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JERICO-S3 DELIVERABLE

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

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1. EXECUTIVE SUMMARY

WP4 provides a practical demonstration of how JERICO-RI Pilot Supersites (PSS) are to be implemented in order to become a network of Supersites, by establishing or improving their communication and steering at multiple levels, and their links to other observatories, RIs and regional initiatives.

This deliverable reports the main activities of different PSSs and their Actions, including the main scientific and institutional advances. Within their regions, PSSs have provided a framework for thematic and interdisciplinary collaboration, joint use of resources, and planning and executing common activities. PSSs covered well a range of Key Scientific Challenges and Specific Scientific Challenges, set in JERICO-S3 WP1 as strategic objectives of making observations. PSSs also studied the organisational challenges, when implementing PSSs and moving towards sustained Supersites.

This deliverable summarises the major findings for each PSS, analyses PSS implementation from the perspectives of the most commonly addressed Specific Scientific Challenges, considers integration aspects, from different points of view and analyses how PSS implementation period has improved JERICO-RI's contribution to innovation and technology developments.

In doing a self-assessment of PSS implementation, we conclude that JERICO-RI Supersites could be a key driver in the systemic change in coastal observations, towards integrated, regionally coordinated, transnational, multiplatform and multivariate observations. This would require a strong commitment from participating nations for sustained funding for transnational observing systems that are ultimately cost-effective and with higher capacity, but not for all parts under national control.

We conclude by providing an outlook for JERICO-RI Supersites, by providing the key lessons learned during PSS implementation, listing additional needs for further integration and providing a future vision. The main conclusion is that JERICO-RI Supersites could be key elements in providing consistent pan-European data and products for the most complex coastal research questions, and as tools to meet the most demanding international commitments, but it requires consensus among participating nations to fund such developments.

2. INTRODUCTION

JERICO-S3 WP4 provides a practical demonstration of how JERICO-RI Pilot Supersites (PSS) are to be implemented to become a network of Supersites, by establishing or improving their communication and steering at multiple levels, and their links to other observatories, RIs and regional initiatives.

JERICO-S3 Deliverable D4.4, "*Assessment of PSS implementation*" reports on scientific and institutional advances of JERICO-S3 WP4, "*Pilot Supersites for innovative coastal monitoring*". It provides a synthesis of Pilot Supersite (PSS) implementation, and analyses of the progress in the integration, innovation and delivery of data and products. It provides an evaluation of PSS success with an outlook on coastal Supersites and contribution towards a sustainable JERICO-RI.

2.1 JERICO-RI Pilot supersites – background for D4.4

The concepts of Supersites in environmental Research Infrastructures generally and in coastal environments specifically were detailed in JERICO-S3 Deliverable 4.1 "*JERICO-S3 Pilot Supersite monitoring strategies*" (Seppälä and Frangoulis 2021). Particularly, D4.1 describes how the concept of Supersites in the coastal domains may be different from the terrestrial ones.

Typically, the Supersites (or, as there is no agreement of nomenclature, similar intensive measuring sites) are highly instrumented and sustained observatories with harmonized and standardized measurements and a high capacity (quality and quantity) for observations (see Hari et al 2016, Seppälä et al 2023b). For marine systems, as compared to terrestrial ones, a specific challenge is that physical and biological dynamics take place at the mesoscale - in horizontal scales up to tens to hundreds of kilometres – and with various submesoscale processes at nested spatiotemporal scales. Thus, the coastal Supersite needs to cover such scales with adequate horizontal coverage and vertical resolution. To meet the requirements for mesoscale and submesoscale observations, coastal Supersites need to have multiplatform sampling strategies as no single platform can provide such observation density.

Subsequently, in D4.1 (Seppälä and Frangoulis 2021) we defined that

> *"The JERICO Supersite is a regional (or sub-regional) coastal marine observatory. As marine observatories are considered infrastructures dedicated to multiple in situ observations (from air–sea interface to seafloor interface) at appropriate spatiotemporal resolution, in a restricted geographical region, maintained over long timescales, and designed to address interdisciplinary objectives, driven by science and society needs"*

As the coastal areas are typically transnational, this needs to be reflected in the structure of Supersites. To test the Pilot Supersite concept in coastal waters, we selected four regions: the Gulf of Finland (GoF PSS), the North-Western Mediterranean (NW-MED PSS), the North Sea and English Channel (forming a twin-PSS; NSEA/CHANNEL PSS), and the Cretan Sea (CRETAN PSS) (Figure 2.1). The Pilot Supersites (PSS) were different in their size and number of partners, including altogether twenty JERICO-RI partner institutes from 11 countries (Finland, Estonia, Germany, France, Italy, Spain, The Netherlands, Norway, Belgium, United Kingdom, and Greece). Three out of the four Pilot Supersite areas tested were inherently transnational combining platforms and activities from different nations. One of the PSSs (CRETAN PSS) was only in waters surrounding Greece, but even that had a transnational element build-in, as several collaborators from other countries were included in the implementation of it. Thus, a key element in JERICO-S3 study of PSSs was to understand how such transnational coastal observing systems can be structured and integrated, and how they could be jointly steered. Networking and communication between Supersites were yet another objective for the study.

Additional complexity in coastal Supersites is the multitude of observing needs and scientific challenges. JERICO-S3 WP1 has provided a list of Key Scientific Challenges (KSC) for coastal domains and for JERICO-RI to meet. In JERICO-S3 D1.2 and D4.1, we made a preliminary assessment of how the observational capacities in the different regions are already suited for various KSCs (Seppälä and Frangoulis 2021, Coppola et al 2023). For each PSS we had defined a range of activities ("Actions", see Table 2.1 and Section 3) some of which directly targeted specific KSCs. Some of the KSCs were studied in all PSSs, while some only at specific locations. Overall, the multiplicity of targeted KSCs entails the requirement to observe a huge number of different variables in combination, another peculiarity of the coastal Supersite.

Figure 2.1 JERICO-S3 regions for Pilot Supersites

Following the detailed implementation plan for each PSS and their specific Actions, as given in D4.1, a two-year study period started in January 2021. For each Action, we defined their specific objectives, key external partners (organisations) and platforms included, additional sources of data, timetable, and detailed description of Action. In addition, for each Action, the plan listed best practices used or to be developed, description of data flows, data QC routines, data management issues, expected results and users of results as well as a plan for dissemination of results.

After one year of implementation the JERICO-S3 D4.2 "*Assessment and refinement of D4.1 after 1 year of PSS implementation*" (Frangoulis et al 2023) assessed the activities which took place in 2021. D4.2 provided a PSS-specific summary of overall developments against what was originally planned, and a basis and reasoning for modifications of the workplan of each Action.

Then, JERICO-S3 D4.3, "*Progress report on PSS implementation*" (Seppälä et al 2023a), provided PSSs activity reports in 2021 and a refined implementation plan to PSS Actions, to be followed in 2022.

Table 2.1 List of JERICO-RI Pilot Supersite Actions studied in 2021-22

GoF PSS #1	Harmonized observations
GoF PSS #2	The performance of operational forecast models
GoF PSS #3	Optical data for Ocean Color product validation
GoF PSS #4	Detection of cyanobacterial blooms
GoF PSS #5	Mapping the deep-water oxygen conditions
GoF PSS #6	Biological interplay with the carbonate system
GoF PSS #7	Forecast models for cyanobacterial blooms
GoF PSS #8	Extreme events affecting phytoplankton - AQUACOSM collaboration I
GoF PSS #9	Promotion of the use of PSS data and products
GoF PSS #10	Connecting the other RIs in the region
NW-MED PSS #1:	Reconstruction of the 3D coastal dynamics
NW-MED PSS #2:	Impacts of river discharge to coastal ecosystems
NW-MED PSS #3:	Extreme events affecting phytoplankton - AQUACOSM collaboration II
NW-MED PSS #4:	Biogeochemical data and ocean colour products
NW-MED PSS #5:	RI interactions
NW-MED PSS #6:	Transnational integration
NSEA PSS #1	Harmonized observations of regional C fluxes
NSEA/CHANNEL PSS #2	Riverine input to the North Sea
CHANNEL PSS #3	Harmonized observations of plankton biomass, diversity and productivity dynamics
CHANNEL PSS #4	Products for Eutrophication Status Assessment
NSEA/CHANNEL PSS #5	Intercomparison of phytoplankton distribution using data integration
NSEA/CHANNEL PSS #6	Identification of Observational Gaps
NSEA/CHANNEL PSS #7	Cross-regional communication between PSSs (North Sea and Channel)
NSEA/CHANNEL PSS #8	Support to EU directives and ecosystem management
NSEA/CHANNEL PSS #9	Interaction with other RIs on ecosystem studies, eutrophication, coastal management and carbon fluxes
CRETAN PSS #1	Solubility and biological pumps
CRETAN PSS #2	Improved approximations of Primary Production
CRETAN PSS #3	Extreme events affecting phytoplankton - AQUACOSM collaboration III
CRETAN PSS #4	Upscale of Regional Data to a wider area
CRETAN PSS #5	New sampling strategies, new technologies, best practices
CRETAN PSS #6	Partnership building

2.2. On the structure of D4.4

The report of Pilot Supersite implementation in D4.4 is organised as follows.

Chapter 3 provides a PSSs activity report of implementation.

Each report includes a **Key Message from the Action,** providing a take home message of the work done and a quick overview of the content.

The **Main achievements** section provides the progress report of the Action. It describes and details the main parts of the actual work done, reflecting what was originally proposed in the D4.1 and as refined in D4.3. This part reports the main scientific and institutional advances, and describes the activities done by providing key information on

- Actual work done in PSS Action
- Engagement with users
- Dissemination with links to publications, workshops, data, products, etc.
- Best practices developed and used
- Data flows created
- Data QC routines created
- Data management issues faced and solved
- Innovations and products created
- Links to other Actions, PSSs and JERICO-S3 WPs and other communities

Chapter 4 provides an **overall assessment of PSS activities**, including synthesis per PSS, synthesis of common Key Scientific Challenges addressed and analysis of various aspects of integration within PSSs, as well as PSSs contribution to innovations.

In **Chapter 5** we list key items for **communications and dissemination**. **Chapter 6** includes internal review of PSS implementation, analysing it against the future of JERICO-RI. In **Chapter 7**, we provide a final outlook for future JERICO-RI coastal Supersites.

3. PILOT SUPERSITE ACTIVITY REPORTS

GoF PSS #1 Harmonised observations

Key Message from the Action

PSS was improving regional harmonisation of observations, at various phases of the data value chain, including participants outside PSS and JERICO-RI partnerships. Though GoF PSS partners have been collaborating for a long time, PSS activities offered a new structure and perspective for cooperation.

Main achievements

Joint sensor calibration workshops (Figure GoF-PSS#1) were held in February 2021 and 2022 at SYKE Marine Research Laboratory in Helsinki. Due to covid, workshops were organised virtually, and participants sent their sensors for intercomparison and intercalibration. Fluorometers (Trios micro-fluo and Turner Scufa sensors for Chlorophyll (Chla), Coloured dissolved organic matter (CDOM), phycocyanin) from SYKE FerryBoxes, from buoys managed by FMI jointly with Åbo Academi and University of Helsinki, and from SMHI (Kasken IRS) were included in the workshop in 2021 and 2022. In 2022 three fluorometers from HCMR (CRETAN PSS) were included.

Chla and phycocyanin sensors were calibrated with algae cultures, while CDOM sensors with quinine sulphate. The calibration ensures that various FerryBox and buoy platforms in the Baltic Sea produce consistent results, in terms of fluorescence.

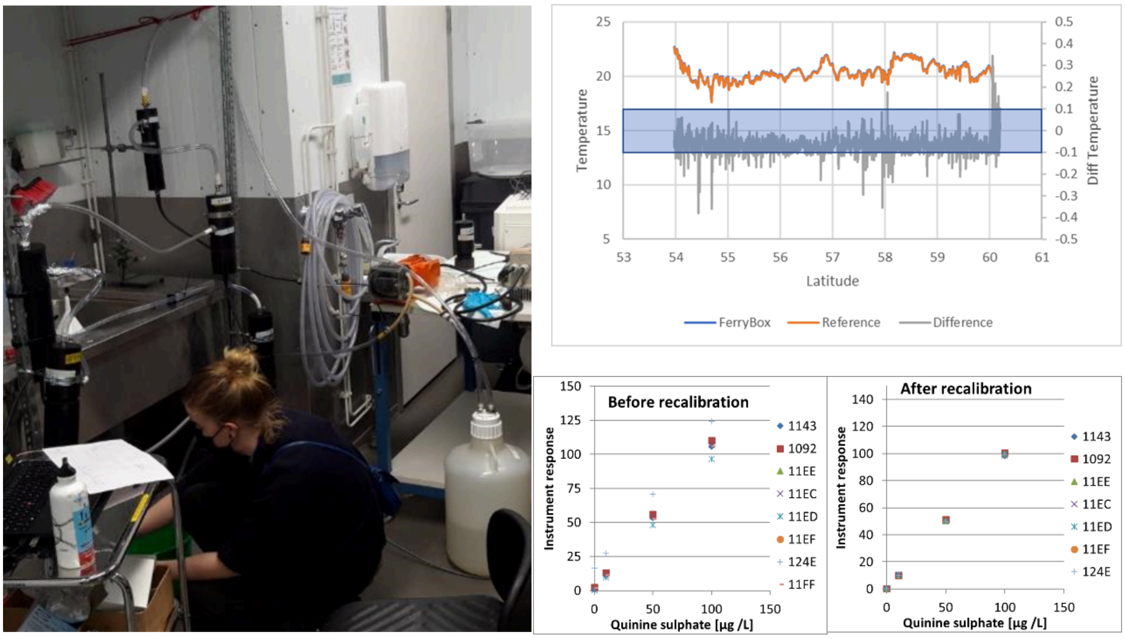


Figure GoF-PSS#1: Left: Calibration of GoF-PSS field fluorometers ongoing. Right, up: Comparison of FerryBox temperature sensor readings with reference sensor. Right, bottom: PSS-GoF CDOM fluorescence sensor responses prior and after joint calibration.

Virtual harmonisation WS was organised on 8 March 2021, discussing the overall harmonisation of sensors and calibration practices in GoF PSS for carbonate system, temperature and salinity, oxygen, and fluorescence. Presentations are available at [WP4 workspace](). WS took further steps in agreeing QA/QC of sensor observations and to advance consistency of different datasets. The workshop introduced current best practices among partners for different variables. Another aim was to distribute knowledge about which types of activities are ongoing in the Baltic region. Participation included all PSS partners and additional JERICO-S3 partners from Sweden (SMHI, link WP3) and Greece (HCMR, link CRETAN PSS) and non-JERICO participants from Finland (University of Helsinki, City of Hanko, City of Helsinki) and Estonia (Estonian Marine Institute, EMI). In 2022, a smaller meeting was organised 14th February to provide a technical update of Ferrybox measurements in the Baltic (participants: SYKE, FMI, IOW, TalTech, HCMR, SMHI, EMI, Univ. Helsinki, City of Helsinki).

Additional actions included:

- SYKE participated in FMI cruise in late 2020 to validate their glider measurements using water sampling and traditional laboratory analyses (for Chla and CDOM), linking to FMI activities in EURO-ARGO and GROOM.
- SYKE and IOW realised improvements in temperature sensor validation for FerryBox line they operate jointly at ferry FINNMAID linking to GoF-PSS#6 (Biological interplay with the carbonate system) and Task 6.3.3.
- Salinity sensor validation onboard ferry FINNMAID was improved, and results have been immediately communicated between SYKE and IOW.
- Discussions on sensor calibration between SYKE and Chelsea Technologies Ltd (UK) and related TA project allowing further harmonisation between sensor types measuring CDOM (This was delayed and finally TA was not realised for technical reasons).
- Meeting with IOW, SYKE and FMI onboard ferry FINNMAID on 10.8.2021; to review recent developments on the joint platform, to discuss issues for maintenance, future work & projects, and data & calibration issues.
- Within Finnish Marine Research Infrastructure FINMARI, a national buoy network was established, chaired by SYKE, and including FMI as member, aiming to streamline maintenance, sensor calibrations, data QA/QC and data availability. As part of GoF-PSS #1, a joint meeting with TalTech was organised on 23 Nov 2021, to present TalTech experiences on buoy operations to FINMARI.
- Flowthrough data QC code developed by SYKE (for CMEMS activities) has been shared with FMI, to be further used in Utö fixed station and linking also to Task 7.5.2.
- FMI participated in pCO2 intercalibration WS held by ICOS-OTC in 2021/08, in aim to harmonise/coordinate JERICO coastal and VOS pCO2-observations with ICOS observations (link to task 6.3.3), as well as to other PSSs that participated in the same WS.
- SYKE was among organisers of a session "Building a Metrology Framework for Ocean Observation" in 2021 IEEE International workshop on Metrology of the Sea (4-6 Oct 2021), and presented a paper co-authored by all GoF-PSS partners (Seppälä et al, 2021) providing an overview of current collaborations within Baltic FerryBox community and an outlook for next actions. This activity links to the MINKE RI project.
- In August-September 2022, a TA project (IGB, coordinator of AQUACOSM) visited FMI and SYKE to harmonise competences and transfer knowledge for plankton imaging technologies. This has relevance at the European level, through the collaboration between JERICO-S3 and AQUACOSM-plus RIs to develop best practices and technology solutions among European Research infrastructures.
- GoF PSS harmonisation and calibration activities were presented during MINKE Workshop "An introduction to metrology for young and early career marine scientists 15.-17.11.2022 in Helsinki" with approx. 30 international participants.
- FMI has prepared national coordination plans to improve QA/QC of oxygen optode and CTD observations.

GoF PSS #2 The performance of operational forecast models

Key Message from the Action

The current setup of the JERICO-RI allows us to assess the GoF operational forecast model product performance reasonably well, but the re-establishment of cross-gulf FerryBox measurements and initiation of continuous observations in the eastern part of the gulf is necessary. Likewise, continuous current measurements and nutrient measurements in the deep layer should be started.

Main achievements

Eutrophication is still the main environmental issue to tackle in the GoF. CMEMS operational model products give near real-time 3D information about the situation in the gulf and potentially could be used in the assessments of eutrophication status. In this Action, products BALTICSEA_ANALYSISFORECAST_PHY_003_006 and BALTICSEA_ANALYSISFORECAST_BGC_003_007 were analysed by TalTech. To understand the uncertainties of the products, GoF PSS data (from TalTech, FMI, SYKE) were used to estimate the performance of operational model products. The Action analysed and disseminated discrepancies in hydrography and biogeochemistry between PSS in-situ observations and CMEMS operational forecast model products at the GoF PSS.

The FerryBox data, collected at 4 m depth along the gulf, revealed seasonal patterns in the discrepancies between the model product and measured temperature. Temperature was underestimated by the product (about -1 to -2 °C) during the period when the heat flux was positive from the atmosphere to sea (until August), while it overestimated temperature in autumn when the heat flux towards the sea was negative. Salinity was rather overestimated (although not always) in the transect.

Temperature deviations in the upper layer did not reveal any regular spatial pattern, while salinity was rather more overestimated in the Baltic Proper (western) side of the transect, while the central GoF model occasionally underestimated salinity. Latter was probably related to the mesoscale and submesoscale processes that are active in the GoF (Salm et al., 2023). Interestingly, salinity in the upper layer was rather underestimated at Keri station, while in accordance with the FerryBox transect, salinity was rather overestimated in the upper layer in the Baltic Proper according to Argo floats. Lower salinity in the upper layer at the location of Keri in the product might be related to the inexactness of circulation simulation.

Thermocline appeared to be smoother in the simulation. The latter and described discrepancies in the upper layer properties point to too strong vertical mixing in the thermocline in the model. The halocline tends to start at shallower depths in the product than in the real sea. Latter is valid in all the locations of vertical profiling (Keri, Utö, Argo floats) (see Figure GoF-PSS#2). The deep layer is fresher in the product than in real life. Thus, although the halocline starts shallower, it is smoother and not as strong as the measurements show.

Both the seasonal deviations in the upper layer and smoother halocline indicate too strong vertical mixing in the simulation. Latter causes bias to weaker stratification and likely modifications in geostrophic forces, which in turn might cause inaccuracies in circulation simulation (Liblik et al., 2022). Stronger vertical mixing causes decreased density in the deep layer water mass and higher density in the upper layer. Likewise, it reduces the share of the cold intermediate layer water mass in the water column structure. One result of the stronger vertical mixing was too high oxygen concentrations in the deep layer. This bias is valid in all locations of vertical profiling (Keri, Utö, Argo floats). The deep layer of the GoF is usually hypoxic, but the product virtually does not show hypoxia there.

Overall, the main issues and tendencies of discrepancies of the products can be found in the GoF PSS data. There is a lack of cross-gulf information. It was originally planned to include the Tallinn-Helsinki FerryBox data in the PSS, but due to the covid pandemic, implementation of a new FerryBox system, and finally changes in the ferry line (the vessel with the FerryBox installed onboard was sent to Ireland) did not allow us to collect the data. However, Tallinn-Helsinki measurements are necessary to re-establish, as it would give valuable information on cross-gulf mesoscale processes (upwellings, downwellings), which remarkably affect the water column habitat.

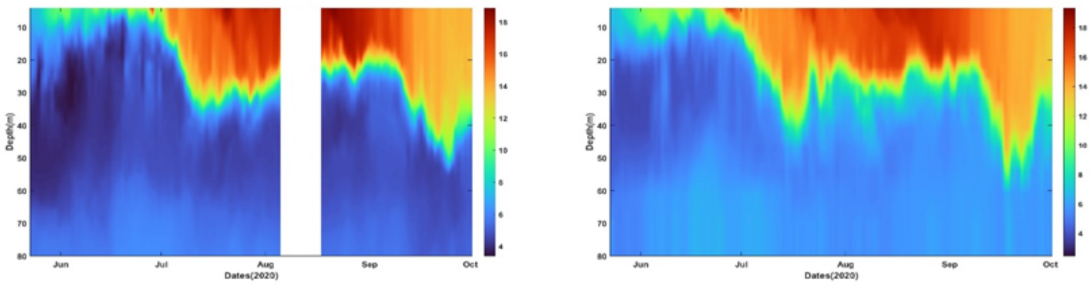


Figure GoF-PSS#2. Temperature measured by Keri profiler and product temperature in 2020.

The easternmost continuous measurements in the GoF PSS are at Keri. To further develop the JERICO-RI in the GoF, it would be beneficial to start sustainable autonomous measurements in the eastern part of the gulf. We did trial point measurements of temperature, salinity, and oxygen in Estonian waters near the Russian border at 80 m depth in this area in 2022 for 6 months. Our conclusion is that another sustainable, permanent measurement station in JERICO-RI in the eastern part of the gulf would enhance the estimates and assessments of the pelagic habitat.

There are no sustainable current measurements in the PSS. Latter would help to explain the role of advection in the observed variability in the water column. Another shortcoming is the lack of nutrient observations, particularly in the deep layer. Initiation of continuous nutrient measurements in the mooring would help to understand the nutrient dynamics in the deep layer. Latter is important, as internal variability of nutrients, e.g., phosphorus load from sediments and its flux from the Baltic Proper, are one of the largest sources of uncertainties in understanding the eutrophication-related processes.

GoF PSS #3 Optical data for Ocean Colour product validation

Key Message from the Action

Observations from sensors on different platforms and ocean colour data provide complementary insights into many coastal processes, but their interoperability, coordination and compatibility still need to be improved. This Action strengthened the regional dialogue in GoF with Ocean Colour community and took regionally important steps ahead in using such data by describing relationships between various optical proxies for phytoplankton and CDOM.

Main achievements

GoF PSS#3 strengthened the connection between the observing community and the Ocean Colour community within the region. Joint optical sensor intercomparison and calibration with GoF PSS#1 provide a basis for consistent datasets. Due to covid, joint transnational field campaigns were not possible.

For 2021 and 2022 SYKE collected complete datasets for Chla, phycocyanin and CDOM fluorescence at FerryBox FINNMAID and Utö Observatory and for 2022 similar results are available at FerryBox Silja Serenade. In addition, discrete water samples for laboratory analysis of Chla (all platforms) and CDOM (Utö, only 2021) were taken.

Despite the recent developments in Ocean Colour -based estimation of Chla in the optically complex Baltic Sea (Brando et al 2021), the results are not yet fully satisfactory and there is a clear need for additional in situ data. FINNMAID Chla results (2007-2020) from discrete samples were made available through CMEMS in 2021 and were discussed in a paper by Elovaara et al (2021). This paper provides annual climatologies and long-term trends of Chla concentrations, indicating that Chla levels have remained the same throughout the transect, suggesting that eutrophication has not been alleviated.

SYKE has also updated a database for FerryBox data and created an API-service containing flow-through water quality measurements starting from 1998, accessible by OGC-compliant WMS and WFS-requests (*Link to WP11*).

There was a dialogue with the SYKE Earth Observations team, how to better streamline observations with EO data. For a practical demonstration, we have started to extract EO data (raw reflectance data and concentration estimates) for location of Utö observations, to be followed by data mining for FerryBox routes. This will allow us to efficiently create match-ups between EO data and observations and to merge these two data streams scientific ecosystem studies in future. As second demonstration, already operational, FerryBox results can be overlayed with EO data in SYKE's TARKKA service (See Figure GoF PSS#3).

Specific 3-day measuring campaigns at Utö Observatory were conducted by SYKE in April-September in 2021, to measure optically active water constituents by various optical techniques as follows: Chla (Continuous measurements: in vivo single waveband fluorescence, spectral absorption, spectral fluorescence; Discrete samples: concentration, spectral absorption, spectral fluorescence), CDOM (Continuous measurements: in vivo single waveband fluorescence; Discrete samples: DOC concentration, spectral absorption, spectral fluorescence), Particulate matter (Continuous measurements: turbidity, backscattering; Discrete samples: Total suspended matter). This data still needs to be analysed in detail, allowing us to determine specific inherent optical properties and understand better how different optical proxies vary within optically complex water in the Baltic Sea and which type of measurements are better suited for field truthing of satellite data.

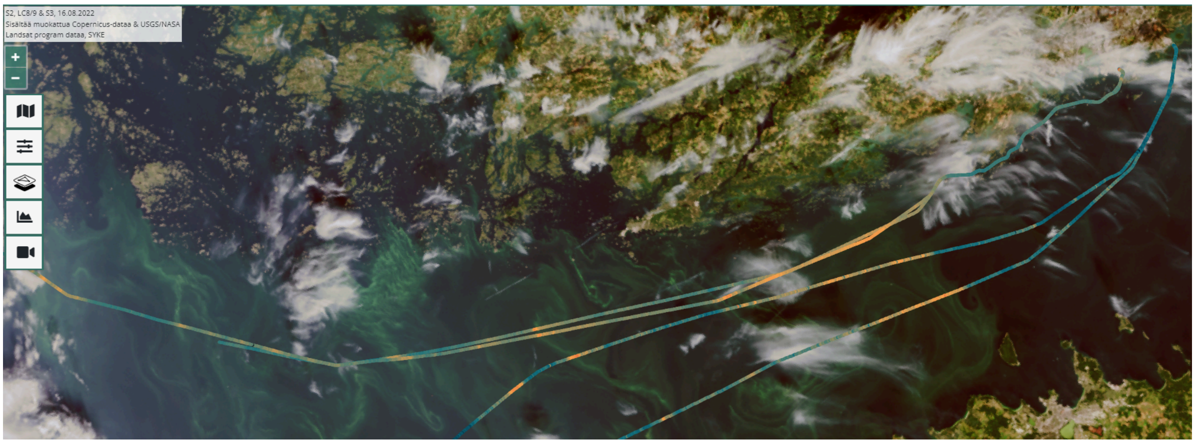


Figure GoF PSS#3. Satellite image of the cyanobacterial bloom in GoF PSS, 16th August 2022, overlayed with FerryBox phycocyanin observations from Silja Serenade (two upper lines) and FINNMAID (two lower lines) for the same day, as displayed in SYKE TARKKA service (wwwi4.ymparisto.fi/i4/eng/tarkka/). Since late 2021, TARKKA allows overlaying historic FerryBox data (Chla, turbidity, phycocyanin, salinity, temperature) with satellite observations from Sentinel-3 OLCI, Sentinel-2 MSI, Landsat-8 OLI and Envisat MERIS satellite instruments.

One of the key interests for EO in the Baltic are cyanobacteria bloom surface accumulations, causing nuisance for fisheries and recreation and having also cascading effects in ecosystem functioning. As Utö Observatory provides very precise information on cyanobacteria abundance using imaging technologies (See GoF PSS#4), it provides an excellent site to compare with EO data (*Link WP7, D2PTS*). During the preliminary discussions with the EO community (Scripps Institution of Oceanography, US), we noted how the in-water analyses by imaging and analysis of surface accumulations with EO provide a complementary view of the bloom development, showing large biomass increase in water column prior their accumulation in the surface (manuscript in preparation).

In connection to other ongoing projects, we have had workshops and meetings planning to improve validation of FerryBox Chla fluorescence data and provide it to databases to be available with EO data. Within CMEMS Ocean Colour-tac we aim to provide such data from GoF PSS in 2022-23. Providing such spatially extensive data is also of interest to HELCOM (delivered through ICES) and we have delivered to them validated FerryBox data, to be compared with other data.

As continuation of the activities, combination of EO data and observations in GoF PSS area is targeted in three recently funded EU-projects. AQUA-INFRA supports the ongoing development of the EOSC as an overarching research infrastructure and includes engagement of marine and freshwater marine communities working with EO data and observations. OBAMA-NEXT will test and improve EO methods and novel in situ observations for pelagic biodiversity observations. LandSeaLot project has a Baltic Sea component concentrating in the detection of carbon fluxes from land to sea using both methods.

GoF PSS #4 Detection of cyanobacterial blooms

Key Message from the Action

Automated routine for near real time recognition of cyanobacteria biomass and species structure was created using imaging methods and artificial intelligence-based classification. The methodology was used in operational weekly algae reviews in the Gulf of Finland and widely disseminated.

Main achievements

Annual intercalibration of phycocyanin sensors used in FerryBox, Utö Observatory and profiling buoy platforms, was done by SYKE as part of GoF PSS#1.

Ferrybox data of phycocyanin fluorescence was collected during summer months using ferries FINNMAID (2021 & 2022), Silja Serenade (2022, data in 2021 is deficient as covid affected ships operations) and Utö Observatory (2021 & 2022). FerryBox data is visualised at near real time at marinefinland.fi portal, also as part of VA (*link WP11*). As co-developed with WP7 D2PTS, NRT data visualisations, with hourly updates, are made available at FMI swell portal including also historic data since 2018.

At Utö Observatory an Imaging FlowCytobot (IFCB) was installed in the beginning of 2021. Instrument samples local phytoplankton community at 20-min intervals and takes images of Chla containing cells. Data flow was developed with FMI and SYKE from Utö observatory to FMI server and further to cloud computing infrastructure provided by the national scientific computing centre (CSC). Based on the classified images and framework created by Kraft et al (2021), a Convolutional Neural Network (CNN) classifier was created and tuned and images were labelled in near real time (2-3 hours after their retrieval). The code is available at https://github.com/veot/syke-pic. The results, biomass, and species composition of filamentous cyanobacteria were thereafter provided back to FMI server and plotted in near real time at swell portal. The development of this service was created in collaboration with the PHIDIAS EU-project and national FASTVISION project and WP7 D2PTS.

Description of data pipeline and operational classification system was published by Kraft et al (2022) (see Figure GoF PSS#4). The paper also demonstrates how a good phytoplankton recognition can be obtained with transfer learning utilising a pre-trained CNN model. Phytoplankton image data, used to create and validate CNN model have been published at EUDAT B2SHARE data repository (Data set names: SYKEphytoplankton_IFCB_2022 & Data set name: SYKEphytoplankton_IFCB_Utö_2021).

Selection of phytoplankton images from Utö station has been imported to EcoTaxa (ecotaxa.obs-vlfr.fr), as part of EcoTaxa D2PTS, using a project-tag "IFCB Utö 2021 JERICORI Gulf of Finland Pilot Supersite". Further, this subset has been submitted to EMODnet Biology.

Weekly algae review, launched by SYKE in summer, used the data sources described above, to inform the public and authorities on nuisance algae blooms. The reviews were published at SYKE Baltic Sea portal, which is also part of VA (*link WP11*), and they are archived at SYKE website. In 2021, cyanobacteria bloom started as very intense, but despite hot weather conditions favourable to cyanobacteria development, the observed biomass did not peak to extreme values. In 2022, bloom started at the turn of June and July peaking in mid-July and again in mid-August, due to a heatwave.

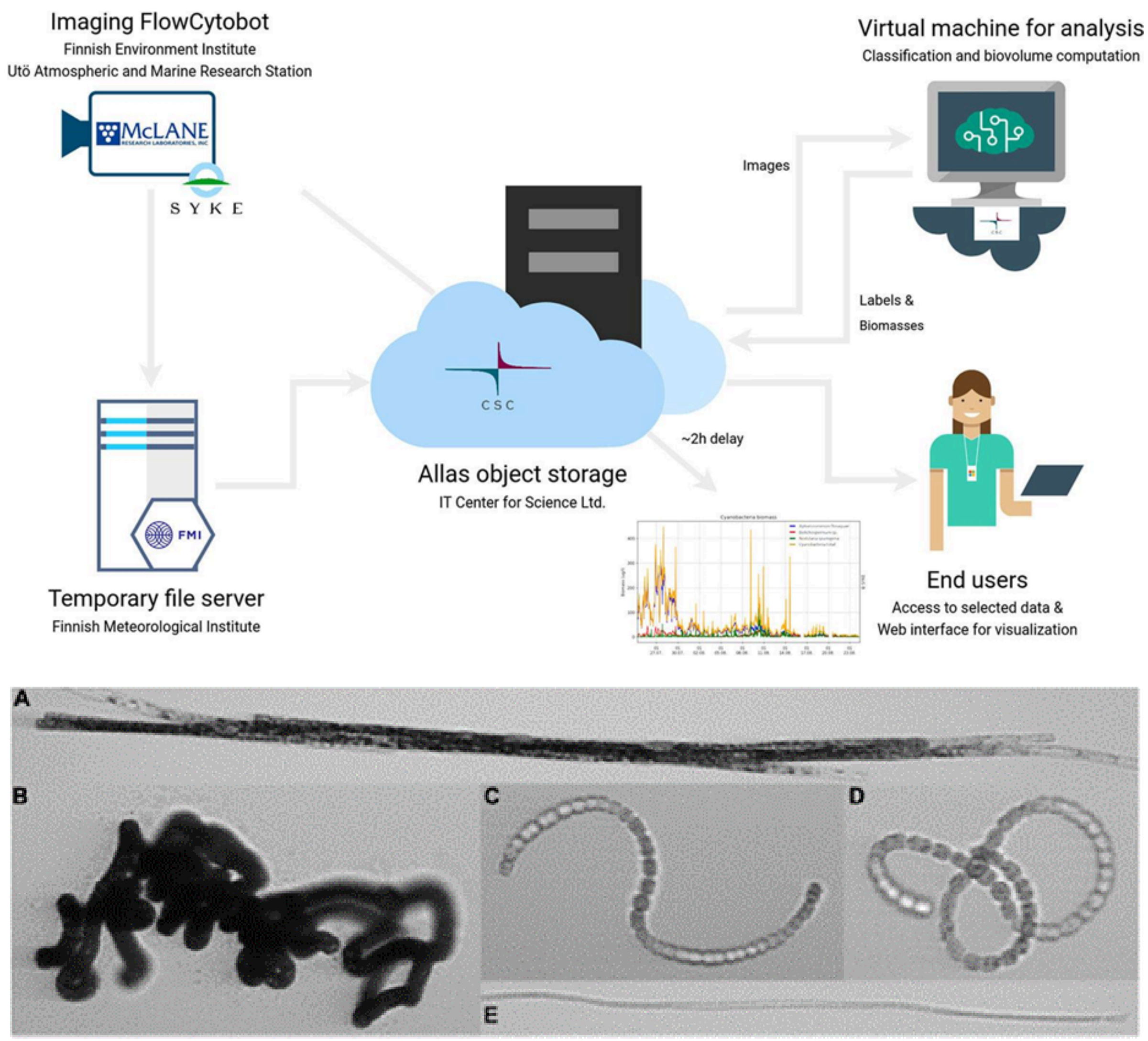


Figure GoF PSS#4. Scheme of phytoplankton image data flows and processing created to obtain NRT products for biomass and species structure during cyanobacteria blooms (Kraft et al 2022) (up). Examples of the images of bloom forming cyanobacteria (Kraft et al 2021) (down)

As a link to WP5, we participated in delivering information to questionnaires for imaging, flowcytometry and fluorescence. In addition, in 2021 Cytosense pulse shape and imaging flowcytometer was taken into operational use in Utö Observatory.

A review of the development in cyanobacterial detection methods was published ([Haraguchi et al 2021]), highlighting the use of fluorometric and imaging methods and providing examples from GoF PSS data collected in 2021. Newsflashes on the [observations] and [results] of the Action have been published in JERICO-RI webpage. The developments made in GoF PSS#4 have been presented during various meetings, including [National FINMARI researcher days in 2021], 10th and [11th FerryBox workshops] in 2021 and 2022, [ASLO symposium] in 2021 and [BSSC symposium] in 2021.

An informal European network for IFCB started in 2021, SYKE being among participants (together with participants from various other PSSs and IRSs), and various aspects of data collection, analysis and AI-algorithms have been discussed.

GoF PSS #5 Mapping the deep-water oxygen conditions

Key Message from the Action

The current setup of the JERICO-RI observations allows a good oxygen mapping of the Gulf of Finland. Based on this study, yet another station in the eastern part of the basin in Estonian waters would enhance the accuracy and trustworthiness of the mapping.

Main achievements

Oxygen depletion is one of the consequences and indicators of eutrophication. Benthic oxygen conditions and thickness of the near-bottom hypoxic-anoxic layer vary considerably in the synoptic time-scale (Liblik et al., 2013; Lips et al., 2017; Stoicescu et al., 2019) and this variability is difficult to capture by conventional research vessel based monitoring in the Gulf of Finland. Oxygen distributions derived from Copernicus Marine Service reanalysis and forecast products considerably overestimate oxygen concentrations in the deep layer of the Gulf of Finland.

The action included data collection from PSS partners and TalTech produced at least weekly near-bottom oxygen maps in the GoF. We used data from research vessel surveys, Keri profiler station and Argo floats in 2020-2021 to illustrate the potential of JERICO-RI GoF PSS to create such a product.

Spatial hypoxic (<2.9 mg l^{-1}) maps were calculated based on the data of 1) solely Keri profiler, 2) Keri profiler and Argo floats, and 3) shipborne monitoring. Oxygen fields were first interpolated and then extrapolated considering the bathymetric data of the Baltic Sea Bathymetry Database (data.bshc.pro, 2022.05.10). In the case of solely Keri profiler data, only extrapolation was done. From the interpolated-extrapolated fields, hypoxic area maps of the Gulf of Finland were created, and hypoxic areas were calculated. Hypoxic areas calculated from the shipborne observations and autonomous GoF PSS observations were compared, and linear regression and correlation were calculated. The correlation was stronger in the case when Argo floats and Keri profiler were both included ($r^2 = 0.97$, $n = 8$, $p < 0.01$) while it was slightly lower when only Keri profiler data was used in the mapping ($r^2 = 0.90$, $n = 8$, $p < 0.01$). Thus, we use the mapping results created by combining the Keri profiler and Argo floats.

Hypoxic areas ranged from 550 km^2 to 1050 km^2 from May to September 2020. The largest hypoxic areas were detected in late June, or early July. Reversal of estuarine circulation, weakening of haline stratification, and diminishing of the hypoxic area occurred in mid-September. Spatial statistics of benthic oxygen conditions for the period are shown in Figure GoF PSS#5 as mean, 5% percentile, and 95% percentile of benthic oxygen concentration. Hypoxia was present for the whole period in the deeper parts of the gulf. The presence varied at the coastal slope in the depth range of 60-90 m, where halocline and oxycline vary. Thus, according to the bathymetry, when halocline and oxycline were shallower, the meridional extent of hypoxic water mass is narrower, and its eastward extent was smaller.

This Action demonstrates that the production of daily benthic oxygen maps for the Gulf of Finland is possible and reliable. The main reason for the quite good reliability of this simple approach is the nature of the Gulf of Finland. Temporal variability in the deep layers of the gulf is high while the spatial variability in the deep layer in the weekly timescale is quite small. This means that if the water in the deep layer is hypoxic at the central part of the gulf, it is very likely the same at the entrance of the gulf. The maps can be created in near-real time (daily basis) and in principle, the same method (Argo floats combined with Keri profiler and checked against occasional RV mappings) can be used to provide 3D fields of variables.

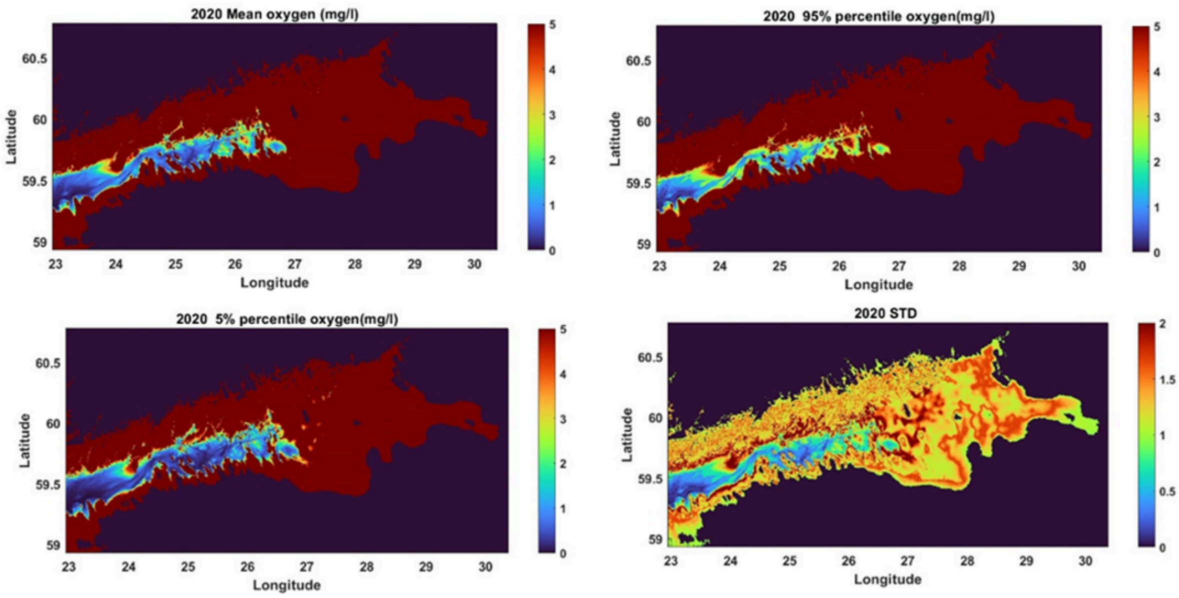


Figure GoF PSS#5 Mean, 5-percentile, 95-percentile and standard deviation of near-bottom oxygen concentration (mg/l) in June-September 2020.

We did not have autonomous measurements from the eastern edge of the potentially hypoxic area. Liblik et al. (2013) noted that after a strong reversal event of estuarine circulation in winter the eastern part of the gulf remained ventilated for a few months. However, it was not clear if the latter occurs in winter and early spring only or if those long ventilation events occur also in summer. Our limited mappings with RV suggested that when oxygen conditions were poor in the Keri area, the same occurred also in the eastern part of the gulf, i.e. the lack of measurements in the east does not cause large uncertainties in estimates. Anyhow, to increase the trustworthiness and further develop the JERICO-RI in the Gulf of Finland it would be beneficial to start sustainable autonomous measurements in the eastern part of the gulf. We did trial point measurements of oxygen in Estonian waters near the Russian border at 80 m depth in this area in 2022. We observed oxygen concentrations above hypoxic levels until mid-May. Bottom-layer changed to hypoxic after mid-May and stayed anoxic from mid-July until the end of August when slight ventilation occurred. However, anoxia was re-established by the beginning of October. We suggest that another sustainable, permanent measurement station in JERICO-RI in the eastern part of the gulf would enhance the estimates and assessments of the pelagic habitat.

The product does not cover specific and local peculiarities of the Finnish coastal archipelago. Seasonal hypoxia occurs there in the deeper spots between islands. The volume of the hypoxic water in these spots is small compared to the Central Gulf of Finland and needs to be addressed by national efforts.

Once the Russian invasion of Ukraine is over and the political situation allows, it is beneficial for the JERICO-RI to seek data exchange and integration with observations in the easternmost part of the gulf, i.e., in Russian waters as despite the shallowness of this area oxygen depletion occurs also there (Eremina et al., 2012).

GoF PSS #6 Biological interplay with the carbonate system

Key Message from the Action

Carbonate system measurements and interpretation in the GoF PSS provided new insights into regional and seasonal variability, and biological control of pCO_2. The Action promoted the harmonisation of measurement and data processing methods, established knowledge transfer between partners, and encouraged future monitoring efforts.

Main achievements

The Action promoted harmonising regional carbon system measurements, helped the ecosystem assessment of the Baltic Sea, provided operational carbon system data and supported strategic planning of future sampling strategies. In 2021, pCO_2 and pH were measured continuously at Utö by FMI and SYKE with only small maintenance gaps. Due to the covid and ICOS OTC pCO_2 intercalibration workshop, pCO_2 measurements onboard Silja Serenade by FMI were offline until September 2021. pCO_2 measurements onboard FINNMAID by IOW were not compromised by covid though technical issues of the ferry led to a 2-month data gap in spring 2021. In 2022, Utö and FINNMAID were operational, while measurements at Silja Serenade were sporadic due to technical problems.

With the onset of the JERICO-S3 project, IOW demonstrated the use of a continuously operated spectrophotometric pH instrument at FINNMAID. A manuscript is currently under preparation (Avila et al., in prep.), and was presented at the HELCOM scoping workshop on acidification held in November 2022. The technological experience can be readily used to implement the technology on the other operational surface observation lines.

In March 2021, a workshop was organised for the best practices of several variables including pCO_2 (GoF PSS#1). FMI provided information on Utö while IOW presented those for FINNMAID and overall challenges while integrating and harmonising GoF PSS carbonate system measurements. In August 2021, IOW, SYKE and FMI met to review carbonate system measurements used by IOW, to agree on improvements in supporting temperature observations, and to plan forthcoming actions. A few T-S units were calibrated in the certified calibration lab at IOW, to support GoF PSS carbonate system measurements. To improve dialogue, transfer knowledge between groups, and analyse joint data from GoF PSS, PhD student Honkanen (FMI) visited IOW in 2021 for 1 month.

FMI participated in the ICOS OTC's 1st pCO_2 intercalibration workshop in summer 2021 by providing three instruments. The workshop aimed for the harmonisation of pCO_2 measurements to reach high measurement precision. In addition, partners are finalising a manuscript for pCO_2 and pH sensor intercomparison experiment INTERCARBO (JERICO-NEXT's TA project), which includes participants also from other regions. This work will enhance the current carbon system measurement methods and their precisions.

While the backbone of carbon flux estimates in the GoF PSS are surface measurements using FerryBox systems, they have an inbuilt issue that ships with fixed schedules are often at the same location at the same time of day. As there is a strong diurnal variability in the carbonate system in highly productive coastal regions (Figure GoF PSS#6), we did an assessment of the bias this caused to the surface observations (Honkanen et al. 2021, see related news), using data from Utö, and showing the power of integration of FerryBox and fixed station multiplatform data. It also contains a validation of Utö's flow-through system for pCO_2 measurements. Data of the study is available from Zenodo.

In the BSSC2023 conference Honkanen et al. showed a 5-year time series of the air-sea CO_2 exchange at Utö showing that the sea area is a net source of the atmospheric CO_2, with small overall interannual variations. Haraguchi et al presented a study on high resolution temporal dynamics of phytoplankton at Utö in BSSC2021 conference, linking the shifts in phytoplankton community as observed with pulse-shape recording flow cytometry to the CO_2 dynamics. During the FINMARI science days (March 2022) a joint

JERICO-FINMARI-EUROARGO session was organised, including talks by Honkanen and Haraguchi based on pCO_2 data collected at Utö. The video of the session, and videos for sediment trap deployment, to study carbon flux from pelagic to benthic compartments, and introduction of Utö activities were published at FINMARI YouTube channel.

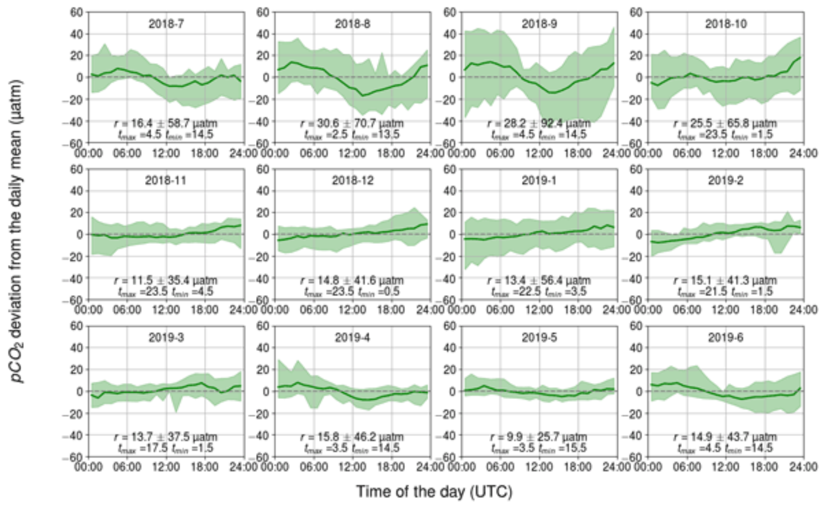


Figure GoF PSS#6. Observed monthly pCO_2 diurnal variability due to biological transformations. Data collected at Utö (Honkanen et al. 2021)

TalTech and IOW interpreted pCO_2 data from six monitoring cruises by TalTech in 2018, for which IOW had joined with an automated surface pCO_2 system (Lainela et al., in prep). The work provides new insights into the seasonality of the CO_2 cycling of the Gulf of Finland and the adjacent Gulf of Riga, regions so far understudied. The work led to exchange of knowhow on continuous pCO_2 observation technology and hydrographic conditions. IOW established a pCO2 climatology for the Baltic Sea based on the pCO_2 data available through the Socat data based using model-derived EOF patterns for smart extrapolation (Bittig et al., in press). The approach will allow for an estimation of where additional data are mostly needed to improve pCO_2 uncertainty, already pointing to an enormous potential of the integrated use of the SOOPs Finnmaid, Tavastland and Silja Serenade.

Linking to Subtask 6.3.3: "Guidelines and strategy for carbonate systems data management", IOW and FMI collected regional protocols for carbonate system measurements, identified gaps in best practices and interacted with ICOS-OTC and SOCAT. In 2022, they organised a joint PSS-IRS "Workshop on Best practices strategy for coastal carbonate systems data management" during the JERICO-days in Lisbon. Information on the current situation throughout the European coastal zone was combined and the most efficient ways to harmonise the observations and data flows were discussed.

Through the atmospheric station Utö and the SOOP FINNMAID, both embedded in the ICOS ERIC, there exists direct exchange with the respective atmospheric (ATC) and ocean (OTC) head organisations and networks. In 2022 FMI and SYKE suggested that the carbonate system observations on Silja Serenade will be included in the ICOS-OTC. The participation was approved by ICOS Finland and the Academy of Finland and will take place in 2023-24. Combined with the ICOS-OTC observations of FINNMAID and Tavastland, the FerryBox lines will cover the main basing of the Baltic Sea, with a possibility for cross-validation on the intersecting locations.

In 2022, SYKE conducted a survey for the Finnish Ministry of Environment examining how the future national cost-efficient monitoring of the Baltic carbonate system should be organised. It is evident that continuous observations will have a key role in this task, JERICO-RI platforms being the forerunners. Project highlighted the need for coordination of regional and international measuring efforts, as started during the PSS phase. The first national actions have taken place in 2023, in improving carbonate system monitoring.

GoF PSS #7 Forecast models for cyanobacterial blooms

Key Message from the Action

Operational cyanobacteria observations are available from various platforms and readily usable for forecast models. As the operational forecast models for cyanobacterial blooms are not yet well developed in the GoF PSS region, a novel forecasting system was designed using synthesis of multiplatform data as an initial estimate of bloom status.

Main achievements

As already described in GoF PSS#4, availability of cyanobacteria observations was improved, and even species-specific observations are now available in near real time from Utö Observatory. Utö data is transferred to the FMI server and visualised on a www-page. Visualisation of FerryBox FINNMAID data is available at marinefinland.fi portal and at SYKE's TARKKA service. Additional data sources identified (but not yet available operationally) include a profiling buoy network maintained by FINMARI consortium partners in Finland and measurements at Keri by TalTech.

Literature and the internet were screened for the availability of operational cyanobacteria forecast models. It turned out that suitable operational models forecasting the extent of blooms are not available. As a static prognosis, each year SYKE provides an early summer risk assessment of cyanobacterial blooms in the sea areas near Finland, based on the amounts of nitrogen and phosphorus available for the algae measured during the previous winter. The model is very coarse and does not consider the actual weather conditions driving the blooms.

During this task FMI started to develop a system designed to help in creating short term forecasts for cyanobacteria situation development. The system is based on synthesis of available data from satellites, FerryBox measurements and potentially other sources. These data are weighted and assimilated to form a gridded initial state that represents the estimated condition of cyanobacteria at initial time. The last similar state generated is used where fresher data is unavailable, these are weighted based on proximity.

To estimate the reliability of this initial state, the model also incorporates a 'reliability field' based on the spatial and temporal proximity of the most recent data (see Figure GoF PSS#7). As such the result of the system is given as an approximation of the cyanobacterial state, as well as a reliability field, giving an estimate on the uncertainty of the given area. (Areas with more recent data are more reliable than ones where the data is extrapolated further in time or space). The development is done so that weights and balances of separate data sources are easy to change based on experiences, as well as the shape and size of the output grids, so that they fit to the next steps of the simulation.

A system has been successfully implemented to download SYKE's algae product in geotiffs, as well as assimilate this data together with the data from the FerryBoxes. These are then compiled and expanded to form a gridded field. One of the features of the tool is its capability to interpolate and extrapolate data in areas where information might be lacking. The tool considers the presence of land masses during interpolation. To create an estimated current state of the cyanobacteria, the system combines previous states with new data, applying weights based on their distance and time from each point of interest. Alongside this, a field is generated that describes the reliability of each point, based on how distant or recent the last available data point is. The system has been designed to be highly flexible. All variables, multipliers, and factors are easily modifiable, which allows for easy calibration and adaptation by experts in the field.

Next steps in this development would use the generated fields as initial state for drift model, OpenDrift along with forecasts from NEMO circulation model, to estimate the algae situation 1-5 days forward, weighting the growth based on local sunlight and temperature, giving the user possibility to tune several factors directly based on their assessment on the situation.

As such the end aim is not to create a biological model of cyanobacterial growth, but rather an expert tool to better estimate the current situation on existing data, and the development of the situation, based on their expert knowledge of growing potential.

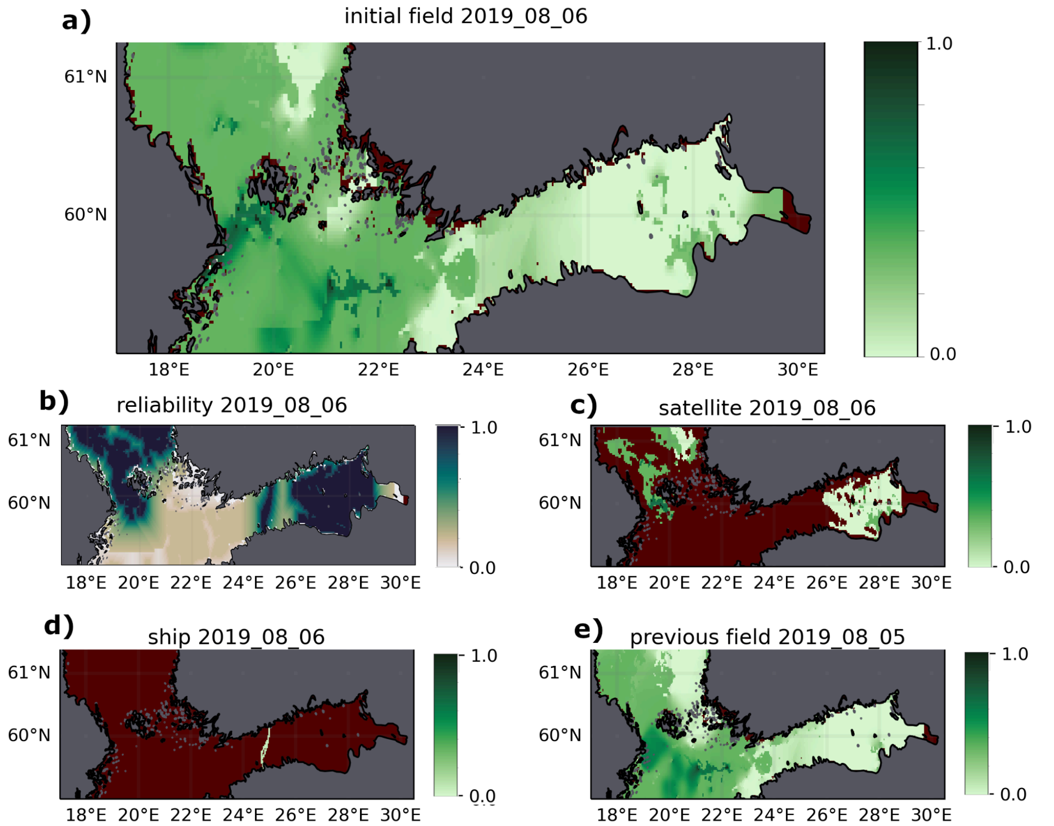


Figure GoF PSS#7.: Example of the process: a) shows the initial field generated, b) the reliability score of the initial field. c), d), e) are data-fields applied to generate a) and b). C) is derived from SYKE's satellite product, d) from Algaline FerryBox and e) is the initial status of the previous iteration. As can be seen from b), reliability is higher in areas with fresher data. Scale in b) is reliability from 1 (close, recent data) to 0 (no data). Rest has arbitrary units of likelihood to have algae bloom from 1.0 (high probability) to 0.0 (highly unlikely).

GoF PSS #8 Extreme events affecting phytoplankton - AQUACOSM collaboration I

Key Message from the Action

A joint JERICO-AQUACOSM mesocosm experiment to study the effect of heatwave on the Gulf of Finland plankton ecosystem was carried out. Action was supported by the Transnational Access program, providing funding for three visiting AQUACOSM research groups.

Main achievements

Water sample (4 x 1 m^3 containers) for mesocosm experiment was taken on 19^{th} August 2022 during a research cruise of RV Aranda, and it was transported to the SYKE indoor mesocosm facility on the same day. To boost phytoplankton growth, nutrients were added in the 1 m^3 containers. After 3 days of incubation period, water was transferred into 320 L mesocosms (12 units) and the heatwave treatment was started. Initial water temperature was 16°C, and the experimental temperatures were 16, 18, 20 and 22°C (each in triplicate mesocosms). Daily manual sampling for biological and biogeochemical variables was augmented by using a continuous sampling with AquaBox system measuring water temperature, Chla/CDOM/cyanobacteria fluorescence, O_2, FRRF-fluorometry, pCO_2, pH, Imaging (Imaging Flow Cytobot) and cytometry (Cytosense). Experiment lasted for 10 days.

The sea surface temperature anomalies have been studied using FerryBox data 2007-2020, for a transect between Helsinki (FI) and Travemunde (DE). A paper describing climatologies, anomalies and trends in temperature, nutrients and Chla has been published in CMEMS Ocean State Report #6 (Elovaara et al 2021) and it aided us in determining the realistic temperature manipulations for the experiment.

Three Transnational Access projects were funded (WP8), providing the access to the mesocosm experiment. All the projects were linked to AQUACOSM-plus partners, and they included altogether 13 visitors. From SYKE, approximately 15 scientists and analytical staff members participated in the experiment full time (see Figure GoF PSS#8).

In the 2nd JERICO-S3 TA call, a project AQUA-Action 1 by IGB (Leibniz Institute of Freshwater Ecology and Inland Fisheries, led by Dr. Stella Berger) was accepted for access to SYKE MRC-lab during the mesocosm experiment. The main objectives were to study how Baltic Sea plankton community is responding to extreme events such as sudden shifts in temperature and to utilise this opportunity for transfer knowledge and harmonisation of competence between European Research infrastructures, by collaboratively further developing best practices and technology solutions especially for plankton imaging. IGB is coordinating the AQUACOSM-plus INFRAIA project which has a considerable amount of research activities in plankton imaging. Scientific teams of IGB and SYKE successfully shared knowledge and harmonised competences for plankton imaging technologies during the time course of the indoor mesocosm experiment. In particular, the SYKE-team helped the IGB-team to set up the Imaging Flow CytoBot in the AQUABOX for benchmark comparison of taxa identification and abundance measurements with the convolutional neural network (CNN) developed by SYKE (Kraft et al. 2022).

In the 3rd JERICO-S3 TA call, a project OBS-EXP-Bridge by CNRS-MARBEC (Marine Biodiversity, Exploitation and Conservation, CNRS – Université de Montpellier), led by Dr. Francesca Vidussi was accepted. Main objectives of the project were to i) study the metabolic and structural responses of plankton communities of the Baltic Sea to a simulated heatwave using high-frequency sensors of LAMP-Sensor-System and a Low-Cost-Sensor System that they have developed, ii) compare the high-frequency data obtained by LAMP-Sensor-System and Low-Cost-Sensor System with those acquired by host SYKE laboratory using the AQUABOX-device and iii) compare the responses of the Baltic Sea communities to heat wave obtained by LAMP-Sensor-System which those obtained previously in the NW-Med Sea during in situ mesocosm experimentations that they have realised in the frame of TA of AQUACOSM-plus between April 25 and May 25 2022. A clear marked day-night cycle of oxygen concentrations with values increasing during the day and decreasing during the night were observed in all mesocosms. This is due to the biological metabolism showing oxygen production by phytoplankton encompassing consumption during the day and only oxygen consumption by plankton during the night. The decreasing trend in oxygen concentrations along the experiment was noted in the 20 and 22°C mesocosms, probably due to the plankton activity in these mesocosms leading to minimum values at the end of the experiment of about 10-15% less than those observed at the beginning of the experiment. The oxygen concentration daily cycles will be used to estimate oxygen net and gross production, and oxygen respiration (Soulié et al. 2022) and thus evaluate the effect of the simulated heat-wave on the plankton oxygen metabolism.

Also in the 3rd JERICO-S3 TA call, a project BalHObEx by HCMR (led by Iordanis Magiopoulos) was accepted. This project had objectives to investigate the effects of extreme heat waves on the marine plankton food web via a mesocosm experiment and compare and combine the results from the above mentioned mesocosm experiment with findings in the natural environment. The samples were collected for the analyses of viruses (abundance and cytometric groups) and viral production, heterotrophic and autotrophic bacteria (abundance, cytometric groups, pigments per cell, relative size), autotrophic nano-flagellates (abundance, pigments per cell, relative size) and microplankton (abundance and diversity) from both the mesocosm experiment and the FerryBox samplings during summer 2022.

Detailed reports of the above mentioned projects are available at JERICO TA pages for 2nd and 3rd TA calls. TA activity was presented in the media on the JERICO-RI webpage and AQUACOSM-plus webpage. An additional article was published in AQUACOSM-plus webpage. Several publications are planned from the experiment. Existing links with AQUACOSM-plus were strengthened, and a joint presentation of the RI-RI mesocosm experiments from the three PSSs (CRETAN, NW-MED and GoF) was made during the 3rd AQUACOSM-plus GA Meeting in a session on RI-RI interactions (17-21 October 2022 Romania). A video about the mesocosm experiment was published.

Figure GoF PSS#8. Participants of the mesocosm experiment, including SYKE-team and TA projects (Left) and example of plankton images taken during the experiment using Imaging FlowCytobot (right)

GoF PSS #9 Promotion of the use of PSS data and products

Key Message from the Action

During the Action, partners have participated at the meetings of regional stakeholders and given presentations for local authorities and stakeholders. The main message conveyed has been about the combination of innovative technologies with conventional monitoring to improve the confidence of assessments.

Main achievements

Various GoF PSS Actions, the overall JERICO-S3 PSS study and its objectives, as well as JERICO-RI has been promoted to various stakeholders. Specifically, communication with the relevant regional stakeholders (BOOS, HELCOM working groups) has been active. Following activities have been included in the Action

- GoF PSS activities have been disseminated in BOOS annual meetings in the planning phase (Nov 2020) and after the first year of implementation (Nov 2021).
- TalTech is responsible for the HELCOM Oxygen debt indicator assessment based on the data from 2016-2021 (agreed at HELCOM S&C WG meeting on 04.03.2021). TalTech has participated in HELCOM EG EUTRO work for eutrophication assessments, especially to collect oxygen profile data from the Gulf of Finland to be used for the development of shallow water oxygen indicator (EG EUTRO on-line meetings on 22.04.2021, 01-02.09.2021, 25-26.11.2021; GoF shallow water indicator meetings on 22.09.2021, 11.11.2021, 23.11.2021).
- SYKE has been collaborating with HELCOM, within frames of Baltic Data Flows project, and providing FerryBox observations and especially validated Chla fluorescence observations for assessments.
- GoF PSS continuous phytoplankton imaging data and products from were presented to HELCOM Expert Group for Phytoplankton in Sept 2023, while discussing the role of emerging technologies in phytoplankton monitoring
- GoF PSS activities were demonstrated to representatives of the Ministry of Environment, Finland (24.5.2021).
- GoF PSS data and findings was used in a project "Monitoring Baltic Sea carbon cycling: Carbonate system (BalticCarbon)" funded by the Ministry of Environment, Finland (2022-23), highlighting the needs of continuous carbonate system measurements from various platforms.
- GoF PSS data for algae blooms have been efficiently used in weekly SYKE algae reviews.
- TalTech analysed flow-through data from RV Salme and suggested possibilities to include this data stream into the monitoring and assessment system of surface layer Chla and pH and/or pCO2 (reports and presentations to the Ministry of the Environment; May 2021 and December 2021).
- FMI's new wave rider buoy at Utö has been found especially useful by Pilots and other stakeholders.
- The wave observations combined with other observations at Utö are also used as a reference for remote sensing observations by a coastal radar at Utö, Korppoo weather radar, and satellite-based observations.
- Among other PSSs, GoF PSS Actions have been presented to the JERICO-S3 community in large, during a specific PSS progress report meeting (21.9.2021) and during a workshop of multiplatform observations including EuroGOOS, EuroSea-project, NAUTILOS-project and MINKE-project (18.11.2021).
- FINMARI Board, and directors of FMI, SYKE and the Ministry of the Environment visited Utö station in August 2022. JERICO-RI and GoF PSS activities were presented to them.

- Methane leaks from NordStream gas lines, after an explosion, were observed at Utö in September 2022. This was also noted by all major media companies e.g. the largest newspaper in Finland, Helsingin Sanomat
- GoF PSS activities were presented in the MEMFIS conference of environmental monitoring, in Stockholm in November in 2023.
- As noted in each individual GoF PSS Action, many publications have been made using GoF PSS observations and several other targeted dissemination actions have been carried out.

GoF PSS #10 Connecting the other RIs in the region

Key Message from the Action

JERICO-S3 activities at GoF PSS have well established connections to several other environmental RIs active within the region and various collaborative activities were identified.

Main achievements

In the EU, the number of environmental RI's is continuously increasing, leading to potentially overlapping activities and administrative efforts as well as to the increase of synergies and needs for coordination. Coordinating the work may save both administrative and technical efforts and ensure collecting seamless and multi-use datasets.

GoF PSS connects JERICO-RI regionally to several other environmental research infrastructures. All Finnish components of GoF PSS belong to national FINMARI-RI, while Keri Station in Estonia is part of Estonian Environmental Observatory. Part of the GoF PSS, Utö atmospheric and marine research station is a joint research facility of ICOS, ACTRIS, HELCOM, EMEP and GAW Regional station. Utö site is also part of national INAR-RI's. FerryBox in FINNMAID is part of ICOS-RI and during the PSS period the participation of Silja Serenade was approved by ICOS Finland. FMI is a partner in EURO-ARGO ERIC, while Argo data is also supporting GoF PSS observations. SYKE is a partner in EuroFleets+, as well supporting data collection. SYKE is partner in AQUACOSM+, and besides a joint activity for mesocosm experiments (GoF PSS#8), there are overlapping interests for plankton imaging. SYKE is also a partner in the recently started MINKE INFRAIA project, which aims to improve collaboration between national metrology institutes and oceanographic institutes, work which is very relevant for JERICO-RI. Finland joined EMBRC ERIC in 2024 and SYKE's mesocosm facility is part of it. The Finnish-Estonian-German activities on GoF PSS are in a close interaction with GOOS.

Specific interactions during implementation phase of GoF PSS with other RIs included:

- To increase GoF PSS interactions with other relevant infrastructures, FMI proposed including the current JERICO pCO2 observations on FerryBox at Silja Serenade in the ICOS-OTC VOS network in 2021, this was accepted in 2023.
- In 2021, discussions between the JERICO partners and DANUBIUS were started. In the recently funded LandSeaLot EU-project, JERICO, DANUBIUS and EO communities join forces, improving the observing capacities along land-to-sea interface.
- Interaction between the GoF PSS partners and ICOS-OTC have started in 2021 by the FMI participation in ICOS-OTC intercomparison WS in Belgium, where the experiences from JERICO-NEXT TNA activity INTERCARBO were shared with the participants. In 2021 also a joint research activity combining JERICO-RI and ICOS observations was published (Grönholm et al 2021), showing that LNG-powered shipping, if equipped with low-pressure engines does not reduce the greenhouse gas emissions. The results were disseminated through several channels, including the largest Finnish newspaper Helsingin Sanomat.
- AQUACOSM-plus partners had TA projects in JERICO-S3 TA call to visit SYKE MRC-lab (in frames of GoF PSS#8) to study the effect of heatwaves on plankton and Utö Observatory aiming to improve harmonisation of plankton imaging methods between RIs.
- MINKE project organised a workshop for introduction to metrology for young and early career marine scientists at SYKE in Nov 2022. JERICO-RI observations were demonstrated during the workshop.
- Practical work at the sites where two or more RIs are active has been done in collaboration. The same applies to dissemination.

NW-MED PSS #1: Reconstruction of the 3D coastal dynamics

Key Message from the Action

The Action reconstructed 3D coastal dynamics of NW-MED from multiplatform observations and models. The impacts of coastal dynamics on particle dispersion were investigated.

Main achievements

Action combines various transinstitutional and transnational activities, using a multiplatform approach, in studying the coastal dynamics of NW-MED PSS.

In 2021, the WMOP (a high-resolution ocean forecasting system implemented over the Western Mediterranean Sea) data assimilation system was adapted to ingest data from moorings along the NW Mediterranean slope, in addition to satellite SLA & SST, T-S profiles and Ibiza Channel HF radar velocities. SOCIB and PdE mooring data have been assimilated in the operational model, contributing in particular to help constraining the model surface salinity. In this context, SOCIB has updated the glider-derived Balearic Channels transports by water mass characterisation. This extension provides nearly 10 years continuous monitoring of these transports, supported by high resolution modelling comparisons (Hernandez-Lasheras et al 2021). These data have investigated the increase in salinity in the mixing line between LIW and WMDW between 2013 and 2019 (long-term vs. rapid change). Presentations are available in WP4 Google Drive.

The Action depends strongly on *in situ* platforms deployed regularly to acquire physical data inside the PSS (SOCIB, CNR, ILICO which includes MOOSE, SOMLIT, COAST-HF). In this context, continued occupation of the Canales Ibiza Channel and Mallorca Channel monitoring lines by glider vehicles (continuous), R/V SOCIB science cruises (seasonal) and ARGO profiler launches updated the Balearic Channels transports by water mass characterisation. With now 10 years near continuous monitoring of these transports, this will be supported by high resolution modelling discussed above. In the Italian side, HF radar network and Corsica Channel mooring are continuously running.

Observations for NW-MED were intensified during the PSS-period. The coverage of the HF radar system by CNR has been extended with the antenna installation in Celle Ligure. The radar network now includes 5 antennas along the Ligurian coast and new installations to the west are envisioned within ongoing EU projects, in order to provide a continuous surface current monitoring network shared by Italy and France. The Corsica Channel mooring has been visited for maintenance and data download every 6 months.

The analysis of drifter data sets and in situ observations of the water column in the western Mediterranean Sea (CALYPSO 2019 experiment with CNR and SOCIB) lead to the investigation of the 3D frontal dynamics in relation to wind forcing. The paper studying the convergence of marine currents, and the associated vertical velocities, has been recently published by Esposito et al (2023).

In February 2022, an Argo float was deployed in the Balearic area within the CALYPSO2022 experiment in which both CNR and SOCIB collaborated. The profiling instrument tracked the evolution of a cyclone under the effect of strong Mistral wind events. The analysis of the collected dataset (available at https://fleetmonitoring.euro-argo.eu/float/6903816) is in progress.

In April 2022, the AMBO (Autonomous Multiplatform Biophysical Observations) multiplatform experiment was performed in the La Spezia-Cinque Terre area (Italy). The activity is an example of the fruitful cooperation within the JERICO-S3 framework among the following Italian and French partners: CNR-ISMAR Lerici, ENEA, CNRS and ALSEAMAR. The aim of AMBO was to carry out a comprehensive study of the water masses exchange and overall dynamics through a multiplatform and multidisciplinary approach, focusing on the inter-comparison and combination of essential physical variables measured through different observing systems, as well on the link between circulation patterns and biochemistry, in the North-Eastern Ligurian waters (see Figure NW-MED PSS#1). The multiplatform approach of the AMBO experiment involved the combination of remote and in situ complementary observing systems spanning physical and biogeochemical parameters, such as HF radar network, glider, drifters, CTD water samplings and FerryBox. AMBO focuses on the development of methodologies to combine surface and water columns observations, the development of metrics to study vertical transport associated with frontal structures, as well as on the investigation of submesoscale frontal dynamics and associated vertical processes, which play a key role in the transport of nutrients and biological particles with significant consequences on the marine ecosystem. The experiment targeted the evolution of the coastal dynamics in terms of fronts, eddies and biogeochemical properties both at the surface and along the water column. The combination of the observations from the available in situ and remote platforms evidenced the high-resolution variability of surface features and as well the seasonal warming process of the water column down to 500m depth. The analysis and publication of the dataset is in progress.

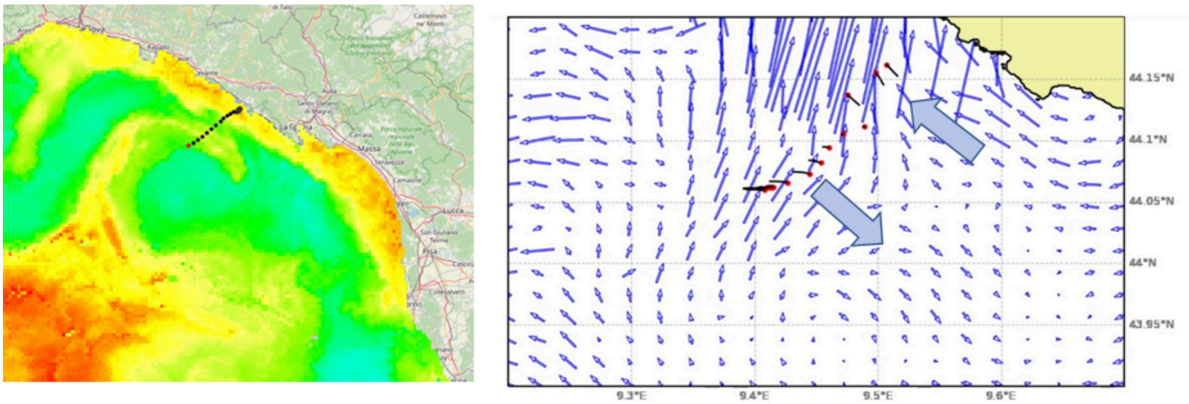


Figure NW-MED PSS#1. Left panel: Chla image from satellite and glider transect crossing a filament on an anticyclonic circulation. Right panel: sea surface currents from HF radar with drifter trajectories evidencing a strong shear area along the glider transect (from AMBO project).

For the abovementioned activities, the data flows are available by the national coastal research infrastructures through their threads or other web servers and QC routines have been used for RT data flagging of gliders and radar platforms (including links to WP5 and WP6). The best practices and standard operations have been established and applied from EURO-ARGO, EMSO and the on-going OceanGliders (EUROSEA project WP3).

NW-MED PSS #2: Impacts of river discharge to coastal ecosystems

Key Message from the Action

River input databases from Spain, France and Italy were gathered and compared in order to highlight best practices concerning the same measured parameters, sampling frequency and methodology. A demonstration action was conducted in front of the Ebro River with operational platforms to study the impact of river inputs on coastal ecosystems.

Main achievements

Real-time river input databases from Spain (Ebro-Llobregat system DANUBIUS), France (IR ILICO MOOSE) and Italy were gathered and compared in terms of acquired parameters, sampling frequency and objectives. The initial goal was to standardise all databases and take benefit of best practices if available. CNRS contacted all the partners but very few documentations on best practices are available, so CNRS has just listed the available database, parameters and strategies. DANUBIUS partner on the Spanish side is no longer active as the project is stand-by. The Ebro-Llobregat Supersite is part of the DANUBIUS system and data is available in real-time through the CHEBRO website. The Rhône-Têt system is part of the IR ILICO and data are available through the MISTRALS website. The Arno River database is not yet available in real time, but the maintenance is done by Regional Council of Toscana. Main parameters are gauging for all rivers, but water quality (temperature, conductivity, SSC, DO, pH) are not monitored at the same frequency and not all year round for the Arno River. Harmonisation of monitoring strategies are difficult due to different strategies and scientific questions to address.

The main input for this Action was the organisation of a joint campaign on the Garcia del Cid with CSIC (Spain) and CNRS (France) which occurred in September 2021 in front of the Ebro River. This campaign was dedicated as a demonstration action using operational services (buoys, satellites, glider, boat) to study the impacts of river discharge to coastal ecosystems and acquire glider ADCP data to validate/compare with HF Radar data (see Figure NW-MED PSS#2).

HF Radar measurement highlighted the high frequency spatio-temporal variability of surface currents impacted by northern wind pulses. Inertial structures have been identified and confirmed by ADCP-glider measurements which showed shear structures in the whole water column. Inertial currents could be important in the coastal area in mixing processes and resuspension of sediment in the coastal area. The combination of both glider and HF Radar is an interesting in-situ and real-time system to monitor the coastal dynamics.

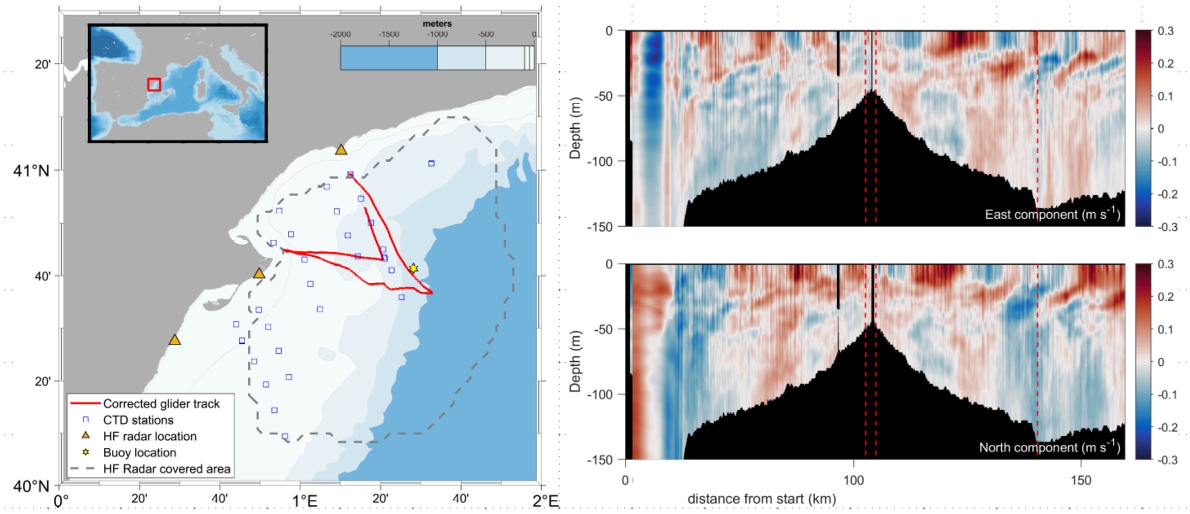


Figure NW-MED PSS#2. Left: Map of the Ebro shelf showing the glider track in red and the HF Radar measuring area. Right: East and North components of the ADCP-glider.

NW-MED PSS # 3: Extreme events affecting phytoplankton - AQUACOSM collaboration II

Key Message from the Action

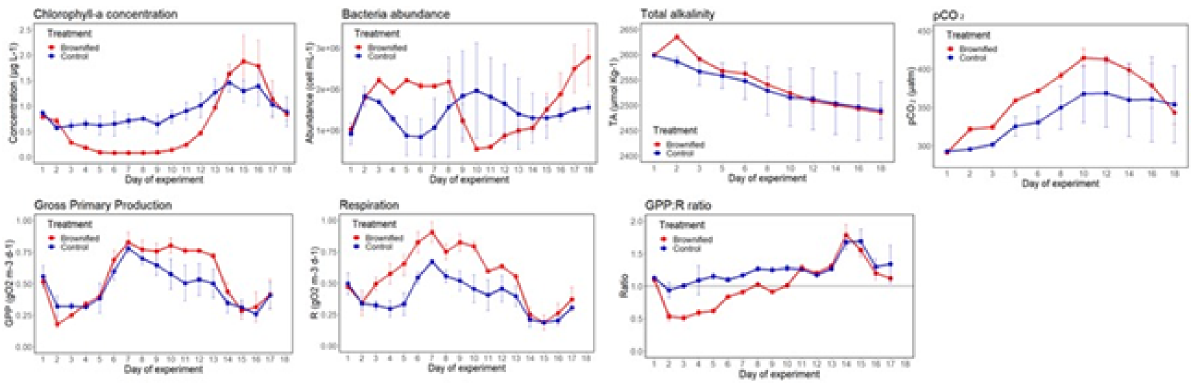
The effects of terrestrial dissolved organic matter input and temperature increase on phytoplankton community responses were investigated in 2021 in synergy between "Observations" and "Experimentations" communities from JERICO-S3 and AQUACOSM-plus. In addition, more collaborations and exchanges of knowledge were successfully established in 2022 regarding the responses of phytoplankton communities to heatwave between the NW-MED, GoF and CRETAN PSSs producing the scientific added-value to highlight the consequences of global change in the marine system.

Main achievements

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

The preliminary results of this experiment highlighted that brownified river flood inputs are not always rich in nutrients, it depends on the transition time of the river water to reach the coastal marine water. The arrival of river flood including the particulate organic matter (POM) to the coastal water engendered the light decrease which reduced the Chla concentrations and gross primary production (GPP) in the brownified treatment at the beginning of the experiment (Figure NW-MED PSS#3). Then, the POM which were suspended or settled in the mesocosms provided the material for remineralisation which can lead to increase heterotrophic marine bacterial activities and respiration rates (R) and also to change the phytoplankton community. Total alkalinity increased during the first two days of the experiment and then decreased continuously at the same level of the control treatment until the end of the experiment. The pCO_2 increased in the most part of the experiment under brownified condition and at the end of the experiment became at the similar level of the control treatment. These preliminary results show how quickly the carbonate system reacts to changes in biological processes in response to a river flood brownification and how fast and relevant can be the alkalinity removal by small calcifying molluscs in this system, providing relevant information also for the observational JERICO community.

Overall, under a river flood brownification, the GPP : R ratios decreased at the beginning of the experiment and system became heterotrophic due to increase of bacterial activities (respiration), but also those of some mixotrophic organisms which their activities can tend towards heterotrophy rather than autotrophy. Finally, after 10 days of runoff arrival to coastal water, the system became again autotrophic, similar to the control treatment underlining the important resilience of this coastal system.



Unpublished data from Couboulès et al., Soulié et al. and Cantoni et al. in preparation.
Contact: Behzad.Mostajir@umontpellier.fr

Figure NW-MED PSS# 3. In situ mesocosm experiment realised in the frame of France national Program (ANR) RESTORE and opened to Transnational Access of European project AQUACOSM-plus (May 2021). The panels show results from control mesocosms (blue) and those treated by addition of terrestrial matter (red) for Chla concentrations, bacterial abundances, total alkalinity, pCO_2 by daily sampling of mesocosm's waters, and gross primary production (GPP), respiration (R) and their ratio (GPP : R) measured continuously in high frequency (every 1 minute) using automated sensors immersed in the mesocosms. Note that values of GPP : R > 1 signify the Autotrophy and GPP : R < 1 the Heterotrophy of the system.

The results of the microcosm experimentations where the effect of brownification alone, water temperature increase alone, and both stressors together were studied and compared with the control (untreated) treatment showed that firstly, the effect of river flood brownification is more important than that of +3°C water temperature increase, and secondly, the combination of two stresses induced higher effect than each stressor alone which can underline the synergistic interactions between them.

To make a bridge between JERICO-S3 and AQUACOSM-plus communities and to establish more collaborations and exchanges of knowledge in the frame of JERICO-S3 between the two PSS of GoF and NW-MED regarding the responses of phytoplankton communities of these two contrasted climatic ecosystems to heatwaves, five scientists of our group (CNRS) from NW-MED suggested a TA project to JERICO-S3 to participate to a mesocosm experimentation to study the effects of heatwaves in Baltic Sea planktonic communities in August-September 2022. The project was accepted (see GoF PSS #8) and this participation facilitated the development of better harmonisation and best practices to deploy the sensors between these teams, interpretation of results, etc. which provided the added-value for researchers, engineers, technical staff and post-docs of two institutes participating at these two PSS of JERICO-S3.

Action included various dissemination and collaboration activities:

- Marine plankton community responses to terrestrial dissolved organic matter input realising by CNRS-MARBEC on MEDIMEER infrastructure (May 2021)
- Oral presentation by Cantoni et al (2022). The role of freshwater sources and river freshets on carbonate chemistry: differences in Arctic and Mediterranean coastal zones, in C4 Workshop, Climate Change and Carbon Cycle, 22-24 June 2022, CNR Research Area, Pisa, Italy
- Joint JERICO-S3 and AQUACOSM-plus study on Baltic Sea heatwaves (6th September 2022), including a video and dissemination through AQUACOSM-plus.

NW-MED PSS #4: Biogeochemical data and ocean colour products

Key Message from the Action

This action demonstrated our capacity to develop a BGC product in the NW-MED PSS, including Italy, France, and Spain, based on the multiplatform approach. For this, we combined in situ data, a regional 3D model and neural network for CO_2 fluxes and algorithms for improving the satellite ocean colour product of coastal waters.

Main achievements

The activities in this PSS action have been done essentially by L. Coppola (CNRS, Villefranche), C. Ulses (CNRS, Toulouse) and M. Fourrier (Sorbonne Univ. Villefranche) who developed BGC products based on a neural network and a regional model. This activity was supported by sustained in situ observations from SOCIB, CNR, ILICO-RI (MOOSE, SOMLIT, COAST-HF) which operate different platforms (Argo floats, gliders, coastal buoys and ship visits). To realise this action, we used active platforms (Argo floats, ship visits and fixed points observations) to provide real time and delayed mode data that have been qualified after adjustment with in situ reference data (T, S, O_2, pH, pCO_2, TA, TC, nutrients).

Based on these datasets we developed a new module in the 3D coupled physical-biogeochemical-chemical model SYMPHONIE ECO3M-S to simulate the DIC budget and estimate the air-sea CO_2 fluxes in the NW Mediterranean Sea (Ulses et al 2022). The model underlined the key role of the coastal zone near the Rhone river as a CO_2 sink on the annual CO_2 budget.

During the PSS period, a new neural network (NN) has been trained and validated for the NW MedSea (CANYON-MED; Fourrier et al 2020, 2022). It provides synthetic data on the carbonate system and nutrients in the basin for the entire water column. It was trained from historical sea campaigns and validated from long time series, both datasets providing input and output necessary variables. The NN was used to reconstruct pH measurements in some coastal water stations (EOL, SOLEMIO and SOLA buoys) (Figure NW-MED PSS#4). It provided synthetic data to fill the gaps in the time series and highlighted its potential for predicting CO_2 variables in these areas sensitive to climate change and anthropogenic pressure.

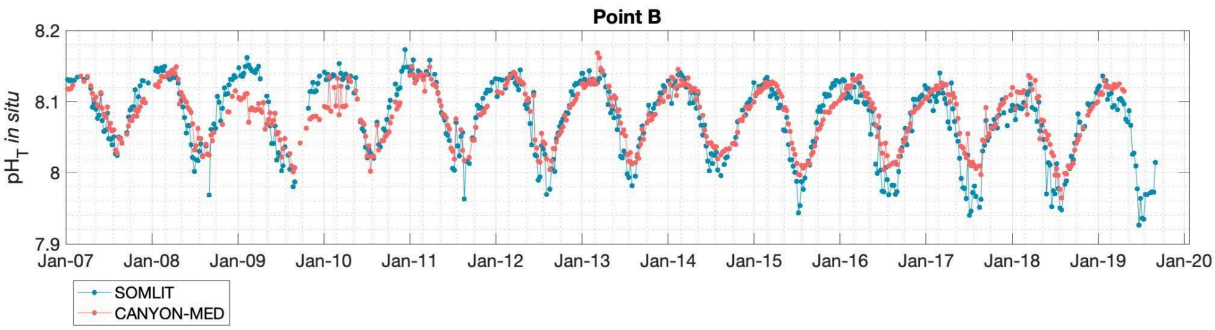


Figure NW-MED PSS#4. pH time series measured at Point B (Villefranche bay) in blue dots compared to pH predicted from CANYON-MED in red dots from 2007 to 2019

Concerning the ocean colour products for coastal waters in the PSS, a new high-resolution Sentinel 2 ocean colour product has been available on CMEMS since April 2021. In parallel, the multispectral algorithm near the Rhone has been improved to remotely detect the wide range of SPM concentrations along a river mouth from ocean satellite data (Ody et al. 2022).

NW-MED PSS #5: RI interactions

Key Message from the Action

The NW-MED is an active region in terms of RI interactions, and during the PSS period, we have demonstrated the interest of RIs in extending their observations to coastal waters, and perform testing activities, and the PSS has provided excellent support to harmonise sea operations and share data for dedicated case studies (e.g., CO_2 variability, biodiversity). Such interactions have also demonstrated our ability and motivation to ensure a complete integrated observation from the coast to the open sea for a multidisciplinary and regional observing system.

Main achievements

This Action aimed to reinforce collaborations between existing RIs (ICOS, EURO-ARGO, EMBRC, AQUACOSM) and the JERICO-S3 PSS activities in NW-MED.

The main interactions took place during the annual MOOSE-GE cruises (summer 2021 and 2022) in the PSS region, where Argo floats and biological samples were managed to extend our observation capacity and multidisciplinary approach. During such campaigns biological samples have been analysed to identify zooplankton species using imagery and genomics approaches (seawater and nets samples) which are essential for the EMBRC augmented observatories (Kiko et al. 2022). In parallel, core Argo (TS) and BGC-Argo (DO) floats have been regularly deployed and collected in this area which provide a great potential to validate and qualify new variables and sensors (pH, TA, TC, nutrients from CANYON-MED, see NW-MED PSS#4).

During the 2021-2022 period, the ATL2MED demonstration mission offered the opportunity to collaborate with ICOS through the processing, qualification, and valorisation of data in the form of a manuscript (in progress) on the study of CO_2 flux variability at the air-sea interface over the entire PSS region using surface drones (SAILDRONE) and active measurement stations in the PSS (fixed buoys and gliders). NW-MED PSS participated in the ICOS intercomparison sensor exercise in summer 2021 which aimed to test the precision of different pCO_2 sensors mounted on different platforms (coastal and open sea). A paper is under revision (Martellucci et al 2023).

The NW-MED PSS#3 group participated in scientific collaborations with AQUACOSM-plus to test the impacts of long-term trends observed in in-situ observations on phytoplankton communities (e.g. increases in T and pCO_2). To this end, several experiments have been carried out in mesocosms to highlight the mechanistic responses of different phytoplankton communities to future changes in marine systems. This type of work has brought the two consortia closer together, which could prove beneficial for the future of JERICO-RI.

Another RI interaction took place between UPC Obsea observatory as NW-MED PSS node and EMSO ERIC offered support during the EMSO physical access project TRIPLE-VTESTS at the NW-MED observatory OBSEA. CTD data collected in coastal regions are often dynamically changing which is a major impediment to derive any process related information from those data. Only longer time series and comparison with nearby coastal stations can help to detect events or trends in data. In this case the data were collected with the idea to understand to what extent mobile platforms can assist in this process, i.e. how data that are collected from vehicles sent out from the buoy station to locations nearby can contribute to a more comprehensive picture of on-going processes. The calm weather conditions that lasted for several days during the time the data had been collected allowed for a detection of a warm current, possibly an eddy, passing the OBSEA station in a distance of a few kilometres. A series of CTD profiles had been recorded during a field test campaign. The maximum water depth was at 30 m. Data is already published by Waldman et al (2023).

NW-MED PSS #6: Transnational integration

Key Message from the Action

This action promoted integration of the regional and European initiatives like MONGOOS and EU projects to disseminate results, new products and to align its strategy towards a regionally integrated observing system.

Main achievements

During the period 2021-2022, the PSS participated in two MONGOOS meetings to present the different actions and a strategy towards the future JERICO-RI in terms of multi-platforms approach and RI collaborations. In the annual workshop 2021, coastal HF radars from PdE and CO_2 activities were presented. In 2022, we presented the SWOT mission with cal/val applications in the NW-MED, and some models applied and based on PSS observations.

In parallel, some actors in NW-MED PSS have participated in the new EUROGOOS Fixed platforms task team (TT) which aims to harmonise the observations operated by the fixed buoys and moorings. In this TT, we enlightened the role played by the JERICO consortium in the coastal waters and the Best Practices developed in JERICO.

NSEA PSS #1 Harmonised observations of regional C fluxes

Key Message from the Action

In the NSEA PSS, coastal carbon observations were quality controlled, harmonised, and published on the SOCAT database, and subsequently used in estimations of regional sea-air carbon fluxes, resulting in regional air-sea flux estimates spanning most of the southern and central North Sea, and trends over the past 5 years. Further improvements are noted in the dissolved and particulate organic carbon measurements and assessments.

Main achievements

This Action builds on the investigations of the carbon cycle in the North Sea that have been ongoing for many years. PSS work expanded the activities, and connections between PSS partners were intensified.

At Hereon, the long-time dataset of partial pressure of CO_2 (pCO_2) in the North Sea collected on two ships of opportunity, the M/V Lysbris Seaways and M/V Hafnia Seaways, using membrane-based sensors has been quality controlled and published. The Lysbris Seaways QC-ed dataset for fCO_2 (2013-2020) has been ingested in the SOCAT database, v2022 (Macovei et al. 2022b), also available at Pangaea (Macovei et al. 2021c). This was a product of extensive QC, including careful comparison to available SOCAT data, even in dynamic environments like the Skagerrak (Macovei et al. 2021b). This is an ongoing initiative within the NSEA PSS, and within JERICO-S3 FerryBox activities. Parts of the QC-ed datasets were used in North Sea air-sea flux studies, highlighting the recent air-sea flux changes in the central and southern North Sea and that the rate of change in surface water CO_2 exceeded the rate of change in the atmosphere (Macovei et al. 2021a). This study continues the work of data QA/QC, analysis, and integration of the FerryBox JERICO-based carbon-related datasets in regional and global datasets like SOCAT and contributes to NSEA PSS estimates of regional carbon fluxes.

Surface pCO_2 data QC was extended to the newest Hereon FerryBox line, the M/V Magnolia Seaways, installed in 2019. Carbon sequestration, primary production and hydrodynamics were studied during two consecutive fall seasons in 2019 and 2020. Mesoscale advective and late fall bloom events significantly affected the North Sea surface water carbon uptake capacity (Macovei et al. 2022a, Figure NSEA PSS#1), and this study prompted further analysis on spring-neap tidal influence on lateral C fluxes in 2021 and 2022 (Macovei et al. 2023, Macovei et al in prep).

The published pCO_2 dataset has been shared between Hereon and Deltares through the European FerryBox database, to integrate these data in modelling efforts within NSEA PSS#5 and in a visualisation platform. Additional collaboration between AWI and Hereon has been identified on studying pCO_2 variability in the German Bight region.

Installation of carbonate system sensors by NIVA on the ship Norrøna (Denmark to Iceland, NorSOOP) was delayed due to covid. However, NIVA operated a FerryBox line between Oslo-Kiel (incl. Skagerrak IRS, WP3) providing relevant input data for the NSEA PSS. Comparisons between water column and FerryBox measurements for the Norwegian coast (including Skagerrak) have been made focusing on organic carbon (Frigstad et al. 2020) and a paper including inorganic carbon (CT/AT, pCO2, pH) is in progress.

In 2023, Cuxhaven Stationary FerryBox became part of ICOS-D network, after a 5-year trial period was granted in 2022 as a pilot estuarine station. This will contribute to the understanding of the land-sea carbon fluxes in this region, since the Elbe estuary has undergone tremendous changes since the 1980s, which have significantly influenced its carbonate system (Rewrie et al. 2023).

At Hereon, the Tesperhude Research station in Germany, with FerryBox and carbonate system sensors is being deployed by the end of June 2022 in the Elbe River, above

Geesthacht weir. This provides a direct connection to Elbe-North Sea Supersite in DANUBIUS-RI, within which the installation of the Tesperhude station is coordinated.

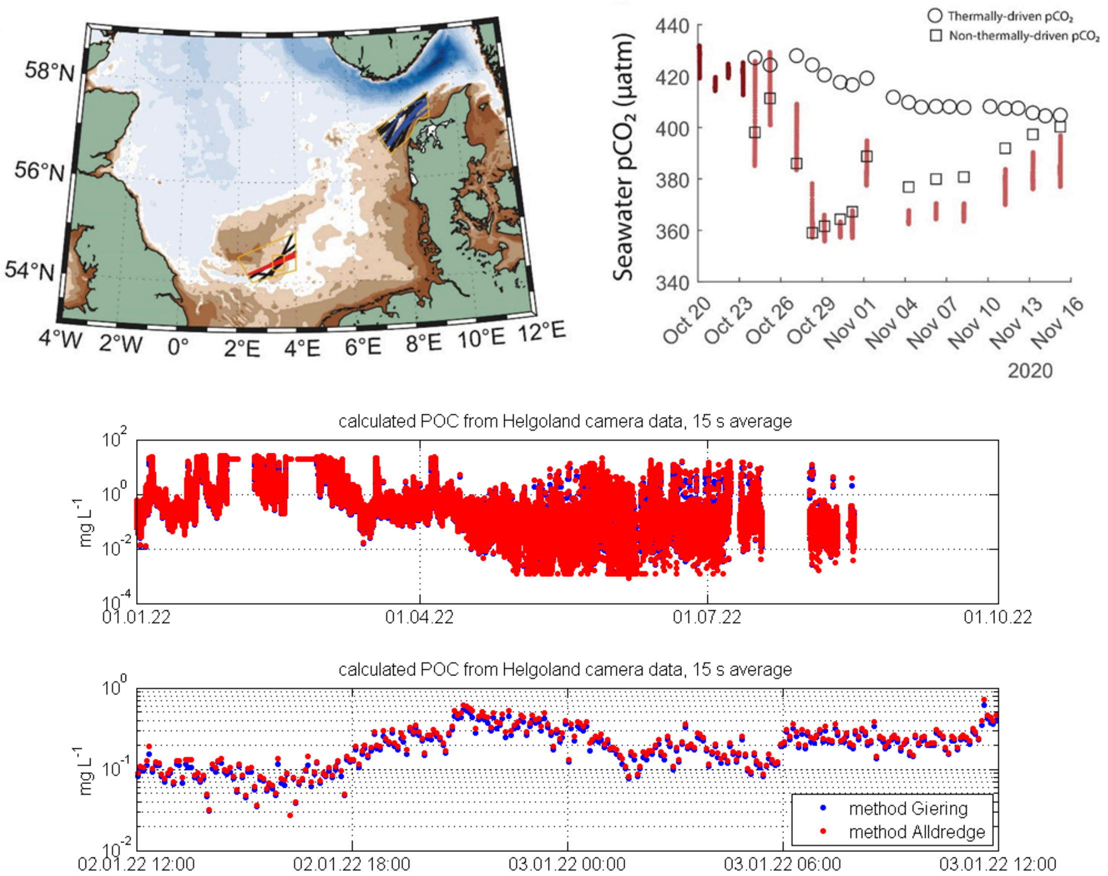


Figure NSEA PSS#1. (Up) Seawater pCO_2 drawdown from a late-fall mesoscale event. (Up Left panel) Past tracks of Lysbris Seaways in NS PSS (black) in the region of the advectively driven low pCO_2 event (blue) and the biologically driven low pCO_2 event in fall 2020 (red) measured on the M/V Magnolia Seaways. (Up Right panel) Measured pCO_2 before and after the Central North Sea bloom, initiated on October 25, 2020 (the two shades of red) and expected average pCO_2 values, calculated using the pre-event pCO_2 measurements and only applying the thermodynamic effect of changing water temperature, as well as the non-thermal component. (Middle) Example segments of the time series data from the Helgoland Underwater Observatory of POC concentrations calculated from images; from January to September 2022, as well as of a random 24-hour period (bottom).

Imaging data, collected from the profiling lander installed at the Helgoland Underwater Observatory (Hereon and AWI) in the south-eastern North Sea from Jun 2021 to Sep 2022, has successfully been used to calculate particulate organic carbon (POC) concentrations. Due to the continuous and temporally highly resolved nature of the imaging data set, this represents an unparalleled opportunity to investigate POC dynamics from seasonal to minute-by-minute time scales (see Figure NSEA PSS#1).

NSEA PSS partners, led by Hereon and NIVA have taken steps to develop a SOP for underway pCO2 measurements with membrane-based sensors including data correction. An ongoing collaboration with ICOS and industry (4H-Jena Engineering) has been led by Hereon for intercomparison between membrane based pCO_2 sensors and traditional General Oceanics high precision CO_2 gas-equilibrator system aboard a container vessel, which crosses regions of the North Sea. The first experiment was done in 2020, and preliminary results were presented at the 2022 ICOS conference (Macovei et al. 2022c). At Hereon, a TA project was done in fall 2023, where researchers from the Bulgarian Academy of Science visited Cuxhaven Station and learned about FerryBox deployment, in-situ carbonate system and nutrient measurements.

NSEA/CHANNEL PSS #2 Riverine input to the North Sea

Key Message from the Action

Providing harmonised data for riverine input to the North Sea and Channel, useful for scientific questions (e.g., long-term land-use change vs extreme event effects) or reporting tasks (monthly vs annual), remains challenging due to spatio-temporally varying measurement strategies and data FAIRness, as well as observational gaps and robust general-use gap-filling algorithms. Improvements can be built on existing methods to be tested and shared at the level of EC and NSEA PSSs; for pan-European coastal regions future collaboration between JERICO and DANUBIUS will be helpful.

Main achievements

In this Action, Hereon, Deltares, AWI, NIVA and IFREMER identified some general challenges for calculating riverine substance input into the NSEA/CHANNEL PSS (and coastal waters in general). There is a lack of data FAIRness. Finding data is generally challenging because it is distributed over a variety of sources, many of which are not in English. Water flow and constituents are often measured at separate locations in one river. Correction factors exist to account for this discrepancy for some but not all rivers. Discrepancies also exist in the temporal resolution, with discharge mostly recorded at sub-daily frequency but water quality measurements conducted fortnightly to monthly.

Load calculations require concentration and flow values to correspond, since this is often not the case, but higher frequency flow measurements are often available from nearby locations, the geographical shift must be accounted for. IFREMER and Hereon developed, for the Seine (France) and Elbe (Germany) rivers, a simple method of calculating correction factors. The slope of a linear regression predicts the flow at a station with roughly fortnightly measurements from daily mean values measurement at a downstream station (e.g., in the Elbe river, the factor is 0.915). The method provides a good representation of the flow at the upstream water quality station; the r^2 is 0.98 and the intercept is not statistically distinguishable from zero.

We tested three gap filling methods because daily values of water constituents are required by some scientific tasks as well as several monthly or annual load calculation methods:

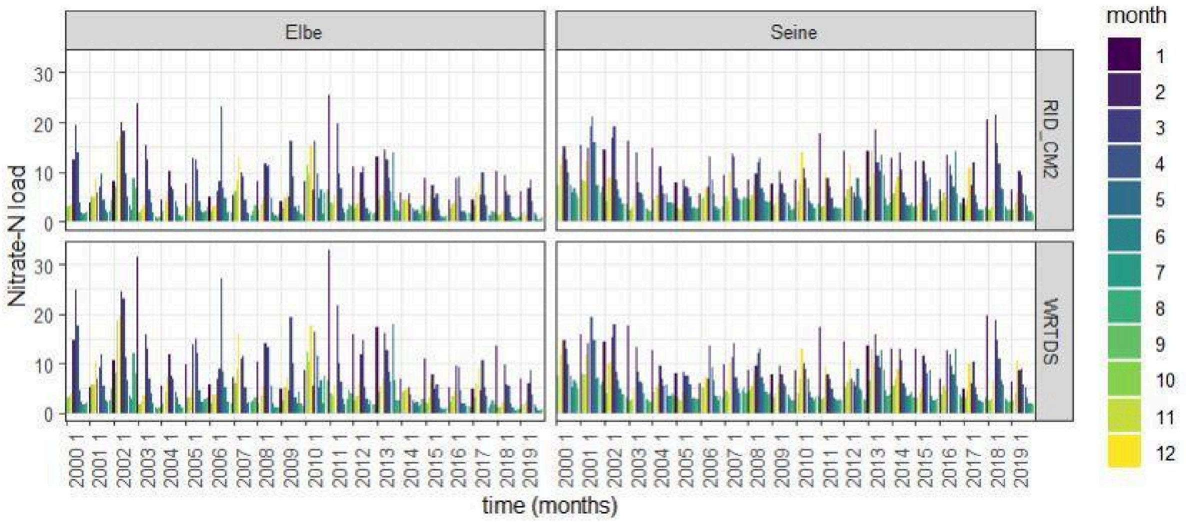
- Linear interpolation of monthly or fortnightly concentration values to daily time series
- A method available in the R CRAN package "TTAinterfaceTrendAnalysis" calculates the median of the values at a time scale (e.g., weeks or fortnights) to replace all missing values at the same time scales among years.
- A fill value based on the constituent's seasonality and short-term variability.

A comparison of simple linear and spline interpolation of nitrate concentrations in the Elbe and Seine rivers with the gap filling method based on seasonality and leading values show that:

- The inclusion of seasonality in the calculation smoothes the results by moving values towards the climatology. Furthermore, either new (i.e., counterfactual) values must be calculated for times when sample values exist, or the transition between measured and filled values presents an unrealistic pattern.
- A better fitting climatology function might slightly improve the results, but the principal bias remains.
- The smoothing method is problematic especially for studies concerning (extreme) events.
- A simple linear interpolation appears to be most faithful to the original data and best preserves the value and position (i.e., date) of the turning points.

We use the Seine and Elbe data to compare loads calculated via OSPAR RID (RTREND) and statistical modelling algorithm Weighted Regressions on Time, Discharge, and Season (WRTDS, in the "EGRET" R package). OSPAR RID equations account for low frequency measurements by adapting the calculation method to the number of annual values. The WRTDS flux calculation method models concentration as a function of trend, discharge, and season, plus a random component.

The figure NSEA/CHANNEL PSS#2 shows monthly nitrate loads from the Seine and Elbe rivers, calculated with daily flow values and roughly fortnightly nitrate concentration values using the OSPAR RID method and WRTDS method (Seine: *ln*(RMSE) = 0.133, $r^2_{ln(conc)}$ = 0.481, $r^2_{ln(flux)}$ = 0.959, SE = 13.4%; Elbe: *ln*(RMSE) = 0.226, $r^2_{ln(conc)}$ = 0.777, $r^2_{ln(flux)}$ = 0.946, SE = 22.9%).



NSEA/CHANNEL PSS#2: Monthly nitrate-nitrogen loads from the Elbe and Seine rivers as calculated via WRTDS and OSPAR RID approaches.

Compared to "raw" values of nitrate fluxes calculated with the RID CM2 methods, filling methods give good results and allow calculating monthly fluxes with more data. Annual nitrate loads calculated with the different methods are similar ($r^2 > 0.9$ among methods) and show strong differences from "raw" data load calculation (i.e., without a gap-filling method) for years in which several months are not monitored.

Our results pertain to large rivers with high frequency monitoring. To go further, these methods must be applied on medium and small rivers with less frequent monitoring. Further collaboration among the JERICO partners and inclusion of DANUBIUS partners will enable testing methods on a larger variety of river-sea systems and provide better, more generalizable, conclusions and a more robust dataset.

The NSEA/CHANNEL PSS #2 initially included mainly partners from the NSEA part of this twin PSS. The inclusion of the Channel part expanded our integration activities. Since the project started, we have held six meetings of the NSEA PSS core group. First meetings were held to discuss the integration of an existing, frequently updated European River Loads Database curated by Sonja van Leeuwen (NIOZ) with JERICO-RI. Preliminary plans were made to contribute to the Database and host it with JERICO-RI.

NSEA/CHANNEL PSS #3 Harmonised observations of plankton biomass, diversity, and productivity dynamics

Key Message from the Action

Transfer of knowledge and harmonisation of competences was effective, and the best practices for plankton imagery and fluorometry observations were further developed. Participation in joint cruises, workshops on data treatments, exchange of operational practices and tests of analytical tools were the main elements for knowledge transfer.

Main achievements

Integrated phytoplankton observations (incl. flow cytometry, imaging, multispectral and variable fluorometry) were carried out on various platforms (FerryBox, cruises, monitoring networks, autonomous fixed stations/moorings). Changes in functional and taxonomic diversity and photosynthetic parameters were addressed across the PSS region. Through collaborations between partners and joint research effort, the large-scale observations allowed for regional spatial variability to be investigated using a complementary set of molecular, chemical, and imaging tools (Aubert et al. 2022).

High frequency phytoplankton observations were conducted during various cruises:

- 2020-21 R/V Endeavour by CEFAS in Western English Channel and Celtic Seas. Flow cytometry data confirmed that nanophytoplankton and microphytoplankton were responsible for the blooms at the edge of the Celtic Sea.
- 2020 and 2022 R/V Thalassa by CNRS-LOG and IFREMER in the English Channel and North Sea. Spatial distribution of phytoplankton was studied at high resolution by coupling an automated flow cytometer (CytoSense), a multispectral fluorometer and a Fast Repetition Rate Fluorometer (FRRf). Cruise in 2020 included collaboration with GoF PSS using ImagingFlowCytobot. The inter-comparison of the techniques guided the further deployments.
- 2022 RV Simon Stevin by VLIZ and CNRS-LOG in the North Sea and English Channel. The aim was to compare the protocols of the FlowCAM and the automated flow cytometer. Metadata of the cruise can be found on the IMIS platform of VLIZ. The biological data will be available via the Marine Data Archive (vliz.be) and LifeWatch Data Explorer. A meeting for workflows of data processing and analysis and data sharing was held at CNRS LOG in Aug 2022. Photosynthetic parameters from FRRf *in situ* profiler (natural light) were compared to those recorded on board (artificial light).
- 2022 cruises (n=3) by HEREON in the southern North Sea. Results suggest an important role of the dinoflagellate *Noctiluca scintillans* in the shift from diatoms to dinoflagellate-dominated waters. The CPICS images were analysed with machine learning techniques and revealed *in situ* feeding strategies of *N. scintillans,* their prey types, and interactions with other organisms, promoting the understanding the functional role and dynamics of this species under future climate conditions.

Macovei et al. (2022a) showed that high-frequency observations can reveal the impact of mesoscale phytoplankton blooms on carbon sequestration (see PSS#1). We used FerryBox measurements of Chla fluorescence, pCO2, pH, salinity and temperature to capture these mesoscale dynamics during a late phytoplankton bloom (Oct-Nov 2021). Bloom was not visible via satellite imagery at this time of year, but was found to have a significant impact on the carbon sequestration, compared to the trend observed over the past 5 years.

Long-term observations included:

- Automated sensors (CytoSense/Sub, Fluoroprobe) deployed in French waters from the Bay of Somme (E. Channel) to Dunkerque (North Sea) as a complement to local (SRN IFREMER) and national (REPHY, PhytOBS, SOMLIT) observing networks of the French Research Infrastructure for Coastal and Littoral Observation (ILICO).

- A coastal-offshore transect (Radiale Baie Saint Jean-DYPHYRAD) was sampled at higher than usual resolution and combined with reference methods (pigments, microscopic counts), automated imaging systems, CytoSense, and *in vivo* fluorometers. Drivers of phytoplankton outbursts and community occurrence and changes at different scales were studied in relation to changes in marine ecosystem state.
- The interannual variability and phenology of blooms (incl. *Phaeocystis globosa)* were explored by combining reference and automated approaches (Z. Hubert MSc thesis 2021, PhD ongoing). Photosynthetic production (FRRf) was studied along the coastal gradient. Seasonality of photosynthetic production was compared using two main algorithms. Different successions of five main functional phytoplankton groups were followed along the coastal-offshore gradient and interannual trends were explored.

High Frequency fixed autonomous stations and moorings included:

- The smart multisensor observation platform Costof2 was installed in the [MAREL Carnot platform] (Halawi Ghosn et al. 2023), representing the core of the EMSO Generic Instrumentation Module (EGIM). Additional measurements with a spectral fluorometer and a flow cytometer were done in spring 2021 and 2022. Spring bloom dynamics of *P. globosa* and diatoms were studied with a CytoSub in 2021 & 2022, to identify variability at different scales (K. Robache MSc thesis). The deployments are linked to the tests of the cEGIM station in the bay of Seine (WP7) with an on-board intelligent system controlling data acquisition depending on the environmental context.
- The Helmholtz Underwater Observatory (HUWO) in the North Sea has been running since 2020 (affiliated with the COSYNA) by Hereon and AWI. The HUWO comprises a central node with several permanently submerged landers, to which environmental measuring equipment (CTD, turbidity, Chla, oxygen, ADCP) are attached. The HUWO's profiling platform contains CPICS alongside a CTD. Plankton and particle imaging data were collected from June 2021 to August 2022, at a high temporal resolution.

Automation in data treatment and analysis included:

To extract relevant information from complex data sets, IFREMER, ULCO & LISIC improved the management of large data matrices (link to WP6). Data validation and QC tools were proposed, as well as adaptations to analytical methods for completion, regularisation, clustering and learning of these series to optimally extract information and thus predict future events (link to WP11). A combination of multivariate, multi-source and multi-scale approaches were set to account for the complexity of interactions among environmental parameters and pressure/impact effects. IFREMER developed an automated analysis tool for plankton image recognition that can be used during cruises in near real time, combining image processing techniques and deep learning algorithms. The tool was tested on FlowCam data but could be implemented on other devices. A GUI was developed to update the graphical outputs to visualise the results in near real time (Wacquet & Lefebvre, 2022). The first-year survey was analysed in the frame of F. Verhaeghe's engineer thesis.

To strengthen the collaboration within PSS, the activities reinforced the dynamics of data FAIRisation, improving data flows and the associated development of data pre-processing and processing tools. New collaborations and projects were carried out for observations in wind parks and monitoring and prediction of HABs by IA/ML.

Meetings of the Action included:

- Workshop on "Data Mining for Integrated Observation Systems", 2 sessions: 18 Oct and 8-9 Dec 2021, organised by IFREMER and ULCO/LISIC.
- JERICO Joint PSS/IRS meeting, 26-27 Sep 2022, HEREON, Geesthacht.
- Series of workshops (with WP5 and WP6) for best practices in using automated techniques for monitoring phytoplankton's functional and taxonomic diversity

NSEA/CHANNEL PSS #4 Products for Eutrophication Status Assessment.

Key Message from the Action

Based on expertise gained through implementation of research activities from NSEA/CHANNEL PSS actions #2, #3 and #5, and from optimised monitoring programs and data flows, regional data from the PSS was combined. This data was used for developing and demonstrating new products on impacts of eutrophication that contribute to regional ecosystem assessments and reporting.

Main achievements

All NSEA/CHANNEL PSS partners contributed to the data flow, providing information for models and OC products calibration, and making available results (combining in situ, modelling and OC data) and expertise to eutrophication assessments needs (MSFD, OSPAR).

Partners have developed procedures (up to specific tools) to overlay monitoring data that are in ICES databases (and used in the OSPAR eutrophication tool, COMPEAT) with other datasets, with a view to submitting more datasets to be included in OSPAR eutrophication assessments and streamlining data flows. The work in this Action shows where JERICO-RI can contribute to filling OSPAR data gaps and what additional activities need to be done (such as quality control and calibration) to make JERICO-RI data useful for OSPAR and the MSFD. Datasets used in the Action included those of SRN, REPHY, and REPHYTOX.

IFREMER and Deltares provided model results on primary production to the OSPAR working group on ecological modelling: ICG-EMO (Van Leeuwen et al., 2023). The Deltares model has been validated with available observations of primary production from PML. This showed that primary production in the current model version is still overestimated. The IFREMER model has been validated with data from its own monitoring programs (including those optimised within the CHANNEL PSS). Main results in the EC PSS area are relevant. Combining model results and OC products (Chla), IFREMER was able to define nutrient reduction scenarios for several rivers for the French part of the CHANNEL PSS.

The other significant achievements were related to (i) the tests of the reliability of satellite and modelling-derived products integration in the eutrophication assessment procedure directly (as data to be process) or indirectly (as high-resolution data to support assessment based on low resolution data), (ii) the development and test various monitoring scenarios and the impact on eutrophication assessments, (iii) the development of numerical methodologies/tools to optimise the processing (incl. QA/QC procedures) of high resolution datasets from buoys and FerryBoxes (linked to WP 11 on Virtual Access).

During the workshop on NSEA/CHANNEL PSS in Geesthacht in September 2022, Deltares and RWS organised a session jointly for JERICO-S3 task 4.3.3 and task 2.5 to collect information on potential contributions of JERICO observations to biodiversity and eutrophication assessments. To this end an overview was first presented on indicators used in the assessment and the current observation data that are used for the assessment. Next, we discussed in groups on novel observations methods by JERICO partners that can enhance data availability in future assessments. These included:

- for pelagic food web indicators on phyto- and zooplankton composition in groups and size classes from: imaging flow-cytometry, spectral light absorption and in-vivo fluorescence.
- for food web indicators: primary production from continuous oxygen or pCO2 recording, FRRF and PhytoPAM.
- for eutrophication indicators: Chla vertical profiles, oxygen near the seafloor.
- for ocean acidification: measurements of at least two of the four measurable variables representing the carbonate system: TA, DIC, pH and pCO_2.

- for litter: litter in the water column and on the seafloor.
- measurements of ambient underwater noise.

It was concluded that variables used in the NSEA/CHANNEL PSS mainly are related to the first four bullets/themes. From the user perspective it is important that data are quality controlled, comparable/coherent across data providers and accessible, including the relevant metadata on methods used, position, time etc. A good example is adding measured pCO2 data to the SOCAT database, which indeed has been used for the OSPAR Ocean Acidification assessment.

All these results and expertise were combined with other contributions from the OSPAR and MSFD communities, from local to EU levels, contributing to the possibility of proposing a complete and quantitative eutrophication assessment in the Channel area as early as 2022 (Lefebvre and Devreker, 2022). The overall assessment of the eutrophication status at the OSPAR (NE Atlantic) scale has recently been published.

CHANNEL PSS #5 Intercomparison of phytoplankton distribution using data integration.

Key Message from the Action

In-situ observation data from different portals and PSS partners have been collated in one model validation database and their FAIRness and spatial and temporal resolution has been evaluated. Models by Deltares and IFREMER have been applied for estimation of pre-eutrophic Chla and nutrient concentrations in support of threshold definition for OSPAR and MSFD.

Main achievements

Available in-situ data have been aggregated from publicly accessible data portals with FAIR data: EMODNET, SOCAT and COSYNA. These data have been complemented with additional data from JERICO-S3 project partners (Hereon, VLIZ, RWS, CNRS, CEFAS, IMR, IFREMER, SMHI, RBINS) and other organisations (PML, NLWKN, MSS, NIOZ, Denmark). These data include FerryBox transect data, fixed location sensor data and sample-based data. All data have been put in the same BODC format, duplicates and obvious mistakes have been removed and all observations have been aggregated at the level of relevant model variables and nearby observations have been aggregated on a grid.

In the process of collating the data for the database it became clear that there are many more observations in coastal waters than are available through EMODNET. However, a lot of work is required in the quality control, cleaning and formatting of that data. Funding and personnel time is often lacking to do this work. It also became clear that a joint procedure is lacking and much needed for validation and calibration of fluorescence data.

Comparison of sample-based data of SPM and Chla with time series of turbidity and fluorescence sensors in Belgian coastal waters showed that sample-based data insufficiently capture natural variability and extremes (Fettweiss et al., 2023).

The current Deltares biogeochemical model (DCSM-FM) has been extended to include inorganic carbon, so the carbon cycle can be modelled completely, in addition to the nutrient cycles. Two additional model variables were added: TIC and alkalinity. The chemical equilibrium of carbon fractions was calculated with the existing module for pH simulation, based on Roy et al. (1993). The model produced output for pH and pCO_2 concentrations that could be validated with observations from FerryBoxes, available from Hereon (Macovei et al., 2022b) and the SOCAT database maintained by ICOS-RI. This enables a more elaborate validation of the simulated primary production and remineralisation processes involved in the N, P and C cycles.

The model validation results for winter mean DIN and DIP and growing season mean Chla showed that the nutrient concentrations were simulated well, but Chla was overestimated (Figure NSEA/CHANNEL PSS#5). Further validation with pCO_2, pH and primary production data also showed that primary production rates were overestimated, possibly due to too fast remineralisation of nutrients in summer.

Deltares and IFREMER used their models in an ensemble modelling exercise initiated by OSPARs working group on ecological modelling, on request of OSPARs working group for eutrophication. This supported the definition of coherent threshold values for eutrophication assessments for OSPAR and MSFD. Satellite data were used both for the validation of the models, as input on suspended matter concentrations and for calculating weighted averages from the model ensemble. A paper was published showing how an ensemble of models can be used to quantify and reduce the uncertainty in modelling results (van Leeuwen et al., 2023).

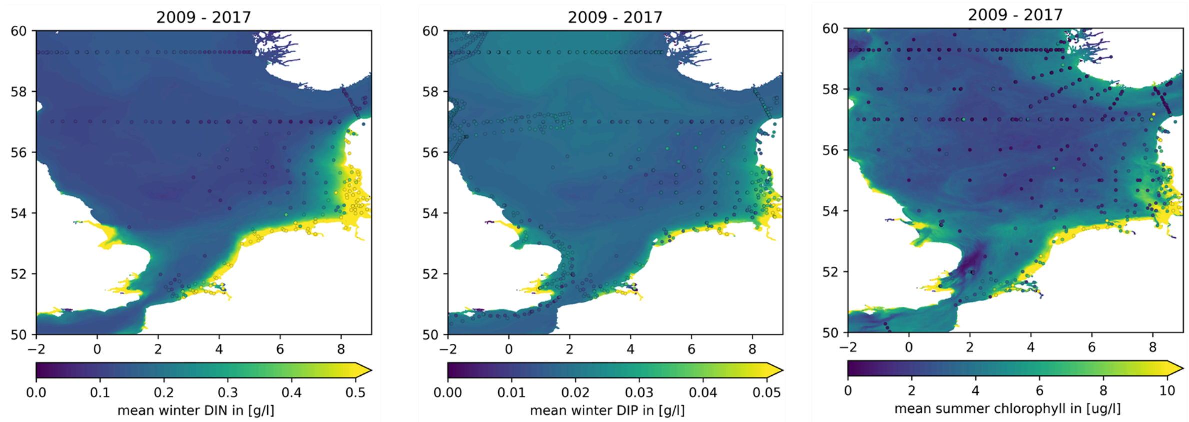


Figure NSEA/CHANNEL PSS#5. Validation results comparing season mean nutrient and Chla concentrations for 2009 - 2017 of the Deltares model (background colour) with corresponding in-situ observations from the NWDM database (circles).

Results were presented in a webinar for JERICO-S3 partners in the NSEA/CHANNEL PSS (in collaboration with Action #7). The model also includes the Bay of Biscay, the Celtic Sea and Irish coastal waters and has been used for these areas as part of the OSPAR ensemble modelling effort.

NSEA/CHANNEL PSS #6 Identification of Observational Gaps.

Key Message from the Action

The overall scientific aims of the NSEA/CHANNEL PSS were related to the refinement of the regional carbon budget including terrestrial inputs, coastal carbon cycling, and biological carbon fluxes as well as, to assess regional eutrophication status, phytoplankton biodiversity and productivity, and their modulations. Jointly, the twin PSSs have identified gaps in observations and interactions that hamper regional studies of carbon cycle and eutrophication.

Main achievements

The Action analysed which are the key structural and institutional challenges hampering the optimal use of resources and contributing to non-closure of observational gaps.

Some issues arose from a lack of in-person interaction due to the pandemic situation (2020-2022) with partners outside the JERICO-S3 consortium with Research Infrastructure (e-Infrastructure, Observation Infrastructure). The efforts to establish contacts need to be intensified to broaden our approach and collaboration/cooperation. The scientific community needs to rely more on what already exists and benefit from the support provided by RIs, databases, and data distribution portals. Without this optimization, many resources are allocated to tasks without much added value. Students and some researchers are led, due to lack of knowledge or advice, to develop products and services that already exist. Consequently, the evolution of scientific knowledge does not evolve in proportion to that of the means of observation, banking, and calculations. Based on joint NSEA/CHANNEL PSS workshops and on specific local workshops during which the participants were asked to identify the activities to be stopped, created, developed, or continued, we can propose the following conclusions/recommendations:

- Stop & Think: Stop to reduce the complexity of what we study with the argument that the topic is not answering a societal need (reductionist approach). We need to take some risks, propose new approaches and new concepts even if it is not "bankable".
- Optimise observation programs in transboundary areas by sharing resources, develop joint planning activities.
- Increase observation in transitional environments (estuaries and harbours).
- Rethink observation programs taking into account recent advances in fundamental knowledge and technological developments, new scientific questions (with adaptation of spatial and temporal coverages) and the (real) needs of society, as defined by stakeholder dialogues.
- Continue to develop biological and physico-chemical sensors, including the development of harmonised analysis procedures (including metrology), Data Management Plans and the implementation of intercalibration exercises.
- Improve FAIRness.
- Use the existing infrastructure before considering any development. This is valid for sensors, and methods as well as for data banking, data dissemination and use, product and service development.
- Clarify access to observation data sources from local, national, and European levels.
- Propose methods for integrating data from different sources and covering different spatial and temporal scales (in situ/satellite/modelling).

For specific topics such as modelling, the conclusions are as follows:

- Integrate new processes and new parameterisations.
- Propose common forcing/reference conditions.
- Promote the ensemble modelling approach.
- Continue to use modelling in environmental assessments (definition of thresholds, creation of evolution scenarios, remediation proposals (e.g., calculation of percentage

reduction in nutrient inputs) and improve the acceptability of the results by stakeholders (e.g., by including uncertainty estimates linked to the modelling results).

For specific topics such as phytoplankton observation, the conclusions are as follows:

- Stop promoting a «one-fit-for-all» approach: as the environment is complex; we need to combine methodologies, scales, disciplines and approaches.
- Stop assessing phytoplankton biomass, abundance, diversity, and primary production on the basis of data that are too sparse, not representative for contrasted environmental conditions and not comparable (i.e., there is a need to solve the Fluorescence vs. Chla issue).
- Strengthen observation via "omics" approaches.
- Continue long-term surveys based on well-designed spatial and temporal strategies to integrate most of the processes involved in bloom dynamics.
- Consider satellite products to fill the *in-situ* observation gaps and accordingly consider *in-situ* data to validate satellite data (matchup), use all of those to calibrate models.
- Add more *in-situ* measurements and experimental approaches to handle physiology of phytoplankton in order to better estimate primary production and consequently carbon fluxes.

It is obvious that the JERICO-RI project has created more links between the partners involved in Channel and North Sea Observation. Beyond a general sharing of experiences and expertise, the involvement of the partners of the two PSS has evolved. Thus, Action #2 dedicated to nutrient inputs and only concerning the NSEA PSS has been extended to the EC PSS area. This approach is in line with the will to work at the scale of the land-sea continuum, but also at the scale of the sea-sea continuum (transport and advection of water masses, transboundary aspect). This continuum approach is one of the major obstacles to coastal observation. Although efforts are being made and projects aim to improve multidisciplinary and trans-disciplinary between marine and land-based specialists, research along this continuum is still very fragmented.

NSEA/CHANNEL PSS #7 Cross-regional communication between PSSs (North Sea and Channel).

Key Message from the Action

To harmonise observation and generate data and products, it is essential to communicate between the PSSs by establishing collaborations and exchanging skills and experience. The actions mentioned were very successful and hopefully will continue under the JERICO-RI framework.

Main achievements

Cross-regional collaboration and communication have been realised at four different levels:

1) Practical arrangements in monitoring surveys where partners have shared facilities and implemented new technologies for studying phytoplankton. For example, CNRS LOG has joined the annual survey in 2022 organised by the VLIZ for monitoring the Belgian coast and across the English Channel (Thames Estuary), adding to the survey the observation of variables to estimate the primary production.

2) Joint workshops and webinars have taken place to discuss between partners their approaches, tools, and results. For example, a two-day NSEA/EC/KASKEN workshop at Hereon (Germany) was organised on the 26-27 September 2022. Updates were provided from each region on ongoing work, and synergies and potential collaborations were identified. Discussions were held regarding the work towards milestones and deliverables. Wider discussions also included the needs of data for OSPAR assessments and how JERICO infrastructure could provide the data in JERICO PSS and IRS sites. A webinar was led by Deltares to present the work related to Action #5 to the partners of the PSSs (February 2022): "*Introduction to the NWDM database and model application*". The objectives of the webinar were to present the database established by Deltares and showed how data from the different PSSs partners are important for implementing a model for assessing the water quality assessment (WFD and MSFD) and more precisely eutrophication. Fifteen persons across PSSs were participating in the webinar.

3) Sharing data and collaboration for harmonising the collection of data as well as the data processing. For example, IFREMER and HEREON have organised several meetings to collaborate and share experience for harmonising the processing of nutrient fluxes (Action #2). CEFAS and IFREMER have shared integration tools, data processing from FerryBox, CTD and earth observation images for describing the status of the pelagic habitat. Partners from the NSEA PSS (Hereon) have shared quality control for pCO_2, temperature and salinity datasets from ships of opportunity with Deltares. CEFAS and CNRS LOG have agreed to share flow cytometry data on phytoplankton diversity and physical/biogeochemical data from the English Channel to map the phytoplankton diversity based on functional types. They have also agreed about performing joint analyses through automated analytical tools.

4) Having strategic discussions on future observing structures. For example, further discussions regarding the collection of data and samples from a ship of opportunity (The Connector) sailing across the North Sea have led NIVA, RWS, Deltares and CEFAS to establish a close collaboration for sharing maintenance responsibilities as well as the information for assessment purposes.

NSEA/CHANNEL PSS #8 Support to EU directives and ecosystem management.

Key Message from the Action

OSPAR has shown in its recent assessments for the Quality Status Report 2023 that innovative ocean observation techniques are useful to fill data gaps. Potential matches of OSPAR data needs and datasets provided by the JERICO-S3 community have been identified.

Main achievements

The focus of this Action was to investigate the potential use of novel measurements by the NSEA/CHANNEL PSSs in the OSPAR assessments for the OSPAR Quality Status Report 2023 (QSR 2023). QSR 2023 provided a basis for the MSFD 2024 reporting.

Relevant for JERICO-RI, in their recent assessments for the QSR 2023 OSPAR has embraced various novel data collection techniques for eutrophication, pelagic habitats, food web and ocean acidification assessments. These ideally would provide long time series (10 years or more), be quality controlled, comparable/coherent between data providers and methods (for the same variable) and accessible in databases that include metadata (see also Action #6). Furthermore, it takes time for OSPAR experts to fully acknowledge benefits of new data sets. Since the production of the QSR 2023 assessments took place in parallel with the JERICO-S3 project, it was not possible to transfer the newly produced PSS data into the OSPAR assessments. However, existing databases that also host PSS data were used, such as SOCAT.

From the eutrophication assessment a data gap analysis in eutrophication assessment areas that partly or fully overlap with the Channel Region was presented to the PSS team. This gap analysis and data gaps related to other themes were subsequently presented in the Geesthacht workshop (26-27 September 2022) and a discussion was held whether (future) data products could solve these data gaps. A number of potential matches were identified (see Action #4). It was concluded that further steps towards actual use of data measured using novel techniques in future assessments would require more interaction at the technical level between the data providers and the experts involved in the OSPAR assessments.

The QSR assessments are finished, and the next step is an inventory and evaluation of the knowledge gaps, including data needs. This will lead to an update of the OSPAR science agenda in 2024. Data providers can access the OSPAR science agenda.

The OSPAR Hazardous Substances and Eutrophication Committee has tasked the Dutch and French delegations to strengthen the links between expert communities and the relationships between OSPAR and the JERICO-RI community in 2023.

NSEA/CHANNEL PSS #9 Interaction with other RIs on ecosystem studies, eutrophication, coastal management, and carbon fluxes.

Key Message from the Action

Contacts with other RIs have been deepened on local as well as on management levels and especially the intense discussion of collaboration measures continued and culminated in close collaboration with DANUBIUS-RI through a shared station and with ICOS-ERIC through integration of a station in their network. Intense collaboration during preparation of a shared Horizon Europe proposal intensified the exchange with those two RIs additionally.

Main achievements

During the JERICO-S3 general assembly in June 2022, the work that had been initiated at the 2021 general assembly was continued. As part of an "interconnection day" collaborations with other RIs were discussed in more detail. The collaboration with other RIs in the NSEA/CHANNEL PSS concentrated on establishing working relationships with other RIs when useful and helpful. This effort involved national RIs (such as ILICO and COSYNA) as well as collaboration with European RIs. The work done in WP2 fed directly into the NSEA/CHANNEL PSS efforts in that common goals and interests, the pursuit of common research questions and funding opportunities and the setup of a future communication structure was tested in the PSS.

The facility installation of the shared observation station in Tesperhude (Germany) in the lower part of the Elbe River that had been designed and planned together with DANUBIUS-RI finished. The station became operational in spring of 2023. This collaboration involved agreements on data sharing, shared QA/QC procedures and management of the station. In this context, efforts were undertaken to ensure consistency of the measurement at the new station with the existing Cuxhaven station at the river mouth.

The Cuxhaven station at the Elbe River mouth, operated by Hereon, has been integrated into the ICOS network and has become ICOS' first coastal observation station. As a consequence, ICOS standards and procedures have been implemented leading to a closer integration of JERICO-RI and ICOS-ERIC.

Shared proposal work has been undertaken with DANUBIUS-RI and ICOS-ERIC working towards several integrated labs (leading to the LandSeaLot project initiated in 2024). For the NSEA/CHANNEL PSS two regions participate actively in this: the Seine Estuary and Bay region is involved with the topics of nutrients, biodiversity, and morphology; the Wadden Sea-Rhine-Elbe region is involved with nutrients, carbon fluxes and carbon budgets. The project started in 2024 providing a successful future collaboration with these RIs. But already the intense proposal design and writing process served to integrate the communities and initiated discussions about common ground, differences and work ahead.

Regional integration in the Elbe-German Bight area has been fostered with DANUBIUS-RI through implementation of a shared site in Tesperhude.

The actions carried out within the EC PSS have been highlighted in various regional and European bodies. This has contributed to the initiation of reflections for the setting up of projects in this workshop area (PPR Ocean & Climate, PEPR One Ocean, LandSeaLot project within the HORIZON-CL6-2023-GOVERNANCE). Moreover, in the framework of strategic reflection on the role of Coastal Observation in the IFREMER Coastal Unit, the EC PSS model is being used as an example of integration. Since the EC PSS coordination is particularly involved in the French RI ILICO, links with other RIs were fostered and began to be strengthened (OZCAR, RZA, EMSO Fr, Euro-Argo Fr, OHIS).

CRETAN PSS #1 Solubility and biological pumps

Key Message

The creation of new time series and data flows of the carbonate system was successful, which enabled the study of its variability and drivers. The combination of platforms, tools and variables, and the interaction with partners and ICOS was key for this success.

Main achievements

This action focused on in situ data whereas the carbonate model approach is described in Action #4 and new algorithms in Action #5. Since December 2020 a pH sensor and a pCO_2 sensor were deployed on the POSEIDON Heraklion Coastal Buoy (HCB) (contributing also to Actions #4, #5) but unfortunately not on the FerryBox (FB) as initially planned[1]. The pH sensor (SP200-SM, Sensorlab) was deployed at subsurface, on HCB providing pH data every 3 hours in near real time (NRT). The CO_2 sensor (CO2-Pro Atmosphere, ProOceanus) was also deployed at subsurface on the POSEIDON Heraklion Coastal Buoy (HCB) providing air and sea CO_2 data every 6 hours in delayed mode (DM). In parallel, to check the sensors operation, during the regular RV visits at HCB, water samples were taken for pH analysis as well as for dissolved inorganic carbon (CT) and total alkalinity (AT) analysis. The pH samples were analysed using a lab pH instrument (AFT-pH, Sunburst Sensors), which was regularly checked against the TRIS buffer as reference material. The CT and AT samples were analysed using a VINDTA 3C which is regularly checked against seawater reference materials. As additional data sources the following were used: a) satellite T, Chla (CMEMS SST; CHLa) used to derive CO_2 (see Action #5) b) SMAP salinity (from www.remss.com) used to derive TA (see Action #5) c) reanalysis carbonate products from CMEMS.

A key outcome of the action was the marine pCO_2 time series (1.5 year in total) obtained, which is, to the best of our knowledge, the first in the Eastern Mediterranean (based on data available on SOCAT) (Figure CRETAN PSS#1). The comparison of seawater CO_2 from the sensor with estimates of CO_2 (calculated from pH & AT and pH & CT of seawater samples) using CO2SYS had a RMSD ~29 and 9 µatm when calculated from AT & CT and pH & AT. The AT & pH pair was the most consistent with measured pCO_2. Finally, the pCO_2 data were used to study existing and new regional algorithms (see Action #5, Frangoulis et al. 2024).

Concerning the air CO_2 time series obtained at HCB, the comparison with the nearby atmospheric station of FINOKALIA (measurements with PICARRO) showed good correlation during the entire period, with a difference of approx. 5 ppm.

Another key outcome was the pH time series obtained for almost two consecutive years which is to the best of our knowledge the second one at high frequency (<day) obtained in the Eastern Mediterranean (an annual cycle done in Saronikos Gulf in 2013; González-Dávila et al. 2016). The DM data provided by the pH sensor, after processing, were in good agreement with data from samples (Figure CRETAN PSS#1). The pH data were used, as pCO_2, to study existing and new regional algorithms (see Action #5, Frangoulis et al. 2024).

It is important to notice that the combination of pH and pCO_2 at the same location is also a major outcome. For both pH and pCO_2 the diel to seasonal variability appeared to be mainly driven by sea-surface temperature.

Best practices, both for sensor operation and data processing for pH and pCO_2, were established in HCMR-NIVA partnership and in collaboration with other users of ProOceanus CO_2 ATM (VLIZ, Thanos Gritzalis) as well as manufacturers (ProOceanus and Sensorlab).

[1] Unfortunately, because of delays due to technical issues in installation and ferry line reschedules by ship operator, the FB system became operational only after the end of the implementation period.

For best practices for installation of CO_2 sensor on FB, several meetings were held: HCMR-NIVA meeting was done in June 2021, HCMR-NIVA and manufacturer (SubCtech) in May 2022, and other FB users (11th FB workshop; September 2022)[1]. The integration and analysis of in situ, with estimated (algorithms), satellite derived, and model output gave the opportunity to evaluate optimum observation strategy (Action #5, Frangoulis et al. 2024).

Data QC routines for DM data were established for CO_2 and pH, whereas the NRT pH data QC procedure is under improvement to automatically include a correction from temperature and salinity data obtained by the HCB buoy sensor. The DM best practices for CO_2 data processing were discussed with other users of ProOceanus CO_2 ATM (VLIZ, T. Gritzalis) as well as manufacturer ProOceanus. Data flows for a) carbonate system associated variables (T, S, meteo, O_2, Chla) were already handled, by CMEMS In Situ Thematic Assembly Center (INS TAC) whereas for b) pCO_2 data, submission was made to SOCAT (January 2022 and 2023). The pH (sensor and bottle) data were submitted to SDG14.3.1 and EMODnet.

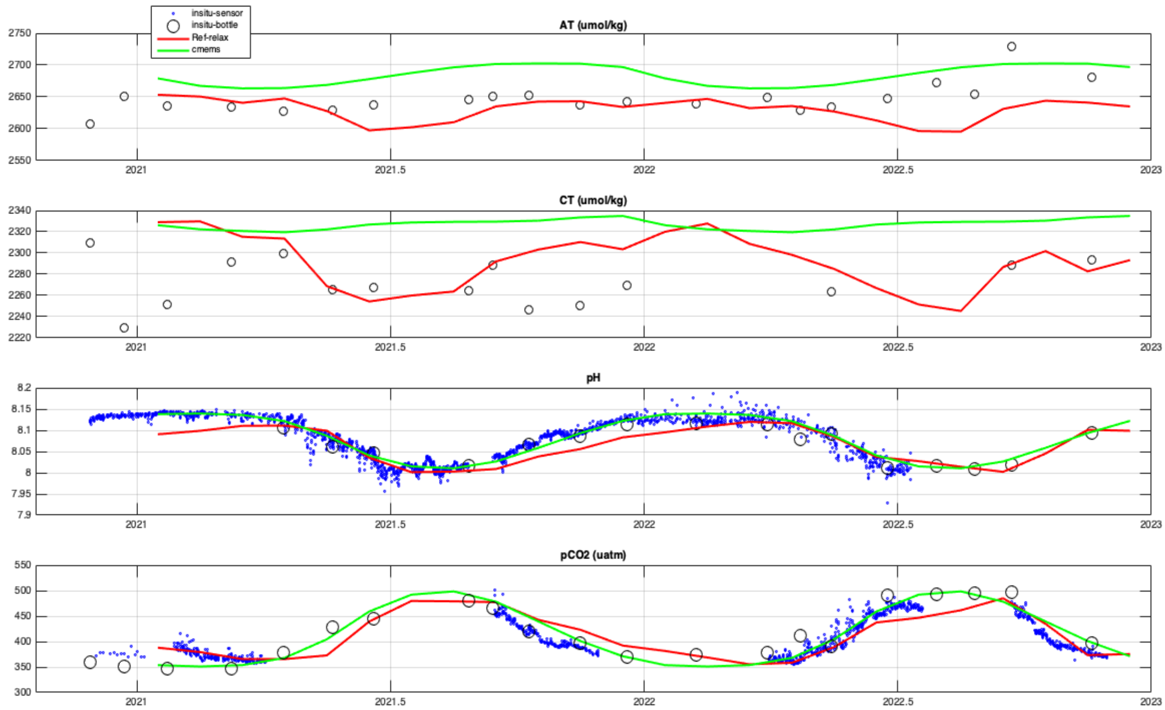


Figure CRETAN PSS#1. In situ carbonate system data at HCB from sensors (blue dots: pCO_2 and pH) and bottle samples (circles: AT, CT, pH and estimated pCO_2 from AT&pCO_2). Green and red lines show model output from CMEMS and ERSEM-HALTAFALL (with CT/AT relaxation, see Action #4). The CO_2 sensor was removed from April to August 2021 for the ICOS pCO_2 inter-comparison workshop.

This action was presented to all PSSs, the JERICO-S3 community and WP leads, in a modelling session of ARW#2 in April 2021, the ARW#3 in March 2022, a WP4 progress meeting in September 2021, a joint PSS-IRSs carbonate workshop in June 2022 (contributing to MS34 and D6.8). Dissemination was also made posts: JS3 webpage, POSEIDON webpage; newsletters: EuroGOOS newsletter, OA Med-hub newsletter, and conferences: Ocean Carbon from Space Workshop 2022 (ESA, SOLAS), 5th ICOS Science Conference 2022, 2nd GCOS Climate Observation Conference 2022 (EUMETSAT, GCOS, WMO). Interaction was enhanced with FINOKALIA station (ICOS, ACTRIS). New interactions were established with ICOS marine, SOCAT, SDG14.3.1, EMODnet as well as with pH and pCO_2 sensor manufacturers (Sensorlab, ProOceanus).

A manuscript has been published (Frangoulis et al. 2024) in the special issue Time-Series Observations of Ocean Acidification: a Key Tool for Documenting Impacts on a Changing

Planet in Frontiers of Marine Science. Important products were the provision of NRT pH, pH data submission to SDG14.3.1 (first national submission) and to EMODnet, and CO_2 data submission to SOCAT. Other databases are considered for other parameters (GLODAP for bottle data of CT, AT, pH) or for regional data (CARIMED) (see Action #5).

CRETAN PSS #2 Improved approximations of Primary Production

Key Message

The in situ data collection allowed us to improve model predictions. The new methods for primary production tested will allow observations on in situ platforms to further improve model validation.

Main achievements

This action included two tasks allowing to improve approximation of primary production (PP): a) feeding model PP predictions by optimizing the use/quality of current datasets and b) investigating innovative PP observation systems.

#2a For the first part, the HCMR 3D biogeochemical model (Kalaroni et al., 2020 and references therein), currently operational within [POSEIDON forecasting system](), was further validated and model parameterization was slightly modified to obtain a better fit with available data from various sources: satellite GlobColour Chla, bio-argo Chla profiles (2012-2022), HCB and E1-M3A fixed platform (pH, pCO_2, nutrients, Chla, bacteria, CTD casts) and from NW-MED PSS (DYFAMED station nutrients). Data before 2021 (i.e., implementation period) were used as well in order to enrich the data set. The main model updates and tests were:

a) The light attenuation coefficient was obtained from satellite derived diffuse attenuation coefficient (GlobColour KD490). This results in a more realistic simulation of deep Chla maximum, particularly in the more oligotrophic Eastern Mediterranean, as compared with Bio-Argo (not shown) and HCB Chla profiles (Figure CRETAN PSS#2).

b) The dissolved inorganic nutrients assimilation rate (phytoplankton affinity parameter) was increased, as suggested Tsiaras et al. (2017). This change resulted in a better fit with observed (lower) concentrations of nutrients at HCB and DYFAMED (not shown). The simulated net PP (surface) at HCB Fig. #2-1 is significantly increased (+46%) when phytoplankton nutrient affinity is increased in the model. The observed increase in both Chla (Figure CRETAN PSS#2) and nutrients at HCB during the beginning of 2019, which is not captured by the model, is related with a flooding event (see Action #3b), resulting in elevated land-based nutrient discharge that is not described in the model.

c) The impact of Chla light dependence was also investigated, adopting a variable C:Chl ratio in the calculation of model Chla and comparing the simulated Chla horizontal/vertical variability with the observed, obtained from satellite ocean colour and bio-Argo profiles. This variable C:Chl ratio results in a decrease of near surface Chla and an increase of Chla maximum (Figure CRETAN PSS#2). The latter results in a better agreement with the observed Chla vertical distribution, obtained from bio-Argo profiles (not shown), illustrating the importance of C:Chl variability. However, the simulated deep Chla maximum, adopting a variable C:Chl ratio, appears a bit overestimated, as compared with data at HCB station (Figure CRETAN PSS#2-1). At surface, this difference was relatively small, found within the in situ data inter-annual variability. When compared with satellite near surface Chla, the modified model Chla with variable C:Chl ratio appeared slightly underestimated throughout the year (Figure CRETAN PSS#2-1). Overall, the main model deviation occurs during the winter-spring bloom period with an underestimation in the NW Mediterranean and overestimation in the Levantine basin, which may be partly attributed to an underestimation/overestimation of vertical mixing (Kalaroni et al., 2020).

#2b Beneficial to this action, for a future application of PP observation on in situ platforms of the E. Mediterranean was the work done in Actions #3, #5 testing successfully in oligotrophic waters (i.e. mesocosm) two methods. The first method was a novel PP sensor, a version of which (MicroSTAF, Chelsea Technologies, UK) has applicability on gliders and Argos and the second using O_2 sensors on buoys and Argos (Action #5). The possibility of incorporating these PP methods to POSEIDON existing platforms is discussed in Action #5.

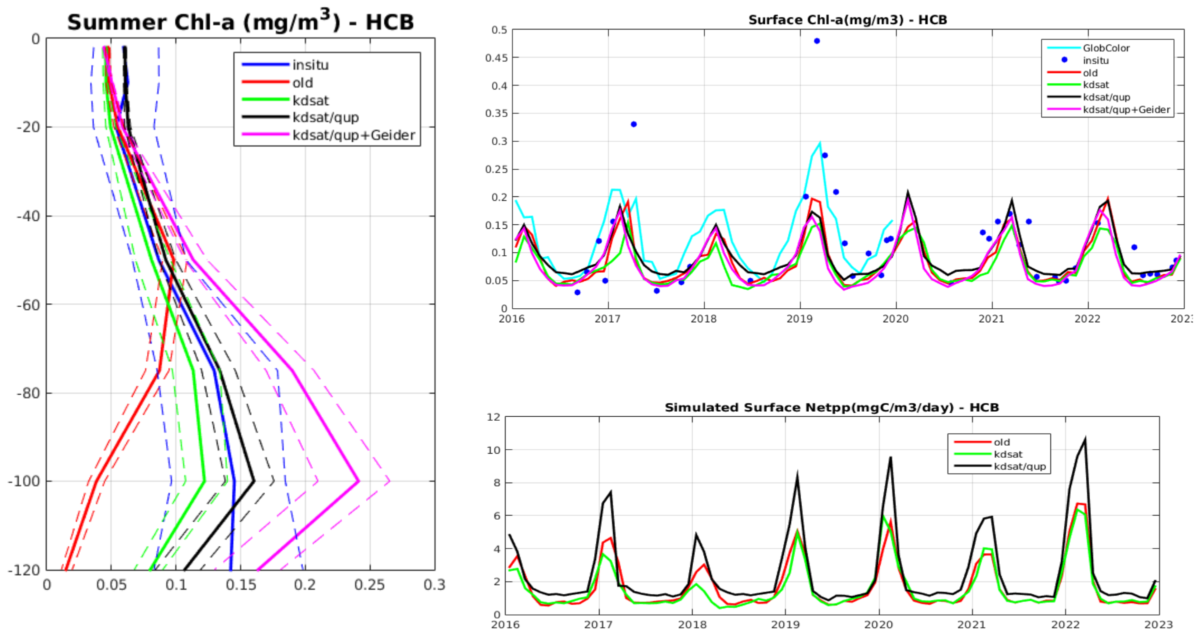


Figure CRETAN PSS#2. Left: Simulated (2016-2021) summer Chla vertical distribution (left) at HCB station with different model parameterizations, against in situ data, with mean (solid lines) and min/max (dashed lines) values indicated. Right: Simulated (2016-2021) surface Chla and net PP at HCB. [old: previous version; KdSat: see point a) in text; Kdsat/quP: see point b) in text; Kdsat/quP+Geider: see point c) in text]

Concerning data management, a new data QC delayed mode routine for Chla (and other variables) was developed using a multivariate approach, presented in the 55th International Liege colloquium on ocean dynamics (Stamataki et al 2024) and is considered in a manuscript under preparation (Action #5).

New practices for in situ PP observations in oligotrophic areas were tested (Action #5), including one in collaboration with an industry user (Chelsea Technologies, UK). Progress in practices of optical fluorescence sensors and flow cytometry for in situ applications, were made between PSSs partners, by attendance of HCMR to GoF PSS #1 Algaline fluorometer sensor harmonisation workshop (Feb 2021), and especially by attendance of SYKE, CNRS-MIO to mesocosm experiment in CRETAN PSS (Actions # 3, 5). This work is to be continued (HCMR, SYKE) within 2023 via MINKE project aiming for traceable calibration of field fluorometers.

Dissemination of these new phytoplankton observation practices was made via multiple posts (detailed in Action # 5), as training, and specific communication to AQUACOSM-Plus (Action #3). Modelling action progress was presented to all PSS, JERICO-S3 community and WP leads in September 2021.

CRETAN PSS #3 Extreme events affecting phytoplankton - AQUACOSM collaboration III

Key Message

An RI-RI mesocosm experiment provided a test-bed for phytoplankton monitoring methods and guidance on optimum and new phytoplankton sensors. In addition, a multiplatform approach was used to study the effect of extreme rain events.

Main achievements

#3a. For the mesocosm activity, during the first year the stage was set: a) a novel PP sensor LabSTAF (TA from Chelsea Technologies Ltd), that was later used in the mesocosm, was first tested in the PCL lab (input from Action #5) in October 2021, b) several preparatory meetings of PSS partners and the HCMR members of AQUACOSM-plus (June & December 2021, January 2022) were held, and c) on site visit of mesocosms (HCMR, SYKE, Chelsea Technologies Ltd). During the second year, the 10-day mesocosm experiment took place in May-June 2022 at HCMR facilities in Crete. The aim of this experiment for the AQUACOSM-plus community was to study the effect of episodic introduction of airborne microbes into the marine ecosystem. For JERICO-S3 community the aim was to use mesocosms to establish new sampling strategies and best practices, with focus on making these transferable to existing in situ platforms of the CRETAN PSS and E. Mediterranean in general (contribution to Action #5). In particular, to use mesocosms (i) to study extreme event effects on phytoplankton with new sampling strategies (i.e., methods, sensors) and (ii) to compare several phytoplankton sensors and lab analysis methods, for biomass and PP, under oligotrophic conditions. The experimental plan was agreed within partnership, and AQUACOSM-plus. Natural coastal seawater enriched with airborne aerosols and microbes, as well as dust from the Sahara Desert were used. In total 11 mesocosms were used. Two of them were dedicated for the aims of JERICO-S3 participants, which were combining both sensors and sampling:

- with the *sensors* deployed inside the mesocosms the following variables were measured: Chla Fluorescence, single turnover active fluorometry to monitor PP, temperature, salinity, surface and underwater downward irradiance, oxygen. The oxygen data were also used to estimate community respiration and net community production (see details in Action #5).

- with the *samples* taken from the mesocosms, several phytoplankton variables were obtained: extracted pigments (HPLC, total and fractionated Chla), cell counting/imaging and primary production (see details in Action #5). The associated variables measured using samples were: nutrients, FDOM, DOC, microbes, zooplankton, total light absorption.

Phytoplankton biomass remained very low throughout the experiment and non-photochemical fluorescence quenching was very high due to intense sunlight, thus conditions which are very challenging for field fluorometers. Fluorometers from the three manufacturers were compared against laboratory analysis of phytoplankton pigments. In addition to fluorometry sensors, the AutoSTAF and oxygen sensors demonstrated capacity to provide in situ approximations of primary production under oligotrophic conditions (see Actions #2, 5). The results will guide the selection of sensors to be used in such oligotrophic conditions (see Action #5) and contribute also to other projects (e.g., MINKE in efforts towards traceable calibration of field fluorometers).

Dissemination of the mesocosm experiment was made in JERICO-RI social media networks and MINKE webpage. Existing links with AQUACOSM-plus were strengthened, and a joint presentation of the RI-RI mesocosm experiments from the three PSSs (CRETAN, NW-MED and GoF) was made during the 3rd AQUACOSM-plus GA Meeting in a session on RI-RI interactions (17-21 October 2022 Romania). JERICO-S3 TA calls opened possibilities for testing additional sensors and to connect with industry users (Chelsea Technologies Ltd). Action progress was presented to all PSSs, JERICO-S3 community and

WP leads in September 2021 and at the ARW#3 in March 2022. Transfer of knowledge was performed as training, during the June 2022 mesocosm experiment, when CNRS-MIO provided training to HCMR on the use of the new Cytosense of HCMR. Finally, HCMR colleagues participated to GoF PSS mesocosm experiment on heat wave effect on microbial food web in SYKE in August 2022 (GoF #8).

#3b. For the in situ activity of Action #3, the effect of extreme rain events on phytoplankton was studied using two sub-activities. The first one used a multiplatform approach centred around Chl-a fluorescence. In situ and satellite data were collected from 2019 until 2022: rainfall/precipitation (ECMWF), SST, Chla from Satellite (CMEMS, Globcolour) SST, SSS from HCB buoy and SST, SSS, Chla from glider and CTD casts. An extreme rainfall event occurred in late February 2019 in the Cretan Sea causing a subsequent increase in seawater's turbidity and Chla concentration. The extreme event was detectable simultaneously in different variables (i.e., salinity, turbidity, Chla and DO) by multiple platforms (buoy, glider, CTD, satellite) (not shown).

For the second in situ activity, a mooring CTD (measuring T, S, oxygen, fluorescence, turbidity) was deployed in 2022 (with sampling frequency 1h) at the seafloor observatory of the Underwater Biotechnological Park (UBPC) of HCMR during three periods varying from 1 to 3 months. The UBPC location provided a higher possibility of exposure to the effect of extreme rain events (being more coastal than POSEIDON buoys) and more frequent check/recovery (1-2 months) compared to the POSEIDON buoys (6-12 months). In mid-October 2022 an extreme rain event caused an abrupt increase in turbidity and decrease in salinity, a less pronounced decrease of DO, and a progressive decrease of Chla which however increased later together with DO (Figure CRETAN PSS#3). This increase of Chla concentration was also detected by satellite images (CMEMS, Globcolour), although without a previous decrease. The dataset will be also processed to examine the extreme event effect on estimated of Gross PP and Net Community Production (following Soulie et al. 2022 and references therein; see Action #5). The measured variables (T, S, oxygen, fluorescence, turbidity) were provided as additional environmental data to the EMO BON (European Marine Omics Biodiversity Observation Network) observatory site.

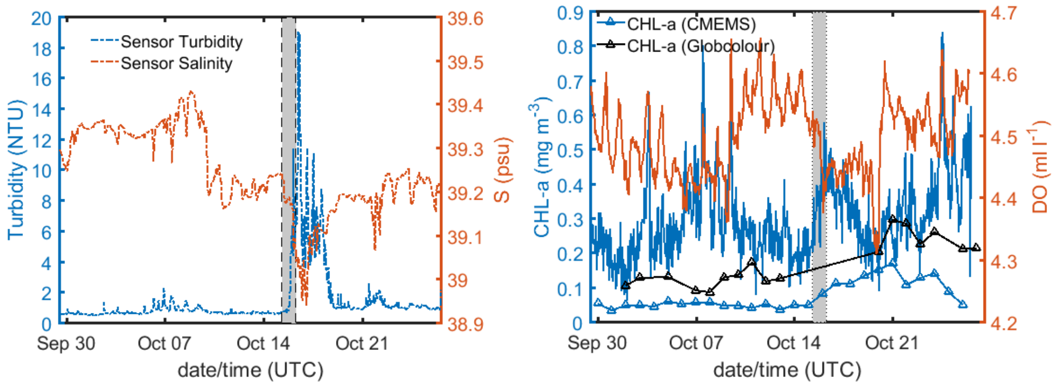


Figure CRETAN PSS#3. Observations during an extreme rain event occurring in mid-October 2022. Left panel: Turbidity, Salinity, Rain; Right panel: Chla, O_2 (in situ) and two satellite Chla products (Rainfall period in grey).

Dissemination was made via a post on the JS3 webpage , HCMR - POSEIDON webpage , HCMR – IMBBC webpage, tweet from EMBRC. A presentation was made in the 55th International Liege colloquium on ocean dynamics and is considered in a manuscript under preparation targeting the multiplatform and multivariate method for QC that will include as application the above two extreme events. In situ data were managed using existing data flow and QC from CMEMS INS TAC. Regarding mesocosm data, there is no defined

(AQUACOSM-plus) data management procedure. These will be delivered to selected databases during manuscript(s) preparation (data under analysis, no selected journal yet).

CRETAN PSS #4 Upscale of Regional Data to a wider area

Key Message

The comparison to in situ data (CRETAN and NW-MED PSSs) allowed us to identify important factors regulating the simulated carbonate system and model drift/bias. The model allowed us to identify the Cretan Sea footprint for different carbonate variables in the Mediterranean.

Main achievements

#4a The model used was ERSEM coupled to a carbonate system model (HALTAFALL) that permits the calculation of CO_2 partial pressure (pCO_2), pH and carbonate system components (H_2CO_3, HCO_3, CO_3), using dissolved inorganic carbon (CT) and total alkalinity (AT) as model state variables (submitted to advection, diffusion etc). The seawater pCO_2 is influenced by biogeochemical (photosynthesis, respiration) and physical (solubility/temperature) processes, as well as by the air-sea CO_2 exchange, based on the pCO_2 difference with the atmosphere. The air-sea flux is calculated as a function of temperature and wind speed. AT depends on nutrients. As in the case of salinity, water fluxes (i.e., evaporation-precipitation) have an effect on AT and CT, resulting in their concentration (evaporation) or dilution (precipitation).

A series of sensitivity simulations were performed to identify the most important factors regulating the simulated carbonate system. When evaporation was not considered, CT and AT decreased significantly. The same was observed, but to a less degree, when reducing the Atlantic water CT/AT. Finally, without biological feedback there was a significant increase of CT, but small effect on AT. The sensitivity simulations allowed also to identify potential model drift/bias in comparison to in situ data from Eastern (HCB) (Fig. #1-1) and Western Mediterranean stations (DYFAMED, Villefranche) (not shown). To correct the model bias, a series of simulation experiments were performed, increasing the evaporation fluxes, decreasing the net CO_2 uptake or a combination of both. Even though the adopted changes resulted in a decrease of the model bias, the deviation from in situ data was still significant. The effect of other model parameterizations (e.g., air-sea flux, air CO_2 concentration etc) was examined, but was not found to have an important impact on the results. Results were compared to in situ data and to CMEMS reanalysis product, after what surface AT and CT were relaxed to a monthly climatology (from 2010-2014 reference simulation), in order to remove this bias and obtain a better fit with in situ data (Figure CRETAN PSS#1). Such a relaxation is commonly used for salinity, to prevent a model drift due to systematic errors in the adopted water fluxes. Further investigation is necessary to optimize biogeochemical model parameters and other involved processes (e.g., Atlantic water input, water fluxes/atmospheric forcing etc) in order to obtain a better fit with observed data, without a relaxation on CT/AT.

#4b The model output over 2010-2021 was used to identify the footprint of HCB station for different variables, following Henson et al. (2016) methodology. A contiguous region was identified, comparing the model time series of a given variable at the station location with the time series in surrounding model grid points. When these have a similar mean value (within 2 standard deviations) and variability (linear correlation is statistically significant at the 95% level, i.e. $p<0.05$), the point is considered to be characterized by similar conditions with the station. With this procedure, for each variable, a contiguous region is created, for which the station data may be considered representative. The identified footprint of HCB is shown for different variables in Figure CRETAN PSS#4-1 and compared with Henson et al. (2016) footprint for E1-M3A. The PO_4, Chla and net PP footprint appears similar with Henson et al. (2016). The SST, pCO_2 and pH footprint extend to the Western Mediterranean, thus appearing higher than Henson et al. (2016). For the pCO_2 and pH this could be attributed to the dominant role of temperature in pCO_2/pH seasonal variability. When temperature normalized pCO_2 (at 13ºC) is used, the footprint of pCO_2 is much lower and similar with the dissolved inorganic carbon (DIC). A slightly lower footprint is found for

AT in the same area, being similar with surface salinity. An even lower footprint is found for CO_2 air-sea flux, which, interestingly and in contrast with other carbonate variables, covers the Cretan Sea and part of the Aegean, instead of the Eastern Levantine. This might be related to the different wind regime, dominated by Etesian winds in the Aegean.

The action was presented the JERICO-S3 community during ARW#2 Modelling session (activities from all PSSs) in April 2021, and WP4 meeting in September 2021. First results were presented in the 5th ICOS Science Conference 2022. A manuscript was published (Tsiaras et al 2024) in the special issue Time-Series Observations of Ocean Acidification: a Key Tool for Documenting Impacts on a Changing Planet in Frontiers of Marine Science.

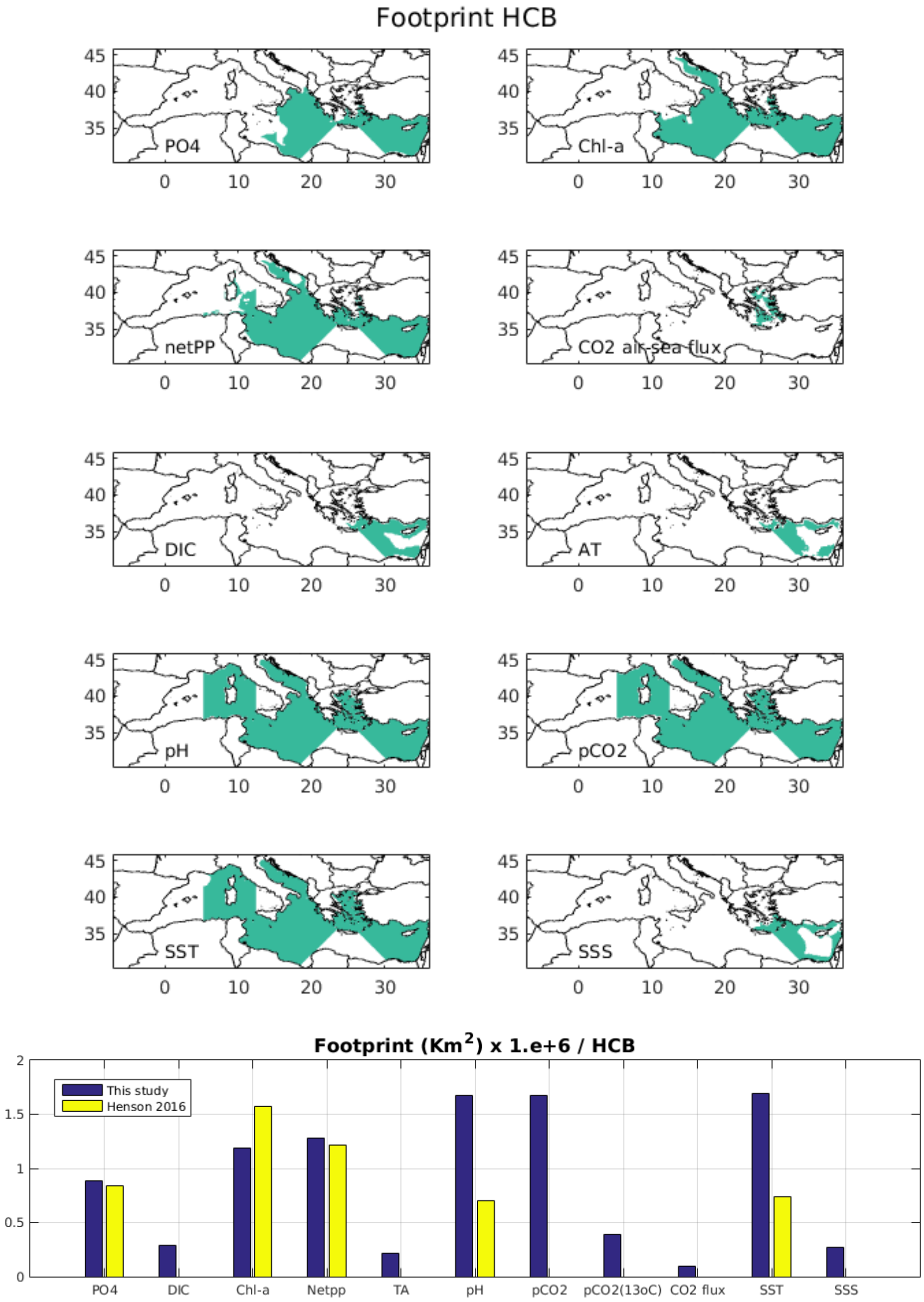


Figure CRETAN PSS#4. Upper part: Footprint of HCB station for surface PO_4, Chla, net primary production, CO_2 air-sea flux, pH, water CO_2, dissolved inorganic carbon (DIC), total alkalinity, temperature, salinity. Lower part: HCB station footprint total area (Km^2 x 10^6) from this study, compared to E1-M3A footprint area from Henson et al. (2016).

CRETAN PSS #5 New sampling strategies, new technologies, best practices

Key Message

Advances were made in new sampling strategies, new technologies and best practices of phytoplankton observations, with examination of their applicability to CRETAN PSS platforms. The multiplatform/multivariate approach contributed to data QC/gap filling and study of extreme events. Existing algorithms for carbonate variables were tested and new ones created. Data submission to specialised portals for carbonate variables was initiated.

Main achievements

#5a The mesocosm experiment (Action #3) demonstrated the potential of the existing platforms of CRETAN PSS (gliders, Bio-Argos, buoys, Ferrybox, RV visits) to provide improved (Chla) or new (PP, flow cytometry) phytoplankton observations. A large set of sensors was tested to identify optimum sensors for phytoplankton sensing under low phytoplankton biomass. The sensors tested were: Trios Nanoflu, Chelsea Technologies Unilux, Seabird FLNTU (Chla by Fluorescence) and Chelsea Technologies Ltd LabSTAF and AutoSTAF (single turnover active fluorometry to monitor PP). In addition, Gross PP (GPP) and Net Community Production (NCP) were estimated from oxygen sensor data (Seabird, Aanderraa), based on the method by Soulie et al. (2022 and references therein) established by mesocosm experiments in NW-MED PSS. The potential of integration of the tested sensors in existing CRETAN PSS platforms is summarised as:

a) **Chla fluorescence sensors.** Potential for integration in HCMR Ferrybox, Buoys, Glider, Argo. Integration in gliders, Argos and buoys, but requires some technical solutions (data logging/communications)

b) **Cytosense.** Potential for integration on HCMR Ferrybox and regular R/V visits.

c) **LabSTAF/AutoSTAF/MicroSTAF.** For LabSTAF potential for integration on HCMR Ferrybox and regular R/V visits. For AutoSTAF potential for integration on buoys. For MicroSTAF potential for integration on gliders (maybe also Argo in the future). AutoSTAF and LabSTAF were tested for the first time in the region.

d) **PP using a O_2 sensor.** Potential for integration on gliders, Argos, buoys. This method for estimating GPP and NCP, was tested with a O2 sensor (+CTD, Fluor, Turb) deployed in the mesocosm and in the UBPC (see Action #3) confirming the potential of integration to a buoy. A similar approach for application in CRETAN PSS Argo, glider is under examination.

The last two methods [i.e. c) and d)] provide potential for in situ PP monitoring in the region.

During the mesocosm experiment, in parallel to the sensors deployed, various lab methods (i.e. based on discrete sampling) for phytoplankton biomass and production observing were compared under low biomass conditions. These included, conventional and new methods: extracted pigments (HPLC, total and fractionated Chla by fluorescence, spectral absorption measurements (OSCAR, TRIOS Gmbh), phytoplankton cells from flow cytometry (Cytosense, Horiba) and imaging (Cytosense), primary production by bottle incubations (using C13, C14, O_2) and by LabSTAF.

Regarding dissemination, progress was shown in WP4 meeting in September 2021 and the ARW#3 in March 2022. The LabSTAF and AutoSTAF activities were demonstrated to JERICO and AQUACOSM mesocosm experiment participants as well as via posts on JERICO-S3 webpage and POSEIDON webpage. For the O_2 sensor (+CTD, Fluor, Turb), deployed in UBPC a post was made on the JS3 webpage , HCMR - POSEIDON webpage , HCMR – IMBBC webpage , EMO BON. Dissemination of fluorescence sensors tests was made in JERICO-RI social media networks and MINKE webpage A publication (white paper) of most successful practices for oligotrophic waters is considered (e.g. at Ocean Best practices).

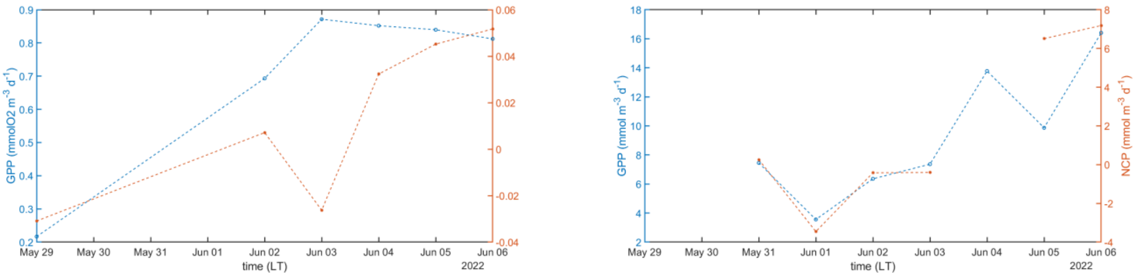


Fig. CS #5-1. Daily GPP and NCP estimated by in situ DO measurements from the two mesocosms.

#5b The multiplatform in situ approach applied in the CRETAN PPS demonstrated its potential via two examples: (i) the study of extreme events' effect on phytoplankton (see Action #3) and (b) the study of the carbonate system by providing additional variables, gap filling tools, model improvement, optimum estimation method and optimum sampling strategy (see Action #1). It is also important to mention that it created or enhanced interaction with ICOS, SOCAT and SOLAS.

Dissemination of the multiplatform QC method was made in a JERICO workshop on multi-platform observations in November 2021 (to JERICO, EuroGOOS, EuroSea, Nautilos) and in the 55th International Liege colloquium on ocean dynamics. A manuscript focusing on this method with application on extreme event detection is under preparation.

#5c Practices for field operation/maintenance of pH and CO_2 sensors, poorly applied in the E. Mediterranean before JERICO-S3 PSS implementation, were largely established. Practices for lab analysis of samples for pH, CT & AT were also improved. These practices and related data processing were established by HCMR-NIVA in collaboration with other users and manufacturers (Action #1). Participation in an ICOS instrument inter-comparison workshop provided additional experience on practices with CO_2 sensors. New practices for CO_2 data submission to SOCAT and pH data to SDG14.3.1 were established and datasets uploaded. HNODC has been contacted for a submission of pH data to EMODnet. CARIMED and GLODAP portals are also considered for future submissions. The submission to SDG14.3.1 is the first national submission of pH data to SDG14.3.1 to our knowledge.

#5d An important product was testing various regional algorithms of AT estimation from SSS (Frangoulis et al. 2024) which paired with in situ pH data allowed to estimate pCO_2. The estimated pCO_2 then was compared to the measured one obtained at HCB. In addition, new algorithms for CO_2 estimation using explicitly satellite data (SST or SST&Chla) as well as estimation of TA using satellite SSS were developed and the estimated CO_2 was compared to measured CO_2 data (Frangoulis et al. 2024).

Dissemination of tested existing and new carbonate algorithms was made in the Ocean Carbon from Space Workshop 2022 (ESA, SOLAS), the 5th ICOS Science Conference 2022 (13-15 Sep 2022) and the 2nd GCOS Climate Observation Conference 2022 (EUMETSAT, GCOS, WMO) and via a publication (Frangoulis et al. 2024). Action progress was presented to all PSS, JS3 community and WP leads in September 2021 and in a carbonate workshop in June 2022 (contributing to MS34 and D6.8). A manuscript is under preparation with the community that participated in the ICOS intercomparison workshop (which includes other PSS).

Finally, the integration and analysis of all data- in situ, estimated (algorithms), satellite derived and model output- gave the opportunity to optimise the future carbonate observation strategy, adopting a better cost/benefit approach of the observing system by readapting sensor location and using estimation algorithms with remote sensing data (Frangoulis et al. 2024).The activation of CO_2 measurements on the FB, initiated unfortunately after the implementation period[1], will allow to further improve this observation strategy.

CRETAN PSS #6 Partnership building

Key Message

The large majority of partnership building was successful with several mutual benefit activities initiated. Few remained at the level of planning and only one as an expression of interest. Moreover, the partnership was expanded to additional initiatives than those initially planned.

Main achievements

The Action worked at several levels of partnership: alliance with other environmental RIs, collaboration schemes between PSSs and IRSs, promotion of the added value of integrated coastal observations to regional, European and international initiatives. Most achievements mentioned below are described briefly in this section as they are detailed in the above actions.

#6a Partnership building with RIs included joint studies, access/provision of supporting data and new technologies as well as demonstration of cases of partnership/collaboration.

- AQUACOSM-plus. A mesocosm experiment in collaboration with AQUACOSM-plus provided a test bed for multiple phytoplankton sensors while providing support in the continuous monitoring of phytoplankton responses in mesocosms (see Action #3a) and guidance for selection of sensors used in situ under oligotrophic conditions (see Action #5).

- ICOS-ERIC. CRETAN PSS together with other PSSs participated to the ICOS intercomparison workshop in June 2021, the outcome of which will be presented in a manuscript under preparation (see Action #1). Various disseminations of the CO_2 observations activities (including with the FINOKALIA atmospheric station), have contributed to partnership building with ICOS (see Action #1). In late 2022 Greece became member of ICOS with atmosphere (including FINOKALIA) and ecosystem stations. HCB, was the only marine station candidate, that although meeting the criteria (having successful submissions to SOCAT since 2022, see Action #1), its integration was postponed for financial reasons.

- EMBRC-ERIC. First, in 2021 water sampling was made at the HCB station to provide additional EBV data for EMBRC-ERIC, on biodiversity of procaryotes and small eucaryotes, bacteria metabolism, and metagenome/metabarcoding sequencing of marine fungi following the practices of EMO BON stations. Second, in 2022, the CRETAN PSS benefited from a test bed at the UBPC station to study the seasonal variations of phytoplankton dynamics in relation to extreme rain events, while providing additional environmental data series to the EMO BON observatory site of EMBRC (see Action #3b). Finally, the HCB temperature data collected were used to setup a simulation of the June 2021 marine heatwave occurring in the Aegean Sea, in order to replicate this event in aquaria to identify stress response in sensitive sessile sponges through RNA sequencing. This study was performed in the frame of the MACCIMO (Multi-level Approaches to assess Climate Change Impact to Marine Organisms).

- LifeWatch-ERIC. An initial contact was made with LifeWatch Colleagues at HCMR and their interest in pH data from HCB station was expressed. Common activities will be pursued in the near future.

- EURO-ARGO ERIC. Data from Euro-Argo were used, jointly with those of other platforms, in modelling improvement activities (Action #2a) while new technologies/methods with applicability on Argos were tested opening the possibility of PP in situ observations in the Eastern Mediterranean (Action #5a). The responsible of Euro-ARGO reference database (Coriolis; C. Coatanoan) and of MedArgo delayed mode QC (A. Gallo) were contacted to establish data management procedures for provision of CTD casts to the reference database.

- EuroGOOS. CRETAN PSS partners (HCMR, SYKE, NIVA) participated in the EuroGOOS coastal working group, biology working group and FerryBox task team meetings, where PSS activities were discussed. The FerryBox activities in the Cretan Sea were presented in the 11th FB Workshop. Action #1 was presented via the EuroGOOS newsletter .

- ACTRIS. The enhanced interaction with FINOKALIA atmospheric station, a member of ACTRIS, was presented to the 5th ICOS Science Conference 2022.

#6b The collaboration schemes between PSSs and IRSs provided transfer of knowledge, supply of supporting hardware and human resources, in order to tackle regional and common research questions. Progress in practices of various sensors, lab analysis methods and flow cytometry for oligotrophic in situ applications, were made between PSSs partners (CRETAN, GoF, NW-MED), especially via participation to the CRETAN and GoF PSS mesocosm experiments (see Action #3, 5). In addition, carbonate chemistry sensors and fluorescence sensor testing/development in May-June 2022 was done with members of the NS-IRS, GoF PSS, and NW-MED PSSs. Transfer of knowledge between PSSs was also made as training (see Action #3), application of methods previously established in NW-MED PSS (Action #5) and attendance to GoF PSS Algaline fluorometer sensor harmonization workshop.

Collaboration between PSS and IRS as well as to wider JS3 community was presented during: a modelling session of the JS3 ARW#2 in April 2021 (Action #4), a WP4 progress meeting in September 2021, the ARW#3 in March 2022, a joint PSS-IRSs carbonate workshop in June 2022 (Action #1, 5) and a joint presentation of CRETAN, NW-MED and GoF PSSs to AQUACOSM-plus in October 2022 (Action #3). A manuscript is under preparation with the community that participated in the ICOS intercomparison workshop which includes several PSS (Action #1).

#6c Regional, European and international initiatives where beneficial to and benefited from the CRETAN PSSs actions. Demonstration of this was provided with dissemination to these initiatives of new products, challenges and future needs resulting from a PSS approach.

- Med GOA-ON. Activities and challenges related to pH observations were presented to the OA Med-hub (Action #1)

- SDG14.3.1. The first national submission of pH data SDG 14.3.1 was made using the HCB time series bottle and sensor data (Action #1).

- MonGOOS: A joint NW-MED/CRETAN PSSs presentation initially planned to be shown in October 2022 MonGOOS Workshop, was cancelled due to inability to attend in person.

- ESA, EUMETSAT, SOLAS: Use of satellite data was beneficial to all actions (#1 to #5) while new algorithms for CO_2 estimation using explicitly satellite data were produced (Action #5). Dissemination of in situ data beneficial for satellite algorithm validation as well of the tested existing and new carbonate algorithms was made to SOLAS, ESA and EUMETSAT (see Actions #1, #5).

4. ASSESSMENT OF PILOT SUPERSITE IMPLEMENTATION ACTIVITIES

Based on our experience with JERICO-S3 Pilot Supersites, the structuration of a coastal RI with Supersites would be ideal for research when studying coastal phenomena or processes that are dynamic and/or complex, occur rapidly, require monitoring of multiple variables and provision of operational forecasts (e.g., impact of extreme events on biology). Coastal Supersites seem particularly suitable for conducting regional research studies across national boundaries. In fact, Supersites could provide an integrated homogeneous framework that is modular, flexible, interoperable and remains consistent through transnational coordination, as well as with uniform practices and data management procedures. This framework could combine multidisciplinary expertise with a variety of existing tools (in situ platforms, remote sensing, modelling), high-frequency measurements and well-established links with different RIs and between neighbouring countries with common research interests. In parallel they could provide test-beds for evaluating new technologies on different types of in situ platforms and over diverse environmental conditions.

JERICO-S3 PSSs covered a range of Key Scientific challenges and Specific Scientific Challenges (Coppola et al 2023) well. On top of regional objectives, several more general ones were shared among PSSs. Notably, these included:

- impacts of land-based discharges
- region connectivity and transport of water masses and materials
- pelagic biogeochemical processes and their interactions
- carbon fluxes and budgets
- long-term observations to resolve climate change impacts

Among these topics, those with interactions between PSS were the most pronounced, also reflecting the connections with other WPs.

Studying the organisational challenges, when implementing PSSs and moving towards sustained Supersites, was an important target as well. The main challenge here was the relatively short duration of the PSS period and also that a true national/organisational commitment cannot be obtained during a short-lived project.

Section 4.1 summarises the major findings for each PSS. These findings are reflected against the original scientific and organisational objectives of PSSs that were identified in D4.1 (Seppälä and Frangoulis 2021). Section 4.1 also summarises the major gaps, challenges and lessons learned, as identified during PSS implementation. Section 4.2 analyses the PSS implementation from the perspectives of the most commonly addressed Specific Scientific Challenges. Section 4.3 deals with integration aspects, from different points of view. Finally, Section 4.4 analyses how the PSS implementation period has improved JERICO-RI's contribution to innovation and technology developments.

4.1. Synthesis of PSS implementation per PSS

GoF PSS

Highlights

The Baltic Sea observing community has a long tradition in sharing knowledge & data, collaboration in technologies, using the same platforms and sharing the workload towards joint goals. GoF PSS work has reinforced this and provided a framework and future vision for these transnational operations. During PSS implementation period, large improvements were done in regional harmonisation of observations, at various phases of the data value chain, including participants outside the PSS and the JERICO-RI, and including also other RIs. This was realised though calibration workshops and by use of common platforms, both having an aim to improve joint use of resources and to create common data products. Such harmonisation and sharing of information within region are especially vital for emerging observations, like carbonate system variables in the GoF PSS. The advances were conveyed towards key regional stakeholders to update them when new technologies and products might be usable within region and which steps might need additional support.

Eutrophication, which causes phytoplankton blooms is a major concern in the Baltic Sea, and some of the GoF PSS Actions aimed to improve observational capacities to detect them. To describe the magnitude and spatiotemporal distribution of cyanobacterial blooms, a combination of multiplatform sampling and EO data is required and was developed during the GoF PSS studies. We reviewed the development in multiplatform cyanobacterial detection methods used so far and developed near-real-time neural network classification of cyanobacteria species using imaging, further compared with EO data. New approaches for modelling the blooms were tested.

Another symptom of eutrophication is anoxic bottom layer, which is widespread in the Baltic Sea. GoF PSS observations allowed O2 mapping and to assess the Copernicus BGC model products reasonably well. As a conclusion of this activity, it is recommended that the spatial extension of some measurements need to be improved, by re-establishment of cross-gulf FerryBox measurements and adding observations in the eastern part of the GoF. Continuous current measurements and nutrient measurements in the deep layer should be started.

GoF PSS Actions showed strong and effective collaboration with other RIs during the practical implementation. Activities of ICOS were evident at many platforms, and JERICO BGC observations are clearly providing support to understand the biologically related dynamics of carbonate system variables. The mesocosm experiment demonstrated collaboration with AQUACOSM, in studying the same research question, how heat waves affect plankton communities, using experimental methods jointly with observations. Specifically, collaborations improved the use of novel technologies, e.g., imaging, in such studies.

GoF PSS joined regional key marine institutes, and this status has provided a feeling of better credibility and authority within the region. GoF PSS studies allowed to establish connections to several non-JERICO partners within the region, e.g., with those who were participating in harmonisation workshops. PSS work was disseminated within the institutes, related ministries and other stakeholders and a high level of national support was observed. As noted above, connections to other RIs is relatively straightforward within the region, as the amount of actors is relatively low and national marine infrastructures are well organised. From GoF perspective, connections between PSSs and IRSs have been efficient in several thematics, like phytoplankton and carbonate system research.

Identified gaps, challenges and lessons learned

Despite developments seen in the harmonisation and use of joint platforms, we still need to work for this topic. Demonstrating the use of joint long-term information products would be necessary to increase the motivation of researchers to cooperate and for research institutes to understand why transnational work is necessary. However, this requires more long-term funding and resources.

The need to speed up the spreading of information was noted during PSS period. A more active forum to communicate on data needs and technologies (e.g., selection of sensors) would be needed. Similarly, connecting better to other regions (including other PSSs) would be required if pan-European products are desired. This is likely to evolve through structuration of JERICO-RI activities. As funding was quite limited for PSS period, also the number of people directly involved and committed was relatively low.

Observation gaps were identified for some variables and plans to jointly cover these have been established. To succeed in this, the dialogue must continue even after the PSS period. HELCOM cooperation serves as a good role model in the region.

NW-MED PSS

Highlights

Key scientific topics for NW-MED PSS were related to the North Current, a major geostrophic current in the region, which plays a key role to connect coastal observing communities and networks within the region. A second major topic for NW-MED PSS was the influence of riverine inputs. The PSS studies included joint multiplatform and multidisciplinary campaigns, modelling, working with databases and combining experimental and observational studies. This region has an active multiplatform approach with repeated cruises, fixed platforms and autonomous moving platforms and is an excellent location to demonstrate transnational and trans-institutional activities, also connected to other RIs.

NW-MED PSS intensified regional observations including e.g. HF Radars, Argo-floats and moorings. Joint multiplatform campaigns using a combination of autonomous platforms (HF Radar, gliders, drifters) and targeted water samplings was noted as an effective strategy to study the BGC-physical coupling in the coastal area. Observation data was assimilated to reconstruct the 3D coastal dynamics of the coastal current, to further investigate its impact on water mass characteristics, particle transport and biological species distribution. A demonstration action was conducted in the La Spezia area in April 2022 with operational platforms to monitor and investigate small scale coastal dynamics and biophysical coupling.

River input databases for Ebro, Rhone and Arno rivers were listed and compared within partnership to highlight main measured variables, sampling frequency and methodology, providing a strong link with DANUBIUS-RI. A demonstration action was conducted in front of the Ebro River in September 2021 with operational platforms to study the impact of river inputs on coastal ecosystems. The work highlights how a multiplatform approach using HF Radar, field campaign at sea, buoys, gliders are suitable to study the impact of river inputs in the coastal area. HF Radar measurement highlighted the high frequency spatio-temporal variability of surface currents impacted by northern wind pulses and ADCP-glider measurements showed shear structures in the whole water column which could have an important impact on mixing processes and resuspension of coastal sediments.

The effects of terrestrial dissolved organic matter input and water temperature increase on the phytoplankton community were investigated in 2021 by collaborations between JERICO-S3 and AQUACOSM-plus communities. More exchanges of knowledge were established in 2022 between the NW-MED-Sea, GoF and CRETAN PSSs to highlight the consequences of global change in the marine system using a combination of experimental and observational approaches. The work has resulted in strong scientific dissemination and several scientific papers are published and are in preparation.

The use of multiplatform approach, regional 3D model and neural network to augment the capacity to study air-sea CO2 flux and pH variability in the NW Mediterranean Sea was demonstrated. This was proven to be a powerful tool to fill the gaps in coastal time series and to provide synthetic EOVs not directly measured with good uncertainty.

NW MED PSS has the support of two strong national RIs (SOCIB and ILICO). Overall, different technological expertise was shared among partners during PSS period. Data workflows and models were matured and benefitted from the networking. The integration tools are made ready for partnership.

NW-MED PSS demonstrated reinforcement with other RIs, e.g., during campaigns biological samples have been analysed (linking to EMBRC), multiplatform studies have included ARGO floats, collaboration with ICOS has been done using surface drones, NW-MED PSS participated in the ICOS intercomparison sensor exercise, and collaboration with EMSO included the work at OBSEA observatory. Collaboration with AQUACOSM is already noted above. The PSS also benefited from the strong involvement of its observing systems in different ERICs and many European projects towards operational oceanography and marine science, which allowed the early adoption of data quality control procedures and the availability of data in the GDAC and EU portals. Dissemination of PSS activities towards MONGOOS has been done.

There is a strong national commitment for studies, as highlighted e.g., by French projects RIOMAR and FUTURE-OBS, in which Gulf of Lion shelf and Rhone river will be observed carefully for the next 6 years with potential propositions for long-term observation and JERICO-RI design (e.g. DNA, contaminants, smart platforms, higher resolution models, etc.).

Identified gaps, challenges and lessons learned

The ocean colour products did not progress, as originally planned, as the timescales of the operations did not match, simply the implementation period was too short to plan and implement such activities.

A challenge observed for this PSS was a lack of biogeochemists and biologists in the group, (e.g., for benthic studies), partly explained by the history of the research teams but also strongly influenced by the low amount of funds allocated to the topic hampering the possibilities in creating new connections. Clearly in the next phases in developing Supersite concept for the region this needs to be addressed and the study topics need to be co-designed with these communities.

Improvements in defining societal key challenges, and how to contribute to regional and pan-European visions need to follow. This will ensure that the products meet better the needs of stakeholders and end-users.

NSEA/CHANNEL PSS

Highlights

The twin-PSS merged a large number of research institutes (11 altogether) for studies at the English Channel and North Sea, especially looking for connections between PSSs in different regions. Main topics for collaboration included terrestrial inputs, coastal carbon cycling, and biological carbon fluxes as well as, the assessment of regional eutrophication status, phytoplankton biodiversity and productivity. The PSS was largely built on previous cooperation, but many new connections were also created during the work. Beyond a general sharing of experiences, data and expertise, the involvement of the partners of the two PSSs has evolved. During the work it has proved important that the PSSs communicate with each other to share their experience and improve their best practices.

Within the NSEA/CHANNEL PSS, integrated phytoplankton observations were carried out combining reference methods and innovative automated methods for different platforms. Based on optimised monitoring programs and data flows, regional data were combined for use in developing and demonstrating new products on impacts of eutrophication contributing to regional ecosystem assessments and reporting. The work included joint workshops to transfer knowledge on new technologies, creating new data vocabularies and processing tools, feeding also other PSSs and communities in large. In addition, knowledge was transferred based on the best available science within EU Directives and Regional Sea Convention working groups.

Potential matches of OSPAR data needs and datasets provided by the JERICO-S3 community have been identified by NSEA/CHANNEL PSS. New products on the impacts of eutrophication were developed and demonstrated contributing to regional ecosystem assessments and reporting. NSEA/CHANNEL PSS models have been applied for estimation of pre-eutrophic Chla and nutrient concentrations in support of threshold definition for OSPAR and MSFD.

The intense discussion of collaboration measures continued and culminated in close collaboration with DANUBIUS-RI through a shared station and with ICOS-ERIC through integration of a station in their network, and with both through a shared proposal, eventually funded (LandSeaLot). In addition, part of the CHANNEL PSS area (Bay of Seine) will be observed carefully for the next 6 years with French national projects.

Carbon observations within regions were quality controlled, harmonized and published on the SOCAT database; subsequently used in estimations of regional sea-air carbon fluxes. As a result, regional air-sea fluxes (including trends over five years) could be calculated for the southern and central North Sea. Providing harmonized, useful data for riverine input to the North Sea and Channel remained challenging due to spatio-temporally varying measurement strategies and data FAIRness. Gaps in observations and interactions that hamper regional studies of carbon cycle and eutrophication have been identified.

In-situ observation data from different portals and partners have been collated in one model validation database. In the process, the FAIR availability and spatiotemporal resolution of these data has been evaluated. The Deltares biogeochemical model, including both the Channel and North Sea has been validated with this coherent dataset.

The NSEA/CHANNEL PSS contributed to education and training with their workshops. New connections to non-JERICO partners opened new perspectives and new projects, and some of the activities spun out into the projects in the overseas territories.

Good examples of cross-regional collaboration and communication were realised at four different levels, i) shared field surveys, ii) joint workshops, iii) sharing data and datatools, and iv) joint strategic planning, all key elements for transnational Supersites and for their network, forming a basis for Best Practices between Supersites' communications.

Identified gaps, challenges and lessons learned

Despite the large number of partner institutions within NSEA/CHANNEL PSS, too few people were involved in practical implementation, reflecting the relatively low funding contribution. While moving towards Supersites, there is a need for stronger commitment from the scientific community, research infrastructure teams, from institutes and funding agencies as sustainability of financing and other resources are needed.

Specifically, NSEA/CHANNEL PSS was missing physical oceanographers in its team. This shortcoming needs to be addressed in the next phases to improve multidisciplinarity.

Providing harmonised data for riverine input to NSEA/CHANNEL PSS was challenging due to lack of data FAIRness and differences in measurement strategies This calls for end-user driven co-design of such observations in future, where JERICO-RI can play a role.

CRETAN PSS

Highlights

CRETAN PSS included only waters surrounding Greece, and in situ observations were made by a single Greek institute (HCMR). However, PSS included a dense multiplatform and multidisciplinary observation network and participation from other PSSs and IRSs to advance observing capacity. All the Actions included such collaborative element. It may thus be considered as a study site of nationally operated Supersite including strong collaborative components.

CRETAN PSS improved the capacity of carbonate system monitoring in the Eastern Mediterranean, providing groundbreaking timeseries; the first marine high resolution pCO_2 time series (based on information available from SOCAT), the first time series with combination of 4 carbonate variables and the second time series for pH. This work included combination of various platforms, tools and variables and fluent collaboration with PSS partners and also with ICOS. The related data flows were created, and data was submitted to SOCAT, SDG14.3.1 and EMODnet. Carbonate system modelling was improved as well using multiple platforms, tools, and variables. Carbonate system studies were published and disseminated efficiently in several conferences.

Estimation of phytoplankton biomass and productivity is challenging at CRETAN PSS, due to very low biomass. PSS acted as a test-bed (combining field observations with lab and mesocosm experiments) for guidance on optimum and new phytoplankton sensors integration in platforms of oligotrophic waters. Advances in new tools for primary production observations and model predictions were taken during the PSS period. New sensor systems were tested in laboratory and during mesocosm experiment, along with traditional methods, jointly with sensor manufacturer, PSS partners and AQUACOSM-plus. Several new sensors were found sensitive enough and could be applicable for various platforms in the future.

Biogeochemical modelling was further improved with focus on Chla and primary production simulations, 3D model was validated and parameterization was slightly modified using multiple platform and satellite data sources from the entire Mediterranean Sea. Overall, multiplatform data is noted as key to improve model predictions for biological components.

Development of multiplatform/multivariate approach contributed to the improvements in the data QC and gap filling. This is exemplified in a study to detect effects of extreme rain events on phytoplankton by combining data from buoy, glider, satellite, and RV visits.

Important part of CRETAN PSS was the partnership building within PSS, between PSSs, with IRSs and with other RIs and initiatives (like AQUACOSM-plus, ICOS, EMBRC, LifeWatch, EURO-ARGO, EuroGOOS, ACTRIS, SOCAT, GOA-ON). Such collaborative scheme allows efficient transfer of knowledge, supply of resources, joint studies (with improvements in further funding), share of work, and access to relevant data, tools and products.

Identified gaps, challenges and lessons learned

During the implementation period there was a lack of sufficient spatio-temporal coverage. Main reasons for this were: i) lack of (sustained) platforms from neighbouring or other countries partners directly involved to regional field operations and ii) continuity in operation of infrastructures. Overall, implementation period of 2 years demonstrated the added value of multiplatform, multi-EOV&EBV and multi-RI approach but was insufficient to demonstrate full capacity of PSS.

A key gap identified is the lack of sustained funding for system maintenance and for participation to RIs. This is mainly related to maintenance of national funding, which is hard to tackle. At best, we need to disseminate the activities in various forums and emphasize the value of measurements to society.

4.2. Synthesis of the common Key Scientific Challenges addressed by PSSs

PSSs contributed to various Key Scientific Challenges (3 KSCs, which were further divided into 16 Specific Scientific Challenges), as reported in D1.2 and D4.1 (Coppola et al 2024, Seppälä and Frangoulis 2021, also note evolution in the KSCs as D4.1 relied on the earlier version of them). Some research topics addressed by Actions were very region-specific, but there were also synergies and cooperation between regions in many cases. Such collaborative cases are exemplified here, with three examples, as a guidance how to find balance between regional and pan-European integration. While coastal Supersites are expected to contribute to the national and regional strategies and monitoring plans, there needs to be also a strong pan-European aspect with common objectives and sampling strategies, including a joint steering of operations. Such joint and coordinated actions are key to developing thematic services for JERICO-RI.

KSCs (and Specific Scientific Challenges) related to carbonate system and phytoplankton studies were the most widespread, being covered by several Actions of all PSS, whereas topics such as river-coastal system were dealt by two PSS (NW-MED PSS and NSEA/CHANNEL PSS). The study of extreme events by combining the use of in situ observations and mesocosm experiments was included in three PSS. Several other topics were handled by one PSS only (e.g., deep oxygen conditions GoF PSS or circulation dynamics NW-MED PSS). Overarching topics, like the intercomparison of methods/sensors as well as the improvement of tools (e.g., models) and data management methods were elements present in many Actions in all PSSs.

Land-Ocean Continuum, riverine inputs

Two PSSs (NW-MED and NSEA/CHANNEL) focused on improving river-coastal system best practices, data collection, database gathering/standardisation/harmonisation, calculation of riverine substances input to coastal waters and exploration of new/complementary methods. Significant efforts on data management have identified important challenges (NW-MED#2, NSEA/CHANNEL#2, discussed in section 4.4 integration in data management). A joint multinational (France-Spain) multi-platform campaign aimed to collect (Ebro) river data to study the impact of river discharge on coastal ecosystems and to acquire glider ADCP data to validate/compare HF radar data (NW-MED#2). Calculation methods for riverine substances input to coastal waters were improved to better study their impact on coastal ecosystems (NW-MED#2, NSEA/CHANNEL#2). Several new or improved platforms/tools were explored with other RIs and communities. A mesocosm experiment, conducted in collaboration with AQUACOSM, investigated the impact of brownified river flood inputs on coastal marine waters (NW-MED#3). New ocean colour data and improved algorithms were used to study SPM along a river mouth using satellite data (NW-MED#4). The need for continuous observations to study SPM dynamics in coastal regions was noted (CHANNEL#5). Since 2022, a research station with FerryBox and carbonate system sensors has been operating in the Elbe River in collaboration with DANUBIUS-RI (NSEA#1). Besides these Actions directly studying the land-sea continuum, several others also contributed to studying the effects of land-derived discharges (e.g., phytoplankton blooms fuelled by riverine nutrients loads).

Regarding the Land-Ocean Continuum, even though there was no actual subject-specific cooperation between PSSs on this topic, the various PSS observations and developed tools are also usable in other areas. In JERICO, a common understanding of the importance of this research topic, development needs and key partners has emerged. One example of this is JERICO's strong role in the planning of the LandSeaLot project initiated in 2024, focusing on the land-sea interface, and it can be seen that all of the PSSs are, in a way or another, a part of the regional Integration Labs of this new project.

Carbonate system

In situ observations of the carbonate system were carried out by several PSSs using a multi-platform approach (NW-MED#4, NSEA#1, CRETAN#1, GoF#6), with one PSS initiating a new regional time series for pH and pCO_2 (CRETAN#1), another initiating a new river-based station and having an estuarine station becoming part of ICOS-D (NSEA#1). In addition, one of the mesocosm experiments, carried out jointly with AQUACOSM, investigated how quickly the carbonate system responds to changes in biological processes in response to a river flood brownification (NW-MED#3). Many of these observations were combined with the improvement of tools, i.e., carbonate models (NW-MED#4, CRETAN#4, CHANNEL#5, GoF#6) neural networks and algorithms (NW-MED#4, CRETAN#5) (see also 4.4 innovation in products) and pCO_2 instruments intercomparison during an ICOS workshop. Moreover, the development of carbonate data management in terms of harmonisation, QC and publication (e.g., SOCAT, SDG 14.3.1) was also done (NSEA#1, CRETAN#1, see 4.4 integration in data management), including regional conventions acidification assessments (see 4.4 innovation with new data flows) and providing strategic planning of future sampling strategies (GoF#6, CRETAN#4).

In studying the carbonate system, the cooperation between different PSSs included especially work towards Best Practices. The PSSs participated in a PSS-IRS workshop on best practices for carbonate measurements, identifying the carbonate system measurement protocols used. The follow up work D6.8 "*Best practices guidelines and strategy for coastal carbonate systems*" (Rehder et al 2024) concludes that the topic still requires further attention until coastal carbonate system measurements are fully standardised. This work requires collaboration also beyond the JERICO partnership, and already during PSS implementation all PSS actions related to the carbonate system included interaction with ICOS at multiple levels (see 4.4. integration with RIs).

Phytoplankton

Measuring phytoplankton, their biomass, community composition or productivity was part of several Actions in all PSSs, contributing to various scientific questions. The study of the impact of extreme events on phytoplankton was approached in several ways. Three PSSs, together with AQUACOSM, investigated the effects of extreme events on phytoplankton because of heatwaves (GoF#8), organic matter discharge from rivers (NW-MED#3) and extreme rainfall (CRETAN#3). In parallel, improved in situ phytoplankton data collection/analysis/management methods have been proposed to investigate the impact of extreme events (NSEA/CHANNEL#2, CHANNEL#5, CRETAN#5). Different instruments/methods to measure phytoplankton abundance/biomass and production were compared (GoF#1, GoF#3, NSEA/CHANNEL#3, CRETAN#3, CRETAN#5), including novel methods to estimate primary production (CRETAN#3, NSEA/CHANNEL#4) and instruments to monitor phytoplankton's diversity (GoF#4, GoF#7, GoF#8, NSEA/CHANNEL#3, CRETAN#3, CRETAN#5). Practices and calibration for fluorescence sensors were harmonised (GoF#1, NSEA/CHANNEL#3). The complementarity of in situ phytoplankton observations and ocean colour data was investigated (GoF#3, NSEA/CHANNEL#6, CRETAN#3). Improvement of modelling mainly concerned primary production (CRETAN#2, NSEA/CHANNEL#4, CHANNEL#5) and assessment of phytoplankton operational forecasts (GoF#2). Finally, eutrophication was a topic of particular focus of the GoF and NSEA/CHANNEL PSSs (GoF#2, GoF#5, NSEA/CHANNEL#7). This was also the case for HAB (cyanobacteria) blooms for GoF PSS (GoF#3, GoF#4, GoF#6).

Although the structure of the phytoplankton communities varies between sea areas and the observation technology must be somewhat optimized for them, the basic principles and techniques are almost the same everywhere. The use of various technologies among PSSs has been thoroughly mapped in D5.1 "*Catalogue and checklists for existing biological plankton sensors that will be implemented in JERICO-S3*" (Gallot and Artigas 2021), and related questionnaires for best practices have been completed. Joint work has included both practical and theoretical workshops for sensor calibration and use, comparison of various sensor types in different waters, and various networking activities (e.g., active participation in the European network for Imaging FlowCytobot users). While standardisation of these methods is tedious, the JERICO community has taken advances in joint calibration practices and use of metadata vocabularies, being first steps for pan-European shared products.

4.3. Overall analysis of the progress in the integration within PSSs

Regional integration

Within their regions, PSSs have provided a framework for thematic and interdisciplinary collaboration, joint use of resources, and planning and executing of common activities. PSSs have created new connections, transfer of technologies and knowledge, and scientific results within their regions. During the PSS implementation, we have seen that some of the observations and challenges have become regional in nature instead of being only national ones. For many study topics, improvements have been (or could only be) obtained by applying transnational and multiplatform sampling strategies.

Transnational integration was key for all PSSs, with some of them having specific actions on this topic (NW-MED#6, NSEA/CHANNEL#7), others having an already set collaboration which became more structured and focused (GoF, CRETAN) while CRETAN PSS spotted the lack and need of neighbouring countries' participation. Trans-institutional collaboration was a key element in practically all the Actions, and was realised through joint field experiments/campaigns/cruises, mesocosm experiments, river data collection or comparison, carbonate data collection or analysis, harmonised plankton observations, sensor intercomparison, validation and calibration, monitoring programs and data flows at regional level, phytoplankton database aggregation, support of EU directives and multisensor data collection of ocean colour use. Many of the above were also supported by JERICO TA projects. It is important to notice that there was also interaction with institutions not participating in JERICO-S3.

Integrating and manoeuvring transnational & multiplatform observations is tedious, however, and clearly requires the setting of common goals and incentives (institutional, national, regional). The next steps in regional integration should include clear demonstration, towards stakeholders at nations and regions, the added societal value of transnational and multiplatform approaches, and the technology requirements for it, as noted in the JERICO-DS Technology Roadmap (Seppälä et al 2024).

Pan-European integration

Ultimately, the JERICO-RI coastal Supersites should work closely together, using harmonised methods and having comparable sampling strategies to fuel pan-European research questions. It is asking too much that this could have been demonstrated already during a short test period of two years and rather limited funding. However, the first steps were taken, and demonstration of pan-European integration of PSS activities are given for various thematics in section 4.3. Further integration will probably take place within these themes, or guided by similar clear research questions, while JERICO-RI matures towards sustained structures.

During the two-year implementation period, PSSs and IRSs held several joint meetings and workshops that increased their sense of togetherness. These meetings have been characterized by openness and trust, different sites and regions have not competed with each other, but the goal has been to build observation capacity together.

Communication between PSSs was especially promoted at the NSEA/CHANNEL PSS (#7, see Section 4.2), highlighting that several different levels of collaborations are needed, including shared practical work, joint events, sharing of resources and having joint strategic planning. Sharing practical work was also realised at the CRETAN PSS, where other countries contributed to the development of Greece's national observations, while also gaining their own experience of new measuring techniques and conditions.

Integration of practices

All PSSs carried out several activities for transferring knowledge regarding their practices which significantly contributed to integration. This included contributions to D5.2, "Electronic Handbook for Mature Platforms" (Mantovani et al. 2023) which addresses best practices in the context of four mature JERICO observation networks: moorings, high frequency radar coastal monitoring, FerryBoxes and underwater gliders.

PSSs partners organised and attended several workshops related to practices such as the one for best practices on carbonate measurements, on "Data Mining for Integrated Observation Systems" and a series of Workshops of WP5 and WP6 to discuss about best operational and analytical practices for deploying automated techniques for monitoring phytoplankton's functional and taxonomical diversity. An NSEA/CHANNEL PSS workshop focussed on novel practices that can enhance data availability in future assessments (plankton indicators, eutrophication indicators etc). Some PSSs had specific activities to evaluate the status of certain best practices such as for river input data collection (NW-MED#2). Collaborations between JERICO-S3 and AQUACOSM-plus, and related TA projects, (NW-MED#3, CRETAN#3, GoF#8) greatly contributed to the exchange of practices between observing and experimental communities.

Having exchanged the status of their practices, gaps were spotted, such as a joint procedure for fluorometric sensor intercomparison and calibration lacking in some regions (CHANNEL#5), whereas it was already set in others (GoF#1, GoF#3). Some PSSs benefited from these exchanges to develop new practices for their region (e.g., for the carbonate system in CRETAN PSS), others developed a new SOP such as for underway pCO2 measurements (NSEA#1) or to harmonise phytoplankton automated observations practices (GoF#1), also including high frequency and spatial resolution (CHANNEL#3).

Integration in data management and data flows

Integration of data management within PSSs covered various aspects like harmonisation, publication, QC sharing, data flow creation, etc. These efforts were mostly focused on variables related to the carbonate system, river inputs and phytoplankton.

Efforts for carbonate system data management included QC sharing, harmonisation and publication (NSEA#1, NSEA/CHANNEL#7, GoF#6, CRETAN#1, CRETAN#5) including first data flows created for some regions (CRETAN PSS). PSS partners joint their efforts also for river database identification, comparison and standardisation (in NW-MED and NSEA/CHANNEL). This indicated challenges due to data gaps as well as multiple sources, frequency and availability. Improvements to overcome these challenges built upon existing methods, were tested and shared, in collaboration with DANUBIUS (NW-MED#2, NSEA/CHANNEL #2). A step forward in this data management collaboration with DANUBIUS was made via agreements on sharing data, QA/QC procedures and overall management of a station in Elbe River (NSEA/CHANNEL#9).

Integration efforts on phytoplankton data management from various sources concerned identification and improved availability (CHANNEL#4, CHANNEL#5, NW-MED#2, NSEA/CHANNEL#2, GoF#3, GoF#6) as well as harmonisation of analysis, vocabulary, flow (CHANNEL#3, GoF#7), QC sharing and formatting (CHANNEL#5, GoF#1). Some data flow improvements targeted specific applications like OC products calibration (CHANNEL#4, GoF#3) or model validation (CHANNEL#4, CHANNEL#5, CRETAN#2). An important outcome was that the various sources identified made obvious that there are many more phytoplankton observations in coastal waters than are available through single aggregators such as EMODNET and that a lot of work is required in the quality control, cleaning, and formatting of the data (CHANNEL#5).

A major aspect was the various new data flows created or used in assessments: publication of long time series of bottle data of Chla (GoF#3) and carbonate data from areas with strong gaps (CRETAN#1, CRETAN#5), using pCO_2 data for OSPAR Ocean Acidification assessment and streamlining data flow with combination of datasets for OSPAR eutrophication assessments (CHANNEL#4).

Besides the harmonization in data management per se, described above, there were also efforts in data acquisition harmonization regarding: carbonate observations from various sources (NSEA#1, GoF#6), phytoplankton observations including intercomparison, calibration and QA/QC (CHANNEL#3, GoF#1, GoF#3) and river monitoring strategies (NW-MED#2, NSEA/CHANNEL#2, NSEA/CHANNEL#9). The latter spotted challenges due to observational gaps and different strategies, scientific questions, that the collaboration JERICO-DANUBIUS was and will be helpful to resolve.

Integration with other RIs

While high level collaboration and teaming up with other RIs and initiatives was a task for JERICO-S3 WP2, a lot of practical regional collaboration took place within PSSs. All PSSs had specific actions on partnership with other RIs and regional initiatives. The TA project mechanism has proven to be a useful tool for RI-RI collaborations. Several partners in various PSSs were already highly involved in their respective national RIs, and their activities during the implementation period have strengthened the direct links between national RIs and other RIs (listed below). Initially existing links were identified and new contacts, if missing, were established with contacts being at personal/institutional level. Then the following specific joint activities were done with:

- AQUACOSM. Three mesocosm experiments (NW-MED#3, GoF#8, CRETAN#3), demonstrated the importance and capacity of RI-RI collaboration in combining experimental (mesocosm) and observational studies for e.g., the study of extreme events. In addition, experiences in the use of high frequency sensors and imaging devices were efficiently shared.
- EMSO. A smart multisensor marine observation platform was installed in the MAREL Carnot platform representing the core EMSO Generic Instrumentation Module (EGIM) (CHANNEL#3).
- EUROARGO. The Argo floats deployed (several from PSS partners) provided a great potential to study coastal hydrodynamics (NW-MED#1), to validate and qualify new variables and sensors for pH, TA, TC, nutrients, (NW-MED#5), for estimates of primary production (CRETAN#5, CRETAN#6) and for model improvement (NW-MED#4, CRETAN#2). The data management procedure for providing additional CTD casts to the EUROARGO reference database was set in additional regions (CRETAN#6).
- EMBRC benefited from the various physical and BGC data collected as well as from biological samples (including for genomic approaches) collected during campaigns (NW-MED#5, CRETAN#3, CRETAN#5).
- ICOS and SOCAT. All PSSs participated in the ICOS sensor intercomparison in summer 2021, aiming among others to harmonize/coordinate JERICO coastal and VOS pCO_2-observations with ICOS observations. Additional collaboration with ICOS-ocean also made for sensor intercomparison (NSEA#1) and specific missions on the study of CO_2 flux variability at the air-sea interface (NW-MED#5). Cuxhaven Stationary FerryBox became part of ICOS-D network in 2023 after trial period as pilot estuarine station (NSEA#1, NSEA/CHANNEL#9). FerryBox line Silja Serenade become part of ICO in 2023 (GoF#6). Greece entered ICOS-atmosphere program in 2022. HCB station, the only Greek marine station, although meeting the ICOS criteria was not included due to lack of funding. Interactions were made also with ICOS atmosphere (GoF#6, CRETAN#1, CRETAN#5). The SOCAT database (managed by ICOS) was enriched with data from PSSs (CRETAN#1, CRETAN#5, NSEA#1) and was used for model validation (CRETAN#1, CRETAN#5, CHANNEL#5).
- DANUBIUS. The JERICO-DANUBIUS collaboration was proven to and will be helpful to resolve challenges in harmonization of river monitoring strategies (NW-MED#2, NSEA/CHANNEL#2). In addition, new observational activities (shared site in the Elbe River operational since spring 2023), were designed together with DANUBIUS with joint management including data sharing and common QA/QC procedure (NSEA1, NSEA/CHANNEL#9). The alliance with DANUBIUS resulted in a new project, LandSeaLot, which is taking the use of PSS developments.
- MINKE. Work with the metrology community of MINKE included organisation of specific session at Metrology of the Sea conference and demonstration of JERICO-RI calibration activities during a MINKE training workshop (GoF#1). Overall, the sensor calibration activities at GoF and CRETAN PSSs are closely linked to those of MINKE.

Integration through multiplatform and multivariate approach

A multiplatform and multivariate approach is the very essence of the coastal Supesites and a starting point for PSSs to demonstrate how JERICO could add value to our ability to answer the multiple key scientific and social challenges the coastal ocean is facing.

All PSSs used multiple platforms and measured multiple variables at the same time. This approach demonstrated the advantages: i) of using many different platforms (NW-MED#1, CRETAN#1, CHANNEL#3), ii) of specific twins like glider with HFR radar to monitor coastal hydrodynamics (NW-MED) or fixed station with FerryBox for carbonate measurements (GoF#6, NSEA#1) and c) even of a single platform being highly multivariate for field truthing of satellite data (GoF#3). The future optimisation of multiplatform observing strategies was considered by PSS during the implementation period (GoF#2, GoF#5, CRETAN#5).

We organised a JERICO-RI workshop on multiplatform observations on 18th Nov 2021, with contributions from EuroGOOS and EuroSea, MINKE, NAUTILOS and TechOcean projects. The workshop described the specific pan-European and regional needs for sustained and consistent multiplatform observations for coastal marine areas, highlighting the challenges set by the complexity of coastal ecosystems. Summaries of multiplatform approaches from each PSS were presented, including highlights of cyanobacteria bloom monitoring (GoF), impact of river inputs in the coastal area (NW-MED), phytoplankton productivity and diversity in coastal areas (NSEA/CHANNEL) and carbonate system and salinity multiplatform observations contributing to the improvement of data quality check, model validation and process confirmation (CRETAN).

Overall, the promotion of the multiplatform approach is very much linked with all other parts of integration presented above. Without regional and pan-European integration and harmonisation, and in the absence of integrated data flows, the multiplatform approach will not succeed. And turning it other way round, consistency and cost-efficiency of European coastal observations will not improve without seriously considering the harmonisation and integration aspects of the multiplatform approach, promoted by JERICO-RI.

4.4. Innovation in data and technology products

All PSSs have been using recent technologies and innovations in the Actions. While some of the Actions were more related to harmonising already well-established methods and ways of making observations, some actions targeted finding new solutions and promoting them. Innovation in data products concerned various aspects such as modelling, data processing/delivery and satellite data ground-truthing as well as contribution to assessments (eutrophication, HAB, water quality) for EU directives and beyond (e.g., OSPAR).

Starting from carbonate system observations, the existing physical-biogeochemical-CO_2 models were improved, by combining multiplatform observations, modelling, neural networks and new algorithms for carbonate variable estimations using satellite data (NW-MED, CRETAN). New observation methods were tested and promoted to stakeholders (GOF#6).

The estimation of primary production was approached using new analysis tools and methods (CRETAN#2, CHANNEL#3, GoF#6) and imaging methods allowed to investigate POC dynamics (NSEA#1). Concerning data management, NRT data delivery and analysis was created for cyanobacteria species data using imaging (GoF#7) and a NRT analysis-system was set-up for near-bottom oxygen maps (GoF#5). Large part of data management efforts concerned processing with new numerical methodologies/tools: to handle large data matrices for completion, regularisation, clustering and learning/ combination of multivariate, multi-source and multi-scale approaches (CHANNEL#3, CRETAN#5), to optimize the processing of high-resolution datasets from buoys and FerryBoxes (NSEA/CHANNEL#4) and to fill data gaps and correct river load calculations (NSEA#2). The data processed were valuable also for satellite data ground-truthing, and creation/validation of satellite algorithms (GoF#3, CRETAN#5).

The new products on eutrophication impacts developed will contribute to regional assessments (OSPAR, HELCOM) while providing information for models and OC product calibration (CHANNEL#4), together with evaluations of performance of models that could be used for eutrophication (GoF#2, GoF#9, CHANNEL#4, CHANNEL#5) or HABs assessments (GoF#7). It became clear that JERICO-RI can contribute to filling OSPAR data gaps and test the reliability of satellite and modelling-derived products integration for eutrophication, pelagic habitats, food web and ocean acidification assessments (NSEA/CHANNEL#8). It was also evident that PSSs partnerships were important for implementing a model for assessing the water quality assessment and more precisely eutrophication for WFD and MSFD (NSEA/CHANNEL#7, CHANNEL#5).

Innovation in technology products concerned sensors and analysis tools (imaging, molecular). A smart multisensor marine observation platform (EGIM) was installed in the MAREL Carnot (CHANNEL#3), a glider with light transmission sensor (GoF#3) as well as an autonomous plankton sampling and analysis instrument AquaBox (GoF#6). Various new technologies for phytoplankton and primary production in situ observations were tested (NSEA/CHANNEL#7, GoF#8) including their applicability in oligotrophic systems (CRETAN#5). Automated methods for plankton image recognition were developed (CHANNEL#3, GoF#4, GoF#8) including as a complementary combination of imaging, molecular and chemical analysis (CHANNEL#3).

5. COMMUNICATIONS AND DISSEMINATION

A webpage to provide an overview of PSS activities was created at https://www.jerico-ri.eu/projects/jerico-s3/pilot-supersites/. It provides basic information on PSSs and some highlights from D4.1. The sub-pages describe each PSS: their main characteristics, platforms and measured parameters included, as well as listing the Actions with their specific objectives.

The JERICO-RI news included several ones from PSSs:

- TalTech recover the Keri cable bottom profiling station in the Baltic Sea.
- Marine plankton community responses to terrestrial dissolved organic matter input realising by CNRS-MARBEC on MEDIMEER infrastructure
- The Gulf of Finland Pilot Supersite prepares for the bloom of blue green algae
- The Helgoland Underwater Observatory (HUWO), part of the JERICO-RI North Sea Pilot Supersite, begins to collect real-time images of plankton
- 23th summer of concerted observation and communication of cyanobacterial blooms
- A Single Turnover Active Fluorometry sensor LabSTAF tested successfully in the oligotrophic Cretan Sea PSS
- Understanding the fluxes and balances of energy, materials and ecosystem dynamics at the North Sea and English Channel Pilot Supersite
- A first pH annual cycle in the Cretan Sea
- Joint JERICO-S3 and AQUACOSM-plus study on Baltic Sea heatwaves
- LASE-NOPAH TA: levels and air-sea exchange of nitrated and oxygenated polycyclic aromatic hydrocarbons in the Cretan Sea
- In the Cretan Sea PSS, JERICO-S3 collaborates with EMBRC to complement data series at the Eastern Mediterranean EMO BON observatory and study the effect of extreme events on phytoplankton productivity
- Coastal EGIM (cEGIM) was deployed by IFREMER on Friday 24th of April on the SMILE site in the English Channel JERICO-S3 Pilot Supersite
- COSYNA Revolutions in Coastal Observation: JERICO-RI Virtual Access
- A first marine CO2 time-series in the Eastern Mediterranean
- Keri Profiling Station: A Crucial Hub for Monitoring Gulf of Finland's Dynamic Ecosystem

In addition, several partners had their own dissemination activities through their web pages and social media.

PSS-related topics were included in numerous internal meetings and workshops. The major cross-cutting internal collaborative events included the following PSS-specific sessions:

- Regions workshop during Kick off meeting, San Sebastian, Spain, 17.-21.2.2020
- Regions workshop, during JERICO-WEEK 2021, online, 19.-23.4.2021
- PSS progress meeting, organised as separate online meeting 21.9.2021
- Multiplatform workshop, during JERICO-DS General Assembly 2021, Brussels, Belgium, 18.11.2021
- Regions workshop: PSS progress meeting, during JERICO-WEEK 2022, online, 15.3.2022
- IRS/PSS interaction workshop, during JERICO-DAYS 2022, Lisbon, Portugal, 29.6.2022
- Regions workshop: PSS Status update, during JERICO-Week 2023, Rovinj, Croatia, 19.4.2023
- Workshop: Region approach within JERICO, during JERICO-S3 Final General Assembly, Brest France, 19.6.2024

PSS-specific studies were presented in numerous external meetings, most important ones have been noted in the respective Actions in Section 3. Key wholistic summaries of PSS activities were presented as:

- Seppälä et al: JERICO-RI coastal Pilot Supersites for integrated, multidisciplinary and harmonized observations. Virtual ASLO 2021 Aquatic Sciences Meeting, 22.-27.6. 2021
- Seppälä et at: Synthesis of JERICO-RI coastal Pilot Supersite implementation: towards integrated pan-European multiplatform coastal observations, in the 10th EuroGOOS International Conference, 3.-5.10.2023, Galway, Ireland, resulting also a conference proceeding publication (Seppälä et al 2023b)

6. INTERNAL EVALUATION OF PSS IMPLEMENTATION

While the progress of PSS implementation was reported and several times during progress meetings (see Section 5), the advice how the operations should be tuned was received directly from the partnership. After the implementation period, we asked the partnership for more wholistic feedback, during a JERICO-week in April 2023, in Rovinj. In this section, we shortly summarise the results.

First, we asked, **what are the key findings of PSSs that should be highlighted in the forthcoming ESFRI proposal documents.** The summary of answers (n=19) emphasises that the key findings to be highlighted should include:

- New observations
- Collaborations (regional, between PSS, PSS-IRS, RI-RI)
- Harmonization
- Integration
- Showing added value created in PSS

Based on these results and earlier discussions, we aim to go further in publishing demonstrations how PSSs have progressed harmonisation in pan-European observing systems in some specific topics (e.g., phytoplankton and/or carbonate system observations) and how such harmonisation and integration may lead to a systemic change in the observations strategy.

Second, we asked about dissemination, and eventually the responses guided us to have a presentation during 10th EuroGOOS conference. In addition, the results boosted the need of having thematic discussions between PSSs, finally realised during the final GA in June 2024 with presentations focusing on the various aspects of integration that have come up during the implementation of the PSSs.

We continued by asking if JERICO-RI should continue integration from Pilot Supersites towards Supersites (Figure 6.1) (for PSS vs Supersite proposed criteria see Table 1 in Seppälä and Frangoulis 2021). We also asked those who answered to provide comments for their ranking, with following notes coming up:

- *We need more PSS interactions and exchanges; Pilot experience was too short; Need also more discussions with IRS; Keep regions (PSS+IRS) as implementation plan for ESFRI proposal.*
- *In the future JERICO-RI regions should not be different between IRS and PSS, all regions should be components of the implementation/operation at the same level. Then, we could have selected supersites inside these regions as places for concentring experimentation in specific research axes or highlight specific actions.*
- *The RI should be inclusive in order to be fully pan-European.*
- *Meeting social expectations seem compatible with the implementation of a few numbers of supersites as well.*
- *PSS should be considered as targets to be reached for each JERICO region not as the basis for the implementation of the RI. Geographical delimitation of Supersite should be precised as well.*
- *Working regionally allows people of different scientific disciplines to work on a common object and is, IMHO, the only practical solution to get inter-disciplinary observations.*
- *Build further on current collaboration to jointly address regional needs with stakeholders (for example on effects of offshore wind in North Sea with OSPAR and member states).*
- *I wonder whether all of JERICO should be one site.*
- *Where the PSS approach is sufficient for regional needs, perhaps some more regional integration is needed in some sites? Also some IRS "hotspots" might be able to advance to (pilot) supersites.*
- *Better link between PSS and IRS at the scale of MedSea.*
- *Joint products are great possibility.*
- *Maybe, because I am not completely clear what role SuperSites would have in a future JERICO strategy.*
- *JERICO needs to bring along all countries as it develops and not focus too much on particular sites or the value add of developing supersites should be clearly presented.*
- *Need to decide common terminology. Mix of PSS and IRS is confusing and probably not a workable solution for a future RI.*
- *Either called "Super Sites" or "Regional Integrated Observation Systems", the way would be to better integrate the actors already involved and to invite external partners/observation key actors that are not included in JERICO yet. To cork at the national level (if observation is coordinated at the national level), local (if at the provinces level) and/or institutional level.*
- *As discussed during the session, it is not important how to name the sites but I strongly recommend to continue with the development of specific concentrated sites within regions*
- *Different models of SuperSite have been piloted in J-S3. We need to analyse these different models and decide on what a JERICO-SP could be in the future, before deciding if we should continue or not along this line. It should be based on a clear/demonstrated added-value of the SuperSite model beyond what is done without SuperSite.*
- *PSS, IRS should may be not kept for the future, but rather a region "concept", showing larger scales areas and terminology that will be easier to understand?*

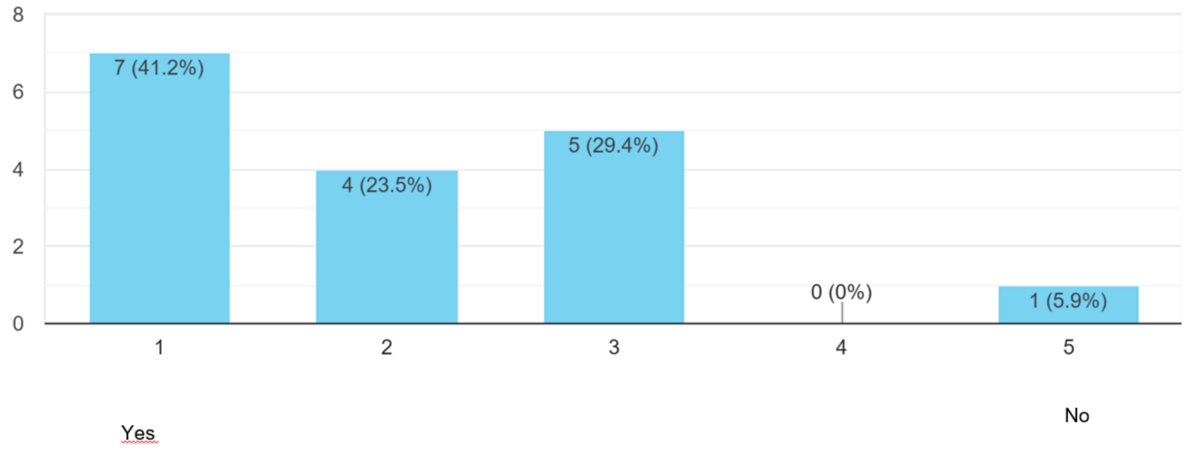


Figure 6.1. Responses to the question, whether JERICO-RI should continue from Pilot Supersites towards Supersites.

While summarising the results, from WP4 point of view, we noted that there is still some confusion in the definition of PSS, IRS and Region. Region being a whole sea-basin, often divided into subbasins and being transnational. IRS (Integrated Regional Sites) were set up in JERICO-S3 to discuss and promote integration within regions. While PSSs are a set of multiple observing platforms, with multivariable capacity, ultimately jointly (transnationally) coordinated by involved institutes and nations. As such, a region (or sub-region) can have a single, several or no PSSs, depending on the capacities of institutes in the region and the needs of such structures in providing the required observations.

Our second reflection is regarding the name, as "Supersite" was finally selected based on the analysis done in D4.1. We would stress that the name does not matter, but the definition does with JERICO-RI having coordinated, integrated, cross-talking, highly-instrumented, multiplatform, multi-interface, multivariable, transnational, interdisciplinary, flexible, long-lasting, FAIR & cost-efficient observation sites at various regions, solidly connected to other RIs, initiatives and industry.

While planning the future of JERICO-RI Supersites, we need to consider a fit-for-purpose framework, being able to provide observations the science and society needs and can afford. Then the discussion goes back to structuration and coordination of observations in general. Platforms targeting single or few variables, with low complexity (aka Standard observatories as presented in D4.1) do require harmonisation and decisions for sampling strategies alike (where, when, how often, by whom), but they do not need much other coordination. Being relatively unexpensive (likely, but with exceptions!), they may be highly distributed (think about water level measurements as an example), but they cannot necessarily contribute (or at least not alone), to several Specific Scientific Challenges (Coppola et al 2023). Once we move towards Advances observatories, being single platforms able to provide multidisciplinary measurements, the requirements for coordination increases. At the same time, the ability to provide observations to more complex Specific Scientific Challenges increases once they are coordinated in regional/European scale. Currently we have such systems available, like Euro-Argo ERIC providing floats to measure several variables for different purposes. It is hard, however, while aiming to contribute to multiple Scientific Challenges and coastal products, to see the build-up of a separate research infrastructure for each platform type, and eventually they need to come together for harmonisation to create coherent data. One example of such harmonisation is a sensor calibration, as sensors deployed in different platforms should have similar calibration practices if the final aim is to pool the data into a consistent product. In this the JERICO-RI multiplatform sampling strategy demonstrated (during the PSS implementation period) its fit-for-purpose for coastal observations, having harmonised and matching services and tools for all platform types and sensor types in a single RI, which is key to a systemic change able to address multiple Scientific Challenges and reply to new ones.

Supersites can be part of this systemic change in coastal observations. As presented by Revelard et al (2021), ocean observation suffers from organisational silos, we are often safeguarding our own observations for our own research needs (as a person, team, institution, nation, …) and not considering global needs of what should be observed, when and how – and how could we as there is not yet well developed international coordination for observations to guide such behaviour. Transnationally operated and jointly steered Supersites could have a big role in the process, and this requires altruism, by acknowledging that observations are done for a common good, not only for own needs. And actually, altruism should be an inbuild property of Research Infrastructures, providing data, tools and products for science and society, not only for RI operators. It is through the complexity of multiple Specific Scientific Challenges that this links back to Supersites, as to answer these questions we need to perform jointly planed dedicated multiplatform studies in transnational waters in a harmonised way, and we need a structure for this.

A question that is still difficult to fully answer at this stage is how future JERICO-RI Supersites should be defined in terms of size and volume. We examined several types of PSSs, as exemplified in Section 3. Some were quite concise in terms of size, partners and platforms (e.g., CRETAN), some were a bit more complex, especially in terms of partners (e.g., GoF and NW-MED), while one of PSSs actually consisted of two neighbouring sea-regions with large number of partners (NSEA/CHANNEL). The latter could almost be considered representative of the region itself, while the others were clearly subsets of regional observations. Moving forward, we recommend starting with smaller Supersites, including a few locations, a few nations, and a few platform types, and expanding capacity as coordination and harmonisation develops.

What could not be explored during PSS, but which is vital to Supersites, is how the nations will actually commit to jointly coordinated transnational Supersites. Before moving forward, the question must be clearly posed to ministries and institutes (then eventually to EU directives driving national commitments), whether they are ready to finance such transnational observing systems that are ultimately cost-effective and with higher capacity, but not for all parts under their control.

7. OUTLOOK FOR JERICO-RI SUPERSITES

JERICO-S3 WP4 provided a study of coastal Pilot Supersites as a novel integrative framework for thematic and interdisciplinary regional collaboration, joint use of resources, and planning and executing common activities. Work was divided into five coastal regions and numerous studies were completed. PSSs have created new connections, transfer of technologies and knowledge, and scientific results within regions and between regions. Improvements were obtained in developing multiplatform sampling strategies and in integrating transnational observations including jointly with other RIs. The observations obtained are very diverse, as explained above, and the analysis of the results will certainly continue in the future.

To conclude the study, we present a few reflections for the i) main lessons learned, ii) additional needs for further integration, and iii) future vision, if JERICO-RI would like to include Supersites as key observing structures. We expect that these points and topics will be discussed among JERICO-RI partners while preparing the next ESFRI proposal.

Lessons learned

- The two-year period, even though the funding was insufficient, was enough to develop scientific cooperation and integrate research activities (though some activities would have benefitted from a longer study period). However, it was not long enough to find out very precisely how the national observation strategy should or could be changed so that the Supersite concept establishment would be possible. This needs to be addressed once we have a clearer vision on the JERICO-RI's structure.

- During the implementation period several observations were intensified in all PSSs. This taught us that maintaining a PSS at full capacity requires considerable effort, especially in terms of human resources. It was particularly challenging to keep all platforms running simultaneously at optimum operational level while providing QC data and feeding databases and models. However, the increased institutional effort required was balanced by the sharing of resources between partners, demonstrating the value of combining transnational and multi-platform sampling strategies.
- Observation gaps and deficiencies in methodologies have been better identified during PSS studies. To fill these gaps, Supersites need to be strategically planned, coordinated, and funded, and there needs to be good trust and communication between Supersite partners.
- Though the JERICO-RI community is working a lot towards harmonising methods, creating best practices and creating joint data products, there is still a lot of work to be done. More incentives and resources are clearly needed for this work.
- Although the PSS implementation study was largely based on the dual role of partners, as providers of RI and as the scientific community using it, working with external scientific communities (e.g., through TA projects) helped to define the Supersite role. Such communications should be increased.
- The JERICO PSS community greatly benefited from the sharing of expertise between PSSs. In certain cases, some experts were missing (e.g., physicists of hydrodynamic conditions, benthic biologists) who should have been included to better cover the expertise. To comprehensively develop RI operation and research, joint training and information sharing must be increased.
- The capacity of the multiplatform approach with extended EOV and EBV coverage was well demonstrated, despite the relatively small number of people directly involved in the PSS actions. Maintaining this capacity in the long-term is very challenging as sustainable funding for infrastructure maintenance (including staff) is a key gap. Long-term maintenance requires greater commitment from the scientific community, institutes, nations and funding agencies (sustainable funding and other resources).
- Although some assessments (e.g., eutrophication, oxygen indicator) were carried out and presented to stakeholders, overall, the societal needs and products that PSS could provide to stakeholders and end-users were not optimally explored/disseminated during the implementation phase - likely reflecting the low funding.
- Region-specific examples of good collaborations were identified, ranging from practical work and harmonisation to high impact science (e.g. land-sea continuum, multiplatform, experiments, observations). Regions are a good concept for JERICO-RI implementation, but it needs to be better specified (regional vs. European vision and vs. national vision) including key societal challenges. There is also a need to connect better between regions.
- The RI-RI collaborations carried out convincingly and cost-efficiently provided added value to all parties. The existing presence of PSS members in the key national and European marine RIs was crucial in this networking. These connection points allowed to identify overlaps and common goals, while highlighting that some gaps are due to lack of methodologies, or deficiencies in the spatio-temporal distribution of observations. This bottom-up approach for RI-RI connections needs to be aligned with a strategic top-down approach.
- New alliances have started to form (e.g., RI-RI activities, new projects), making use of PSSs. While thePSS demonstration period is over, the question remains how to take these activities further and build more connections (e.g., common workshops,

calibration exercises, joint project proposals). In this direction, TA projects have proved to be a useful tool for collaboration.
- Dissemination with clear objectives provided means that were helpful in promoting PSS activities. Promoting through different partners, channels, other projects and RIs with common interests, and making joint posts with other RIs and projects, allowed reaching a wider audience.

Needs for further integration within Supersites

- To better demonstrate the value of transboundary integration of national research infrastructures to meet the common needs.
- By demonstrating high quality science and user stories, Supersites could convince the partnership, and beyond, of the benefits of sharing and harmonisation. Such demonstrations may also attract additional countries in order to better cover poorly observed areas.
- Strategically, activities of Supersites need to be streamlined to fulfil the data needs from the EU policy realm and to interact with relevant expert groups in Regional Sea Conventions. Also, activities need to be streamlined with national and regional monitoring and observing strategies.
- Supersites should promote better integration of JERICO-RI with remote sensing and modelling communities, by providing key sites for collaborations and co-design of observations to the needs of these communities.
- Supersites should act as regional leads, and possibly as service providers, for sensor calibration, testing and validation.
- Also, Supersites should act as key regional sites working with industry, e.g., with sensor manufacturers, blue economy companies and consulting companies making additional observations. They should also promote the integration of new technology on in situ, in particular autonomous, platforms.

Future vision

Based on the experiences gained during the PSS implementation period we envision that JERICO-RI coastal Supersites in the future could become:

- focal points for the planning and study of complex, dynamic coastal phenomena, and processes with a co-design of multiplatform coastal observations and experiments, together with other RIs, and including modelling and EO.
- key elements in EOOS in providing consistent pan-European data and products for the most complex coastal research questions, and as tools to meet the most demanding international commitments.
- regional leaders in providing consistent and pan-European EOV/EBV data and products. Supersites could support the JERICO-RI to act as facilitator in implementing the workflow of reliable (tested, harmonised, ongoing) and transparent (accessible data & metadata) to European public data portals for all sensor observations.
- focal points linking RIs regionally, in particular for planning joint activities.
- regionally coordinated, flexible and modular transnational observation structures to assess emerging needs.
- test-beds for new technologies and reference systems for multiple variables and covering multiple environmental conditions.
- key points along the land-to-sea and air-sea interfaces, to improve observation capacities, best practices, and databases gathering/harmonisation. For the land-to-sea interface this will be done in close collaboration with the DANUBIUS Supersites. A further step in this direction is the recently funded EU project LandSeaLot, where JERICO, DANUBIUS, ICOS and EO communities join forces. For the air-sea interface this will be done in close collaboration with ICOS and ACTRIS.

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