, and (2) the monitoring of macrobenthic activity and bioturbation at the sediment-water interface and in the upper sediment column. The main new technological developments within JERICO-S3 include: (1)

the integration of the BEATRISS system, (2) the design and building of a new benthic chamber allowing for repeated measurements of total oxygen fluxes, and (3) the implementation of a plane view system and associated software developments for the processing of time series of top-down images of the sediment-water interface. Details on the overall set of included sensors are provided in Deliverable D7.4.

Due to the fragility of oxygen microelectrodes, ACOBS has been designed to achieve short-term (i.e., typically a few days) repeated deployments in both transitional and coastal (i.e., over the whole continental shelf) environments. Along the same line, data storage is achieved by internal loggers for all ACOBS components. Moreover, due to the limitation in the penetration of the Sediment Image Profiler within the sediment column, ACOBS is mainly designed to be used in cohesive (fine) sediments although it could be also deployed in reduced configurations within sandy sediments. Both the deployment strategy and the exact configuration of the device can thus be adapted to the specificities of both the tackled scientific question and the regional/local environment.

There are two main levels of integration associated with the development of ACOBS. First ACOBS is integrating, within the same, device a large set of sensors (see above and D1.4 for a complete list). Second, ACOBS provides integrated simultaneous time series of physical (e.g. temperature), chemical (e.g., oxygen concentration), biogeochemical (e.g., O2 fluxes) and biological (e.g., macrobenthos activity and bioturbation), which will facilitate data processing and interpretation especially in terms of the identification of factors controlling oxygen fluxes at the sediment-water interface.

Figure 10. Two general views of the main frame of ACOBS showing (1) the microelectrode profiler (O2 diffusive fluxes), (2) the benthic chamber (O2 total fluxes), (3) the BEATRISS system (O2 total fluxes), and (4) the Eddy-covariance system (O2 total fluxes. . (Taken from D1.4)

Due to its specificities and plasticity, ACOBS can contribute to a large variety of the Scientific challenges (both KSCs and SSCs) identified by JERICO-RI (see the list in D1.1). Currently foreseen applications are mostly dealing with KSC#1 "Assessing changes under the combined influence of global and local drivers" (SSCs "Land Sea ocean continuum. impacts of land derived discharges and exchanges with open ocean" and "Ecosystem biogeochemical processes and interactions") and KSC#2 "Assessing impacts of extreme events" (SSC "Impacts of rare and extreme events").

The field tests of individual ACOBS components started in September 2023 and the first deployment of ACOBS in an integrated configuration will take place during May 2024 in the Arcachon Lagoon.

3.1.3. The Water-Sample filtering and Preservation device - WASP

Finally, the Water-Sample filtering and Preservation device - WASP is a system composed of water samplers and filtration systems, which in Jerico-S3 have been integrated with a ferrybox system (Figure 11). The WASP consists primarily of two sampling devices: a modified Phytoplankton and Particle Sampler (PPS) and an ISCO refrigerated autosampler. The samplers operate while integrated with a FerryBox platform that is equipped with sensors for measuring salinity and temperature, chlorophyll-a, fluorescence, coloured dissolved organic matter fluorescence (cDOM), and turbidity. The PPS portion of the WASP has been disassembled from its original in situ deployment configuration and modified for use on a FerryBox system, its main function to filter seawater for the collection of phytoplankton for environmental DNA (eDNA).

Thus, the developed WASP device enables integrated observations in relation with the observation of phytoplankton which can be related to the following KSC (SSCs): KSC#1 "Assessing changes under the combined influence of global and local drivers" (Biodiversity trends), KSC#2 "Assessing impacts of extreme events" (Impacts of rare and extreme events), KSC3 "Unravelling and predicting the impacts of natural and anthropogenic changes" (Resolving climate change and anthropogenic impacts, disentangling impacts/scales).

Figure 11. Ferry line equipped with a ferrybox system that will be used for the demonstration (left). Commercial system adapted to a portable cooling enclosure for sample collection and preservation (right).

In terms of integration, the main interest for JERICO RI and other communities is the demonstration of the potential of a broadly adopted cost-effective platform, the ferrybox, to integrate a new capacity for measurements of a broad variety of life forms. The first results will also guide the community of operators in understanding the potential and limitations of the method, its porting to other platforms, and the production of reusable methods, SOPs., etc. The method is of particular interest to communities interested in the study of biological processes, leading to other disciplines, from primary production and ocean health assessment indicators to the discovery and study of new species, development of new sensors, validation of remote sensing techniques.

First tests have been carried out in the Eastern North Sea but can be reproduced on other vessels equipped with a ferrybox system, requiring investment in the equipment (commercially available, moderate adaptations needed) and applying the method described in JERICO-S3 deliverable D7.4. Besides the inherent value of the integration described above, preservation techniques were tested and compared, leading to results that are valuable for operators and users of such sampling, filtering and preservation systems.

3.2.Data-to-Products Thematic Services

In this section, the main reference document is the deliverable D7.5 on Pilot D2PTS demonstration: Data-to-Products Thematic Services, Virtual access, Coastal Services. Two examples of D2PTS are showcased here, as tools developed by JERICO which contribute to the integration of coastal observations in the field of ocean hydrography and biogeochemical processes.

3.2.1. Estimation of sea water masses types and transport monitoring from Gliders

The **Glider transport toolbox** (Juza, 2022; https://doi.org/10.25704/RBZS-V023) has been developed in the framework of WP7 for the processing of glider data to monitor and visualise the ocean circulation and variability as observed by glider measurements. The developed metrics and diagnostics are: (1) vertical sections of temperature, salinity, density and geostrophic velocity, (2) Temperature/salinity diagrams and water mass identification, and geostrophic transports (total and per water mass). This tool is executed in an operational way in the Ibiza Channel integrating automatically new missions and generating updated figures in the application "Sub-regional Mediterranean Sea Indicators" (https://apps.socib.es/subregmed-indicators/; Juza et al., 2020; 2021).

The glider toolbox applications are mostly dealing with KSC#1 "Assessing changes under the combined influence of global and local drivers" (SSC "Ecosystem biogeochemical processes and interactions"), the application process-oriented studies (in relation with KSC#2 and eventually KSC#3) will depend on the sampling strategy designed for the glider missions.

The added value of this development in terms of integration is that it offers the possibility for multi-disciplinary variables integration. The tool also allows the use of biogeochemical (BGC) data from glider measurements (chlorophyll-a concentration, oxygen concentration and saturation, and turbidity). The processing applied to BGC data is the same as for the physical variables in order to be able to relate BGC values to the hydrographic properties and water mass transports. This tool allows addressing and relating key scientific topics that are relevant for society: climate change, ocean health and biological impacts.

The tool has been developed and applied to the SOCIB glider endurance line in the Ibiza Channel. This area is a well-known biodiversity hotspot (Coll et al., 2010) and a choke point of the western Mediterranean Sea (Heslop et al., 2012; Juza et al., 2013) with complex topography and circulation. The significant variability of the meridional circulation at the scales of weeks and few kilometres has been explained through the variability of the water masses in the vertical, with very relevant implications on the marine ecosystem (e.g., Bluefin Tuna, Jellyfish). The structure of the toolbox allows adapting the codes through the modifying of specific/individual functions. In particular, the toolbox could be extended to (1) model data interpolated at the glider space-time positions, and (2) gliders deployed in other channels (such as in Gulf of Finland). This work follows several Open Science principles providing open-source code, open access publication and open access application (Juza and Tintoré, 2020).

3.2.2. Biogeochemical (BGC) state of coastal areas

This thematic service combines near-real-time (NRT) observations on the Gulf of Finland (GoF) providing regional, combined multiplatform observations products. These observations include physical, biological and chemical observations done with three VOS-lines (Voluntary Observing Ship - lines) and two fixed stations. Demonstration includes the combined data products for two purposes: 1) Information on Harmful Algae Blooms and 2) Remote sensing reference to verify satellite data in real time.

These HABs impact many of the coastal activities by the GoF, like fisheries and recreation, and they also impact the value of coastal properties. To inform the public on the development of these blooms during summer, the Finnish Environment Institute gives out a weekly harmful algal bloom situation review. This demonstration provides near real time data on the cyanobacteria abundance to be used in weekly algae reviews and a visual display of data to the public and scientists. Satellite remote sensing is widely used to detect anomalies in the Baltic Sea, e.g. related to algae blooms, physical phenomena, and river loads. In this demonstration, an overlay of continuous measurements on top of satellite images is provided as an immediate proof of the events.

This service is an example of data and platform integration to resolve observational needs in relation to KSC#1 "Assessing changes under the combined influence of global and local drivers" (SSC "Ecosystem biogeochemical processes and interactions") although it can also be related to KSC3 "Unravelling and predicting the impacts of natural and anthropogenic changes" (Resolving climate change impacts).

Services created in this D2PTS are used by SYKE in their weekly national cyanobacteria reviews which provide a comprehensive overview of the state of cyanobacterial blooms throughout Finland's inland and coastal waters and the Baltic open sea area. Data products are available for managers, scientists, and the public. Both demonstrations lay the foundation for the creation of consistent regional datasets and the needs for having online data available. Although this development has been demonstrated locally the tools and techniques developed can be transferred or duplicated in other coastal areas.

4. Integrated observation through Transnational access to infrastructures

JERICO-S3 Transnational Access (WP8) main aim was to provide access to JERICO Research Infrastructures and Resources (including fixed platforms, gliders, cabled observatories, ferryboxes, calibration labs and a range of specialist equipment) for researchers or research teams from academia and industry. To this end JERICO-S3 has launched four competitive calls in the period 2022-2024, offering funding support for developing research and technological projects which are evaluated, selected and monitored by an expert panel. The Jerico-S3 TA Selection panel (SP) comprises a broad range of International marine scientific and research expertise strengthened with industry insights and knowledge. The adopted procedure is built on the principles of transparency, FAIRness and impartiality. Submitted proposals are checked by the JERICO-S3 TA Office to ensure formal compliance with access rules and then undergo a three-step selection process involving: (1) Validation of each proposal by a panel of Internal Jerico S3 Project members, based on scientific excellence, innovation and impacts on the state-of-the-art; (2) Final assessment and selection by the SP, which will recommend a short-list of proposals eligible for support; (3) Proposals are validated by the relevant facility operators, (users shall interact directly with the facility operators during the preparation of their proposals, to confirm that their targeted facilities are suitable for the planned experiments). More information on the selection criteria can be found here: https://www.jerico-ri.eu/ta/evaluation-and-selection/ and in deliverable D13.3.

The scope of TA experimentation projects developed during JERICO has been very broad, encompassing projects focused on technological testing, validation, and intercalibration. However, several TA projects were specifically aimed at the study of the marine ecosystems and to enhance monitoring and predictive capabilities from a multidisciplinary perspective. These projects involve integrating various sensor platforms, such as glider experiments, to achieve sound scientific results. Indeed, the selection process of the TA projects. It is worth highlighting the wide geographical scope of the actions (Figure 12) which have involved 10 different host countries, more than 120 users from 25 nationalities in 39 completed projects.

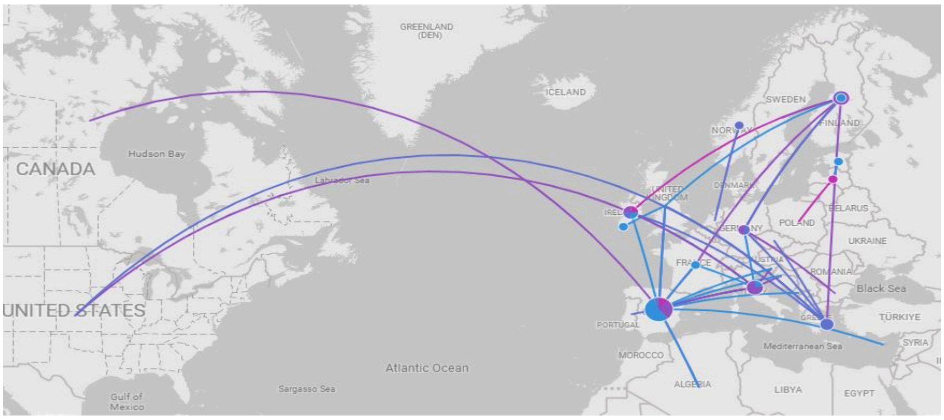

Figure 12. User map and relative number of hosted TA projects by the different countries offering JERICO infrastructures per call (fuchsia, violet, light, and dark blue are used for the 1,2,3 and 4th TA calls)

Table 2 offers a list of TA projects, which, by different means, have demonstrated a clear contribution of JERICO community to integrated observation and its benefits for the coastal science. These projects encompass a wide range of oceanographic research, including the study of circulation patterns, nutrient dynamics, planktonic responses to extreme events, and the impact of environmental factors on marine ecosystems. Key objectives include confirming monitoring lines to contribute to policy objectives, investigating the effects of extreme heat waves on planktonic food webs, and exploring ecological connectivity between different areas.

In Table 2, their contribution to the different KSC and SSCs is provided, as well as details on the region and infrastructures/institutions involved in the actions. The selected projects have contributed to KSCs 1,2 and 3, in questions related to ecosystem BGC processes, land-sea continuum, impacts of rare and extreme events, or anthropogenic impacts, among others. They have involved integration at different levels, from data to sensors and platforms, to integration between regions and RIs and actions focusing on citizen science. A set of specific examples which showcase progress beyond the state of the art, in terms of sensor integration, multidisciplinary integration and integration of different communities are detailed further in the following subsections.

Table 2. Summary of Transnational Access projects showcasing progress towards the implementation of integrated ocean observations: regions involved, relation to JERICO Science Strategy and type of integration considering different items (integration of data, data-models, methods, sensors, platforms, approaches, disciplines, regions, RIs). In bold, the examples highlighted further down.

Acronym (#n TA call)	Project Title *(JERICO PROVIDER - required infrastructure; external partner)*	Short Summary	Relation to KSC and SSC	Type of Integration:
ABACUS (#1)	Algerian Basin Circulation Unmanned Survey (**SOCIB - glider;** Università degli Studi di Napoli "Parthenope", Italy)	Algerian Basin (AB) circulation, data collection in the Marine Strategy Framework Directive (MSFD) including physical, biochemical properties and acoustic data (to identify wind and rain patterns, as well as the presence of marine mammals) Final Project Report	KSC1 (Ecosystem BGC processes and interactions)	data, sensors, platforms

EMPORIA (#1)	Exploring the mesoscale processes in the area of freshwater influence in Gulf of Riga (**TALTECH - glider**; Latvian Institute of Aquatic Ecology, Latvia)	Dynamic processes (vertical features, movement of water masses, upwellings/downwellings, coastal gradients, freshwater influence etc.) and impact on the GoR environment by conducting high-resolution glider surveys Final Project Report	KSC1 (Land-Sea continuum, Ecosystem BGC processes and interactions)	data, sensors, platforms
FRIPP-spring (#1)	Frontal dynamics influencing Primary Production: investigating the onset of the spring bloom mechanism through gliders (**SOCIB -glider**; ISAC - Institute of Atmospheric sciences and Climate, Cagliari section, Italy)	Multisensor sea-glider mission supported by modelled and remotely-sensed data, to study the impact of frontal dynamics on the Phytoplankton production and distribution as inferred from fluorometric measurements. Final Project Report	KSC1 (Ecosystem BGC processes and interactions)	data, sensors
S100_Bio (#1)	ANB Sensors S Series: Longterm Biofouling Deployment (**UPC - OBSEA underwater observatory**; ANB Sensors, UK)	Test the ANB Sensor S1100 over a prolonged period of time, observing seasonal changes in weather and biodiversity.Final Project Report	KSC1 (Ecosystem BGC processes and interactions)	sensors
BalHObEx (#3)	Baltic Sea Heat Waves: Observation and Experimentation (**SKYE- MRC-lab and Alg@line;** Hellenic Centre for Marine Research, Greece)	Holistic approach on the effects of extreme heat waves on the planktonic food web via a mesocosm experiment. Final Project Report	KSC2 (Impacts of rare and extreme events)	data, methods, platforms, disciplines, RIs
CABS(#3)	Capacity Building for Autonomous Biogeochemical Sensing in the SW Black Sea (**Helmholtz-Zentrum hereon GmbH - ferrybox;** Institute of Biodiversity and Ecosystem Research, Bulgaria)	Study the effect of eutrophication on sea grass beds and biodiversity along the southern Black Sea Coast. Final Project Report	KSC1 (Ecosystem BGC processes and interactions, Carbon budget and C02 systems)	sensor, platform, disciplines
FRIPP-CEE (#3)	Frontal dynamics influencing Primary Production: Carbon Export Experiment (**SOCIB - glider;** CNR-ISAC, Cagliari, Italy)	Multisensor sea-glider mission supported by modeled and remotely-sensed data, to study the impact of frontal dynamics on the Phytoplankton production and Carbon export. Final Project Report	KSC1 (Ecosystem BGC processes and interactions, Carbon budget and C02 systems)	sensor, platform, disciplines
GliderBloom (#3)	Use of FMI glider during the EMB-cruise GER – FIN -GER (**FMI - glider**; Leibniz-Institute for Baltic Sea Research Warnemünde, Germany)	Algae bloom N2 fixation, focusing on nitrogen dynamics and its relationship to cyanobacterial bloom by increasing the vertical and temporal coverage. Final Project Report	KSC1(Ecosystem BGC processes and interactions), KSC3 (anthropogenic impacts)	sensor, platform, disciplines
OBS-EXP-Bridge (#3)	Bridge between OBServation and EXPerimentation communities of JERICO and AQUACOSM (**SYKE - MRC-lab**; MARBEC CNRS, France)	Study the metabolic and structural responses of plankton communities of the Baltic Sea to heat wave. Final Project Report	KSC2 (Impacts of rare and extreme events)	sensor, data, disciplines, RIs
PoGo (#3)	Po delta to Gulf of Trieste: Microbiological connectivity study and field testing of a Video-CTD probe prototype	Physico-chemical and biological parameters effect on microbial community dynamics; ecological connectivity between sites by coupling microbial analysis with oceanographic observations and numerical modelling. Final Project Report	KSC1 (Connectivity and transport, Ecosystem BGC processes and interactions)	sensors, platforms,
IMAPOCEAN	Integrated Multilevel Active Passive Ocean Current (**MI - Smartbay**, University of Massachusetts Dartmouth, US)	Expand IMAPOCEAN into Galway Bay and the Atlantic Ocean. Citizen science experiment which combines deep and midlevel ocean current research using tilt current meters as well as an ocean surface flow current recording unit, built by students.Final Project Report	KSC1 (Connectivity and transport)	sensor, citizen science
LISTEN (#4)	Glider Mission to Resolve Mixing in the Southern Baltic (**TALTECH - glider**; UI, Poland)	Water mass structure, stratification, and mixing processes in the key areas for the transport of highly saline and oxygen rich waters originating from major Baltic inflows towards the central and eastern Baltic basins.Final Project Report	KSC1 (Ecosystem BGC processes and interactions)	sensor, platform, data

4.1.Sensor integration

Different TA projects contributed to advance technical developments and demonstrated potential of sensor integration in coastal areas. ABACUS and FRIPP projects showcased the sensor integration onboard gliders for the study of biogeochemical process and biology. In the case of the ABACUS project besides physical and BGC data, a hydrophone was mounted to collect acoustic data. In the project S100_Bio (#1) a test of sensor integration was led by the private company ANB Sensors. The main contribution of these projects was to the KSC1 "Assessing changes under the combined influence of global and local drivers" (SSC "Ecosystem biogeochemical processes and interactions").

ABACUS focused on the physical and biochemical characteristics of the Algerian Basin (AB) circulation. The project aimed at confirming the importance of the ABACUS monitoring line across the AB between Palma de Mallorca and the southern part of the Algerian basin. Among ABACUS main objectives we can highlight: (i) To identify the physical and biochemical variability of the different water masses that are present between Balearic Islands and Algerian coasts at surface and intermediate depth; (ii)To collect high resolution data able to describe the sub-basins dynamics; (iii)To assess the ocean description capabilities of several satellite products when approaching coastal areas, also comparing them to glider in situ data; (iv)To explore the potential of glider measurements for ecosystem monitoring (fish stocks to cetaceans). The ABACUS project contributed to data collection in the Southern European Seas, one of the main EU maritime policy objectives, as outlined in the Marine Strategy Framework Directive (MSFD). Then. FRIPP project was designed to observe ocean frontal dynamics in terms of horizontal and vertical velocities; instabilities; mixing and enhanced dynamical stratification and then, study the impact of such frontal dynamics on primary production namely CHl concentration and Oxygen distribution), during the first onset of the early spring bloom. Phytoplankton community composition was characterized through an Optical Community Index.

In the project S100_Bio (#1) the private company ANB Sensors, which develops pH Sensors for oceanographic, environmental and water resource management applications, conducted a test on their last pH sensor in the OBSEA observatory. ANB pH Sensor S1110 is a cost-effective, intelligent, self-calibrating, and low-maintenance pH sensor, suitable for various detection platforms, including oceanic monitoring and suited for long-term oceanographic pH monitoring. The key objective for the project was to validate and evaluate the performance of the S1100 over a prolonged period, observing seasonal changes in weather and biodiversity. One of the main achievements was proving the performance of the S1100 in a lab, as well as the verification from the end user that the sensor was indeed easy-to-use.

Other projects demonstrating advances in sensor integration were MultiNuds (lab tests), and ACMaREMAS (glider). Although the projects highlighted here focused on specific study areas the main results and progress in terms of sensor integration can be considered replicable in other areas and applicable to different scientific objectives.

4.2.Multidisciplinary (physics-biogeochemistry-biology) integration

In addition to ABACUSs experiment, which combined physics, biogeochemistry and acoustic abundances sensors and data and was described in the previous section, the projects

BalHobEx, OBS-EXP-Bridge and LISTEN showcased a set of multidisciplinary research activities, on the integration of physics, biogeochemistry, and biology.

BalHObEx project followed a holistic approach to study the effects of extreme heat waves on the planktonic food web of the Baltic Sea. The main aim was to investigate the effects of extreme heat waves on the marine plankton food web via a mesocosm experiment. Mesocosms allow experimentation on whole plankton food webs in close to real-life conditions and they are considered the most reliable way to test hypotheses and predict effects of environmental pressures on the complex marine ecosystems. Results from the mesocosm experiment were compared and combined with findings in the natural environment in order to get a more complete view on the effects of the heat waves on natural plankton communities of the Baltic Sea. This TA project was also highlighted in section 3.2.2, since it was integrated in a set of other experiments led by three different PPSs.

LISTEN main aim was to perform a high-resolution CTD, oxygen and chlorophyll-A transect along and across the Slupsk Furrow in the Southern Baltic Sea using an ocean glider (CTD, Oxygen, chlorophyll-A, turbidity) to complement and enhance the IO PAN standard ship-borne measurements (CTD, ADCP, dissolved oxygen and VMP). The goal was to study water mass structure, stratification and mixing processes in a key area for the transport and mixing of highly saline and oxygen-rich inflow waters originating from the Major Baltic Inflows towards the central and eastern Baltic. The outcomes consisted in 3D fields encompassing temperature, salinity, chlorophyll-A, turbidity, oxygen saturation, and oxygen concentration, among others. and provided insight on vertical phytoplankton migrations (such as dinoflagellates, chlorophytes etc.), water temperature spatial and temporal fluctuations, and the sub-mesoscale variability. In addition, an acoustic experiment was conducted by deploying a mooring equipped with hydroacoustic modem and a glider with a GAN (Glider Acoustic Node consisting of the acoustic modem, data integrator and buoyancy package) to test and provide a concept for mooring-glider data transfer.

4.3.Community integration

In general, all TA projects have a strong component of community integration. As explained at the beginning of the section they oblige collaboration between research institutions and between countries since the lead team of the project and the providers cannot have the same nationality. Then, the different TA activities also enabled interaction between several non-JERICO institutions (and private companies) and JERICO participants. The two examples highlighted here went a step further though the involvement of an additional research infrastructure and the promotion of citizen science. The first example, already described in the previous sections, is OBS-EXP-Bridge which showcases integration between JERICO and AQUACOSM research infrastructures, and between communities working on in-situ observation and experimentation.

The second example is the IMPAOCEAN project. which included a citizen science initiative. The two main science objectives of IMPAOCEAN were to quantify the transport of intermediate and deep waters and to monitor ocean surface flow through active drifting ocean drones. Then, the aim of this project was to engage the public (students) in ocean current research through building different tools for studying ocean currents. These tools were the SeaHorse Tilt

Current Meter and Drifters, equipped by GPS to monitor surface ocean current flow. The students could follow their student drifters on this website https://studentdrifters.org/tracks/

5.CONCLUSIONS

JERICO science strategy emphasizes the importance of integrated observation as a fundamental requisite for the understanding of coastal complex processes. During JERICO-S3 the implementation of integrated observation has focused on the integration and harmonization of coastal observatories across various European coastal regions, encompassing different aspects, from regional collaboration and technological innovation to the development of scientific data products and experimentation.

The assessment of the implementation of multidisciplinary and integrated observations, has been undertaken tacking into account different dimensions and components of JERICO-S3:

- The regional dimension, from IRSs and PSSs activities
- The experimentation in PSSs demonstration activities
- The technological innovation through WP7 and JERICO-CORE D2PTS developments
- The access to the facilities through the TA call (WP8)

The contribution of each of these components to the JERICO-RI science strategy, encompassing its Key Scientific Challenges (KSCs) and Strategic Scientific Challenges (SSCs) is analysed and summarised in Table 3.

Table 3. Contribution of the different JERICO-S3 components to the JERICO science strategy Key Scientific Challenges (KSCs) and Strategic Scientific Challenges (SSCs).

Key Scientific Challenges	Specific Scientific Challenges	Experiments in regions	Technical solutions			D2PTS		TA
			PSP	ACOBS	WASP	Glider	BGC	
KSC#1 Assessing changes under the combined influence of global and local drivers	Land Sea Ocean continuum.		■	■	■			■
	Sea-atmosphere interface. Quantification of inputs		■					
	Connectivity and transport. Pathways of water	■	■					■
	Biodiversity trends		■		■			
	Ecosystem biogeochemical	■	■	■		■	■	■
	Carbon budget and carbonate system	■	■					■
KSC#2 Assessing the impacts of extreme events	Impacts of rare and extreme events	■	■	■	■	■		■
KSC#3 Unravelling and predicting the impacts of natural and anthropogenic changes	Resolving climate change impacts		■		■	■		
	Resolving anthropogenic impacts	■	■		■			■
	Disentangling impacts/scales				■			

Then, an overview of the nature of the integration spanning data, methodologies, and platforms, including collaboration beyond JERICO-S3 and other research infrastructures is provided in Figure 13.

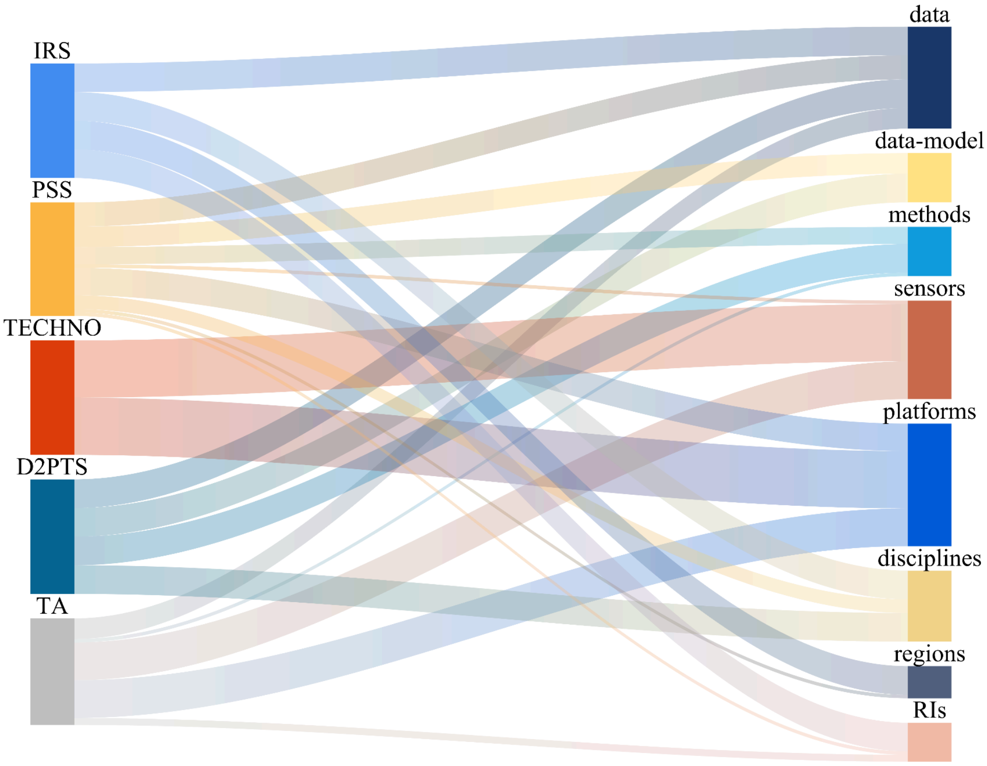

Figure 13.Sankey diagram on the contribution of the different JERICO-S3 components to the different types of integration, encompassing data, data-model integration, sensor and platforms integration, multidisciplinarity and integration within of between regions and RIs.

The project's structure, with a regional dimension based on Integrated Regional Sites (IRSs) and Pilot Super Sites (PSSs), showcases the capacity of the infrastructure for coastal monitoring and research across Europe. IRSs (WP3) serve as hubs for organizing and harmonizing existing coastal research activities, both within and between regions, fostering a more unified approach to coastal science. PSSs (WP4), on the other hand, are at the forefront of demonstrating the benefits of integrated, multidisciplinary, and multiplatform observation capabilities.

The advancements in ocean observation technology and the development of the Data-to-Products Thematic Services (D2PTS), as demonstrated by the activities in WP5, 7 and 11, not only represent a step further in the development of technology, IoT and data solutions, but also showcase the importance of technological evolution in supporting comprehensive oceanic research.

Finally, the Transnational Access (TA) program of JERICO (WP8) has been instrumental in promoting integrated observations by providing researchers with access to JERICO's state-of-the-art coastal observatories and facilities. This access has supported an important number of collaborative efforts that have shown essential progress in integrated ocean observation.

6. ANNEXES AND REFERENCES

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