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Deliverable abstract

This document summarises the results obtained during the GROOM II project. First, it defines the context in which GROOM II sits, i.e. what are the present and future observation needs, highlighting the challenges facing oceanographic research, underscoring the importance of a cohesive and integrated solution, and how it requires diverse observation methods to effectively capture oceanographic data. Then, it expands on how these requirements have shaped the current European Marine Research Infrastructure (MRI) landscape.

Second, If the capacity of Marine Autonomous Systems (MAS) to deliver high quality data at high spatio-temporal scale is now well acknowledged, to ensure a consistent and efficient use and uptake of the technology, the MAS community, and this is being more and more acknowledged by policy makers, believes that a GROOM RI harnessing the advantages of these platforms should be set up. This would fill the gap in the MRI landscape and support the activity to better face the observing challenges.

The GROOM II partners have designed the relevant RI capable to answer the growing need of a MAS related RI, and to respond to present and future aforementioned challenges. This distributed infrastructure will provide services to internal as well as external users, ensuring high quality, efficiency and optimisation of all related MAS activities. The added value lies in the coordination of the nodes and takes advantage of their expertise and capacity, avoiding duplication and providing economies of scale.

The added value has been thoroughly investigated, assessing if it overcomes the costs of GROOM RI. This document concludes that the services provided by the RI will enhance the EU MAS capacity, and bring sufficient added value for it to be relevant. This will in any case be closely monitored through a series of KPIs and KIIs.

GROOM II finalisation marks the end of the design phase of GROOM RI. Next steps have been described and assessed. If the governance and organisation will in the end be tied to the legal status of GROOM RI, the requirements to set up a functioning RI have been developed, looking at other RIs and at the specificity of the timeline of GROOM and its specificities.

Deliverable executive summary
The Ocean is facing Grand Challenges[1], requiring better knowledge of the mechanisms in place, which derives from more and better observations of the ocean. For at least a decade, MAS have played a central role in this process. They have become ubiquitous for observing the ocean, particularly with the multi-platform approach, providing high quality data across various spatial and temporal scales while minimising carbon footprint, and at relatively low cost. In Europe, the development of MAS operations is reaching its limits, and requires a more sustained and structured approach to support the rise of autonomy that is required. Stronger collaboration and coordination, setting common objectives and developing common tools is required to support operators all across Europe and increase quality and efficiency of the use of the platforms. GROOM RI will provide this needed coordination as well as means to develop common tools, based on a shared cyber infrastructure, acknowledged Best Practices, dedicated Training and Capacity Building, to support operations at base, at sea, and data management. GROOM RI will provide fit-for-purpose services to both internal and external users, for the benefit of Marine Frontier Science, Ocean Observing and the Blue Economy. Accessing GROOM RI services will ensure being part of the RIs ecosystem, which means that, among other rules, endorsed Best Practices will be used and clear costing will be provided, so that the services are of the best quality possible. Sharing of capacity through the services will allow simplification, standardisation and homogenisation, avoiding duplication. This added-value will cover the expenses of the central hub. Finally, GROOM RI will be embedded in the landscape, supporting MAS coordination activities (Oceangliders, EuroGOOS and OASIS), linked with both platform and thematic MRIs, to better support EOOS and GOOS/GCOS. The GROOM II design phase has proven the need of a GROOM RI and the interest of partners to join. More refinement will be pursued in the preparatory phase, of which the shape is being discussed right now by potential leading partners.

[1] Borja A., 2023. Grand challenges in ocean sustainability. Front. Ocean Sustain. 1:1050165. doi: 10.3389/focsu.2023.1050165

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List of Abbreviations

AUV	Autonomous Underwater vehicle
BP	Best Practices
EC	European Commission
EGO	Everyone's Gliding Observatories
EOOS	European Ocean Observing System
EOSC	European Open Science Cloud
ERIC	European Research Infrastructure Consortium
ESFRI	European Strategy Forum on Research Infrastructures
FP	Framework Program
GCOS	Global Climate Observing System
GES	Good Environmental Status
GOOS	Global Ocean Observing System
GOOS-RA	Global Ocean Observing System- Regional Alliance
GTT	Glider Task Team
HEI	Higher Education Institutes
KER	Key Exploitable Result
KII	Key Impact Indicator
KPI	Key Performance Indicator
MAS	Marine Autonomous System
MRE	Marine Renewable Energy
MRI	Marine Research Infrastructure
MSFD	Marine Strategy Framework Directive
NODC	National Oceanographic Data Center
NRT QC	Near Real-Time Quality Control
OASIS	Observing Air-Sea Interactions Strategy
OBPS	Ocean Best Practices System
OCG	Observation Coordination Group
OO	Ocean Observing
OOS	Ocean Observing system
PI	Principal Investigator
RPO	Research Performing Organisation
SDG	Sustainable Development Goals
SG	Strategy Groups
USV	Uncrewed Surface Vehicles

1. Background

The idea of setting up a glider community in Europe emerged in October 2005 and the EGO[2] (Everyone's Gliding Observatories) network was launched by several teams of oceanographers, inspired by the pioneering work of a group of American scientists who were themselves guided by Stommel's Vision[3], interested in developing the use of gliders for ocean observations and willing to set up a strong glider community. In 2005, EGO stood for "European Gliding Observatories", but it was decided in 2009 that it was more appropriate to rename it to "Everyone's Gliding Observatories" to reflect the international composition that was reached after only 3 years.

In 2010, a core group from the European EGO groups initiated two projects: GROOM and the EGO COST Action, aiming to progress towards establishing a European Research Infrastructure (RI) and a community for underwater gliders. The GROOM project was a design study supported by the INFRA FP7 pillar. It analysed the scientific case and the hardware and information technology characteristics necessary for a distributed European research infrastructure exploiting the highly innovative features of gliders in the context of Euro-Argo and EMSO, the two European Research Infrastructure Consortiums (ERICs) recently established in 2014. The focus was on sharing and optimising access to resources to operate gliders and the related R&D. This foundational work also aimed to meet in particular the needs of the Ocean Observing Systems (OOS), the Global Ocean Observing System (GOOS) and European Ocean Observing System (EOOS). The EGO cost Action analysed the desirable organisation of the user network and enabled the sharing of resources and expertise that were beginning to emerge in Europe at the time. This was materialised in a Memorandum of Understanding that brought together almost all the concerned European groups.

These initiatives were continued on certain themes with the creation of the EuroGOOS GTT in 2015, and above all the launch of the OceanGliders program, a GOOS associated program, in September 2016 to support active coordination, inclusiveness and enhancement of global glider activity for the benefit of GOOS. This effort has also helped lay the foundations for several projects considering a wider range of marine autonomous platforms in Europe, like Uncrewed Surface Vehicles (USV), while the landscape of marine Research Infrastructures (RIs) in Europe underwent an important mutation with the creation of networks or other RI projects such as JERICO RI and EuroFleets, in parallel with the consolidation of national RI policies.

GROOM II, a project funded under H2020 "INFRADEV-01-2019-2020 Design Studies", represents a continuation and expansion of these initiatives, which now includes other types of marine autonomous vehicles, and is embedded in a richer and more complex context of marine networks and RIs, with an increased number of stakeholders. In fact, it's worth noting that long-range underwater and surface observation platforms - today gliders are the most popular - hereinafter referred to as Marine Autonomous Systems (MAS), share many common features and are generally operated by the same organisations, a fact that FP7 GROOM had already anticipated and that H2020 GROOM II now sees as a coherent ensemble.

GROOM II defined in detail the components of a European Marine Research Infrastructure exploiting MAS, for excellence in scientific research, sustained observation of European seas and the global ocean, and innovation in support of the blue economy. It built on its predecessor FP7 GROOM and the history of the glider community (figure 1), took an in-depth look at the current organisation of European marine and environmental RI and how it is likely to evolve, as well as the different national dynamics and their RI roadmap.

[2] *https://www.ego-network.org/dokuwiki/doku.php?id=public:whatisego*

[3] *Stommel, Henry. "The Slocum Mission." Oceanography, vol. 2, no. 1, 1989, pp. 22–25. JSTOR, http://www.jstor.org/stable/43924447.*

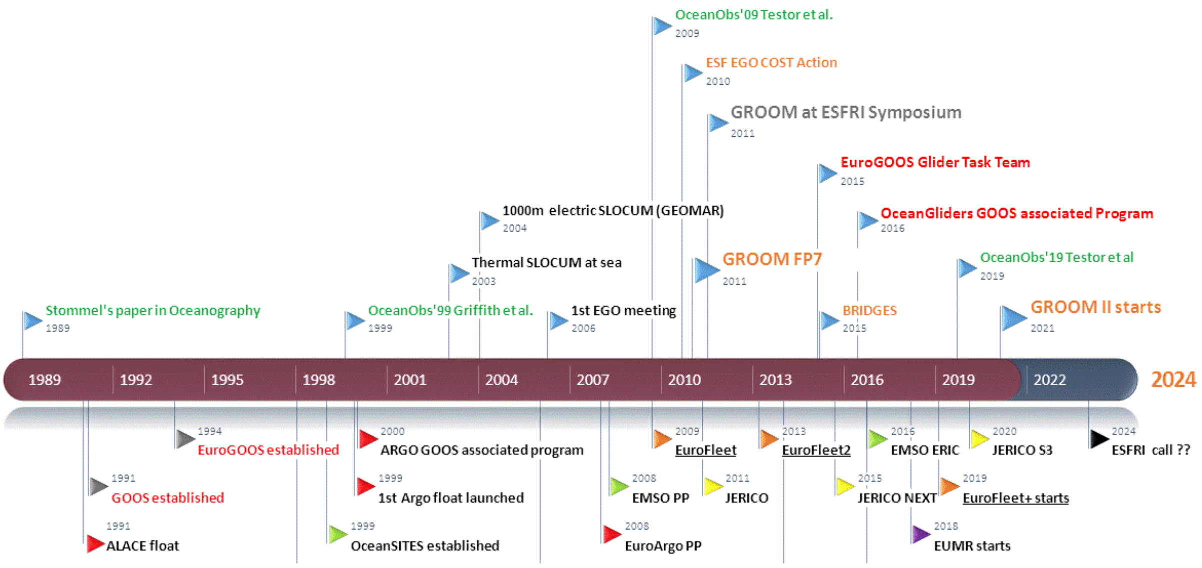

Figure 1: The GROOM history.
Above the timeline are the major events that have marked the development of glider (and more recently MAS) science, both worldwide and in Europe. Below, other key events relevant to this story or to other European MRIs.

By exploiting synergies and opportunities for collaboration or even integration with other RIs and possible industrial partnerships, it can thus contribute to the realisation of the European Research Area's common research and innovation mission and support countries' own needs. The project has thus defined the overall organisational structure of an infrastructure dedicated to MAS that responds to the European RI strategy as analysed in particular by the European Strategy Forum on Research Infrastructures (ESFRI) (see below), which the countries involved could support for implementation in the coming decade.

2. Context

92% of the carbon on Earth that is not locked up in geological reservoirs (e.g., in sedimentary rocks or coal, oil and gas reservoirs) resides in the ocean. This represents a major control on atmospheric CO2 and makes the ocean and its carbon cycle one of the most important climate regulators in the Earth system, especially on time scales of a few hundred years and more. The ocean also contains as much organic carbon (mostly in the form of dissolved organic matter) as the total vegetation on land. Primary production in the ocean, which is as large as that on land, fuels complex food-webs that provide essential food for people (IPCC, 2019[4]). Climate change relies importantly on understanding ocean physical and biogeochemical processes and their evolution due to climate change. Understanding and monitoring this evolution is the aim of Global Climate Observing System (GCOS) and GOOS, two observation systems that emerged after the 2nd World Climate Congress in Geneva in 1990 and have since been gradually consolidated as systems of observing systems based on national capabilities and an organisation based on meta-organisations such as the WMO and UNESCO.[5]

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[4] *IPCC, 2019: IPCC Special Report on the Ocean and Cryosphere in a Changing Climate [H.-O. Pörtner, D.C. Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska, K. Mintenbeck, A. Alegría, M. Nicolai, A. Okem, J. Petzold, B. Rama, N.M. Weyer (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, 755 pp. https://doi.org/10.1017/9781009157964.*

[5] *IPCC, 2013: Summary for Policymakers. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T. F., D. Qin, G.-K. Platter, M. Tignor, S. K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P. M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.*

Climate change also impacts the ocean, posing threats to ecosystems, economies, and cultures worldwide. With three-quarters of mega-cities situated along coastlines and 40% of the global population - 50% is foreseen in 2050 - residing within 100 km of the coast, the ocean holds immense significance for human life. Its diverse ecosystems are essential for our survival and well-being. This is the motivation behind Goal No. 14 "Conserve and sustainably use the oceans and seas for sustainable development", one of the 17 Sustainable Development Goals (SDGs) adopted in 2015 by the UN General Assembly, or a European directive such as the MSFD.

Sustained observations of the marine environment are crucial for understanding ocean climate, ecosystems, and human impacts. Efforts to monitor climate appropriately, and also to ensure the conservation and sustainable use of the oceans, and to achieve Good Environmental Status (GES) in Europe's seas, require comprehensive data and sustained observation mechanisms. The GOOS and the EOOS initiatives aim to align and integrate ocean observation capacities of operational services, research organisations and, increasingly, citizens.

Barely a decade after the emergence of GCOS and GOOS, and as the EOOS initiative was established, MAS - first gliders, then also uncrewed surface vehicles - had already become essential vehicles to carry scientific payloads for most environmental observations from the surface down to 6000m, together with other platforms such as research and opportunity vessels, profiling floats, drifting buoys and fixed points, the ensembles of platforms enabling in principle sufficient coverage of the spatial and temporal spectrum of ocean dynamics and variables to be monitored to allow, with satellite observations and numerical models, the analysis and forecast of the state of the ocean.

A sustained implementation of the so-called multi-platform approach, supported with wide collaborations and international data integration, facilitates real-time data accessibility and can dramatically enhance monitoring strategies. This approach has gained momentum in Europe, driven by increasing and more complex environmental needs, EU policies, continuous European support by Framework Programs for Research and Innovation (FPs), and technological advancements. But this type of integration requires at the very least precise and in depth coordination of observation systems and their operators, on a continuous and long-term basis, at global, European and national levels, in order to effectively harness the approach at its full potential.

In this respect, MAS are at the heart of this organisational challenge, thanks to their performance in the field and increasing innovative capabilities. MAS main contributions to the observing system are the mobility and steerability to tackle concrete ocean features, persistence to gather medium and long term high resolution time series and potential to deploy in large numbers at relatively low cost, increasing data spatial and temporal resolution. MAS can be deployed in sufficient numbers to provide a network of platforms and sensors that provides ample sampling capacities, at unparalleled space and timescales, both in open and coastal oceans.

In Europe, to achieve a coherent, optimised and sustained support in terms of infrastructure for marine research and sustained ocean observation, the needs for adequate Marine Research Infrastructures (MRIs) became rapidly obvious to the Directorate General for Research and Innovation and then to the member states. The ESFRI Roadmaps have largely contributed to setting up the MRI scene in Europe: three ESFRI landmarks partially or entirely dedicated to marine observation, ICOS ERIC[6], Euro-Argo ERIC[7] and EMSO ERIC[8], have been established as ERIC. In parallel, since 2010, the FP INFRAIA and INFRADEV calls have led to the development of series of European MRI projects such as GROOM (2 projects), JERICO (4), Eurofleets (3), and later EUMR, MINKE and EuroGO-SHIP (hereafter the 'MRI projects'). These MRIs, legally established either as ERICs or projects, can be broadly divided in two categories: platform-oriented and thematic. While the former concentrates on optimising the observation capacities, developing services to support operations and use of the platforms (Argo

[6] ICOS ERIC | ICOS (icos-cp.eu). The ICOS Ocean Thematic Centre (OTC) is the marine component of ICOS.
[7] Euro-Argo ERIC
[8] EMSO ERIC

floats, moorings, ships and gliders), the latter focuses on developing data products on specific themes (coastal zone multi-platform paradigm in JERICO RI, biology for EMBRC, carbon measurements for ICOS OTC). Both approaches combined provide a complete vision of the ocean observing needs, platform oriented RIs developing operational capacities, services and products taking advantage of the specificities of each platform, that can provide adequate FAIR data to thematic RIs that transfer these FAIR data into data products and knowledge oriented to their theme.

MAS are ubiquitous in the described multi-platform approach and the underlying technologies (robotics, sensors, artificial intelligence, big data, etc.) are rapidly evolving and increasing the overall capabilities. MAS uptake is all the more relevant to help reduce the Ocean Observing System carbon footprint as part of wider efforts to increase environmental sustainability. Efforts, such as the Future Marine Research Infrastructure (FMRI) program in the UK, aim to transition to carbonless operations through the development and increased usage of autonomous platforms in the integrated observing system. Because of these aspects, it is envisioned that by 2050 more than half of the ocean observations can be provided by MAS, shifting the paradigm of multi-platform ocean observation towards a mass autonomy provided by MAS along with the profiling floats of the ARGO program (figure 2. See also box 1).

In this general context, the line taken by GROOM II is that MAS must be represented by GROOM RI, a legal entity that can ensure the overall viability of the entire MRI landscape, and of course to guarantee efficient use of the systems and provision of services.

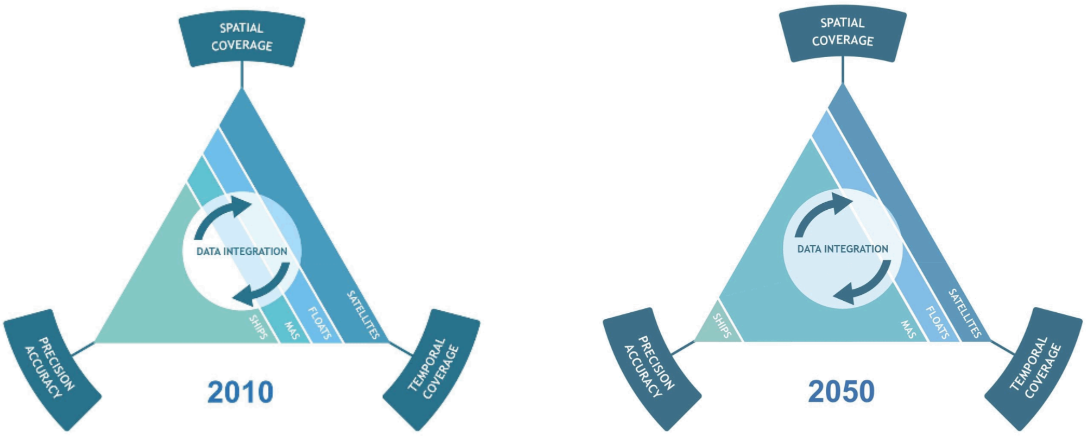

Figure 2: The rise of autonomy[9]
Prospects for the different sources of ocean observations (satellites, floats, MAS and ships) in 2010 and 2050 (from NZOC - the rise of autonomy)

To achieve these objectives, and to cope with the uncertainties surrounding the viability of an RI for MAS due in particular to the diversity of organisation and funding systems in each European country, establishing the foundations for structural collaboration and strong commitments between European MAS players was the main challenge faced by GROOM II.

The GROOM II project provides with GROOM RI the sustainable framework needed to offer the MAS services required by marine research in Europe, EOOS and GOOS, and beyond to economic players and society at large. It defines the components and organisation of a MRI as a legal entity at European level for MAS maintained by its members, and builds on established networks such as the EuroGOOS Glider Task Team (GTT) to ensure that all MAS operators in Europe (over 60 entities) contributing to EOOS and GOOS use the infrastructure services.

[9] https://fmri.ac.uk/fmri/sites/fmri/files/documents/NZOC-WP4-Report.pdf

Box 1: Net zero oceanographic capability and net zero ocean observations. The 2016 Paris Agreement set an ambitious target of limiting global warming to 1.5°C . To reach this target, global emissions will have to be progressively reduced to reach net zero emissions by 2050. Achieving these targets will require a substantial reduction in global CO2 emissions, and all CO2-emitting sectors are concerned.

The shipping sector is of course also concerned, and the 175 member countries of the International Maritime Organization (IMO) have agreed to reduce shipping emissions to zero by 2050. The national policies currently being implemented also concern research vessels. Several R/V operators are now integrating emission reduction measures and preparing the evolution of their fleets towards the goal of neutrality. The issue of reducing emissions from oceanographic fleets is also being addressed in some countries, such as the UK and France in the framework of the G7 Future of the Seas and Oceans Initiative (FSOI), by considering the more global question of reducing the carbon cost of ocean observations and research performed by R/V and other platforms.

Figure: A research vessel, powered by green fuels, becomes one part of a more complex, adaptable ecosystem supporting the research. Data flows from multiple platforms are used by multiple users.

The aim is to minimise the overall carbon cost of observations by considering the carbon cost of the platforms used, as a function of the quantity, spatial and temporal distribution and quality of the observations sought, to get a carbon cost of the observations themselves. It is clear, for example, that the Argo program's contribution to global observation of the first 2,000 metres to assess heat content has an infinitely lower carbon cost than equivalent observations collected by R/V, assuming of course that this is possible. This is the path explored by the Net Zero Observation Capability (NZOC) program[10] in the UK. NZOC has defined a methodology for assessing the carbon cost of different platforms according to energy source, distance travelled and other criteria. For example, a glider powered by primary batteries emits ten times more per km than a glider powered by secondary batteries.

This approach makes it possible to design OOSs with a minimum carbon cost. But this makes sense if OOSs are underpinned by a form of European or even global infrastructure that would allow more strategic approaches to OOS design, but also the stability for much-needed collaborations between operators involved in an OOS. Such an 'infrastructural' approach would allow inclusive planning and prioritisation processes. This could lead to an improved integrated design of the low-carbon OOSs to ensure that gaps in space, time or variables are addressed, that operations work optimally in the data value chain, including with forecasting systems and digital twins in order to meet more requirements and applications.

Reference: [D4.1 - Report on plans for an EU contribution to OceanGliders, the GOOS/GCOS and EOOS, and data delivery on a sustained basis]

[10] https://noc.ac.uk/facilities/ships/net-zero-oceanographic-capability

3. Why GROOM RI?

3.1. MAS - the platforms

The main advantage of a MAS is that it can be operated remotely, facilitating long lasting operations and limiting at-sea missions that can be dangerous, to perform a wide range of measurements with exceptional spatial and temporal resolution along its trajectory. And when deployed in large numbers over large areas and for long durations, they complement very efficiently other observing platforms that provide data with less spatial or temporal resolution, while minimising the carbon footprint of observations.

MAS technology, by bridging the time/space information gap, can provide the missing information to answer major scientific objectives (see OceanGliders Task Teams[11]), which are linked to the understanding of the coupled physical and biological ocean processes from observations at the right resolution and coverage, in particular in the coastal-open sea transition zone and other sub-sampled areas.

The adoption of MAS has steadily risen across academic, industry and defence sectors since the early 2000s. Indeed, their capability, paired with a relative affordability, has made them accessible to a number of scientific teams primarily focused on ocean physics and biogeochemistry. They were then integrated into the portfolios of research organisations and operators of GOOS, complementing other *in situ* observation platforms (ships, moorings, floats) to provide 'marine facilities' tailored to demand.

The continuous refinement of gliders includes the integration of new sensors and improved operational capabilities (such as larger ballast volume and 'back-seat' driver feature), at more competitive prices and with a lower energy consumption, providing longer missions and a wider range of data collection capacity. For example, one unique capacity being developed is for under-ice operations through acoustic positioning. There is also a growing offer of USV with different capabilities and still heterogeneous toolchains to operate them. There are many MAS and sensor manufacturers of very different sizes and structures, competing in what remains a niche market with a majority of small customers. This situation is not conducive to the emergence of standards for control and data interfaces.

This makes the use and the knowledge transfer from different teams complex, as they use different platforms, and develop their own tools to operate their equipment, which have to be adapted constantly. The lack of strong coordination and unification at a higher level prevents from using the full potential of MAS, as institutions cannot rely on off-the-shelf tools widely available to the community, which fragments the operations and makes it impossible to scale up activity by joining forces and simplifying operations. This complexity to start, develop and sustain an activity hinders the uptake of MAS at the scale that the OOSs require. Optimising operations remains challenging for various applications, particularly with different platforms and sensors, which can only be achieved through a sustained infrastructure.

The need for coordination and integration of technical tools has been recognised from the outset, and the community has got structured but without structuring funding, which prevents the effective development of modern common tools adapted to the challenge of mass deployment of MAS by numerous users with varied profiles. Nonetheless, some progress has been made, for example in standardising the real time data management, which was a vital necessity to ensure the flow of data to data centres in real time.

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[11] https://www.oceangliders.org/taskteams/

KER 1: A common cyber Infrastructure. The project GROOM II has addressed this “cyber challenge” by defining in detail the cyber infrastructure able to overcome it (see 4.5). Strong commitments at European level are now needed to make it possible to develop this cyber infrastructure, which is essential for extending the use of MAS and improving their cost-effectiveness.

3.2. The European MAS community

The efforts to create a glider community in Europe started after the first deployment in 2004, and key players in this community now have almost two decades of experience using MAS at sea. The activity has developed since, and nowadays, 19 European countries host 61 facilities, owning more than 200 MAS platforms (180 underwater gliders and 20 USV) and have performed more than a thousand missions at sea[12] (figure 3). Europe hosts one glider manufacturer (Alseamar, selling the Seaexplorer), and major USV manufacturers (Sailbuoy, Autonaut, Exail, etc). A number of manufacturers providing miniaturised sensors that can be installed on MAS have also emerged, including several spin-offs from research organisations that had developed sensor prototypes with the support of European projects. Some of these instruments are being widely used on gliders.

Within this timeframe, some countries have expanded their presence like Norway and Sweden, some, like the UK, have consolidated while others have stagnated or decayed, like France. But still, most activity can be described as laboratory programs pushed by researchers, with very few organisations ensuring sustained and medium- to long-term commitment to the MAS facility both for research programs and for sustained observation, which is believed to be the needed approach for more systematic and wide scale use of MAS, in line with the Policy Brief of the European Marine Board on sustained ocean observations[13].

The operators, at European and global levels, have early on understood the importance of collaboration and have launched initiatives to structure the community, and Europe has been a driving force at a global scale. GROOM RI will seek to interact and develop synergies with these initiatives, providing sustained funding and capacities to these powerful yet rather fragile groups of experts and non-experts, that are based on the goodwill of few scientists, which cannot really be pursued as is in the future and the development of the MAS activity. One of the greatest achievements lies in the efficient Data Management system that has been initially developed during GROOM-FP7.

Given the current landscape, the most relevant groups that need to interact with GROOM RI are the EuroGOOS GTT and the EuroGOOS Data Management, Exchange, and Quality Working Group (DATAMEQ WG). Furthermore, it is of interest to introduce and analyse how a GROOM RI best links to OceanGliders that is the global coordination body for underwater glider activities and is an accepted link to GOOS/GCOS via the Observation Coordination Group (OCG) of which it is a member.

Concerning USVs, while the technologies are evolving very rapidly, they are more recent and less mature. During the span of GROOM II, the will to form a surface vehicle community emerged, led at the international level by the Observing Air-Sea Interactions Strategy (OASIS) SCOR working group#162, the UN Decade OASIS project, while at the European level, support for consolidating the community came from the former H2020 EuroSEA project (2019-2023). This effort has been pursued by GROOM II to determine the actors, their capacity and ways to set up a lasting community.

A key question that GROOM II considered in this respect has been to identify commonalities that could be translated into common GROOM RI services for underwater and surface long-range vehicles, which are the autonomous vehicles grouped together under the acronym MAS and which are the central platform for GROOM RI. This progress needs to be continued and will largely depend on the structuring of the USV community at global level, and also on interactions with the meteorological

[12] Only deployments registered in the EGO database have been counted.
[13] *Sustaining in situ Ocean Observations in the age of Digital Ocean, EBM Policy Brief 2021*

services that are highly concerned by the USVs, but this work is crucial in order to avoid further fragmentation, which would be detrimental to integrated in-situ observation.

Figure 3: MAS facilities in Europe.
The interactive chart can be reached at https://www.groom-ri.eu/groom-ri-and-the-mas-european-landscape/. Some details show up when clicking on the flag of the facilities in the webpage.

KER 2: MAS community integration. GROOM RI must and can play a central role in leading and coordinating MAS actions in Europe, and ensuring that its services meet the needs of as many communities as possible. Collaborating with EuroGOOS, OceanGliders and other GOOS players to share the requirements and scientific knowledge needed for MAS operations, and best practice is a logical and feasible approach since most of the GROOM II project partners are active in EuroGOOS and OceanGliders.

Reference: D3.2- Financial sustainability at Regional, National and EU levels

3.3. The MRI landscape

Since 2007, the European Commission has been pursuing an active policy of developing MRIs through various initiatives and funding programmes, in collaboration with the Member States and ESFRI (Figure 4). It also reflects that Europe aligns with GOOS and its observing networks (Argo, OceanSITES, GO-SHIP, OceanGliders, …) that are mainly platform-oriented while more thematic and EU-specific RIs are also supported.

The aim has been to enhance scientific knowledge, foster innovation, in line with the European Research Area's ambition, consistent with support for sustainable use of the oceans and seas and related European maritime strategies and directives. Over the years, numerous initiatives, programs, and funding mechanisms have been established to support MRIs, for science, innovation and societal needs. This diversity reflects the complexity of marine sciences and the various needs that emerged from the research communities, but has also somewhat led to fragmentation, with different initiatives often operating in isolation. Close collaboration is in practice always difficult to achieve effectively, and, except for very recent initiatives (e.g. GEORGE, ANERIS, AMRIT Horizon European projects), integration is beyond scope for the moment.

Box 2: Profiling floats and underwater gliders complement each other for ocean observation. Observing the ocean from the coast to the ocean interior poses the challenge of ensuring the continuity of observations at the level of the continental slope or other critical regions such as straits. The Argo network, with the Argo core profiling floats and now even more so with Argo One floats, has demonstrated that it can monitor the key EOVs in the ocean interior on the spatial and temporal scales relevant for the general circulation.

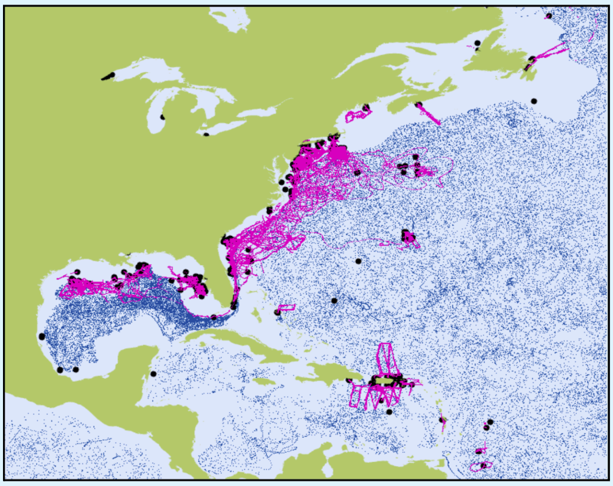


Figure: Distribution of Argo floats profiles (blue) and glider profiles (pink) along the eastern coast of America

In regions of highly variable bathymetry, such as straits or the continental slope, or in energetic areas such as boundary currents, or sub-mesoscales, a high density of Argo profilers is difficult to maintain. The figure shows the complementarity in the key region of the western boundary current in the North Atlantic. It also shows, off the coast of Puerto Rico, how the gliders can provide targeted observations in the region of generation of tropical cyclones.

In these regions, the use of gliders has become central in observing systems as soon as operators were able to ensure their continuous presence. This has led to the creation of the OceanGliders Boundary Ocean Observing Network and the 'Storms' Task Team to provide coordination for an efficient global observing program with gliders in the boundary regions or in the regions of tropical storms.

A first prerequisite for effectively harnessing the complementary nature of these two types of observation was met very early by adopting for the gliders in OceanGliders the data standards used by the Argo programme, which now makes it much easier to use these two types of data coherently.

Moreover, taking into account the global priority on the coastal ocean (SDG14, UN Ocean Decade), the 2021 ESFRI landscape analysis[14] highlights the need for "long-term observation to address transversal scientific and societal challenges acting at various spatio-temporal scales". More generally, it asks for a paradigm shift as the MRIs "have to evolve, be adapted and increase scientific knowledge and understanding" to better impact society, politics and industry. For that, the whole range of MRIs, platform oriented ones and thematic ones, have to work in synergy to meet the needs of their end-users. The development of new technologies, including remote-controlled autonomous systems, is also expected to deliver additional benefits from the RIs, according to this analysis.

Finally, the recent 2024 ESFRI landscape analysis[15], for the first time in such analyses, mentions that "environmental RIs also engage in joint activities with operational services providers. [...] Science-based operational information services (such as Copernicus, weather, and risk management services) rely on research results and RI service provision, especially in the areas of modelling and observation. Conversely, research communities take advantage of operational observations and model outputs in shaping observation strategies.". This is a key message for MRIs, as the majority of them are already engaged in such a dialogue, and use CMS and C3S services among others, but without any real formalisation, with Copernicus in particular, concerning the supply of observation data.

[14] ESFRI roadmap 2021 - strategy report on research infrastructures
[15] ESFRI Landscape Analysis 2024

From inside the MRI world, the issue of developing a structural cooperation framework between MRIs was targeted at the EuroGOOS conference in May 2021[16]. During this, several policy challenges and issues were identified. These included:

- The current ocean observing system landscape is very complex and there are several established RIs and ERICs focusing on different aspects of ocean observations, but not encompassing all the assets used today for ocean observation;
- Collaboration among RIs and ERICs is needed to highlight what can be achieved through this collaboration;
- The various elements of the ocean observing system are currently developing in kind of silos, and better coordination is needed.

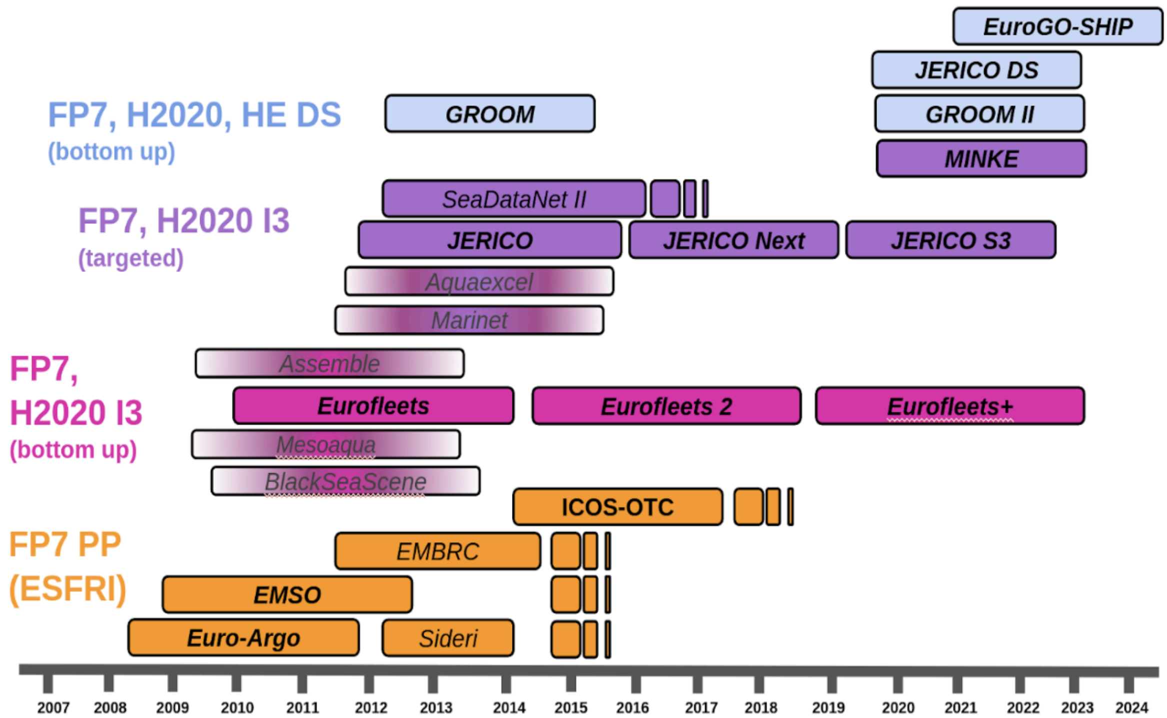


Figure 4: The European MRI history, leading to a fragmented landscape.
Adapted from "Reasons for the EU to optimise / integrate its research infrastructures in marine sciences?", Hervé Péro, INFRA/DGRI/EC, The future of the 21th century Ocean Conference, 2011, Brest, France

By not further investing in a MAS RI within the European Ocean Observation infrastructural landscape Europe risks falling behind other countries, notably the USA, where MAS have been widely adopted, with major benefits, for IOOS for example, the links between research and industry having been decisive in this. Indeed, it would be detrimental in terms of Europe's observational capacity, and would imply reduced scientific discoveries, missing operational and environmental benefits, limited technological advancements, and reduced international collaboration.

If one considers the space that these platforms occupy in the European observing capability today, and should have tomorrow, the lack of a MAS RI in the near future and beyond would be definitely noxious, and would become the 'missing link' in the multiform approach making it unattractive: MAS can expand the geographical footprint of fixed point observation (EMSO), operate in coastal waters (JERICO), start embarking carbon sensors (ICOS) and complement the ARGO observation array if deployed to sample oceanic phenomena that are not well covered by Argo floats which definitely provide a great spatial coverage but only at scales of 300 km and 10 days and can not operate well in

[16] V. Fernández, A. Lara-López, D. Eparkhina, L. Cocquempot, C. Lochet, I. Lips (Eds) EuroGOOS. Brussels, Belgium. (2021). Proceedings of the 9th EuroGOOS International Conference 'Advances in Operational Oceanography: Expanding Europe's Observing and Forecasting Capacity'. 3 – 5 May 2021. DOI: 10.13155/83160

the boundaries such as upwellings (see box 2). It would be all the more nonsense to develop MAS activities in these different existing MRIs, given that remote sensor operation is already being developed on the platforms they rely on. The cyber infrastructure for remote operation of systems at sea defined by GROOM II (see 4.3.2), some components of which are currently under development, would have a powerful role here in integrating the ensemble of MRIs.

The hypothesis of merging GROOM RI with an existing or planned RI might seem the most natural. It has in fact been examined since FP7 GROOM and reconsidered here, notably with Euro-Argo ERIC, EMSO ERIC and JERICO RI. In fact, it comes up against two major objections. As we have seen, these RIs are the result of a long process of design - and some have just started like for EuroGO-SHIP - around a scientific question and one or more platforms to bring together the concerned observations. However important this question may be, it covers only part of the spatial and temporal scales of oceanic processes (see section 4.2), and thus limits the scope of the RI. EMSO, for example, has studied the possibility of including gliders, but limiting them to an extension of observations around its fixed-point observatories. Similarly, JERICO RI includes gliders and already provides some preliminary services for their implementation and data exploitation, but limits their scope to the coastal ocean. The second objection is organisational, even political. To be in favour of merging RIs, the members of the various RIs must master several technologies and have a critical mass of personnel to implement them, develop services and conduct research around broader scientific issues. There are only a very small number of organisations in Europe where this would theoretically be possible, and in fact these same organisations form the core of the existing RIs presented above. The contradiction here is that it is these organisations that prefer to maintain the current silo structure. In conclusion of the report (section 8), we shall see that recent incentives from the EC and the evolution of global observing systems are likely to encourage organisations to overcome this contradiction, and that merging could eventually become a possibility. It is also likely that this merging process will be done step by step, in line with the needed integration of facilities at the national level which we see occurring now in some countries, which may have a leading role in the integration/merging process.

In view of the above, GROOM RI is definitely the indispensable final piece in this complex MRI landscape (figure 5): a GROOM RI and its services into the European MRI landscape would play a central role in complementing the existing RIs and platforms and expanding the overall benefit, as well as even offering the possibility of pooling certain services, as a very early step toward full integration and merging.

KER 3: Completeness of the MRI landscape and integration. To ensure the coherence of an integrated ocean observation capacity in Europe and its ability to address the challenge of ocean observation for society in a low-carbon world, it is crucial that a MAS RI is established in the current landscape. GROOM RI can then provide integrating tools and services that will benefit the whole community to conduct ocean observation operations on a very broad spectrum of problems, from fundamental research and sustained ocean observation to more applied monitoring.

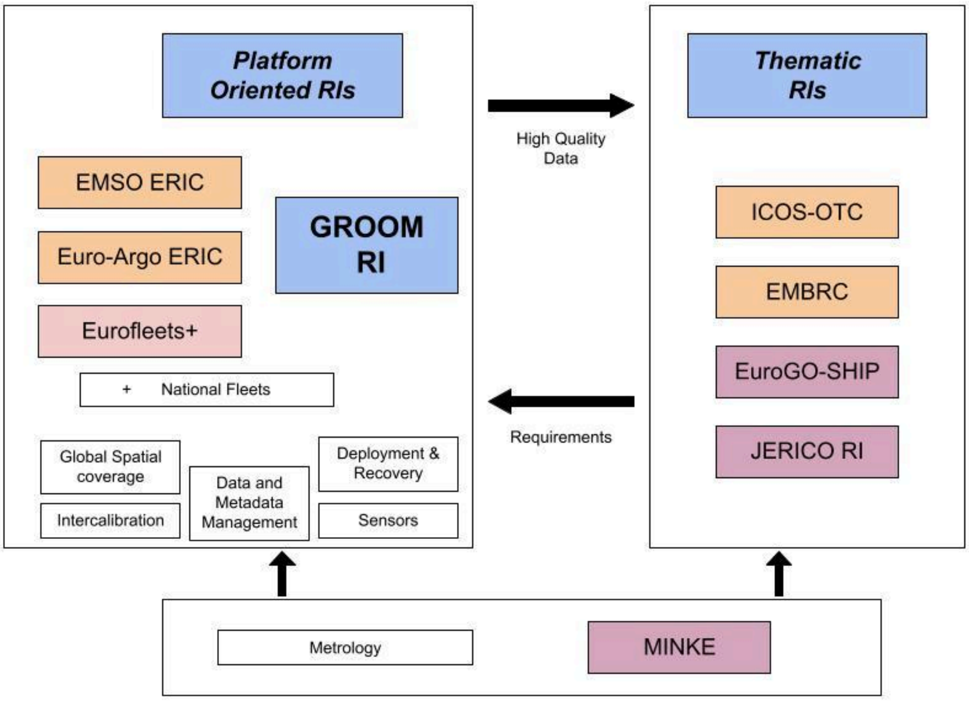


Figure 5: Synergies and complementarity between MRIs.
The figure illustrates a consolidated multi-platform approach at European level in which GROOM RI is the missing piece in the platform-oriented RIs, providing the required observational complete capacity in the multiplatform paradigm. Colours represent the legal statues of the MRIs. In orange are the ERICs, in light red is the AISBL Eurofleets+, and in purple are the landmarks that are EU projects.

Reference: [D2.2 - Integration of the GROOM RI at European and Global level]

4. What is GROOM RI?

GROOM RI is the distributed research infrastructure for MAS in Europe designed by the GROOM II project to demonstrate that the MRI landscape can only achieve completeness, coherence and efficiency with GROOM RI. GROOM RI aims to provide all the services required by the owners of MAS to implement them for research, sustained observation activities and beyond and also gives access to external users.

4.1. GROOM RI identity

4.1.1. Vision

Be the **European Research Infrastructure** harnessing the advantages of MAS to provide **high-quality ocean observation data and services** for the benefit of society, enabling scientific excellence and moving towards net-zero activities.

This vision reflects the fact that the trend - anticipated by H. Stommel as early as 1989 - towards mass use of autonomous systems that consume very little energy, has become a reality and is irreversible (figure 6). In action, it reflects the need to understand oceanic processes and to observe them down to the smallest scales, which is necessary if we are to understand and thus control the global threats to climate and biodiversity.

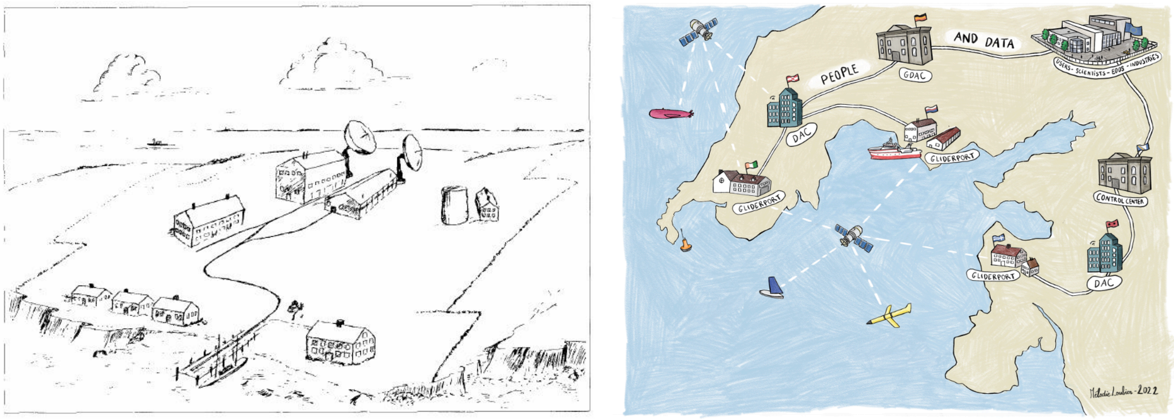


Figure 6: H. Stommel 1989 vision and today's GROOM RI vision.
Moving from the 'Slocum Mission Control Center on Nonamesset Island' envisioned by H. Stommel to GROOM RI vision of a distributed ensemble of 'gliderports', data and control centres, calibration and hardware facilities, and a central hub providing access to the users.

4.1.2. Mission

This European Research Infrastructure **integrates national infrastructures** for MAS to provide access to platforms and services to the broadest range of scientific and industrial users, as well as other ocean observing RIs. It maintains a **unique centralised provision of cyber-infrastructure, data and knowledge for the optimised use of MAS** to study climate and marine environments, and to support operational services and the blue economy.

GROOM RI's mission reflects the fact that, to be effective, ocean observation with MAS must be widely integrated. Some services, such as the cyber component, even need to be centralised at European level to enhance capacity and for cost efficiency. The parallel here with satellite operations is relevant because without centralisation the coherence of the system as a whole is impossible. Euro-Argo has already demonstrated this for the data component by centralising data collection in a single centre in Europe. GROOM RI faces both the challenge of reception of data - and the EGO community has already achieved a lot for that (see 'background' above) and the challenge of teleoperation by humans or AI agents.

By fulfilling this mission, GROOM RI makes this technology available to as many people as possible at a cost that benefits from scaling-up.

4.1.3. Objectives

The following objectives fully describe everything GROOM RI can offer. Because of the obvious and very strong technological driver in the field of automation and AI, these objectives also make it possible to move when relevant towards cross-platform integration of services relying on an IT infrastructures with advanced features, an evolution that seems desirable and unavoidable (see 3.3 - MRI landscape and 8 - Conclusion).

Objective 1 concerns the coordination of MAS activities with meta-organisations and other entities at European and global level, ensuring the coordination of research and observation activities, and the provision of the necessary services tailored to the needs of all organisations that operate MAS directly or which activity depends directly on MAS data.

Objective 2 concerns the development and supply of these services, which guarantee economies of scale and overall objectives that can only be achieved through the integration of these services, all of which, as we have seen above, are one of the underlying reasons for the creation of GROOM RI. It also concerns the development and provision of access to all the numerous technological developments that will affect the MAS sector in the years to come, so as to ensure that the activities of MAS users can evolve easily in the face of the wall of innovation.

1) **To be a fit-for-purpose infrastructure that:**
   a) **facilitates and harmonises access to MAS services,**
      i) acting as a common voice in connection with global efforts (GOOS, EOOS, ENVRI community, etc…),
      ii) co-designing common strategy, setting priorities, etc…,
      iii) mapping user requirements, creating external partnerships, and strengthening cooperation.
   b) **support MAS operations** tailored to needs of:
      i) research Performing Organisations and Higher Education Institutions,
      ii) observing platform operators in the coastal and offshore ocean supporting national and European RIs, in particular the ESFRI landmarks Euro-Argo, EMSO, EMBRC, ICOS OTC and JERICO RI[17],
      iii) ocean operational agencies, National Meteorological and Hydrological Services and the other operational agencies involved in marine environmental management, producing or requiring in-situ observations to improve operational models and services - this includes the European level with Copernicus Marine and Copernicus Climate,
      iv) enterprises in the blue economy who need support for MAS in particular for innovation in the related technologies and services.
2) **To deliver high-performance services by:**
   a) **providing efficiency and economy of scale,**
      i) integrating, facilitating and harmonising MAS activities within Europe,
      ii) developing a coherent organisation with exchange of world-class services between the infrastructure nodes,
      iii) developing shared / common IT infrastructure and data management system,
      iv) assessing legal aspects of operations and infrastructure use,
      v) progressing toward net-zero operations.
   b) **being the leader in MAS technology development,**
      i) monitoring the emerging requirements, acting as a catalyst in lobbying for the development and integration of new sensors and data value chain,
      ii) developing EU standards for mission planning and piloting, as well as for the preparation, maintenance, deployment and recovery of the MAS,
      iii) supporting training & capacity building and mechanisms for joint glider operations in the European glider community.
3) **To ensure high quality data production and good access to data through:**
   a) **developing shared Best Practices (BPs) and training for MAS operations, data collection, processing and dissemination,**
   b) **developing EU standards for sustainable data management systems,**
   c) **enabling a centrally managed dialog between data providers and data management systems to enable FAIR Data.**

[17] Today JERICO RI is a potential applicant to the update of the ESFRI roadmap, not a landmark yet.

Objective 3 focuses more specifically on the role of GROOM RI in guaranteeing that the quality of the data obtained from the MAS is maintained and that it flows seamlessly into the 'data lake'. This objective may seem implicit, but faced with the massive and very rapid transformation in data infrastructure at national and European levels, particularly its technical structuring and organisation, it is essential that GROOM RI can support its users to ensure that their data meets the required standards and that they can remain agile in the face of the challenges posed by these transformations.

4.2. GROOM RI Scientific framework

The GROOM RI scientific framework considers the contribution of MAS to scientific research in ocean and climate sciences - as well as to associated technological developments - in an international context that is the only one fully relevant to ocean observations. Indeed, this had already been analysed in depth during FP7 GROOM from the point of view of physical and biogeochemical processes. In GROOM II we have mainly considered the contribution of GROOM RI to research from the point of view of an infrastructure and services making it possible to tackle the 'Grand Challenges' that drive global research, such as the measurement of oceanic CO2 fluxes and marine biodiversity.

There are 2 MAS networks that are considered by GOOS. OceanGliders, a component of the integrated GOOS[18] was launched in 2016 and supports national, regional and global initiatives to maintain and expand the capabilities and application of gliders to meet key global challenges such as improved measurement of ocean boundary currents, water transformation, storm forecast and ocean health, as well as passive acoustics and data assimilation which are the identified scientific domains of application for glider data collection. For other MAS a scientific framework is being set up at the international level in the framework of OASIS to better study air-sea exchanges at the global level. Both networks fill great gaps, in the coastal area in particular, and align with the identified 3 GOOS application areas: climate, ocean health, and operational services. The GROOM RI we envision here provides systematic, focused, high quality data in this framework, and enables us to further develop the GOOS services.

In addition to long-term and sustained ocean observation, gliders and other MAS have demonstrated their capacities helping us to understand the ocean through many process studies, often involving fleets of gliders and other MAS combined with other observing platforms (ships, profiling floats, moorings…) and sometimes in very challenging environments (under sea ice, hurricanes). Equipped with several sensors and utilising the full spectrum of technologies (from managing different sensors to a fleet of heterogeneous MAS), gliders and other MAS can make possible a never-ending transition from traditional knowledge to frontier science.

Over the past two decades, numerous scientific experiments involving gliders and other MAS equipped with several sensors have been carried out with the aim to better understand the physical and biological interactions. With their capacity to simultaneously measure biological (through optics, active/passive acoustics, video, water samplers, and soon DNA probes), chemical (oxygen, nutrients, pCO2, pH, and hydrocarbon sensors) and physical measurements (temperature, salinity, currents, turbulence sensors) at high resolution, gliders and other MAS are indeed invaluable tools to study interactions between physical, biological and chemical processes. Noteworthy, gliders and other MAS have also been used in marine geosciences to study volcanoes and seeps. Figure 7 illustrates as a 'Stommel's diagram' the sampling capacities of gliders and other MAS with respect to the oceanic processes. Deployment strategies with a single platform or a fleet of platforms make it achievable to study all the oceanic processes that lead to fluxes of energy and matter in the ocean.

[18] Testor P. et al. (2019): Oceangliders: A glider component of the integrated Global Ocean Observing System, Front. Mar. Sci., 6:422 | doi :10.3389/fmars.2019.00422.

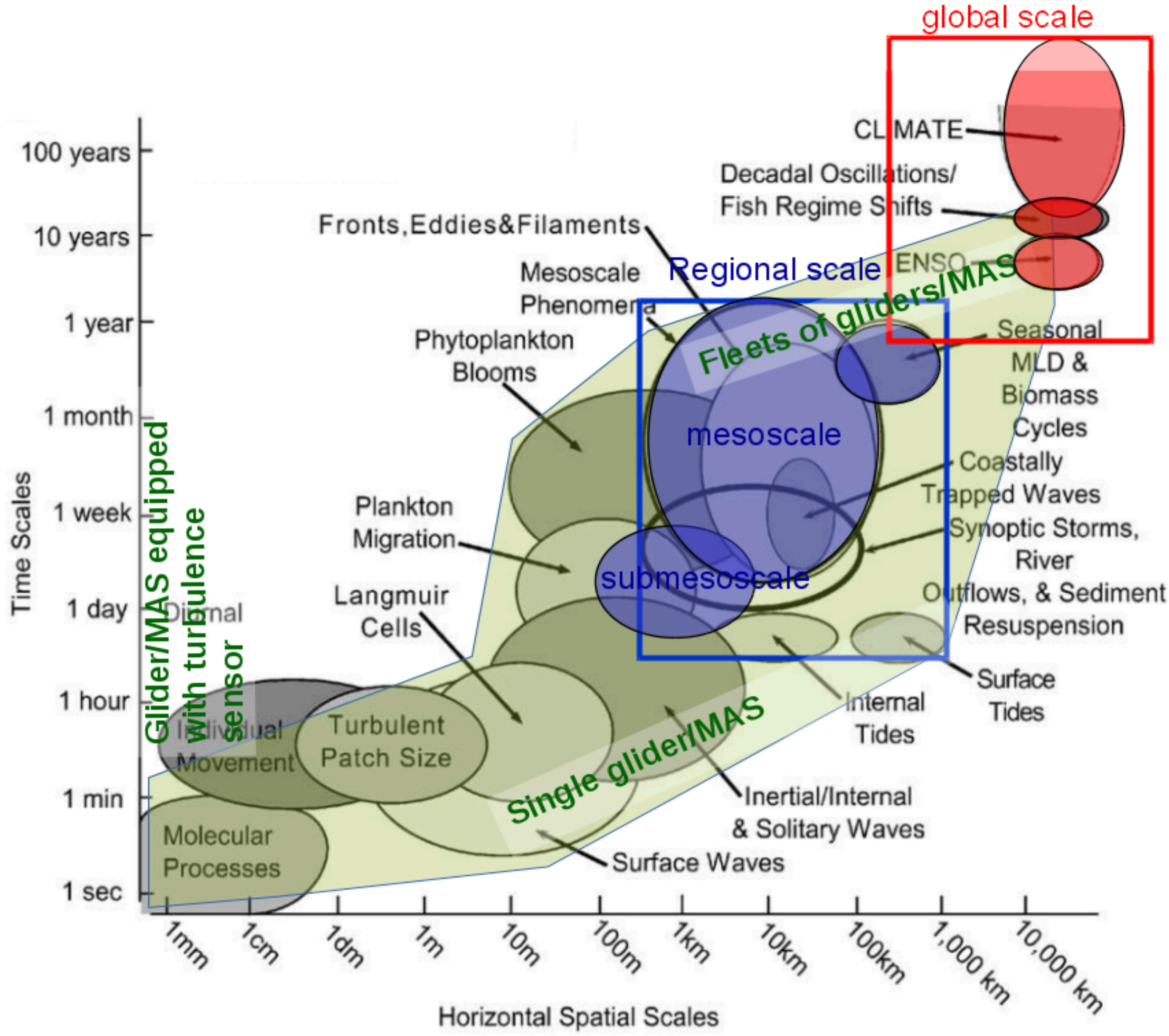


Figure 7: Stommel's diagram of time and space scales of oceanic processes (ellipses).
The regional and global scales are highlighted in dark blue and red, respectively. The light green area shows the sampling capacities of gliders and other MAS. Gliders and other MAS have effectively only been used during the last two decades and their sampling capacities are somehow cropped to 20 years but as time goes this will further expand.

Groups of gliders and other MAS ("fleets") can be deployed according to the observing needs. By making use of smart software, MAS fleets can operate in a coordinated and highly sophisticated manner. This opens a wide perspective for research but achieving such complex experiments needs a high level of cooperation which can be routinely achieved only with fleets of interoperable gliders and other MAS.

The scientific grand challenges that gliders and other MAS can address force today the ocean observing community to seriously engage into the world of bi-directional communications and interoperability. With the growing variety of platforms and sensors, it is beyond the capacity of isolated researchers to carry out long term observations or ambitious process studies. From the point of view of ESFRI RIs, which are generally supposed to act as service providers to researchers - in particular those services linked to bi-directionality, which can be also exploited by other RIs - and not as research institutions, GROOM RI's positioning is central in our view. By providing the full set of services that enable the multi-platform approach to deliver its full potential thanks to MAS, GROOM RI can enable European research organisations to position themselves on all the research issues of today and tomorrow. It should be noted, however, that there is one area that has received little attention in Europe, even though the technological potential is there: under-ice observation using gliders (and profiling floats) in polar environments. GROOM RI could certainly play an accelerating role here.

KER 4: **Coordination and interoperability for scientific research.** Gliders and other MAS, equipped with a diverse payload, can provide biological, biogeochemical and physical measurements. They also provide the capacity to observe the ocean at very small spatial and temporal scales over large areas and long periods of time thanks to their endurance and potential instrument rotations and deployed as a fleet, it is possible to observe almost any oceanic processes. GROOM RI provides the interoperability and coordination permitting to truly exploit this capacity by enhancing the deployment capacity, whether alone or in swarms.

References: D4.1 - Report on plans for an EU contribution to OceanGliders, the GOOS/GCOS WP4 and EOOS, and data delivery on a sustained basis ; D4.3 - Report on GROOM RI in contributing to statutory monitoring frameworks and maritime/naval information

4.3. GROOM RI Technical framework

The GROOM RI technical framework considers how the cohesive integration of existing national technical infrastructures into GROOM RI not only generates added value in terms of operations and cost reduction, and facilitates access to GROOM RI facilities, vehicles and services across Europe and beyond, but also contributes to making the marine research utilising MAS possible. Indeed, the adoption of a consistent set of tools and procedures provided as services by the RI can help maximise and harmonise data quality between partners and users, which is GROOM RI's ultimate technical objective with MAS. By enabling the full range of technical services required for MAS operations to be integrated at the European scale, this framework can then support marine frontier science and ocean observing efforts, establish services adequate for Public policies, Market & Innovation and facilitate the relation with ESFRI landmarks and other marine Research Infrastructures and finally GROOM RI Governance and Financial sustainability (see below section 6 and 7).

The design aims to provide an agnostic technical framework to support GROOM RI, that is generic enough to complement and impact other EU Ocean Observing RIs, helping cross RI collaborations and integration. The framework offers an inclusive and unifying vision to integrate the MAS technical activities necessary to observe the ocean considering also the wider synergies with other Ocean Observing platforms and communities.

The GROOM RI technical framework is built with four pillars mapping the key activities for the lifecycle of MAS operations and two horizontal cross cutting workstreams, cyber infrastructure and BP to bring coherence to those activities (figure 8). The GROOM RI services will be built on this technical structure, considering user requirements and generating FAIR data. The framework modularity should help to distribute activities across different nodes and facilities.

A MAS-Workflow operation has been modelled in parallel with the framework, as shown in the figure 9. The workflow captures the lifecycle of MAS operations and matches each step with the corresponding colour in figure 8, demonstrating the activities that the technical framework will focus on.

Any operation begins with campaign design and resource allocation. These activities are part of program management, and a GROOM RI coordinating resources across the RI must lead first to better resource utilisation by coordinating nodes and enabling them to share underutilised resources.

Activities involving hardware, preparation, deployment, piloting, recovery, transport, and refurbishment are already developed, with multiple operators having considerable expertise within the boundaries of a future GROOM RI. Yet, solutions have been developed in silos and prevent a robust and optimised interoperability and adaptability of the operations. GROOM RI by developing a cyber infrastructure can provide shared tools that will enhance the overall capacity.

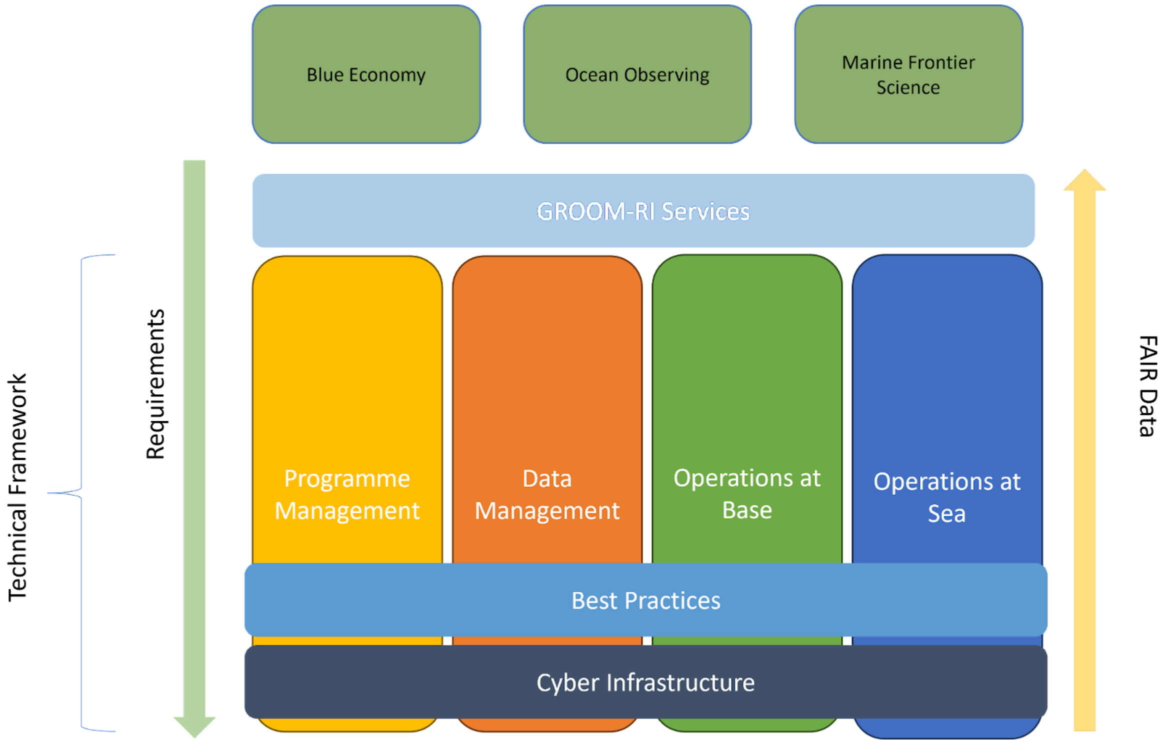


Figure 8: GROOM RI technical framework.
The figure shows very schematically the functional organisation of the envisioned technical infrastructure. The colours in the stick diagrams illustrate sets of functions, each corresponding to a pillar. These same colours are used in the following figures.

GROOM RI with dedicated resources focusing on the Nodes' adoption and use of BP in all these areas can thus have a transformative capacity across Europe. These activities correlate with the operations at base and sea.

Finally, data management activities run in parallel with many of these activities. They are more mature and formalised in the entire framework, as they have been performed and developed for years in multiple European projects. However, even with this in mind, a future RI will enable these activities to thrive and cope effectively with the massive increase in the flow of data and maximise its value as soon as it is received (see box 3).

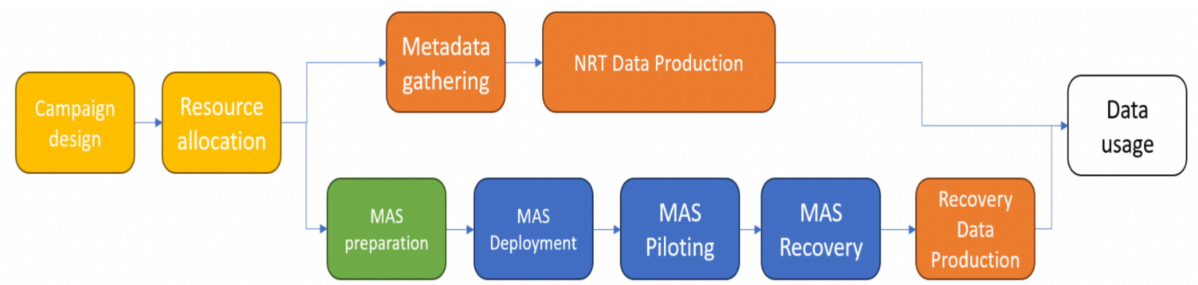


Figure 9: The MAS Workflow
It illustrates the activities needed around MAS operations, linked to the framework pillars

Box 3: The challenge of managing mass observation of the oceans. The World Ocean Database (WOD) is the world's largest database of ocean profile data. The data is uniformly formatted, quality controlled and publicly accessible. It is the reference tool that shows how more than 20 years of coordinated effort to incorporate data from institutions, agencies and individual researchers into a single database creates a unique service for oceanographic, climate and environmental research. It is maintained by NOAA's NCEI.

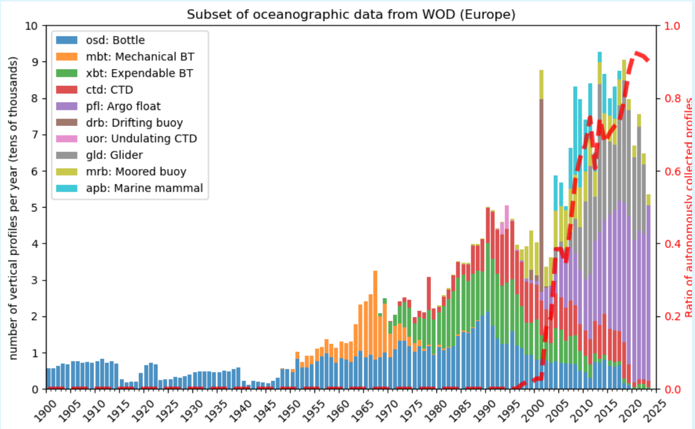
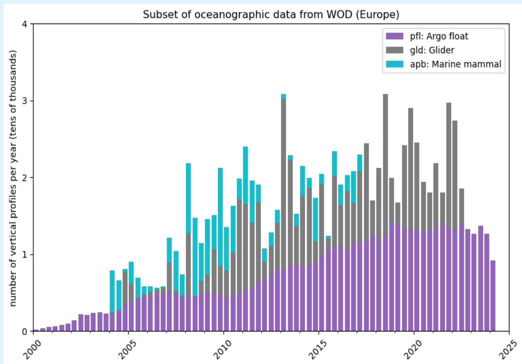


Figure: number of observations (vertical profiles) by the different types of platforms collected by European organisations (source: World Ocean Database). The red dotted curve is the ratio of profiles collected by autonomous platforms over the total.

The figure shows the number of observations originated from European organisations. From the 2000s onwards, the deployment of the Argo network led to a very significant increase in the number of observations, soon followed by those made with gliders and, more recently, animal borne observations. This growth is accompanied by a decline in the profile collected from R/Vs, particularly XBTs. The decline from 2020 onwards can no doubt be attributed to the COVID pandemic and other economic factors such as fuel prices.

It also indirectly demonstrates the effectiveness of data management. In the case of Argo data, by building the network with a very small number of DACs, the distribution of data - that are real time ones - is very efficient and reaches the WOD without delay. In the case of gliders, there is a very large number of operators who, for the most part, collect, process and distribute the data themselves. Many are not connected in real time to national or global centres capable of distributing data rapidly, if not in real time. As a result, data are collected by the WOD with a delay of around one year, as can be seen from the decline in the number of data items in 2023 and 2024.



Zoom of the figure above with only profiles from autonomous mobile platforms.

KER 5: **A technical framework to improve operation and cost efficiency.** The GROOM RI technical framework improves operations and cost efficiency, maximises data quality and harmonisation, and supports Marine Frontier Science and Policy.

The framework represents a significant advancement in the integration and optimization of MRIs in Europe. By providing a cohesive, modular, and comprehensive set of tools and services, it supports high-quality marine research and fosters collaboration and innovation across the scientific community and beyond.

Reference: [D6.1 - Technology roadmap of GROOM RI]

4.3.1. Best Practices

"A BP is a methodology that has repeatedly produced superior results relative to other methodologies with the same objective: to be fully elevated to a best practice, a promising method will have been adopted and employed by multiple organisations"[19]. Developing, converging, and adopting MAS related BP has been a major challenge of the European and worldwide MAS community and beyond, aiming at improved quality, harmonised and facilitated activity. OceanGliders community has started BPs related to variables (O2, Salinity, currents,...) that cover all the technical aspects for operations and data management. These BP can cover:

- **Operation checklists**: (pre) launch, (pre) deployment, glider shipment, mission, recovery, piloting, site selection, quality assurance;
- **Equipment performance**: Calibration of sensors, compasses etc, sensor sensitivity, power requirements, platform autonomy etc.;
- **Metadata and data standardisation:** from operations on land/at sea to data processing and dissemination;
- **Communication and sharing, agile processing**.

Implementing BP is a long process of development, it is a community process that requires a lot of energy to get BP convergence, adoption/endorsement and publication to happen. As of right now, the BP in their actual state lack sustainable funding and that creates a:

- **Lack of discoverability**: Certain organisations or groups have internal documents and methods that have not yet been published or tested by other organisations;
- **Lack of convergence**: Going from a pile of technical operation procedures to a coherent, inclusive but yet concise methodology document that is holistically accepted, is perhaps the most difficult bottleneck in this process;
- **Lack of continuity**: The review and endorsement process might span over several years. Staff changes, the end of funded projects and other changes halt progress and impede the BP setup;
- **Lack of moderation/leadership**: The fragmentation of efforts between short-term projects, different EU Directorates, and regional and international bodies decreases efficiency and results in duplication of effort and contradicting results.

For GROOM RI, the BPs are a horizontal workstream that can be established and maintained effectively, enhancing consistency in operational areas. GROOM RI will provide endorsement of the BP, and ensure that all its operations follow these BPs (adoption) to ensure maximum quality and performance. GROOM RI will also contribute by creating new BP, such as BP for the use of the GROOM toolbox, or pushing less mature fields (surface vehicles for example).

The endorsement of the BP by GROOM RI follows the standard approach of the IOC-Ocean Best Practices System (IOC-OBPS)[20], which is ideally suited to the purpose, and should be made known to the EC with a recommendation to include the BP in a future EC-moderated Ocean Observations BP platform[21]. GROOM RI's endorsement of a BP could help it become part of directives (such as the Water Framework Directive and Marine Strategy Framework Directive) and EC recommendations for collecting ocean data.

Without the coordination support that was provided through EU-funded projects, namely GROOM II and EuroSea on OceanGliders BP, the development of BP stagnates. GROOM RI should fund and host some FTE to power up the community. The development of these must be done in conjunction with other European Infrastructure initiatives and international coordination initiatives, such as the

[19] https://www.oceanbestpractices.org
[20] https://www.oceanbestpractices.org/
[21] EC/DGMARE has launched a call for tenders for the development of an information system for assembling and disseminating best practice and standards in ocean observation.

IOC-OBPS project and the global underwater glider coordination group OceanGliders. GitHub and other community-driven tools are central and must be considered to avoid work replication, and enable active collaboration of a large group of users, eventually leading to efficient BP adoption by the community.

KER 6: **Support BP effort.** By providing means for developing, implementing and endorsing robust BPs, GROOM RI will significantly enhance the efficiency, reliability, and quality of MAS operations, fostering a more integrated and collaborative marine research community.

Reference: D6.3 - Best Practices for Data Management, Operations, Maintenance and Fault Reporting

4.3.2. Cyber Infrastructure

A common issue across organisations operating and managing MAS in Europe is the lack of dedicated, coherent and fit-to-purpose cyber infrastructure, a digital environment in which to operate, pilot, and maintain all MAS fleets. Most organisations lack the resources to develop quality software, and the few that can do this do it in isolation, creating software that is not interoperable, like maintenance databases or some basic MAS automation. Organisations also lack human resources to develop operational infrastructure. Some endemic problems prevent the development of more solid cyber infrastructure:

- lack of standards and interoperability of MAS ecosystems;
- lack of resources to maintain, run, patch, and update IT systems;
- lack of open-source tools for command and control of MAS from most manufacturers or institutions.

The lack of support for a shared piloting and cyber infrastructure to support field operations is not an unattainable problem, European initiatives have produced common cyber-infrastructure to support scientific communities. We can cite some flagship initiatives:

- the Global Glider DAC at Coriolis, as the central distribution point of glider data for Europe;
- the ARGO DAC, implemented by EuroArgo, which nowadays does not only deliver QC data, but provides user-friendly tools to search for datasets;
- and closer to the services GROOM RI could provide, there are the cyber-infrastructures to operate distributed arrays of astronomy telescopes, including marine telescopes, that need complex remote operation, such as the marine KM3Net Neutrino Telescope, or in the industrial world, the infrastructures to operate autonomous uncrewed aerial vehicles Swarms, such as AeroStack.

All these initiatives have some commonalities; one, they aim to provide high quality distributed cyber-infrastructure for a large number of users, and two, they are all about acquiring and/or distributing data. These two points are key here, and GROOM RI aims to provide cyber-infrastructure from a different angle, providing piloting services and support for field operations while also relying on the existing infrastructures for data distribution.

The key recommendations:

- GROOM RI must create a Cyber Infrastructure and Command and Control Working group;
- GROOM RI must find sustained funding to deliver a community-driven command and control ecosystem;
- GROOM RI must design an open autonomy ecosystem to allow scaling up autonomy;
- GROOM RI must push international standards to enable the interoperability and integration of MAS C2 systems, collaborating with important players in this field;
- GROOM RI must develop all the autonomy ecosystems as individual containerised portable solutions that can be used standalone;
- GROOM RI must develop the autonomy ecosystem in a way that is easy to deploy and use by non-DevOps users; for example, a non-expert user should be able to deploy the systems as

services in the European Open Science Cloud (EOSC) with a couple of clicks;
- GROOM RI to become an EOSC provider of digital services;
- GROOM RI should amalgamate the existing expertise and know-how from the already existing ecosystems and use them as the base of the new GROOM RI infrastructure;
- GROOM RI must demonstrate the added value to communities with demonstrators of coordinated multi-institution deployments of MAS operated using the GROOM community tools.

Interfaces and methodologies for mission planning and execution

One of the most innovative and revolutionising aspects of the GROOM II work is the design of an Autonomy Ecosystem Architecture to help with the piloting and the adoption of MAS platforms.

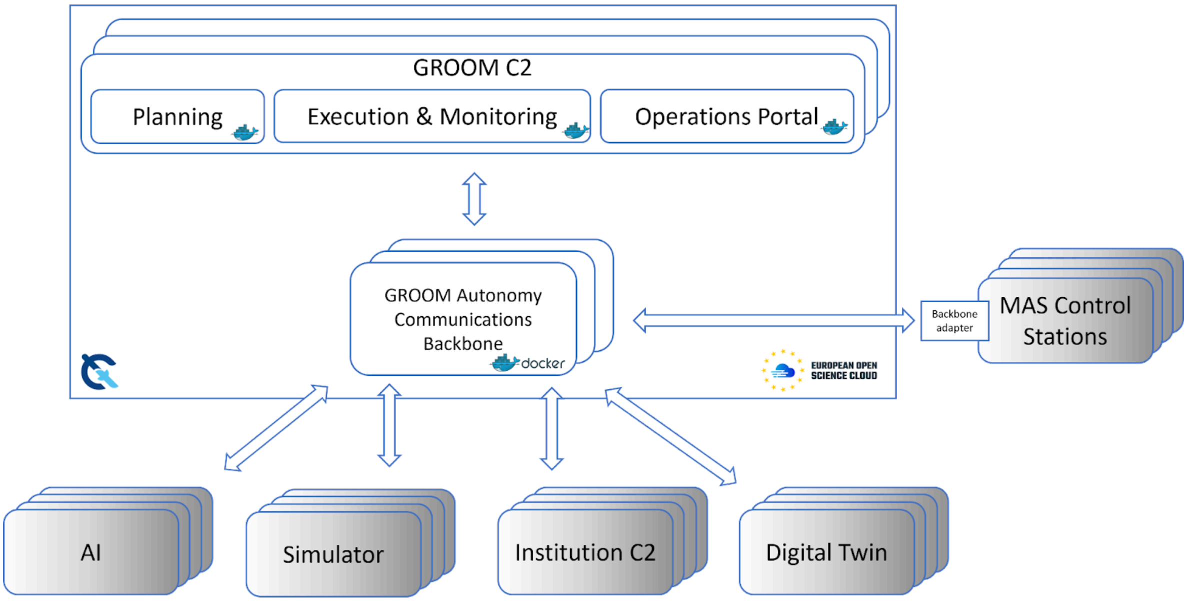


Figure 10: GROOM Autonomy Ecosystem Architecture.
It envisions a series of systems (in the middle) developed by GROOM RI, providing piloting tools and facilitating the integration with other systems developed and maintained outside of the RI (grey boxes).

The design's primary goals are to facilitate the adoption of better piloting tools, collaborate on mission planning, help distribute piloting, and increase the uptake of AI systems. The ecosystem must also help reduce the need for dedicated IT for smaller groups and ease system integration tasks.

In the diagram, the grey boxes are part of the GROOM ecosystem but are not necessarily developed and maintained by GROOM RI. The Autonomy Communication Backbone enables the integration of components to interoperate and communicate while reducing the coupling of systems.

The figure 11 shows an example workflow of an imaginary operation; nowadays, that kind of distributed operation requires the different partners to exchange plans using emails, attaching the plans to heterogeneous formats like Word documents, KML files or any other format. There is no single point in following the piloting or exchange and tracking operational decisions.

KER 7: A cyber infrastructure to enhance operational capacity. By developing a comprehensive cyber infrastructure, GROOM RI significantly enhances the operational capabilities, interoperability, and scalability of MAS operations, fostering a more integrated and innovative marine research environment.

Reference: [D6.4 Interfaces and methodologies for mission planning and execution]()

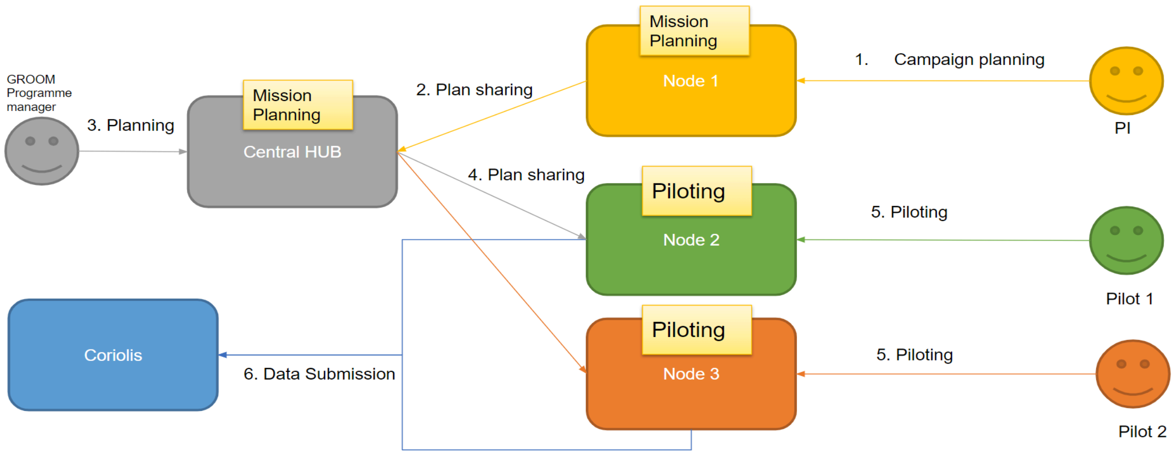


Figure 11: Example of a multi operator workflow within GROOM RI, each colour representing a different node.

4.3.3. Programme management

Programme management is the framework's first pillar. It will improve operations at sea, optimise resources within the network, and potentially help with cross-node piloting, as organisations can offer and request those resources. The same can be said about sharing cyber resources like proprietary control stations. Programme management will be led by the Central Hub in conjunction with the correlated nodes.

4.3.4. Data management

MAS, and GROOM RI, the data system is rather complex with real-time data during in-field operations and, with recovery of the devices and applications of advanced delayed mode quality control procedures. On the vehicles, a variety of different sensors are being operated and very specific and dedicated data quality control procedures are required. In addition, the initial data recovery is in the nation's hands and thus has to eventually follow the country's data archiving requirements. In that sense, it is not really comparable with Argo/EuroArgo, a system entirely built upon real-time data and thus concentrates on advanced real-time data quality control procedures and uncertainty estimates. Moreover, the real-time data is provided via almost unique communication centres via Argos satellite data single-point delivery; marginally, few teams use Iridium satellite communication for changing the sampling rates of the floats.

For MAS, the bidirectional link is not an option, and each operator has its own communication centre, which is central to the operations and considerably changes the situation. GROOM RI data management will enable harmonisation through agreed metadata and formats across nations/PIs and create close links with National Oceanographic Data Centers (NODCs), EMODnet, Copernicus Marine In Situ TAC and other Data aggregators. GROOM RI will further enable EU/global data and metadata harmonisation through established and used Best Practices, and the development of common tools established in line with EU data groups (NODCs, Seadatanet, EMODnet, Coriolis, etc…)

All these GROOM RI developments will be disseminated and spread to the wider MAS community through participation in the EuroGOOS GTT and DATAMEQ WG.

Reference: [D6.2 - Data management roadmap for the GROOM RI](#)

4.3.5. Operations at base

Operations at the base are all physical activities around the platforms between deployments. These operations can include vehicle refurbishment, sensor calibration, or sensor integration. All the institutions operating gliders and other MAS traditionally perform these activities. However, consistency across the nodes is challenging to solve from an RI angle.

We can summarise the operations at the base in the following activities:

- MAS refurbishment and preparation involves all activities required to prepare the MAS platforms for an optimal state to be deployed;
- sensor calibrations, either in-house or sent to a calibration facility;
- sensor integration, if new sensors are required for operations;
- transports: Sometimes, the platforms must be moved around facilities for refurbishment or calibration or deployed in different parts of the planet.

Each facility currently performs all these activities, and there needs to be more consistency across them; for example, while NOC, GEOMAR or HCMR will all refurbish their gliders and operate them, they are not guaranteed to be prepared for the same specifications. If GROOM RI wants to provide consistent datasets, all the platforms and sensors must be ready to be equivalent to the accepted levels by all GROOM RI partners and the user community. This is the role of the GROOM-RI Best Practices described in D6.3. The BPs are a horizontal workstream that brings harmonisation, and having GROOM RI endorse BP paired with the cyber infrastructure will provide the needed consistency.

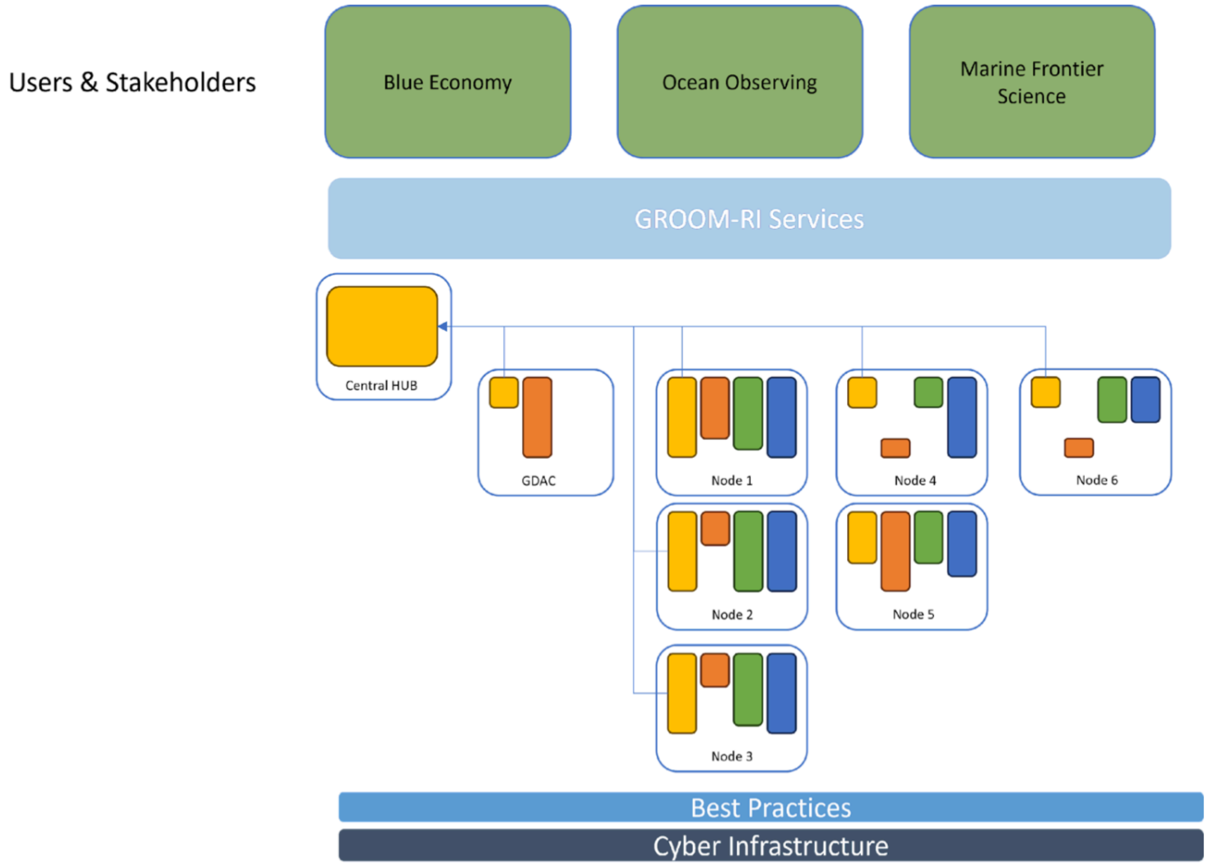


Figure 12: Technical framework assembly.
The length of the sticks in the diagrams symbolises the node's greater or lesser ability to contribute to the concerned pillar.

4.3.6. Operation at sea

Deploying and operating gliders and other MAS are central activities as they require resources to go to sea and to keep operating the platforms once deployed. There are several areas where GROOM RI makes significant contributions to improve the current state.

As in previous points, having endorsed and agreed on best practices for the deployment and operation of MAS will provide consistency in the data delivery and certainty to field and remote operators on what to do at any stage.

Regarding piloting tools and automation, GROOM II has dedicated two tasks and one deliverable (D6.4) to studying the matter. GROOM II is designing an ambitious open cyber infrastructure and software ecosystem to improve the current landscape.

Reference: D6.4 - Interfaces and methodologies for mission planning and execution

4.4. A distributed infrastructure

To set up this infrastructure, the future GROOM RI must capitalise on already in place actors. The capacity is scattered among all the MAS operators in Europe, and GROOM RI, adding a coordination and direction level (the central hub) to the participating agencies (the nodes) will consolidate the European capacity and avoid duplication of efforts, leading to an effective provision of integrated services over several nodes. By dedicating resources to GROOM RI, and with the central hub ensuring the complementarity and coordination of the contributions, all the building blocks of GROOM RI will be provided, ensuring a complete technical framework and a full capacity. Each node will provide a fraction of the total GROOM RI, as shown in the following figure 12.

This results in a distributed infrastructure, based on a central hub acting as an access point and coordinating the nodes, as symbolised in the following figure 13.

4.4.1. Central Hub

The **Central Hub** is key to delivering the operational programme, and engages in the following activities:

- coordination of node activities, to ensure alignment with the European directives (MSFD, CFP, etc…) and support to EOOS and GOOS;
- support to the Nodes in their activities;
- RI services entry point for external users;
- KPI monitoring to assess the activities and the effectiveness of the RI;
- dissemination & outreach activities.

4.4.2. Nodes

The **Distributed Nodes** are the participating Agencies, and will engage in providing one or more of the following resources:

- expert personnel, to ensure scientific and technical domain knowledge, ensure highest data and operation quality, and foresight for improvement of the RI;
- provision of expertise to develop MAS activities in Europe (in terms of observation needs, technological gaps, etc…);
- specialised workshops, to build, develop and spread capacity within the whole RI;
- vehicles & sensors that can be accessed by other partners of the RI;
- sea access and logistics to enhance operation capacities;
- IT and physical infrastructure for operation, support and innovation;
- data flow and management, to ensure FAIR data.

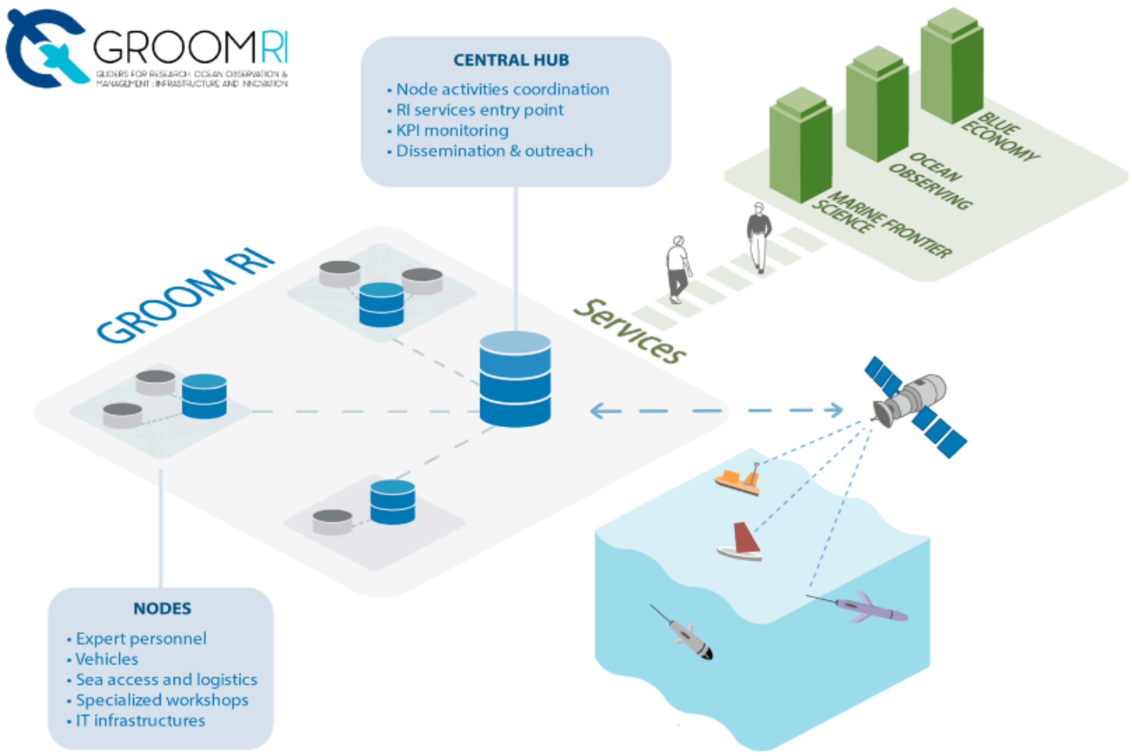


Figure 13: Overall GROOM RI's distributed architecture for the benefit of Marine Frontier Science, Ocean Observing and Blue Economy.
The square grey nodes correspond to each member country. Within the square, the facility symbolised in blue is the national focal point or 'lead GROOM national entity' which coordinates the other 'GROOM national entities' symbolised in grey according to the rules or practices in force in the country.

5. GROOM RI Services

5.1. Internal & external services

Tasks and activities that GROOM RI Nodes perform for each other within the organisation are designated as "Core Internal Services" or "Core Processes". On the other hand, tasks and activities requested by and provided to external parties are an "External Service". In essence, many activities could either be internal or external. In either case, access to the services will follow a predefined procedure.

5.1.1. Services provided by the central hub with the help of the nodes

Service	Description
Pan European Coordination	GROOM RI is key to ensure that European leadership strengthens and consolidates the global OceanGliders coordination activity with direct links to GOOS and GCOS via the OCG. The RI assists partners in coordinating with other frameworks (e.g., EuroGOOS GTT) and connects with other European stakeholders as well as global RIs. By being at the centre of all these activities, GROOM RI effectively navigates the complex landscape of marine RIs and best represents the partners while benefiting all the different stakeholders involved.
Outreach	GROOM RI coordinates a joint approach to disseminating the work done by the RI and its partners. These efforts will help the partners better communicate with the public while also saving resources through this common approach. GROOM

	RI leverages its position in the European landscape to collaborate with other Ris and networks (Ocean Observation integration).
Software Repositories	GROOM RI provides resources to help manage open-source software repositories with software version control tools. These tools will also be used to converge on best practices. The connection between these best practices and code will become very natural. These resources will also support the prioritisation of issues and moderate online debates, giving consistency to the entire system.
Data Management, Sharing, & Harmonization	GROOM RI coordinates and supports efforts to manage, harmonise, and standardise metadata, evolving data, and new formats. The RI collaborates with national data centres, global DACs, and EU data aggregators to assist with the uptake of gliders' observations by these wider user communities (NRT QC and FAIR data dissemination into GOOS, EOOS, & ENVRI communities). The coordination by the RI assists with the adoption of gliders and other MAS observations from wider user communities, thus making those observations as efficient and accessible as possible.
Best Practices	GROOM RI facilitates and takes part in the establishment and evolution of best practices on the operations of MAS to incorporate them into the appropriate platform(s) (OBPS). The RI establishes a dynamic process to endorse new best practices and incorporate them into the OBPS for continual improvement. The development of GROOM RI's best practices and Ocean Gliders' best practices are closely related and inform each other. Nevertheless, since there will be more specific EU best practices in the future, GROOM RI's best practices may not be applicable globally. *Reference: [D6.2 - Data management roadmap for the GROOM RI]*
Procurement	GROOM RI will coordinate purchases on behalf of the partners to get more competitive offers from marine system hardware manufacturers and distributors (e.g., gliders, sensors, etc.) and services (e.g., Iridium, Argos, AIS, etc).
Piloting e-Infrastructure	GROOM RI provides a catalogue of e-Infrastructures, including electronic services, networks, archives, databases, and databanks at the partners' level. In addition, the RI deploys and grants external users access to piloting e-infrastructures of the RI partners. The RI facilitates joint collaborations and access to unique capabilities to support operations. GROOM RI contributes to the development of software needed by the partners. This software will also be maintained on open repositories following best practices in software development. Other potential tools to be developed include risk assessment and mission simulation and rehearsal tools.
Legal Frameworks	GROOM RI supports and facilitates diplomatic clearances and other legal matters (e.g., shipment regulations) involving the operations of MAS. The research infrastructure's support and depth of experience will make the whole administrative process of deploying gliders and other MAS in water frictionless and efficient from drafting contracts, providing templates for diplomatic clearance, and requesting Marine Scientific Research. The RI provides expert services and connects with the best practices developed by the RI.
Training	As a central hub, GROOM RI facilitates and organises those training activities

	among GROOM RI partners. GROOM RI maintains and increases its partners' skills by organising targeted technical training on MAS, metadata and data handling, mission planning, and other skills as the need arises. The RI also scans the marine research landscape for training opportunities with external bodies to both offer and receive training. *Reference: D2.3 GROOM RI scientific and technical training and capacity building)*
Networking & Capacity Building	GROOM RI identifies gaps of capacity and capability in the GROOM network. The RI facilitates and fosters collaborations among its partners and external institutions to fill those gaps by developing new ways of operating innovative technology and new legal frameworks. All these activities will then feed back to new best practices and training programs for the new capability to further strengthen the marine RI landscape.
Support to Innovation	GROOM RI fosters cooperation with Industry by providing data, dedicated services, and experimental facilities to the private sector. In addition, the RI supports innovation by organising training opportunities for industry stakeholders. Lastly, the RI collaborates with the private sector to develop and evaluate new components, instruments, and capabilities. *Reference: D5.2 - Ensuring continued evolution of glider services*

Table 1. List of services provided by the central hub, its description and associated deliverables.

5.1.2. Services provided by the nodes with the support of the central hub

Service	Description
Environmental Monitoring	GROOM RI facilitates the coordination and implementation of baseline environmental surveys on water properties, operational met-ocean studies, and monitoring services for national governments. The RI has the capacity to estimate the environmental conditions of direct influence on coastal or offshore engineering projects and selects appropriate solutions to facilitate goal achievement (e.g., implementation of marine infrastructures, sustainability of marine protected areas, etc.).
Operations & Maintenance	GROOM RI Nodes have the full or only a partial range of capabilities from the preparation and maintenance of MAS instruments to the deployment and recovery of MAS. Throughout this process, GROOM RI Nodes work together and with users to implement all necessary protocols to ensure the optimal operation of these systems.
Hardware (spec. sensors) Calibration & Integration	GROOM RI develops standardised protocols for instrument testing, integration of new instruments into MAS and sensor calibration. This may be in the form of providing expert services and connecting with the best practices of GROOM RI. Calibration and Integration activities done in the Nodes by GROOM RI will use these protocols.

Table 2. List of services provided by the nodes, its description and associated deliverables.

Reference: D.5.1 - Glider Services for Public and Private Needs

5.1.3. External services

Work products GROOM RI provides for third parties are considered "External Services" or "External Products." We refer here to government agencies, research institutes, and more generally any scientific and commercial entities that would possibly require or benefit from work products GROOM RI Nodes provide to these third parties. Some of these External Services/Products may include analyses, datasets, live-stream data, and/or reports. These external services are the result of cooperation between GROOM RI Nodes exchanging core services (and possibly supported by third party suppliers) and concern:

- Fishery Management & Scientific Support;
- Marine Renewable Energies;
- Climate Observations;
- Statutory Ecosystem Monitoring/Assessment Ecosystem Stressors.

These can be provided to private users, but will also be provided by the nodes as in-kind contributions (wide access to data collected during sustained observing lines for Statutory Ecosystem Monitoring or Climate Observations).

Reference: D.5.1 - Glider Services for Public and Private Needs

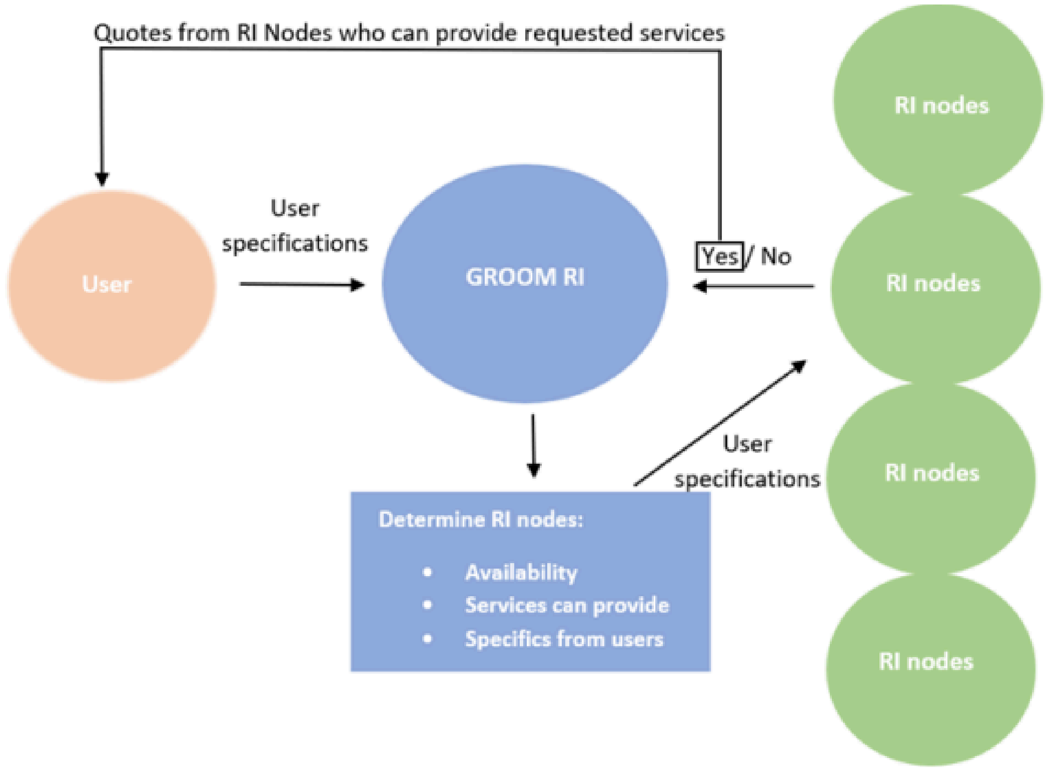


Figure 14: Market-driven access to GROOM RI.
For external users, it is the nodes that provide the service and, where there is a charge, bill the user for it.

5.2. *Access policy and rules*

Defining a common access strategy is complex due to the heterogeneity of the partners operating MAS in Europe. Today, the MAS facilities that can become the future GROOM RI Nodes are all governed by very different rules derived in many cases from specific funding and, in the best case from established national rules for RIs. The services the facilities provide to users are also of a different nature and heterogeneous across the GROOM II partnership.

5.2.1. Access types

The above mentioned services are accessed through 4 types of defined access:

- **Market-Driven Access,** where a user accesses a node, the GROOM RI Central Hub serving as a

broker (see figure 14);
- **Coordinated-Driven Access,** where a user accesses to GROOM RI Nodes, harmonisation ensured by Central Hub;
- **Excellence-Driven Access,** which needs dedicated resources, like TA funding for example, and goes through a selection process with a call for proposal and an evaluation process;
- **Wide-Access**, concerning BP and documentation on the repositories, as well as real time and delayed mode data).

5.2.2.Policy and rules

The following policy and rules for both the nodes and the users have been designed as follows:

For the nodes:

- if the access generates observations, the data must be FAIR, and open, and a data management plan must be created;
- the nodes providing facility access must follow GROOM RI-approved Best Practices
- while nodes are free to define which services they offer, once they do, they must treat users fairly and in a non-discriminatory way in compliance with the future GROOM RI ethics policy;
- nodes will provide clear costings to users following a GROOM RI standard costing template;
- nodes will establish the appropriate start and end times for facility access;
- nodes must have clear and documented terms and conditions specific to the services they offer.

For the users:

- if the access generates observations, the data must be FAIR, and open, and a data management plan must be created. This is the same rule as the one for the nodes;
- there will be a single data management plan for both the node and the users;
- GROOM RI will have an ethics policy that users will have to comply to;
- users must agree to the local rules of the Node.

In order to facilitate this access:

- GROOM RI must provide expert resources to help users apply to nodes in different countries if they want to access resources and services from those nodes;
- GROOM RI should support the complete diplomatic clearances for the RI nodes;
- GROOM RI should provide an online portal or tool (catalogue) to allow external users to explore services;
- GROOM RI should provide an online tool to show RI users the current GROOM RI partner's operations, allowing more effective planning and sharing of resources;
- GROOM RI should provide a light touch standardised template to allow users to request their requirements for access;
- If GROOM RI adopts the MFP or an equivalent, the system must develop and include access and planning for shoreside facilities;
- To guarantee wide access to data, GROOM must work with data centres across Europe, producing consistent data workflows and data outputs independent of the data centre so users of GROOM RI will know that no matter which GROOM node operates the MAS and which data centre manages the data, the results are of the same level of quality and the data is delivered following the same mechanisms.

Reference: D2.1 GROOM RI access policy and rules

6. What is GROOM RI's added value?

6.1. GROOM RI answers operators needs

Within the task T2.4 - Engagement of other countries/stakeholders, a survey was sent to MAS users in Europe, specifically asking for interest as a user or the capacity to provide the designed services, to ensure that every proposed service is in line with the needs of the operators.

The figure 15 shows, for each service, the number of potential users and the number of potential providers. A ratio of 4 to 1 can be considered as a reasonable threshold for the need of developing an infrastructure component. It is even more true for 8 to 1. The higher the ratio users over contributor ratio shows growing interest in such service, while also emphasising the need for the RI to provide such service as the number of capable providers might be limited. For example, the Piloting e-infrastructure would be widely used but only one institution should have the capacity to provide such service, hence the need to internally develop a digital ecosystem capable of providing this service.

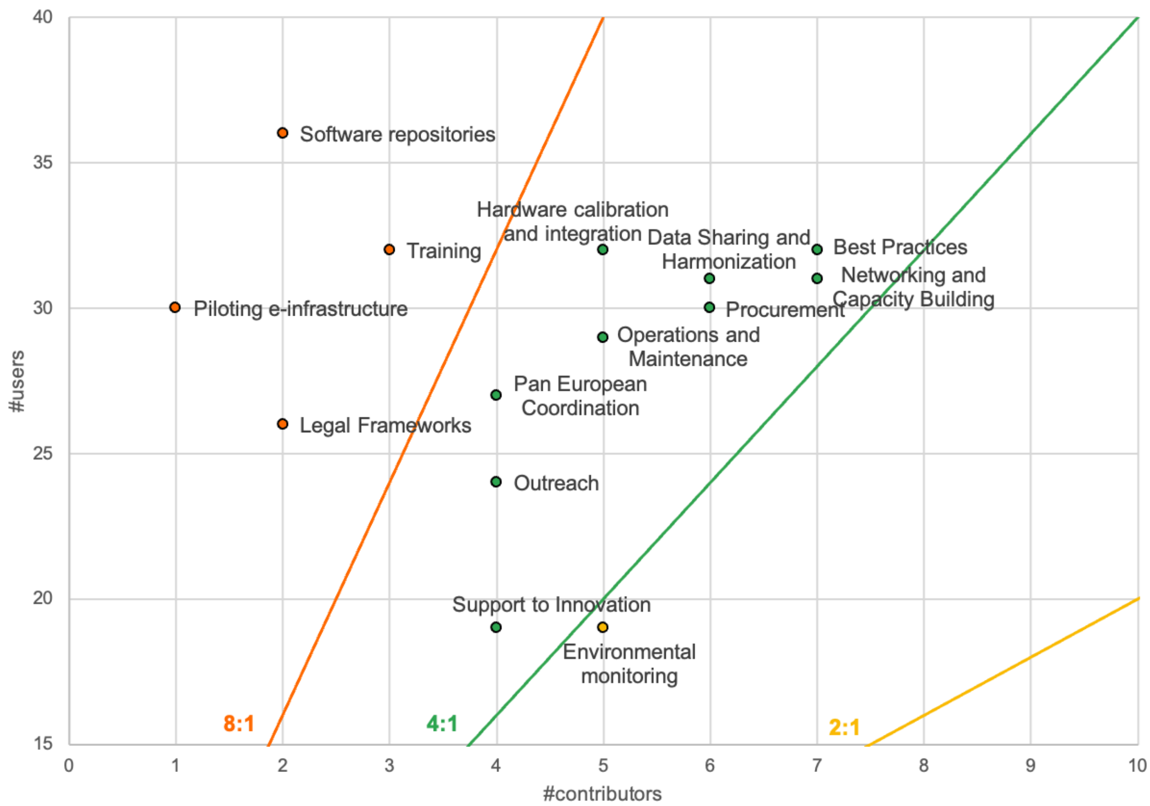


Figure 15: Potential number of users by service compared to the number of contributors.
This graph displays the provider-to-user ratio. The top region of the diagram (numerous users) means that GROOM RI provides fit-for-purpose services that are of interest for many users, the right region (numerous providers) means that GROOM RI has the capacity to provide the service. The 3 lines (yellow, green, orange) represent respectively the 2:1 ratio, meaning that for 1 contributor, there would be 2 users, the 4:1 and 8:1 ratio, showing some potential prioritisation of the services to be provided by GROOM RI.

KER 8: Services for the users. GROOM RI has aligned its service offerings with user needs, helping to prioritise high-demand services, and optimising Resource Allocation. This ensures that GROOM RI can meet the needs of its users effectively and sustainably. Software repositories, Training, and developing a piloting e-infrastructure are the first priorities of GROOM RI.

6.2. GROOM RI provides cost efficiency

During the project and during GROOM FP7, several surveys were sent to all identified MAS facilities to define the costs associated with MAS (only gliders as there is no sufficient feedback for USV in Europe yet) operations, and to define the areas where GROOM RI could bring the most added value in terms of cost reduction and efficiency optimisation. While these numbers vary greatly between countries/facilities - mainly because there is currently no well-established common accounting system for glider CapEx/OpEx analysis[22] - and mission types, the cost categories we have considered and the data we have collected have enabled us to create a cost analysis methodology that we feel is appropriate for the optimization objective sought in GROOM RI. A first obvious conclusion is that GROOM RI, by coordinating the activity of the nodes, would facilitate this type of survey and enable more solid figures to be gathered[23].

A glider mission averaged[24] cost estimates has been calculated during the project and is shown in the following table:

- The marginal cost represents the extra cost induced by adding one glider at sea for a mission. It includes the costs directly related to the glider at sea: batteries, iridium, and first level maintenance of gliders (consumables, transportation and vessel hire, and insurance);
- The intermediate costs include marginal costs, salaries, data management and overhead (defined as a % of the overall costs, typically 10-20);
- Consolidated costs include all the functioning costs including depreciation to give the most complete acknowledgment of what the facilities pays.

Costing type	**Included costs**	**Total mean cost (1 month mission)**
Marginal cost	iridium + batteries + transport+ calibration	6 700 €
Intermediate cost	(Marginal cost + Salary) *(1+indirect costs)	11 000 €
Consolidated cost	Intermediate cost + Glider depreciation	25 000 €

Table 3. Mean operation costs associated with a glider deployment, depending on the calculation method. These numbers represent a mean value, but strong variation exists. Standard deviation could be estimated in further studies to improve the representativity of the presented results.

The two main cost items are the investments & purchasing of platforms, and the salary of the personnel. The current average cost of human resources is one full-time equivalent (FTE) for 70 glider days a year, while the platforms themselves are far from being fully utilised (today, a glider spends on average only about 1 month a year at sea). As a result, GROOM RI must support operators in their day-to-day activities to achieve greater efficiency, and develop tools and methods to optimise the use of the platform - both the duration of use and the human resources required to operate it - by sharing and developing services for external users to deploy MAS that would otherwise have remained on the shelf. Days at sea/FTE/year (operators efficiency) and Days at sea/MAS/year (platform efficiency) are two critical KPIs to monitor for an RI devoted to MAS supposed to be deployed in large numbers. Regarding gliders, numbers such as 100 Days at sea/FTE/year and 60 Days at sea/glider/year, were reached by the CNRS glider facility before it was closed in 2021, and today, a

[22] Transnational Access (TA) cost analysis methodologies established in previous projects offering glider TA, available in a very small number of facilities, also highly variable, were considered where relevant.

[23] As noted in a number of studies, like the EMB policy brief on “Towards Sustaining in situ Ocean Observations in the Age of the Digital Ocean”, the lack of a methodology for evaluating the costs of observations, which is the core activity of many MRIs, is a structural handicap that we have had to face, like others.

[24] The data collected do not allow us to compute robust standard deviation. The average hides a great deal of variability, mainly due to highly variable wage costs from northern to southern Europe and the different types of mission (area of deployment, duration, etc…).

few European teams certainly exceed these figures, while some American teams (e.g. SOI, APL/UW, Rutgers Univ., ...) have long since surpassed them. These KPIs are essential today, when the question of the contribution of RIs to sustained ocean observation and the costs involved have become central, particularly in view of the growing importance of EOOS. These KPIs, if they are to be truly meaningful in the context of a distributed infrastructure serving a very diverse community of users implementing MAS themselves, must be accompanied by a set of other quantitative and qualitative indicators.

During the project, in conjunction with OceanOPS/WMO and the EuroGOOS GTT, which is responsible for supplying EuroGOOS with similar indicators, we have set up data collection tools to help build these and other indicators. For example, the collected data can be used to assign a level of activity to each facility according to its nature (lab activity, or institutional IR, etc.) but also according to its institutional stakeholders (RPO, University, Operational Agency, etc.).

These data were of course used to construct indicators specific to the performance of the GROOM II project, in particular for WP2 and its positioning in the MRI landscape. These are presented in the appendix.

Through its services, GROOM RI can thus help drastically reduce costs by sharing and diminishing operating (and purchase) costs, increase operation quantity and quality levels by supporting operators with Best Practices, training and developing digital infrastructure for the pilots, etc.

In the absence of a recognised methodology for evaluating the analytical costs of MRIs, it is impossible at this stage to provide robust direct figures for the added value of GROOM RI on operating costs (operator efficiency). But experience from existing ‘proto-services’ and the projections we can make for other services like piloting show that this added value will exceed by far the additional cost incurred by the operation of the IR itself (financing of the central hub), and that the intrinsic performance of the nodes measured by the efficiency of GROOM RI services will be considerably higher.

KER 9: GROOM RI cost-efficiency. As MAS (glider) operation costs greatly vary across countries, GROOM RI has developed a comprehensive cost analysis methodology for glider missions, facilitating better cost management and optimization. GROOM RI has also established critical KPIs, such as Days at sea/FTE/year and Days at sea/glider/year, to improve efficiency and platform utilisation. The added value will surpass the added cost of GROOM RI (financing the central hub).

Reference: D3.2- Financial sustainability at Regional, National and EU levels

6.3. GROOM RI ensures that MAS activity in Europe is in-line with Global and European Policies and GOOS/EOOS, and develop the dialogue with policy-makers

GROOM RI should be represented in the EOOS Operations Committee, as a “relevant European Research Infrastructure” to “provide perspective and information on opportunities, encouragement and enhancement of existing collaborations, identification of gaps in observational data, technology for their FAIR-compliance transformation and interested communities and stakeholder.” (EOOS Terms of Reference[25]).

Hence, GROOM RI should be established as a representative of European countries performing MAS operations. GROOM RI can be nations’ one-entry point at expert level for MAS operations into GOOS/GCOS via OceanGliders for underwater gliders and be embedded in and fostering the emerging OASIS community around surface vehicles. Also, making GROOM RI a member of EuroGOOS GTT (similar to Euro-Argo with its associated Task Team in EuroGOOS) and DATAMEQ WG could enable a robust exchange mechanism with GOOS/GCOS via “the European component of GOOS” - EuroGOOS.

[25] https://www.eoos-ocean.eu/wp-content/uploads/2021/12/EOOS_OC_ToR_14Apr2021.pdf

Through accurate monitoring of the activity that leads to clear communication, and alignment with the EU priorities, GROOM RI can develop sustained dialogue with Policy makers, ensuring the Implementation of a sustainable fit-for-purpose, service-oriented GROOM RI, which today is difficult to conceive, for example for the needs of EU framework directives. This will facilitate the delivery of increased Ocean Observations at lower cost, higher frequency and resolution with a lower ecological impact in terms of carbon footprint. It will also ensure that GROOM RI becomes a world-class sustainable infrastructure to better service sustained ocean observation, and to foster innovation for new technologies, services and products for all monitoring needs, including for the Blue Economy.

KER 10: **GROOM RI dialogues with policymakers.** By being the single entry point, and acting as a central voice for MAS operators, GROOM RI promotes EU MAS to Policymakers for the benefit of EOOS, and ensures that GROOM RI provides fit-for-purpose services in line with European requirements.

Reference: D4.2 - White Paper on the GROOM RI position in EOOS

6.4. GROOM RI benefits society and tackles the Grand Societal Challenges

Societal benefits are mostly indirect, which increases the difficulty in identifying, describing, and quantifying anticipated benefits and impacts of GROOM RI on society. As opposed to national operations, GROOM RI, as a European RI, opens up ocean observation data and infrastructure to a wider global community that can improve their data products. Therefore these outputs, the knowledge and technological solutions facilitated by GROOM RI, have a global impact:

- Improving the quality, reliability, interoperability, availability, and findability of marine data products and services; forming dedicated services for climate studies and data assimilation;
- Reducing the number and/or impacts of environmental emergencies (e.g., preventing, predicting, mitigating harmful algal blooms, geohazards, extreme meteorological events) and operational monitoring in general;
- Helping public authorities to establish policies and EU Marine directives with relevant observational data.

GROOM RI sets up structural elements that allow integration of GROOM RI partners in European and international initiatives, more specifically GCOS and GOOS at global level, and EuroGOOS and EOOS at European level which ultimate goals is to deliver the relevant information to support a sustainable ocean, with the long-term ocean observation they provide.

KER 11: **GROOM RI supports EOOS/GOOS through its operations.** GROOM RI contributes to a cohesive and comprehensive global ocean observation network, further amplifying its impact on societal benefits through better data integration and collaborative efforts.

Reference: T5.1 - Key societal benefits of a sustained glider infrastructure

6.5. GROOM RI supports the blue economy

The MAS sector is growing and the capacity of the platforms is expanding. GROOM RI can be the main correspondent for the manufacturers to ensure that the products developed are in line with the operators requirements. Also, expanded monitoring capacity of the platforms (see box 4) allow to provide services to the industrial actors, like performing environmental impact studies for the following sectors:

- Applications to meet European Marine Directives;
- Defence and Maritime Surveillance;
- Marine Renewable Energies (MRE): Offshore Wind, Wave, and Tidal Energy;
- Deep Sea Observation and Potential Exploitation.

Box 4: GROOM RI capacity to support innovation with European SMEs and large companies. Several GROOM II partners have demonstrated their ability to innovate in the field of MAS by setting up projects with SMEs and major companies to develop, integrate and validate new platforms and sensors, and also to apply these innovations to meet the needs of the blue economy, particularly with a view to improving the carbon footprint of industrial activities or assessing their environmental impact.

Figure: the 2 prototype developed by Alseamar, the Deep Explorer (2400m) and the Ultra Deep Explorer (6000m)

This is demonstrated by a series of ongoing projects. Firstly, the H2020 BRIDGES project has developed two deep-sea gliders to explore the ocean down to depths of 6,000m, or around 98% of the ocean surface. These two prototypes have achieved a TRL of 4 to 5 and their development is now continuing on a national scale. Numerous payload components have been developed during BRIDGES, some of which having reached TRL 9. These include a 'universal' connector to make it easier to integrate sensors into platforms, as well as new sensors, such as a miniaturised version of an optical imaging device, a water sampling system or a nutrient 'lab on chip' analyser, some of which are now on the market and meeting real demand.

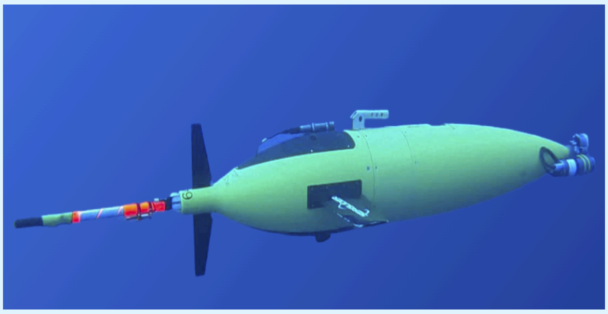


Figure: The Seaglider Bioglider, equipped with a UVP-6 (front) and an EK80 (bottom)

As part of the BioGlider project financed by the MARTERA Cofund, these developments achieved during the BRIDGES project, were then used to integrate this optical imaging device, as well as a miniature acoustic echo sounder, on several commercial glider platforms. These 'Biogliders' open up new prospects for research in marine biology and ecology, as well as for applications in fisheries management and aquaculture. This is the case for example thanks to the recently funded Sustainable Blue Economy Partnership CliN-BluFeed project, which aims to advance the *calanus* fishery in the Norwegian Sea as a sustainable, climate-neutral blue resource for the aquaculture industry. It will do this by harnessing the potential of BioGliders in combination with remote sensing, artificial intelligence (AI), simulation modelling and experimental studies.

This series of projects demonstrates the ability of GROOM RI's partners to raise the TRL of MAS technology to industrial applications and to enable European companies and research centres to access technologies capable of helping to meet major national challenges in their countries, such as France's "Grands Fonds Marins" challenge to explore undersea volcanoes with deep-sea gliders that the BRIDGES project has prototyped, or, as we have seen, Norway's challenge to decarbonise the aquaculture industry.

For the industries looking for the above-mentioned types of services, GROOM RI, acting as the coordinating entity, can ensure that the services are provided under conditions that correspond to current industry standards through joint obligations for both nodes and industrial users. The 'market-driven' access model is adequate for that.

GROOM RI has engaged with the private sector by establishing the IAG-MAS, the Industry Advisory Group for Marine Autonomous Systems, which brings together leaders from over 20 organisations that specialise in manufacturing MAS and marine sensors as well as maritime service providers. The IAG-MAS workshops have produced a set of inter-related outcomes for the emerging research infrastructure:

- Identifying emerging applications relevant to MAS that need large scale coordination to be properly addressed;
- Identifying and designing a framework of cooperation between the private sector and the GROOM RI.

Collaboration with industry is a much broader subject than GROOM RI as such can address. It is a challenge for all MRIs which should be addressed together by collaborative approaches such as those developed by the past ENRIITC project, for example. Another structured approach to this issue for the sustainable observation of the oceans with technologies that engage the productive sector in Europe, is considered by the EOOS framework through its EOOS technical forum, to which several GROOM RI partners contribute.

KER 12: GROOM RI eases interactions with industry. By providing a unique contact point for the scientific community to the private sector, GROOM RI ensures that researchers priorities are acknowledged by manufacturers, and that services provided by the GROOM RI reach the quality standards required, building trust among partners for the benefit of the Blue Economy.

Reference: D3.3 - Financial sustainability with industry

7. The establishment of GROOM RI

7.1. GROOM RI structure

GROOM RI shares a large number of features with similar objectives with other MRIs, such as Euro-Argo, whose governance models have been tried and tested. The GROOM RI governance model (figure 16) will also be similar with:

- a Board of Members including all members of GROOM RI, the ultimate decision authority;
- a Management Board that manages day-to-day life of GROOM RI resources applying the Board of Members decisions and proposes new directions based on GROOM RI capabilities. It requires around 5 profiles[26], each corresponding to a FTE or a % of it:
    - 1 Director General / Project manager;
    - 1 Scientific officer;
    - 1 Programme manager;
    - 1 Administrative officer;
    - 1 Communication officer.
- and Service Groups coordinating the operations of the four framework pillars, the two horizontal workstreams and two additional functions transversal within the MRI landscape, under the supervision of the Management Board:
    - Programme Management, Data Management, Operation at base, and Operation at sea;
    - Best Practices connected to other initiatives at EU and international (OceanGliders) levels, and Cyber Infrastructure design, development and maintenance;
    - Harmonisation and integration within MAS operators in Europe and with the other MRIs;

[26] This does not take into account IT resources for the Central Hub, that could be accounted as in-kind contributions from the host of the Central Hub.

- IAG-MAS to develop links with industrial stakeholders and foster the Blue Economy.

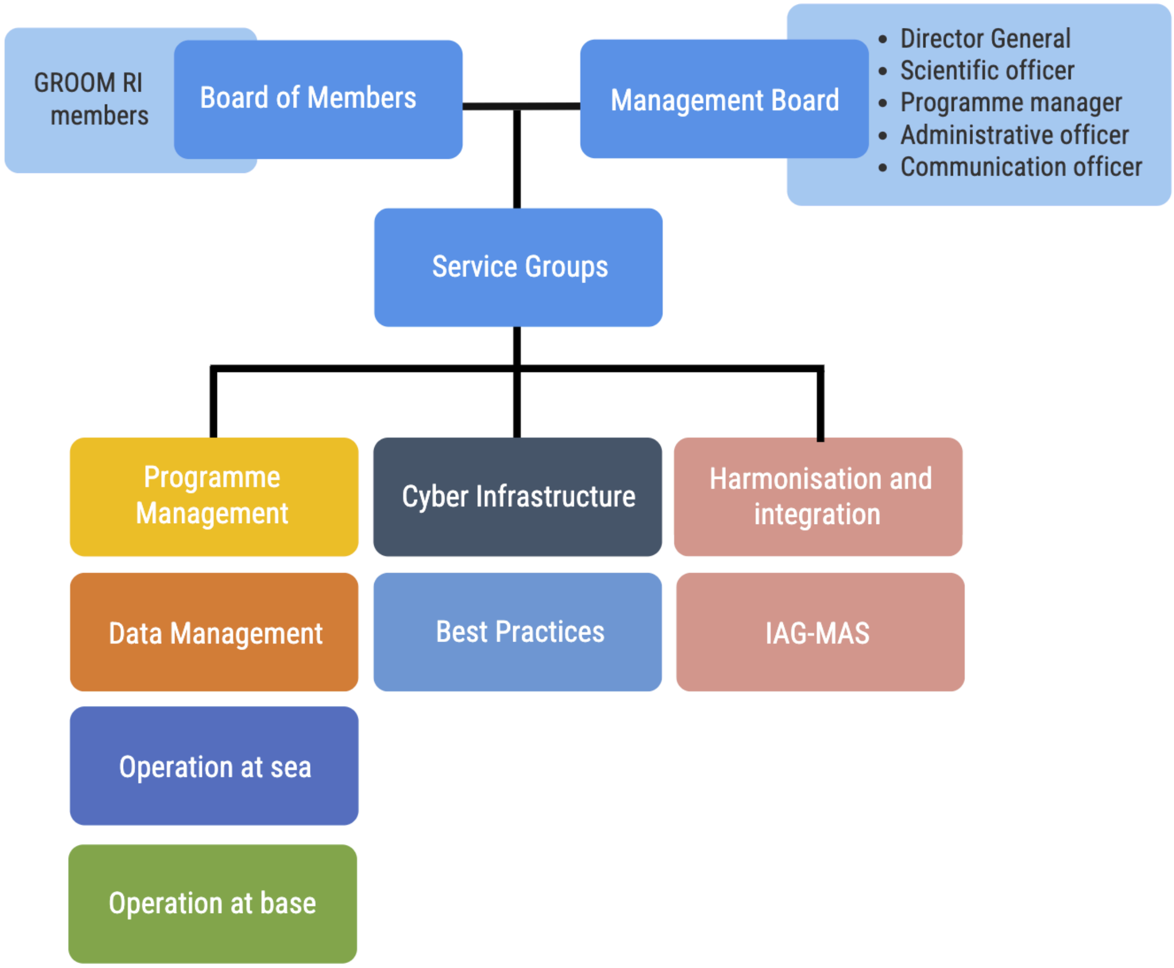


Figure 16: GROOM RI governance model

The Nodes operate with direct resources, and as part of GROOM RI, agree to a multi-annual commitment of resources through service agreements and under contract with GROOM RI itself or external users (through the Central Hub). Commitment lies in particular in terms of MAS to be deployed and contribution to the data system, and coordinated activities through the Central Hub. All resources engaged by the Nodes in support of the GROOM RI objectives and the provision of its services are considered as contributions to GROOM RI. Depending on the final legal status of GROOM RI, a member country can organise and coordinate all national facilities under the National Node, or each facility can be a member, a part of the distributed nodes of GROOM RI on its own. In either scenario, the facility defines its in-kind contribution to the RI and allocated resources that will represent a fraction of its total capacity.

KER 13: GROOM RI provides sustainability with controlled resources. By requiring long term commitment by the nodes in terms of service provision and MAS operations, embedded in a simple structure composed of a Management Board supervised by the Board of Members, and supported by the Working Groups, GROOM RI efficiently maintains and develops MAS sustained activity in Europe.

Reference: D3.1 - Governance and legal aspects

7.2. Key Performance and Impact Indicators (Scientific Impact, Access, Training and Education Impact, Economic Impact, Social and societal Impact)

One of the keys to success in maintaining a sustainable RI is to ensure that the resources engaged are properly exploited and provide significant results, in particular that they enable an increase in productivity as analysed in 6.2. To that end, Key Performance Indicators (KPIs) are project management tools used to monitor the performance of a RI, vis-à-vis its objectives and the efficient use of resources. GROOM RI will establish a set of indicators to assess its impact and thus its long-term sustainability, based e.g. on work done by the Organisation for Economic Cooperation and Development (OECD, 2019) to develop a framework to assess the socio-economic impact of research infrastructures. Also, Key Impact Indicators (KII), that can be considered as KPIs will be developed by GROOM RI to monitor the transformative effect of an RI.

These key performance & impact indicators must ensure that GROOM RI can answer the following objectives proposed in the Report of the ESFRI Working Group (WG) on Monitoring of Research Infrastructures performance (2019)[27]:

- optimising data use is monitored by assessing the FAIRness of data (e.g. by creation and monitoring of DOIs);
- optimising operations, by measuring days at sea/glider/year;
- enabling scientific excellence, by measuring the number of (high-quality) publications;
- delivery of education and training, through e.g. the number and diversity of trained persons;
- enhancing collaboration in Europe, with the number and diversity of partners of the RI (see 3.2 MAS - the European community);
- facilitating economic activities, by monitoring the link with industry;
- outreach to the public through direct contact and online dissemination.

Reference: D3.2- Financial sustainability at Regional, National and EU levels

7.3. Requirements

This project has concluded the need to establish a formal RI with dedicated means. The PI driven approach that has shaped the MAS activity in the last 2 decades has definitely reached its limits to face the future requirements and the increase of activity that is required in Europe. Nor does the option of merging GROOM RI with existing or planned RIs seem feasible today (see section 3.3). Therefore, GROOM RI should be set up as a formal legal entity and should follow a life cycle as established by ESFRI (figure 16).

[27] https://www.esfri.eu/sites/default/files/ESFRI_WG_Monitoring_Report.pdf

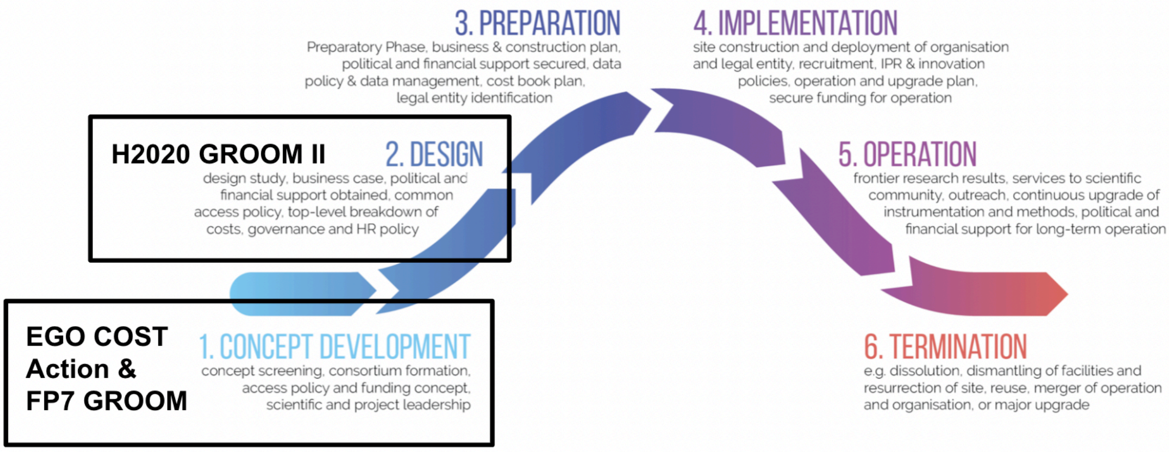


Figure 17: ESFRI Research Infrastructure lifecycle.
The two rectangles illustrate GROOM RI's current position in this life cycle, defined after the three projects devoted to it.

GROOM RI has now finalised a design phase and could evolve to the preparation phase, to develop business plan, validate political and financial support, data policy & management, cost book plan and legal entity identification.

Nations and institutions have assessed their potential commitments to GROOM RI: some countries are capable and ready to join GROOM RI, others still need time at national level to get organised and provide an unified answer, and some still need more precision about the shape of GROOM RI or their ability to contribute as nodes.

Most partners will at first not be willing to pay important membership fees for GROOM RI, as most are already involved in numerous RI and other entities. The paid fee would mostly serve to support the Central Hub (~5 FTE). The shape of the RI will depend on the capacity of the partners to engage, as the constraints in terms of human and financial resources are increasing and most partners are already involved in multiple RIs. It seems clear here that the current silo organisation model analysed in section 3.3 is showing its limits. But GROOM II has also shown that there are several avenues for integration that could overcome the current problems, and that synergies and integration of services between MRIs are now unavoidable.

This has been taken into account and therefore, GROOM RI business model will aim at limiting membership fees, and most of all, GROOM RI will provide a clear description of the added value, both quantitatively and qualitatively, and relying on monitored KPIs to assess the performance of the RI. A first assessment has been made in D3.2, and more thorough investigation with more robust numbers will help precise the business model and the balance between GROOM RI inherent costs and optimisation gains.

7.4. Legal entity identification

The final legal status of GROOM RI will depend on multiple parameters:

- The needs: MAS operations in Europe that will be and already are required require sustained funding and commitments, a general upscaling of the fleet's capacity that will be made possible by more collaboration and coordination.
- The capacity: as mentioned, countries are willing to engage but are restrained in terms of funding and commitment capacities, as they are already engaged in multiple other RIs and coordination networks. To define to what extent they can engage requires further internal dialogues with their stakeholders.
- The opportunities in the landscape: EC pushes for integration and development of synergies of the MRIs. The possibilities for merging have been investigated. Euro-Argo ERIC applies the

OneArgo line of conduct and is currently bound to concentrate to Argo floats, even when considering the similarities between the MAS and floats; EMSO ERIC has investigated adding gliders to complement the spatial resolution of their sites, but the outcome was negative; JERICO RI operates gliders, but the restriction to coastal zones would drastically limit GROOM RI's range of actions. JERICO RI being a thematic RI, synergies and complementarity are evident and both have an important role to play together; EuroFleets is an interesting option, and a MoU has been signed during the project, but discussions have not gone further. yet gone any further. In fact, the merger of any MRI with EuroFleets would imply a completely new model of collaboration between national R/Vs IRs and is a challenge for which no country is prepared today. The creation of synergies between European MRIs has been materialised with the launch of AMRIT project (see Conclusion and Perspectives), which regroups the above listed ERICs and projects in order to build the first blocks towards the creation of an operational EOOS.

		ERIC	Non-Profit	Network
Participation	Who	Nations	Anyone	Anyone
	Popularity	+	++	+++
Sustainability	Commitment	Long-Term	Member Fees	Free
	Funding	+++	++	+
	Project participation	+++	+++	-
	Visibility	+++	+++	+++
Cooperation	Establishing/Sharing of BP	+++	+++	+++
	Data management	+++	++	++
	Common Deployments	+++	+	-
	Links with other RIs	+++	++	+
Coordination	System Design	+++	++	+
	Contribution to global	+++	++	++
Integration	Mission planning	+++	++	+
	Service Provision	+++	+	+

Table 4. Comparison of the characteristics of the different possible legal statuses for GROOM RI, from most (ERIC) to least (network) sustainable.
The + indicates the importance of each characteristic, from 0 (-) to maximum (+++).

Establishing a RI is a long process and the landscape is rapidly evolving, which might mean that some results of GROOM II will be irrelevant when GROOM RI enters operation phase. That is why starting small with the adoption of proto-services already in place, while still developing the concept and implementation of the GROOM RI is viable, to set the first bricks of the future RI and start providing services to the users.

Multiple options are available, and one big difference is the timeframe to set up. While setting up an AISBL can take only a few months, an ERIC takes multiple years, and the two can be relevant at different times. One option is for GROOM to start as an AISBL or equivalent to produce some first services and gain expertise, while at the same time entering the ESFRI roadmap (with the next update in 2025) to mature as a functioning RI.

8. Conclusion and perspectives

Thanks to the GROOM II project, the EU MAS community has matured and converged on a design for the GROOM RI that addresses the present needs and prepares for the future ones. The design of GROOM RI already influences all Ocean Observing activities with a unifying vision grouping independent pieces in a highly coherent system to allow effective collaboration with other RIs in Europe (Euro-Argo, EMSO, JERICO RI, EuroFleets or ICOS OTC) and beyond.

Firstly, GROOM RI will enable and promote innovative and frontier research, with researchers able to apply for access on multiple platforms to explore processes on multiple spatial and temporal scales. Secondly, GROOM RI will support MAS operations, developing and providing coordination and tools that currently do not exist or are difficult and expensive to create, and third, it will allow for a coherent and sustained design of observing strategies in ocean observing systems thanks to pull together a central hub to help with the coordination of such activities. By monitoring EU MAS operations, synergies and coherence can be created for data collection and operations. By requiring a sustained commitment from countries and stakeholders, GROOM RI can play a decisive role in the observation strategy for EOOS in European EEZs and beyond for GOOS by coordinating its efforts with other countries in the OceanGliders programme. Finally, thanks to pull and coordination efforts, GROOM RI will support a more coherent and systematic approach to EU Member States' covenant monitoring programmes at the regional level (highlighted as a gap in MSFD assessments of GES).

GROOM RI is proposed as a distributed infrastructure with a Central Hub and several Nodes. It offers services provided synergistically by the various nodes according to their capabilities, ability and commitment to the RI. The Central Hub ensures coordination and manages access to services directly or as an intermediary between the users and the Nodes. All the services provide the environment needed to exploit the platforms and enable users to implement MAS and innovate in the technical fields or in the services that MAS can provide, improving data quality and simplifying data flow.

GROOM RI should be built with moderate investments (direct and in-kind) from the leading country hosting the Central Hub and (direct and in-kind) contributions from the Nodes. The integration of the Nodes and the simplification brought about by the services provided in synergy by the nodes will enable significant economies of scale to be achieved, which will allow compensation for the running costs of the central hub. Indeed, GROOM RI will:

- Support operators for more efficient and qualitative work and optimise the use of platforms;
- Enable data management harmonisation across nations and PIs and create close links with nations' NODCs and other data aggregators;
- Avoid duplication of costs and efforts through structural collaboration and sharing of services;
- Increase the quantity and quality of MAS products operations for Frontier Marine Research, Ocean Observation and the Blue Economy;
- Drive the MAS community to have more common and structured dissemination, training and capacity-building activities that will upskill human resources at national and European levels and increase knowledge and expertise in the European MAS landscape;
- Help to better combine MAS activities with other Ocean Observing and Modelling activities;
- Provide guidelines for industrial operators, technological development, and testing facilities;
- Foster the sustainability of the activity to maintain and develop MAS operations in Europe;
- Allow the RI to fully exploit the members' capabilities through defined overarching access policies encompassing the complexity and variability of the future GROOM RI nodes.

Such an integration of Nodes with a Central Hub to allow this list of benefits is not possible today, mainly because of institutional barriers that prevent partners from relying heavily on each other for different services. However, a great deal of progress has been made during this project towards such integration.

The organisations adhering to the GROOM RI concept have realised and evaluated the benefits of a Central Hub and Nodes offering a number of services, and that the current situation with more or less embryonic services duplicated in each node is wasting a number of FTEs and does not allow them to scale up and achieve a level of quality compatible with their ambition. A formalised GROOM RI structure with long-term commitments from the partners within a European framework is definitely the way forward.

GROOM II has indeed developed a mature design for the future GROOM RI, and the next steps are being evaluated. The evolution of the discussions throughout the project has enabled progress on national positioning and potential leaders capable of fostering an infrastructure at the EU level. Having realised the complexity of the infrastructure required to operate MAS, particularly in large numbers, most potential partners in the European countries operating MAS have acknowledged the vital need for collaboration and integration of critical components and the added value of GROOM RI to achieve this. The participation of potential organisations and countries in the construction of a legal entity for GROOM RI still needs to be finalised, depending on their internal capacity and alignment with the decisions of the lead countries. The two critical partners in the project, ARMINES-ENSTA and NOC, have set up a team which is currently continuing this process and finalising consultations with the national focal points toward a decision on the next phase, possibly an application to the next call for the 2026 update of the ESFRI roadmap.

Global awareness - particularly within the G7 countries, as is currently being analysed by a G7 FSOI working group on RI for ocean observation - that MAS can definitively make a difference for a more integrated vision of ocean observation highlights the need for much more integrated infrastructures, first at national, then regional and global level, with powerful synergies between these infrastructures and between countries, or groups of countries as in Europe.

This need for a more integrated approach within the RIs is also an issue with other disciplines, as shown by the recent ESFRI analysis and the direction taken by the calls under the INFRA pillar in Horizon Europe. This seems evident in the technological development of new marine sensors, which are perfectly cross-disciplinary and cross-infrastructured, and several projects are already implementing an integrated approach to this, such as carbon measurements (GEORGE project). When it comes to integrating the organisation of research and observation activities across RIs, there are many barriers of all kinds, particularly in terms of cyber infrastructures for operations at sea, which is fragmentary in the majority of MRIs considered here.

Due to the key role of MAS in the multi-platform approach, and the need for a cyber segment to steer MAS with advanced functionalities, the GROOM II partners are uniquely positioned to tackle the cyber infrastructure which is the first of these barriers. It is imperative to have comprehensive standards to describe the flow of information in the data value chain through metadata shared by all MRIs and their members, right from the observation design phase and in a crucial way during the operations phase at sea. This is the aim of the AMRIT project, which has just begun. It is worth mentioning that the resources dedicated to MAS in AMRIT are relatively limited because of our GROOM II project which has paved the way to this integration and that AMRIT will not suffice for sustaining the MAS activity coordination.

It has also become apparent globally that most observation platforms and systems, including on crewed ships, will be remotely operated from now on, an imperative condition for controlling the cost and carbon footprint of observations in large numbers. As we have seen, the remote operation of MAS considered by GROOM RI already requires this, and a suitable, integrated infrastructure will enable significant efficiency and productivity gains. This teleoperation concerns the fully autonomous systems covered in GROOM RI but can also accommodate autonomous instruments on ships for the underway measurement of atmospheric or surface parameters. The complete integration of such a shared service into the group of MRIs considered here now seems achievable by GROOM RI together with the others MRIs. This would be a decisive step towards the fuller integration of these MRIs insofar as 1/ the operating cost of systems, principally their operation at sea, is one of the main burdens on operators and users and 2/ it would result in considerable simplification for users with increased possibilities for research, monitoring and innovation. These two barriers, once removed, will facilitate the evolution towards an EOOS and a GOOS with increased operational capacities meeting the observational requirements and that are economically acceptable.

9. APPENDIX 1: KEY EXPLOITABLE RESULTS

Key Exploitable Results (KER) are identified main interesting results of the project, which has been selected and prioritised due to their high potential to be "exploited" – meaning to make use and derive benefits - downstream the value chain of the project, or act as an important input to policy, further research or education.

The following table A1 lists the GROOM II KERs that have already been presented throughout this report.

KER 1	**A common Cyber Infrastructure**. The project GROOM II has addressed this "cyber challenge" by defining in detail the cyber infrastructure able to overcome it (see 4.5). Strong commitments at European level are now needed to make it possible to develop this cyber infrastructure, which is essential for extending the use of MAS and improving their cost-effectiveness.
KER 2	**MAS community integration**. GROOM RI must and can play a central role in leading and coordinating MAS actions in Europe, and ensuring that its services meet the needs of as many communities as possible. Collaborating with EuroGOOS, OceanGliders and other GOOS players to share the requirements and scientific knowledge needed for MAS operations, and best practice is a logical and feasible approach since most of the GROOM II project partners are active in EuroGOOS and OceanGliders.
KER 3	**Completeness of the MRI landscape and integration.** To ensure the coherence of an integrated ocean observation capacity in Europe and its ability to address the challenge of ocean observation for society in a low-carbon world, it is crucial that a MAS RI is established in the current landscape. GROOM RI can then provide integrating tools and services that will benefit the whole community to conduct ocean observation operations on a very broad spectrum of problems, from fundamental research and sustained ocean observation to more applied monitoring.
KER 4	**Coordination and interoperability for scientific research.** Gliders and other MAS, equipped with a diverse payload, can provide biological, biogeochemical and physical measurements. They also provide the capacity to observe the ocean at very small spatial and temporal scales over large areas and long periods of time thanks to their endurance and potential instrument rotations and deployed as a fleet, it is possible to observe any oceanic process. GROOM RI provides the interoperability and coordination permitting to truly exploit this capacity by enhancing the deployment capacity, whether alone or in swarms.
KER 5	**A technical framework to improve operation and cost efficiency.** The GROOM RI technical framework improves operations and cost efficiency, maximises data quality and harmonisation, and supports Marine Frontier Science and Policy. The framework represents a significant advancement in the integration and optimization of MRIs in Europe. By providing a cohesive, modular, and comprehensive set of tools and services, it supports high-quality marine research and fosters collaboration and innovation across the scientific community and beyond.
KER 6	**Support BP effort.** By providing means for developing and implementing robust BPs, GROOM RI will significantly enhance the efficiency, reliability, and quality of MAS operations, fostering a more integrated and collaborative marine research community.

KER 7	**A cyber infrastructure to enhance operational capacity.** By developing a comprehensive cyber infrastructure, GROOM RI significantly enhances the operational capabilities, interoperability, and scalability of MAS operations, fostering a more integrated and innovative marine research environment.
KER 8	**Services for the users.** GROOM RI has aligned its service offerings with user needs, helping to prioritise high-demand services, and optimising Resource Allocation. This ensures that GROOM RI can meet the needs of its users effectively and sustainably. Software repositories, Training, and developing a piloting e-infrastructure are the first priorities of GROOM RI.
KER 9	**GROOM RI cost-efficiency.** As MAS (glider) operation costs greatly vary across countries, GROOM RI has developed a comprehensive cost analysis methodology for glider missions, facilitating better cost management and optimization. GROOM RI has also established critical KPIs, such as Days at sea/FTE/year and Days at sea/glider/year, to improve efficiency and platform utilisation. The added value will surpass the added cost of GROOM RI (financing the central hub).
KER 10	**GROOM RI dialogues with policymakers**. By being the single entry point, and acting as a central voice for MAS operators, GROOM RI promotes EU MAS to Policymakers for the benefit of EOOS, and ensures that GROOM RI provides fit-for-purpose services in line with European requirements.
KER 11	**GROOM RI supports EOOS/GOOS through its operations**. GROOM RI contributes to a cohesive and comprehensive global ocean observation network, further amplifying its impact on societal benefits through better data integration and collaborative efforts.
KER 12	**GROOM RI eases interactions with industry.** By providing a unique contact point for the scientific community to the private sector, GROOM RI ensures that researchers priorities are acknowledged by manufacturers, and that services provided by the GROOM RI reach the quality standards required, building trust among partners for the benefit of the Blue Economy.
KER 13	**GROOM RI provides sustainability with limited resources.** By requiring long term commitment by the nodes in terms of service provision and MAS operations, embedded in a simple structure composed of a Management Board supervised by the Board of Member, and supported by the Working Groups, GROOM RI efficiently maintains and develops MAS sustained activity in Europe.

Appendix Table A1. List of KERs of the GROOM II project

10. APPENDIX 2: KPI & MAS FACILITIES AND GROOM RI'S POSITIONING IN EACH COUNTRY

This appendix provides a series of KPI that have been developed and used throughout the project to refine the various components of the future RI design, in particular the notion of user versus node. The appendix also provides a country-by-country description of all the entities - called facilities in the tables - relevant to GROOM RI and their present positioning in relation to the future GROOM RI.

10.1. Key Performance Indicators for the project and GROOM RI

Currently, the following KPIs are in raw form, which was sufficient for the project itself, but as they are based on a relational database, they could easily be refined or adapted to become an operational monitoring tool for GROOM RI.

10.1.1. KPI on MRI membership by country

This KPI counts the participation of each country in all relevant MRIs relating to ocean observation, or which include an ocean-related component (Danubius RI, ICOS, LifeWatch). It helps to put GROOM RI positioning into perspective in each country, as detailed in section 3.3.

MRI		BE	CY	EE	ES	FI	FR	GE	GR	IE	IT	NE	NO	PT	SE	UK
MAS activity		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
GROOM II partner			x		x	x	x	x	x	x			x	x	x	x
Infrastructure EU Projects	GROOM RI		x		x	x	x	x	x	x	x		x	x	x	x
	JERICO RI	x		x	x	x	x	x	x	x	x	x				x
	EuroGO-SHIP				x		x	x		x	x					x
	EuroFLEETs +	x		x	x	x	x	x	x	x	x	x	x			
	MINKE				x	x	x	x	x		x		x			x
ESFRI landmarks	EuroArgo				x	x	x	x	x	x	x	x	x			x
	EMSO				x		x		x	x	x		x	x	x	x
	ICOS OTC	x			x	x*	x	x		x	x		x		x	x
	DANUBIUS RI				x	x	x	x	x		x	x				x
	EMBRC	x			x		x		x		x		x	x	x	x
	Lifewatch	x			x				x		x	x				
Other Relevant organisations	EuroGOOS	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	Seadatanet	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x

Appendix Table A2. Participation of European Countries operating MAS systems in MRIs and Infrastructure projects/programs.
Participations in MRIs of countries outside the present GROOM II consortium, which however, were engaged in the framework of the project's work packages, are also presented.

** Finland hosts the ICOS headquarter which supports ICOS OTC data management although Finland doesn't operate any marine ICOS station. ICOS OTC is coordinated by NORCE in Norway.*

10.1.2. KPI on MRI membership by organisation

This KPI counts the participation of the main organisations in all relevant MRIs relating to ocean observation. It helps analyse the current complementarities and fragmentation in the landscape and offers a tool (with the following KPI) to understand where and on which component or service an action could be more efficient. Only organisations part of at least 4 MRIs are listed here. IIt's worth noting that, when it comes to large RPOs like CNRS or CSIC, participation is from their laboratories, but generally, this doesn't lead to internal synergies within the organisation.

	EMBRC	EMSO	Euro-Argo	Lifewatch	ICOS-OTC	Danubius-RI	Euro Fleets+	EuroGO-SHIP	GROOM RI	JERICO RI	MINKE
CNR	x	x	x	x	x	x	x	x		x	x
OGS	x		x		x				x	x	x
HCMR	x	x	x	x		x	x		x	x	x
Ifremer		x	x				x	x	x	x	x
MI		x	x		x		x	x	x	x	
PLOCAN		x			x				x	x	x
UiB	x	x			x			x	x		x
NOC			x		x			x	x		x
CNRS	x	x	x		x				x	x	x
FMI			x		x				x	x	
VLIZ	x				x		x			x	
GEOMAR					x		x	x	x		
CSIC		x		x			x	x			x

Appendix Table A3. Participation of the main European agencies, research organisations or universities in the MRIs most concerned by GROOM RI.
Participating in an MRI means that there is a formal agreement from the entity recognizing that at least one of its components is a member of the ERIC or a partner (or contributor) in the MRI project.

10.1.3. KPI on type of facility

The following KPI presents indicators depending on the type of MAS facility. At present, some indicators have been collected manually, while others, such as the length of time it takes to deploy a SAM, are obtained automatically from the GDACs and OceanOPS. But these indicators are not sufficiently operational and reliable to be used today, and above all, a large number of plants do not manage their data in accordance with current standards, which is a prerequisite for producing such indicators.

	Number of MAS facilities part of	Nb of gliders owned by	Nb of ASV owned by	DAC	Calibration
ERIC	6*				
National RI+	8	53	6	4 (Ifremer - BODC - NMDC -SOCIB)	LNE-INRIM-PTB -NOC
National RI	10	28	2	1 (OGS)	1 OGS - SHOM-Ifremer
Institutional facility	8	29	5	1 (TTU)	
Laboratory facility	22	34	4		
Private Company	3	21	0		

	Number of MAS facilities part of	Nb of gliders owned by	Nb of ASV owned by	DAC	Calibration
Other	2	17	0		

Appendix Table A4. Numbers of MAS facilities in Europe according to the type of facility. See description of type in table A5 of the appendix.
**A MAS facility part of an ERIC means that the entity owning MAS or providing MAS services belongs to an organisation part of one or more ERICs.*

10.2. MAS facilities and GROOM RI positioning in each country

The country-by-country mapping below takes into account all the MAS facilities in the country, presenting them in all their diversity but with a single typology.

Each information sheet gives a general description of MAS activity in the country and its organisation including in terms of the national RI organisation or roadmap if any. An analytical description is given in a table for each country containing data for the MAS facilities in the country, according to the typology in table A5 below, and the GROOM RI services (see list in table A6) that the facility could provide if it became a GROOM RI Node. It also provides the positioning of these entities with respect to GROOM RI and a preliminary positioning of the ESFRI relevant minister(s) or Research Council of each country regarding a potential application to the 2025 call for the update of the ESFRI roadmap.

Item	Description
Facilities	Entity in exclusive or partial charge of MAS activity within a laboratory, organisation, university, ... In most country tables, this entity is designated by the name of the laboratory in which it is located.
Type of facility	● ERIC: when the MAS facility is part of an ERIC member (e.g. the Norwegian NorGliders at UiB contributes to the Nordic Seas facility of EMSO); ● National RI+: an infrastructure (legal entity or under the scientific responsibility of a national organisation) which are part of the national policy on RI roadmap and are subject to budgetary allocation by the national (or regional) government; ● National RI: an infrastructure which is also part of a national policy or RI roadmap but whose scientific strategy and budget management is the responsibility of a national organisation; ● Institutional RI: an infrastructure under the responsibility (adm. and budgetary) of a National Agency, a RPO or a HEI; ● Laboratory activity: a MAS group taking place in the laboratory of a legal organisation without the RI attributes (e.g. there are not dedicated to a larger community); ● Private Company; ● Other: e.g. Maritime Clusters, Environmental NGOs, Associations, etc.
RPO / HEI	List of the legal organisations on which the facility depends.
Potential GROOM RI node	The characteristics of the facility for GROOM RI and the interest of at least one of its stakeholder organisations are present.

Users of GROOM RI services	The characteristics of the facility makes it rather an external user, although he may have shown interest in GROOM RI.
Service intermediary to other RIs	These are nodes whose characteristics make them ubiquitous in the MRI landscape, such as entities with metrology/calibration or advanced data management capabilities. The concerned MRIs along with the shared services are listed.
MAS resources	Number of MAS platforms owned by the facility.
Services	Services (see list in table 2, page 32-33, and their acronym in table A6) maintained by the facility. Only services with a formalised access are considered.
Comments	Comments on the facility.

Appendix Table A5. Structure of the country-by-country mapping tables

Services	Abbreviation
Pan European Coordination	PC
Outreach	OUT
Software Repositories	SR
Data Management, Sharing & Harmonization	DM
Best Practices	BP
Procurement	PR
Piloting e-Infrastructure	PI
Legal Frameworks	LF
Training	TR
Networking & Capacity Building	CB
Support to Innovation	INN
Environmental Monitoring	EM
Operations & Maintenance	OM
Hardware (spec. sensors) Calibration & Integration	CI

Appendix Table A6. Services abbreviation used in the tables by country below

10.2.1. Belgium

Flanders Marine Institute (VLIZ) , an innovation-oriented scientific institute based in Ostend (Belgium), established its Marine Robotics Centre (MRC) in 2018. MRC is a pioneer in Belgium in the field of MAS. With this type of platform, the MRC aims to fill major data gaps in order to advance our scientific knowledge and answer pressing questions in marine and climate research. In addition, the MRC is tackling specific challenges in terms of technological innovation that also have societal and economic impacts. Presently, it owns a glider, an USV and an AUV and other robotic systems. These platforms are made available to the marine research and innovation community. The MRC is also involved in a number of marine research and innovation projects, as well as transnational access programmes for marine research infrastructures.

Research and innovation policies are the responsibility of the Belgian federal government and regional governments. However, Belgium differs from all other EU Member States in that most R&I policies (instruments and budgets) have been transferred to regional governments, each of which enjoys full autonomy in decision-making in these areas. The federal state with its Belgian Science Policy (BELSPO) agency retains certain powers as an exception to this rule like for the new RV Belgica.

Flanders (VLIZ) and the federal government through agencies like the Royal Belgian Institute of Natural Sciences (RBINS) and other federal or regional agencies or universities are part of ICOS OTC, EMBRC, Lifewatch and also participate in the JERICO RI project.

Facilities	**Type of facility**	**RPO / HEI**	**Potential GROOM RI node**	**Users of GROOM RI services**	**Service intermediary to other RIs**	**MAS resources**	**Services provided as a node**	**Comments**
VLIZ	Nat. RI.	VLIZ	y	y		1 glider, 1 USV	PI	Provide connection with E-DITO infrastructure

10.2.2. Cyprus

MAS activity in Cyprus began in 2008 at the Oceanography Centre of the University of Cyprus (OC-UCY) with the formation of the national glider fleet followed by an active contribution to the initial GROOM design study (FP7). After several years of monitoring and research, Cyprus Subsea (CSCS), a private company, began providing services and development around Seagliders and Slocums, in addition to active contributions to the current GROOM II project. Throughout this period, Cyprus was active in OceanGliders, CSCS' director being part of its Steering Team, and chair of the Data Management Team.

National activity recently began at Cyprus Marine and Maritime Institute (CMMI) with development and testing around AUVs and USVs. CMMI is now the national delegate in EuroGOOS. CMMI has committed to supporting the GROOM RI, coordinating MAS efforts, and ocean observing in general, at a national level, something that was previously missing in Cyprus. CMMI has designated resources towards forming a national data centre and the new Research Director of Marine Sciences (Former CSCS' director as of June 2024) is already National Focal Point for GOOS, National Contact point for EOOS Operations Committee, EuroGOOS delegate, and IODE national representative. Although not part of Euro-Argo ERIC, Cyprus has been actively deploying ARGO floats and participating in Eurofleets activities through individual contribution, but hopes to formalise relationships in the coming years. It should be noted that CMMI is partially funded from the Cyprus government, is a public equivalent body, and is well-positioned to discuss marine research infrastructure at the ministerial level.

Facilities	**Type of facility**	**RPO / HEI**	**Potential GROOM RI node**	**Users of GROOM RI services**	**Service intermediary to other RIs**	**MAS resources**	**Services provided as a node**	**Comments**
CSCS	Priv.		y*	y		4 gliders	PI, CI, INN, OM, TR	
CMMI	Other	CMMI	y	y			PC, LF	CMMI is the National Maritime Cluster
OC-UCY	Inst.Fac.	UCY	n	y		1 glider	/	

** Depending on what the legal status of the future GROOM RI will allow.*

10.2.3. Estonia

In Estonia, MAS are used by the Department of Marine Systems at the Tallinn University of Technology (TalTech), who has owned one glider since 2014 and operates in the Baltic Sea. Their key research interest is on multiscale physical processes as well as submesoscale processes, their local and large scale impact on water and matter exchange between the sub-basins, coastal and open sea within the Baltic Sea area.

The structure and basis of operation of Estonia's R&D system are established in the Research and Development Organisation Act established by a 2021-2035 strategy. It includes the Estonian Research Infrastructures Roadmap which currently has eight Core Infrastructures, the marine RIs being part of the Estonian Environmental Observatory (KKobs) Core Infrastructure, TalTech belongs to.

Facilities	Type of facility	RPO / HEI	Potential GROOM RI node	Users of GROOM RI services	Service intermediary to other RIs	MAS resources	Services provided as a node	Comments
TalTech	Inst.Fac.	TalTech	y	y		1 glider	DM	

10.2.4. Finland

The Finnish Meteorological Institute (FMI) started MAS activity in 2015 and operates 2 gliders in the Baltic regions, and now maintains an endurance line in Finnish waters. This activity, as well as all major components of the Finnish marine research community (Research vessels, gliders, Argo floats, profiling buoys, coastal stations, and experimental laboratories), is gathered under the Finnish Marine Research Infrastructure FINMARI.

FINMARI is a strategic investment in the basis of marine research. It has been on the National Infrastructure Roadmap of the Research Council of Finland since 2014, and comprises central marine science branches: biology, geology, fishery research, ecology, marine chemistry and physical oceanography, geography and remote sensing.

Facilities	Type of facility	RPO / HEI	Potential GROOM RI node	Users of GROOM RI services	Service intermediary to other RIs	MAS resources	Services provided as a node	Comments
FMI gliders	Nat. RI+	FMI	y	y		2 gliders	EM, PC	

10.2.5. France

École Nationale Supérieure de Techniques Avancées (ENSTA) and Laboratoire d'Océanographie et du Climat: Expérimentations et Approches Numériques (LOCEAN) from the National Scientific Research Centre (CNRS) started a coastal glider activity in 2005 and actively involved other laboratories, so that in 2008 the Parc National Glider (PNG) was created and managed by the INSU CNRS Technical Division (DTINSU), in order to deploy underwater gliders for the French scientific community. It was installed and operated inside the Mediterranean Ifremer centre and part of the European Centre of underwater technologies (CETSM) and it was initially considered part of the French Oceanographic Fleet Very Large RI (TGIR FOF). From 2009 to 2020, the PNG successfully carried out a large number of research and monitoring missions on behalf of all the French scientific communities, in virtually all the world's seas. Access to the PNG was based on proposals to an annual call for tenders, which were scientifically evaluated by a national commission. Selected projects were simply charged a moderating fee to finance the marginal costs. The PNG glider data was managed by Coriolis, the French In situ data for operational oceanography. The reorganisation of the DTINSU led to the definitive closure of the PNG in May 2021 and the redistribution of the gliders to the organisations to which they belonged: ENSTA, LOCEAN, Centre de Formation et de Recherche sur les Environnements Méditerranéens (CEFREM), Lab. d'Océanologie de Villefranche (LOV), Mediterranean Inst. of Oceanography (MIO) and Takuvik International Research Laboratory Program (Univ. de Laval/CNRS).

Research Infrastructures in France are managed by the Research Ministry. Their funding is dependent on the Constitutional Bylaw on State Budget Acts - "Loi Organique de Lois de Finances'' and they are operated by RPOs (CNRS, Ifremer, etc). Since 2016, the roadmaps for French research infrastructures are partly aligned with the ESFRI roadmaps, which means that, particularly in the environmental field, a number of national RIs mirror the corresponding ESFRI landmarks. This is the case in the marine field (e.g. Argo-France national RI and Euro-Argo ERIC or EMSO-France and EMSO ERIC), where only TGIR FOF is an exception, but it should be noted that Ifremer, which hosts TGIR FOF, is a founding member of the recently created AISBL EuroFleets. The current 2021 French RI roadmap envisages the possible integration of these different RIs into a single RI, the beginnings of which are currently the subject of the Fr-OOS agreement, which brings together all the operational agencies and research bodies concerned.

The role of the metrology organisations should also be mentioned because, as well as being able to support the calibration of MAS sensors, they are playing a leading role in the MINKE project. They are the National Metrology Laboratory (LNE), and the Hydrographic and Oceanographic Service of the Navy (SHOM). Recently, SHOM has started to operate two gliders, including for its MSFD support mission.

Facilities	Type of facility	RPO / HEI	Potential GROOM RI node	Users of GROOM RI services	Service intermediary to other RIs	MAS resources	Services provided as a node	Comments
Alseamar	Priv.		n	y		17 gliders	/	Alseamar uses Coriolis to manage the data from its glider deployments for research and monitoring.
Coriolis	Nat. RI	CNRS, CNES,	y		Euro-Argo: DM	/	DM	Coriolis presently acts as a

Facilities	Type of facility	RPO / HEI	Potential GROOM RI node	Users of GROOM RI services	Service intermediary to other RIs	MAS resources	Services provided as a node	Comments
		Ifremer, IRD, SHOM, Universités Marines						GDAC for Argo and OceanGliders GOOS programmes and supports several others.
CEFREM	Lab. Fac.	CNRS, UPVD	n	y		1 glider	/	
ENSTA	Univ.	ENSTA	y	y		5 gliders	OUT, PC, CB	ENSTA is supervised by the French Ministry of Defence. It conducts dual marine research, including in the field of gliders. It has two campuses, Paris and Brest.
LNE	Nat. RI+	CNRS, UT3, IRD, CNES	y?	n	MINKE: CI	/	CI	Metrology
LOCEAN	Lab. Fac.	CNRS, IRD, MNHN, SU	y	y		5 gliders	DM, BP	The EGO DAC is maintained in relation with Coriolis DAC
LOV	Lab. Fac.	CNRS, SU	n	y		2 gliders	/	
MIO	Lab. Fac.	CNRS, IRD, UTLN, AMU	y	y	EMSO: CI	3 gliders	EM, CI	
SHOM	Nat. RI+	SHOM	y?	y	MINKE: CI	2 gliders	CI	National Hydrographic and Oceanographic Service
TAKUVIK	Lab. Fac.	CNRS, ULAVAL	n	y		2 gliders	/	Franco-canadian international laboratory with polar activity

10.2.6. Germany

The first glider deployment in Europe was performed by the Helmholtz Centre for Ocean Research Kiel (GEOMAR, formerly known as the Leibniz Institute of Marine Sciences IFM) 22 years ago, and Germany has developed a leading expertise in MAS related fields, investigating chemical, physical, biological and geological processes of the seafloor, oceans and ocean margins and their interactions with the atmosphere. Nowadays, GEOMAR, the Helmholtz Centre Hereon, the Navy and more recently the University of Hamburg operate gliders.

- Hereon maintains a monitoring activity in the framework of the Coastal Observing System for Northern and Arctic Seas (COSYNA). It operates SLOCUM gliders.
- GEOMAR - MAS operations are solely in the context of process studies that help to better serve cross-disciplinary science needs. As of mid 2024, GEOMAR operates a fleet of 12 SLOCUM Underwater electric gliders. Operations are guided by science needs and focus currently on the tropical and subtropical North and South Atlantic. Furthermore, GEOMAR operates three Liquid Robotics Waveglider for near surface operations as well as for data telemetry.
- The Experimental Oceanography group of the University of Hamburg specialises in physical oceanography and uses gliders since 2022 to make measurements of oceanographic properties and estimates of turbulent dissipation.
- The technology section of the Center for Marine Environmental Sciences (MARUM) of Bremen University operates a Liquid Robotics Waveglider.

The Konsortium Deutsche Meeresforschung (KDM), which is an association after German law, provides a high level coordination across all civil marine research institutions in Germany. It is the entry point for MAS operations, through its sustained ocean observing Strategy Group (SG OO). The processes related to setting up, prioritising (marine) Research Infrastructure in Germany are done via National Research Infrastructure roadmap (IR) and which is overlooked by the German Ministry for Education and Science (BMBF). For earth and environmental science (among others) the national RI is tightly connected to the operation and budget of the seven Earth and Environment (E&E) German Helmholtz Association institutions. The Alfred Wegener Institute for Polar and Marine Research (AWI), Hereon, and GEOMAR are responsible for marine science specifically. The operations are long term and implemented into the respective institutions budgets which are renewed every 6 years via an evaluation process of a joint proposal by all seven E&E centres.

Germany is contributing to Euro-Argo ERIC via the German Hydrographic Office (BSH) financed under the Ministry for Digital and Traffic (BMDV) serving marine security. There is involvement in and contribution to other ERICs and AISBL, to ICOS via BMDV but except ocean (ICOS OTC) that has no national commitment.

Facilities	Type of facility	RPO / HEI	Potential GROOM RI node	Users of GROOM RI services	Service intermediary to other RIs	MAS resources	Services provided as a node	Comments
BSH	Nat. RI+	BSH	n	y		no	/	

Facilities	Type of facility	RPO / HEI	Potential GROOM RI node	Users of GROOM RI services	Service intermediary to other RIs	MAS resources	Services provided as a node	Comments
GEOMAR	Inst. RI	GEOMAR	n	y		12 gliders 3 Wavegliders	/	
Hereon	Inst. FAC.	Hereon	y?	y		3 gliders	/	
Uni Hamburg	Univ.	Uni Hamburg	n	y		? gliders	/	
MARUM	Lab. Fac.	Marum	n	y		1 Waveglider	/	

10.2.7. Greece

Glider activity in Greece started in 2017 by the Hellenic Centre for Marine Research (HCMR), with the integration of the glider component in the observing network of the Poseidon Observing System. Recently, two more institutes in Greece have implemented gliders in their research, Laboratory of Physical and Chemical Oceanography Aegean University (LPCO) and Remote Sensing Laboratory of the National Technical University of Athens (NTUA).

The National Roadmap for Research Infrastructures (2014–2020) (RIs3) was designed and implemented by the General Secretariat for Research and Technology (GSRT) in the framework of the ESFRI roadmaps and describes the national strategic framework for research and innovation in Greece. Among the 28 research infrastructures that were funded in their first phase of implementation between 2017 to 2021, was the project for a national scale RI HIMIOFoTS (Hellenic Integrated Marine Inland water Observing, Forecasting and offshore Technology System) for the management of the Greek national water resources. HCMR is part of HIMIOFoTS with the Poseidon System and coordinates the project. The Greek glider facility is considered part of HIMIOFoTS.

Greece is contributing to EuroArgo, EMSO, DANUBIUS – RI, EMBRC and LifewatchERICs, while also participating in GROOM RI, JERICO RI, MINKE and Euro - FLEETS+ infrastructure projects.

Facilities	**Type of facility**	**RPO / HEI**	**Potential GROOM RI node**	**Users of GROOM RI services**	**Service intermediary to other RIs**	**MAS resources**	**Services provided as a node**	**Comments**
HCMR	Nat. RI+	HCMR	y	y	EMSO: OM	3 gliders	DM, EM, CB	
LPCO	Lab. Fac.	Univ. of Aegean	n	y		1 glider	/	
Remote Sensing Laboratory	Lab. Fac.	NTUA	n	n		1 glider	/	Is part of the RAMONES EU project considering gliders equipped with radioactivity sensors.

10.2.8. Ireland

MAS activity in Ireland started when the Irish Glider Network (IGN) was established in 2019 as part of EirOOS – Irish Ocean Observing System which is a component of EOOS managed by the Marine Institute (MI). MI operates 3 gliders that are available to the user community for oceanographic surveys on per day access rate.

EirOOS is a multi-platform distributed National Research Infrastructure with the objective to provide ocean and climate monitoring and research platforms to address key national needs and support enhanced Irish participation in European and international research.

Ireland is part of GROOM RI, Euro-Argo, EMSO, JERICO RI, SEADATANET, ICOS, Euro-GOOS, EuroFLEETs, EUMR.

Facilities	**Type of facility**	**RPO / HEI**	**Potential GROOM RI node**	**Users of GROOM RI services**	**Service intermediary to other RIs**	**MAS resources**	**Services provided as a node**	**Comments**
IGN	Nat. RI	MI	n?	y	Eurofleets+: OM	3 gliders	/	

10.2.9. Italy

The interest in glider science of the different Italian institutions can be summarised as public good services and/or for research in public interest. The glider activities are funded primarily by the Ministry of University and Research (MUR) with calls for projects with the aforementioned purposes or for specific research areas (e.g. funds for The National Antarctic Research Program PNRA - since 1985):

- OGS (National Institute of Oceanography and Applied Geophysics) Trieste operates a repeat section in the South Adriatic (since 2013) and some other areas of the Mediterranean for specific projects and in the Ross Sea in Antarctica (since 2020).
- ISMAR - CNR (Institute of Marine Science of the National Research Council) La Spezia has operated repeated transects between Corsica and Balearic Islands since 2015 with the help of Spanish SOCIB.
- Laboratorio di Oceanografia of University Parthenope Naples operates in the Ross Sea (since 2024).
- Laboratory of Experimental Oceanology and Marine Ecology (LOSEM) of University of La Tuscia is interested in the coastal region in front of Lazio region (Rome) for better sea state and weather forecast.
- CMRE (Centre for Maritime Research and Experimentation) - NATO La Spezia is not under MUR and operates in the Mediterranean Sea, and the European subarctic regions, covering areas such as the Fram Strait, Svalbard slope, and Barents Sea.
- ETT is an Italian ICT SME. ETT is coordinating EMODnet Physics and as such has been supporting the mapping of glider activity with OceanOPS and Coriolis.

The recent ITINERIS National Recovery and Resilience Plan (PNRR) project involves the atmosphere, marine domain, terrestrial biosphere, and geosphere (Nov 23-Oct 25). It will build the Italian Hub of environmental Research Infrastructures providing access to data and services and supporting the Country to address current and expected environmental challenges. In the marine domain, the aim is to strengthen the Italian infrastructures and its participation in ERICs. The overall goal will be to create a common database in which all data collected in the past and in the future will be stored. The most ambitious plan is to get real-time data from all platforms. Existing catalogues and formats will be used to ensure the FAIRness of the data. NODC and SeaDataNet will be heavily involved since it is a standardised infrastructure for managing the large and diverse data sets. Thanks to ITINERIS, Glider RI will be potentiated in terms of number of units for OGS and CNR.

Facilities	Type of facility	RPO / HEI	Potential GROOM RI node	Users of GROOM RI services	Service intermediary to other RIs	MAS resources	Services provided as a node	Comments
CMRE	Ins. Fac.	CMRE	n	n		8 gliders	/	Part of NATO. CMRE was part of GROOM FP7 and collaborates with MGEOMETOC COE (see Portugal)

Facilities	**Type of facility**	**RPO / HEI**	**Potential GROOM RI node**	**Users of GROOM RI services**	**Service intermediary to other RIs**	**MAS resources**	**Services provided as a node**	**Comments**
ETT	Priv.	ETT	n	y	EMODnet: DM		/	
ISMAR	Lab. Fac.	CNR	n	y		1 glider	/	
LOSEM	Lab. Fac.	UNITUS	n	y		1 glider	/	
Laboratorio di Oceanografia	Lab. Fac.	Parthenope Univ.	n	y		1 gliders	/	
OGS Glider Station	Nat. RI	OGS	y	y		4 gliders	OM, CI	

10.2.10. Netherlands

NIOZ, the Royal Netherlands Institute for Sea Research, is a leading marine research institute in the Netherlands. National Marine Facilities (NMF) is a division of NIOZ that provides researchers working in the Netherlands with ships, seagoing equipment, data management and qualified personnel to operate these facilities. As part of its renewal, it now includes a 'New Research Equipment' composed of MAS, namely 3 gliders, and other marine robots. NIOZ has acquired these 3 gliders through the Dutch Research Council (NWO) Large-scale Scientific Infrastructure grant (NWO-GWI), awarded in 2020 to a broad nationwide marine research consortium of universities, institutes and TO2 institutions, TO2 being the federation of Dutch applied research institutes.

NIOZ gliders are used in the context of research projects, like the North Sea Atlantic Exchange (NoSE) project to investigate how big the role of the North Sea really is in the uptake of carbon.

NIOZ and NERC (NOC, see UK file below) with Maas Software Engineering have initiated the Marine Facilities Planning (MFP) platform. MFP is a platform allowing MRIs to plan their research vessels operations, but also other types of equipment like MAS. It is becoming widely used by RV operators in Europe and worldwide. GROOM RI has investigated how MFP could support the coordination service that GROOM RI's Central Hub could offer to the GROOM RI members and to its users

Facilities	Type of facility	RPO / HEI	Potential GROOM RI node	Users of GROOM RI services	Service intermediary to other RIs	MAS resources	Services provided as a node	Comments
NMF	Nat. RI	NIOZ	n	y	MFP: PC	3 gliders	/	

10.2.11. Norway

MAS' activities in Norway are flourishing and diversified, ranging from fundamental research activities to advanced services for industry. Several organisations are involved:

- UiB (University of Bergen) Geophysical Institute has a long history in glider science and today maintains a major RI with a national focus (see NorGliders below). Its activities range from fundamental science at high-latitudes, including the polar regions, and intensive monitoring in the Nordic Seas.
- IMR (Institute of Marine Research) is the largest centre of marine research in Norway. It performs research and provides advisory services in the fields of marine ecosystems, fisheries and aquaculture. IMR plans to expand on MAS and use them operationally, in collaboration with the NorGliders facility.
- APN (Akvaplan Niva) maintains a high level of activity with MAS for the study of ecosystems in the Nordic and Arctic seas, including innovative use of optical and acoustic imaging sensors.
- NPI (Norwegian Polar Institute) runs management-oriented scientific research, mapping and monitoring in the Arctic and Antarctica, and provides advice to the Norwegian authorities, covering the fields of climate, environmental pollutants, biodiversity and geological mapping. NPI has developed interest in operating gliders in ice-covered waters, including under ice shelves, has previously accessed gliders through NorGliders, and also contributes to the NorGliders pilot team.
- NTNU (Norwegian University of Science and Technology), through AMOS (Centre for Autonomous Marine Operations and Systems) and AUR-Lab (Applied Underwater Laboratory) has significant activity in the field of marine robotics, including MAS as considered in GROOM RI.
- UNIS (The University Centre in Svalbard) is based in Longyearbyen and conducts Arctic research, offering year-round access to the Barents, Greenland, and Arctic seas. UNIS has previously accessed gliders through NorGliders and plans to establish a glider lab, offering an Arctic glider port.

The Norwegian National Facility for Ocean Gliders, NorGliders (http://norgliders.gfi.uib.no), is based at the Geophysical Institute UiB, and coordinates the operation of ocean glider infrastructure acquired through funding from the Infrastructure programme of the Research Council of Norway. The establishment funding was through infrastructure projects the Norwegian Atlantic Current Observatory (NACO, 2010-2015), the Svalbard Integrated Arctic Earth Observing System (SIOS InfraNor), and the Norwegian node of the European Multidisciplinary Seafloor and water column Observatory (NorEMSO). NorGliders aims to maintain and develop ocean glider infrastructure and expertise in Norway. It facilitates access to gliders and coordinates an operation centre consisting of a team of scientists, technicians, and pilots distributed among various institutions in Norway (UiB, IMR and NPI). The continuation and sustainability of the infrastructure are presently not secured and are based on rental income to research projects and users, as well as new infrastructure project applications. NorGliders is acknowledged to be the national facility for ocean gliders and expert on ocean glider operations, but with no legal status.

Norway is participating in MINKE and Euro - FLEETs+ infrastructure projects - apart from GROOM RI, as well as ERICs: EuroArgo, EMSO, ICOS and EMBRC.

Facilities	Type of facility	RPO / HEI	Potential GROOM RI node	Users of GROOM RI services	Service intermediary to other RIs	MAS resources	Services provided as a node	Comments
APN	Others (non-profit research institute)	APN	y*	y		2 gliders, 5 surface vehicles	OUT, PR, EM, INN, OM, CI	APN plays a key role in Europe in the development of biological gliders (e.g., Bioglider).
IMR	Lab. Fac.	IMR	y	y		2 gliders, 1 AUV, 1 surface vehicle	DM, EM	
NorGliders	ERIC	UiB	y	y	EMSO: OM	10 gliders	OUT, BP, PI, TR, CB, EM, OM	NorGliders also coordinates the glider operations in the Nordic Seas facility of EMSO ERIC
NPI	Lab. Fac.	NPI	n	y		? gliders	/	Polar region
NTNU	Lab. Fac.	NTNU	n	y		1 surface vehicle, 1 AUV, 4 LAUVs	/	
UNIS	Lab. Fac.	NTNU	y**	y		/	OM, EM	Polar region

** Under discussion and depending on what the legal status of the future GROOM RI will allow.*

*** Partner in NorEMSO phase 2 application (funding pending), and potentially a glider port on Svalbard.*

10.2.12. Portugal

Portugal had a late start in the operation of MAS, and only recently the first MAS were acquired by Portuguese Institutions:

- The Hydrographic Institute (IH) from the Portuguese Navy has launched an initiative to start a national pool of autonomous vehicles and operators with the goal of coordinating efforts in this area. IH was funded through the Portuguese Recovery and Resilience (PRR) Program to acquire autonomous vehicles, including gliders, AUVs, and USVs. IH and the Portuguese Institute for Sea and Atmosphere (IPMA) operate the fleet of oceanographic and hydrographic vessels in the country, thus providing access and support to long endurance operations at sea. IH is also the national NODC.
- Laboratório de Sistemas e Tecnologia Subaquática (LSTS) from University of Porto has been funded by EMSO-PT to buy a glider and a long range USV and by PRR to launch a Center for Atlantic operations with the goal of supporting long endurance operations in the Atlantic, as well as the integration of heterogeneous assets for remote piloting and situational awareness with a view to ocean observation. This Center will be connected to similar centres in development in Norway, Sweden, and the United States. LSTS coordinated the H2020 European I3 project on marine robots (EUMR), which, among other important results, highlighted users' appetite for transnational access to MAS, gliders in particular.
- Laboratory for Robotics and Engineering Systems (LARSYS) from Instituto Superior Técnico (IST) have been funded by EMSO-PT and by European funds to buy 2 gliders and other equipment.
- The Institute of Marine Sciences Okeanos of University of Azores has been funded by the regional government of the Azores to strengthen ocean observation capabilities. This started with the acquisition of a glider and there are firm plans for the acquisition of other important assets, including a 30m long oceanographic vessel.
- Observatório Oceânico da Madeira (OOM) from the Agência Regional para o Desenvolvimento da Investigação Tecnologia e Inovação (ARDITI) has been funded by the regional government of Madeira to strengthen their ocean observation capabilities. This will be done with the help of a long endurance USV, AUVS, and a new oceanographic vessel.
- Centre for Robotics and Autonomous Systems (CRAS) from Institute for Systems and Computer Engineering, Technology and Science (INESC-TEC) has also been funded by EMSO-PT to acquire gliders and by other agencies and PRR to acquire a coastal oceanographic vessel and to start a centre for ocean experimentation.

LSTS/University of Porto, CRAS/INESC-TEC, and LARSYS-IST are members of the national Blue Hub, funded by the PPR to promote cooperation and coordination of ocean-going activities. The installation phase of the Blue Hub will be finished by the end of 2025.

In summary, Portugal is a newcomer to the MAS world, but strong investments have created the condition and the critical mass to become a key player in this world. The challenge now is to create a national IR of vehicles and operators in order to coordinate national efforts and collaborate internationally. This challenge owes much to the importance of the Portuguese EEZ in the North Atlantic and the collaborations that these laboratories have with the NATO Maritime Geospatial Meteorological and Oceanographic Centre of Excellence (NATO MGEOMETOC COE), created on the initiative of the Portuguese Navy.

Facilities	Type of facility	RPO / HEI	Potential GROOM RI node	Users of GROOM RI services	Service intermediary to other RIs	MAS resources	Services provided as a node	Comments
CRAS	Lab. Fac.	INESC TEC	y	y	EMSO: OM	2 gliders	OM	
IH	Nat. RI	Portuguese Navy	y	y	JERICO RI: OM	2 gliders	OM	
IPMA	/	IPMA	n	/				IPMA is Portugal's national meteorological, seismic and oceanographic service.
LSTS	Lab. Fac.	UPorto	y	y		1 glider, 1 USV, 3 others	INN, PI	LSTS maintains the NEPTUS software toolchain, an essential link in the 'control' component of GROOM RI's future cyber infrastructure.
OOM	Inst.Fac.	ARDITI	n	/		1 USV		ARDITI is the Regional Agency for the Development of Research, Technology and Innovation.
Okeanos	Lab. Fac.	University of Azores	n	y		1 glider		
LARSYS	Lab. Fac.	IST	n	y		2 gliders		Is part of the RAMONES EU project considering gliders equipped with radioactivity sensors.

10.2.13. Spain

The Canary Institute of Marine Sciences (ICCM) of the Canary Islands government in 2005, and the Mediterranean Institute of Advanced Studies (IMEDEA), a Spanish National Research Council (CSIC) laboratory located on the Balearic Islands in 2006, launched the ocean-gliding activity in Spain, leading to the development of a flourishing MAS ecosystem, in particular through the Offshore Platform in the Canary Islands (PLOCAN) and the Coastal Observation System of the Balearic Islands (SOCIB). At present, five institutions are developing or maintaining MAS activities, with a strong focus on sustained ocean monitoring with MAS and other platforms (e.g. HF radars, fixed points) at their respective regional level:

- Centre for Marine and Food Research (AZTI) located in Biscay Country owns MAS that are used to explore different aspects of coastal dynamics and their effects on marine life and to monitor the coastal area in the South of the bay of Biscay.
- The Spanish Institute of Oceanography (IEO) now part of CSIC is starting its glider activity in the North Western part of the Spanish coast.
- SOCIB operates several gliders in the Western Mediterranean mainly for monitoring purposes. SOCIB has been particularly active in providing glider time in the frame of transnational access (TA) supported by European projects such as the JERICO series.
- With two gliders and a large variety of sensors for the gliders' scientific payload, the Marine Technology Service (SITMA) of University of Las Palmas de Gran Canaria (ULPGC) supports the scientific activity of the Research Groups and Institutes of ULPGC in terms of infrastructure and technical assistance.
- As a national infrastructure, PLOCAN offers a variety of MAS services to its users, including sea trials of technological innovations (vehicles, sensors, etc.). PLOCAN also monitors the Macaronesian seas with MAS, including in the framework of the EMSO's ESTOC regional observatory.

PLOCAN & SOCIB are Singular Scientific and Technical Infrastructures which are co-funded by national and their respective regional government, 50% each, meaning the Spanish Ministry of Science and Innovation (PLOCAN & SOCIB), and the Government of the Canary Islands (PLOCAN) and the Government of the Balearic Islands, respectively (SOCIB). Spain has set up a National Ocean Glider Working Group, made up of the five groups mentioned above and currently under coordination of PLOCAN, to develop a common roadmap for MAS facilities to work collaboratively at a national leveland to interact internationally with a national approach.

Spain has a strong presence in the European landscape through these institutes, that is, GROOM RI, Euro-Argo, EMSO, JERICO RI, EuroFLEETs, DANUBIUS RI, EMBRC, AQUACOSM, Lifewatch, ICOS, Euro-GOOS, EuroGO-SHIP, MINKE, EUMR.

Facilities	Type of facility	RPO / HEI	Potential GROOM RI node	Users of GROOM RI services	Service intermediary to other RIs	MAS resources	Services provided as a node	Comments
IEO-CSIC	Nat. RI	CSIC	n	y		2 gliders	/	The 2 gliders procured (2024) are to specifically support activities for

Facilities	Type of facility	RPO / HEI	Potential GROOM RI node	Users of GROOM RI services	Service intermediary to other RIs	MAS resources	Services provided as a node	Comments
								Santander's IEO facility. In parallel, a procurement of 7-8 gliders as national fleet is expected soon.
AZTI	Inst. Fac.	AZTI	n	y		2 gliders, 1 USV	/	
PLOCAN	Nat. RI+	PLOCAN	y	y	EMSO ERIC: OM	4 gliders, 2 USVs	TR, INN	
SITMA	Inst. Fac.	ULPGC	n	y		2 gliders	/	
SOCIB	Nat. RI+	SOCIB	y	y	JERICO-RI: DM	7 gliders	DM, EM	

10.2.14. Sweden

In Sweden, there are two main actors that work with marine autonomous systems, namely the research groups in the University of Gothenburg (UGOT) and the Voice of the Ocean (VOTO) Foundation. These actors collaborate closely with each other and students from the University are involved in VOTO piloting and operations. There is no formal coordination in terms of research infrastructure, however, equipment, expertise and knowledge is shared nationally via both these actors.

- UGOT owns and manages its own small fleets of gliders for scientific research in climate and oceanography focused mostly on the Southern Ocean but also the Arabian Sea. UGOT acquired its first gliders in 2017 and has been conducting novel glider experiments together with USVs in harsh polar environments. UGOT has hosted international glider schools in 2017 and 2023 focusing on science from gliders and integration to USVs.
- VOTO is a private foundation which has rapidly grown since 2020 to run fleets of gliders. Its mandate is to provide data from the Baltic Sea to improve knowledge of these local seas ultimately to improve the Baltic's health and sustainability.

The Swedish Research Council´s guide to research infrastructure published in 2023 highlights the role of HEIs in conducting RI in Sweden, which is quite specific to that country. It does not specifically address the RI challenges associated with observing the oceans with autonomous systems.

Facilities	Type of facility	RPO / HEI	Potential GROOM RI node	Users of GROOM RI services	Service intermediary to other RIs	MAS resources	Services provided as a node	Comments
UGOT	Lab. Fac.	UGOT	n	y		5 gliders, 4 USV	/	Polar regions, South African coast, Arabian Sea
VOTO	Other (Foundation)	VOTO	y*	y		15 gliders, 4 USVs	EM, DM, OUT, SR, BP, PI	VOTO operates only in the Baltic Sea

** Depending on what the legal status of the future GROOM RI will allow.*

10.2.15. United Kingdom

The UK has been at the frontier of ocean observing with important developments in the field of robotics in the last 30 years including flagship programs like the Autosub Under Ice. Today, the field of ocean robotics is still very active in the UK with development of AUVs and surface vehicles both in the academic and business domains, with companies like Ocean Infinity localising their European headquarters in the UK.

The UK community early embraced the underwater gliders with operations conducted by the Liverpool Proudman Oceanographic Laboratory (now part of the National Oceanography Centre) and the National Oceanography Centre (NOC) circa 2005, the Scottish Association of Marine Sciences (SAMS), the University of East Anglia (UEA) and the British Antarctic Survey starting their own operations around 2010 . There are around 5 gliders in the UK distributed across multiple facilities:

- NOC, hosting the National Marine Facilities (NMF) that support marine science activities operating the National Marine Equipment Pool (NMEP), providing facilities and means to the UK marine research community as a centralised and cost-effective resource which includes the research vessels Discovery and James Cook, a collection of more than 3000 sensors, a world class ROV and around 40 MAS platforms, including gliders, long range and world class AUVs and some surface vehicles. NOC comprises the Science component, NMF and BODC (British Oceanographic Data Centre). The NOC Science component gets funded through national capabilities, while working a lot on science projects with the Plymouth Marine Laboratory (PML) and the SAMS. Glider facilities are provided by NOC, while some other institutes own gliders which they operate alone or in cooperation and support from NOC;
- UEA successfully operates a fleet of 9 gliders globally while also accessing the national pool when required. Mostly focused in process studies, the UEA group has a highly successful scientific production, operating gliders around the globe with a strong presence in Antarctic waters;
- The British Antarctic Survey (BAS) focuses on polar sciences, and hosts a fleet of 10 gliders and 1 USV (Drixt). BAS utilises the national pool of gliders and pilots as required to complement its activities, and uses the NOC facilities for vehicle refurbishments;
- SAMS hosts part of the NMEP, owns two gliders and operates NMEP gliders. SAMS has been key to the continuous monitoring of the ELLET Array, operating gliders continuously for the last 10 years;
- Marine Scotlands, owns a single glider. The activity is still small due to limited resources and expertise, but it is focused on improving monitoring activities in Scottish waters;
- PML operates a variety of MAS in the framework of the Western Channel Observatory (WCO). The WCO also forms the backbone of Smart Sound Plymouth, which is one of the UK's platforms for advanced technology development, led by PML.

The UK Research and Innovation (UKRI) funds and manages frontier research and innovations. The UKRI ecosystem includes the UKRI councils, universities, research centres and industry. Under UKRI, the National Environmental Research Council (NERC) is in charge of Marine Sciences funding world class research facilities like the NMF at NOC and the polar facilities under BAS, both including ships, sensors and robotic capabilities. NERC is currently preparing for a zero carbon future with the Future Marine Research Infrastructures (FMRI) program, which is scoping the capability after 2030, year of replacement for the RRS James Cook. FMRI is considering all possible options from doing a like for like ship replacement to the more extreme option of replacing it all with robotic capability. It is within this context that a future GROOM RI collaboration with FMRI emerges to upscale, share and co-develop the future ocean observing system using autonomy.

The United Kingdom is participating in infrastructure projects, apart from GROOM RI: JERICO RI, EuroGO-SHIP, MINKE, as well as marine ERICs: EuroArgo, ICOS OTC, DANUBIUS RI. The UK is present in about half of the 2021 ESFRI landmarks.

Facilities	**Type of facility**	**RPO / HEI**	**Potential GROOM RI node**	**Users of GROOM RI services**	**Service intermediary to other RIs**	**MAS resources**	**Services provided as a node**	**Comments**
UEA	Lab. Fac.	UEA	n	y		9 gliders	/	
BAS	Nat. RI	BAS	n	y		10 gliders, 1 USV	/	Polar region
Marine Scotland	Nat. RI	Marine Scotland	n	n		1 glider	/	Operates only in Scottish waters
NOC-BODC	Nat. RI	NOC	y	y		0	DM	
NOC-MARS	Nat. RI+	NOC	y	y	MFP: PC*	35 gliders, 9 AUVS**, 4 USVs	all	
PML	Lab. Fac.	PML	n	y		1 USV	/	Using a private glider operator “Blue Ocean Monitoring”
SAMS	Ass.	SAMS	n	y		2 gliders	/	

** See MFP description in the Netherland file.*

*** These AUVs are long range one (AutoSub)*