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GROOM

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I. EXECUTIVE SUMMARY

Whether underwater gliders are used for scientific process studies, monitoring, operational oceanography, or commercial applications, the technical nature of the instrument requires an extensive infrastructure for its operation. The aims of the present document are to provide a guide that can be used by new glider users to assist in the planning of setting up the required infrastructure, and identify where and how the current landscape of glider infrastructure can be developed to enhance the efficiency and output. This document identifies the different roles the various aspects of the infrastructure play. The five main roles are summarised as

1. hardware operations and maintenance,
2. data management,
3. mission planning and piloting,
4. hardware calibration, integration and testing, and
5. public relations.

These roles, subdivided into specific tasks form the five core components of the glider port.

A questionnaire was sent out to all participating partners and its response served as the basis of the detailed description of the state-of-the-art laboratory hardware and field tools. Also, a booklet "A Guide to Glider Ports" was compiled from the response as a separate document, aiming at providing an overview to glider users - and scientists in general - of the facilities and capabilities of glider ports operated by European institutes. In addition to hardware systems, software systems play a vital role in glider ports, ranging from management of glider fleets, piloting and data visualising to mission planning. Important software systems developed are considered herein.

Due to historic reasons, most institutes operating gliders started off developing the required infrastructure, resulting in a glider port, usually hosted by the institute itself. It became evident that most glider ports did not implement all aspects because of limited resources (monetary and personnel) and that many implementation efforts were duplications. The EGO Cost Action (ES0904) and the GROOM project have contributed enormously to increase the level of networking between glider ports in Europe making major advances in terms of understanding of the needs, tool developments and data management, but also reducing duplication and improving efficiency.

As part of a network of glider ports, each glider port may be organised according to a different model. Herein, we define glider port models on the institutional level, national or regional level, SME level and the European level. The centralisation of core components (at a national level) allow processes to be organised more efficiently and evolve to a higher level of sophistication, but also increase the levels of complexity (e.g. in terms of communication between pilot and scientist, and logistics). There is, however, no "best" model, and the preferred implementation depends on the institute's policy and (national) political commitment. However, a European level glider port hosting a European fleet seems suboptimal because of the increased logistical complexity.

To coordinate and manage the distributed European glider ports, a body called Glider European Research Infrastructure (GERI) is proposed. The role of the GERI is to support and encourage the glider developments in Europe, by engaging its partners to share tools and experiment, participate in good practices and standard definition, and provide access to their gliders if they are available. For the near future, the GERI could be implemented by appointing facilitators, who have an overview and contact with all glider ports, act as entry points for other glider users and the scientific community in general, and develop an implementation plan for building the distributed European Glider infrastructure. A bottom-up approach, initiated from participating research institutes would help the consortium to make substantial progress towards a more integrated Research Infrastructure.

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II. INTRODUCTION

Whether underwater gliders are used for scientific process studies, monitoring, operational oceanography, or commercial applications, the technical nature of the instrument requires an extensive infrastructure for its operation. The level of implementation of such an infrastructure depends largely on the way gliders are (foreseen to be) used. Fundamental operating principles are common to all available gliders, and can be found in Eriksen et al. 2001 or Davis et al. 2003, for example.

In the early days of glider technology users who started to use gliders were faced with rather steep challenges. Besides getting acquainted with the glider technology itself, it was evident that many other aspects, such as tools (both hardware and software), operational protocols, and data handling, needed to be developed with no template available and little guidance from manufacturers. This led to a situation where several early-adopting institutes duplicated many efforts in establishing the required infrastructure for themselves. With the community of glider users growing, it became clear that such a *modus operandi* is highly inefficient, leading to unnecessarily high operational costs and below par results. Within the GROOM consortium various steps were undertaken in order to make it easier for new-comers to adopt glider technology and to improve the efficiency and results for existing users of glider technology. In this task of work package five (T5.1), we focus on the shore-side infrastructure required for glider operations. In this document, the main deliverable for the task (D5.1) we define the core components of the glider infrastructure, and we describe the functions of each of the core components, separately. The aims of the document are:

1. to provide a guide that can be used by new glider users to assist in the planning of setting up the required infrastructure;
2. identify where and how the current landscape of glider infrastructure can be developed to enhance the efficiency and output.

To address these issues, a questionnaire was designed early in the project and sent out to all participants in the GROOM project. The purpose of the questionnaire was to collect information on how much of glider infrastructure is already available in Europe, and how it is being used. The information given by the respondents provided the basis for realising the aims set out above.

In this document we first introduce the term *glider port* and describe its core components and tasks from a functional point of view. In Chapter III the state-of-the-art hardware and tools required for a glider port are described in detail. Chapter IV describes important software systems that play a vital role in nowadays glider port. Chapter V sets out the philosophy of a network of glider ports, and how they can be organised in a European context. A concluding summary is given in Chapter VI. For reference, the questionnaire as sent out to all partners is reproduced in Appendix A, see also Figure A1.

Glider port

The term "glider port" has been coined to describe such an infrastructure required to operate underwater gliders and manage the gathered data. The infrastructure contains several aspects that contribute to the overall task of glider operation. The core operations can be divided into five components: hardware operations and maintenance, data management, mission planning and piloting, hardware calibration, integration and testing, and public relations. Each of these components can be subdivided into more specific tasks. The components and their tasks, visualised in Figure III.1, are discussed in detailed below.

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Figure II.1: Five core components of a glider port

Operations and maintenance

The component *Operations and maintenance* is implemented in almost all glider ports. Its tasks can be summarized as

1. glider deployment and recovery;
2. glider preparation and maintenance;
3. development of maintenance tools;
4. development of deployment tools.

Glider deployment and recovery refers to the implementation of the protocols and capability to go out at sea, deploying a glider, launching the mission, recovering the glider and ending the mission,

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respectively. For this task access to sea and ships are essential, as well as skills to handle gliders at sea from small or large boats. These skills are usually easily acquired by a short training from experienced glider users or manufacturers.

Glider preparation and maintenance involves the activities required to prepare a glider for deployment and keeping/making it fit again after use. The make of the glider determines to a large extent how elaborated this task is in practice. The Slocum glider manufactured by Teledyne WebbResearch (USA), and Spray glider manufactured by Bluefin Robotics (USA) under license of Scripps Institute of Oceanography (USA), require the most effort in this aspect. Even at the most basic level, the user is responsible for all battery changes and a ballasting for target water within some 20 g tolerance. The Seaglider manufactured by Kongsberg Underwater Technology, Inc. (USA), under license of University of Washington (USA) on the other hand, requires little preparation and maintenance as it is primarily a closed system. Although the inconvenience of shipping an entire glider back to the manufacturer for a battery change (costs and downtime) has led to an increasing number of Seaglider users that are instructed by the manufacturer to carry out battery changes at their own lab.

Maintenance activities mostly involve cleaning the glider after deployment, ensuring all glider functions are still properly working, and (dis)assembling sensors for calibration.

The development of maintenance tools and deployment tools are tasks that are employed at a few glider ports only. These tasks usually arise out of a need for which no suitable solution has been developed. An example of a maintenance tool is a part of the Glider Fleet Management Tool, GFMT, discussed in detail in Chapter IV, where the administrative complexity of a larger glider fleet required an efficient tool to keep track of the deployment and service history of each individual glider. An example of a deployment tool is BUGS, built on top of the Dockserver-talk API (see page **Erreur ! Signet non défini.**), which displays the positions of (Slocum) gliders relative to the ship from which the deployment is carried out. This tool assists in keeping track of the position of gliders when multiple gliders are in the water concurrently, so that the gliders can easily be retrieved, and the risk of being over-run by the ship from which they are deployed is significantly reduced. The tool is also useful during the recovery phase.

Mission planning and piloting

Mission planning and piloting is an important aspect of the glider port which involves the following tasks:

1. mission design;
2. piloting;
3. development of mission planning and piloting tools;
4. development of glider position forecasting tools.

As a technical platform the glider is flexible though fairly complex. This means that before the mission, the glider needs to be programmed, that is, the glider needs a set of instructions that tells it what to do, when and how. Due to the two-way communication capability of the glider, this set of instructions can be altered during the mission. The mission design involves the programming of the glider, and reflects the (scientific) aims of the mission. Important aspects are where, how deep, how fast a glider should move, how it should sample. A proper mission design accounts for these aspects, while honouring the glider's limitations, such as limited speed, range, depth, and buoyancy drive. In addition, a mission design incorporates measures that prevent damage to or loss of the vehicle itself. In practice, most mission designs are adaptations of previous mission designs (possibly provided by the manufacturers). Writing custom design missions may require some level of experience.

The two-way communication capability of gliders means that from the deployment until the recovery, the behaviour of the glider can be altered: the glider can be piloted. In most cases, piloting means that changes are made to the glider settings resulting from human intervention. One aspect is the possibility of optimizing the flight of the glider. Depending on the ballasting, many parameters can be adjusted to make the glider fly better and save energy. This optimization is carried out while underway from the data of the glider in the water, ideally within a few days after the deployment to

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ensure longer deployments. Furthermore, human intervention is required when a glider does not behave as expected because of a technical problem (hardware or software). Solving issues that arise from technical problems is often not trivial and requires experience and frequently the assistance of the manufacturer. In most cases, however, changes in set of instructions reflect changes in the mission design or the anticipation of a changing environment (currents or density). Common parameters that are changed are waypoints, buoyancy drive, and settings of sensors. Dealing with such changes usually follows a predictive sequence of commands and glider responses, so that most of the work can be diverted to scripts, alleviating the burden on glider pilots.

The extent of automation, provided by scripts, can be taken a step further by mission planning and piloting tools. With these tools, also the content of the changes that is delivered to the gliders is automated. An example is the mission planning tool developed by CMRE (see also Section Planning, page 28) where the glider is directed following an algorithm that objectively optimizes the sampling of the oceanic features of interest. Examples of other tools are warning systems that warn glider pilots in case of anomalies detected in glider behaviour, which further relaxes the task of (human) glider pilots.

Besides tools that automatically tell a glider what it should do, some tools can also be required to predict where a glider will be at given time in the near future (<12 hours). At HZG, for example, a forecasting system is developed that predicts the path of the glider for a period of 12 hours. This information is sent to the shipping authorities (Vessel Traffic Controllers) at 12 hour intervals during each mission in order to reduce the probability of a glider-ship collision (with the aim to make shipping safer). Different glider simulators have been developed, from a basic linear extrapolation from glider data to a 4D simulation in numerical ocean forecasts. In GROOM a package taking into account a risk assessment has been developed and tested (deliverables D5.6 and D4.5).

Hardware calibration and integration

The sensors on board a glider are the primary reason for its existence. The tasks that a glider port can fulfil related to sensors can be summarized as

1. sensor calibration;
2. sensor integration;
3. sensor testing.

The list of available sensors on the glider platform is long and growing, see GROOM deliverable D5.2 for an extensive discussion. Many sensors need some form of calibration to measure the quantity of interest. In practice it is often necessary to send the whole or part of the glider back to the manufacturer, who then disassembles the sensor(s) and ships them to the sensor manufacturer for calibration. This procedure is expensive and time-consuming, but it requires little effort of the glider user.

The significant costs and turnaround time of a manufacturer sensor calibration has led to the wish of many glider users to develop the capability to calibrate the sensors in-house. Some existing glider ports have developed facilities to calibrate optical sensors and CTD in the laboratory or in the field. Examples of these calibration facilities are given in Section III, page 15.

As new types and versions of sensors are constantly being developed by sensor manufactures, and new uses of existing, but not implemented sensors emerge, there is a need from the glider community to have those sensors integrated into the glider architecture. Once integrated, the sensors need to be tested, and a best-practice protocol needs to be developed. The integration and testing of sensors is often done by the glider manufacturer. However, the integration of a specific sensor may not always be a priority of the manufacturer, so that some glider ports may have a need to develop the skills themselves, potentially in collaboration with the glider and sensor manufacturers.

Data management

The data that are generated whilst the gliders are in a mission all arrive at some point in a glider port. Responsibilities of the glider port with respect to the glider data can be listed as

1. data retrieval;

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2. quality control;
3. hosting a data assembly centre (DAC);
4. relaying data to an external DAC or Global DAC (GDAC).

During the mission near-real time data are sent to a server within the glider port using the satellite communication link. After the mission and depending on the glider model, when the glider has been recovered successfully, the data can be off loaded from the glider (delayed mode data). The GROOM consortium has developed an extensive manifest on how to quality check the data and how to recast the data in a format that is accessible with commonly available tools, see reopr D3.3. The data can be made publicly available by transporting them into a global DAC, such as the GDAC Coriolis (<http://www.coriolis.eu.org/>).

Alternatively, some glider ports can use other available database facilities (Regional DAC) . The near-real time and delayed mode glider data can be transported into the RDAC, while being passed through a sequence of quality control checks. These data are then made available to GDACs.

Public relations

The public relations component consists of three tasks:

1. interaction with authorities
2. outreach
3. communication with other glider ports

In particular in busy coastal areas, authorities may require special conditions to be complied with by the glider operator before the execution of a glider experiment is allowed. Furthermore, permission may be required when using gliders in foreign waters. Communication with authorities is expected to become more and more important.

As exhibitions and open-house events invariably show the technical concept of gliders is very appealing for members of the public and children in particular. Therefore, gliders can be used as a bridge to make oceanography more accessible and increase the awareness of the fragility of the ocean-atmosphere system. A glider port can take part in these outreach activities by offering an exhibition area or show-room for visitors to the institute and engage in projects with local schools or museums.

The communication with other glider ports is one of the key tasks of a glider port as this allows glider ports to be networked. Networked glider ports can exchange ideas, services, and personnel so that the efficiency of the networked glider ports is increased while the costs are lowered. A networked glider port may be fully functional, although it does not implement all the tasks of all core components (Figure III.1). In fact, some glider ports may offer just a small subset of these tasks and target a special service, whereas other glider ports offer more tasks and target a wider range of services. In practice, this differentiation makes sense. For example, a glider port near an area that is frequently visited for scientific experiments is valuable even if this glider port solely offers aid in hardware handling (in particular glider deployment and recovery, and to a lesser extent glider preparation and maintenance). On the other hand, a glider port might even be far in-land, not focussing on providing hardware related services, but implementing many of the other tasks shown in the figure, such as mission planning and piloting, or data handling. The concept of networked glider ports is discussed more extensively in Chapter V.

"A Guide to Glider Ports" booklet

In order to establish new links between glider ports, it is important to have an overview of where glider ports are located and in what aspects they are particularly specialised. The fact that a glider port does not necessarily implement all tasks implies that glider ports could be classified according to the range of services implemented. It is tempting to introduce levels to classify glider ports. Although levels can indicate the level of sophistication or number of tasks offered, it offers a poor description of the area of expertise covered. Instead, the GROOM consortium has developed a glider port guidebook to

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characterize the present European glider ports and thus allow users to easily locate the infrastructure available. The guide book has been compiled from data gathered using a questionnaire, sent to all GROOM partners, see Appendix A.

The responses of the questionnaire have also been used as basis for the information presented in Chapters III and IV. Chapter III, describing the facilities that can be found in glider ports, is based on the analysis of questionnaire responses with respect to the details of various glider port components regarding hardware operations and maintenance, calibration and development. Besides hardware and equipment, it is shown in Chapter IV that software is a significant component of a glider port regarding piloting, organising maintenance and data interpretation and evaluation. Data management is described briefly as is the interaction with authorities and the general public, but these are more fully described in GROOM tasks T3.2 and T3.3, respectively. Please see the corresponding Groom deliverables D3.2 and D3.3.

III. FACILITIES

In this section the glider port components related to glider operations, piloting, sensors and data quality control are described in detail. This section provides a state-of-the-art description of the current glider port facilities in Europe.

Hardware operations and maintenance laboratory

A key point in the design of a glider port is the laboratory. A well-designed laboratory has easy access to facilitate transporting gliders and glider equipment. Furthermore, as it is common practice to test satellite communication and positioning systems prior to deployment, the laboratory should also have easy access to an open space with unobstructed sky view. Furthermore, the laboratory should be labelled with exit routes and emergency plans, in line with local health and safety regulations. Examples of glider port laboratories are shown in Figures III.1 and III.2.

The main functions of the laboratory can be defined as:

1. buoyancy testing in tank;
2. adjusting weight and weight distribution;
3. maintaining of and replacing parts;
4. battery changing;
5. preparing gliders for deployment;
6. post-deployment activities;
7. glider storage;
8. show room.

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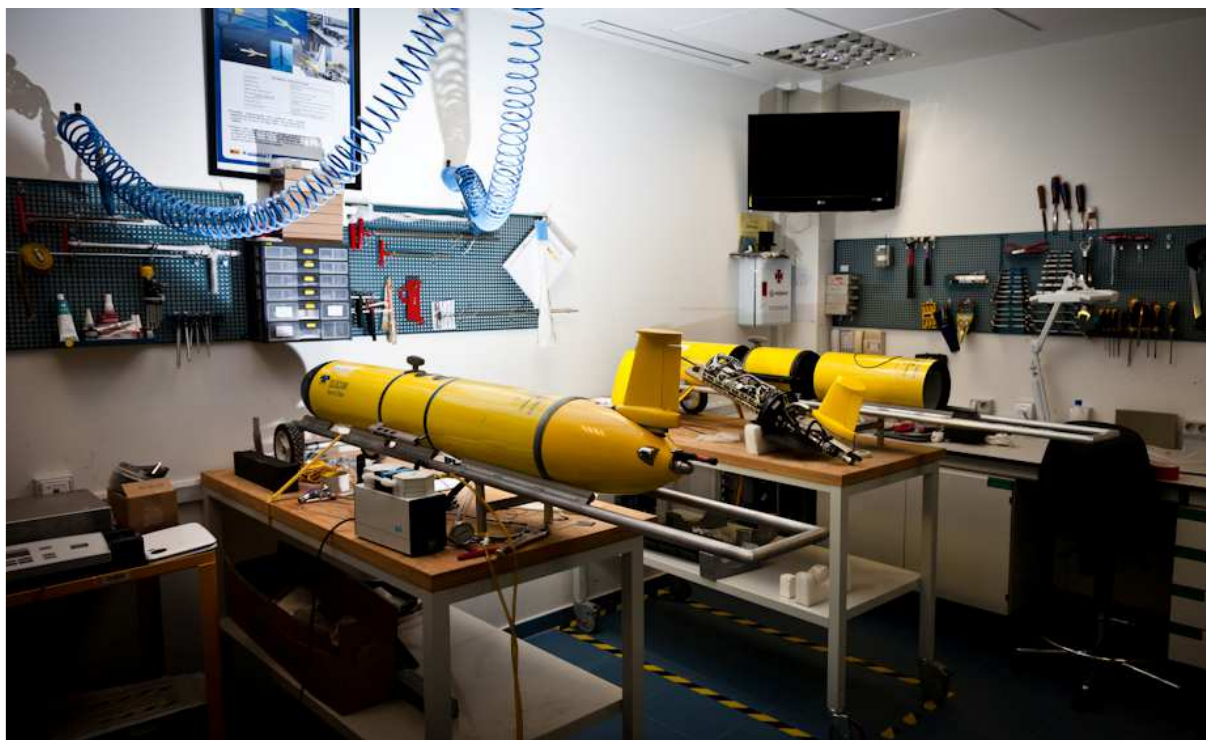


Figure III.1: Glider Laboratory at SOCIB [credits: Balearic Islands Coastal Observing and Forecasting System (SOCIB) and IMEDEA (CSIC-UIB)].

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Figure III.2: Glider Laboratory at HZG

Buoyancy testing and weight distribution

Depending on the type of glider, some of these functions may be of lesser importance. For example, the Seaglider needs only a rudimentary buoyancy trim, which is later fine-tuned during piloting by adjusting the buoyancy centre in software. The initial buoyancy trim is based on dry weights at the time of construction and is updated using a spreadsheet at each refurbishment, so a buoyancy test tank may not be necessary. This is in contrast with the Slocum and Spray gliders, which due to limited buoyancy change capacities need to be well ballasted (typically within 20-30 grams). For this type of glider a ballast tank is a necessity. As usually several cycles of buoyancy testing and adjusting the ballast weight are necessary, the work surface (where the glider is opened and the weight is adjusted) and the ballast tank should be reasonably near each other.

Letting a glider in the tank or removing it, can be done manually by two persons, but because of its weight of about 60 kg, it is preferable to use a crane (see also page 14) for this task. That means that also from this point of view the work surface and ballast tank should be in each other's proximity so that the crane can service both locations.

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Maintaining and replacing parts and batteries

A common activity is that batteries have to be replaced. This is in particular the case for Slocum and Spray gliders, where the user is expected to carry out the replacement himself. This may also affect Seaglider users who have followed a training scheme with the manufacturer to do a battery replacement on site (rather than the typical case in which the Seaglider is shipped back to the manufacturer). As the weight of each battery set varies, this usually means ballast weight has to be added, removed or shifted. Other activities that are recurrent are swapping out parts or sensors. In many of such cases, the glider will be in a disassembled state, prohibiting the work surface to be used for other gliders. Therefore depending on the size of the glider fleet, or planned glider fleet, the number of servicing workspaces should be large enough.

Preparing for deployment

Pre-deployment tests involve testing communication and positioning systems. As they rely on satellite communication, these systems can only be tested when the glider can be brought in a position with clear view to the sky. Therefore the layout of the laboratory should ideally be such that there is easy access to such a space. It is also possible to route a connection to the lab from a roof-installed antenna for frequent communications and positioning testing, but fully assembled testing should eventually take place as well. Furthermore, a pre-deployment activity involves calibrating the glider's compass. As the reading of the glider's compass is very sensitive to artificial magnetic fields, such a calibration can not generally be done indoors. This is because most buildings contain large amounts of steel or iron that causes modifications to the Earth's magnetic field. Therefore, ideally the laboratory would give access to a plan with virtual no iron in the surroundings (including the ground). In addition, Seaglider Fabrication Center has developed a protocol for calibrating the compass at sea during the initial phases of deployment. It requires a special sequence of shallow dives and some on shore processing in order to update the calibration coefficients on board the glider.

Post-deployment activities

Post-deployment operation usually means that the glider is returned to the lab. If not already cleaned, the glider is to be cleaned from biofouling and salt. For this a fresh water hose is required. Furthermore, the data collected should be off-loaded. In theory the data transfer can be done over FreeWave (Slocum gliders), but depending on the duration of the mission, this action may take too long (order of a day). In practice this means that the glider is opened up and that data flash cards are removed and read out using a desktop/laptop PC. For Seagliders, data on board the glider can be uploaded using the serial cable provided, but it is strongly recommended to increase the transfer rate above the default value so the glider does not switch off automatically. If it is planned to open the glider to change the batteries anyway, or if the user is comfortable opening, closing and pulling vacuum on the glider pupa, it is much easier to physically extract the on-board memory card and copy files using a CF-card reader.

Storage

When not being used, gliders should be stored properly. This means its physical presence should not cause any hindrance or dangerous situations for people working in the lab. A practical aspect of a proper storage facility is that a glider can be set aside incomplete or dismantled (which can be the case when waiting for replacement parts). In particular, in an environment with multiple gliders of the same type different parts can get mixed up easily. It is important for the glider laboratory to be large enough to accommodate all gliders and their parts when they are not assembled. The storage has to be clean enough to allow the gliders to be open without danger for the devices. Otherwise the gliders have to be closed which potentially induces more work. An example is given in Figure III.3.

Show room

As gliders are exciting instruments, they are favourite objects to be shown to visitors, such as scientists from other institutes, students and politicians as part of out-reach activities. When designing, it is worthwhile to consider to include a "show room" aspect to the glider laboratory. Besides the gliders

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themselves, in such a show room near-real time data or historic data can be shown on a display, or scientific results as posters.

In order to deliver the functionality described above, a glider laboratory should sport a number of hardware items. This includes a wet area with a ballast tank (if applicable), worktop(s) for glider maintenance, a crane that facilitates moving a glider between worktop and ballast tank and desk space with network connection (LAN or WLAN). Furthermore, shelving is required for storing gliders, spare parts and regular and specific glider hardware tools. A showroom area could consist of panels for posters and display to present (near-real time) data and slide shows. Also a model or demonstration glider could be shown here. Model gliders with transparent hulls revealing the inner-workings have been shown to be instructive in explaining the principle of operation of gliders to a wider public.



Figure III.3: Example of a glider storage [credits: Balearic Islands Coastal Observing and Forecasting System (SOCIB) and IMEDEA (CSIC-UIB)].

Crane and stand

In particular the Slocum and Spray families of gliders require precise ballasting before deployment, which means that as part of the ballasting procedure a glider will have to be put in the water to test its buoyancy several times. For ballast tanks that are not level with the floor, letting a glider in and out the water manually is a potential health risk. Furthermore, in practice most of the maintenance is done by the user, rather than the manufacturer, with the possible exception of Seaglider. This implies that lifting a glider on and off a work surface is a recurrent task. Therefore, if (intended) glider operations involve maintenance done by the user and/or ballasting, then a crane is mandatory.

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Seaglidors on the other hand, can most easily be serviced using a bench- or trolley-mounted rotating clamp. Gliders and large glider segments are most easily moved to and from the clamp or worktops by two people, so that a crane is not particularly advantageous.

Nevertheless, within the European glider community, most institutes that do their own maintenance on gliders have crane facilities in place. Often a glider lab is created in a previously existing laboratory or workspace where a crane is available (mostly ceiling mounted). If a crane needs to be purchased, then portable, floor mounted, or (fixed) ceiling mounted cranes for relatively light loads can be considered, see Figure III.4 for an example.

Pressure chamber

A pressure chamber can be useful to detect any leakages in the glider assembly or a sensor assembly. Despite this, the large costs mean that most institutes will do without. Ideally the pressure chamber should be large enough to contain the whole glider. Presently, only one such a pressure chamber is available in Europe and used for gliders (SOCIB/CSIC, 0.4 m x 2.0 m), see Figure III.5. Other available pressure chambers available in some institutes are too small to contain a complete glider, although they still can be useful in testing the integrity of sensor assemblies, for example. Another way to test pressure on a glider is to make tests in the water if there is an easy access to deep waters and emergency recovery possibilities. This is a bit more risky but if no major leakage is occurring, a glider will likely manage to come up to the surface and call for emergency recovery.



Figure III.5: Pressure chamber [credits: Balearic Islands Coastal Observing and Forecasting System (SOCIB) and IMEDEA (CSIC-UIB)].

Calibration facilities

The calibration of sensors is an important topic. Sensor specific calibration techniques are not covered herein; the reader is referred to D5.3 (Protocols for sampling, sample analysis, inter-calibration of missions, and data analysis for the recommended parameters) for an extensive discussion on this. In this section, we deal with calibration facilities. Having said that, calibration facilities are mostly non-existent in present day glider laboratories. Commonly sensors are calibrated by the manufacturer.

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Some institutes maintain a strict schedule of sensors being calibrated by the manufacturer yearly, biannually, or every 4 years. For Seagliders, which have until recently been returned to the manufacturer for each battery refurbishment, it is often convenient to have sensors calibrated during this time, in particular the CTD and optical sensors. For Slocum gliders, the process is relatively straight forward as most often the sensors are mounted into the science bay. The science bay is a hull section of about 30 cm, which can be removed and shipped in an easy and cost-effective way, without the need to ship the whole glider. Alternatively, sensors can be removed from the hull. Although facilitating the shipping, the unit should be tested for any leakages after re-assembling. A pressure chamber (see previous section) is an indispensable instrument in this case. For Sprays, the sensors would have to be dismounted by the user. Recently, several Seaglider labs have acquired the skills and equipment to change batteries and extract sensors from the glider for calibration. For the common free flush CTD, the sensor and circuitry is un-soldered and mounted into a special housing for calibration. These must be sent to Kongsberg Underwater Technology Incorporated or the University of Washington, who then passes them on to SeaBird Electronics. Other sensors (dissolved oxygen and optical) are very easily disconnected and typically returned to the manufacturer for calibration.

The *de facto* calibration, whether carried out by the manufacturer or at the institute itself, requires the sensor to be disassembled from the hull. When returning the glider or science bay to the glider manufacturer, the process of disassembling, calibration, assembling and testing is organised by the manufacturer. If the calibration is performed at the institute or not under control of the (glider) manufacturer, the testing phase may be a bottleneck, as a pressure chamber may be required.

The limited availability of pressure chambers may also be one of the reasons why only a few institutes have invested in on-site calibration setups. In particular for commonly used commercial off-the-shelf sensors such as CTD's, turbidity sensors and fluorescence sensors, on-site calibration facilities would be an asset for a glider lab. The following list identifies calibration facilities currently existing within the GROOM community.

1. CMRE;
2. HCMR;
3. NERC;
4. OGS;
5. Geomar.

Besides calibration in the lab, sensors can also be calibrated in the field. A common method employed is that during or directly after the deployment and/or recovery of the glider, CTD casts are performed from the deploying vessel. In this way glider sensors, in particular CTD, but also optical sensors should they have their equivalent being installed on to the CTD frame, can be referenced. The CTD frame sensors are usually easy accessible and therefore easily laboratory calibrated. Such a technique is especially useful for CTD referencing for deep diving gliders, as for deep waters the absolute salinity/conservative temperature profiles are very stable.

D5.1



Figure III.6: An in-situ calibration frame, developed at HZG. The frame allows comparing the sensors of two gliders simultaneously, as well a suite of reference sensors (in the centre of the frame). Furthermore, the frame contains three vessels that can be used to collect water samples, controlled from a deck unit.

The same technique can also be used for a low-order referencing of optical instruments, such as turbidity sensors, optical backscatter sensors and fluorescence sensors. The drawback of applying this technique to these sensors is that in the deep ocean absolute values and variability can be quite low, so that it is difficult to establish the (assumed) linear relationship between the sensor output and the concentration or intensity of the substance observed. This can get worse in coastal areas where the observable range can be large, but may also be determined by weather or the environment. An example is suspended sediment concentration, which can vary substantially within a tide and under different atmospheric conditions. Also here the challenge is to obtain calibration data points that cover a significant part of the observable range.

In addition to the issue of obtaining a representative collection of samples, the data obtained by the glider and CTD frame are not co-located. To mitigate this, in-situ calibration methods were developed whereby the glider is mounted onto the CTD frame directly (CMRE/Geomar). Stops at different pressure levels are required to mitigate the different time response of all the sensors.

A specialised solution for shallow coastal waters, developed by HZG, consists of a frame with reference probes for CTD, optical backscatter and fluorescence, and a water sampler capable of taking three 2 litre water samples, that can be analysed for chlorophyll content, suspended sediment concentration via filtration and oxygen content, see Figure III.6.

D5.1

Hardware tools

The operation of gliders requires the use of a number of hardware tools. Here, we deliberately do not consider common hardware tools, such as screwdrivers, wrenches and pliers, but specific tools that may not be present by default in a well-equipped workshop, and may even be specific to a certain type of glider. Below a list given of commonly used tools in the lab, but also at sea.

D5.1

Tool	Remark
Rollable workbenches	
Air compressor	Internal cleaning, O-ring groove cleaning
Dual voltage supply (10V/24V)	Seaglider only
Support frames	For front-end maintenance (Slocum glider)
Glider clamp and bearing mount	Only for Seaglider battery change or sensor extraction
Specialist balance	Max capacity of 60+ kg, and 1 or 2 g resolution
Vacuum pump	Pressure capacity of (Slocum/Spray: 0.4 bar; Seaglider: 0.5 bar)
Pressure Release Valve	Seaglider only
Long T-handle hex keys	
Alternative glider comms tools	
Acoustic Transponder	For locating Seaglider when underwater
Argos Beacon finder (Goniometer)	For locating gliders via transmitted Argos beacons
Glider specific tools	
Argon bottle	This is to prevent humidity in the glider. The air in the glider is replaced by a dry gas
Degassing tool for 1000m Slocum	Tool for removing air bubbles that may be trapped in the oil of the buoyancy pump of Slocum gliders
Communication tools	
Hand-held iridium phone	Allows comms with the glider operator at sea when too far off-shore
Hand-held GPS	For cases when ship's GPS is not available

D5.1

Experimental recovery aids	
3x3x3 m fixed frame net	Aid for recovery from larger vessels. Prototype phase (Geomar)
11 m carbon fibre pole and rope loop	Used for Seaglider recovery from larger vessels (NOC/UEA)
Hooks (~5m)	Used to manipulate the gliders from a medium/large vessel and attach a rope for recovery.
Cargo net and spreaders	Used for Slocum recovery from larger vessels (NOC)
Double looped stick	4 metre long hollow stick with cord and loops on both sides to catch and crane glider during recovery (HZG)

Communications

Iridium (satellite) communication

Generally gliders make use of satellite communication for making a link with a server on shore. Although a number satellite communication systems have been developed by various nations or consortia over the years, it is the Iridium satellite communication system that is used solely today. The advantage of the Iridium satellite communication system is that it provides a global coverage, in contrast with, for example, the Thuraya satellite system, which covers Europe, Africa, Asia and Australia, but not the Americas.

Normally, a satellite connection is initiated using an embedded Iridium modem on the glider platform. A connection is established with a satellite and via possibly a number of satellites the connection is made back to land to *The Gateway*, a data centre in the US. From here the connection is relayed, either via a Public Switched Telephone Network (PSTN) to a conventional modem connected to the server on shore, or via the Internet using a TCP connection directly to the server. The latter method is commonly referred to as RUDICS (Router-Based Unrestricted Digital Internetworking Connectivity Solutions).

In particular for users outside the US, the PSTN solution can have poor connection and data transfer rates. Most likely this is due to occasionally poor quality transatlantic phone connections (for users in Europe). The RUDICS solution does not suffer from badly performing phone lines as the communication from the Gateway to the server is via the Internet. The RUDICS system is therefore the recommended solution.

In order to set up an Iridium account, a SIM card needs to be purchased from a Iridium provider. In case of a PSTN connection a conventional modem is required. In order to set up the RUDICS system, at The Gateway the relay from data centre to the user's server need to be configured. For this a one-off fee is payable of approximately \$1500. The transmission costs are generally lower for the RUDICS system. Depending on the intensity of use of the glider, the break-even point can be expected to be reached rapidly or after a few years.

Another way to use Iridium communications is through SBD (Short Burst Data) messages. This is similar to SMS and do not allow a fully direct link between land and the iridium phone.

Argos communication

In addition to the two-way Iridium satellite communication solution, Slocum gliders also use the one-way Argos satellite communication solution to transmit short messages (typically 32 byte) at 90 second

D5.1

intervals when the glider is at the surface. These messages may or may not be picked up by the Argos satellites. If the message is picked up, it is accessible with some delay of the order of an hour via an online service offered by CLS (Collecte Localisation Satellites) in France. These messages contain the latest GPS information at the time of transmission. Furthermore, if the message is seen by at least three satellites, the position of the glider at the time of transmission can be estimated with accuracy up to 1 km using a triangulation method.

The Argos system is implemented on the Slocum glider for additional safety. If the Iridium system is broken, the Argos system allows the retrieval of accurate GPS information. Even if the GPS is not functional either, (less accurate) positional information is available to assist a glider recovery. Seagliders are, for the same reason, often retrofitted with an Argos transmitter. These transmitters do not encode the measured GPS position however, and localisation is available from the Argos satellite system itself.

Per glider an account needs to be applied for with CLS. Subscription costs are in the order of \$40 per month.

The Argos beacon signal can also be received using an Argos beacon finder, such as the Gonio 400 Argos Direction Finder. These commercially available devices are usually used for locating drifters, but can also be used for glider recovery. In practice this is of little use however, as Slocum gliders are also equipped with a radio telemetry system (see next section), which allows reporting of actual position information from the glider's GPS. For Seagliders, the goniometer may be a useful tool to assist in locating problematic gliders in the field, since there is no radio telemetry system.

FreeWave VHF communication

FreeWave is a radio communication solution operating at the 900 MHz band. This allows users to establish a communication link with a glider up to a range of ~10 km (line of sight), depending on weather and sea state conditions and the height of the antenna. This system is only available for the Slocum glider and all the equipment needed comes with the glider package.

Dangerous goods disposal

Practically all gliders are battery-powered. As most gliders use primary batteries as opposed to rechargeable ones, a fair number of batteries need to be disposed of as waste. For example, a Slocum glider contains around 200 C-cell batteries, which gives an endurance of about 4 (alkaline) or 10 (lithium) weeks, depending on sensor load and glider configuration. The used batteries need to be disposed off in a proper way. Often, a recycling scheme that is already in place in the institute can be used, or used batteries can be returned to the supplier of new batteries. The latter is the case for BatterieLaden, a German company that assembles batteries for Slocum gliders, and Kongsberg Underwater Technology, Inc., the current manufacturer of Seagliders.

IV. SOFTWARE SYSTEMS

Operations: Glider Fleet Mission Tool (GFMT)

Over the years, experience has shown that the activities involved running a glider facility, i.e. maintenance, deployment/recovery and piloting, could be simplified and enhanced with the right software tools at hand. As the glider manufacturers do not currently offer such a solution, the glider community has been developing its own tools. DT-INSU/CNRS developed a software system, dubbed Glider Fleet Control Panel (GFCP, described in detail in D4.4). In this section the Glider Fleet Mission Tool (GFMT) is described. This tool extends the GFCP to the needs on a European level and is currently under development. The GFMT aims at facilitating the operation and maintenance of gliders. It does this by keeping control and track of every step of the operation, from the glider preparation to the sending of (scientific) data and meta-data to a data assembly centre. Furthermore, the tool

D5.1

provides support for recurring actions in piloting gliders, a pre-validation of data using data visualization component, dashboards and automatic reports, see Figure IV.1.

The objectives for GFMT are to:

1. Schedule deployments;
2. Manage equipment purchases and maintenance;
3. Pilot gliders;
4. Manage data processing;
5. Send data and meta-data to a Data Assembly Centre;
6. Export deployment and equipment reports;
7. Provide access to users from a standard web interface.

Most of the features above are available in the GFCP.

Users

The users of the Glider Fleet Mission Tool are organized in glider fleet groups. A group is related to a country, and a country can have several groups. There are different types of users in each group, each with a specific purpose:

- ⑩ **Glider fleet manager** uses the interface to :
 - ⑩ Describe the technical characteristics of his/her group (servers, etc.)
 - ⑩ Add users in this group and manage their profiles
 - ⑩ Create and describe a deployment
 - ⑩ Create and describe a project
 - ⑩ Schedule deployment and maintenance
 - ⑩ Choose the pilot(s) for a deployment
- ⑩ **Fleet technician** uses the interface to :
 - ⑩ Create and describe an equipment
 - ⑩ Register maintenance operation
 - ⑩ Change equipment status
 - ⑩ Add document about equipment, operation, deployment, etc.

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System boundary

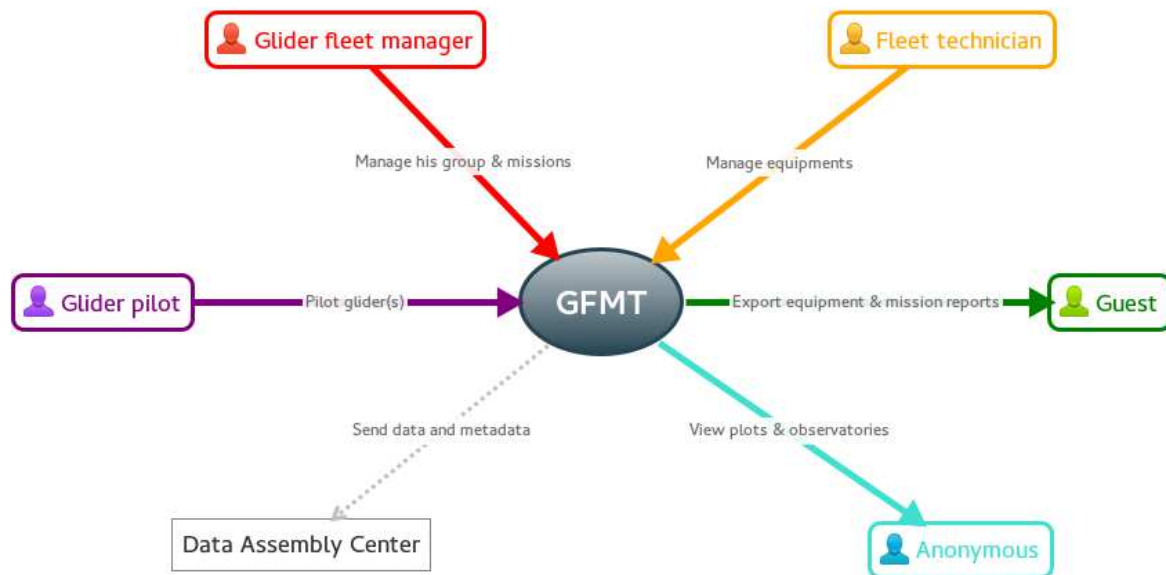


Figure IV.1: Schematic representation of the main functions of the GFMT

- ⑩ **Glider pilot** is chosen by the glider manager for a deployment/glider time :
 - ⑩ Start and stop deployment
 - ⑩ Pilot a glider or a fleet (update glider's files) Update his personal information for the shift (phone, etc.)
 - ⑩ Edit logbook
 - ⑩ Start and stop autopilot
 - ⑩ Save and load autopilot configuration
 - ⑩ Configure alarms
 - ⑩ Save and load alarms configuration
 - ⑩ Restart plots
- ⑩ **Guest** (scientist, glider owner, etc.) uses the interface to :
 - ⑩ View the deployment characteristics
 - ⑩ Configure autopilot
 - ⑩ View plots
 - ⑩ View real time glider map
 - ⑩ Export a deployment report to pdf file
 - ⑩ Export a glider composition on a given date to pdf file
- ⑩ **Anonymous** can (only for the public deployments/projects) :
 - ⑩ View plots
 - ⑩ View real time glider map

D5.1

Flow

The glider connects and sends files to a communication server. Each group has its own communication server (dock-server, base-station, etc.) and can choose between two solutions:

- ⑩ An "agent" (a small python script) is installed on the communication server for each glider of the group and it is used to communicate with distant application servers and send data to the GFMT.
- ⑩ If the group is not able or willing to install the agent on the communication server, the data from the glider have to be uploaded to an FTP server in order to share information with the GFMT.

Between the local communication server and the Glider Fleet Mission Tool, different services provide information processing:

- ⑩ Information service is asked to give information from the GFMT database by the other services.
- ⑩ Messages service is asked to send SMS, email, instant messages to the pilots by the other services.
- ⑩ Alarms service sends alarms to the messages service
- ⑩ Autopilot service modifies mission files, send them to the agent or the the FTP server, and check that the file is reloaded by the communication server.

Data management service makes backups and store the data in a database. It sends formatted data and meta-data to a DAC. Users can interact with the services and therefore with the glider via the human-to-machine interfaces of the GFMT, see Figure IV.2.

D5.1

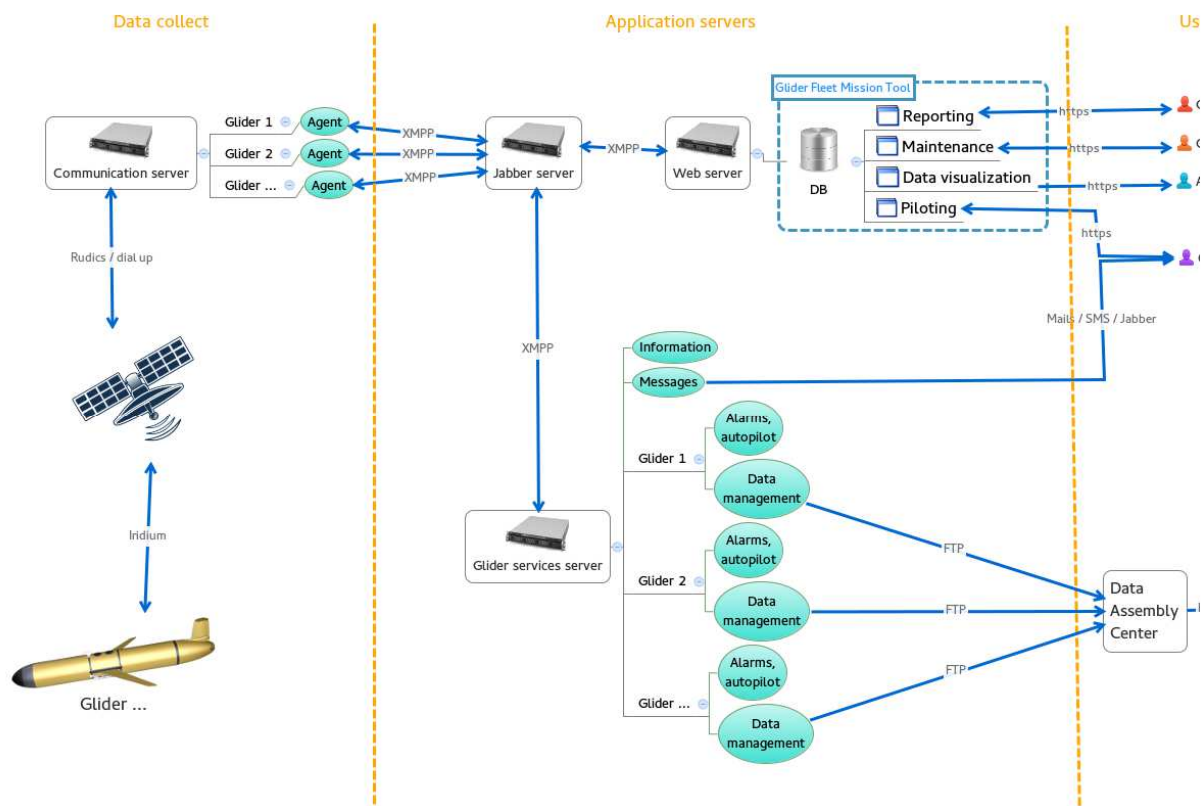


Figure IV.2: Dataflow, from glider to DAC

Three main modules

The three main modules could be used independently. For example, a group can pilot its glider(s) from a local system and use the data management GFMT module only to view science plots and send the data to a DAC, see Figure IV.3.

D5.1

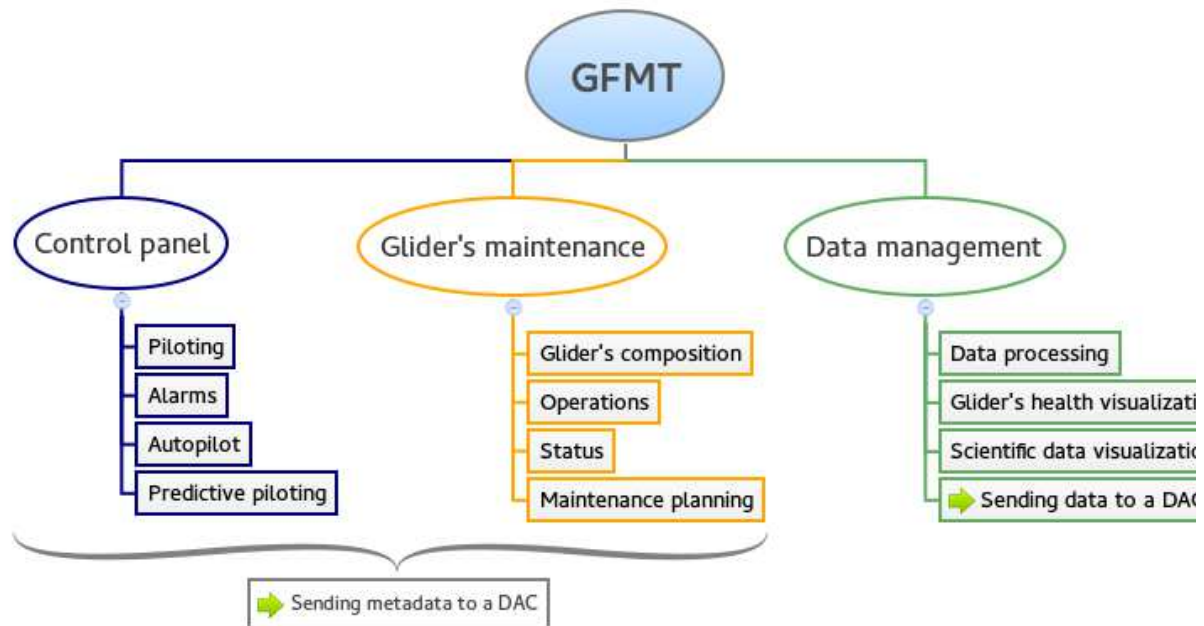


Figure IV.3: The three main modules of GFMT

Computing infrastructure

Dedicated computers or servers or virtual machines (VMs) with the Linux operating system are required for:

- Preparation, test at sea, deployment, recovery: at least 2 rugged laptops.
- Piloting: Manufacturers provide tools to pilot their gliders but they are not really web friendly, so a web server can be set up and software developed for ease of piloting.
- Communication: two servers or VMs. This is critical and must be redundant. Furthermore, each type of glider has to have its own RUDICS setup, with an alternative PSTN line phone number as a redundancy.
- Data processing: reliable desktop (or server or VM) to process the data sent by the gliders and send the data processed to a DAC.
- Back up of the collected data: two file servers for redundancy.

So, eight machines (or VMs) are required, or ten if the group owns two different types of glider (Slocum and Seaglider, for example). If the group chooses to use the Glider Fleet Mission Tool, it saves three servers or VMs.

Piloting/Operations: Dockserver-Talk

For Slocum gliders the shore side software, called dock-server, provides a rudimentary way of automating the actions taken to control the behaviour of the glider, such as uploading new mission parameters and downloading data. Its intended use is that the user can run scripts that issue certain commands automatically, depending on the dialogue seen from the glider and the context. Examples of tasks that can be taken care of by scripts the download of data upon every surfacing, and the upload of new mission parameters. Using scripts it is therefore not necessary for glider pilots to be behind a terminal at the exact time the glider surfaces, even if mission parameters are needed to be changed.

D5.1

Automating the glider piloting can be achieved by selecting an appropriate script and an algorithm that prepares files with new mission parameters. For developing a system that is more responsive, for example one that can include the latest measurements in order to modify the mission parameters, a finer grained control is needed. The Dockserver-Talk package provides an API that allows software programs to be developed that communicate with the dockserver directly. An example of such a program is a program that pilots one glider automatically relative to another (Merckelbach and Riethmueller, 2014). Other applications of the API include those that monitor the dockserver actively. Two applications that have been developed on top of Dockserver-Talk are BUGS (buoys, underwater gliders and ship finder), and a software surface alarm. BUGS allows the position of ships, buoys and gliders to be plotted relatively with respect to the observer's position (ship's GPS for example). The Dockserver-Talk API is central in querying the dockserver for the glider's latest GPS positions. The surface alarm application connects a GSM modem to a dockserver, such that text messages can be sent or phone calls can be made to a configurable list of recipients, depending on the dialogue between the glider and dockserver. The software package is developed in Python3 and is available as free software (open source) from the Sourceforge repositories (<http://sourceforge.net/projects/dockserver-talk/>).

Data management and flow

One key element of a glider-port is to provide users with a system to locate and download the data of interest (near real-time and delayed mode) and to visualize and manage the information.

One of the objectives of GROOM, in particular task T3.2, is to define and apply Quality Control and glider data standards. These procedures should be carried out by Data Assembly Enters (DAC) and forwarded to Global DACs. A set of NetCDF conventions has been defined (EGO, 2013). Suggested glider-specific QC procedures have been developed by GROOM, as well as by the glider manufacturers themselves (Seaglider Quality Control Manual, University of Washington). The latter is carried out in near real time and saved in NetCDF files, but not of the GROOM standard format.

Glider ports can have an agreement with another DAC to manage their data or can act as a DAC or regional DAC. For example, SOCIB/CSIC have developed a data management system following three main principles: data need to be (1) discoverable and accessible, (2) freely available, and (3) interoperable and standardized (Tintoré et al., 2014; Troupin et al., 2014), see Figure IV.4. In consequence, SOCIB/CSIC Data Centre is implementing a general data management system to guarantee international standards, quality assurance and interoperability for glider data. The combination of different sources and types of information requires appropriate methods to ingest, catalogue, display, and distribute this information. The system implemented relies on open source solutions. The glider data life cycle is composed of the following stages: Acquisition, processing, quality control (QC) and standardization, archival (storage in NetCDF and spatial databases), distribution (data web services using Thredds, Geoserver and RESTful own services), catalogue (metadata is provided through the ncISO plugin in Thredds and Geonetwork), visualization (web and mobile applications to present glider data to different user profiles). These data are pushed towards a global DAC. One achievement of GROOM was to set up the respective roles of the all different glider teams to ensure the flow and management of all glider data from this consortium to the global and public data bases.

Distributing metadata and observations to Data Assembly Centres (DACs)

The gliders Data Assembly Centre (DAC) aggregates real-time and delayed mode data and metadata from the various glider ports.

The glider data management performed at the European DAC level (Coriolis Data Center, <http://www.coriolis.eu.org>) is committed to

- provide a single access point for the European glider data and metadata;
- improve the data coherency in term of format, quality, processing chain (clearly documented);

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- set up a capability to serve both operational (within a few hours) and research (best quality after calibration and validation) users.

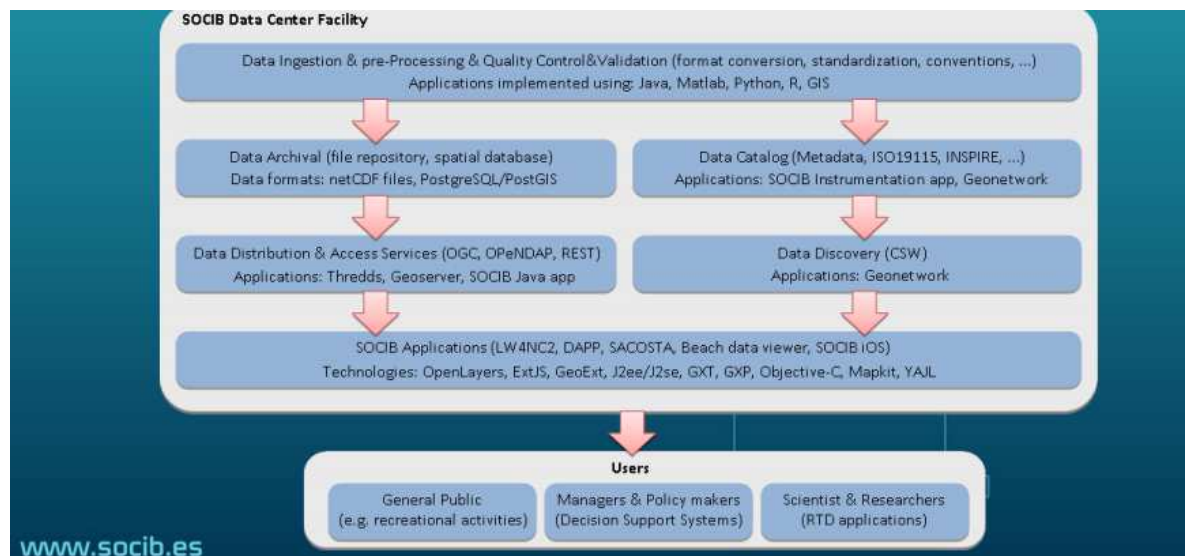


Figure IV.4: Data management_SOCIB-CSIC [Tintoré et al., 2014].

Such a system is being developed in coherency with the development at an international level for gliders (IMOS in Australia, IOOS in USA) and interoperable with other JCOMM networks (such as Argo, OceansITES, Gosud) or IODE standards (SeaDataNet/EU, QUARTOD/USA, GTSP). GROOM is building the European DAC, IOOS the US DAC and IMOS the Australian DAC. Following the Argo floats data-management system, the DACs are building together an international Global Data Centre (GDAC). GROOM glider observations and metadata are preserved and distributed in a standard NetCDF (V3.6) time-series organised by glider-deployment, as this format is the main format used by the ocean-atmosphere science community. Glider NetCDF deployment files follow the Climate and Forecast convention (V1.6) or CF convention.

The Groom NetCDF CF implementation is a significant effort to promote the use of glider data and metadata in ocean-atmosphere science community. The documentation, data provision and data access are publicly available (EGO, 2013; see html link in reference list).

The web page and the User's manual also describe the Quality Control and glider data standards. These procedures are carried out by regional Data Assembly Centres (DAC) and forwarded to Global DACs. Suggested glider-specific QC procedures have been developed by GROOM, as well as by the glider manufacturers themselves (Seaglider Quality Control Manual, University of Washington).

Planning

In order to plan a strategy to sample a region of the ocean, a trade-off is faced between available resources and time on the one hand, and the quantity and quality of observations of the features of interest on the other. Designing an optimal strategy is a challenging task. Furthermore, the environmental conditions of the ocean can be such that they influence the operation of observing platforms such as gliders is significantly. Therefore, a glider fleet mission planner tool has been developed as a deliverable of GROOM (D5.6) to provide a decision support tool to assess the feasibility of a predefined mission before actually performing it.

The software evaluates the risk of pre-defined glider trajectories at any time and location in the European Seas. The risk is evaluated in terms of the feasibility to cover the proposed trajectory during the mission time, assessment of adequate density conditions for the buoyancy engine, the probability of platform failure and the risk of collision with ships. Risks associated to environmental conditions,

D5.1

timely completion of the mission and buoyancy conditions are based on oceanographic information gathered from the operational products of the EU MyOcean Project. Specifically, ocean forecasts in the region and time of interest are automatically downloaded from MyOcean servers. A statistical description of the spatio-temporal variability in the area is then generated. This is defined in terms of a mean state and a covariance describing the spatial correlations in the oceanographic fields. An ensemble of states is generated according to the statistical description. This approach attempts to describe feasible deviations of model forecasts from the real evolution of the environment. Next, the software simulates the glider behaviour along the prescribed trajectory for each member of the ensemble. Probabilities of mission completion and buoyancy risks are derived from the final results of these simulations. Risks associated to the platform failure and ship collision are obtained from Brito et al. (2014) and AIS historical information, respectively.

Optimal sampling designs for a fleet of gliders can also be obtained from the GROOM mission planner tool. For this application, the statistical model encoding the spatio-temporal variability of the environment during the mission time is used to assess the optimal allocation to maximize the information content of the oceanographic data collected by a glider network. The procedure computes the posterior uncertainty resulting from tentative glider trajectories. An optimization engine based on simulated annealing is employed to modify the trajectories in order to minimize the final uncertainty of the field estimate. Details of the optimal sampling procedure can be found in the GROOM deliverable D5.4 "Optimal sampling design methods for North Atlantic/Arctic and Mediterranean Sea". The risk assessment module is then run for each of the optimal trajectories in order to report about their feasibility.

A pre-mission planning tool has been developed at HZG. The main purpose of this tool is to estimate a (Slocum) glider's trajectory and behaviour given a mission file (and corresponding ma-files) and an environment (density and current). The environment can be provided by the numerical output of a general circulation model, or by time series. Currently implemented circulation model outputs are those by the GETM and ROMS models. The output of other numerical models can be used by either making the output compatible with current implemented interfaces by command line tools from the NCO suite (<http://nco.sourceforge.net/nco.html>) or by adding a specific interface. The latter is fairly straight forward to do.

The models consist of two main components. The first component simulates the glider behaviour. This is done by a simplified re-implementation of the glider software, including simulators of the actuators (buoyancy engine, pitch battery motor and fin motor). The second component models the interaction of the glider with the environment, that is the glider velocity is calculated from the set buoyancy change and pitch (from the first component) and the local density (from the environment model) using a steady-state flight model based on the flight model described in Merckelbach et al. (2010). The glider's velocity vector over ground is obtained by adding the glider velocity vector through water and the local current vector as given by the environment model.

Another glider simulator, SIGLID, (L'heveder et al. 2013) has been developed by CNRS with similar functionalities using NEMO model outputs. It has been used on an operational basis in 2008 (L'heveder et al. 2008).

Analysis software tools

Data analysis software is usually developed ad-hoc and tailored to a particular problem or study. However, it is useful to discuss some software tools that work with glider data, as their use is more general and may help to analyse data during deployment or during the mission.

Teledyne WebbResearch provides a (legacy) program GliderView, compiled from Matlab that can be used to visualise data from Slocum gliders. Binaries are available for the Windows platform, whereas on the linux the program can be run if Matlab is installed. Although many users prefer the GliderView program, this program has been superseded by a tool supplied by Teledyne WebbResearch called Datavisualiser. As is true for GliderView, the tool is not designed for scientific analysis, but allows the glider pilot to inspect the glider's behaviour and sensor output. The tool is tied

D5.1

to the dockserver, but can be accessed remotely. Internally the glider data are stored in a mysql database.

Igloo (Inspecting Gliderdata in the Office or Ocean) is a lightweight free software/open source Python application developed at NOC/HZG and serves the same purpose as TWR's Datavisualiser. The main difference is that the program is standalone and works with one or more specific glider data binaries, rather than requiring the burden of a full-blown database system and access to a dockserver machine. In practice, it is also more versatile and quicker in use. Special features of the program are plotting multiple panels of various parameters on a synchronized time axis; plotting two parameters against each other and identifying the original data filename for a given data point. The software source can be obtained from the SVN repository <https://projets.dt.insu.cnrs.fr/svn/groom> (login required, and can be obtained from GROOM partner DT-INSU/CNRS (email: support@dt.insu.cnrs.fr)).

Seaglider users often use a version of a set of visualization scripts to produce real time plots of each dive. This is provided by the manufacturer, and each team has modified it to suit their needs. These "DivePlot" scripts are available in Matlab and Python.

The visualization part of GFCP developed by CNRS (see D4.4) can be used by Seaglider/Slocum/Spray users. It shows maps with current vectors and satellite data as well as vertical sections and profiles. All of these can be grouped into time periods and displayed together (last 2 days, last week, all data). An interface allowing to customize the plots is in its early stage and an extensive use of kml/kmz is made for customizing spatial visualization and the generation of waypoints. It is connected to a piloting web interface. Some other tools have been created by the University of Bergen, which allows user-defined plots and maps, as well as a simple web-based piloting interface. Both systems are open and actually were used by third parties (CNRS, OGS, PLOCAN, UCY, SOCIB, and UiB).

SOCIB/CSIC has developed a Deployment APPLICATION (DAPP – <http://apps.socib.es/dapp>) to display information on the trajectories and data collected by mobile platforms, including gliders. Users such as scientists, researchers, technicians and search and rescue services make use of this application to visualize oceanographic information from gliders and others mobile platforms (Tintoré et al., 2014, Troupin et al., 2014), see Figure IV.5. Additionally, for educational purposes, specific web on glider activities can be built. Per example at SOCIB/CSIC, the website '<http://followtheglider.com/>' presents the autonomous underwater gliders for students, teacher and general public to gain awareness of the importance for coastal research (Tintoré et al., 2014, Troupin, 2014).

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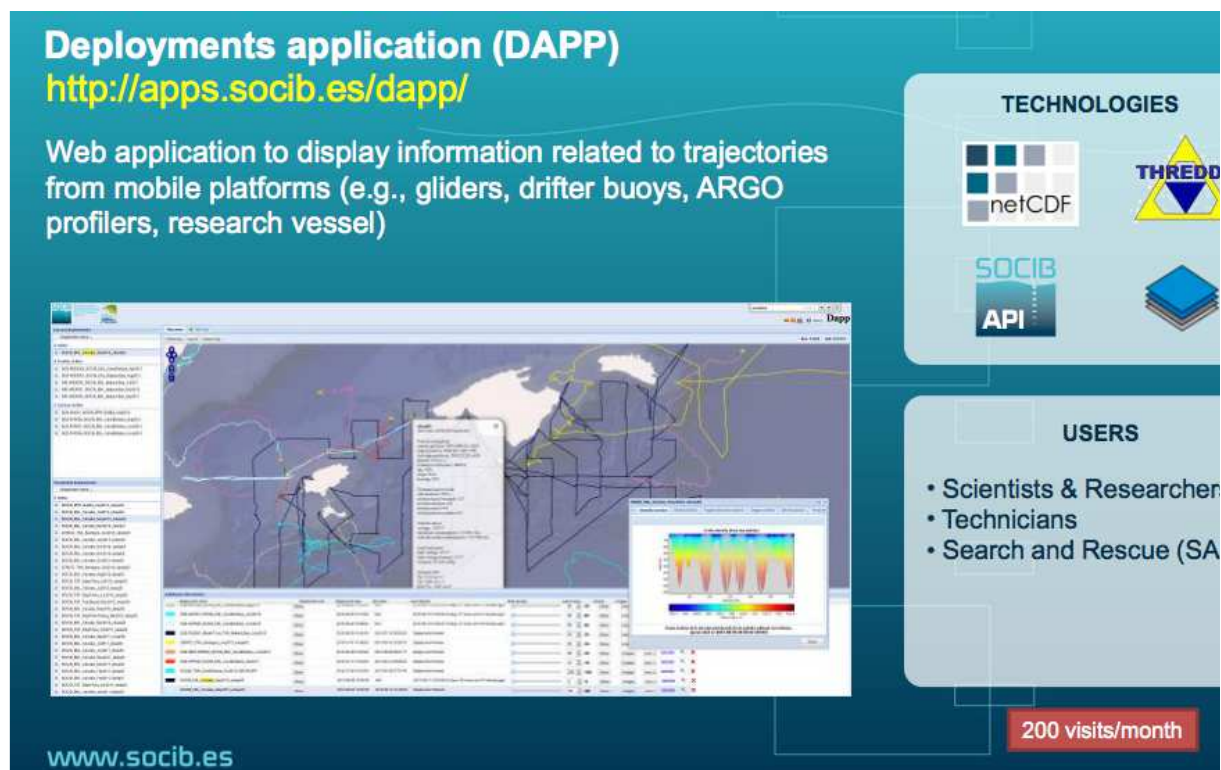


Figure IV.5: Deployments application developed by Balearic Islands Coastal Observing and Forecasting System (SOCIB) and IMEDEA (CSIC-UIB).

V. A NETWORK OF GLIDER PORTS

The fact that many, if not most, glider ports offer only a subset of the total palette of glider related tasks should not be seen as a weakness, but rather a strength. By combining glider ports that offer a different mix of components, the full potential can be exploited while duplicated efforts are reduced. Key in this is that glider ports are linked or networked.

An example of an incomplete glider port is given in Figure V.2. In this cartoon, only a handful of the tasks defined in Figure III.1 are available. Interacting with other glider ports, the missing pieces of the puzzle can be filled in, see Figure V.2. In this hypothetical situation, a small glider port *A* provides the deployment and recovery capability to a larger glider port *B*. Such situation may arise, for example, if the institute that hosts glider port *B* performs experiments in waters that cannot be easily accessed from glider port *B*. Glider port *C*, on the other hand, may have specialised in data management and maintaining a databases with quality control checks implemented. Linking the glider ports *B* and *C* ensures that *C* receives the data from *B*, while glider port *B* is relieved from implementing these routines itself.

D5.1

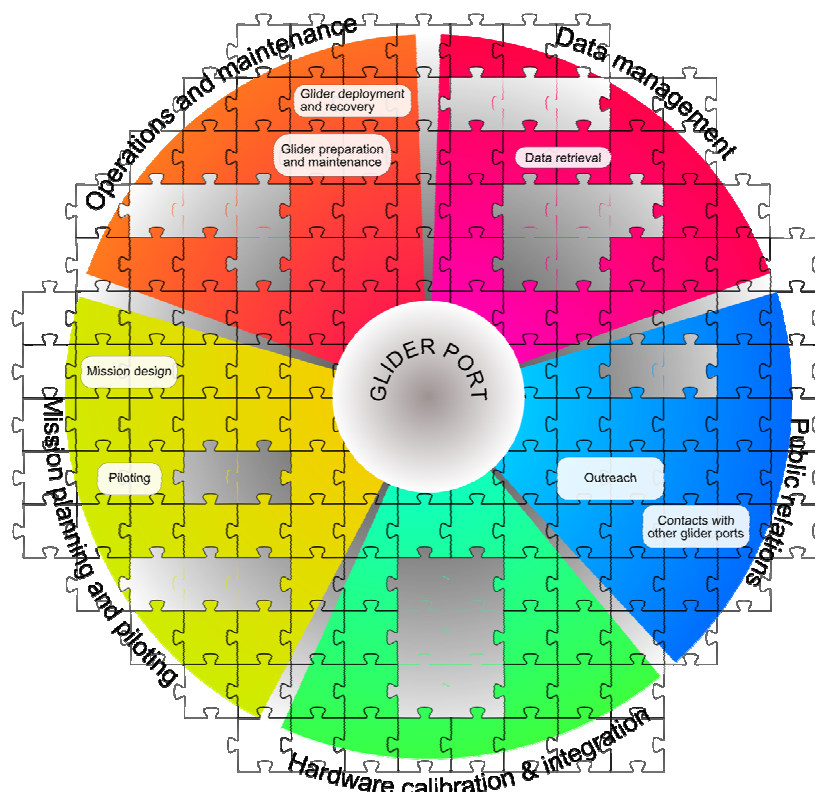


Figure V.1: An example of a glider port with a limited implementation of tasks

In order to further develop the network of glider ports, new glider ports can be set up as a satellite glider port belonging to an already existing glider port. Such a satellite glider port would then most often focus on glider deployment and recovery activities. This scenario is a viable one for institutes that already have their glider port setup, but are involved in field research that takes place at a relatively large geographical or logistical distance. Such initiatives often involve local research stations or institutes and employ or train local people. Such collaborations can spin off into satellite glider ports to develop in mature and more versatile glider port themselves. An example of this is provided with experiments carried out off Peru. Two deployments were carried out by collaborating teams from Peru and France with French gliders in 2008 and 2010. This work allowed the transfer of know-how to colleagues from Peru (IMARPE). At the time of writing they plan to buy three gliders and to deploy them in the framework of a coastal monitoring program.

Another way of networking glider ports is to establish links between already existing infrastructures. Establishing such links is motivated by the fact that by joining forces, facilities and efforts can be shared, duplication of (development) work can be reduced and collaborations in research can be set up. This has already begun through the EGO initiative (European Gliding Observatories) COST Action which supported the informal consortium recently renamed Everyone's Gliding Observatories to reflect its international dimension.

It is clear that networked glider ports provide many advantages. Within EGO and during the course of the GROOM project, significant steps have been made towards establishing a network of glider ports. While the GROOM project is nearing its end, it is necessary that its legacy is kept and even further developed by establishing a *facilitator*, the role of which is, amongst others, to encourage the level of networking between glider ports. Before the scenario of such a facilitator is drawn up, the organisational models of present day glider ports is discussed.

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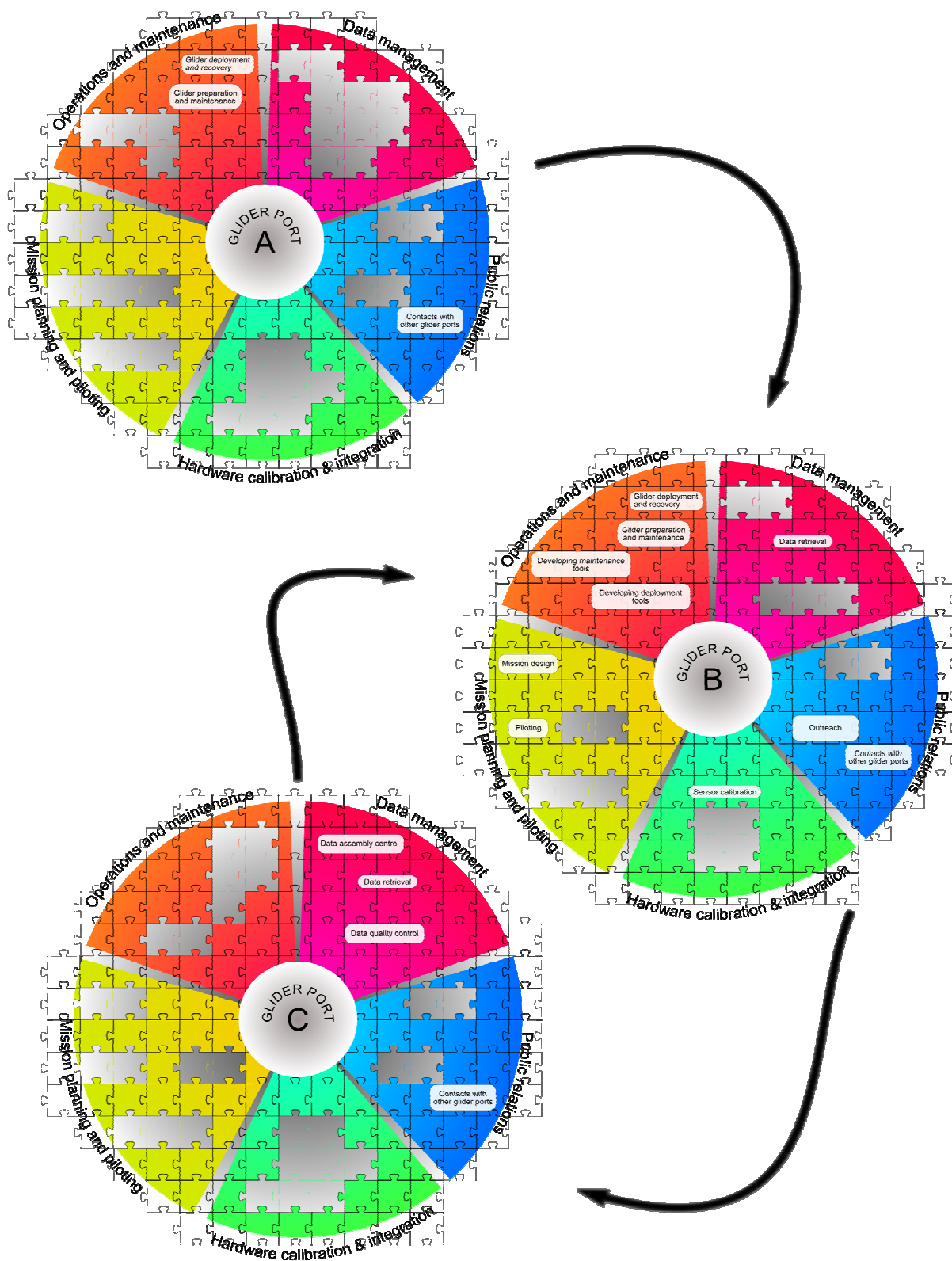


Figure V.2: An example of networked glider ports. See main text for explanation.

Organisational models of glider ports

Four levels of glider ports could be foreseen in the future Glider European Research Infrastructure (GERI): the institutional level, the national/regional level, the SME level and the European level. For each one, the advantages and weaknesses are discussed in order to recommend to what degree each level of glider port is suitable for a Glider European Infrastructure.

Institutional level glider port

Traditionally, glider ports came into existence when early-adopting institutes pioneered the use of gliders. Experience, methods, protocols and hardware and software tools were all still to be acquired and developed. This resulted in institutes with infrastructure that covered the larger part of aspects of the idealised glider port in Figure 1. The model where the glider port is in fact a single institution is referred to as a glider port on the institutional level.

The institutional level glider port is the most common template at which glider port design is based. The institutional level glider port has a number of advantages. Although marketed as low-cost ocean observing robots, the price-tag of a glider still requires a significant amount of funding. Being relatively expensive instruments, the owning institute understandably prefers to have full control over its equipment. In contrast to pool models (see below), gliders managed by an institutional glider port can be used in a more flexible way. This is true for both the planning of the experiment (no formal application to a call is required) as well as the execution of an experiment as the communication lines between pilot and scientist are shortest (often the same person). The fact that a relatively high level of skill is required to be present at the glider port, this organisational model may facilitate the science-driven development of new ways of using gliders and glider data as well sampling strategies.

A drawback of the institutional level glider port model is that the duty cycle of gliders is often low. This is because the number of scientists who analyse the data can be small and endless collection of data serves no purpose and is expensive. The loss of capital when gliders spend a substantial time not being in service could be alleviated by developing a sharing system for gliders. Such a system will also benefit scientists in other countries in Europe who do not have access to gliders because of the substantial initial investment to purchase glider and sensors. Moreover, it would also benefit current and experienced glider users in Europe, as being able to access gliders to design bigger and more complex studies may yield very interesting opportunities.

For an institutional level glider port to operate efficiently and cost-effectively, it is mandatory that the glider port is well-connected to other glider ports for reasons discussed extensively above. Nevertheless, the level of networking currently implemented is suboptimal and still improvement can be made by sharing software tools, data and calibration facilities, for example. Despite the requirement of a relatively high level of expertise needed for even a small glider fleet, and the large array of hardware and software facilities, this modus operandi eventually be the only model implemented if there is no driving force or political will to organize on a national or regional level.

National or regional level glider port

In particular for countries or regions with a relatively high concentration of institutes involved or interested in experiments where gliders play a key part, it may make sense to concentrate a host of glider port tasks in a single glider port. This glider port then serves the whole glider fleet on the national or regional level. Such a glider port can be part of an existing institution (having evolved from a "classic" institutional glider port, for example) or set up as an independent entity.

As the fleet of gliders serviced is usually large, it becomes viable to invest in well-equipped laboratories, and a highly skilled team. Rather than implementing the glider port tasks for many institutional glider ports, these tasks need to be implemented once for a single glider port only. A national or regional level glider port has more potential to implement more glider port tasks and of a higher level of sophistication. Because of the concentration of activities, a national/regional glider port is also the pivot in terms of operational aspects (deployment and recovery). Having tight relationships with various researchers or research institutes inevitably means that glider operations take place in a wide range of regions. From an operational point of view it makes sense for national/regional glider

D5.1

ports to develop their network of satellite glider ports that facilitate the logistics, deployment and recovery.

The advantages of a centralised glider port are clear: the serviced glider fleet can be maintained and operated to high standards, relieving scientists from this burden and having the potential to make glider technology easily available to scientists of institutes that do not own gliders themselves. The duty cycle of individual glider hardware is also like to increase, making more effective use of capital.

In contrast to an institutional level glider port the management structures need to be centralized. Knowledge of the status of individual gliders (being active in an experiment, being stored, or being serviced) needs to be documented and available to a large team of glider technicians and operators, as well as scientists who plan the experiments and use the data. This has created its own challenges, and the software tool GFCP has been developed to handle the management of a larger glider fleet. See Chapter IV.

Up till present day, only France and Norway have centralised their glider fleet into a single glider port. Spain has invested in two regional level glider ports, located on Mallorca and Gran Canaria, serving the Mediterranean and Atlantic Ocean, respectively. UK and Italy use a mix of centralized facilities (MARS, RITMARE) and institutional glider ports.

Small to medium enterprises as glider ports

The GROOM infrastructure is distributed among major European centres including academia, institutes for fundamental and applied research, industries and small and medium enterprises (SMEs). The emphasis between the concentration of different know-how and the enhancement of glider activities will foster the emergence of high valued services. In a way, SMEs are already part of research infrastructure (battery suppliers, communication services, glider maintenance) and in some cases can be considered as a glider port as they deliver one or several services identified in Figure II.1. The growing part of SMEs glider port in the future is crucial to encourage as it will enhance regional economic activity and employment.

For teams new to gliders, investing in a specific laboratory setup may not always be financially feasible. This creates a need for shared lab facilities. However, should a specific laboratory setup exist, providing access to such facilities to others may require additional investments, in particular personnel, so that shared facilities are not common yet among existing glider ports. This is where companies/SMEs (Small and Medium Enterprises) may step in for whom providing services is a key component of the business model, in contrast to research institutes. It is conceivable that a number of glider ports are operated by SMEs with a focus on sensor calibration, software development, data management and glider piloting.

GROOM partner AWI has outsourced piloting to the company Optimare for a period. A restructuring of the company and a significant rise in the fees for the services has led to the reduction in attractiveness of this option financially. Now AWI has set up their own group of pilots (with initial training from Optimare).

GROOM partner Geomar is also an institute using outsourcing. They occasionally outsource the ballasting of their SLOCUM electric gliders (G1) to a local company (K.U.M. Umwelt- und Meerestechnik Kiel GmbH, Kiel, Germany) and has had very positive experiences. The "training" was done at the GEOMAR facilities (a representative from the company was helping with the ballasting and later did it himself). As a side effect, the company designed "standardized" steel weights to be mounted to the battery packs. Depending on the project and other factors the company may be asked to provide the service.

European level glider port

The scope of a national glider port could be widened further to a European level. In addition to the advantages of a national glider port, a European level glider port could organize a glider fleet that is composed of gliders owned by institutes in different countries. Likewise a national glider port creates increased accessibility for research institutes in the same country; a European level glider port would

D5.1

do that on a transnational level. The European level glider port would also lower the financial threshold faced by those organisations that want to make use of gliders or scientists in research institutes that do not own them, irrespective in which country the institute is based. Also levels of specialisation and the extent to which expensive spare parts can be stocked may be affordable for a European level glider port, thereby making the European glider community less dependent on the support of the glider manufacturers. Furthermore, a European level glider port will have a stronger leverage to negotiate lower prices battery packs and telemetry costs.

The implementation of a European level glider port can be done by centralising most of the glider tasks in one geographical location, or as a network of glider ports in various geographical locations or countries, possibly steered from a common board. Centralizing glider fleet and facilities in one location is suboptimal, however, as the higher level of centralisation comes at a increased level of logistic complexity and dependency on regional specificities. Hence, there is a need for distribution of the facilities.

Roadmap for a Glider European Research Infrastructure

The GROOM consortium is responsible of about 20-30% of the glider activity in the world and has a critical size in terms of staff and budget (45 FTE and 9 Meuro/year in 2013, see D5.7). This is a significant part of the marine observational effort that rose from a bottom-up approach, coordinated through the EGO COST Action and the GROOM project. This design study shows the capacity of the consortium in terms of coordination by collecting, synthesizing and redistributing information among the partners. This has led to major advances in terms of understanding of the needs, tool developments and data management.

The consensus of the GROOM consortium is that the development of the glider infrastructure should be managed and coordinated at a European and international level. We define the Glider European Research Infrastructure (GERI) as a body that coordinates and manages the glider fleet and services in Europe. As such, the GERI does not house physically a glider fleet or facilities. The GERI could be an entity on its own, or based on already existing distributed infrastructures. Its managing and coordinating role facilitates making glider technology available to other European countries or institutes. Furthermore, acting as an umbrella for the European glider community, the GERI can be the representative body for the community in international arenas. This also brings a stronger leverage to negotiate lower prices for consumables, in particularly battery packs and telemetry costs. In addition, a global management of the fleet and an easy access to services and knowledge will enhance the glider scientific activity.

A networked glider port set up allows most tasks to be centralised and optimized in terms of resources. To date, most tasks of the glider port components (see Figure II.1) are implemented by glider ports hosted by research institutes, which can be reluctant to accommodate tasks of other glider ports. The offering of services does not generally match the philosophy of a research institute, but this is changing as can be shown by the Trans National Access (TNA) to gliders activities developed in JERICO which was particularly a success. This TNA allowed an access to institutional/national infrastructures as a whole, to scientists who did not have access to such infrastructures otherwise. This might be a concept to be developed along the five components of a glider port. It could be thought of institutional/national glider port providing access to components of their infrastructures (such as piloting, ballasting etc.) in a European context.

An example is piloting where the effort of piloting their own gliders is often already a challenge in terms of available personnel. Moreover, since piloting requires in practice a significant amount of personnel effort during a mission, centralising piloting can bring clear advantages when considering this at the EU level:

1. the gliders are controlled by a few experienced pilots with the help of pilots in training;
2. small pilot teams are consolidated since experienced pilots can handle multiple gliders;
3. it becomes cost-effective to develop sophisticated pilot tools.

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Sharing/centralising the piloting could really result in a higher quality glider mission at lower costs. The implementation of such a shared tool would require further work because of difficult liability issues and the necessity to establish a mechanism to account for the efforts of the different institutes. The TNA is one model. Another model could be shaped along the lines of the exchange of ship time currently carried out by the research fleets in Europe to optimize transits. An insurance contract for all the concerned gliders could facilitate to overcome reliability issues.

Other components that could benefit in a similar way are data management and shared laboratory facilities. Data management could be done by experts at a few regional centres with specialised knowledge and tools for quality control formats, or archiving, for example. A shared lab facility could be implemented for a dedicated setup. Examples are sensor calibration facilities or a pressure tank accessible to the consortium. By centralising the know-how and expensive hardware it may become cost-effective to operate such facilities. For a sensor calibration facility this could mean that an institute that operates a glider port is not required any more to send a glider or science bay to the manufacturers in the USA for a sensor calibration. Such a calibration involves expensive shipping, unnecessary administrative work because of temporary ex- and import between the EU and USA, and long turnaround times (3-4 months).

The concept of a services delivery can be organized through the "Service Access" mechanism. This mechanism is a scheme that governs how services can be offered between institutes at a European level. Also, SMEs as part of the GERI can deliver some of these services. Making use of the services of an external company for some specific tasks is a strategy supported by the GERI.

Aim of Glider European Research Infrastructure

Building a glider port depends on the motivation of each institution, region or country. For example, in Germany, there is a loose consortium of glider teams able to control the whole chain (from purchasing to recovery) of a glider experiment and that is why Germany did not develop a national glider port. On the other hand, France has decided to centralise most of their glider activities to include purchasing, maintenance, calibration, etc. There is no bad or good solution in these cases. In order not to suppress innovation, any institution must remain free to develop their glider activities in the way which is more appropriate for their own purposes.

The aim of the Glider European Research Infrastructure is to support and encourage these developments in Europe by giving access to the so-called infrastructure that will cover many aspects of the glider activities. The GERI will not impose administrative constraints to institutions and has no interest to control the European glider fleet. The only way to encourage the use of glider is to make scientist free to organize themselves the way they want and **facilitate the propagation of the tools, the best practices, the standards and giving access to different services through the infrastructure**. The GERI will develop the synergies between glider ports and enhance the use of the distributed European glider fleet. Then, the GERI will be articulated around the existing glider port whether institutional, regional or national. The GERI will not interfere in the way glider ports use their gliders. However, the GERI will encourage its partners to share tools and experience, participate to good practices and standard definitions when appropriate and provide access to their gliders if they are available.

For the near future, it seems crucial to appoint facilitators, whose activities are:

1. maintain an overview of all glider ports, encourage communications between glider ports
2. serve as an entry point for institutes who may also setup glider ports
3. serve as an entry point for wider science community
4. serve as a representative of the glider community like it is done for other platforms of the GOOS (such as Argo) in the framework of the JCOMM.
5. develop an implementation plan for building the distributed European Glider infrastructure across the five components of a glider port

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Considering the volume of such coordination tasks, a bottom-up approach should be the most efficient. It could be initiated from participating research institutes by funding about one FTE each to help the consortium to make substantial progress towards a more integrated Research Infrastructure. This approach avoids the necessity of a broad political consensus, but requires the commitment of the institutes.

VI. SUMMARY

A significant part of the world's underwater glider operations are executed by European institutes. Whether gliders are used for scientific process studies, monitoring, operational oceanography, or commercial applications, an extensive infrastructure is required for its operation. After an initial period when a few early adopters of glider technology were on their own designing and setting up the glider infrastructure, a bottom-up approach, coordinated through the EGO COST Action and the GROOM project has led to a consortium of networked institutes collecting, synthesizing and redistributing information among its partners. This has enabled the consortium to sketch a picture of the requirements of a glider infrastructure, assisting new glider users in planning and setting up their own glider infrastructure, and, more importantly, identifying where and how the current landscape of glider infrastructure can be developed to enhance the efficiency and output.

The term "glider port" is coined to represent the ground-based segment of glider infrastructure.

A glider port can consist of the following 5 core components:

1. hardware operations and maintenance;
2. data management;
3. mission planning and piloting;
4. hardware calibration, integration and testing;
5. public relations.

A glider port, usually hosted by an institute, can implement one, a few or all of these components, depending on the role of the glider port, available resources and vision of the institute with respect to the use of gliders. Of these core components, the components "data management" and "public relations" are only briefly discussed herein as they are covered in greater detail in the deliverables D3.2 (Data flow and processing) and D3.3 (Capacity building and training), respectively. Herein the focus is on the components "hardware operations and maintenance" and "mission planning and piloting", and to a lesser extent, "hardware calibration, integration and testing" covered in more detail in D5.2 (Payload assessment).

Based on a questionnaire sent to all GROOM partners, a list of required glider infrastructure components available among European institutes was compiled and described in detail. The list includes *i)* various aspects related to hardware operations and the maintenance laboratory, such as battery change operations, glider preparation, specific tools/aids (water tank, crane) , *ii)* required tools for communication between gliders and the ground station, and *iii)* the disposal of dangerous goods. Based on the answers given to the questionnaire, a guide to European glider ports was compiled, as a separate document.

The tools developed as part of the component "mission planning and piloting" are mostly software systems. An advanced system developed by GROOM partner DT-INSU/CNRS is the Glider Fleet Control Panel (GFCP). The development of this tool was initiated because of the challenges with respect to glider maintenance and piloting faced by DT-INSU, who manages the entire French glider fleet (>15 units). This tool aims at facilitating the operation and maintenance of gliders. It does this by keeping control and track of every step of the operation, from the glider preparation to the sending of (scientific) data and meta-data to a data assembly centre. Furthermore, the tool provides support for recurring actions in piloting gliders, a pre-validation of data using data visualization component,

D5.1

dashboards and automatic reports. Its successor, the GFMT, will also keep accounts of various user profiles, each with a specific list of rights and limitations. Depending on a user's role (fleet manager, technician, pilot, scientist, or even member of the public), the user will be able to interact with the glider or glider data in accordance with his/her profile.

Apart from other, smaller software systems such as Dockserver-talk, an application programming interface (API) to create programs that interact directly with the Teledyne WebbResearch Dockserver software, a number of software tools have been developed aimed at facilitating the planning of missions. One application, developed by CMRE in GROOM, aims at planning the mission such that the feature of interest is sampled in an optimal way and/or minimising risk of the mission. Other planning tools have been developed to assess the performance of the glider in a particular (unknown) region with expected strong variability in currents or density, for example. These tools, developed by CNRS and HZG, combine a glider model with numerical model output to simulate a particular mission setup.

Another series of software tools have been developed aiming at the data analysis. A good example is the Deployment APPLication (DAPP) developed by SOCIB/CSIC, aimed at displaying information on the trajectories and data collected by gliders and other mobile platforms. Besides useful for scientists, this system, available through a web interface, and a accompanying website, tries to raise the awareness of the general public of the importance for coastal research.

Having described the components and tasks that a glider port can accommodate, it is also clear that many, if not most glider ports only implement a subset of these. Rather than a weakness, this should be considered a strength, as *network of glider ports* offers all the components and reduces the duplication of efforts.

The scope of glider ports can be implemented at different levels:

1. Institutional level glider port;

This is the traditional way, employed by early glider technology adopters, and tries to cover most of the aspects of the idealised glider port.

2. National or regional level glider port-facilities;

This allows for a more complete and sophisticated implementation of activities, and hardware (including gliders). Resources are concentrated, while reducing duplication of efforts.

3. Small to medium enterprises (SMEs) as glider ports;

This level implements usually a small part of the glider port spectrum (operational tasks) and can interact well in particular with a number smaller institutional level glider ports.

4. European level glider port.

This level widens the scope of a national or regional level to a transnational level, facilitating transnational access of gliders, implementing higher levels of specialisation and providing a stronger leverage to reduce costs of consumables.

Of all these levels, the institutional level glider port is implemented most frequently. This is due to historic reasons: in the early days each institute would have to implement their own infrastructure. However, it is still the case for institutes in countries that have no policy in setting up a national or regional level institute, or countries that have no experience with gliders.

Some glider port tasks have been outsourced to companies, creating SME glider ports. In Germany, for example, the services of companies have been used to pilot or ballast gliders. In such a setup, the companies implement a (limited service) glider port as a SME, reducing the (personal) burden on the contracting institute level glider ports

France and Norway have implemented a glider port on a national level, whereas Spain implemented regional level glider ports. The UK uses a mix of centralised facilities and institutional

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level glider ports. These implementations bring additional advantages, such as the development of increasingly sophisticated tools (e.g. GFMT) and providing access to glider technology to groups of scientist in institutes that do not own gliders.

In the current context there is no preferred way of establishing glider ports. In some cases an institutional level glider port is the preferred option, and in other cases, a national level glider port. An important factor is the will and political commitment of a country to support national level glider ports. This becomes even more important when it comes to European level glider ports, which have not been implemented. The key factor, however, is that glider ports are networked.

The EGO Cost Action and the GROOM project have contributed enormously to increase the level of networking between glider ports in Europe as seen it today. It is deemed crucial however, that, to consolidate the major advances made in terms of understanding of the needs, tool developments and data management, the development of a Glider European Research Infrastructure (GERI) should be managed and coordinated at a European and international level. The GERI is not meant to be an entity that imposes administrative constraints or controls the European glider fleet. Instead, the role of the GERI should be to support and encourage the glider developments in Europe, by engaging its partners to share tools and experience, participate to good practices and standards definition when appropriate, and provide access to member gliders if they are available. For the near future, the GERI could be implemented by the appointment of facilitators, who *i)* maintain an overview of all glider ports, encouraging communications between glider ports, *ii)* serve as an entry point for institutes who may also setup glider ports, *iii)* serve as an entry point for wider science community, *iv)* serve as a representative of the glider community, and *v)* develop an implementation plan for building the distributed European glider infrastructure. A bottom-up approach, initiated from participating research institutes would help the consortium to make substantial progress towards this more integrated Research Infrastructure.

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APPENDIX A GLIDER PORT QUESTIONNAIRE

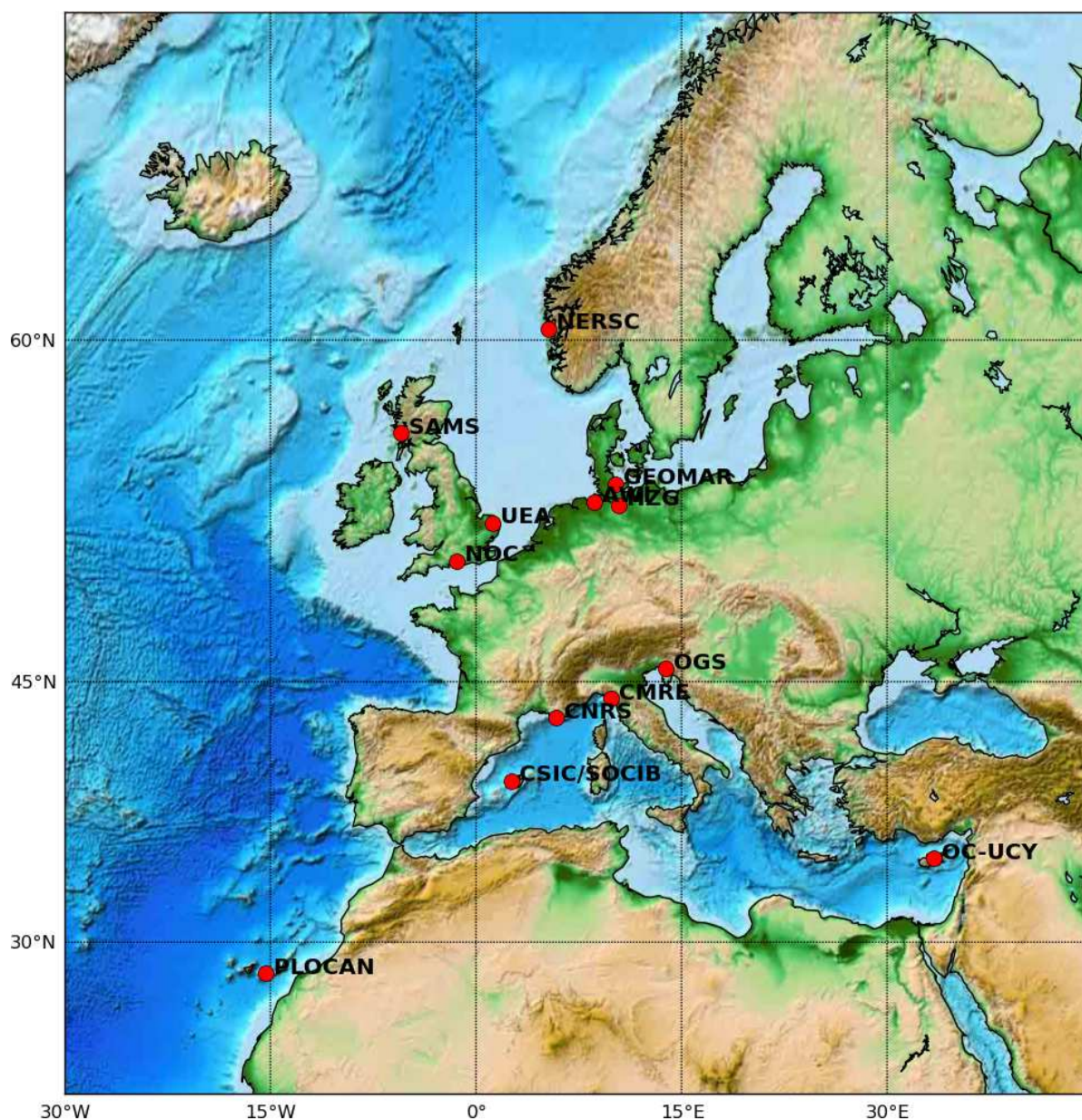


Figure A1: Map of respondents to the questionnaire