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Report and dataset from gliders experimental campaign

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SHORT ABSTRACT FOR DISSEMINATION PURPOSES

Abstract

This report presents the preparatory activities and preliminary data framework for the experimental campaign involving the Wave Glider SV3 platform, operated by Consorzio LaMMA upon request by CNR ISMAR, within the PRIN PNRR AIMS project. The campaign aims to collect high-resolution, spatially-varying wave data and constitutes a core component of the in-situ strategy designed to validate both remote sensing products and numerical model outputs. These data are essential for training artificial intelligence models focused on inferring wave period from sparse observations.

Originally scheduled for early 2025, the ASV deployment faced administrative and technical delays, leading to its rescheduling for Summer 2025 (July-September), with a potential follow-up in Autumn to better capture seasonal variability. The campaign is coordinated by CNR, with trajectory planning support from Politecnico di Torino (PoliTO).

To support AI algorithm development in the absence of real ASV data, a mitigation strategy was implemented through the generation of synthetic datasets. These were built using the WW3 model along planned Wave Glider trajectories and are included in this deliverable to provide continuity in model training and validation activities.

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LIST OF PARTNERS

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1	Politecnico di Torino 1859	Politecnico di Torino	POLITO	Torino
2	ROMA TRE UNIVERSITÀ DEGLI STUDI	Universitá degli studi di Roma Tre	ROMA3	Roma
3	Italian National Research Council	Consiglio Nationale delle Ricerche	CNR	Firenze

ABBREVIATIONS

Acronym	Description
ADCP	Acoustic Doppler Current Profiler
ASV	Autonomous Surface Vehicle
SLP	Surface Level Pressure
SST	Sea Surface Temperature
WG	Wave Glider

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EXECUTIVE SUMMARY

This report, title D1.4 - Report and dataset from gliders experimental campaigns, presents the research conducted under the AIMS project, which seeks to enhance marine conditions monitoring through the integration of artificial intelligence and satellite data. Funded by the European Union's NextGeneration EU program, the project focuses on the understanding of wave phenomena by combining satellite and in-situ data from wave buoys, specifically addressing current limitations in satellite data management, spatial-temporal discontinuities, and limited measurable parameters.

This deliverable outlines the planning and preliminary implementation of the experimental campaign based on the Wave Glider SV3 autonomous platform, operated by Consorzio LaMMA on behalf of CNR ISMAR, within the PRIN PNRR AIMS project framework. The campaign is a key step in the in-situ data acquisition strategy supporting the development of AI-driven tools for the inference of wave parameters, especially wave period, from satellite and model inputs.

Despite the scientific relevance and technological readiness of the ASV-based measurement campaign, the execution phase encountered several significant administrative and technical challenges that led to a delay in operations. Originally planned for early 2025, the deployment had to be postponed to the Summer-Autumn window (July-September 2025), primarily due to:

- Software licensing issues: the mission control and telemetry software for the Wave Glider requires an annual license renewal. Delays in license procurement created a tight scheduling constraint for the mission's execution.
- Lack of immediately available funding: key operational steps–including vessel rental, subcontracting of field technicians, and external mission support–required financial commitments that were not feasible in the initial months due to the absence of allocated budget lines at CNR ISMAR.
- Funding block at CNR: a general administrative freeze on fund availability within CNR occurred at a critical phase of the PRIN PNRR

project implementation, affecting both operational and coordination activities.

- Pending inter-institutional agreement: the use of Wave Glider equipment and infrastructure, currently operated by LaMMA, requires formal authorization through a bilateral agreement between CNR and the Consortium. Although the agreement text has been jointly drafted and agreed in principle, it remains unsigned at the time of writing, preventing full operational engagement.

These issues underscore the importance of early administrative planning in the execution of large-scale, interdisciplinary projects that rely on shared technological assets and inter-institutional cooperation. The upcoming mission, scheduled between July and September 2025, is expected to overcome these limitations and deliver the anticipated dataset, although in a late phase of the project.

To mitigate the impact of the delay and ensure continuity in data availability for AI model training, a synthetic dataset was generated using the WW3 wave model, simulating plausible Wave Glider trajectories. These data are included in the current deliverable to support ongoing algorithm development and to maintain alignment with project milestones.

1. Description of the Wave Glider SV3 Platform

The Wave Glider SV3 is an advanced Autonomous Surface Vehicle (ASV) developed by Liquid Robotics, designed to perform long-endurance missions at sea by leveraging wave and solar energy for propulsion and power. Within the AIMS project, the SV3 operated by Consorzio LaMMA, in coordination with CNR ISMAR, serves as a strategic tool to collect high-resolution, spatially distributed wave and current measurements. These in-situ data are essential for the validation of satellite-based observations, numerical wave models, and for the training of Artificial Intelligence algorithms aimed at estimating wave parameters such as wave period.

1.1 General Features

The SV3 is equipped with a two-body structure: a surface float and a submerged glider connected by a tether. The surface float hosts solar panels and communication systems, while the underwater glider, moving vertically with wave motion, converts energy into forward propulsion. This system enables persistent deployments of weeks to months with minimal energy consumption and logistical overhead.

Key features include:

- Power autonomy: solar panels with battery storage enabling mission durations up to several months.
- Navigation and control: GPS-based autonomous navigation and real-time control via satellite communications (Iridium).
- Software suite: mission planning, adaptive routing, and health monitoring tools, all accessible remotely.
- Environmental robustness: operational in sea states up to 6 and wind speeds up to 25 m/s.

1.2 Scientific Payload for AIMS

The SV3 used in AIMS is equipped with a specific suite of sensors optimized for sea state characterization. In particular, among other sensors, the tools more suitable to fit the needs of the AIMS project are:

- Wave sensor package: includes GPS, IMU (inertial measurement unit), and motion sensors (accelerometers, gyroscopes) to compute directional wave spectra.
- Current profiler: a compact Acoustic Doppler Current Profiler (ADCP), at 300 kHz, enabling the measurement of near-surface current profiles.
- Auxiliary sensors: optional modules include sensors for sea surface temperature (SST), salinity, dissolved oxygen (DO), winds (through an acoustic anemometer sensor) and atmospheric pressure.

A 3-channel Fluorometer is also implemented for cholorphyll-a measurements and to detect possible traces of different hydrocarbons (heavy and light hydrocarbons).

Wave data from the SV3 are processed onboard to derive spectral parameters such as significant wave height (Hs), peak period (Tp), mean direction (θ), and directional spreading. These are transmitted in near-real time to the shore, ensuring fast data access and adaptive mission control.

Sensor	Parameter	Description
GPS + IMU	Wave elevation, direction, velocity	Used to compute directional wave spectra
Inertial Motion Unit (IMU)	3D acceleration, pitch, roll, yaw	Captures wave-induced movement of the float
Compact ADCP (Teledyne/RDI)	Surface current profiles (upper 5 m)	Measures velocity profiles below the float
SST sensor	Sea Surface Temperature	Mounted near the float base
Optional barometric sensor	Surface Pressure	For atmospheric-sea coupling studies (if installed)

1.3 Role in the AIMS Project

In the AIMS project, the Wave Glider plays an important role in the spatial characterization of wave fields, acting as a mobile sensor that complements fixed moorings and satellite overpasses. Its ability to navigate pre-defined or adaptive transects enables the exploration of mesoscale gradients and spatial variability, which are often unresolved by point measurements or satellite-derived products. In AIMS, SV3 missions are designed to:

- Validate satellite wave parameters along their ground tracks.
- Provide training data for AI-based wave period and height estimation.
- Support numerical model tuning and uncertainty quantification.

The platform's flexibility and autonomy make it ideal for exploring dynamic coastal and open-sea environments, especially when integrated into a broader multi-platform observational strategy.

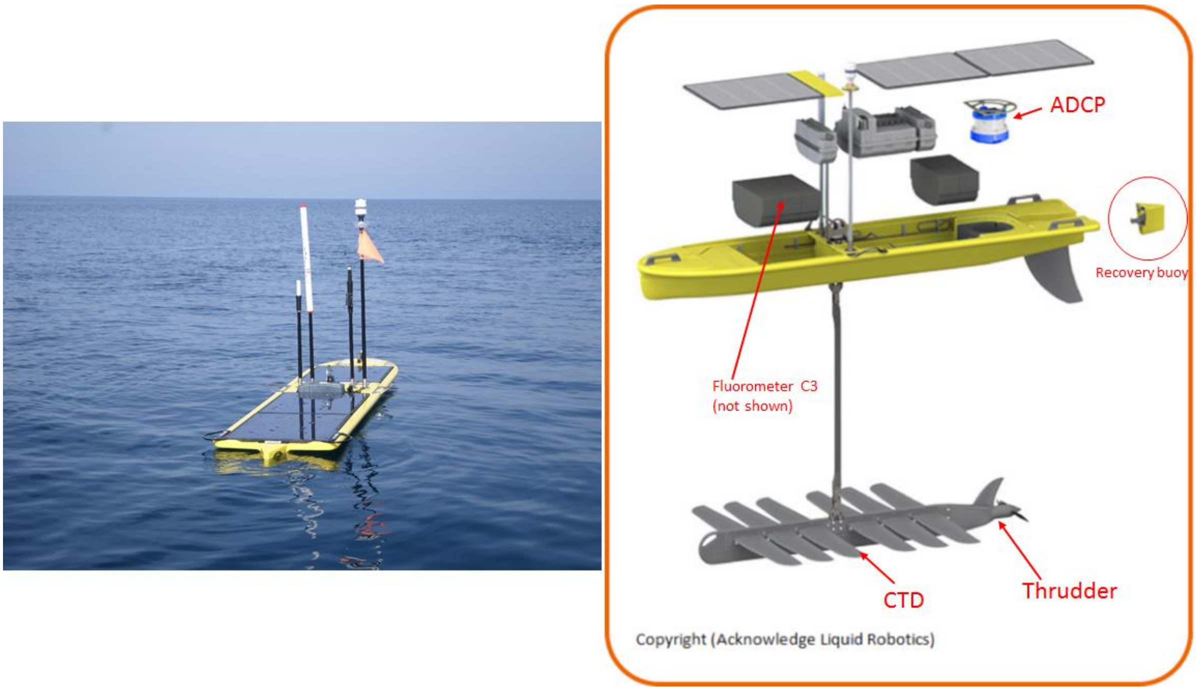


Figure 1 – Wave Glider ASV schematic architecture (on the left) and LaMMA SV3 WG (on the right).

2. Reference Campaigns and Sample Data

Although the experimental campaign foreseen within the AIMS project has been rescheduled due to administrative and technical constraints, the Wave Glider SV3 platform has already been successfully deployed in several earlier missions coordinated by Consorzio LaMMA. These reference campaigns serve as proof-of-concept for the vehicle’s ability to collect reliable wave and current data, and provide relevant benchmarks for both planning and simulation of future missions.

2.1 Ligurian Sea Mission (2017)

In 2017, the SV3 Wave Glider (WG) carried out several missions in the Ligurian Sea to characterize coastal current systems and validate satellite-based marine products. This was part of the SYMPA (Satellite assets Integration for Marine Protected Areas) project [1], which aims to provide physical and biogeochemical data for marine protected areas (MPAs) in the Western Mediterranean. The mission took place between September and October 2017, comprising the following sub-missions:

- 22 September 2017: One-day mission along the La Spezia coastal area, in collaboration with ENEA.
- 25-29 September 2017: Five-day mission offshore La Spezia, in collaboration with the Italian Navy.
- 24-26 October 2017: Three-day mission in the Santa Teresa (ENEA)/Cinque Terre MPA area, in collaboration with ENEA.

These missions aimed to collect in-situ data necessary for validating the SYMPA-TL service. Key observations included preliminary validation of satellite and model-based estimations of marine parameters, such as sea surface temperature (SST) and chlorophyll-a concentrations, using data collected by the WG. The WG's performance, particularly around the 5 Terre MPA, showcased its potential for operational deployment in difficult coastal zones, highlighting its adaptability to varying sea conditions. Despite facing some technical challenges, such as sensor misconfigurations that affected biogeochemical measurements from the CTD and fluorometer, the WG successfully covered approximately 50 nautical miles during the mission.

Data from the CTD and fluorometer were used to compare in-situ measurements with model outputs from the SYMPA Earth Observation (EO) and model components. While the number of WG sampling sites was relatively small, some general conclusions can be drawn. For example, the comparison between the WG's in-situ data and SYMPA model outputs revealed a bias error of less than 0.3°C in 70% of the temperature cases. In certain areas, particularly those closer to the coastline, temperature errors ranged between 1°C and 1.5°C when compared with fluorometer data.

When comparing SYMPA model outputs with WG data from the 5 Terre MPA, the accuracy of certain parameters, such as temperature and chlorophyll-a concentrations, was promising. However, discrepancies were observed, especially near the coastline, where the resolution of satellite data and the limitations of the model affected prediction quality.

In conclusion, the WG demonstrated its ability to collect data under varying weather conditions, even during the night. Its ease of deployment and manoeuvrability make it an invaluable asset for ongoing oceanographic research and monitoring of MPAs.

In Fig. 2, the route of the wave glider in the three campaigns mentioned above.

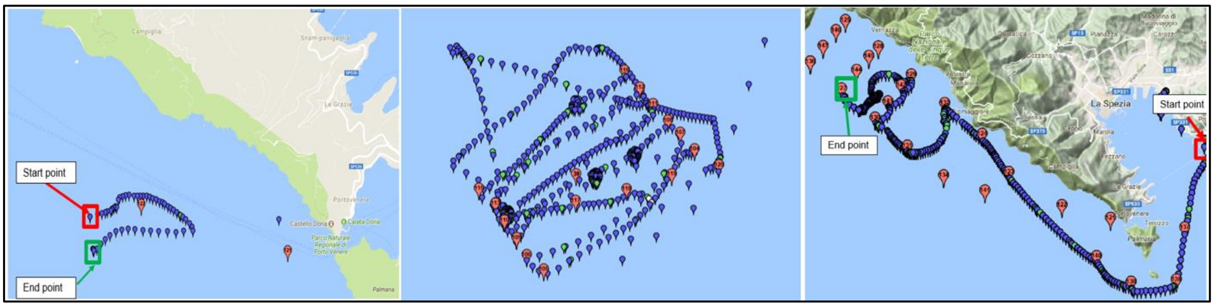


Figure 2 – The route of the wave glider for the campaign in the La Spezia coastal area (on the left), offshore La Spezia (in the center), and in the Cinque Terre MPA area (on the right).

2.2 Corsica channel Survey (2018)

In July 2018, the Wave Glider SV3 was deployed in the Corsican Sea as part of the Diane Lagoon-Bonifacio campaign. This mission was conducted aboard a shellfish farmer boat in collaboration with the Ifremer staff, and took place in a region characterized by intense marine traffic during the busy summer season, with many pleasure boats and regular ferry lines operating. The operational area ranged in depth from 30m to 450m, with areas near Bonifacio exhibiting highly variable bathymetry, sometimes less than 10m.

The mission lasted 13 days, from July 19 to July 31, and followed a predefined transect in a nearshore area, avoiding the busiest shipping routes and potential conflicts with larger vessels. The mission focused on the collection of physical and biogeochemical parameters, as well as testing the capabilities of the ADCP at different depths, particularly in the upper marine layers.
The wave glider collected the following data:

- Directional wave spectra at 30-minute intervals
- Surface current profiles from 0.5 to 100 m depth
- Sea Surface Temperature (SST) and basic meteorological parameters
- A camera mounted on the nose of the glider continuously detected plastic in the sea.

Additionally, the glider was equipped with CTD, fluorometer C3, and GPS wave sensors. The mission encountered challenges due to marine traffic, especially near Bonifacio, where strong currents and frequent vessel traffic required close monitoring and support by Ifremer staff. The Wave Glider was able to collect valuable data while maintaining safety during its deployment, with average speeds ranging from 0.7 to 1.1 knots. The return leg of the mission faced difficulties due to counter-currents, reflected in the lower speed of the vehicle.

The collected data showed excellent consistency with the LaMMA Tyrrheno-ROMS hydrodynamic model outputs and with the WW3 regional wave model, providing a solid foundation for comparative analysis and model refinement.

In Fig.3, the route of the wave glider and the WG speed during the first leg and the return leg are shown.

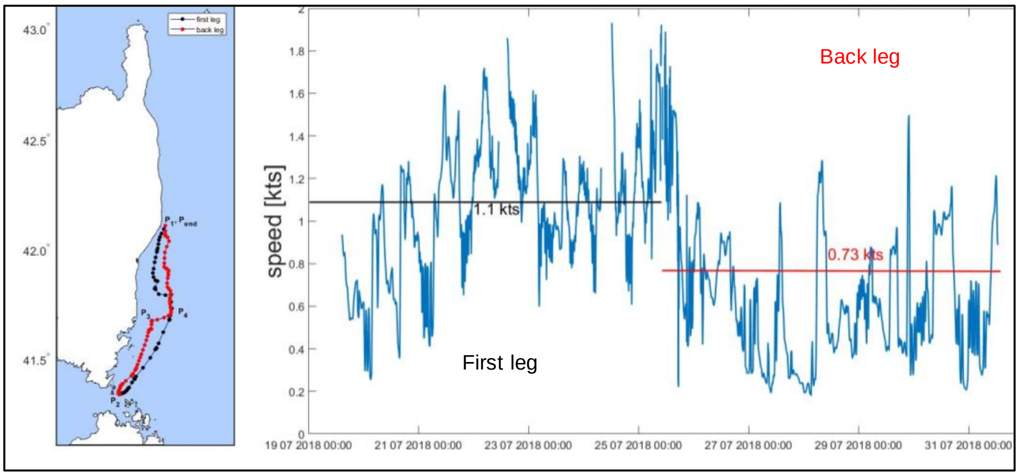


Figure 3 – The route of the wave glider and the average WG speed, during the first leg and the return leg, are shown.

3. Mitigation Action and Synthetic Data Acquisition

In response to the delays affecting the planned ASV-based campaign, a mitigation strategy was implemented to ensure the continuity of the data collected by the Wave Glider SV3 during a stream required by the AIMS project–particularly for the training of AI models tasked with wave period inference. This strategy involved the generation of a synthetic dataset reproducing the type, resolution, and spatial distribution of data that would have been acquired by a real mission.

3.1 Objective and Rationale

The AIMS project wants to compare different in-situ experimental campaign in their ability to provide enough information to train the AI algorithms; in doing so, buoys and ASV are compared in terms of duration to reach a given performance of the training. Therefore, the absence of real ASV data would have limited the project's progress; on the other hand, a synthetic equivalent can ensure meaningful conclusions as well as the correct progression of other work packages. The synthetic data serve to:

- Simulate a realistic glider mission in terms of coverage, resolution, and data typology;
- Provide initial input for model training, tuning, and validation tasks;
- Enable consistency checks with satellite and moored buoy observations already available.

3.2 Methodology

Synthetic data were generated using outputs from the **WaveWatch III (WW3)** regional wave model, operated by CNR and LaMMA. The methodology followed these steps:

Definition of virtual trajectories: PoliTO and CNR collaboratively designed plausible glider paths across the Northern Tyrrhenian Sea, including:

- Coastal-to-offshore gradients
- Cross-shelf transects
- Satellite track overlaps
- Satellite track crossing
- Random-walk

Model extraction: WW3 outputs (Hs, Tp, Dp, spectral energy density) were extracted at 1-hour intervals along the virtual tracks.

Data formatting: The resulting time series were converted into CSV/NetCDF formats consistent with the actual Wave Glider data structure, including:

- Time (UTC)
- Latitude/Longitude
- Winds (m/s)
- Hs (m), Tp (s), Dp (°)
- wave spectral bins

While not equivalent to in-situ measurements, the synthetic dataset provides an essential early input to AI and model assimilation tasks. Limitations may include the absence of measurement uncertainty, lack of true sensor noise and trajectory-induced variability, and dependence of such dataset on model accuracy and resolution.

Nonetheless, the dataset will be released as part of this deliverable and documented accordingly for traceability and reproducibility.

3.3 Example of Synthetic Dataset Construction

A practical example of the synthetic dataset generation process is provided below.

Attached to this report is a map showing the planned Wave Glider trajectory (Figure 4), superimposed onto the moored buoy grid discussed in Deliverable D1.3, where buoys are spaced approximately one nautical mile apart. The trajectory is designed such that the Wave Glider, moving at an average speed slightly above one knot, reaches the vicinity of a different buoy every hour—the default time resolution for directional wave spectra sampling.

Following this route, the glider sequentially "visits" each buoy according to the following sampling sequence:

- Timestep 1 → BB1
- Timestep 2 → BB2
- Timestep 3 → BB3
- Timestep 4 → BB6
- Timestep 5 → BB5
- Timestep 6 → BB4
- Timestep 7 → BB7
- Timestep 8 → BB8
- Timestep 9 → BB9
- Timestep 10 → BB6
- Timestep 11 → BB5
- Timestep 12 → BB4

After 12 hours, the cycle restarts from BB1. This creates a periodic sequence where each synthetic spectrum is associated with a logical "glider position" at a given timestamp, corresponding to a buoy location.

Using this methodology, continuous synthetic time series were constructed over periods of five full days, selecting the corresponding wave spectrum for each hour according to the defined sequence. An extract of the resulting synthetic spectra is attached for reference. This synthetic mission setup can be replicated in other areas and repeated for an arbitrary number of cycles, providing a flexible framework for generating training datasets for AI model development and for preliminary model-data validation tests.

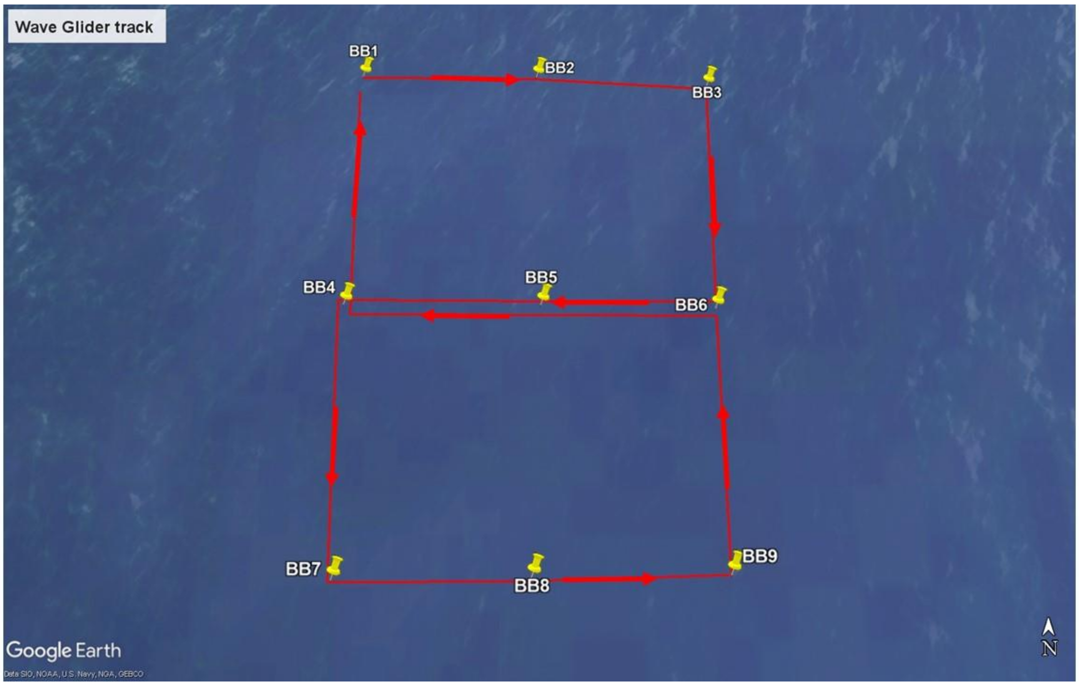


Figure 4 – Wave Glider virtual tracks for synthetic data acquisition

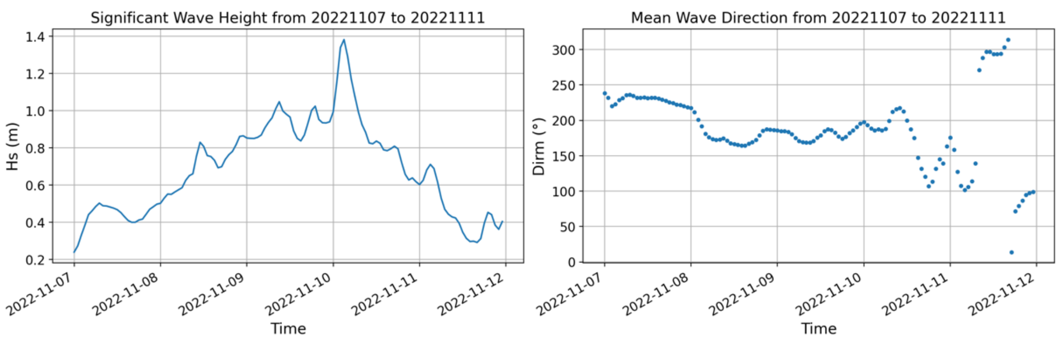
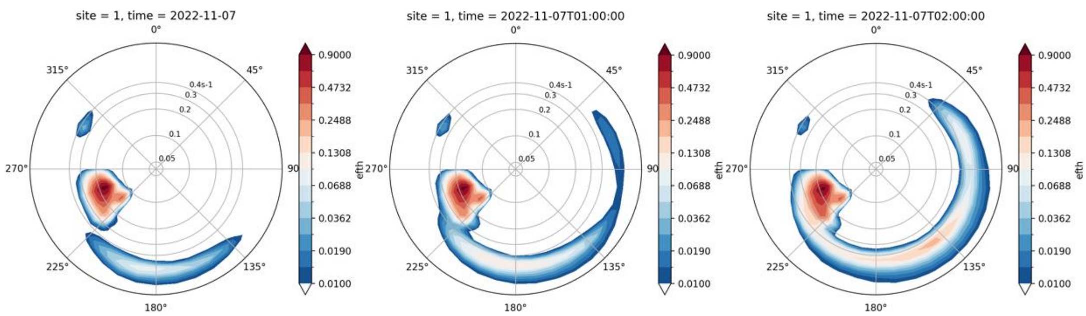


Figure 5 – Examples of Hs and Tp recorded along the specified WG virtual tracks



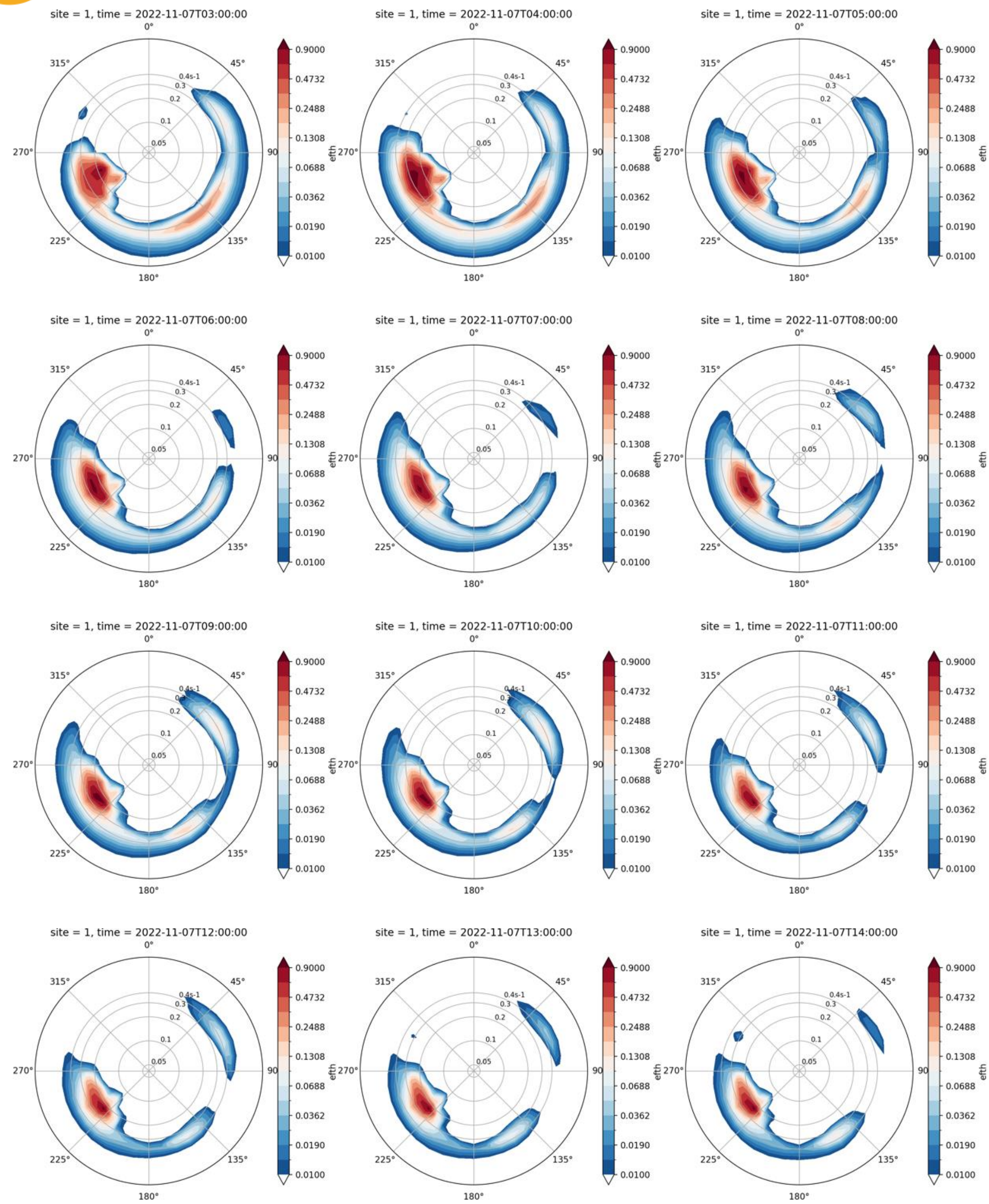


Figure 6 – Examples of wave spectra recorded along the specified WG virtual tracks

4. Next WG Campaigns: Mission Plan

With administrative and technical conditions now converging toward operability, the Wave Glider SV3 experimental campaign is entering its planning phase. This section outlines the mission plan for the upcoming deployments, detailing the scientific rationale, targeted regions, logistical framework, and expected data products.

4.1 Scientific Objectives

The forthcoming missions are designed to address key goals of the AIMS project, including:

- High-resolution spatial validation of satellite-derived wave parameters (especially wave period and direction)
- Provision of high-quality datasets for training and testing AI algorithms
- Support to numerical wave model tuning

These objectives require mission routes that intersect satellite tracks and sample diverse environmental regimes.

4.2 Target Area and Trajectories

The missions will be conducted in the Northern Tyrrhenian Sea, focusing on areas characterized by coastal-to-offshore transitions, and quite relevant for validation of Copernicus satellite products and WW3/SWAN model outputs.

The proximity to the Tuscany coastline and its major ports will facilitate the WG deployment and recovery operations.

Planned trajectories will be included as an annex to this document. Routes will be refined based on final software availability, weather forecasts, and maritime traffic regulations.

4.3 Operational Setup

- Mission duration: up to 14 days per deployment
- Data acquisition: continuous sampling of wave spectra, and integral wave parameters
- Transmission: periodic telemetry via Iridium; raw data stored onboard
- Monitoring: remote control via WGMS platform; daily status checks

A dedicated coordination unit (CNR-LaMMA) will oversee operations, supported by PoliTO for adaptive mission refinement if needed.

Upon completion, data from each campaign will be quality-controlled and archived in standardized formats (NetCDF, CSV); integrated with other AIMS data streams (buoys, satellite) and finally used for comparative model validation and AI algorithm training.

A full report will detail the campaign outcomes, sensor diagnostics, data performance, and integration results.

5. Future steps

The upcoming Wave Glider SV3 missions will represent a significant step forward in the implementation of the AIMS project's in-situ data acquisition strategy. To ensure that the collected data can be effectively used within the project's scientific and technological framework, a number of follow-up actions are foreseen.

Following the completion of the campaigns, all datasets will be subjected to quality control and validation procedures. Data will be archived in standardized formats (NetCDF, CSV) and made available through the project's data infrastructure. In addition, metadata, mission logs, and sensor diagnostics will be fully documented to support reusability and transparency.

Coordination among CNR, PoliTO, and Roma Tre will ensure that the data products meet the needs of both AI and modeling teams.

To facilitate current and future activities involving shared assets, the following actions are planned:

- Finalization of the inter-institutional agreement between CNR and Consorzio LaMMA
- Definition of common operational protocols for ASV deployments
- Development of internal training programs and documentation to support continuity

Acknowledgments

The authors wish to thank the technical and administrative staff of Consorzio LaMMA for their support during the preparation of the experimental campaign and synthetic dataset. Special thanks are extended to the teams involved in sensor integration, mission planning, and licensing management.

We also acknowledge the contribution of Politecnico di Torino in defining the synthetic glider trajectories and supporting the methodological development of the mitigation strategy.

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References

[1] Brandini C., Costanza L., Dorinzo B., Fattorini M., Lapucci C., Taddei S., Sympa ESA IAP ARTES 20 Demonstration Project, ESA Contract N.: 4000115881/15/UK/ND, SYMPA Traffic Light Service Validation report, 28 January 2018, Doc-Id: REP-WGLIDER ver: 3.3

[2] Grare, L., Edson, J. B., & McGillis, W. R. (2021). Instrumented Wave Gliders for Air-Sea Interaction and Upper Ocean Measurements. Frontiers in Marine Science, 8, 664728. https://doi.org/10.3389/fmars.2021.664728

[3] Liquid Robotics. (2017). *SV3 Wave Glider Base Specifications*. Liquid Robotics, a Boeing Company. [Disponibile su richiesta dal produttore o rivenditori autorizzati].

[4] Manley, J. E., & Willcox, S. (2010). The Wave Glider: A persistent platform for ocean science. *OCEANS 2010 IEEE - Sydney*, 1-5. https://doi.org/10.1109/OCEANSSYD.2010.5603536