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1. EXECUTIVE SUMMARY

This Deliverable is the final report on integration activities in JERICO-S3 WP3: Integrated Regional Sites. Integrated Regional Sites (IRSs) are presented in the context of past Deliverables and JERICO-S3 strategic recommendations in Chapter 2: Introduction. This is followed by nine regional integration stories highlighting various integration activities that occurred during the project period within IRSs, between multiple IRSs, and between IRSs and Pilot Supersites (WP4; PSSs) are presented in Chapter 3: Main report. The integration stories in Chapter 3 represent topics from the WP3 roadmap plan that was established in Deliverable 3.1; the topics include regional integration, interoperability/harmonisation, business case, and organisation. The integration stories ranged from scientific integration/harmonisation achievements related to coastal phytoplankton observations and circulation, to organisation/business case activities that resulted in improved coastal observations and cooperation between partners and IRSs/PSSs. Conclusions from WP3 activities are presented in Chapter 4, and the final chapter also includes lessons learnt and recommendations for future regional integration activities within JERICO-RI.

2. INTRODUCTION

Integrated Regional Sites - recap

In JERICO-RI, observing platforms are distributed over many diverse European coastal regions, and individual platforms and observations are mostly performed on a partner or institutional level. Work Package 3 (WP3) in JERICO-S3 has focused on organising, harmonising, and integrating existing coastal observing activities and initiatives within regions and between regions. At the start of JERICO-S3 the following Integrated Regional Sites (IRS) were formed to further develop regional and pan-European integration of coastal observation systems:

- Northern Adriatic Sea (NA)
- Iberian Atlantic Margin (IAM)
- Bay of Biscay (BoB)
- Kattegat-Skagerrak-Eastern North Sea (KASKEN)
- Norwegian Sea (NS)

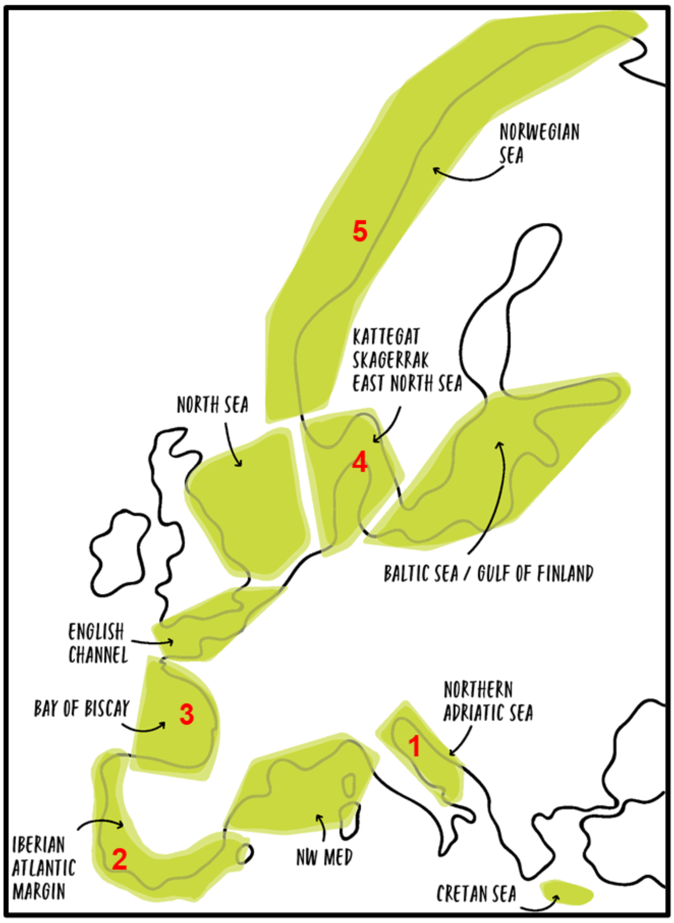


Figure 2.1. Location and approximate geographic extent of the JERICO-S3 Integrated Regional Sites: 1) Northern Adriatic (NA), 2) Iberian Atlantic Margin (IAM), 3) Bay of Biscay (BoB), 4) Kattegat-Skagerrak Eastern North Sea (KASKEN), and 5) Norwegian Sea (NS). Note that other regions not numbered are the locations of Pilot Supersites covered by WP4.

This regional structuration brings together the national partners responsible for operating platforms and observations, to ensure that coastal observing efforts are tailored towards the needs and requirements of local/national/regional levels, while at the same time enabling JERICO to be coordinated and harmonised to address observational and societal needs at a pan-European level. The main aims of WP3 have been to coordinate and develop region-specific observational strategies and approaches, promoting cooperation, integration, and development between countries adjacent to coastal observing regions, as well as providing a co-operational framework for regional data management and accessibility. The work in WP3 has been structured in four tasks: T3.1. Coordination and links to other WPs, T3.2. Development of regional IRS strategy and business and sustainability plans, T3.3. Integration and harmonisation within and between regions, and T3.4. Regional data harmonisation/delivery and products.

An initial analysis (D3.1) was made for each IRS that included scientific partners involved, main scientific questions, observational strategies, regional organisation, financial sustainability plans, and plans for future development. This showed that there were considerable capabilities and possibilities within each IRS related to scientific, organisational frameworks and infrastructures. In addition, the observational needs of key scientific challenges in the European seas were reasonably covered by IRSs. The strategies for coastal observations, however, were mainly driven by regional and/or national key societal and scientific challenges, as well as by the requirement for national monitoring programs in the frame of the MSFD and the WFD. Furthermore, financial sustainability was generally fragmented and secured mainly at institutional or in some cases at the national level. To further develop IRSs and address gaps, a road map was developed towards improving certain aspects of coastal observations in each region as well as specificities in terms of organisation and financial sustainability. The roadmap included specific points related to: regional integration activities, interoperability/harmonisation activities, business case activities, and organisation activities. These networking activities would promote development within individual nations with relevant stakeholder/scientific institutions and trans-national for the individual regions and all region workshops would be important for progressing on integration at the regional level.

In D3.2 (Report on integration progress within and between IRSs), a mid-project update on roadmap activities on the integration progress was reported for each IRS, between IRSs, and in some cases between IRSs and WP4 Pilot Supersites (PSSs). A substantial number of networking activities had been carried out according to roadmap topics especially on improving integration (e.g. NA-IRS and BoB-IRS had focused efforts towards consolidating coastal observing efforts in their regions including non-JERICO-S3 observations) and harmonisation (e.g. IAM-IRS and KASKEN-IRS had focused efforts towards topic-based harmonisation and development, such as multiplatform observations and carbonate chemistry). However, it was found that development of the business cases for the IRSs remained a challenge, where national funding and/or plans for funding were mentioned for each IRS, but regional or multi-national funding mechanisms/agreements were not in place and posed difficulties in terms of coordinating funding from different national ministries and other sources. Finally, the formal organisation of IRSs also posed challenges (somewhat linked to the business case challenges), and bilateral MoUs represented the extent to which organisations have been formalised. It was identified that “a definition of a common target for the organisation scheme of the future JERICO regional components” was important in the development of IRSs during the remainder of the JERICO-S3 project and subsequent efforts.

Deliverable 3.3 (Recommendations based on regional data handling and accessibility) reported on the availability of data from each IRS, and performed a self-assessment of the Findability and Accessibility attributes of FAIR (Findable, Accessible, Interoperable, and Reusable) for two platforms. At present, the data handling in the individual IRS is handled at the institutional level, and largely available through national data centres, several IRS report that data are aggregated at a regional lever through ROOS (Regional Operational Oceanographic System), while to a lesser extent available at the European level (EMODnet, CMEMS). There are differences between platform types, where for example, HF radars are well coordinated at the European level which has trickled down to the regional and national levels. Other platforms, for example FerryBoxes, could benefit from a similar common approach that could be adopted by regions. This high degree of platform dependence in terms of FAIR criteria for data handling and accessibility, also complicates multi-platform integration, which is one of the main aims of the JERICO. A recommendation from D3.3 was to provide clear guidelines for the JERICO requirements in terms of data handling and accessibility at all levels (national to European), for example: is it sufficient that data from individual platforms are available in national databases, or should all IRS data be available in European aggregators with a tag that links the data to JERICO and respective region?

Summary of recommendations from D1.2 for WP3 IRSs

Within WP1 (Science Strategy) the deliverable on **Regional approach (D1.2)** summarises how JERICO addresses the regional specificities as well as the common scientific and societal challenges across regions. For this deliverable, a questionnaire was sent out to the leads of individual IRS and Pilot Super Sites (PSS), to identify which Key Scientific Challenges (KSCs) and Specific Scientific Challenges (SSCs) were addressed by the individual regions. Table 1 (from D2.1) shows which KSCs are addressed across regions, in addition the regions were asked to rate how relevant the KSCs were, how they are currently addressed and collaboration between regions.

Table 2.1. (from D1.2 Regional approach). The KSC and SSC currently addressed for each region: North S: North Sea, EC: English Channel, NWM: Northwestern Mediterranean, CS: Cretan Sea, BS/GF: Baltic Sea:Gulf of Finland, BOB: Bay of Biscay, NAS: Northern Adriatic Sea, IAM: Iberian Atlantic Margin, K/S: Kattegat/Skagerrak, Norw S: Norwegian Sea

		Pilot Super Sites					Integrated Regional Sites				
KSCs	Specific Scientific Challenges	North S.	EC	NWM	CS	BS/GF	BOB	NAS	IAM	K/S	Norw. S.
Assessing and predicting changes under the combined influence of global and local drivers	Land-Ocean Continuum	■		■			■		■		■
	Sea-atmosphere interface										
	Connectivity and transport			■			■		■	■	
	Biodiversity		■				■		■		
	Primary productivity		■		■					■	
	Ecosystem functioning	■			■	■		■		■	
	Carbon budget and carbonate system	■				■				■	
Assessing the impacts of extreme events	Extreme events: impacts on ecosystems			■	■	■	■	■			
	Extreme events: coastal hazards						■		■		
	Harmful Algal Blooms		■			■				■	■
Unravelling the impacts of natural and anthropogenic changes	Climate change impacts					■	■		■	■	
	Eutrophication		■	■		■					
	Impact of big cities			■							
	Litter and plastic			■			■	■	■	■	
	Contamination			■					■	■	■
	Unravelling impacts					■	■				■

A distinction is made that while both PSSs and IRSs are considered JERICO regions, the PSSs have a 2-year implementation period (with demonstrations of multi-disciplinary and multi-platform observing capabilities and data provision), while the IRS have not had similar demonstration activities, and have focused on more regional networking activities on monitoring strategies, common scientific challenges and sustainability plans.

The main conclusions of D1.2 with relevance for IRSs is that not all KSCs and SSCs are addressed at the same level and connections between regions still need to be improved to provide accurate products and share knowledge on technologies and/or data expertise. For example, KSC1 (see Table 1) is generally addressed more widely across regions than KSC2/3, which was related to the fact that it can more easily be assessed based on current in situ observations, whereas the other two require greater technological maturity and integration. A key gap identified in D1.2 is that there is a difficulty in building coherent, harmonised, and effective regions in JERICO-S3, which comes from the complexity of relevant interconnected processes in coastal waters, heterogeneity of regional implementation status, long-term expert commitment, and data sharing. There is a recommendation that future JERICO-RI should play a key role in centralising scientific actions with a pan-European vision to increase collaboration between regions and sharing of data and expertise. This would demonstrate the added value of a pan-European JERICO infrastructure, compared to a network of national observatories focused on regional challenges.

Integration stories within IRSs and between IRSs/PSSs

This Deliverable presents integration stories related to roadmap activities (regional integration, interoperability/harmonisation, business case and organisation) related to KSCs/EOVs that have been developed and carried out in the JERICO-S3 project. Integration stories highlight significant progress in terms of developments within and across IRSs, as well as in collaboration with PSSs, in terms of:

- Automated plankton observations in the KASKEN and NA IRSs (together with GoF and NS/EC PSSs)
- Integrating data from multiple observing platform providers and multiple platforms in the IAM IRS
- Building cooperation and knowledge exchange on glider platform operations with the BoB and IAM IRSs
- Interoperability/harmonisation of carbonate system observations across all IRSs and PSSs
- Harmonising chlorophyll fluorescence, cDOM fluorescence, and turbidity measurements in the KASKEN IRS
- Building transboundary capacity for coastal risks in the BoB IRS
- Building cross-border/multi-national collaboration and organising efforts in the NA IRSs
- Building transnational FerryBox collaborations in the NS IRS and NS PSS
- Collaboration across national and multi-national RIs in the NA Sea IRS

3.MAIN REPORT

This section of the deliverable presents integration success stories both within and between IRSs/PSSs. Each subsection focuses on specific integration activities that were carried out in a single IRS, multiple IRSs, or combinations of IRSs and PSSs within the JERICO-S3 framework. The activities presented here are related to integration (e.g., building regional cooperation, collaboration with ERICs, etc.), interoperability/harmonisation (e.g., regional data handling, data products/services, etc.), business case (e.g., engagement with users/stakeholders, advancements in financial sustainability, etc.), and organisation (e.g., Memorandum of Understandings, cooperation across partners/countries, development of roadmaps, etc.). The descriptions include a background of the activities, what was carried out during the JERICO-S3 project, and challenges and barriers that were identified so that future activities can be improved.

3.1 Automated plankton observation developments across IRS/PSS (KASKEN and NA IRSs, GoF and NS/EC PSSs; SMHI, IMR, NIVA, CNR, CNRS, SYKE)

3.1.1 Short background

Phytoplankton are the dominating primary producers in the global oceans 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 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. Today there are approximately 15 Imaging Flow Cytobot's in Europe and a European IFCB user network is in operation, see below. 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 Fiskebäcskil, Sweden. JERICO contributed to the workshop, presentations etc. are available at https://www.globalhab.info

Marine environmental DNA (eDNA), i.e. the bulk DNA in a sea water sample, may reveal valuable information about the diversity and abundance of phytoplankton, as well as detect larger marine species which shed DNA into the environment. Metabarcoding, i.e, sequencing short fragments ("barcodes") of eDNA is a novel method that is very useful for investigating phytoplankton diversity. Single species of particular interest, such as harmful algae, may be detected and quantified by quantitative eDNA methods (qPCR, ddPCR). Metabarcoding was used by manually collecting samples with a FerryBox system in the Baltic Sea and the Kattegat-Skagerrak in an earlier JERICO project. (Hu et al. 2016). Samples were also collected using R/V Svea (Latz et al. 2024). In JERICO-S3, NIVA has evaluated an automated sampling device as part of the FerryBox system on ferry Color Fantasy, see below.

3.1.2 JERICO partners and non-JERICO funding

Automated plankton observations have been used in both JERICO Integrated Regional Sites (IRS) and in what has been called Pilot Super Sites (PSS). IRS KASKEN (Kattegat-Skagerrak-Eastern North Sea), IRS Northern Adriatic Sea, the Gulf of Finland PSS, and the North Sea PSS are the best examples. The following partners have been involved in the work: *CNRS, ULCO, France; CIM/IRB, Croatia; IMR, Norway*; *ISMAR/CNR, Italy; NIVA, Norway; SMHI, Sweden; SYKE, Finland.* The various partners also had co-funding from institutional and national funding sources.

3.1.3 Data integration

An important step during the data integration is to create a training data set for supervised machine learning (AI-assisted image analysis) by manual identification of planktonic organisms (Fig. 3.1.1). 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 is 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.

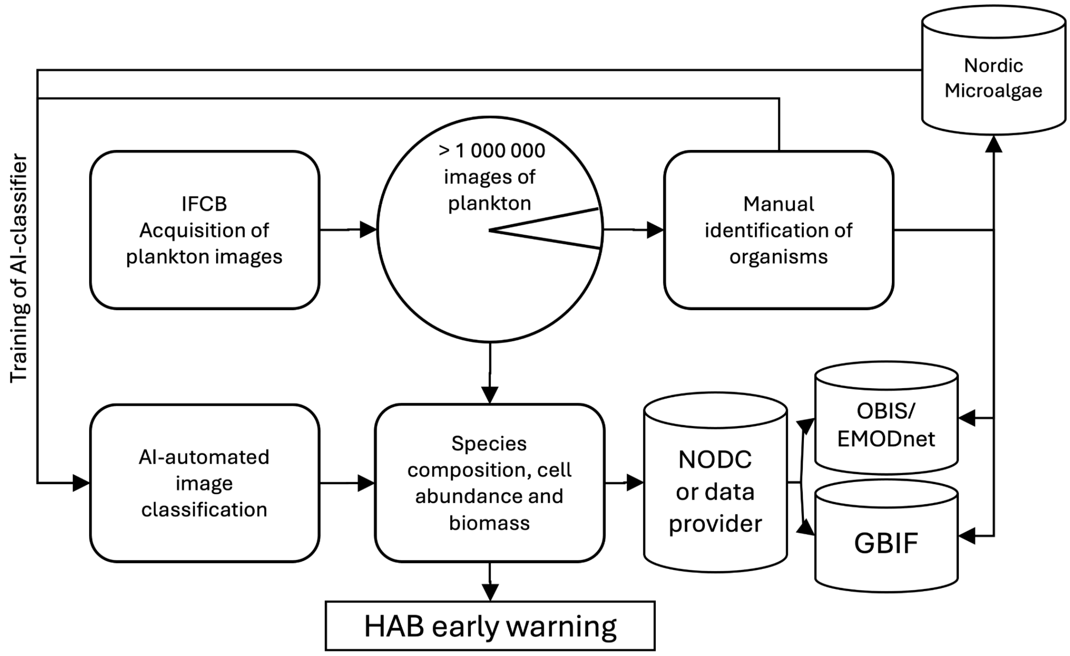


Fig. 3.1.1. The figure illustrates the most important steps in the data flow from images of plankton acquired using the Imaging Flow Cytobot (IFCB).

3.1.4 Procedures - automated imaging

Automated plankton imaging instruments, mainly the Imaging Flow Cytobot and in some cases also the Cytosense (camera version), have been deployed in ferrybox underway systems by SMHI (R/V Svea), CNRS/ULCO (different research vessels), NIVA (M/S Color Fantasy) and SYKE (merchant vessel Finnmaid). In addition instruments have been deployed as part of stationary ocean observing systems by SYKE (Utö ocean observatory), IMR (Torungen Skagerrak ocean observatory), by CIM/IRB (Adriatic Sea) and by ISMAR/CNR (Adriatic Sea, Acqua Alta Oceanographic Tower).

The instruments collect images of phytoplankton and microzooplankton automatically, often several thousand images per sample. AI-assisted automated image analysis is used to analyse the images to produce data on phytoplankton diversity, cell abundance and biomass. The method is also called supervised machine learning. Creating training data sets by manual annotation of images by phytoplankton identification specialists is a critical step in the method. There is currently a move from random forest based methods to other approaches. The JERICO partners participate in this through the European IFCB user network and through projects outside JERICO.

3.1.5 Cooperation between institutes and countries

European users of the Imaging Flow Cytobot have joined efforts in the European IFCB user network (Karlson 2021; Fig. 3.1.2). On-line meetings are arranged approximately every two months, more often when needed. At present the development of classifiers are in focus. There is also cooperation within IRS KASKEN with on-site workshops in Norway and Sweden. The EuroGOOS Biological Observations Working Group (BIOWG) is producing a best practice document for operating the IFCB and similar devices. In a Digital Twin - BioFlow project, led by SMHI, there is ongoing work to harmonise data flows from data providers (often National Oceanographic Data Centres) to EMODnet and GBIF. There is also cooperation with IFCB users outside Europe, mainly with the large user community in the USA.

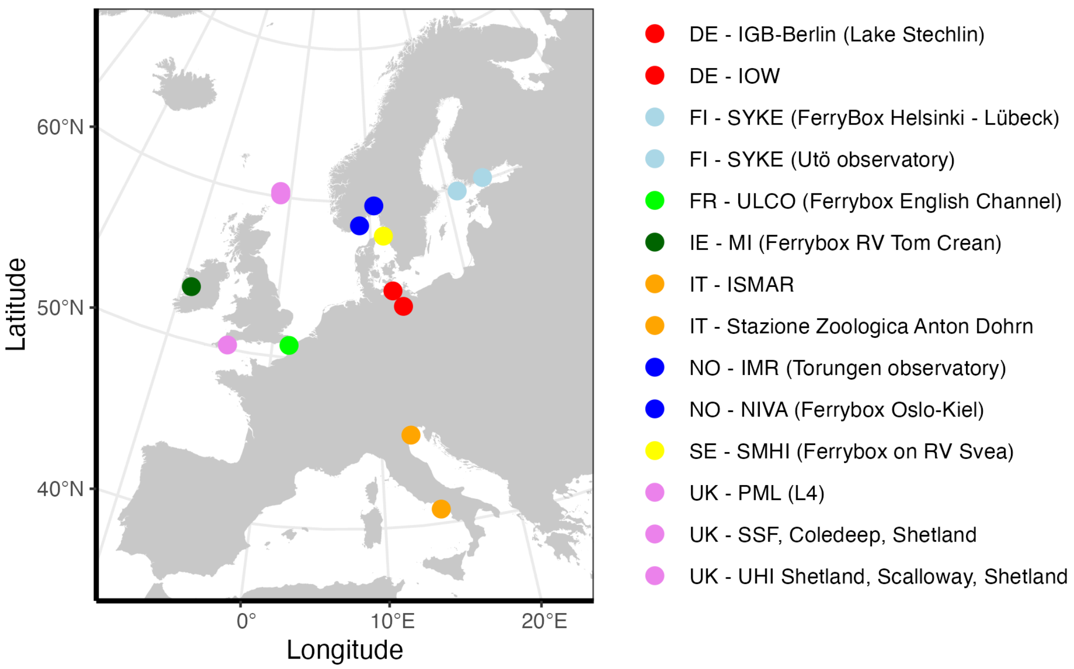


Fig. 3.1.2. Approximate locations of Imaging Flow Cytobots in Europe and names of institutes operating the instruments (May 2024).

3.1.6 Procedures - automated sampling of environmental DNA

The Water-Sample filtering and Preservation device - WASP has been described in detail in the JERICO-S3 Deliverable 7.4. It consists primarily of two sampling devices: a modified McLane Phytoplankton and Particle Sampler (PPS) with 24 ports, and an ISCO refrigerated autosampler, which operate while integrated with a FerryBox platform (Fig. 3.1.3). Filtration of seawater for environmental DNA, and methods for preservation of eDNA in the PPS has been extensively tested (JERICO-S3 Deliverable 7.4). In particular, preservation of eDNA was tested with seawater spiked with clonal algal cultures (a so-called "mock community"). The requirements of the preservation method was that it should be practical both in the field and for downstream procedures (i.e., isolation of eDNA), and that it should preserve the DNA well enough to leave the PPS with the filters inside at ambient temperature for several days. Lysis buffers designed to preserve DNA often become viscous at temperatures below room temperature, and may clog the tubing. Furthermore, using lysis buffers would require collection and DNA isolation from the whole volume of buffer in the tubing, which is not feasible. The test of preservation methods showed that ethanol (EtOH) preserved DNA better than the other methods considered, which were RNALater and cooling the PPS at 4 °C. We also tested freezing at -20 °C, but it is currently not possible to freeze only the filter holders while they are attached to the PPS. DNA preservation was assessed both by quantification of DNA from single species by quantitative PCR, and by looking at the overall taxonomic composition of the eDNA as revealed by metabarcoding of the 18S V4 marker region.

Autonomous operation of the WASP was tested on two cruises on board MS Color Fantasy in the KASKEN IRS, 5.-6. December 2023, and 19. April 2024. For each water sampling event one filter was filtered in a single port of the PPS, and two filters were filtered with a manual bench top system. The PPS filter holder and tubing was subsequently filled with EtOH. The bench top filters were removed from the holder with clean forceps, placed in an Eppendorf tube with EtOH, and stored at -20 °C. By the end of the cruises, the EtOH was flushed out of the PPS, the filters were removed from the filter holders with sterilised forceps, placed in Eppendorf tubes where fresh EtOH was added and stored at -20 °C. The results from the field demonstrations were described in detail in JERICO-S3 Deliverable 7.7.

As EtOH may dissolve cell membranes, there was a concern that when EtOH was pumped through the filters in the PPS, the cell genomic material would also get flushed out. However, comparison of eDNA recovery and taxonomic composition between the PPS and bench top filters revealed no significant differences for these particular filters (PES membrane filters with pore size 0.45 µm) (Fig. 3.1.4).

Fig. 3.1.3. The WASP sampler developed in WP7 that includes a modified Phytoplankton Particle sampler (McLane) and an refrigerated autosampler for bulk seawater connected to a FerryBox system for autonomous sampling of eDNA (photo: Anette Engesmo).

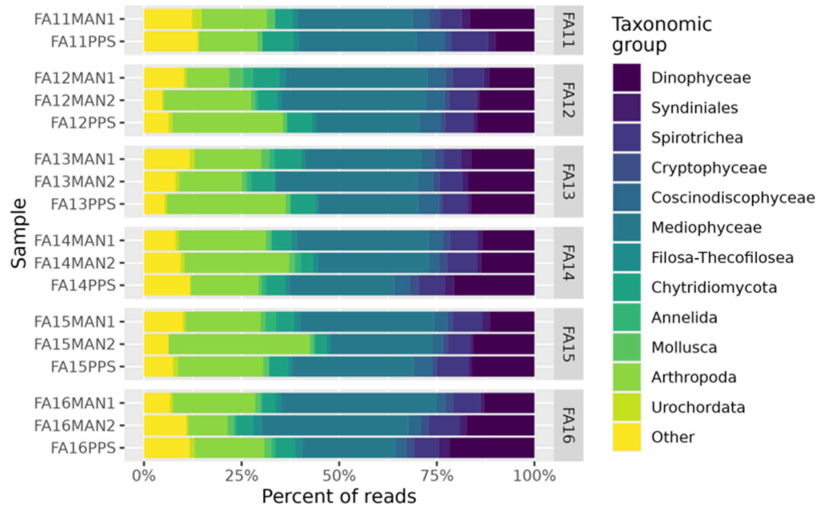


Fig. 3.1.4. Taxonomic composition of environmental DNA sampled and preserved in the PPS vs. manual bench-top filtration (bars marked "PPS" and "MAN", respectively). A "read" is a DNA sequence from metabarcoding. The comparison did not reveal systematic differences between the two methods.

3.1.7 Use case KASKEN IRS, R/V Svea (Baltic Sea and Kattegat-Skagerrak)

SMHI operates an Imaging FlowCytobot as part of the Ferrybox underway system on R/V Svea (Fig. 3.1.5). Samples are collected approximately every 25 minutes which corresponds to approximately every 5 nautical miles (~10 km). AI-assisted automated image analysis (supervised machine learning) is used to process millions of plankton images to produce quantitative data on phytoplankton diversity, and biomass (Fig. 3.1.6 and 3.1.7). Early detection and early warnings of Harmful Algal Blooms are in focus.

Fig. 3.1.5. Left: R/V Svea, middle: Ferrybox system with IFCB and right: Locations of IFCB samples collected during one week long monitoring cruise in August 2023.

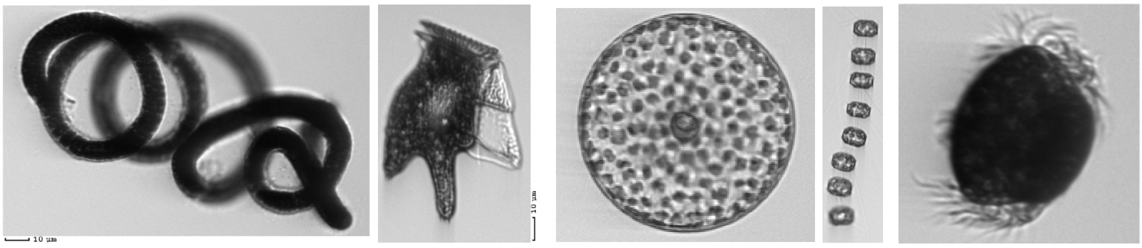


Fig. 3.1.6. Examples of phytoplankton images from the Imaging Flow Cytobot on R/V Svea.

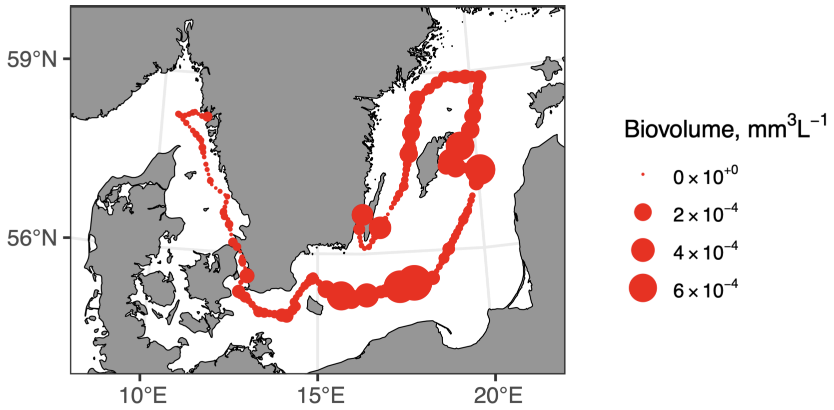


Fig. 3.1.7. The map illustrates the distribution and biovolume (~biomass) of the toxin producing cyanobacteria *Nodularia spumigena* in July 2023. Preliminary data from IFCB on R/V Svea.

3.1.8 Use case GoF PSS, Utö Marine Station and FerryBox onboard Finnmaid (Baltic Sea)

At the Gulf of Finland (GoF) PSS, automated detection of cyanobacterial blooms has been improved using IFCB at Utö Marine Station, as part of activities in WP4 (Seppälä and Frangoulis 2024) and WP7 (Solabarrieta et al. 2023). IFCB has been deployed sporadically at Utö since 2017 and continuously since 2020 (Kraft et al. 2022). IFCB is part of Utö Marine Station flowthrough system, sampling water at 5 m depth from 250 m offshore. Underwater pump distributes the water in the measuring cabin, equipped with a suite of flow-through sensors, especially targeting carbonate and phytoplankton variables (Honkanen et al. 2021, Kraft et al. 2022).

JERICO-S3 GoF PSS activities supported demonstration how IFCB could identify different bloom forming filamentous cyanobacteria taxa and estimate their biomass (Kraft et al. 2021). High-frequency observations (20 min resolution) allow to analyse how environmental forcing (temperature, salinity, light, mixing) affect the dynamics of cyanobacterial bloom intensity and taxonomic composition. The results highlighted that the data acquired by IFCB and microscopy were comparable. The work continued with the operationalisation of IFCB at Utö for near real time cyanobacteria detection (Kraft et al. 2022, see Fig. 3.1.8). This included steps of

i) creation of data pipeline from Utö station to cloud computing platform,

ii) development of Convolutional Neural Network (CNN) machine learning tool to classify image data into classes (n=50), including probability thresholds to filter out images not correctly assigned to the existing classes,
iii) publication of the CNN code in github (https://github.com/sykefi/syke-pic),
iv) publication of the phytoplankton image data sets (doi.org/10.23728/b2share.abf913e5a6ad47e6baa273ae0ed6617a and doi.org/10.23728/b2share.7c273b6f409c47e98a868d6517be3ae3), including importing subsets of data to EcoTaxa and EMODnet Biology (using a project-tag "IFCB Utö 2021 JERICO-RI Gulf of Finland Pilot Supersite"),
v) visualising data as part of JERICO-S3 Virtual Access, at swell.fmi.fi/hab-info/
vi) using the data during weekly algae reviews at GoF PSS, to inform public

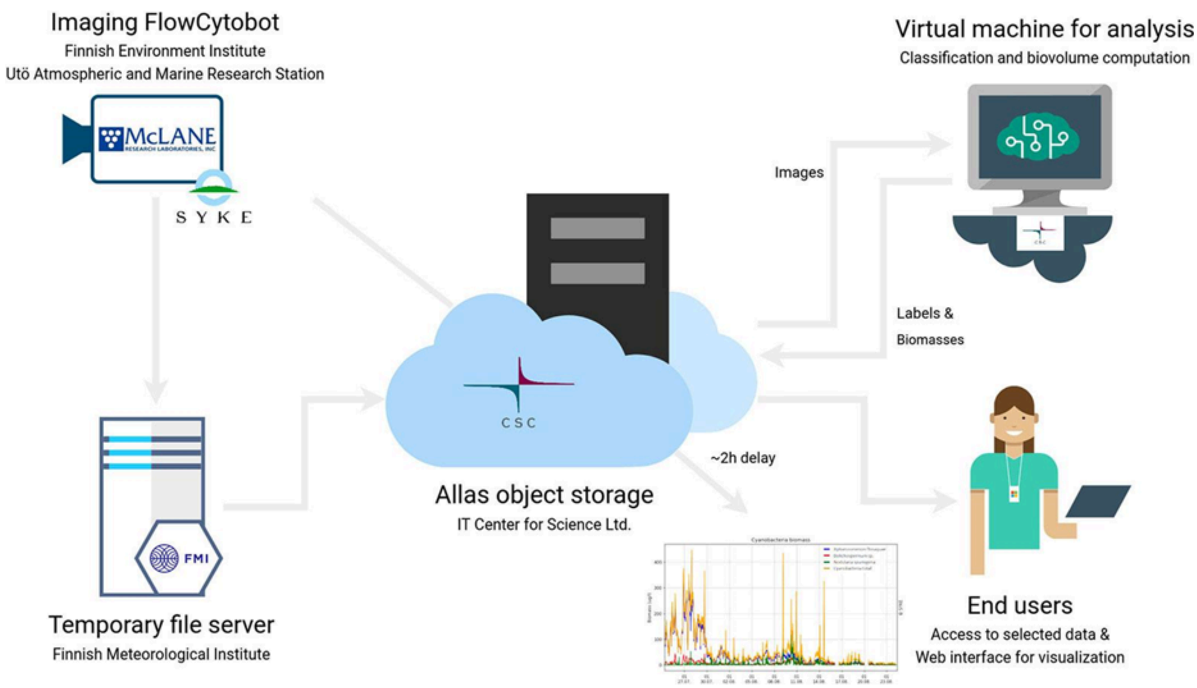


Fig. 3.1.8. A schematic of the processing of the phytoplankton images obtained at Utö station with an Imaging FlowCytobot. The cyanobacteria species information obtained is presented on a web site and can be used to aid in the weekly HAB reviews. (Kraft et al. 2022)

Activities have included sharing the knowledge within JERICO partnership, especially including collaborations with English Channel (CNRS-ULCO) for analysing a joint data and to set up their IFCB following experiences from Utö Marine Station. Active participation in the IFCB network has facilitated transfer of information to wider user groups. A specific activity within JERICO-S3 was a TA project AQUA-ACTION, where RI-RI collaboration for harmonisation and high-throughput analysis of plankton images was initiated with the AQUACOSM community, led by IGB (DE) (www.jerico-ri.eu/aqua-action-1_final_project_report/ and www.jerico-ri.eu/aqua-action-2_final_project_report/). Next steps, based on the JERICO-S3 developments, have been installing the IFCB onboard Ferry Finnmaid in 2023, as part of the FerryBox flowthrough system to collect phytoplankton biodiversity data across salinity gradient of the Baltic Sea, using IFCB at experimental mesocosm setup in AQUACOSM RI, and additional developments in CNN classifiers and code.

3.1.9 Use case KASKEN IRS, FerryBox Color Fantasy (Skagerrak-Kattegat-Belt Sea)

NIVA operates an Imaging Flow Cytobot alongside a FerryBox system on MS Color Fantasy that operates between Oslo and Kiel every second day (Fig. 3.1.9). The FerryBox system measures environmental parameters such as temperature, salinity, chlorophyll fluorescence, cDOM fluorescence, etc. Imaging Flow Cytobot samples are run about every 10-15 nautical miles and one sample is analysed approximately every 30 minutes. Imaging is triggered by fluorescence and scattering of particles. The images are analysed with AI-assisted automated image analysis (supervised machine learning) and produce quantitative data on phytoplankton diversity and biomass. Phytoplankton biomass and diversity is monitored, and special attention is paid to registering harmful phytoplankton species and high biomass events such as algal blooms.

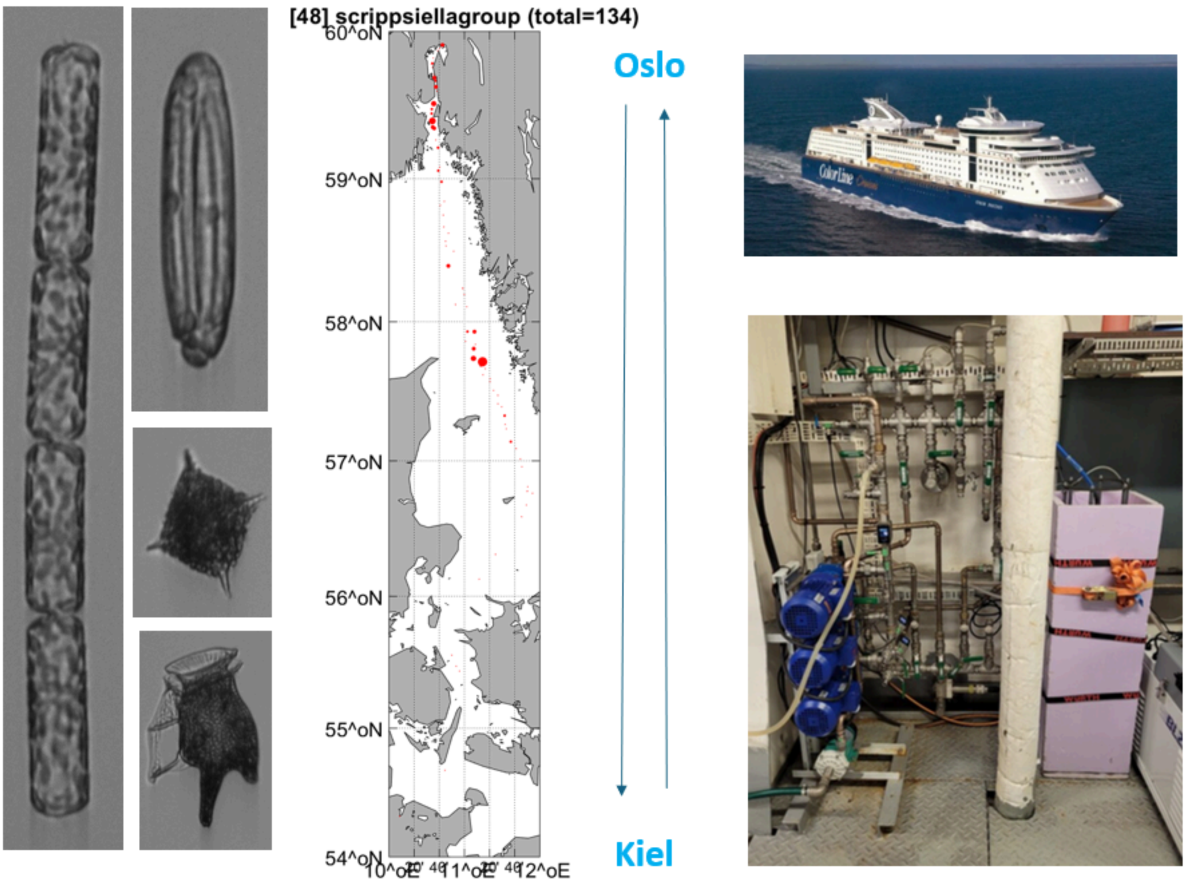


Fig. 3.1.9. Some results from the IFCB onboard Color Fantasy. To the left Imaging Flow Cytobot images from cruises in the wake of the storm Hans in August 2023. The transect shows the abundance of the *Scrippsiella*-group between Oslo and Kiel in June 2022. To the right Color Fantasy (top) and the Imaging Flow CytoBot in its pink styrofoam cooling box in the machine room of Color Fantasy (bottom).

3.1.10 Use case KASKEN IRS, ”Coastal Observatory Skagerrak”

IMR operates an Imaging FlowCytobot in the Bay of Flødevigen, Skagerrak coast, at a fixed sampling point (Fig. 3.1.10). The IFCB monitoring is coordinated with the ongoing monitoring of harmful algae. At this time, IFCB sampling is carried out every other day. The IFCB will eventually be linked to the “Coastal Observatory Skagerrak” (COS) located at the Torungen Lighthouse outside Arendal. The IFCB will be connected to a FerryBox system measuring physical and chemical parameters along with biology. The COS systems will monitor the Norwegian coastal current. IFCB will be an important part of this monitoring point, using AI-assisted automated imaging analyses (machine learning) to produce quantitative information on phytoplankton, with focus on Harmful algae blooms.

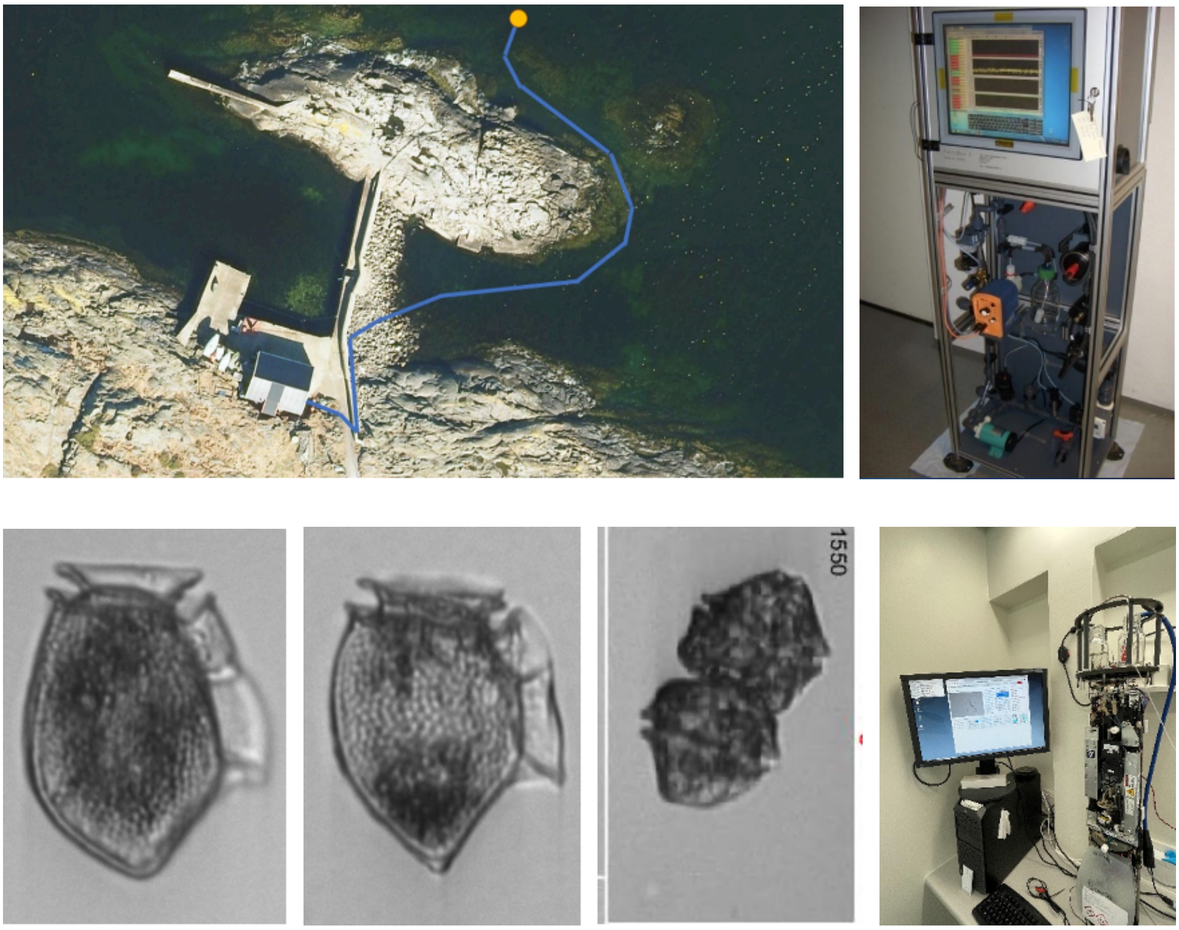


Fig. 3.1.10. The ”Coastal Observatory Skagerrak” (COS) located at the Torungen Lighthouse outside Arendal. The yellow point indicates the water intake at 10 m. IFCB will be connected to a FerryBox system.

3.1.11 Use case N. Adriatic Sea IRS, Acqua Alta Oceanographic Tower)

CNR ISMAR plans to operate an IFCB on the “Acqua Alta” Oceanographic Tower (AAOT) located in the Gulf of Venice 8 nautical miles from the coast (Fig. 3.1.11). The infrastructure was installed in 1970 as an early warning system mainly to have real-time data for tidal and weather forecast for the town of Venice but during the last decades marine ecological studies have been developed focused mainly on plankton communities. For most of EOVs AAOT is already equipped with state of the art sensors. AAOT is part of several research infrastructures such as JERICO, DANUBIUS and eLTER. In the frame of the activities dedicated to the study of ecological time-series monthly discrete samplings are conducted to analyse biological parameters that still are not measured with automatic systems such as dissolved nutrients and plankton taxonomy. Currently the IFCB is used to have parallel measurements along with classic Utermöhl counts at the inverted microscope, this comparison is the base to build a site specific classifier. During summer 2024 a seawater line will be installed to allow the IFCB to run on-site and feed a real-time data system. The Imaging Flow Cytobot will be located in the onboard wet lab and linked to the infrastructure LAN. Samples will run about approximately every 30 minutes. Imaging will be triggered by fluorescence. Special attention will be paid to registering harmful phytoplankton species given the presence of nearby mussel farms.

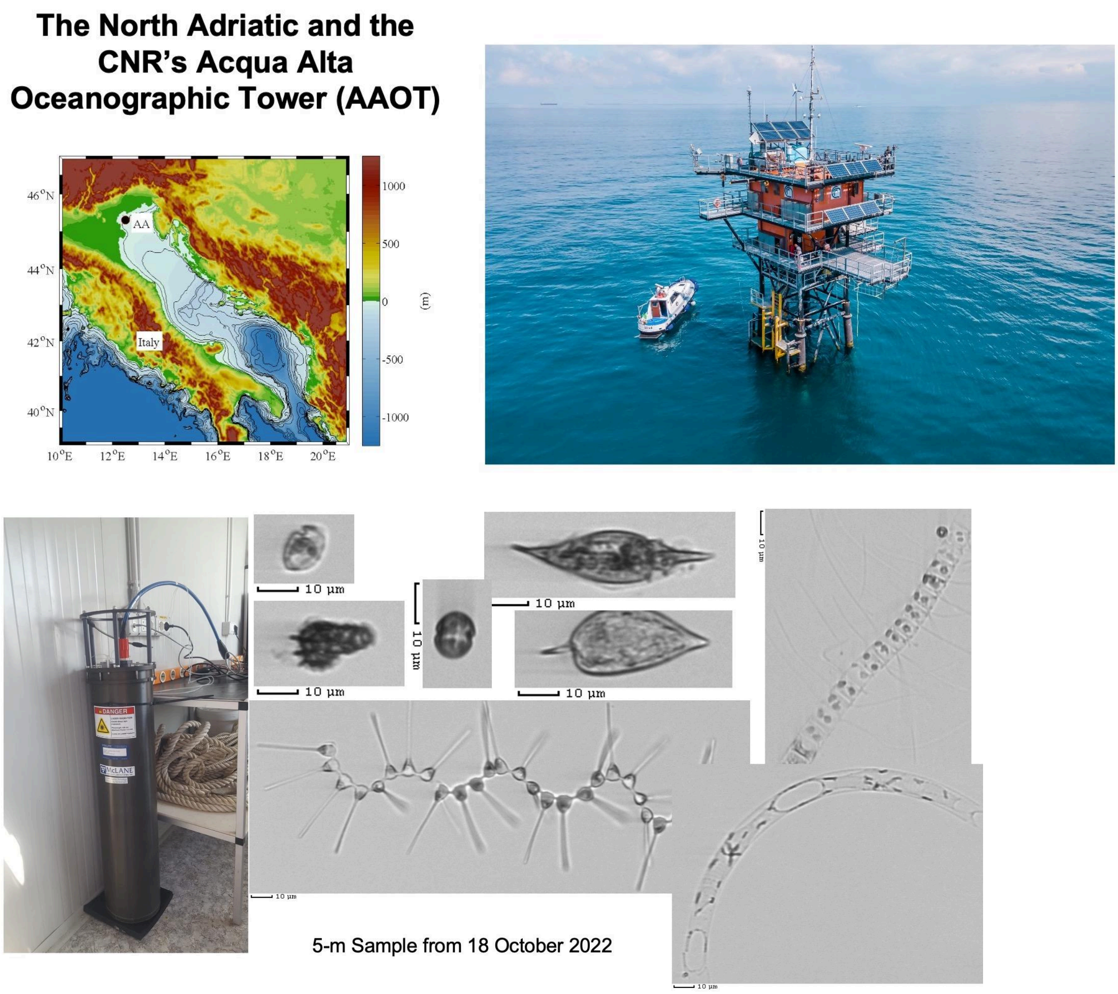


Fig. 3.1.11. Location of the FlowCytoBot inside the wet lab of the AAOT and some images acquired during an LTER sampling campaign.

3.1.12 Use case Northern Adriatic Sea IRS, Croatia

In an effort to build the infrastructural base for a regional observation system in the Adriatic Sea on the eastern Adriatic coast, the Center for Marine Research installed 2 oceanographic buoys in the northern Adriatic Sea and connected the respective data flows with 5 additional oceanographic buoys installed by the Croatian meteorological service. Common parameters measured are: Wind speed, Wind direction, Air temperature, Humidity, Visibility in air, Air pressure, Rainfall intensity, Wave height, Wave direction, Surface water current (speed and direction), Water currents throughout the water column (speed and direction), Chla concentration (1m), Seawater temp, Seawater Salinity. The two buoys installed in the northern Adriatic Sea additionally measure: CO2 pressure (1m), CDOM (water column), FDOM (water column), Phycoerithrin concentration (water column), CHLa concentration (water column), Sea water salinity (water column), Sea water temperature (water column), Sea water transparency (water column), PAR (water column), Seawater pH (water column), Seawater Oxygen concentration (water column). The oceanographic buoys are equipped with a self aware data acquisition system that adapts the sampling regime of additional biological sensors depending on the abovementioned oceanographic parameters. As additional biological sensors currently Cytosense imaging flow cytometers are installed at 2 m depth. All data are transferred to servers on land in near real time at 10 min intervals. The oceanographic buoys are visited monthly for reference sampling and measurements as well as for maintenance. Remote access to the entire system is realised through a webinterface system that allows direct access and programming of all components of the system in real time. The system of oceanographic buoys are part of a digital twin of the Ocean project for the eastern Adriatic Sea and will be part of the JERICO-RI. The following Figures 3.1.12-3.1.14 shows the oceanographic buoys as well as examples for the results from the biological sensor package.

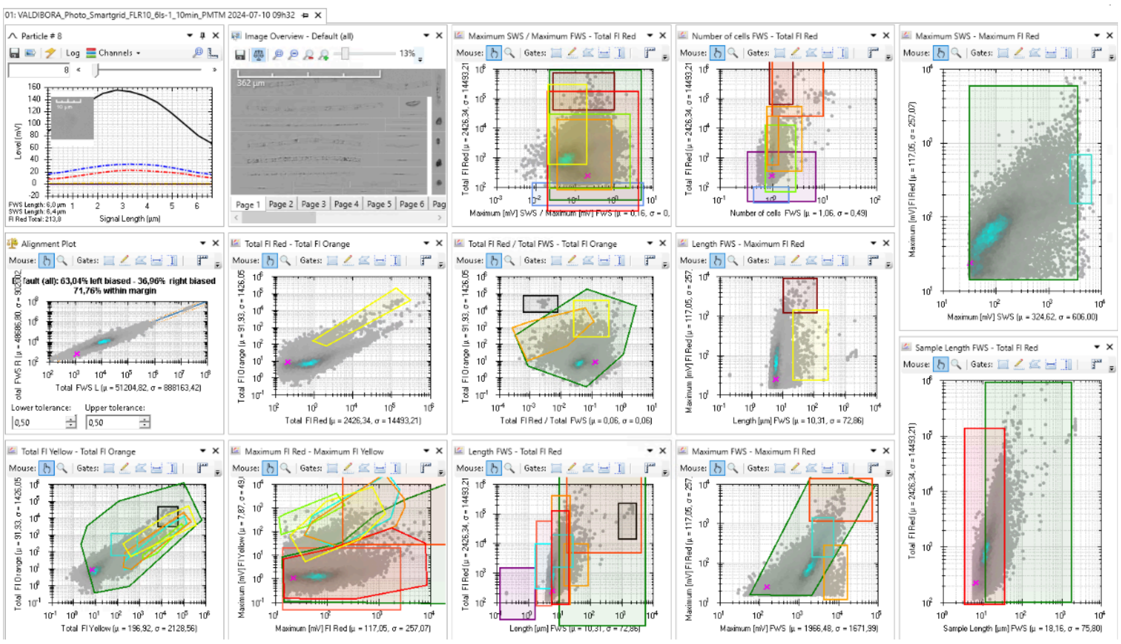


Fig. 3.1.12. Example results from the flow cytometry unit triggered by high attenuation values in the water column.

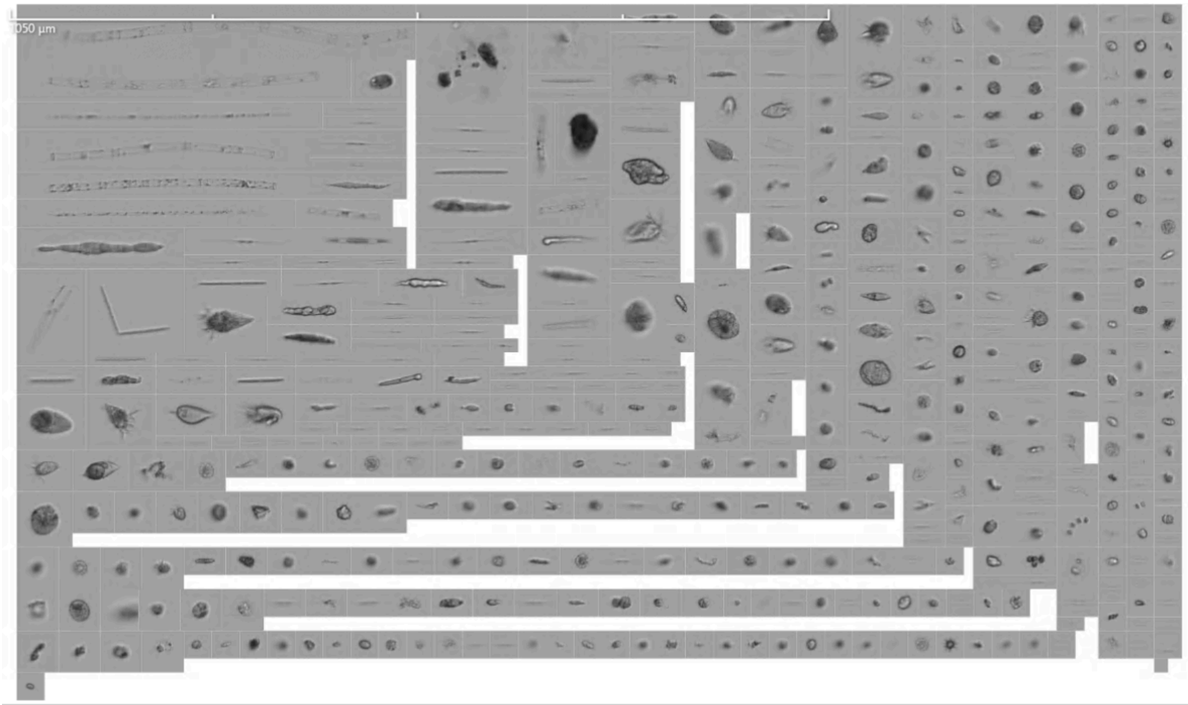


Fig. 3.1.13. Example results from the imaging unit triggered by high attenuation values in combination with low Chla concentrations.

Fig. 3.1.14. Aspect of one of the oceanographic buoys in the northern Adriatic Sea (left: outside of the buoy with the city of Rovinj in the background. Right: inside of the buoy during maintenance and sensor adjustment)

To further consolidate regional and pan-European interoperability of operational observatories, operators from the Center for Marine Research participated in 2 workshops for the operational application and for the data-management and data-analysis of biological data sets acquired by imaging flow cytometers organized by the JERICO-community: Workshop on plankton imagery (https://www.jerico-ri.eu/events/workshop-on-plankton-imagery/) and TT-CYTO: Tips and

Tricks towards flow cytometry data FAIRness (https://www.jerico-ri.eu/events/tt-cyto-tips-and-tricks-towards-flow-cytometry-data-fairness/)

Automated integration with satellite data is currently under development and an intercalibration exercise for CO2 data within the northern Adriatic is planned. The system of oceanographic buoys is currently active and integrated with several EOVs in the operational monitoring of the national waters of Croatia.

3.1.13 Future perspectives for automated plankton analyses

Automated phytoplankton analysis is today an operational method in harmful algal bloom warning systems, in marine monitoring and in phytoplankton research (e.g. Kraft et al. 2021). The quality of data produced is close to, but not equal to, results from microscopy. The advantages are mainly speed and sampling frequency. The methods for automated image analysis for identifying organisms are working well, but they are also still in development. Novel AI-based approaches are applied. A key part of this is the manually annotated images, i.e. the training data sets for supervised machine learning. A first step in sharing these images between IFCB users has been made by providing links to datasets at the Nordic Microalgae web site https://nordicmicroalgae.org/annotated-images/ (Torstensson et al. 2024). A planned, future development is to integrate the images in the database at Nordic Microalgae to make them searchable and downloadable in a more user friendly way compared to today.

Metabarcoding of eDNA is to a large extent complementary to microscopy and image based analyses. Metabarcoding reveals a higher diversity than the morphology based methods since also the small phytoplankton (< 5 µm) are included. These small organisms lack morphological features that make them possible to differentiate using light microscopy or e.g. the Imaging Flow Cytobot. Automated sampling is possible today, see section on sampling by NIVA. A next step would be automated sequencing to get results on ship. To accomplish this the whole sequence of sampling, DNA-extraction, PCR, sequencing and bioinformatics is needed.

3.2 Pilot study on integrating data from specific platforms/regions in the Iberian Atlantic Margin Integrated Regional Site (IH, PdE, PLOCAN)

3.2.1. Introduction.

The Iberian Atlantic Margin Integrated Regional Site (IAM IRS), defined in the framework of JERICO-S3 WP3 ("Integrated Regional Sites"), comprises the coastal ocean areas of a large geographical region that includes the western Mediterranean Sea (Alboran Sea), the Strait of Gibraltar, the south and west continental margins of Spain and Portugal in the Gulf of Cadiz, continuing, to the north, along the western coasts of Portugal and Spain, up to the Coruna area (N Spanish coast) and, to the south, to the insular shelves of the Canary Islands archipelago (Fig. 3.2.1). This large coastal ocean area is under a broad range of pressures and forcing agents, It is well exposed to the North Atlantic energetic conditions. It includes the key area of the Strait of Gibraltar, through which the exchanges between the North Atlantic basin and the Mediterranean Sea take place. It receives influences from far regions of the North and South Atlantic that are transported to this area along the NW African slope (e.g. Antarctic Intermediate Water influences observed along the Moroccan slope and potentially reaching the Gulf of Cadiz area). The IAM.IRS area is under the influence of seasonal changing atmospheric conditions, largely modulated by the influence of the Azores High pressure system, acting in association with the Icelanding Low pressure system and with low pressure systems that develop,in some periods of the year, over the Iberian Plateau (in the centre of the Peninsula) or in the North Africa region. Multi-annual variability in these conditions is associated with the atmospheric regimes that prevail in the North Atlantic, connected for example with the North Atlantic Oscillation (NAO).

3.2.2. The Pilot Study

Being a cross-road of influences, the IAM IRS presents a particularly interesting case study to assess the importance of the integration of observations collected by different institutions, along the coastal ocean areas of different countries. This integration is a fundamental requirement to our ability to understand these coastal ocean environments, which evolve not only as the results of the local forcing conditions (local atmospheric forcing, river inputs) but also due to influences of remote origin that propagate or are transported to the study areas.

This perception motivated the development, in the framework of JERICO-S3 WP3, of a Pilot Study focussing the integration of coastal ocean observations on the IAM IRS. The Pilot Study was aimed to explore the add.value of this integration to advance in the understanding of Transboundary Transport and Connectivity (Case Study 1) and of Extreme Events (Case Study 2). In this report, some results derived from the ongoing work of the first case study are discussed in section 3.2.4.

3.2.3. The Data Sets

The two case studies described above were developed using a broad set of observations collected by the partners of JERICO-S3 that contribute to the IAM IRS: Instituto Hidrografico (IH, Portugal), Puertos del Estado (PdE, Spain) and Plataforma Oceánica de Canarias (PLOCAN, Spain). In Portugal, IH operates the MONIZEE infrastructure, with observing capacities installed along the complete coastal ocean area of the Portuguese mainland (additional capacities also installed in the Archipelagos of Madeira and Azores). For the periods selected for the Pilot Study, these include 5 HF radar stations, 4 multiparametric buoys, 3 wave buoys and 12 coastal tide gauge stations. In Spain, PdE operates the PORTUS operational oceanographic system, which integrates (in the IAM IRS area, along the Spanish mainland coast and Canary Islands) 9 HF radar stations, 17 multiparametric buoys, 10 wave buoys and 39 coastal tidal gauge stations. PLOCAN operates an observing infrastructure installed in the Canary Islands archipelago and integrating HF radar stations, test site for ADCP measurements and test site for BGC sampling. PLOCAN also operates a fleet of mobile vehicles, such as gliders, which were used in Case Study 1 (Transboundary Processes and Connectivity).

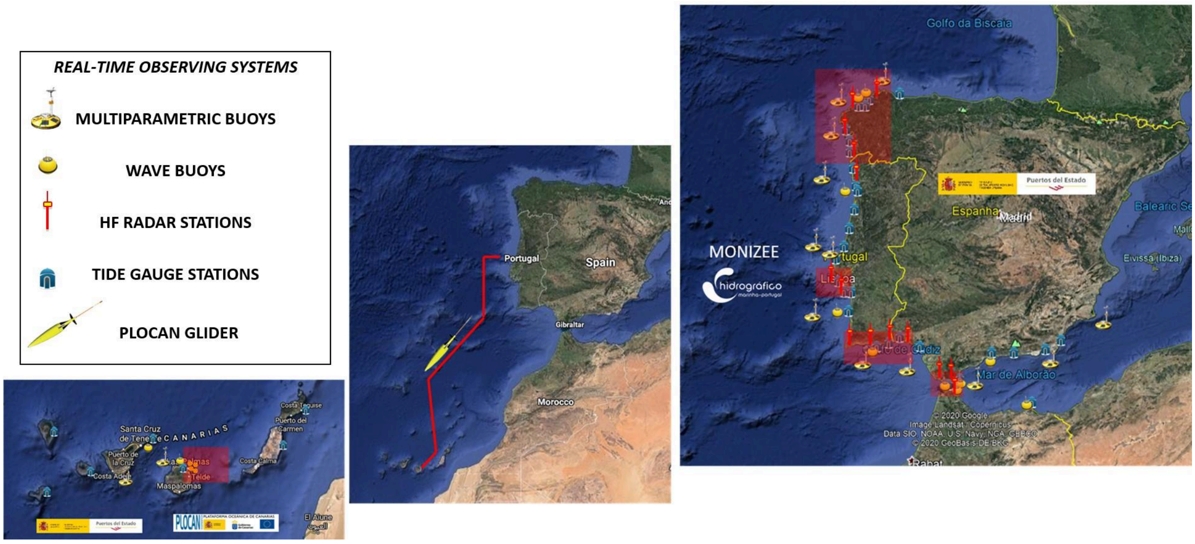


Fig. 3.2.1. The observation capacities operated by IAM-IRS partners and used in the Pilot-Study.

Each one of the two Case Studies previously mentioned focused on a specific time period of interest and used the observations that were more relevant to explore the processes of interest. In Case Study 1 (Transboundary Transport and Connectivity), the analysis was focussed on the period between January 2020 and May 2020, for which a comprehensive set of observations was available from the different observing platforms. For Case Study 2 (Extreme Events), the attention was focussed on two particular time periods, the first one from 25 February to 10 March 2018, correspondent to the passage of storm Emma over the area, and the second one from 10 to 20 October 2018, correspondent to the passage of Hurricane Leslie over the area.

Data from JERICO partners used in the Pilot Study.

The IAM IRS Pilot Study used the following observations collected by the platforms operated in the area by the three JERICO-S3 partners:

<u>HF Radar Stations:</u>

- Surface current observations provided by HF radar stations operated by IH (W and S Portuguese margin) and PdE (Strait of Gibraltar and Alboran Sea, SW Spanish margin, NW Spanish margin);

<u>Fixed Platforms Offshore:</u>

- Near Surface (~ 1-3m depth) current observations provided by single-point currentmetes installed in PdE Multiparametric buoys (Strait of Gibraltar and Alboran Sea, SW Spanish Margin, NW Spanish Margin);
- Subsurface current (from ~10m to 90m depth) measured by Acoustic Doppler Current Profilers (ADCPs) installed in IH Multiparametric buoys (W and S Portuguese margin);

- Near Surface(~ 0.5 - 3m depth) temperature observations provided by multiparametric buoys and wave buoys operated by IH (W and S Portuguese margin) and PdE (Strait of Gibraltar and Alboran Sea, SW Spanish Margin, NW Spanish Margin);
- Subsurface temperature provided by thermistors installed in IH Multiparametric buoys (W and S Portuguese margin);
- Near Surface (~ 1-3m depth) salinity observations provided by PdE Multiparametric buoys (Strait of Gibraltar and Alboran Sea, SW Spanish Margin, NW Spanish Margin);

<u>Gliders:</u>

- Temperature from surface to maximum depth 1000m provided by PLOCAN glider;
- Salinity from surface to maximum depth 1000m provided by PLOCAN glider;

<u>Coastal Stations:</u>

- Sea Surface Height at the coast provided by tide gauges stations operated by IH (W and S Portuguese margin) and PdE (Strait of Gibraltar and Alboran Sea, SW Spanish Margin, NW Spanish Margin);

Complementary data used in the study:

<u>Remote Sensing L4 Products from Copernicus Marine Service (CMEMS)</u>

- Sea Surface Temperature
- Sea Surface Height
- Surface Chlorophyll

<u>Numerical models</u>

- Model SAMPA (PdE)
- Model NEMO 3D fields of T, S,Current, SSH (CMEMS)
- ERA-15 reanalysis of the European Centre for Medium-Range Weather Forecasts (ECMWF) model, fields of Surface Sea Level Pressure and Wind at 10m height (Copernicus Climate Change Service)

<u>Bathymetry</u>

- Bathymetry (EMODNET, GEBCO)

3.2.4 Characterising the regional expression of coastal ocean conditions evolution in the IAM IRS - a few examples.

Results from the ongoing work on Case Study 1 ("Transboundary Transport and Connectivity") are used in this section to illustrate the importance of the integration of different observations and complimentary data in gaining a deeper understanding of the evolution of condition in the IAM IRS.

The discussion conducted in Case Study 1 is based on the analysis of the subinertial variability of the different relevant parameters, i.e. only the variability with periods equal or longer than 36 hours is retained. This corresponds, for example, with the variability in coastal ocean conditions associated with the response to atmospheric synoptic systems or with the forcing of ocean circulation offshore. The high frequency variability (such as the one associated with tides - in this area dominated by the principal lunar semidiurnal constituent M2 - or with short wind episodes of duration one day or less) is removed by low-pass filtering the time series of the different parameters measured by HF radars, multiparametric and wave buoys or tide gauges.

Case Study 1, as previously described, was focused on a specific time period (01 January to 31 May 2020). The near surface measurements collected by the multiparametric buoys installed along the upper continental slope, offshore the mainland coasts of Portugal and Spain that are comprised in this IRS (Fig. 3.2.2, near surface temperature), reveal that the study period covered an important part of the seasonal cycle, from the end of the winter regime to the transition to the summer regime, with a clear transition being observed at the beginning of April 2020.

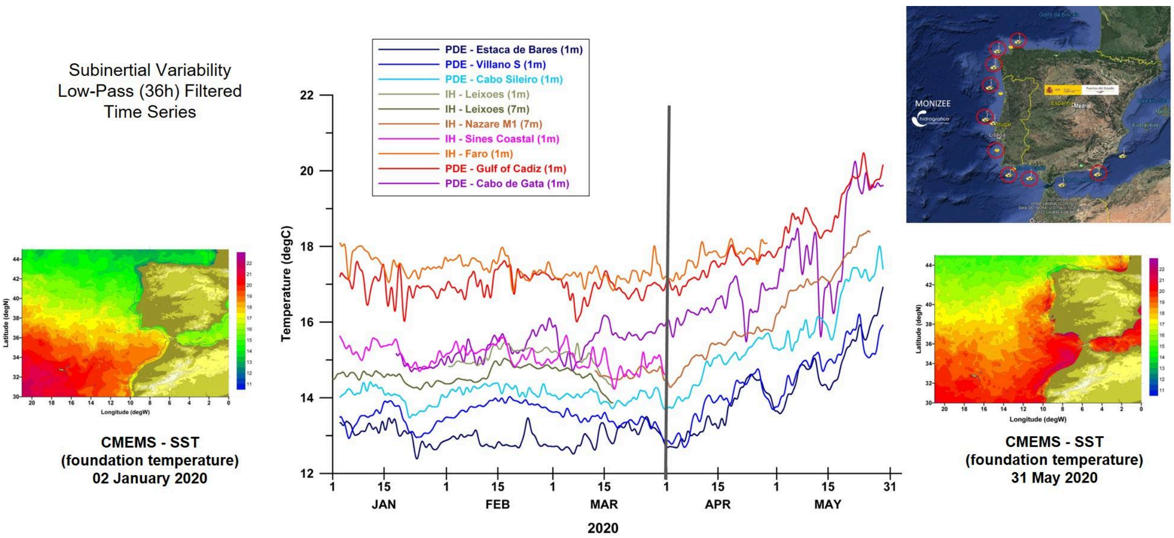


Fig. 3.2.2. Time series of low-pass 36 hours near surface temperature measured at the multiparametric buoys (and, in one case, also wave buoy) of IH and PdE (red circles in map on the top right of the figure).

Transport processes and connectivity along the continental margin of IAM-IRS

The response of coastal ocean waters to the evolution of atmospheric forcing conditions during this time period is inferred from Fig. 3.2.3, which shows the alongshore component of EAR15 wind at 10m height above the sea, at three locations offshore the N Spanish coast, the W Portuguese coast and the S Portuguese coast. The red segments of each one of the three time series correspond to periods of downwelling favourable winds (promoting onshore transport of the waters offshore in the direction of the coast and a predominant shelf circulation following the direction that leaves the coast to its right - e.g. northwards offshore the W Portuguese and Spanish coasts) while blue segments correspond to periods of upwelling favourable winds (promoting offshore transport of the waters in the upper layers, leading to the replacement, near the coast, of these waters by cold and nutrient rich subsurface waters, and a shelf circulation in the direction that leaves the coast to its left - e.g. equatorward offshore the W Portuguese and Spanish coasts).

Offshore the northern and western Iberian coasts, downwelling conditions prevail until mid February / mid March, and upwelling conditions become dominant for the rest of the period of interest. Along the south coast of Portugal and Spain it is more difficult to identify a prevailing type of conditions, along the study period. The winter atmospheric conditions affecting this global area is largely influenced by the Azores High pressure system evolution (centred in the middle of the North Atlantic), being modulated by the regime of the (winter) North Atlantic Oscillation (NAO, the atmospheric pressure dipole between the Azores High and the Icelandic Low pressure system). Negative phases of the winter NAO correspond to years during which the Azores High migrated, during the winter, to regions of the North Atlantic located south of the Iberian Peninsula. During these winters, the Atlantic coasts of Portugal and Spain are under a westerly and southwesterly atmospheric circulation, leading to predominant periods of downwelling conditions. This seems to be the case for the period in 2020 discussed here.

In spring, the Azores High migrates to a more northern position, offshore the western Iberian coast. Under these conditions the Atlantic Iberian margin becomes located in the eastern limb of the High, influenced by persistent northerly winds. These winds promote a well defined summer upwelling season along the W coasts of Portugal and Spain, with important manifestations such as large upwelling filaments. The trigger of this regime, in 2020, seems to have occurred by mid March, as suggested by figure 3.2.3.

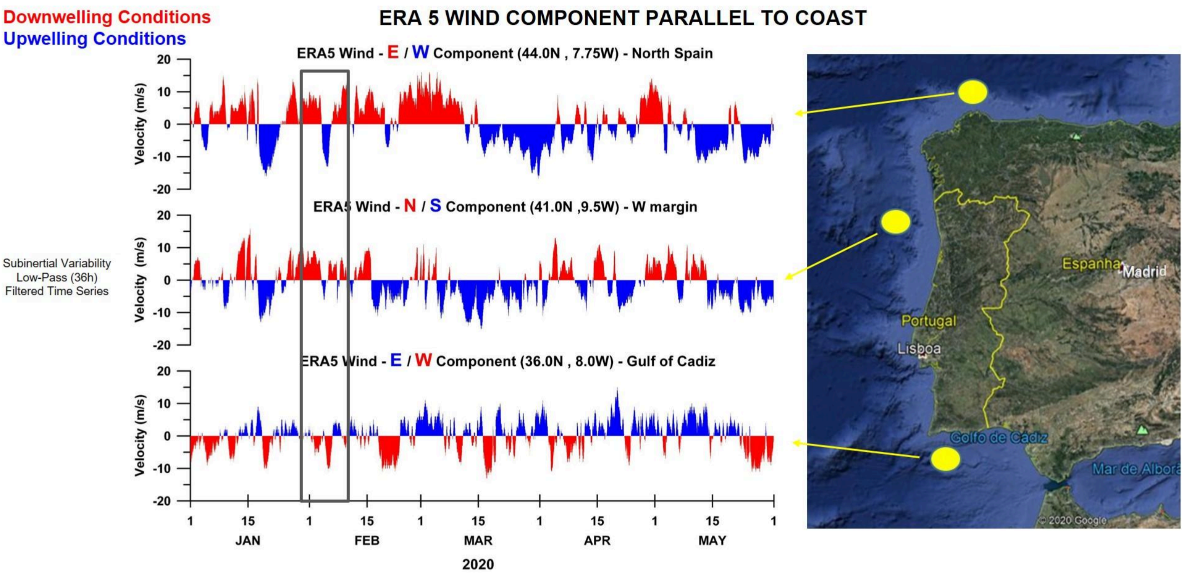


Fig. 3.2.3. Time series of low pass (36 hours) ERA-15 winds at 10m above sea surface at 3 locations in the IAM-IRS continental area. Only the wind component parallel to the coast is represented (see text for details). The black rectangle indicates the period discussed in detail.

To illustrate how different coastal ocean areas along this regional domain can be connected by transport processes, we focus now on the period from about 28 January to 8 February, indicated by the black rectangle in Fig. 3.2.3. The ERA15 maps of the wind at 10m height (not shown) reveal that, during this period, the area was under the influence of the western limb of an anticyclonic atmospheric circulation, with the southern coasts of Portugal and Spain influenced by easterlies and the western coast influenced by southerlies. The evolution of the Sea Surface Temperature measured by satellite (Fig. 3.2.4) suggests a poleward along margin circulation in the global area, from the Gulf of Cadiz, progressing along the western Iberian outer shelf and slope and continuing along the northern Spanish margin in the Bay of Biscay. Such a circulation patterns could promote the transport of surface waters from the Moroccan margin along the Gulf of Cadiz, and from there further northwards along the western coasts of Portugal and Spain.

The different observation platforms installed along this global area and contributing to JERICO provide a complementary view of the conditions, reinforcing the perception of this circulation. In the southern part of the area, the current measurements provided by the multiparametric buoys operated by PdE and IH are presented in Fig.3.2.5a, in the form of the (low pass) eastward current component, which for these two systems basically corresponds to the alongslope current (positive if directed eastward). The PdE multiparametric buoys measured the current used a single-point currentmeter installed at about 1m depth, while IH buoys measured the currents using a downward looking ADCP 300 kHz installed at 7m depth, providing hourly measurements of the current profile between about 10m depth an 90m depth.

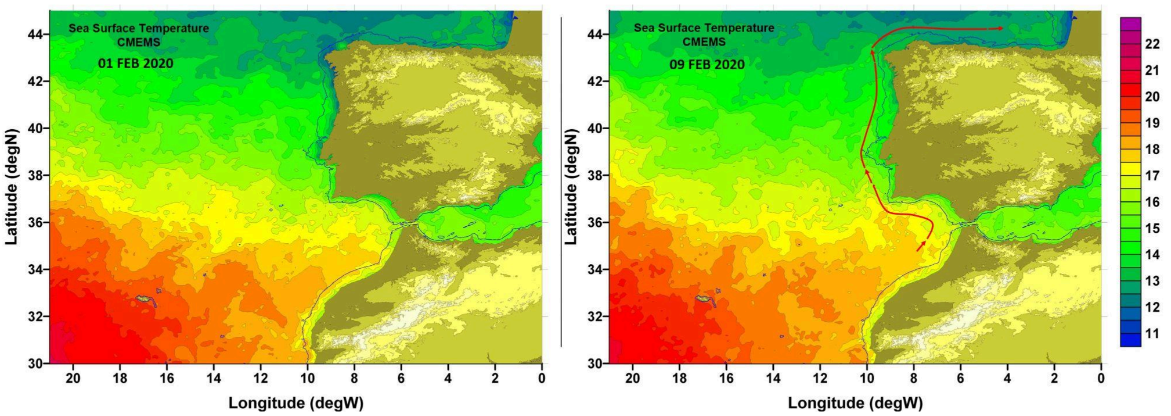


Fig. 3.2.4. Evolution of the foundation sea surface temperature observed from satellite between 01 February 2020 (left panel) and 09 February 2020 (right panel). The blue line indicates the shelf break (200m isobath). The red line in the right panel aims to suggest the possible continuous alongslope transport that was established in this regional area during the period in discussion. The temperature scale (in ºC) is provided at the right of the figure.

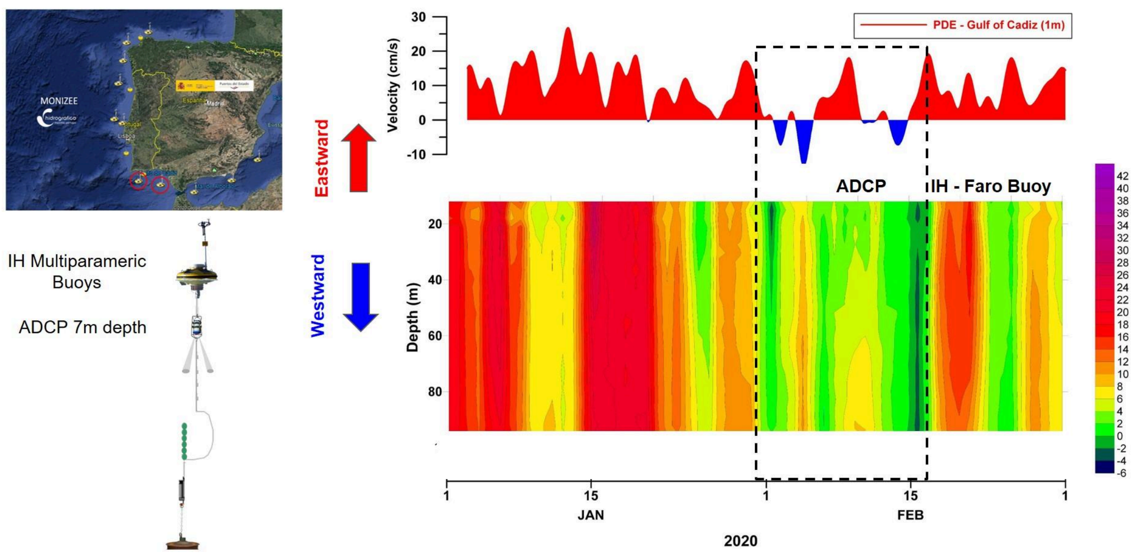


Fig. 3.2.5a. Low pass filtered current measurements collected by multiparametric buoys installed in the south coasts of Portugal and Spain (position indicated by red circles in the top left panel), using a single-point currentmeter installed in PdE buoy (top right panel) and and ADCP installed in IH buoy (bottom right panel, current speed scale in cm/s included). The scheme of IH buoy is presented in the bottom left panel.

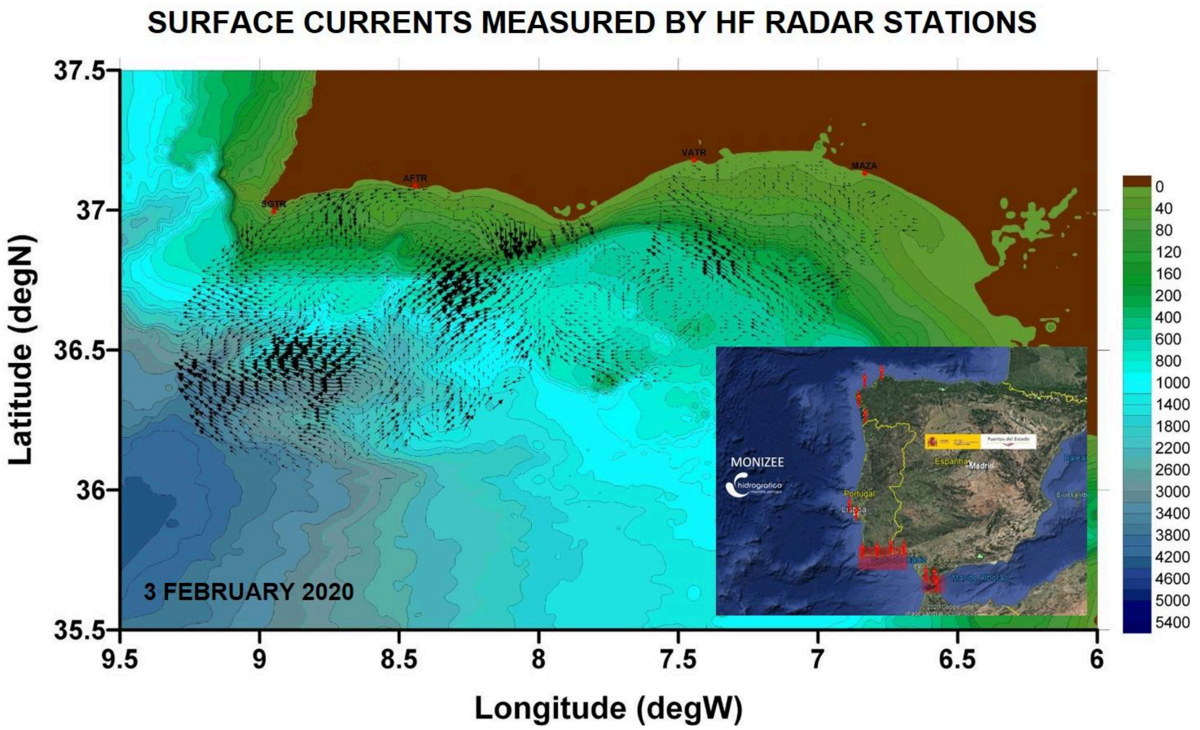


Fig. 3.2.5b. Low-pass filtered (36 hours) surface current at 00:00 on the 3 February 2020, measured by the HF radar stations operated by IH and PdE along the southwestern Iberian coast (station locations presented in figure). The scale of bathymetry (in metres) is presented on the right.

These systems revealed that westward flow was in fact measured in both the buoys between 1 February and about 17 February 2020 (Fig. 3.2.5a). The HF radar system installed in the areas, which include 3 stations operated by IH along the southern Portuguese coast and 1 station operated by PdE in the southwestern Spanish coast, showed how this alongslope flow was circulating around Cape Saint Vincent, in the southwest tip of the Portuguese coast, and how it interacted with the complex shelf circulation inshore (Fig. 3.2.5b).

Further north (Fig. 3.2.6), in the central part of the western Portuguese coast, the HF radar stations operated by IH provide evidence of poleward flow along the slope offshore Lisbon, following the slope around the southern flank of the broad Estremadura Plateau (current encircled by the red ellipse) and suggesting a continuity with the flow that was observed to turn around Cap Saint Vicent. In this area, the HF measurements for the area further onshore also showed westward flow from the Tagus river mouth, raising the possibility that riverine influences from the Tagus river can reach the outer shelf/upper slope area and be incorporated in the observed poleward flow, being transported further north (interaction area encircled by the blue ellipse).

Why integrated, real time observations of these shelf and slope flows are so important?
Coastal influences can impact regions far from their sources due to the important dynamical processes that occur in the coastal ocean domain. River plumes, for example, are advected by the wind forced shelf and slope currents. Fine sediments can be exported offshore in long submarine canyon and reach the slope environment, from where they can be transported by important slope currents.

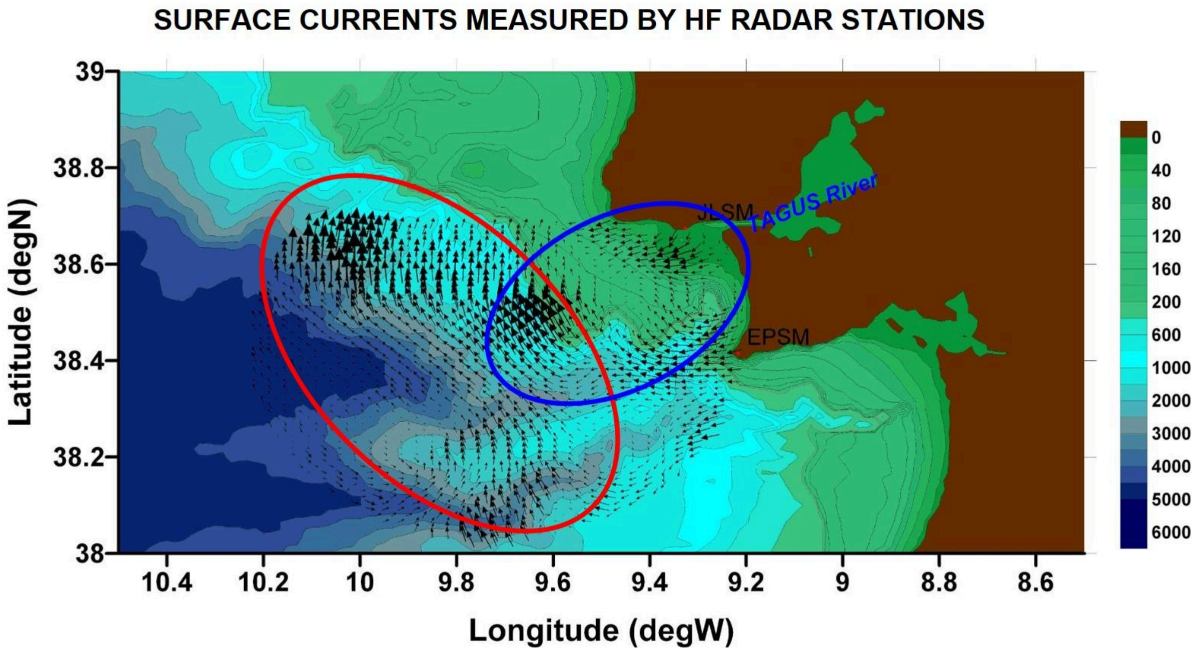


Fig. 3.2.6. Low-pass filtered (36 hours) surface current at 00:00 of the 3 February 2020 measured by the HF radar stations operated by IH on the central western Portuguese coast (Lisbon area, station locations presented in figure). The scale of bathymetry (in metres) is presented on the right. The blue and red ellipses are discussed in the text.

Off the NW coast of Portugal and Spain, the surface single-point currentmeters installed in the multiparametric buoys of PdE showed that poleward flow was re-established by the end of January, after disruption by a major winter upwelling event, and continued until the end of the period presented in the figures (Figure 3.2.7a). In the IH buoy installed offshore the northern Portuguese coast this was less clearly shown in the ADCP data, a result that can eventually be associated with the configuration of the slope topography in the area (to be confirmed by further analysis of the data).

Why integrated, real time observations of these shelf and slope flows are so important?
Many commercially important species spawn during the winter months off the W coast of Portugal and Spain. The occurrence of important winter upwelling events, such as the one observed during the second half of January 2020 (figure 3.2.7a), can transport fish egg and juveniles offshore, to the outer shelf and upper slope. With the reversal of conditions and re-establishement of surface poleward flow, these eggs and larvae are transported poleward, to areas far from the spawning grounds. Observations are crucial to understanding this interaction between the across-shelf and along-shelf circulation and predict its impacts on the coastal ocean ecosystems and resources.

The HF radar station operated by PdE along the NW Spanish coast clearly depicted this poleward flow that extends from the W Portuguese coast to the N Spanish coast, into the Bay of Biscay. The poleward flow is particularly strong on the NW corner of Iberian Peninsula, with the currentmeters installed in PdE multiparametric buoys indicating subinertial currents of 40-60 cm/s and sometimes even higher.

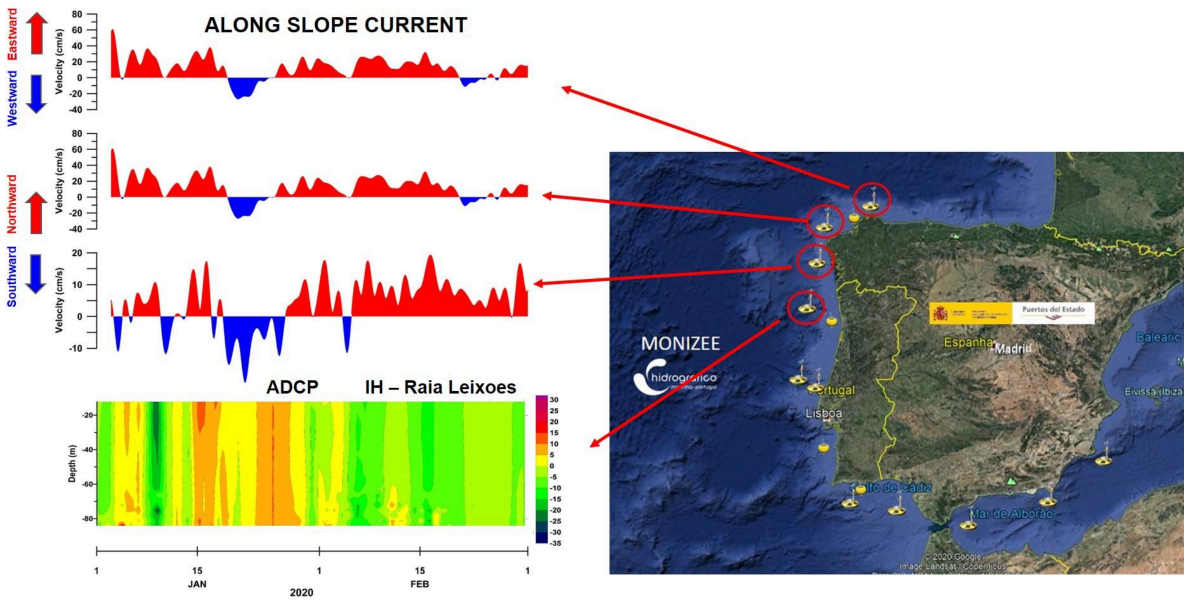


Fig. 3.2.7a. Low-pass filtered (36 hours) current measured by IH and PdE multiparametric buoys for the period of detailed analysis (figure on the left) and map with the position of the buoys (figure on the right).

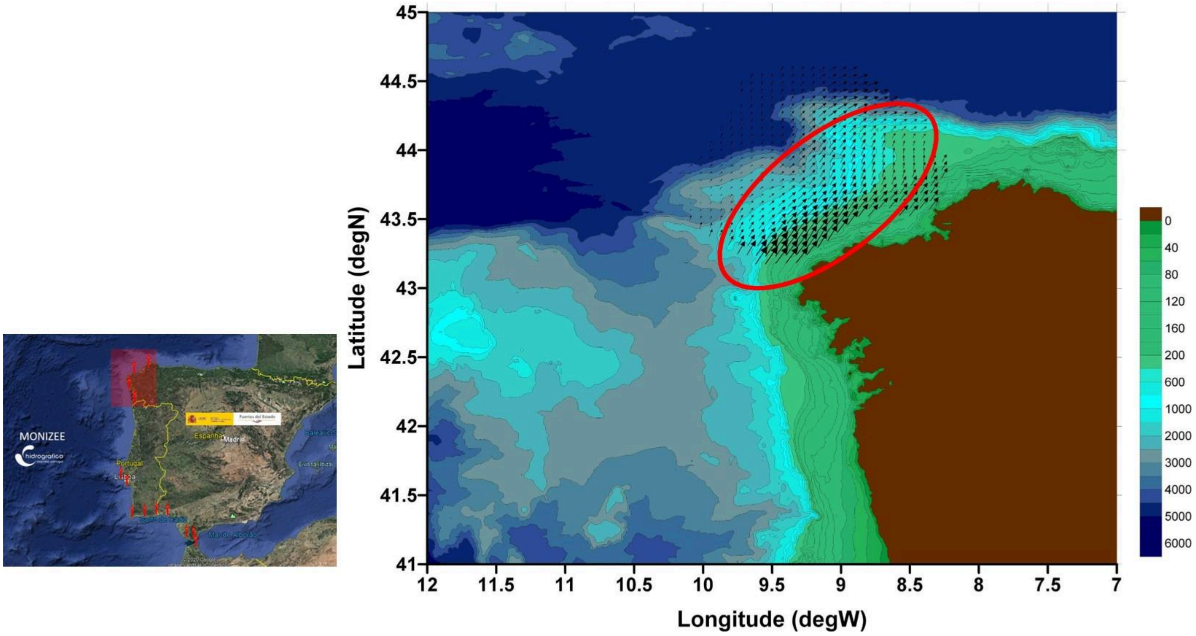
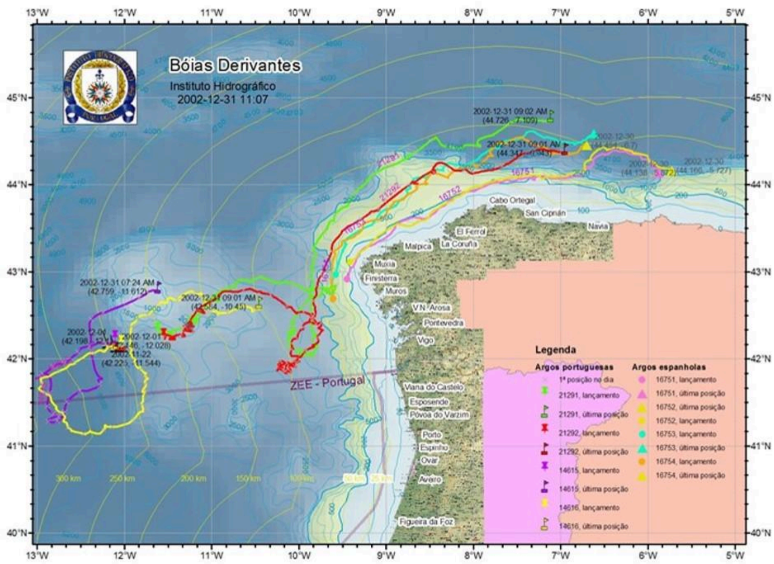


Fig. 3.2.7b. Low-pass filtered (36 hours) surface current at 00:00 of the 3 February 2020 measured by the HF radar stations operated by PdE along the NW coast of Spain (station locations presented in bottom left panel, red area). The scale of bathymetry (in metres) is presented on the right. The red ellipses highlight the area of maximum poleward slope current.

Why integrated, real time observations of these shelf and slope flows are so important?

The poleward slope circulation observed, from January to May 2020, by the fixed platforms and HF radars installed offshore Portugal and Spain, represents a powerful mechanism to redistribute, along a broad regional area, the influences from the open ocean that reach the coastal ocean outer boundary. The figure below is one of the crisis support products delivered by IH on the 31 December 2002, during the Prestige oil spill crisis. Its includes the tracks of surface floats deployed by IH, between 22 November and 04 December 2002, in the area where the tanker sank on the 19 November 2022. These floats followed the main oil spills that were released during the sinking of the ship. The figure also includes the tacks of surface floats deployed by Spanish institutions, in December 2002, on the NW Spanish slope, when the main oil spills reached the continental slope off NW Spain and Portugal. The presence of the poleward slope current is clearly evident, advecting the floats along the continental slope and into the Bay of Biscay area. This current was the main reason why what could have been a localized problem become a regional crisis, impacting 3 countries.



See the similarities between these float tracks in winter 2002 and the surface current field observed by the PdE HF radar stations on the 3 February 2020 (figure 3.2.7b.).

To explore the nature of the slope circulation observed by the different observing platforms operated by IH and PdE along the mainland coasts of Portugal and Spain, it is essential to also observe the open ocean forcing over the continental slope, on the outer boundary of the coastal ocean environment. For the period selected for this case study (January-May 2020) these observations were provided by the glider of PLOCAN, which conducted a section with depart offshore Nazare (central part of the W Portuguese coast), on the 7 February 2020, and arrival in the Canary Islands, on the 5 May 2020. The glider mission was partially funded by the European project iFado and was possible by a collaboration between PLOCAN and IH, with the deployment of the PLOCAN glider being conducted with the use of one of the IH hydrographic vessels.

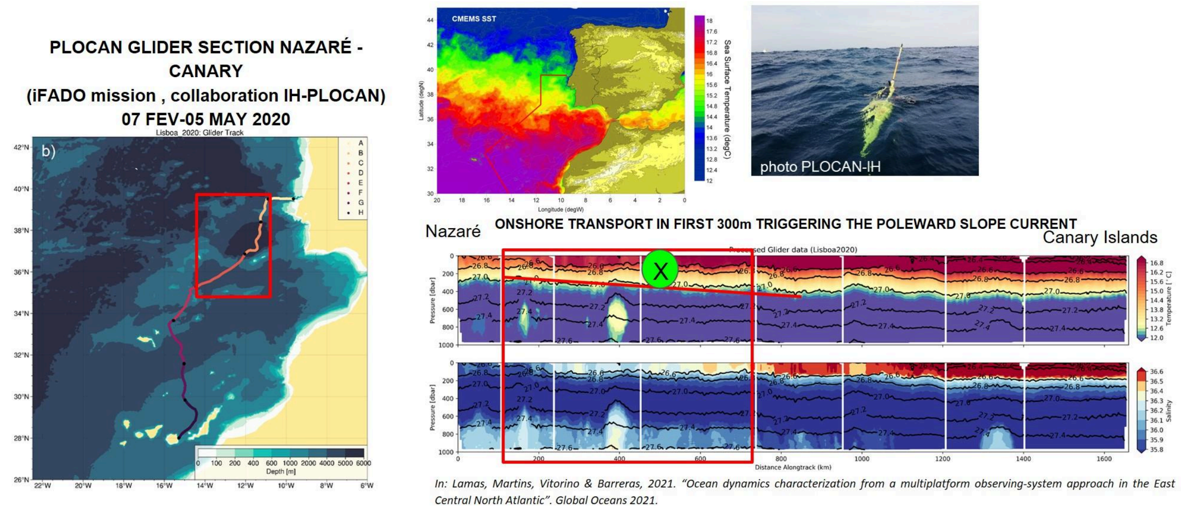


Fig. 3.2.8. PLOCAN glider mission track with the geographical area relevant for this study indicated by the red rectangle (left). Implementation of the glider track over the Sea Surface Temperature from satellite (middle top). Photo of PLOCAN glider (top right). Temperature and Salinity sections from surface to maximum depths of 1000m (bottom right), with indication of the geographical area relevant to this study (red rectangle), of the general slope of 27.0 isopycnic (red line) and of the inferred geostrophic flow direction in the upper layers (green circle). Adapted from Lamas et al. (2022).

The long glider section (Fig. 3.2.8) crossed the Azores Current eastward extension, allowing a unique insight on the forcing of the Northeastern Atlantic basin circulation over the continental margins of NW Africa, Gulf of Cadiz and Western Iberia. In the area indicated by a red rectangle, the glider section shows an important meridional density gradient in the upper 300-40m (and associated gradients of temperature and salinity), offshore the SW Portuguese coast. This is consistent with geostrophic flow directed onshore in the upper 300m. It is this onshore transport impacting the area of the continental slope that corresponds to the main forcing of a slope intensified poleward flow, through the JEBAR (Joint Effect of Baroclinicity And Relief) mechanism. The surface expression of this poleward slope current is modulated by the local wind forcing conditions. The glider section can, then, allow us to quantify the expression of the open ocean influence that was acting, in February and March 2020, to promote the poleward circulation that was observed by multiparametric buoys and HF radars along the coastal ocean areas of Portugal and Spain.

Basin Exchanges (the IAM-IRS case).

The Strait of Gibraltar area, in the transition between the North Atlantic basin to the Mediterranean Sea, represents a particularly key area of interaction inside the IAM-IRS. For this reason, it brings to evidence the importance of integration of the data collected by observing capacities installed along a large geographical area and operated by different partners, from different nations. Here, the relatively fresher North Atlantic water enters the Mediterranean Sea as a surface Atlantic Jet while the saliter Mediterranean Outflow water enters in the Gulf of Cadiz as a subsurface flow, mixing with the surrounding waters and reaching its depth of gravitational stability, spreading from there its influence in the Atlantic, at depths between the 500m and the 1500m depth.

The recognition of the importance that the processes that take place in the the Strait of Gibraltar "choke point" have to the shaping of the mutual interactions between the two basins, motivated a specific study conducted by the PdE team (Lorente, Peréz, de Alfonso & Ruiz, "Pilot Study and Extreme Events", 2024, 65p.). This study is also a good example of integration of observations from IAM-IRS partners, of remote sensing observations and of numerical model simulations. The focus of this study was the 3D characterisation of the Atlantic Jet, with a particular attention to the episodic disruptions of this jet due to unusual atmospheric forcing.

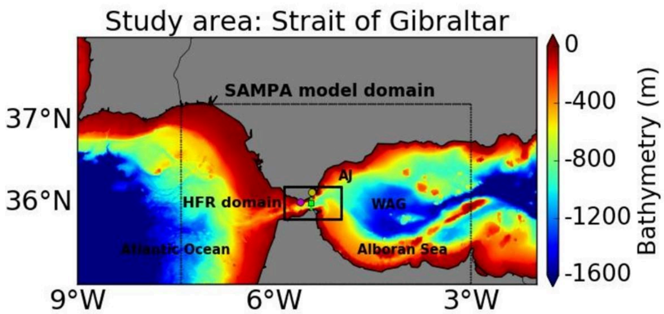


Fig. 3.2.9. Study area considered in the analysis of the Strait of Gibraltar processes. The figure also shows the domain of SAMPA model simulations and the area covered by PdE HF radar observations. The green circle marks the location of the HF node used in Fig. 3.2.10.

The surface currents collected by the PdE HF radar stations installed in the area (Fig. 3.2.9) allow the characterization of the Atlantic Jet during the time period selected for Case Study 1 (01 January to 31 May 2020). The mean surface circulation obtained from the HF radar data collected during the 5 month period (Fig. 3.2.10, left panel), shows the Atlantic Jet as a north-eastward flow with maximum currents of about 100 cm/s in the narrowest section of the Strait of Gibraltar. Hourly HF radar currents at the middle point of the channel where the currents are stronger (green dot in Fig, 3.2.9) are presented in the right panel of figure 3.2.10. They show that the Atlantic Jet is typically fluctuating between speeds of 50 cm/s to 180 cm/s (with peaks reaching 250 cm/s) and very consistently directed northeastward (direction about 73 degrees). But the figure also shows the occasional drops of the current speed below 50 cm/s, that is accompanied by an abrupt change in the orientation of the Atlantic Jet. Some of these periods with longer (about 2 days) persistence were even characterised by a full surface flow reversal.

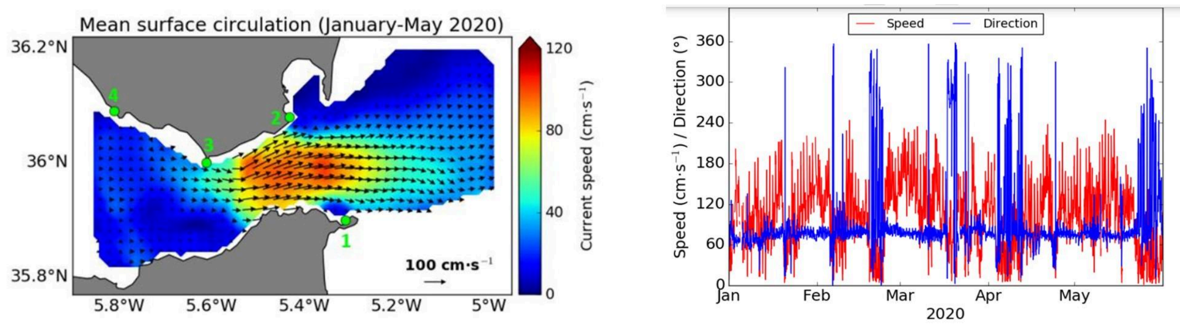


Fig. 3.2.10. The mean surface circulation obtained from the data collected by the PdE HF radar network, with stations installed in Ceuta (1), Carnero (2), Tarifa(3) and Camarinal(4) (left panel). The speed and direction measured by the PdE HF radar stations at the node located in the centre part of the channel, noted by a green dot in figure 2.3.9 (right panel).

To explore how the regional forcing conditions modulate the response of the Atlantic Jet, the study integrated the 2-days averaged maps of sea level pressure wind at 10m height provided by the European Centre for the Medium Range Weather Forecasts (ECMWF) with modelled (using the high resolution coastal model SAMPA) and observed (from the PdE HF radar network) surface circulation fields (Fig. 3.2.11). A strong Atlantic Jet is seen at the beginning of March 2020 (Fig. 3.2.11, upper panel), during the periods characterised by a dipole structure in the meteorological conditions in the Atlantic, with the Azores High pressure system in the middle North Atlantic offshore the Gulf of Cadiz region and a low pressure system of the British Islands, leading to northwesterly winds over the Gulf of Cadiz. Concurrently, westerly winds dominated over the western Mediterranean basin. The SAMPA model simulations for this period show a strong Atlantic Jet, with currents over 100 cm/s in the Strait of Gibraltar, feeding the Western Alboran Gyre (WAG in Fig. 3.2.9). These results are very consistent with the real observations of the surface currents provided by the HF radar stations. The conditions during the first two weeks of March 2020 evolved in a way that led, by 18-19 Mach (Fig. 3.2.11, lower panel) to a northward position of the Azores High and the presence of a low pressure region along the NW Africa area. This promoted the development (for about 2 days) of strong easterlies blowing over the Gulf of Cadiz and Western Mediterranean which become very strong in the Strait of Gibraltar. These winds were able to reverse the Atlantic Jet, the SAMPA model now showing a full reversal of the surface flow that now is directed from the Mediterranean to the Atlantic (Gulf of Cadiz). These numerical results are, again, in very good agreement with the observed HF radar surface currents.

The Atlantic Jet variability described above, shaping the exchanges at surface levels between the Atlantic and the Western Mediterranean Sea (particularly the Alboran Sea), have important biogeochemical impacts. The study conducted by PdE as part of Case Study 1 also analysed these impacts, using the surface fields of chlorophyll that are provided from the Copernicus Marine Service catalogue (L4 gap filled dataset). Figure 3.2.12 shows the evolution of the surface chlorophyll field during the time period concurrent with the integrated results presented in Figure 3.2.11. Its is evident, from this figure, the importance of the periods when westerly winds were blowing over the Gulf of Cadiz and the Alboran Sea areas, promoting important upwelling along the southern coasts of Portugal and Spain and leading to an enhancement of surface chlorophyll concentration (figure 3.1.12, for 1 and 10 March 2020). During those periods, the intense Atlantic Jet was promoting the transport of these influences from the Gulf of Cadiz area into the Western Alboran Gyre. The jet was also more confined to the northern Spanish coast of the Strait of Gibraltar and Alboran Sea, contributing to enhanced upwelling and chlorophyll concentration in this area. The strong easterly winds that affected the area on the 18-19 March, were downwelling favourbales along the southern coasts of Portugal and Spain, which explain the almost general suppression of the chlorophyll coastal maximum values. The small area with maximum values observed near the SW Spanish coast is associated with riverine inputs.

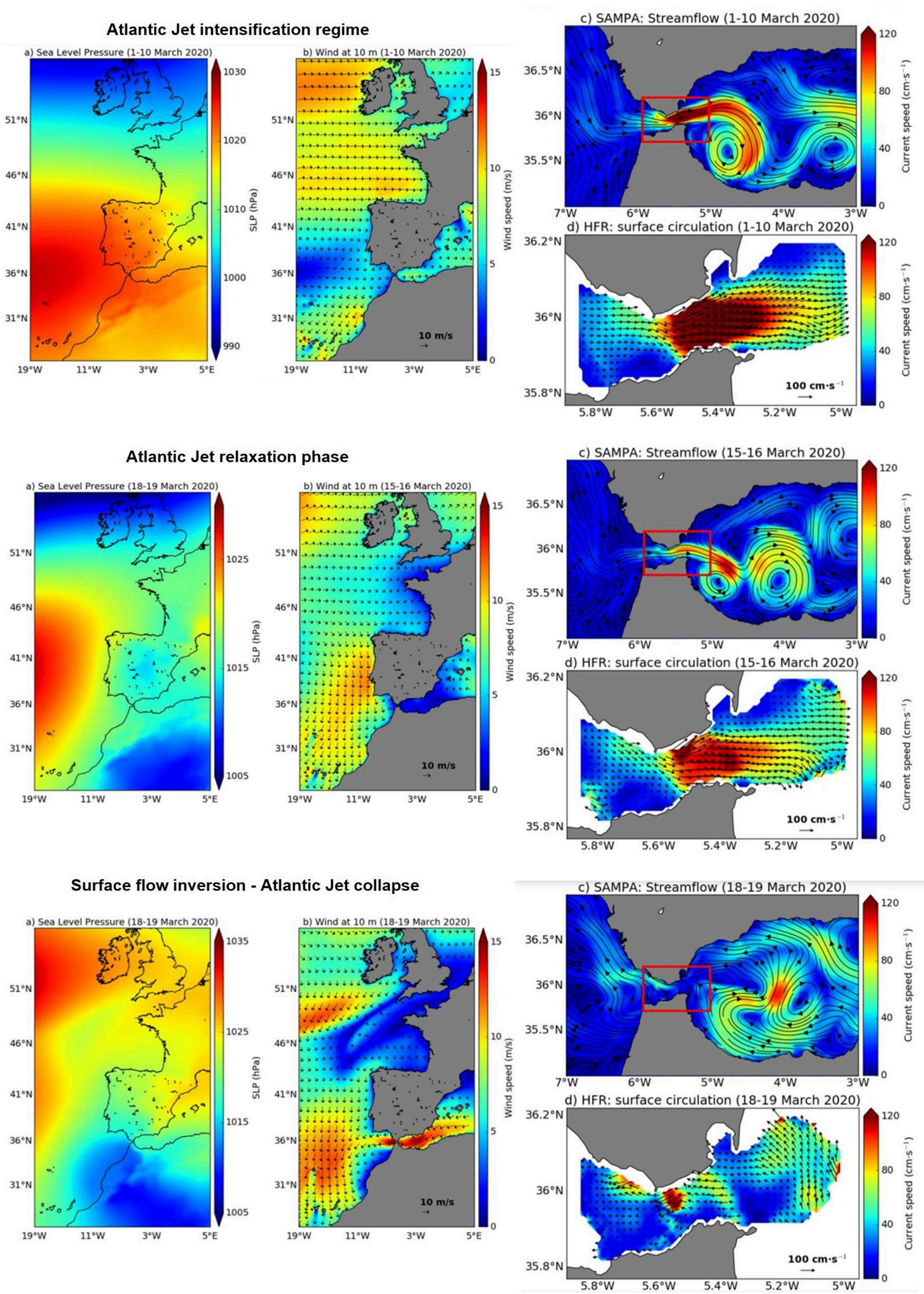


Fig. 3.2.11. Integrated results for the Atlantic Jet regimes, with (top panel figures a to d) the intensification regime, (middle panel figures a to d) the relaxation phase regime and (bottom panel figures a to d) Atlantic Jet collapse regime. For additional details see text.

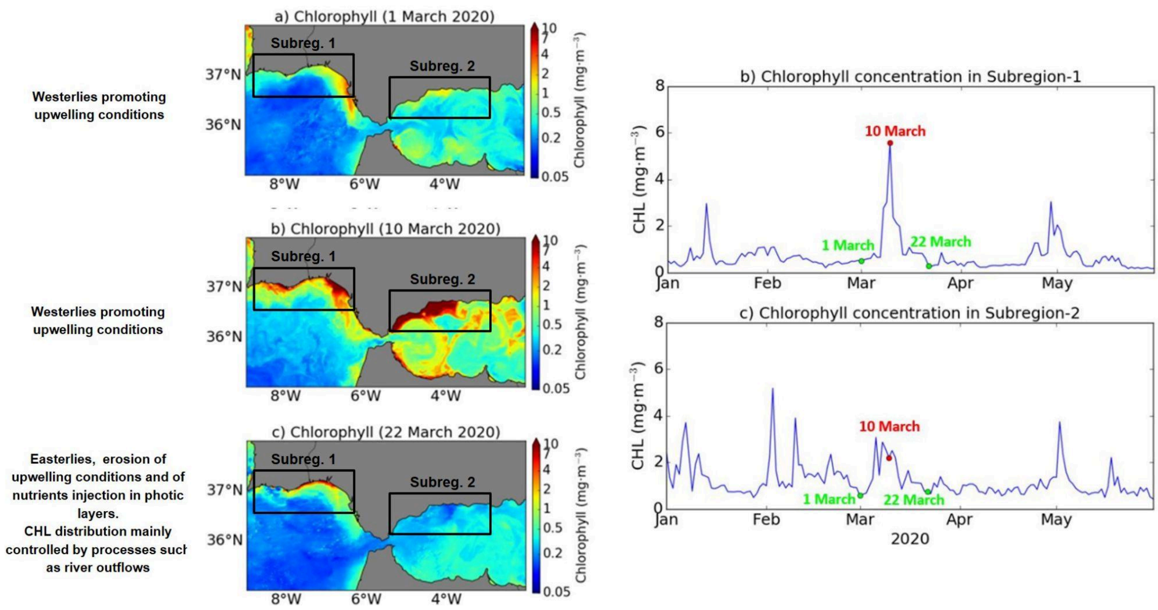


Fig. 3.2.12. Daily maps of chlorophyll (CHL) concentration, as derived from CMEMS satellite L4 product, with subregion 1 and 2 indicated (left panel). Daily timeseries of satellite-derived CHL concentration, spatially averaged over subregions 1 and 2 (right panel).

3.2.5 Ongoing developments of the IAM-IRS Pilot Study.

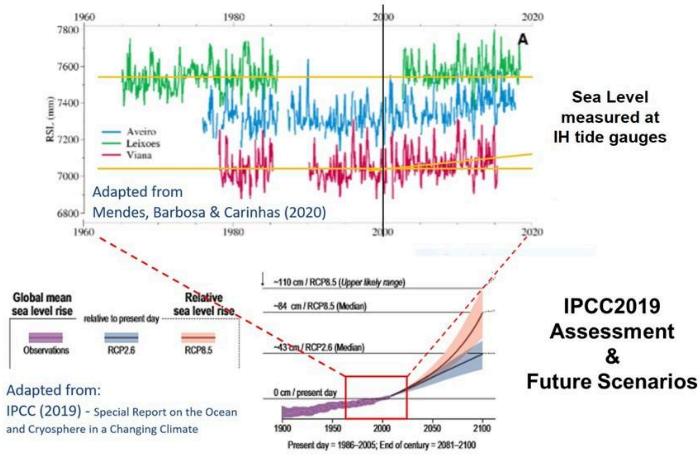
The work initiated in the framework of JERICO-S3 WP3 (Integrated Regional Sites) is still ongoing and is expected to provide a set of different perspectives about the add-value of integration of the observations that are collected by the platforms operated by the partners in the IAM-IRS (which are contributing to JERICO-RI).

The articulation between the partners of IAM-IRS was reinforced during the period in the course of JERICO-S3, with expansion of the observing capacities and improvements in the capacity to develop collaborative work in this area (a particularly important example is provided in section 3.3). This articulation is of key importance to assure the long-term measurements that are required to characterise the long term variability and climate change impacts (see insert text below).

A particularly important development that derived from this Pilot Study was the step forward towards the development of a virtual research laboratory aimed to provide a platform where users (researchers, Blue-Economy actors, environmental managers, decision makers and governmental agencies, schools and general public) can find support to identify, explore and integrate coastal ocean observations and complimentary data. This development is being conducted in the framework of the EU project Blue Cloud 2026. VLAB#1 "Integration of Coastal Ocean Observations Along Europe" is coordinated by IH and jointly developed by IH, SOCIB and IEEE (partners in JERICO-S3). This VLAB has a strong articulation with JERICO-RI, aiming to test the concept of a service based on JERICO-RI expertise in coastal ocean processes and coastal ocean data collection and processing. It is aimed to provide the prototype of a service that can be. in the future. built from the articulation between JERICO-CORE and Blue Cloud.

Why integrated, <u>long-term</u> observations of coastal ocean conditions are so important?

Long term variability associated with decadal and multi-decadal variability on the North Atlantic and climate change can have a dramatic impacts on the coastal ocean ecosystems and on coastal populations of Europe. Understanding these processes, untangling what is the natural evolution of the Earth System from what is related to human pressures, requires a continued observation effort at global scale. The JERICO-RI platforms, covering the pan-European domain with high resolution detail at regional and national scales, provide unique pieces of information to support the research on these processes and the forecast of their evolutions. The figure on the top panel at the right, adapted from a recent study of Mendes et al (2020), shows the evolution during the last 40-50 years of the sea surface height measured by IH tide gauge stations installed at three locations along the western Portuguese coast. The consistent slope of about 4-5mm/year is observed in these series and supports the numerical models scenarios (e.g. IPCC2019, bottom panel). The observations to be conducted in the next decades are key to confirm which scenario is being followed by the real evolution of the Earth system.



3.3 Building cooperation and knowledge exchange between partners on gliders (BoB and IAM IRS; IH, AZTI, PLOCAN)

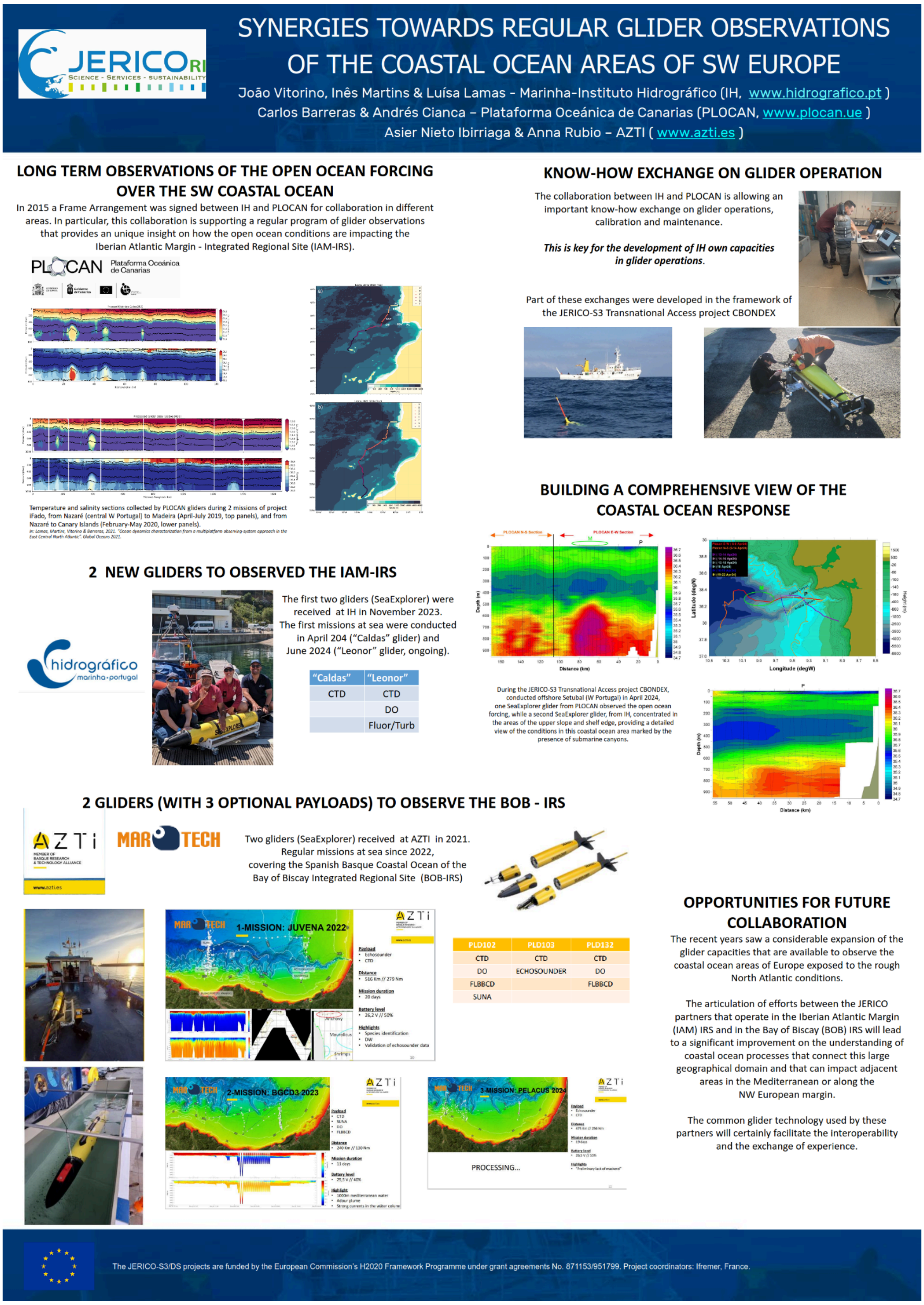


Fig. 3.3.1. Graphical representation of cooperation and knowledge exchange related to glider observations.

Since 2022, AZTI has been working in the setting up of the Pasaia Glider Port in the SE Bay of Biscay. AZTI owns today two SeaExplorer gliders (Alseamar, France) with three different payloads including CTD, oxygen, fluorometry, CDOM, turbidity and nitrate sensors and one echosounder. Since 2022, AZTI has conducted three glider campaigns, two more are planned for 2024. In addition to the campaigns several networking and strategic activities have been conducted to optimise glider operation and set the bases for the operational integration of the gliders to the existing operational observational infrastructure (EuskOOS.eus).

In 2023, based on guidance from the Pasaia Maritime Authority and SASEMAR (Spanish Maritime Safety and Rescue Society), AZTI drafted an operational protocol and necessary documentation to obtain permits for routine glider campaigns. The document addresses risk analysis associated with marine oceanography campaigns using AZTI's glider. It details glider operation and control, the planned mission, associated risks, mitigation measures, and rescue procedures if needed.

Additionally, in 2023, AZTI participated in the Glider School 2023 (https://gliderschool.eu/glider-school-2023/). This annual training event, organised by the Oceanic Platform of the Canary Islands (PLOCAN) in Las Palmas de Gran Canaria, focuses on autonomous marine vehicle technology. The curriculum covers theoretical and practical sessions on hardware and software, conducted in classrooms, laboratories, and open waters. During Glider School 2023, sessions covered topics such as the contribution of gliders to Global Ocean Observing System (GOOS) efforts. AZTI's participation allowed us to stay updated on technology and explore future development possibilities for the Bay of Biscay.

Finally, in December 2023, AZTI participated in the Annual Monitoring Meeting of the National Gliders-USV Working Group, organised by PLOCAN. Alongside AZTI, representatives from institutions such as ULPGC, IEO/CSIC, SOCIB, and PLOCAN gathered at the Government Delegation of the Canary Islands in Madrid. Dña. Beatriz Tejedor, Head of Area at the General Directorate of Large Scientific and Technical Facilities / General Secretariat of Research / Ministry of Science, Innovation, and Universities, also attended the meeting, demonstrating interest in monitoring this national initiative. The agenda included presentations and status summaries from each institution, followed by a roundtable discussion on the present and future of the national glider structure in Spain, addressing capabilities, needs, and opportunities. In June 2024, PLOCAN (leader), SOCIB, AZTI and IEO/CISC submitted a proposal to the Spanish Ministry under the call of National Research Networks to establish the Spanish Committee of Glider Operators (CEOG), with the main objective of contributing to the improvement in the management and national coordination of the current distributed (and disconnected) fleet of autonomous marine observation vehicles (underwater gliders and Uncrewed Surface Vehicles, or USVs) for research purposes. This fleet is associated with the main national entities in this scientific-technical field in Spain, and the goal of the CEOG is to facilitate and promote the use of glider or USVs technologies, and to participate jointly from the CEOG in the activities of international infrastructures and organisations that coordinate the development and operation of these technologies at a European and global scale (Barrera et al. 2024).

3.4 Improvements on carbonate system observations (all IRS/PSSs; all partners)

Carbonate system and ocean acidification observations contribute to all three JERICO-RI Key Scientific Challenges related to predicting changes under the combined influence of global and local drivers (eutrophication, upwelling, etc.), impacts of extreme events (algal blooms, flooding events, etc.), and unravelling the impacts of natural and anthropogenic drivers (anthropogenic increase in CO2, warming, etc.). Several activities were carried out related to carbonate system observations which included inter-regional integration and harmonisation of calibration and measurement techniques and coordination and planning with the Integrated Carbon Observing System research infrastructure (ICOS-ERIC).

Inter-regional integration activities involved all IRSs and PSSs. A workshop on best practices and strategy for coastal carbonate systems and data management was held at a JERICO-Days meeting in Lisbon, Portugal where all IRSs and PSSs participated. Within the KASKEN IRS (SMHI, NIVA) and North Sea PSS (Hereon), organisational activities and a workshop (hosted by Hereon in Geesthacht, Germany) were carried out related to carbonate system observation techniques related to instrumentation, calibration, data analysis, and observations, primarily from FerryBox observing platforms. Most FerryBox systems in the project utilise membrane equilibrator systems, while two partners in the KASKEN IRS and Norwegian Sea IRS developed showerhead equilibrator systems in cooperation with ICOS-ERIC (described below). The Norwegian Sea IRS (NIVA) also contributed to the Cretan Sea PSS activities related to carbonate chemistry observations in the coastal ocean north of Crete. This involved knowledge and competence sharing as well as a field experiment at HCMR Crete focused on carbonate chemistry and phytoplankton physiology (where GoF-PSS partner SYKE also contributed; Fig. 3.4.1). One of the primary objectives from this experiment was to better characterise and constrain total alkalinity and pH measurements with sensor observations.

Fig. 3.4.1. Norwegian Sea IRS and Cretan Sea PSS carbonate chemistry harmonisation activity at HCMR Heraklion, Crete.

Coordination and planning of carbonate system and ocean acidification observations were also carried out in cooperation with ICOS-ERIC, where JERICO-RI and ICOS-ERIC jointly operated observing stations which resulted in sharing of both operations and data aspects of the work (Fig. 3.4.2). In the Northern Adriatic IRS, both PALOMA (CNR) and Miramare-C1 (OGS) are jointly operated by ICOS-ERIC and JERICO-RI. Within the framework of the JERICO-S3 project, the planning for the development of the IRS has leveraged this collaboration to carefully design the instrumental implementation and data flow, maximising the benefits for both consortia. Both stations are providing sea surface pCO2 data according to the high-quality standards required by ICOS-ERIC, while JERICO-RI provides or will provide a suite of ancillary parameters, focusing not only on the surface but also along the entire water column. Additionally, other JERICO-S3 observing platforms, such as HF radars, operate in the area. The combined set of observations has the potential to greatly enhance our understanding of the role of water mass circulation and benthic processes in driving the observed surface pCO2 variability, not only at the two ICOS-ERIC stations but also across a wider area within the Northern Adriatic IRS.

Additional coordination/planning with ICOS-ERIC also was carried out in the Norwegian Sea IRS (NIVA) with the coastal Norway FerryBox that has been part of JERICO-RI for over one decade and previously focused on physical (salinity, temperature), biological (chl a, phytoplankton), and biogeochemical (oxygen, pH, and a membrane-based pCO2 sensor) variables. This FerryBox became an ICOS-ERIC station NO-SOOP-Bergen-Kirkenes (Norway, Ship of Opportunity Program, Bergen-Kirkenes) for CO2 observations along the entirety of western and northern Norway. Close collaboration was established between ICOS-ERIC and the ICOS Ocean Thematic Centre (OTC) where knowledge and expertise was shared related to installation and operation of a showerhead equilibrator system (General Oceanics 8060 pCO2 sensor), as well as calibration and intercomparison in a lab-based experimental tank. Installation and operation knowledge was also shared by KASKEN IRS partner SMHI that operates the RV Svea FerryBox and ICOS station. The JERICO-RI-related knowledge and experience with FerryBoxes and complementary physical, biological, and biogeochemical sensors (e.g., chl a fluorescence, oxygen optodes, pumps/flow meters, automated sampling technologies, etc.) was also shared from the Norwegian Sea IRS to ICOS-ERIC partners in the region. Within GoF PSS, FerryBox Silja Serenade also became an ICOS-ERIC station which includes pCO2 observations done by FMI, while FerryBox Finnmaid has continued as an ICOS-ERIC station and operated by IOW.

In addition, Cuxhaven FerryBox station became a pilot Estuarine Station, part of ICOS-ERIC Germany in 2023, aimed to improve the land-sea interface carbonate chemistry assessment for the North Sea PSS. The station will also be integrated in the upcoming LandSeaLot HE project, which aims to bridge the gaps between the JERICO-RI, DANUBIUS-RI and ICOS-ERIC communities. For the North Sea PSS, the goal is to use the Cuxhaven FB station to help assess carbon fluxes with a focus on the Elbe Estuary and the German Bight.

Fig. 3.4.2. JERICO-RI and ICOS-ERIC jointly operated fixed platform and FerryBox coastal observing infrastructures.

Together with the ICOS-ERIC community, JERICO-S3 partners participated in the 1st ICOS OTC pCO2 instrument inter-comparison exercise in Belgium in 2021, and are contributing to the follow-up assessment with focus on the membrane-based pCO2 sensor assessment and data quality control (https://www.icos-otc.org/sites/default/files/2020-03/OTC_Intercomparison.pdf). In addition, Hereon is conducting an intercomparison between a GO system and a membrane-based HydroC-FT CO2 system on the LOCEAN ICOS underway platform, in a collaboration with 4H Jena Engineering company (Kiel, Germany). The results of this intercomparison experiment will help to communicate the needs for MBS sensor deployments on ships of opportunity, and will be presented during the 2024 ICOS Science Meeting in Paris, France. JERICO-S3 partners from IRSs and PSSs also participated in an ICOS-OTC data processing workshop in 2022, a SapHTies and MINKE pH intercomparison workshop in 2023, and an Ocean Carbon Coordination Project-organised Surface pCO2 workshop in 2023.

3.5 Developing and harmonising the use of fluorescence and optical sensor data from FerryBoxes across regions (KASKEN IRS; NIVA, SMHI)

A harmonisation of the standard operating procedures (SOPs) used by NIVA was carried out by KASKEN IRS partners NIVA and SMHI at a workshop at SMHI and onboard RV Svea in December 2022. This included fluorescence sensors for chlorophyll a (fChla) and coloured dissolved organic matter (CDOM; or fDOM) and optical turbidity sensors. The harmonisation was important since SMHI and NIVA operate coastal observing FerryBoxes that have overlapping geographical coverage - RV Svea (SMHI) goes from the Swedish west coast through Skagerrak and into the Baltic Sea, while MS Color Fantasy (NIVA) operates from Oslo through Skagerrak and Kattegat to Kiel. Furthermore, essential ocean variables such as fChla are important for assessing region wide monitoring initiatives such as the Water Framework Directive or Marine Strategy Framework Directive on good environmental quality. RV Svea's FerryBox operates a Wetlabs sensor with combined Chl-a fluorescence (fChla) and turbidity, and a Trios nanoFLU fDOM sensor. MS Color Fantasy's FerryBox operates a single sensor (Turner Designs C3) that includes channels for fChla, fDOM, and turbidity.

For fChla, the calibration method uses different concentrations of cultured phytoplankton in filtered seawater, which has been implemented by SYKE (GoF PSS) and NIVA for the last 20 years. Four different species were used (Table 3.4.1) to cover the variation one can expect with different strains and the output of the fChl-a relative to Chl-a. Figure 3.4.3 illustrates that the diatom *S. pseudocostatum* and the Cryptomonade *R. baltica* had about the same fChl-a/Chl-a ratio. *Rhodomonas* also has the biliprotein phycoerythrin as accessory pigments. The green alga *D. tertiolecta* which has Chl-a as accessory pigment had about 60% lower fChla relative to Chl-a and the cyanobacteria *A. flos-aquae* had about 10 times lower Chl-a fluorescence yield relative to Chl-a illustrating the challenge to use fChl-a as a proxy in the Baltic where one have cyanobacteria that dominate the Baltic plankton and can cause severe blooms. So for this region also sensors for Phycocyanin (PC) and Phycoerythrin (PE) are important to use. To minimise the variation in fChla, we choose phytoplankton that are commonly found in the monitoring area. For Skagerrak, the diatom *Skeletonema spp.* is often present especially during blooms, and therefore used in the calibrations done by NIVA. The culture is based on *Skeletonema pseudocostatum* cells that were collected in Oslofjorden, and is cultivated under controlled conditions. This is also the phytoplankton that was used in the calibration workshop with SMHI. For the fluorescence sensors on RV Svea that operates in the Baltic Sea, where cyanobacteria are common, phycocyanin- and phycoerythrin-containing species were also used in the sensor calibration.

Table 3.4.1. Phytoplankton species, NORRCA strain ID, origin, and pigments used for calibrations.

Algae	Strain ID in NORRCA	Origin	Pigments
Skeletonema pseudocostatum	NIVA-BAC 1	Oslofjorden, 1962	Chl-a, Chl-c
Dunaliella tertiolecta	NIVA-CHL 26	EPA, Corvallis, USA, 1977	Chl-a, Chl-b
Aphanizomenon flos-aquae	NIVA-CYA 704	Stechlinsee, Tyskland 2008	Chl-a, Phycocyanin
Rhodomonas baltica	NIVA-5/91	Unknown	Chl-a, Phycoerythrin

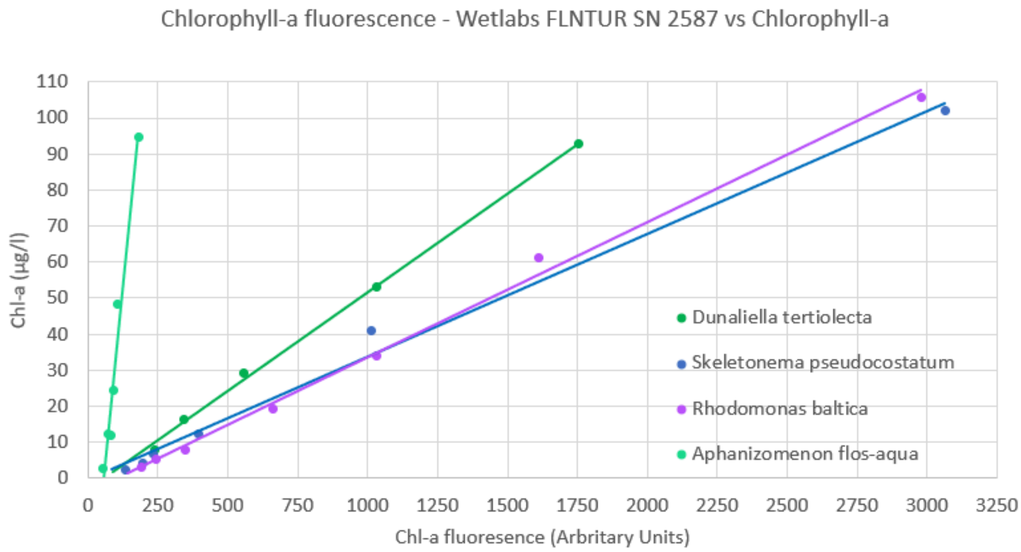


Fig. 3.4.3. Calibration of the Wetlabs FLNTUR Chl-a fluorescence with different algal species.

Coloured dissolved organic matter fluorescence (fDOM) was calibrated with quinine sulphate, using the same method developed with SYKE. Work on fDOM fluorescence data quality has also been carried out in the Horizon 2020 MINKE project. Quinine sulphate (QS) standards are prepared from a stock solution of 7040 mg/m3 in 0.05 M sulfuric acid in the concentration range 0-200 mg/m3. As with chlorophyll-a fluorescence, the calibration is performed in dark conditions. It is also important to prepare fresh QS standard solutions before the calibration, as the fluorescence properties change over time. At RV Svea's FerryBox a Trios nanoFLU fDOM sensor was in operation and this sensor was equipped with a secondary standard (SolidCal) with a certified value of 83.9 (microgram QS/Litre). The control showed low values and a full calibrated with NIVA's SOP for fDOM in the range of 0-200 microgram/litre confirmed an offset of around 10%. In Figure 3.4.4 the sensor readings using the new calibration based on the NIVA SOP showed good performance and the SolidCAL value fits well to the calibration curve. We recommend that this is used regularly to detect any drift of the sensor and eventually establish control cards as recommended in NIVA SOP.

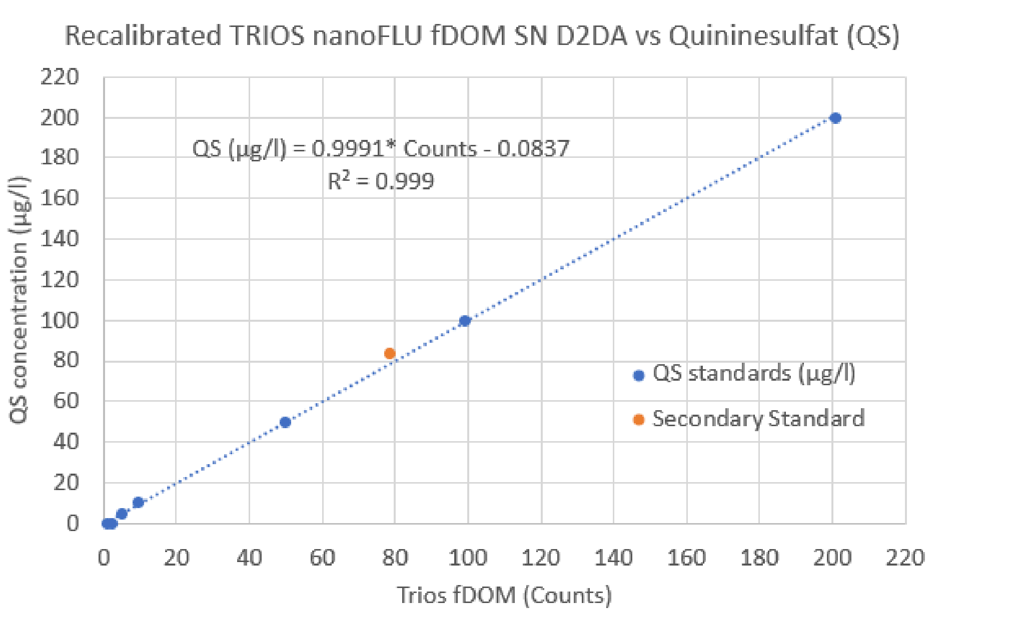


Fig. 3.4.4. Calibration of Trios naniFLU fDOM sensor with quinine sulfate standards. The Trios Secondary standard is shown.

Turbidity is a common sensor in FerryBox systems either as a stand-alone sensor (Seabird, AML) or as combined sensors with Chl-a fluorescence (Wetlabs, Turner). Most of the sensors are calibrated in Formazin Turbidity Units (FTU) or as in the latest ISO-standard Formazin Nephelometric Units (FNU). The Wetlabs combined sensor (SN 2587) used on RV Svea was calibrated using formazin standards and a HACH 2100P turbidimeter as reference (NIVAs SOP). Figure 3.4.5 shows the results of the calibration in the range from 0-50 FNU. This range is sufficient for the Batic proper.

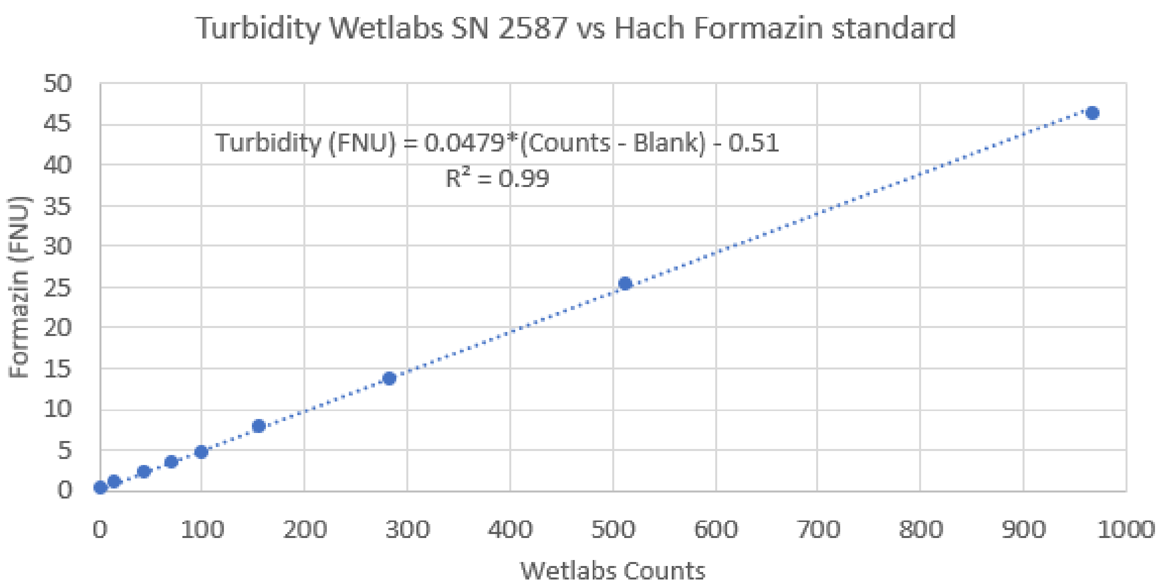


Fig. 3.4.5. Calibration of Wetlabs FLNTUR sensor with Formazin standards.

3.6 Building of trans-boundary capacity on coastal risks (BoB IRS; AZTI)

The Basque coast cross-border region (western Pyrenees) connects the French and Spanish territories on the SE coast of the Bay of Biscay. The Basque region hosts around 3 million people mostly concentrated around the main coastal cities (e.g., Bilbao, Donostia – San Sebastian, Zarautz, Hendaye, Biarritz, Anglet). Among the most urgent concerns in the region, including the broader Bay of Biscay area, several key issues arise pollution from hazardous substances in coastal locations close to urban and industrial areas, eutrophication (with increasing incidence of toxic algal blooms), biodiversity loss, and presence of invasive species (Borja et al. 2018). Global warming and ocean acidification are also escalating concerns, necessitating increased research and international cooperation for monitoring and mitigating impacts. Additionally, the recent and historic events have already demonstrated the vulnerability of the Basque coastal area to extreme events. Clear evidence is the Xynthia (2010) and Hercules (2014) storms, which affected the entire coast of southwestern Europe causing relevant coastal erosion and flooding damage. While acknowledging the significance of all the mentioned threats, since 2021 specific efforts have been devoted to building a trans-boundary capacity devoted to the real-time monitoring and prediction of extreme storm events and their impacts on the coastline, including its relationship with morpho dynamics.

To this end, AZTI has been working with regional partners to build a fit-for-purpose cross-border laboratory named KOSTARISK (Kosta = Coast in Basque). This joint laboratory develops applied research and solutions in observation and modelling of coastal hazards to support coastal risk management. It is associated with the Wave Interaction and Structure team of the SIAME laboratory (UPPA, France), the technological centre AZTI (Spain) and the monitoring and forecasting centre Rivages Pro Tech (RPT) of the SUEZ group (France). The objective of this laboratory is to bring together researchers from the three organisations in the fields of numerical modelling, physical measurement systems and advanced data analysis, for the development of tools to assist in the management and mitigation of coastal risks. KOSTARISK ensures transfer, outreach and capacity building.

The research themes of the KOSTARISK laboratory align with the research issues supported by local and regional authorities. This support has notably resulted in participation with different stakeholders in the funding and management of European projects (e.g, Regions4Climate, MARLIT, MAREA). These recent or ongoing projects will provide an observational database and tools, the scientific utilisation of which will be strengthened and continued through the joint lab. The laboratory's work will also continue to be fueled by the needs of the regions and managers. This is especially supported by the User Assembly of KOSTARISK, which is part of the joint lab governance and dedicated to the link between user needs and conducted research. KOSTARISK has a research plan based in three axis that are fully aligned with the defined user needs:

Axis 1: Characterization of Coastal Risks from Regional to Ultra-Local Scale: identify and better understand the physical processes that control the response of coastal systems to weather and oceanic hazards (indicators to qualify and quantify coastal hazards and their impacts, favouring a multi-scale approach from offshore to the beach and definition of strategies for observing, modelling and mitigation solutions).

Axis 2: Development of Coastal Risk Monitoring and Observation Systems: develop, improve, and sustain innovative observation and monitoring systems dedicated to measuring weather and oceanic hazards, as well as the response of coastal systems to these hazards (establishment and maintenance of observational systems and construction of long-term databases, essential for studying extreme and rare events and integration of automated and real-time analysis and visualisation tools).

Axis 3: Development of Multi-Scale Modeling Tools for Weather and Oceanic Hazards and Associated Risks: develop new approaches to numerical and statistical modelling of coastal risks to enhance the accuracy and relevance of associated diagnostics and their optimal integration into short-term alert systems (forecasting the evolution of risk in the medium and long term by integrating the effects of climate change, particularly at the local scale, enhance the precision of risk management support tools for operational applications).

From a technical perspective, wave propagation, regional current dynamics and tidal models are currently available along the Spanish and French coastlines. Those models are integrated to feed the Wave overtopping Early Warning System which is provided to the local authorities for coastal management purposes. In addition to the models, the Basque multiplatform monitoring network euskoos.eus provides metocean data in real time and boasts an extensive network of more than 20 videometry stations (to our knowledge the densest videometry network in Europe, operating at a cross-border scale) (Liria et al., 2021, Abaila et al., 2024; Fig. 3.6.1). These stations not only offer essential indicators for model validation but also generate both short and long-term data series.

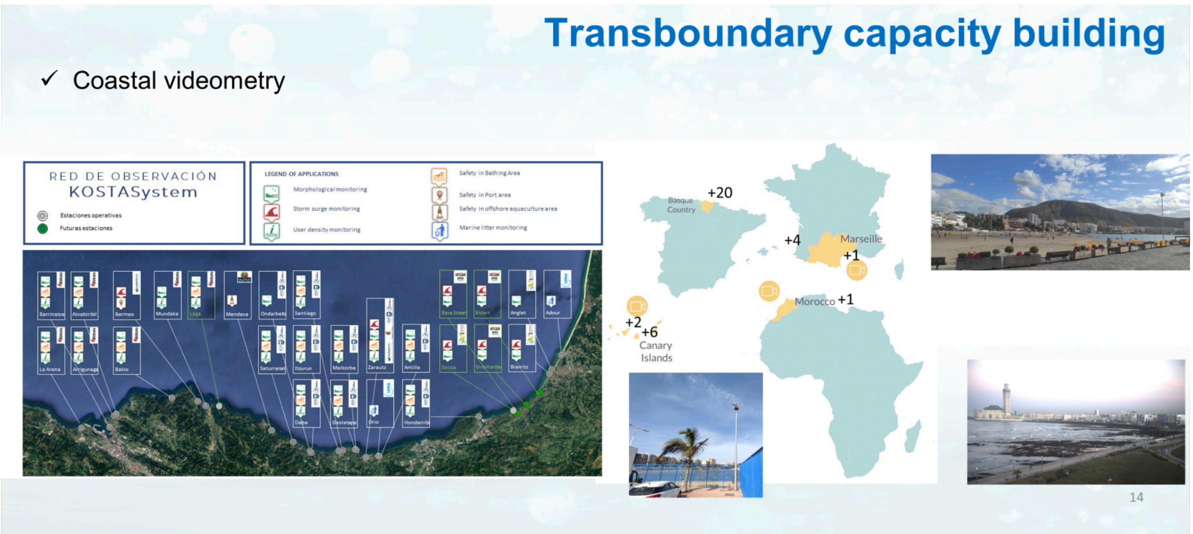


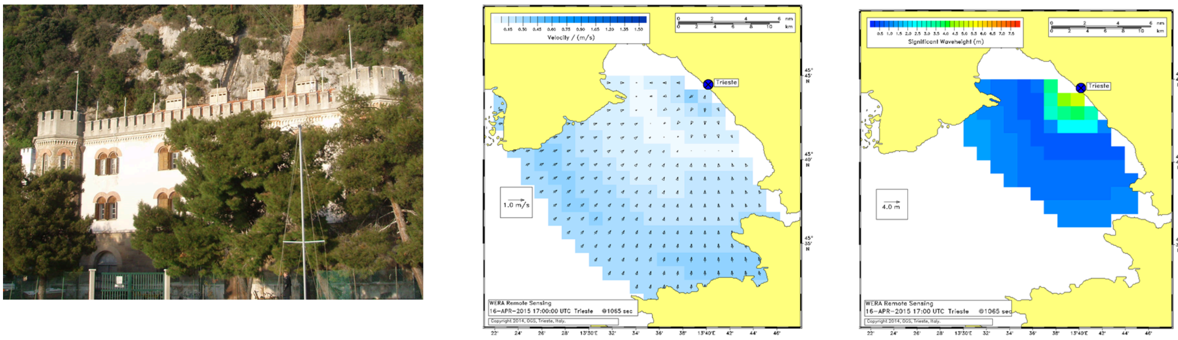
Fig. 3.6.1. Illustration of existing videometry stations in the SE Bay of Biscay operating at a cross-border scale

The laboratory aims for a public utility and support role for coastal managers, in line with the nature and positioning of the partners, all of whom have built a strong collaborative relationship with local authorities over the years. Several joint PhD and postdoc projects are planned and the partners are actively involved in European initiatives (e.g. Copernicus, EMODnet, EuroGOOS, JERICO-S3, EuroSea). A specific plan is set to establish further international collaboration and to foster the emergence of projects at national and European level. KOSTAROSK contributed to the GlobalCoast Pilot Site survey in 2023, more details can be found at: https://www.coastpredict.org/globalcoast/.

3.7 Building Cross-Border collaboration and extending the Northern Adriatic IRS JERICO community (NA IRS; CNR, IRB)

Starting in 2017, a collaboration with the Slovenians from the National Institute of Biology (NIB) was initiated to install two HF-Radar stations for mapping surface sea currents and wave motion in the Gulf of Trieste within the Northern Adriatic IRS. The system, which is still operational, consisted of two stations, one operated by OGS and one by the NIB.

Successively in 2020 with the launch of JERICO-S3, the HF-Radar system was included as part of the Northern Adriatic - IRS (NA-IRS) as part of the Gulf of Trieste Observing System (GoT) with data sharing and visualisation (Fig. 3.7.1).



OGS HF - Radar Site　　　　Current Map　　　　Waves Map

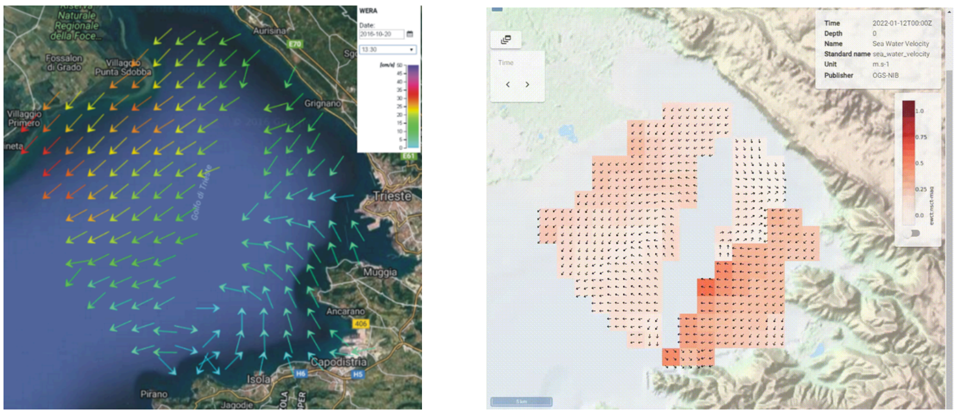


Fig. 3.7.1. HF radar installation sites in the NA IRS (top panels) as well as data visualisation and sharing (bottom panel).

Throughout the period of the JERICO-S3 project, initiatives were undertaken to harmonise and disseminate data, in particular the station network was included as a node of the European HF-Radar network. Two additional HF-Radar stations have since been added, one by the Slovenians of the NIB and one by the Regional Agency for Environmental Protection ARPA-FVG. Currently, there are 4 HFR stations in operation (Fig. 3.7.2). The data are published in near-real-time (nRT) on the European node website: https://www.hfrnode.eu/networks/hfr-nadr-2/

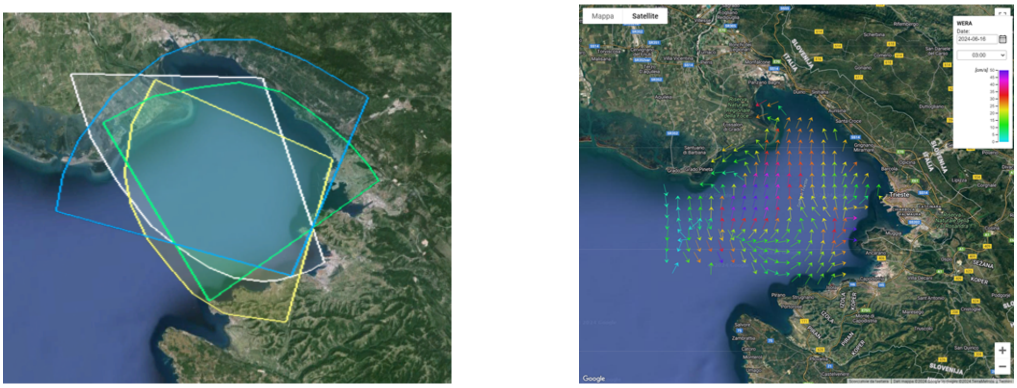


Fig. 3.7.2. Coverage at present by four HFR stations in operation (left) and an example of a data product from the HFR nRT European node website (right).

There is a strong collaboration with CNR-ISMAR of Lerici (SP), as it is responsible for the HFR database of the European node and administrator of the software that also manages the GoT network data. As a result of this fruitful collaboration, in 2022, on initiative of the Croatian (IRB) and Italian (OGS) partners, contacts were initiated with the NIB for a future inclusion of Slovenians in the NA-IRS of the future JERICO-RI. Researchers from NIB also successfully participated as part of a JERICO-S3 Transnational Access project in collaboration with CNR-ISMAR in the NA-IRS.

3.8 Building transnational FerryBox collaborations (NS IRS, NS PSS; NIVA, FAMRI, RWS, Deltares)

Two new transnational collaborations on FerryBox Ship of Opportunity observing platforms were initiated during JERICO-S3 (Fig. 3.8.1). These initiatives included partners from the Norwegian Sea IRS and North Sea PSS. The FerryBoxes cover water masses that transect between multiple national borders and important ecosystems/biomes. The two transnational collaborations are described in more detail below.

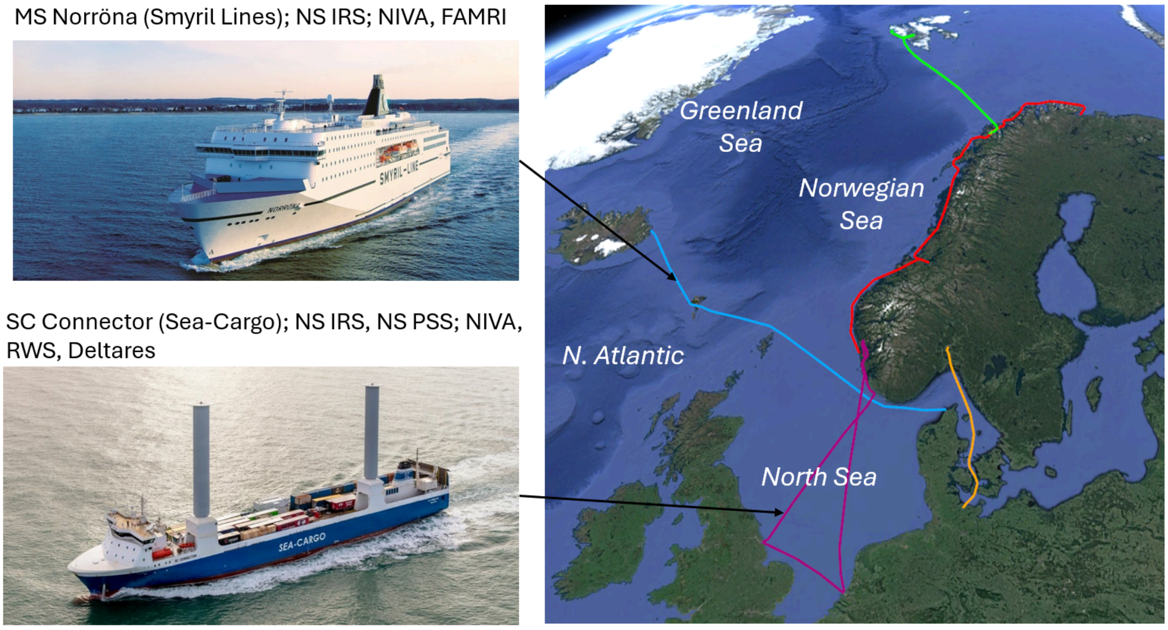


Fig. 3.8.1. Transnational FerryBox collaborations developed within JERICO-S3 on MS Norröna in the North Atlantic and SC Connector in the North Sea.

MS Norröna FerryBox (NS IRS; NIVA, FAMRI)

During the project, new transnational collaboration started between Norwegian Sea IRS partners FAMRI and NIVA. A new FerryBox was installed and began operations on the passenger vessel MS Norröna that operates in the North Sea and North Atlantic between Denmark-Faroe Islands-Iceland. The collaboration was carried out under the auspices of a Memorandum of Understanding that outlined the scientific and operational nature of the planned activities. Several in-person visits were made both to FAMRI at Torshavn, Faroe Islands as well as on board MS Norröna for installation and instrument development. The FerryBox is presently operational with maintenance visits occurring both in Denmark by NIVA personnel and also at Torshavn by FAMRI personnel. A refrigerated automated sampler was also installed for collection of seawater samples that are usually collected by FAMRI personnel at Torshavn. A research project in which FAMRI and NIVA will utilise the Norrøna FerryBox infrastructure, "PHYTO_TRAITS", was recently funded by the Research Council of Faroe Islands North Atlantic Marine Research call.

SC Connector FerryBox (NS IRS, North Sea PSS; NIVA, RWS, Deltares)

Another new transnational collaboration started during the JERICO-S3 project between the Norwegian Sea IRS and North Sea PSS partners NIVA, RWS, and Deltares. This involved a new FerryBox installation on the container ship MS Connector. The ship was selected due to its good coverage of the coastal North Sea and relatively convenient access at ports in Norway, Netherlands, and the UK in its triangular route between the three countries. A Memorandum of Understanding was signed between NIVA and RWS as the main users and operators of the FerryBox. Additional informal agreements are underway with Deltares and University of Hull. The FerryBox installation was initially delayed due to COVID-19 restrictions and access to the ship. Upon completion, a workshop was held in Rotterdam with all partners to introduce the working group to the FerryBox and its operation and maintenance. Additional discussions were carried out regarding potential use in research and monitoring projects as well as long-term financial sustainability for the operation of the FerryBox. A second workshop was carried out near the end of the project period to provide additional maintenance/operations knowledge transfer and some minor upgrades and repairs to the system and sensors. One of the primary goals for the MS Connector FerryBox is to provide phytoplankton chl a sensor measurements and sample collection for eutrophication status monitoring of the North Sea, which is relevant for WFD/MSFD/OSPAR monitoring requirements. Additionally, other phytoplankton-related sensors are planned for future implementation, which include flow cytometric sensors for phytoplankton size and functional groups and sensors to assess phytoplankton photophysiology (e.g., FRRf and LabSTAF instruments).

3.9 Collaboration and integration across research infrastructures (NA-IRS; OGS, CNR)

As part of the Recovery Plan, the Italian Ministry of Research launched the ITINERIS program whose focus is to build the Italian Hub of Research Infrastructures in the environmental scientific domain.

Although JERICO-RI has not yet completed the process of becoming a research infrastructure, the Ministry recognized the scientific importance of the existence of the JERICO community and its high degree of maturity, so it decided to include JERICO-RI among the Italian research infrastructures involved in ITINERIS. Based on this, an important expansion of observational capabilities in the North Adriatic IRS has been initiated, particularly with the inclusion of new HF-Radar stations that will extend the spatial coverage of the network already operational and included in NA-IRS (see section 3.7). The activities within the ITINERIS project then involves a strong effort to integrate data and procedures at the NA-IRS level among the different infrastructures operating on the same areas (JERICO-RI, DANUBIUS, ICOS-ERIC), since the ultimate goal of ITINERIS is to arrive at a research infrastructure hub that acts as a system of systems.

4. CONCLUSIONS

The regional organisation in JERICO-S3 was designed to integrate, harmonise and demonstrate regional and pan-European integration of coastal observations. The primary goal of Integrated Regional Sites (WP3, Networking activity) have been primarily activities 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 PSS (WP4, 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.

The main outcome of WP3 under JERICO-S3 was the formation and development of five Integrated Regional Sites (IRSs), which consist of trans-national coastal regions. Although coastal oceanic processes are not constrained by national borders, prior to JERICO-S3 the coastal observing efforts were organised and coordinated primarily at the individual institute or partner level.

Lessons learnt:

- Organisation of national partners into regional structures such as Integrated Regional Sites (IRS) have greatly benefitted cross-institutional and cross-national cooperation and integration progressing towards a pan-European coastal observing infrastructure
- There are considerable capabilities within each IRS in terms of scientific capacity/expertise, observation infrastructures and organisational frameworks
- IRSs cover many observational needs in relation with the JERICO Key Scientific Challenges (KSCs) in the European seas, however further developments in technological maturity and integration needed for regional and pan-European scale assessments
- Significant progress achieved in terms of consolidating coastal observing efforts in the regions have been showcased by: advances in automated plankton observations, integration across platform and building capacity on extreme events and coastal risks, cooperation and knowledge exchange on glider operations, interoperability and harmonisation on carbonate system and fluorescence measurements, multi-national collaboration and funding for national infrastructures.
- Barriers/challenges include consolidating a shared regional/pan-European strategy and vision for coastal observations, recognizing that funding and priorities for national efforts are driven by national needs and requirements from EU policies (MSFD, WFD)
- Financial sustainability remains a challenge and a barrier for regional integration and integration in general, especially balancing the needs of existing/planned national infrastructures with the need for regional and multi-national funding mechanisms (or lack thereof).
- From IRS experience, real integration and harmonisation of data and procedures is driven and is demonstrated where there is specific scientific need or action. This is hard to achieve by networking activities alone and without financial support.

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Recommendations based on the expectations and outcomes of IRS development and roadmap activities:

- Agreeing on a unified regional structure and scientific strategy for coastal observations for the future JERICO (ESFRI proposal)
- Common guidelines for data handling and accessibility for JERICO platforms
- Transnational/regional agreements and identification of relevant funding schemes to build and support regions to address/target regional issues and observing requirements.

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