BRIDGES
BRINGING TOGETHER RESEARCH AND INDUSTRY FOR THE DEVELOPMENT OF GLIDER ENVIRONMENTAL SERVICES

THE FRAMEWORK PROGRAMME FOR RESEARCH AND INNOVATION
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"Bringing together Research and Industry for the Development of Glider Environmental Services"

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DELIVERABLE D6.2

"Technical Progress Report on the Development of Autonomy and Support Systems for the D and UD Explorers"

Abstract

This deliverable reports on the progress of the technical development of Work Package 6 at M18 of the BRIDGES project.

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v0.x	draft before peer-review approval
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Status / Dissemination Level			
Status		Dissemination Level	
S0	Approved/Released/Ready to be submitted	**PU**	Public
S1	Reviewed	**CO**	Confidential, restricted under conditions set out in the Grant Agreement
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S3	Draft for comments	**CI**	Classified, information as referred to in Commission Decision 2001/844/EC.
S4	Under preparation		

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1 Introduction

1.1 Document Purpose

This document provides a report on the progress of the Work Package 6 tasks to develop the autonomy and support systems for the Deep and UltraDeep Explorer gliders of the BRIDGES project.

1.2 Work Package 6 Overview

Work Package 6 is responsible for integrating information from sensor payloads and developing the platform intelligence needed to perform the missions identified in Work Package 2, with different levels of autonomy and networking.

Work Package 6 will develop and supply the hardware and software required to intelligently manage and control the glider platform, the glider payloads, payload sensor data, and provide support for glider mission planning and operations.

1.2.1 Tasks

Work Package 6 is divided into three main tasks:

1. Task 6.1: Glider platform navigation management and intelligence
2. Task 6.2: Glider sensor payload management and intelligence
3. Task 6.3: Shore-based decision support systems for glider mission optimization

Task 6.1 will:

- Adapt the current SEA EXPLORER navigation management hardware and software for the D and UD EXPLORERS to provide flight management, safety management, data storage and transmission, power supply and management.
- Additional integration and management of a rudder fin for roll control and a thruster for horizontal flight.
- Provision of glider navigation simulators for testing purposes within BRIDGES (ie sensor testing, mission control software testing, training purposes)

Task 6.2 will:

- Develop the Payload Management Controller hardware and software to interface with and intelligently manage the science payload sensors
- Develop platform autonomy for intelligent decision-making based on glider or sensor information, such as:
    - Switching on/off sensors or adapting sampling rates
    - Taking action following a detection beyond a certain threshold
    - And monitoring power consumption for mission time prediction.
- Provision of payload management simulators for testing purposes within BRIDGES (ie sensor integration, data flow and management testing, training purposes)

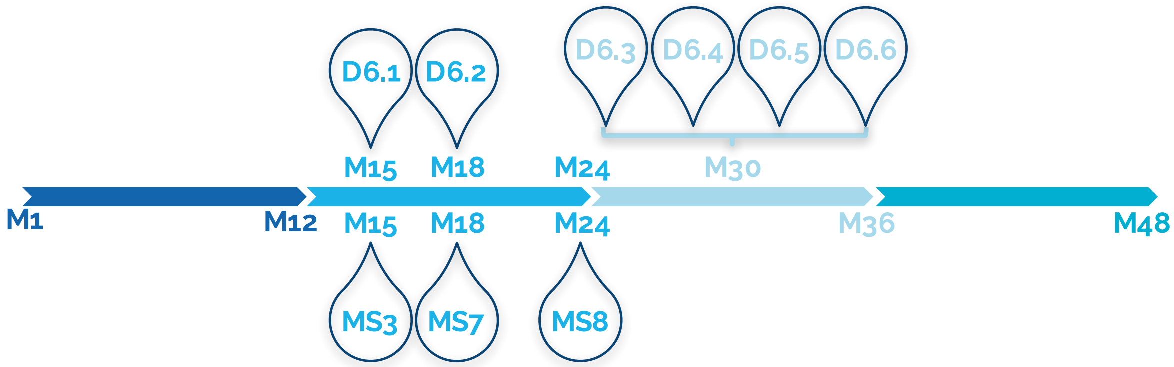
Task 6.3 will:

- Develop glider and glider fleet management software and tools to provide a service-oriented system
- Integration of MetOcean and maritime traffic information impacting glider operations to assess the feasibility of the required service and allow easy planning and configuration of missions (sampling strategies, mission tracks, risk assessment)

1.2.2 Deliverables and Milestones

Work Package 6 included the following deliverables and milestones, in chronological order:

- D6.1: Glider simulator [M15]
- MS3: Glider Simulator [M15]
- D6.2: Technical progress report on the development of autonmy and support systems for the U and UD Explorers [M18]
- MS7: Implementation human interaction intelligence [M18]
- MS8: Modules to design glider sampling strategies and associated risk [M24]
- D6.3: Software for the autonomy level [M30]
- D6.4: User Manual “Implementing autonomy in the U and UD Explorer” [M30]
- D6.5: Software for supporting mission planning [M30]
- D6.6: User Manual “Mission support system for the U and UD Explorers” [M30]



1.2.3 Progress Overview

The Glider Simulator of Task 6.1 has been completed and additional units are currently being manufactured for delivery to other BRIDGES partners for testing and integration purposes.

Task 6.2 of Work Package 6 experienced a delayed start due to a restructure of partners responsible for executing the tasks and a clarification and redefinition of the scope of work required to successfully complete the tasks. These issues were resolved within the first 6 months of the project and work has progressed since M6 and in strong collaboration with the other technical work packages.

Development and supply of sensor payload hardware and software is on track to be tested with WP5 sensors at the end of 2016 (M21-M24) and delivered to WP5 for the sensor payload demonstrations in April 2017 (M26).

Support system development in Task 6.3 has begun and is progressing well, with more resources now ready to be dedicated to implementing this task and coordinating the overall architecture of the system.

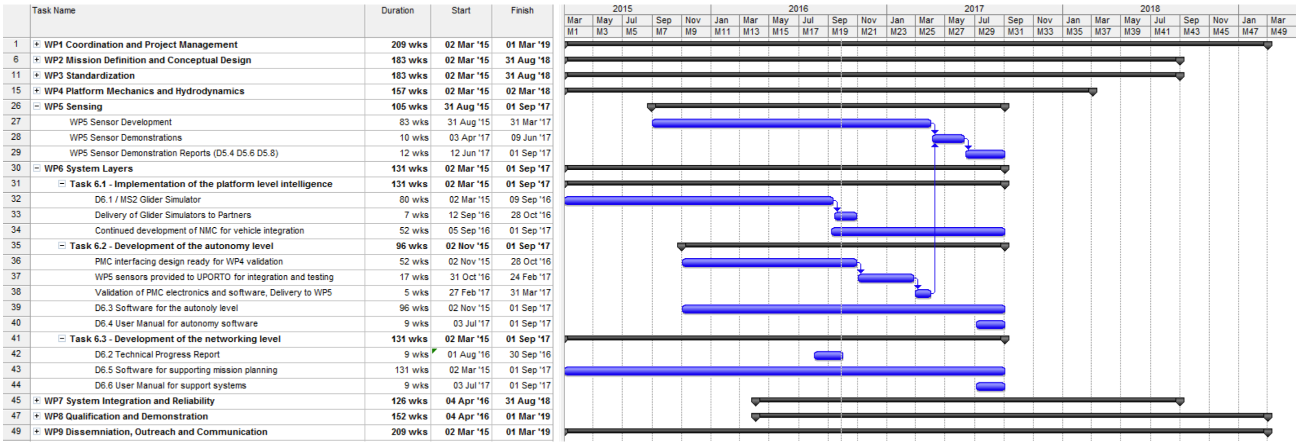


Figure: Overview of WP6 planning.

1.3 Related Work Packages

Work Package 6 is closely related to most of the BRIDGES work packages and requires regular communication and information exchange to complete the tasks, as well as to allow the other work packages to complete their tasks.

Work Package 6 is tasked to implement the glider and sensor behaviours and intelligent decision-making defined in the **WP2** mission definitions, such as adapting sensor sampling rates or switching on/off, or initiating hybrid propulsion mode, in order to be able to provide the services identified for the five key target markets.

Where **WP4** will develop and manufacture the glider platform (the “body” of the glider), WP6 will provide the electronics and software for controlling and managing the glider (the “brain” of the glider). As a result, these two work packages are closely connected and require regular information updates.

Work Package 6 will also provide the interfacing (data, power) and control required for the sensor payloads of **WP5**, as well as simulating hardware and software that can be used for testing and validating the sensors. For successful integration of the sensors, WP5 and WP6 must coordinate and agree on the interfacing specifications of each sensor.

Work Package 6 is also responsible for implementing the recommendations from **WP3** on standardized glider data and metadata, how this is handled and stored, so to ensure a high quality data product can be delivered following each glide mission.

Work Package 6 must also provide input on the software and electronics design for the **WP7** reliability analysis of the vehicle.

1.4 Glider Capabilties

The following table lists the key glider capabilties that will be developed by WP6 in collaboration with WP4 and WP5, and demonstrated by WP8 during the BRIDGES project.

Capability	Measure of Success	Testing of:
Navigate between waypoints	Arrives to distant waypoint and returns to start with 500m tolerance in both cases	- Navigation autonomy
Keep virtual mooring	Maintains 500m radius watch circle	- Navigation autonomy - Support systems
Send sensor information through satellite communication	Data files received on land/on board the vessel	- Payload autonomy - Navigation autonomy - Support systems
Perform hybrid missions by combining propelled and gliding modes	Engages/disengages propeller at the proper time with successful flight in both cases	- Navigation autonomy - Support systems
Adapt flight behaviour to environmental conditions	Abort mission and calls home when senses above background optical signal	- Payload autonomy - Navigation autonomy - Support systems
Turn sensors on and off automatically	Sensors are powered on and off at the proper time with successful operation in both cases	- Payload autonomy
Spiral diving	Stable flight during dive and climb phases	- Navigation autonomy
Constant depth transect of ocean parameters	Data stream received on land and validated with independent sensors	- Payload autonomy - Navigation autonomy - Support systems

Table: Glider capabilities to be demonstrated in WP8.

2 Autonomy Systems

2.1 Navigation System

The navigation system will be developed based on the proven SEA EXPLORER software and electronics, with the addition of a rudder fin to replace the roll device of the SEA EXPLORER and a thruster to be able to move horizontally.

The navigation system is responsible for:

- Flight management of the glider based on pilot configuration and commands, loaded before and updated during a mission
- Safety management including internal monitoring (pressure, leak detection, temperature), alarms for unexpected behaviour or detections and emergency surfacing
- Communication via satellite, radio frequency and Ethernet when at surface or on land
- Data storage, compression and transmission
- Power supply and management

2.2 Glider Simulator

A Glider Simulator has been developed for glider navigation testing purposes, consisting of electronics and associated communication devices operated by the same backseat/frontseat architecture as on the real platform. The aim of this system is to give the ability to the end-user to become familiar with the gliders before experiencing real missions at sea. The simulator will allow the following actions: (a) test mode to command actuators independently to check that everything is working properly; (b) simulation mode with or without actuator to simulate a mission with simulated navigation sensors (depth, heading, pitch, roll, gps). The simulator will be able to react to new commands from either remote piloting or the science payload as in a real mission.

To provide real vehicle behaviour in a safe and easy to use system, the main controller board for the glider prototype was first designed and validated, and all equipment was selected, so that the actual vehicle and Glider Simulator are as similar and compatible as possible for integration and testing purposes.

The Glider Simulator is as follows:

Figure: Glider Simulator front panel (left) and rear panel (right).

The vehicle simulator is a small plastic box (LxWxH: 354x305x97 mm) composed of connectors to connect external devices (actuators, sensors, payload simulator, etc.) and indicators (i.e.: LED) to provide a visual simulation feedback.

This design is complete:

- All the equipment selection has been achieved during the general preliminary design.
- The main controller board has been designed, realized and validated; the same board will be used in the Deep and Ultradeep glider.
- The satellite communication device (electronic board) has been designed, realized and validated; this system will be used in the Deep and Ultradeep glider.

- The positioning device (electronic board) has been design, realized and validated, this system will be used in the Deep and Ultradeep glider,
- The simulation software, based on the final control and command software is almost done, some features still need to be tested and validated,
- Main box and internal frame have been design and is being realized.

For this simulator, the main challenge was to design the very low power consumption controller board considering the vehicles requirements. To be as realistic as possible, we really wanted to use the same board in the vehicle and in the simulator box.

At the end of the project, this system will be added to the DeepExplorer product list as a commercial product for training and testing purposes.

2.3 Payload Management System

The Payload Management Computer (PMC) will be developed to interface with and intelligently manage the science payload sensors.

The PMC will provide a controlled power source and data interface for each sensor from WP5 and implement autonomous management of the sensors. This includes the development and production of dedicated Sensor Controllers (SC) for each sensor from WP5. Each SC will be an optimized PCB with low power microcontroller, DC/DC for power control of the sensor and communication interfaces from the PMC to the sensor.

Five PMC systems will be produced to be used as simulators for sensor testing and for installation in the D and UD Explorers. The systems to be integrated in the D and UD Explorer shall include one PMC and SC for all installed sensors, while the four systems to be used as simulators will include one PMC and one SC.

For both the PMC and SC sub-systems, the design priority is: 1) power consumption, 2) mass, 3) cost, 4) dimensions. Even though the sub-systems need to be low power, they are also required to be capable enough to abide to platform requirements, which include onboard autonomy, interaction with user, data management and logging.

UPORTO have created a board called **SIB** (Sensor Interface Board) to fulfil the task of controlling each sensor. The PMC will withstand up to 8 sensors at the same time and, since each sensor will have its own SIB, this configuration will result in a total amount of 8 SIBs. The decision to have the PMS divided into one central PMC and several SIB aims at providing system scalability (allowing the number of sensors to be modified as needed), modularity (allowing each sensor controller to be viewed as a stand-alone system that can be tested and validated out of the PMS) while also guaranteeing that each sensor data shall be properly handled by a dedicated parser and that the input power is well adjusted. The SIBs will share the same electrical design and layout but will have different firmware accordingly to the sensor they are interfacing.

PMC will be computationally powered by the Stamp9G20 ARM9 Computer-on-Module provided by Taskit GmbH. This device is also used by the glider’s main computer module. Although it lacks a built-in Ethernet interface, the manufacturer provides a shield with Ethernet interface. The PMC will also support an integrated environmental sensor developed specifically for mobile applications (BME280). The choice of this sensor took into account the power consumption, the size and also, the interface with the Stamp9G20. The communication between the PMC and the SIBs will be done through RS-485 allowing the SIBs to be connected in the same communication bus. A signal conditioner circuitry provided by Alseamar will be used to detect water inside the PMS case.

SIB will be powered by an ATxmega32A4 microcontroller from Atmel. This device is a low power, high performance 8-bit AVR microcontroller featuring 32KB self-programming flash program memory clocked at 32 MHz. The main reasons that led to this choice were the high number of I/O interfaces coupled with ultra-low power sleep consumption, its size and weight. The microcontroller will be responsible for controlling directly the sensor and parsing the data from the sensor to the PMC.

All signals external to PMC and between PMC and SIBs are protected from ESD. All the connectors are high quality and high durability and have been accepted or suggested by ALSEAMAR.

PMC board is expected to weight 200 g, while each SIB is expected to weight less than 40 g. The total PMS size shall not exceed 500 g.

Expected power consumption:

Board	#	Max Power Consumption (mW)	Power Consumption in IDLE with Ethernet (mW)
PMC	1	502	221
SIB	8	82.56	0
Total		1162.48	221

Table: Power consumption of the PMC and SIB.

Regarding the progress of the development, there were some delays in closing in final hardware components for both the PMC and SIB boards to meet some of the requirements. Moreover, later wet-section hull adjustments In WP4 prevented finalizing specifications due to uncertainty on size constraints. Now, both PMC and SIB electrical circuit have been accepted by ALSEAMAR and the physical connections between the PMC and the SIBs is being defined. After some study and consideration, both UPORTO and ALSEAMAR agreed with a backplane mount (see figure below).

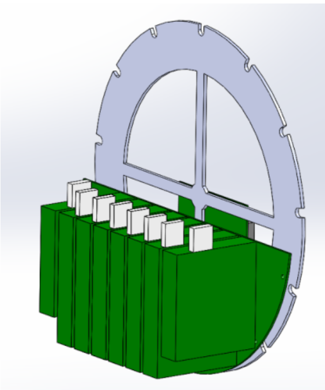


Figure: PMC model mounted on agreed backplane.

The hardware and software is scheduled to be tested with each WP5 sensor over winter 2016, with prototypes ready for delivery for the WP5 sensor payloads demonstrations in April 2017 (M26)/

2.4 Platform Autonomy

The autonomy levels for mission planning will be (i) dynamically surfacing for communication and (ii) intelligently managing the sensor operations for maximizing the mission time by switching off sensor modules. The decision-making needs to be performed onboard and hence the decision-making algorithms must have low computational complexity. A novel sensor fusion algorithm will be developed to optimally determine the next actions:

1. Human-interaction intelligence: In this level, the autonomy module detects some interesting feature but would like to get additional input from the human operator on its course of action. In this case, the vehicle surfaces and transmits the data to the operator at the base station. Once it receives new commands from the base station it begins the mission.
2. Intelligence mission time prediction: The vehicle can take the power consumption levels of the sensors and predict the possible mission time. Further, this time can be used by the mission planning module to determine the mission legs. We will develop a mission time predictor taking the dynamic power consumption and the static power consumption.
3. Intelligent sensing capability: The autonomy module receives steady stream of data from the science payload on different science parameters. The module determines interesting features from the stream and autonomously decides on the sampling rate of the sensors. The sampling rate is a tradeoff on the information collected by the sensors and the power consumed by the sensor which can affect the mission time. This module can also dynamically switch-on and switch-off the sensor module. This intelligence is built into the module. Finally, the system will feedback sensor packages with information about navigation (estimated location) and other engineering data useful for processing actions.
4. Local management of data storage and transmission. Procedures will be implemented in the secondary computer to ensure an adequate internal data storage and preparation of files for satellite transmission

The platform autonomy software is divided in four layers:

- The PMC operating system (OS) that shall be lightweight to reduce power consumption, processing footprint and memory usage. Due to MST's experience with the OS, the open-source GLUED was chosen. GLUED (GNU/Linux Uniform Environment Distribution) is a minimal Linux distribution targeted at embedded systems. OS support for the Stamp9g20 was added to the main repository by MST.
- Autonomy Software Layer that will interface with glider's navigation computer and manage sensor controllers. The delays experienced on the delivery of the preliminary hardware releases of the PMS, pushed the developments back a few months. The developments on this layer are minimal thus far.
- SIB firmware: MST developed a microcontroller toolkit library that provides an API to atxmega class. This library includes communication interface, bootloader, parser, error handling and data frames.
- Device drivers for WP5 sensor list: using in-house hardware, MST wrote and tested sensor drivers for some of the devices that will be installed in gliders, or that are listed as future options. These include:
    - SeaBird CTD

- Turner Design's Cyclops
- Aanderaa's Optode
- WetLabs

Regarding milestone MS7 - Implementation human interaction intelligence (verification: Demonstration in Simulator) initially scheduled for M18 this milestone was **not reached**. There are two main reasons for this:

- MST are awaiting delivery of the Glider Simulator, expected in M20.
- Delays on the delivery of the preliminary hardware releases.

Following the WP6 workshop during the BRIDGES General Assembly in September, an updated plan was agreed upon and the milestone MS7 is expected to be achieved by November 2016 (M21).

3 Support Systems

Working towards a successful European glider industry, BRIDGES is also developing innovative techniques of data sampling and of glider behavior depending on data collected, type of missions or environmental constraints. To achieve this, a software system layer will be developed to integrate fleets of gliders – being the sensing component – into a service oriented system. This system layer will manage the Metocean and maritime traffic information impacting the gliders' operation to assess the feasibility of the required service by a fleet of gliders and to allow easy configuration of the missions. With such an approach, scientists, governmental agencies and regulators, as well as commercial bodies could remotely operate an in-situ sensing system, rather than individual platforms with their own operating constraints.

3.1 Module Development

BRIDGES will develop modules that interface with the glider piloting software to optimally define missions of fleet of D and UD Explorers, and to maximize content of data collected in a spatially extended system by networking gliders. Cooperative unaware and coordinated network configurations will be considered but without direct inter-vehicle communication. The modules will be designed to be portable and able to interface with different piloting software.

The modules that are being developed are described in detail in the following subsections.

3.1.1 Geometric-Based Glider Fleet Optimization

This module helps to define networked sampling strategies based on geometric criterion that does not involve prior information on the field of interest. Sampling points are located to minimize a criterion that is only a function of the distance. Suitable for initial data collection and for small scale exploration and/or regions where historical data are not available. This technique is well suited for servicing offshore oil and gas and sea mining activities.

For this module, UCY has developed a stable version of *γ-planner*, a novel planner which can provide optimal sampling mission design to support underwater autonomous vehicles in combination with other observation instruments such as buoys. The introduction of *γ-planner* addresses the optimization of area coverage by providing sampling strategies of observation networks for exploratory missions where currents are not taken into consideration. A novel optimality geometric criterion is introduced based on the location of the sampling locations and non-sampling locations of the required area of interest. This planning tool has been implemented in MATLAB where a graphical user interface in provided such that the tool can be usable to a wider audience and not just marine scientists specialized in mission planning.

The required inputs for the *γ-planner* are divided into three different categories, Domain parameters, Mission parameters and Glider parameters. Starting with the domain parameters, the user provides the minimum and maximum longitude as well as the minimum and maximum latitude in order to obtain the required are of interest. We then have to provide the Mission parameters which consist of the number of gliders, number of buoys, mission time (in days) and number of waypoints for each glider. The last set of parameters are in regard to the Glider and they are required in order to be able to simulate the glider's flight. For this it is required to specify the glider's velocity, the pitch that will be used and the depth range that the used is interested in.

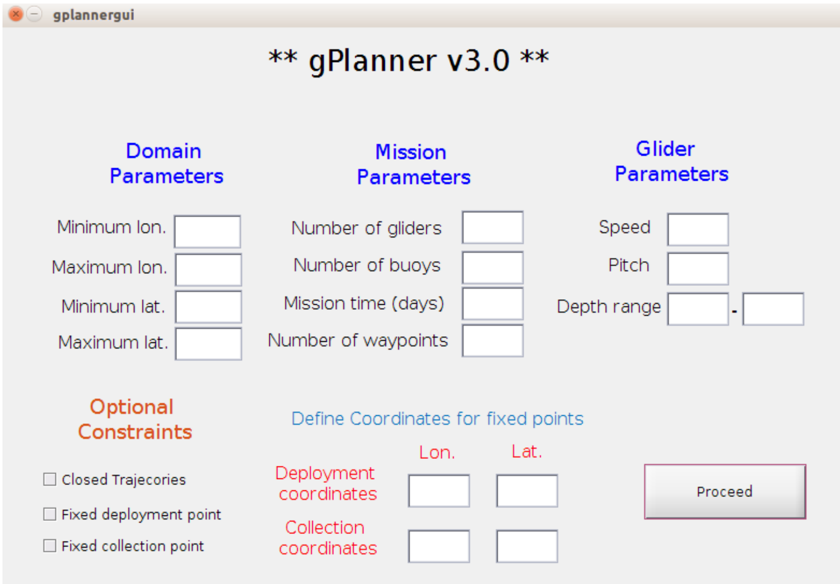


Figure : GUI used for the current version of γ-planner

The *γ-planner* is implemented and compared with respect to two exploratory missions that took place in 2013 (butterfly – similar formation) and 2016 (Crete). In both cases the results are encouraging with the near optimal missions providing a coverage increase of approximately 15%. The *γ-planner* is a valuable mission design tool could significantly reduce the logistic needs for deployment of fleets of gliders and other observation networks.

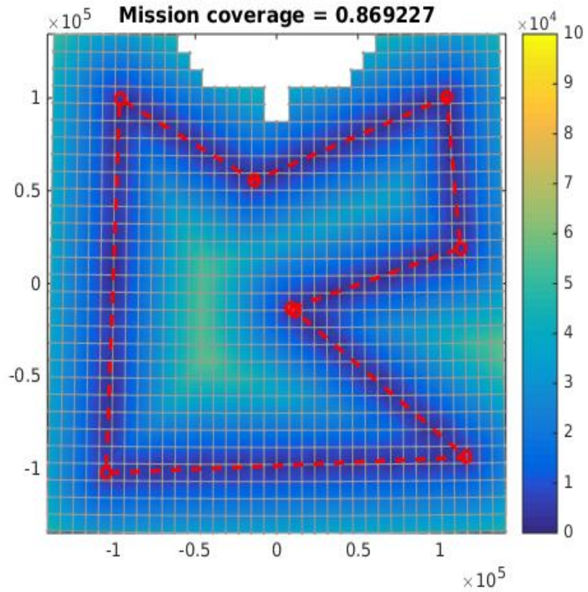
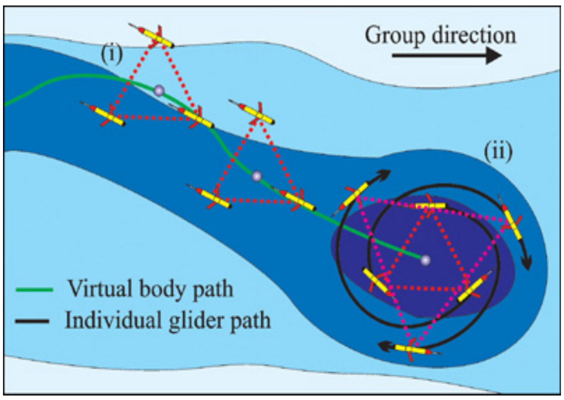


Figure: Butterfly formation in comparison to γ-planner near optimal output. Coverage improved by 13.1 % for the same mission time.

3.1.2 Environment-Based Glider Fleet Optimization

This module defines networked optimum sampling designs using information from environmental prediction systems (MyOcean) to define sampling strategies. Samplings are designed to optimize a covariance based criterion. This technique is more suitable for large scale monitoring of environmental parameters.

The specific module has been further developed by CSCS in corporation with UCY. The UCY and CSCS have a working version of the module which still requires some debugging and optimization in order to yield a stable outcome.



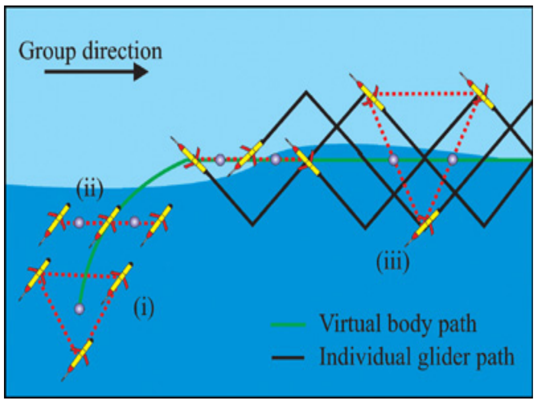


Figure: Glider fleet holding a triangle formation while adapting to and targeting environmental conditions.

3.1.3 Glider Mission Risk Assessment

This module evaluates and assesses the risk of designed missions, either those pre-defined by modules 1 and 2 or defined by users. The risk assessment will consider areas of buoyancy, current and ship collision risks. The module will make use of oceanographic predictions provided by operational oceanographic centres (MyOcean).

There is a first draft (based on FP7 GROOM's similar module) of the specific module in working condition, however all density maps that can be found for free are low resolution with inaccurate outcomes. A high resolution ship traffic density map may need to be purchased. -

3.1.4 Dead-Reckoning Glider Positioning

A dead reckoning function will be integrated in the control and command software to be able to estimate position during a flight, using the hydrodynamic model of the glider produced by WP4. As the glider will dive for many hours (24 hours for a full depth descent and ascent) and travel over several kilometres, it is important to be able to provide a localization for two main reasons: to be able to geographically locate acquired data; and to estimate the experienced current drift in order to compensate the current. Based on a simple and basic model, it will be easily modifiable to consider vehicle dynamic deviations or modifications generated by integration of new payloads and sensors.

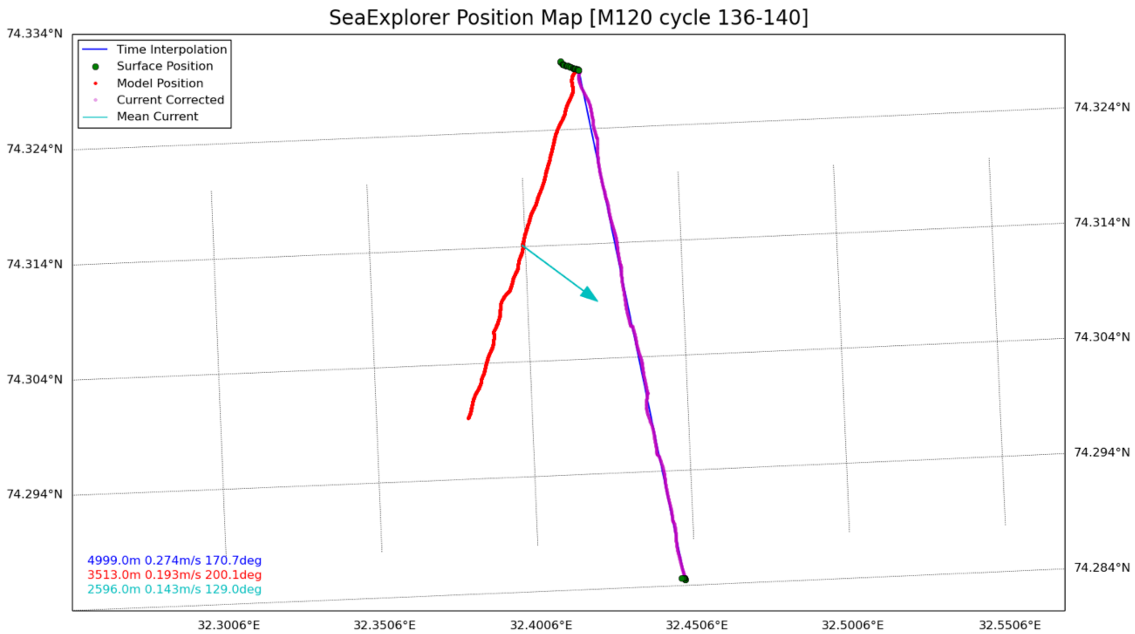


Figure: Dead-reckoning example from a SeaExplorer mission in the Barents Sea, 2014, showing underwater positioning from dead-reckoning (red) and current-corrected positioning (purple).

3.2 Module Integration

These modules will be integrated into a common glider mission support system that facilities the generation, supervision, data display and management for networks of gliders and supports open data exchange and piloting of gliders. This includes establishing two-way information flow to allow near real-time data exchange and commands between the modules and the glider(s).

BRIDGES will take advantage of the 10+ years of European glider experience within our consortium to consolidate the glider tools and modules that have been developed and validated ad-hoc for various missions and projects. Creating a clean and well-structured support system for the modules described in section 3.1 will allow easy integration of the valuable tools that already exist within research institutions, and bringing these tools to the wider glider community.

The support system will assist in following the standards and recommendations provided by WP3 by processing and preparing the glider data for storage and delivery in standardized formats.

Capabilities to display most relevant scientific, navigation and engineering information in an intuitive and efficient way will be developed, utilising different platforms (web, tablet/mobile) to maximise access to glider data.

Within BRIDGES, there are two main platforms for glider piloting that will be focused on for integration of the modules and data display:

- IRIS – proprietary piloting software from ALSEAMAR.
- The EGO network – Open glider community website for glider mission data and piloting (http://www.ego-network.org/).

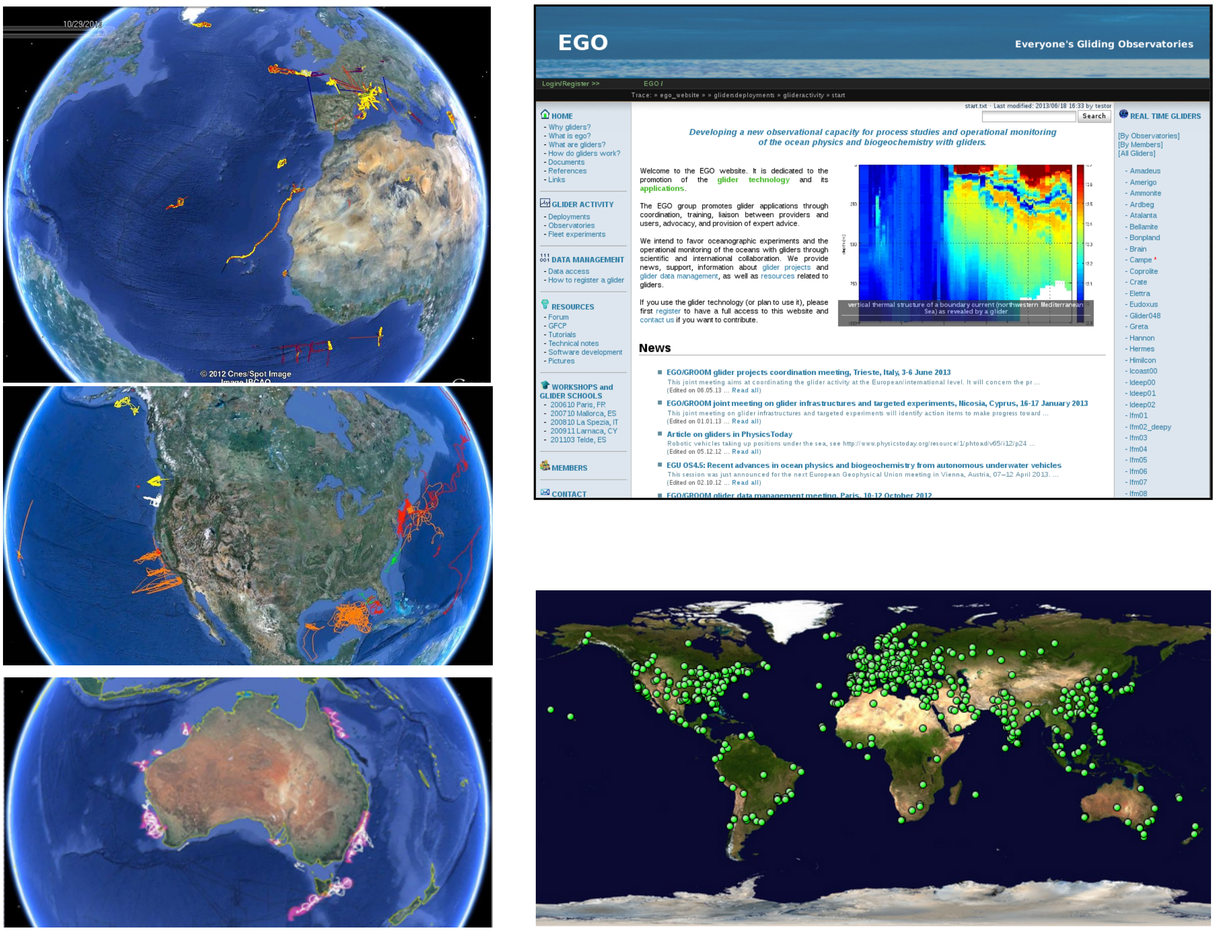


Image: EGO network website and overview of deployments.

To ensure that future modules can be developed by any research institute or company, the interface between IRIS and the modules will be TCP/UDP port broadcasting and communication of information. This allows fast and safe transmission of large amounts of information without compromising performance of the core piloting software.

The EGO network will be upgraded to include the new Deep and Ultradeep Explorers, and will need to receive dedicated data from the IRIS software, either by TCP/IP or by FTP depending on network firewall rules. The EGO network upgrade will result in an excellent tool for dissemination and promotion of the Deep and Ultradeep Explorer demonstrations and future missions, and in general the growing glider activities in Europe.

4 Summary

Work Package 6 is progressing well following a bumpy start due to reallocation and clarification of the scope of work and is on track to deliver the key glider navigation and payload control systems on time for WP5 and WP4 testing and demonstrations.

The key result of Work Package 6 between M1-M18 of the project, the Glider Simulator, has been completed and additional units will soon be manufactured and delivered to technical partners to aide their development and testing.

The next 6-12 months of Work Package 6 will be particularly active in order to meet the deadlines required for the work of other work packages, with further results expected in the form of hardware and software for the Payload Management System and advanced development of the glider mission support systems.