



**Final report on equipment
successfully installed on the RV
Falkor, including preliminary
assessment of measured seawater
properties and automatic systems RV
Gaia Blu (ex Falkor)**



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1. INTRODUCTION

The purpose of this deliverable is to provide an update on the acquisition, installation, and initial integration of oceanographic instrumentation and automated systems aboard the RV *Gaia Blu* (formerly RV *Falkor*). This document outlines the current status of the equipment procured, the progress made in onboard installations, and initial results related to data transmission, real-time data flow, and system interfacing.

Deliverable D5.9, submitted earlier in the project, detailed the instrumentation roadmap for the RV *Gaia Blu*, describing both the strategic vision and the technical planning underpinning the transformation of the vessel into a flexible, modular platform for multidisciplinary research. D5.9 also provided an initial list of instruments selected for acquisition, as well as early installations completed during the ship's transition phase.

Since D5.9, significant advancements have been achieved:

- Most of the planned instrumentation has been successfully acquired.
- Several systems, including the FerryBox and salinometer, have been installed and tested.
- Real-time data transmission and logging functions have been implemented and verified for selected systems.
- A first version of the RV *Gaia Blu* virtual tour and online access platform has been developed.
- Preparatory work for the integration of additional equipment—such as the Remotely Operated Vehicle (ROV), which has not yet been delivered—has been carried out.

This deliverable summarises the progress to date, highlights key milestones, and reflects on lessons learned during the acquisition and integration phases. While no scientific data assessment is presented at this stage, the document focuses on the operational status of equipment and infrastructure, as well as on technical readiness for future deployment during scientific cruises.

2. OVERVIEW OF EQUIPMENT ACQUIRED AND INSTALLED

The outfitting of RV *Gaia Blu* with new scientific instrumentation and support systems has progressed substantially since Deliverable D5.9. This section provides an overview of the current status of equipment acquisition and installation, structured by equipment type and lot.

Most of the instrumentation originally planned has now been acquired. A significant portion has also been installed and tested aboard the vessel. Specific systems, such as the FerryBox and salinometer, have undergone functional testing and initial verification. Others, including the ROV, are still awaiting delivery but the necessary supporting infrastructure is already in place or under preparation. In parallel, key support systems such as onboard computing, data servers, and storage solutions have been integrated to ensure smooth and secure acquisition and management of data streams.

A schematic diagram of the ship's main laboratory and operational areas, with marked locations for instrument installation, is included in the Annex.

The table below summarizes the status of all instruments and systems included in the equipment plan:

Lot	Description	Status
Lot 1	Automatic Data Acquisition System (Ferrybox)	Acquired, installed, and tested
Lot 2	Spectral Absorption and attenuation Sensor and optical backscatter	Acquired, partial installation, to be completed during ITINERIS-EYES cruise in July 2025
Lot 3	Hyperspectral Radiometers	Acquired, installed in May 2025 and under testing
Lot 4	Remotely Operated Vehicle (ROV)	Acquired, with delivery expected by September 20th
Lot 5	Semi-portable Salinometer	Acquired, installed, successfully tested
Lot 6	LIDAR	Acquired, under installation to be completed during ITINERIS-EYES cruise in July 2025

Table 1: Status of all instruments and systems included in the equipment plan

The following subsections describe the status of acquisition and installation by equipment type.

2.1. Underway and automatic acquisition systems

Lot 1: The FerryBox is an autonomous acquisition system designed to continuously measure sea surface parameters during navigation, using seawater drawn from the ship’s intake. These measurements are integrated with navigational data and inlet temperature into a single data file with a 1-minute resolution. This configuration allows for real-time visualization and monitoring of all parameters.

The FerryBox installed on the *Gaia Blu* is equipped with a suite of sensors dedicated to characterizing surface water properties, with a particular focus on carbonate system parameters. The complete list of sensors is provided in Table 2. While most sensors collect data continuously, the HydroFIA-pH and HydroFIA-TA analyzers perform automated spectrophotometric measurements on discrete samples.

Currently, the Wetlabs ECO-Triplet sensor in use is on loan from the spare instrumentation stock at CNR-ISMAR Trieste. The dedicated unit, purchased under Lot 2, will be permanently installed and tested during the ITINERIS-Eyes cruise in July 2025. The HydroFIA-TA analyzer was acquired using funds allocated for shipboard equipment and was integrated into the FerryBox system as part of the overall procurement.

The FerryBox has been fully installed and integrated into the ship’s seawater intake line. An initial test was conducted during a dedicated one-day cruise in the Gulf of Naples on April 10, 2025. Its autonomous operating capabilities—excluding the two colorimetric instruments (pH and total alkalinity)—were further tested and improved during the SPIN-Gela2025 cruise (April 16–28, 2025, Ionian Sea), which helped optimize the coordination between water flow regulation and the FerryBox’s automatic control system, resolving several minor issues.

During the EMSO-SA-2025 cruise (May 17–26, 2025), all three carbonate system parameters (pCO₂, pH, and total alkalinity) were successfully measured continuously during navigation from the Tyrrhenian Sea to the Northern Adriatic. This campaign emphasized the need for dedicated calibration of the total alkalinity analyzer to further enhance data quality. Preliminary results are shown in Figure 1.

Since its installation, the FerryBox has consistently collected data during research cruises and during long-distance transits without scientific personnel onboard, demonstrating strong autonomous performance. During the upcoming ITINERIS' EYES cruise in July 2025, the system is expected to be fully operational, acquiring continuous measurements of all three carbonate system parameters while underway.



Figure 1. FerryBox system being installed in the science equipment room of R/V Gaia Blu.



Figure 2. View of the FerryBox control panel with real-time display of the acquired parameters.

Parameter	Instrument	Acquisition frequency
SW Temperature	SBE 45 Micro TSG	continuous
SW Salinity		
Inlet SW temperature	SBE 38 (from ship's remote sensor)	continuous
Dissolved oxygen (DO)	Optode 4835 Aanderaa	continuous
CO2 partial pressure (pCO2)	Contros HydroC CO2 FT	continuous
pH on "total scale" (colorimetric)	Contros HydroFIA pH	9 min
Total alkalinity (TA)	Contros HydroFIA TA	9 min
Chlorophyll	Wetlab ECO-Triplet	continuous
Chromophoric dissolved organic matter (f-DOM)		
Turbidity		

Table 2. Overview of instruments, parameters measured, and acquisition frequency in the automated underway system.

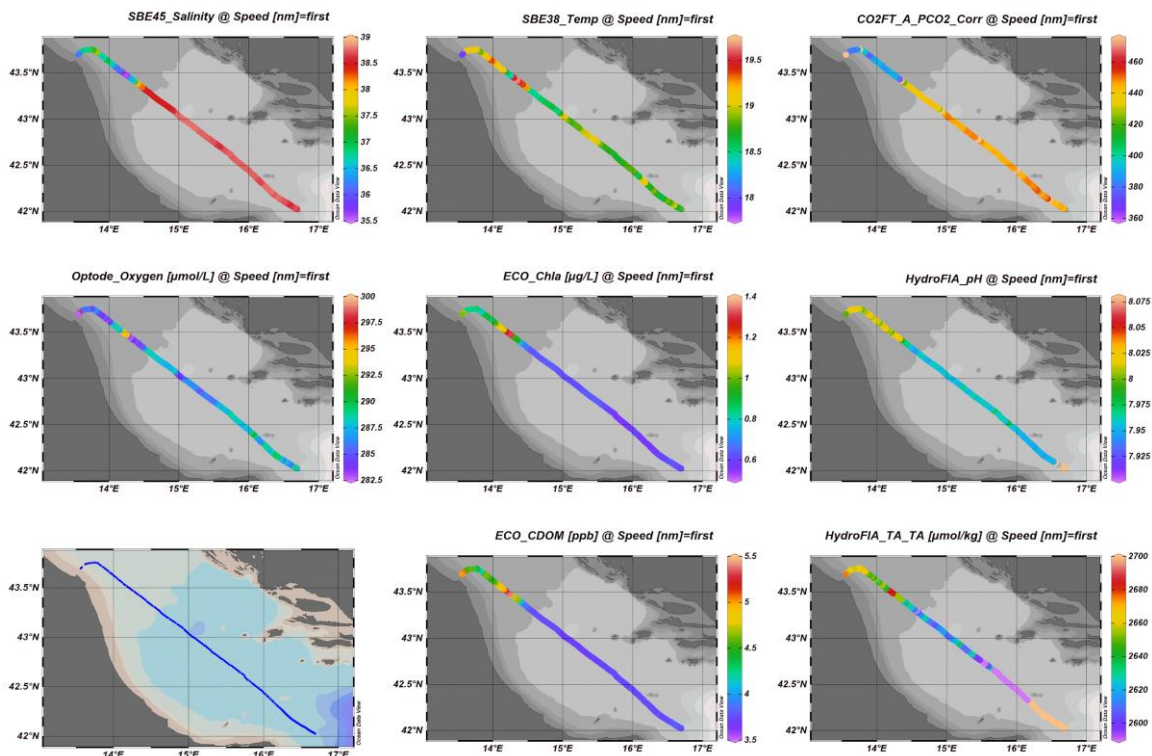


Figure 3. Preliminary results from the EMSO-SA-2025 cruise showing the main surface parameters measured by the FerryBox system during navigation: salinity, temperature, CO₂ partial pressure (pCO₂), dissolved oxygen, chlorophyll, pH_t (total scale), fDOM, and total alkalinity (TA).

Lot 2: The underway system for the acquisition of inherent optical properties (IOPs) includes two optical instruments: i) a spectrophotometer (AC-s), which measures spectral absorption and attenuation of light in seawater across approximately 80 wavelengths in the visible spectrum (400–700 nm); and ii) the ECO-Triplet, which measures light backscattering as well as fluorescence from phytoplankton chlorophyll (Chl) and fluorescent dissolved organic matter (fDOM).

Both instruments are scheduled for installation during the ITINERIS' EYES cruise in July 2025.

The system is designed to operate in a manner similar to that described in Volpe et al. (2021)¹. Briefly, seawater is drawn from the ship's intake in the Science Store and first passes through a dedicated debubbler, which removes air bubbles that could compromise the accuracy of the optical measurements. The flow then passes through an electronically controlled valve, which can direct the water either straight to the instruments or through a filtration system, allowing for the measurement of both total and dissolved optical components.

The acquisition system is configured to autonomously collect surface seawater optical parameters during navigation. These data are integrated with navigational information, seawater inlet temperature, and thermosalinograph measurements into a single file at a 1-minute resolution. This setup allows for real-time visualization and monitoring of all parameters.

Lot 3: The underway system for above-water radiometric measurements is the So-Rad system, developed by the Plymouth Marine Laboratory (PML) within the H2020 MONOCLE project. So-Rad is a low-power, low-cost, autonomous system designed to acquire high-frequency water-leaving reflectance data from non-stationary platforms such as ships and buoys. It achieves this by optimizing the measurement geometry of three commercially available TriOS RAMSES sensors. The So-Rad system was successfully installed and tested aboard R/V *Gaia Blu* on 13 May 2025. It is mounted on the Observation Deck (Deck 6), where the geometry is well suited for high-precision above-water radiometric measurements. The installation process included mounting the control box and motor, and establishing a connection to the vessel's network to enable broadband data transmission.

At user-defined intervals, the So-Rad system performs a series of automated checks to assess whether environmental conditions are suitable for reflectance measurements. These include the quality of positioning data, solar geometry, platform motion, and desired measurement frequency. If all criteria are met, the system calculates any necessary motor adjustments to achieve the optimal viewing angle. To save power, minor adjustments can be skipped according to user preferences. Once aligned, the connected spectroradiometers are triggered and their data are collected.

All operations are logged in plain-text files, and both sensor data and metadata are stored locally and uploaded to the PML server when broadband connectivity is available.

The results of the functional test conducted during installation, along with data acquired during the first month at sea, confirm that the system is fully operational and ready for use in upcoming cruises, with no further calibration or configuration required.

¹ Volpe, G; Dionisi, D; Brando, VE; Colella, S; Pitarch, JaJime; Ciampichetti, S; Ferrara, N; Liberti, GL; Single dual mode (continuous and cast) instrumentation package for inherent optical property measurements: Characterization of the bucket for backscattering observation. *Limnology and Oceanography: Methods*, 19, 8, 510-522, 2021, John Wiley & Sons, Inc. Hoboken, USA



Figure 4. So-Rad system installed on the Observation Deck of R/V Gaia Blu, showing sensor positioning for radiometric measurements.

Lot 6: The Raymetrics Raman Depolarization Fluorescence LIDAR is an innovative atmospheric–marine system designed to perform both atmospheric and ocean surface measurements. It supports the investigation of marine aerosols and physical-chemical processes at the air–sea interface.



Figure 5. Overview of the Raymetrics Raman Depolarization Fluorescence LIDAR system.

Figure 5 shows the main components of the system:

- Lidar head: houses the laser transmitter and receiver within a climate-controlled enclosure;

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- Motorized positioner: enables rotation of the lidar head in both azimuth and zenith directions;
- Control unit: a climate-controlled housing that contains a custom-built industrial computer (Windows 10), Licel acquisition electronics, an uninterruptible power supply (UPS), and the power distribution unit.

The control unit serves as the primary data storage and communication interface.

2.2. Deep-sea and benthic systems

Lot 4: The ROV AEGIR 250—modified to operate at depths of up to 3000 meters—is currently being assembled at the Ocean Robotics laboratories in Sweden. Most of its components, including DC thrusters, electronic systems, 3D orientation sensors, lights, and cameras, have already been installed. The Tether Management System (TMS), heavy-duty winch, and umbilical are also ready. Delivery of the complete system is expected by September 20th 2025.

The supporting infrastructure for the heavy winch—comprising the grillage and sea-fastening elements—is currently being prepared on the cargo deck of R/V *Gaia Blu* and is scheduled for completion by September 24th 2025.

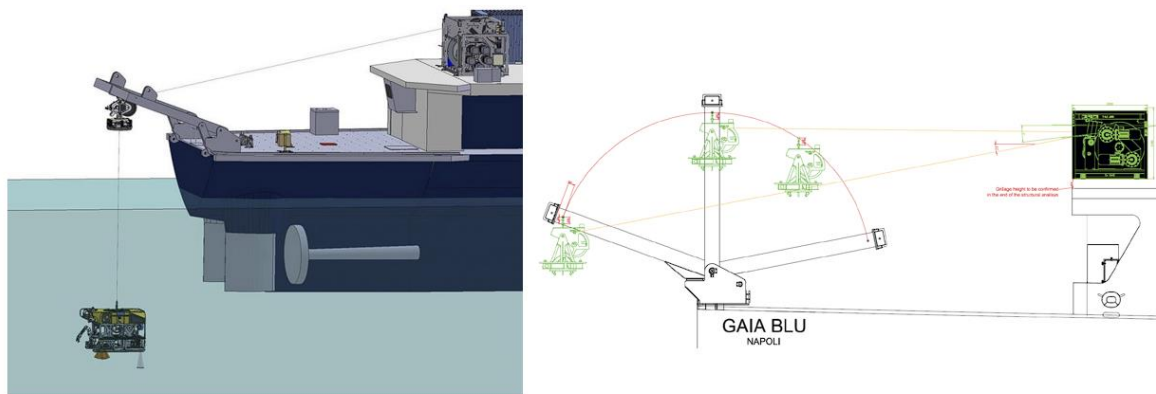


Figure 6. Setup of the heavy-duty winch on the cargo deck of R/V *Gaia Blu*. The ROV will be deployed from the A-frame located at the stern of the vessel.

2.3. Discrete water sampling and analytical instrument

Lot 5: The Guildline Autosal 8400B salinometer was successfully installed and tested onboard RV *Gaia Blu* on 26 May 2025. The instrument is located in the science store, where environmental conditions (temperature, ventilation, vibration) are suitable for high-precision salinity measurements. The setup process included connecting the instrument to the acquisition computer via USB/serial interface, filling the internal tank with MilliQ water, and setting the internal bath temperature to 18 °C. After an initial stabilization period, the instrument was calibrated using IAPSO standard seawater (Batch 169, certified salinity 34.993 PSU, K15 = 0.99983).

Test results demonstrated high stability and reproducibility of measurements: (i) internal temperature remained constant throughout the operation period; (ii) the fluidic circuit functioned correctly with no air bubbles or irregularities; (iii) measured salinity values deviated less than ± 0.002 PSU from certified reference values, well within the manufacturer's specifications; (iv) the dedicated software interface performed reliably, allowing seamless data acquisition and storage.

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The outcome of the functional test confirmed the instrument's readiness for use during upcoming cruises, with no additional calibration or configuration steps required.



Figure 7. Installation of the salinometer in the Science Store on deck 1 of the R/V Gaia Blu.

2.4. Support systems for data acquisition

The effectiveness and resilience of the shipboard data acquisition systems rely not only on scientific instrumentation but also on robust support infrastructure. Over the past months, several upgrades have been implemented to enhance the computing environment, ensure secure data storage, and guarantee operational continuity.

Computing and onboard servers

A dedicated data acquisition server has been installed in the main science control room, designed to collect, store, and manage real-time streams from various automated and underway sensors. The server is equipped with redundant storage drives and high-throughput network interfaces, ensuring seamless integration of all data streams from multiple acquisition units. All scientific systems have been connected to a centralized ship network through structured cabling and secure switches, allowing for data access from different laboratory spaces, including the dry lab and science office. In addition, scientific workstations have been installed and configured with appropriate software environments for instrument control and configuration, preliminary data visualization and QA/QC, remote access and data synchronization with shore-based repositories.

Data backup and storage

The onboard data center has been installed in the ship's server room (Room 322) and includes the following components:

- Tape Library Management System

- DTS Tape Library
- Computing System (configured for cloud/VMware virtualization)
- Archive Storage (SAN & NAS)

The presence of four virtualization/processing systems allows users to create virtual machines for customized data management from various instruments. These virtual environments support tasks such as metadata generation and automated transmission to the shore-based data center.

The system also includes high-capacity storage tapes, where all data collected during oceanographic expeditions are automatically recorded and backed up. This setup ensures the long-term preservation of onboard observational data and provides redundancy in case of hardware failure. Once the vessel is docked, used tapes can be replaced, and the full ones offloaded and transferred to the land-based data center for permanent archiving, allowing the tapes to be reused on subsequent cruises.

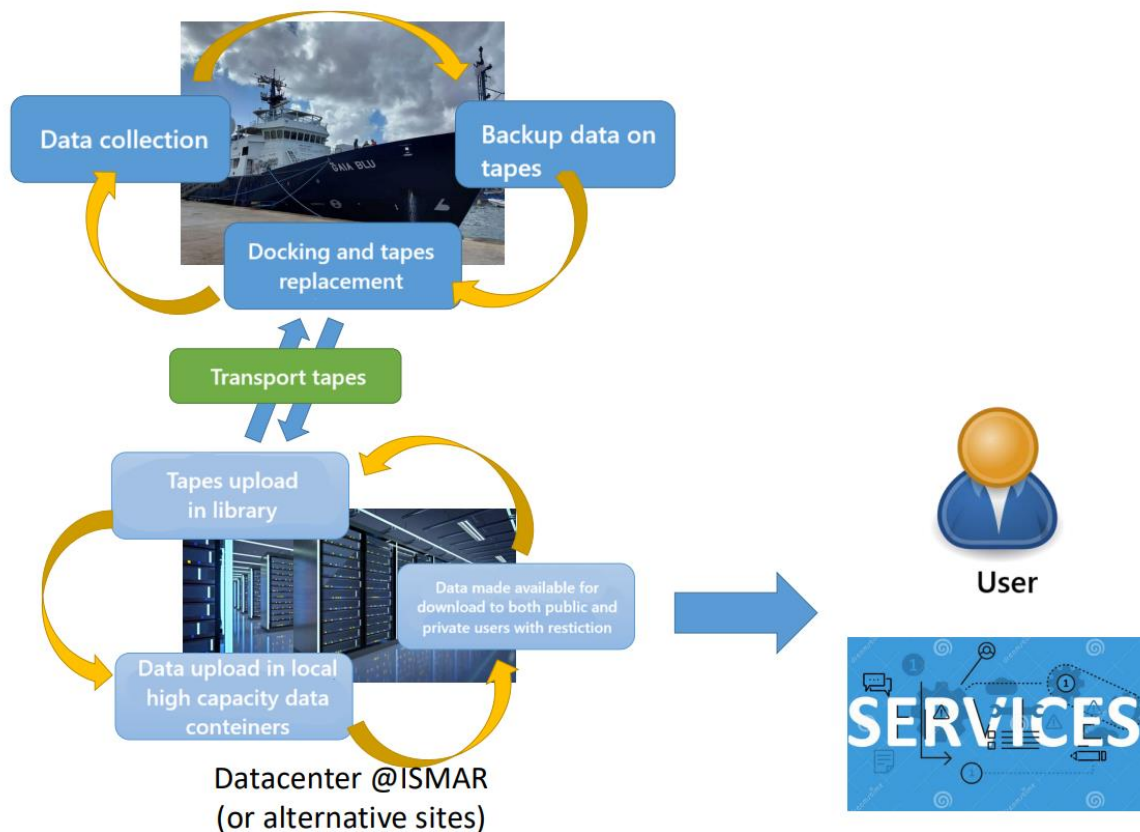


Figure 8. Workflow for data recovery and online availability for user download.

3. DATA TRANSMISSION AND REAL-TIME FLOW

3.1. Integration of real-time data systems

The integration of real-time data systems is a key objective of Task 5.16.4 and is planned for all onboard instruments installed on the RV *Gaia Blu*. This initiative aims to ensure that environmental data collected during navigation is automatically acquired, processed, and transmitted to onshore data centers with minimal human intervention.

3.2. Testing data transmission: FerryBox

The FerryBox system is currently the only instrument for which the full data transmission workflow has been fully developed, implemented, and tested. As such, it serves as a pilot platform to validate the technical feasibility and robustness of the proposed architecture. The successful outcomes achieved with the FerryBox will inform the extension of this workflow to the rest of the instrumentation suite in future phases of the project.

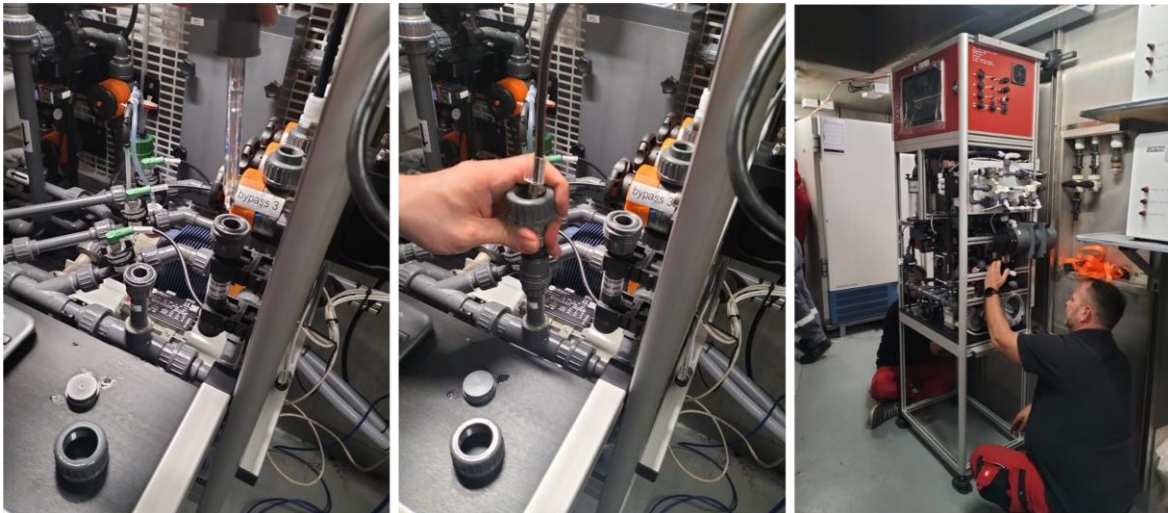


Figure 9. Physical installation of the FerryBox system in the Science Store on Deck 1 of R/V Gaia Blu. The image shows the main housing and sensor units securely mounted onboard, connected to the seawater intake, freshwater line, and the ship's internal power and communication systems.

Interface with the Marine Data Store

A forward-looking component of Phase 5.16.4 is the planned integration with the Marine Data Store, the central repository for all underway data collected within the ITINERIS framework.

Although full integration is still in progress, preliminary steps have addressed the following aspects:

- Data format compliance, ensuring compatibility with established metadata and data structure standards;
- Metadata harmonization, currently using JSON and CSV formats, with future transition to NetCDF to enable ingestion by ERDDAP services;

Test uploads to a temporary environment hosted by CNR-ISMAR, which currently acts as a placeholder for the final repository.

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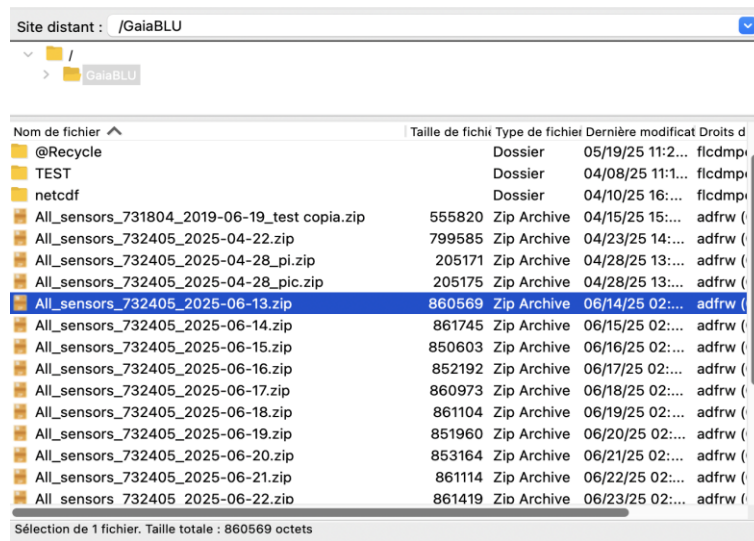


Figure 10. Visual confirmation of successful FTP transmission from the onboard Virtual Machine to the shore-based test server. The FileZilla interface displays the presence of a .zip archive containing FerryBox data and metadata, confirming the proper operation of the automated transfer process.

Data transmission plan

The current data transmission system has been fully automated and extensively tested on the FerryBox.

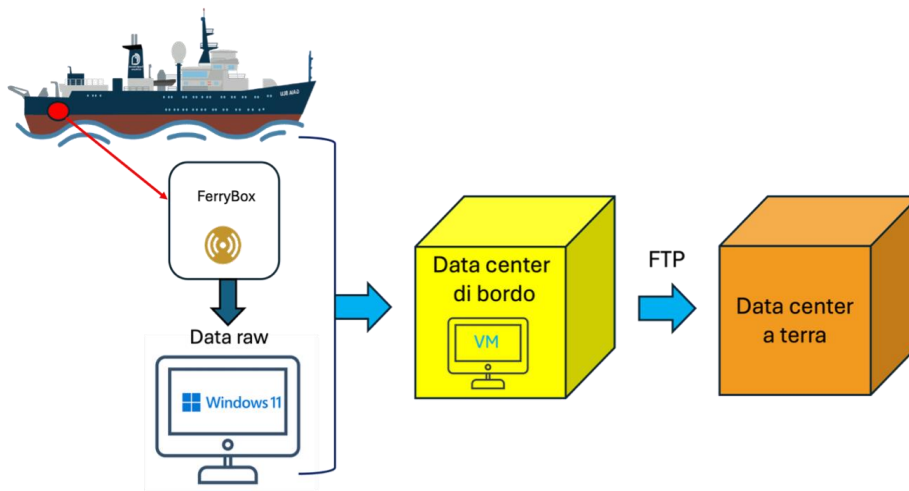


Figure 11. Schematic representation of the automated data transmission workflow implemented for the FerryBox system on R/V Gaia Blu. The diagram outlines the key components of the process—from data acquisition and file sharing over the ship's local network, to metadata processing on the Virtual Machine, file packaging, and final FTP transmission via satellite link to the shore-based test server. Redundancy mechanisms, error logging, and structured directories (e.g., raw/, to_send/, sent/, log/) ensure operational robustness and traceability.

The system architecture includes the following components:

Acquisition: The FerryBox acquires measurements at 1-minute intervals and generates a daily .txt file at 00:00 UTC.

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Local network sharing: Within the shipboard Windows 11 environment, a shortcut ensures that the daily .txt file is copied to a shared folder accessible by the onboard Virtual Machine (VM).

Data processing: The VM runs a suite of Python scripts that:

- Extract dynamic metadata from the .txt file,
- Merge it with static metadata from a local .csv file,
- Generate a .json metadata file and a .csv data file,
- Package the outputs into a compressed .zip archive.

Transmission: The .zip archive is transmitted hourly via FTP (port 21) over the Starlink satellite connection to a remote server.

Testing and validation procedures

The entire data transmission pipeline has been rigorously tested and validated through:

- Unit testing of the Python scripts for parsing and packaging,
- End-to-end system integration testing,
- Stress testing simulating interrupted writes and detection of duplicate files,
- Visual verification of transmitted packages using FileZilla.

```

83 # == FUNZIONE PRINCIPALE ==
84 def process_new_files():
85     log_entries = []
86     now_utc = datetime.now(timezone.utc).strftime("%Y-%m-%d %H:%M:%S UTC")
87
88     processed_files = {f.name for f in sent_dir.glob("*.txt")}
89     new_txt_files = sorted([f for f in shared_dir.glob("*.txt") if f.name not in processed_files], key=
90
91     if not new_txt_files:
92         print("🚫 Nessun nuovo file da elaborare.")
93         return
94
95     # Prendi solo l'ultimo file .txt
96     txt_path = new_txt_files[-1]
97     try:
98         txt_name = txt_path.stem # nome base senza estensione
99         print(f"📄 Elaborazione file: {txt_path.name}")
100
101     # == COPIA FILE IN RAM ==
102     local_txt_path = raw_dir / txt_path.name
103     shutil.copy(txt_path, local_txt_path)
104
105     # == ESTRAZIONE METADATI DINAMICI ==
106     with local_txt_path.open("r", encoding="utf-8", errors="ignore") as f:
107         lines = f.readlines()
108
109     dynamic_metadata = {}
110     data_section = []
111     in_data_section = False
112
113     for line in lines:
114         line = line.strip()
115         if line.startswith("$DATASETS"):
116             in_data_section = True
117             continue
118         if not in_data_section:
119             if line.startswith("$") and ":" in line:
120                 key, value = line[1:].split(":", 1)
121                 dynamic_metadata[key.strip()] = value.strip()
122         else:
123             if line:
124                 data_section.append(line)
125
126     print(f"Metadati dinamici trovati: {dynamic_metadata}")
127     print(f"Righe dati trovate: {len(data_section)}")
128
129     # == METADATI STATICI ==
130     static_metadata = {}
131     if static_metadata_file.exists():
132         df_static = pd.read_csv(static_metadata_file, sep=";", encoding="cp1252", usecols=["Attribut
133         static_metadata = dict(zip(df_static["Attribute name"], df_static["Example"]))
134

```

Figure 12. Excerpt from the Python script developed to automate the processing of .txt files generated by the FerryBox system. The script manages metadata extraction, data formatting, and the preparation of compressed .zip archives for transmission.

Key outcomes

- Reliable detection and selection of completed .txt files (excluding files still being written),
- Generation of clean, well-structured .json and .csv outputs,
- Verified hourly FTP transfers,
- Complete operational traceability confirmed through logging.

Future developments

Planned extensions of this system include (see Section 5, applicable in principle to all onboard instruments):

- Adoption of NetCDF as the standard format for long-term archival and data publication,
- Full integration with the Marine Data Store and distribution via ERDDAP,
- Replication of the validated FerryBox workflow across other onboard systems.

These developments will strengthen ITINERIS's capacity to deliver real-time, high-quality marine data to the scientific community and relevant stakeholders.

3.3. Testing data transmission: spectral attenuation, absorption and scattering sensors

A similar underway system for measuring inherent optical properties (IOPs) has already been deployed on board *Gaia Blu* during several past cruises. Consequently, the complete data acquisition workflow has been developed, implemented, and tested on a Virtual Machine running Windows 11, equipped with the necessary software tools for data acquisition.

The two instruments will be interfaced using Lanmux software from Communication Technology (for the ECO-Triplet) and Compass v2.0 (for the AC-s spectrophotometer). In addition to acquiring data from the ECO-Triplet, Lanmux manages navigation data—directly obtained from the ship's navigation system—and thermosalinograph data, merging them into a single unified data record.

Moreover, Lanmux allows remote operation of the electronically controlled valve to divert seawater flow through the filtration system.

All near-real-time IOP data will be saved on the onboard server and processed daily for quality control. These data will then be merged into single files organized within defined time frames. The exact duration of these time frames is still under evaluation, taking into account protocols from other continuous data streams to ensure consistent integration.

Interface with the Marine Data Store

As mentioned, the continuous IOP system will operate on a Virtual Machine installed on the local server, which is expected to be operationally connected via a live link to the ERDDAP system. Although full integration is still under development, preliminary efforts have focused on:

- Ensuring data format compliance for compatibility with metadata and structural standards;

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- Harmonizing metadata using JSON and CSV formats, with plans to transition to NetCDF for seamless ERDDAP ingestion.

Data transmission plan

IOP data transmission is scheduled to occur daily, allowing for prior validation and testing.

Testing and validation procedures

Acquired data will be quality-controlled daily and converted into a human-readable format. The exact level of processing required for transmission is still under evaluation; it is likely that both raw and processed data will be uploaded to ERDDAP servers to serve diverse user needs.

Future developments

Planned enhancements include:

- Expanding the filtering system beyond the current coarse (5 μm) and fine (0.2 μm) filters to enable measurements of optical properties across a broader particle size distribution, enhancing ecological relevance;
- Integrating the IOP system with the FerryBox's programmable cleaning cycle by automatically switching the IOP intake to the FerryBox outlet during cleaning, thereby reducing manual intervention for maintenance;
- Testing and potentially implementing an automatic start/stop system, similar to that used by the FerryBox, to further minimize human involvement in system operation and maintenance.

3.4 Testing data transmission: hyperspectral radiometers

Interface with the Marine Data Store

The SoRad system is designed to deliver data to processing platforms in near-real time, uploading the data stream directly to Open Geospatial Consortium (OGC)–compliant data services managed by PML. Sensor data, metadata, and logs from the SoRad system are automatically stored in a local database within the control box installed on R/V *Gaia Blu* and are uploaded to the PML server whenever broadband connectivity is available.

Two dashboards provided by PML allow remote monitoring of the sensor's field activity: [SoRad Monocle Dashboard](#) and [SoRad Platform Status Dashboard](#). On these dashboards, the SoRad system installed on R/V *Gaia Blu* can be identified by its code PML_SR015.

A plot of the latest set of hyperspectral reflectance spectra acquired by the system is available at: https://rsg.pml.ac.uk/shared_files/sorad/dashboard-plots/PML_SR015_10_latest.png. See Figure 13 for an example.

Data transmission plan

Raw radiometric data are transmitted continuously throughout the day to the PML servers, where they are calibrated to radiances and processed into individual Level 2 reflectance spectra. This workflow ensures that validation and testing occur prior to data dissemination.

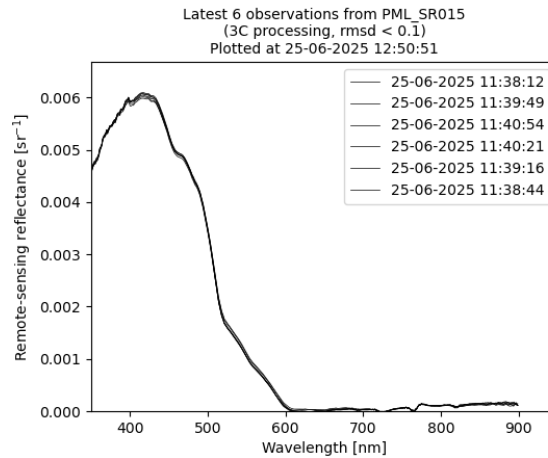


Figure 13. Example of hyperspectral above-water reflectance spectra acquired by the SoRad system onboard R/V Gaia Blu, as downloaded from the PML activity dashboard.

Testing and validation procedures

On a daily basis, the calibrated radiances and reflectance spectra are downloaded from the PML server using the open-source MONDA (MONocle Data Analysis) Python package, which provides tools for retrieving and processing data from the MONOCLE sensor ecosystem. Currently, this task is performed on CNR-ISMAR machines in Rome, where routines for quality control and conversion to NetCDF format are developed for subsequent upload to ERDDAP servers to serve the user community.

An example plot illustrating the output of the radiometric data quality control is shown in Figure 14.

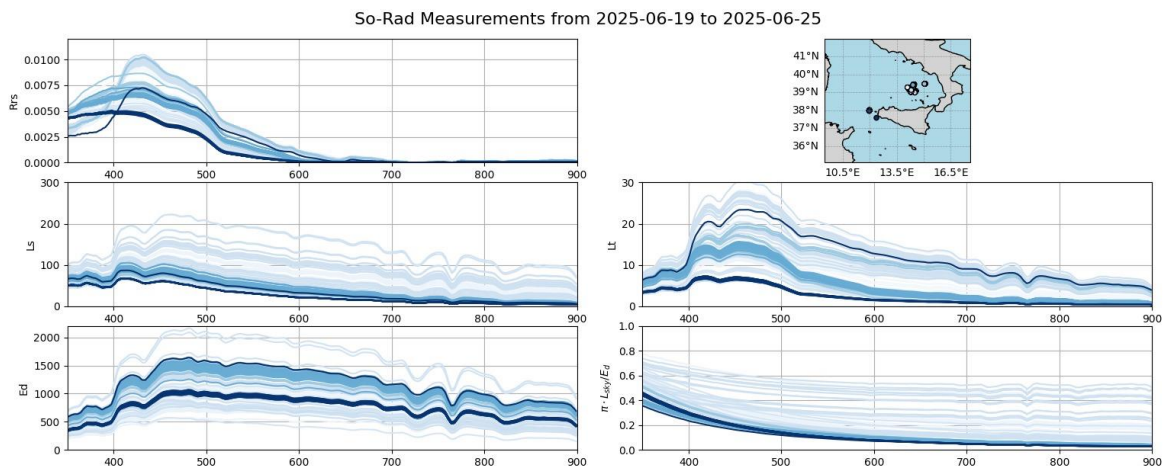


Figure 14. Example of hyperspectral above-water reflectance spectra acquired by the SoRad system onboard R/V Gaia Blu, following quality control procedures currently conducted on CNR-ISMAR machines in Rome.

Future developments

Planned activities include:

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- Conducting a comparison in July 2025 between the above-water reflectance spectra acquired by the SoRad system and those collected by in-water radiometers and profilers during the ITINERIS' EYES campaign;
- Implementing quality control and uncertainty propagation procedures using the HyperCP community processor;
- Automating the download of radiometric data from the PML servers, along with quality control and NetCDF file generation, on the land-based component of the Marine Data Store.

3.5 Testing data transmission: ROV

The ROV is equipped with advanced imaging technology, including both 4K Ultra High Definition and Full HD cameras, enabling detailed observation and documentation of underwater environments. Video data captured by these cameras are transmitted in real time from the ROV to the vessel's control room via a fiber-optic cable integrated within the vehicle's umbilical tether. This high-bandwidth link minimizes latency and ensures responsive, real-time video streaming.

Upon reaching the surface vessel, the signals are converted by fiber-optic media converters into digital video streams compatible with standard monitoring and recording equipment in the control room. Recordings are typically encoded using H.264 or H.265 codecs and saved in MP4 (.mp4) format, which is the standard for ROV video data, ensuring broad compatibility and efficient storage.

In addition, video streams from the 4K camera will be live-broadcast from *Gaia Blu* via satellite connection, enabling real-time public outreach. The live feed will be streamed to a dedicated YouTube channel, allowing remote scientists and the public to watch underwater operations with minimal delay.

An initial transmission test is scheduled for September 2025 in Sweden, focusing on live streaming capabilities. Due to the large file size of the high-resolution recordings, the ROV footage will be stored locally on the onboard data center rather than transmitted in real time. These video files will be downloaded and transferred to shore-based infrastructure at the end of the campaign.

3.6 Testing data transmission: semi-portable salinometer

The Guildline Autosol 8400B semi-portable salinometer, installed in the science store of RV *Gaia Blu*, is not designed for continuous, automated, or remote operation. Instead, it plays a key supporting role in the calibration and quality control of salinity data collected by the ship's underway thermosalinograph and CTD systems.

As such, the salinometer does not participate in real-time data transmission workflows. However, it contributes critically to the reliability and traceability of salinity measurements by allowing precise analysis of discrete water samples against certified reference standards. This ensures that any long-term drift or offset in the shipboard systems can be identified and corrected through the update of calibration coefficients.

Interface with the Marine Data Store

Given the manual nature of the salinometer workflow, data generated from the instrument are not transmitted directly to the ship's data store or shore-side servers. Instead, results from calibration runs are stored locally on a dedicated acquisition PC and subsequently archived by the scientific operator. Calibration coefficients derived from these analyses are periodically updated in the configuration files of the CTD and thermosalinograph acquisition systems. Metadata related to

calibration sessions (e.g., date, batch number of IAPSO standard, temperature setpoint) are logged in the instrument tracking records and can be reported to the Marine Data Store in support of data quality documentation.

Data transmission plan

No automatic data transmission is foreseen for the salinometer, whereby (i) results of each calibration session are reviewed by the operator, (ii) key statistics (e.g., offset from certified standard, repeatability metrics) are summarized in a calibration log, (iii) these logs are manually uploaded to the cruise documentation folder. This approach ensures traceable and controlled updates to the ship's salinity data streams without introducing the risk of uncontrolled automatic corrections.

Testing and validation procedures

The salinometer was successfully tested on board during a dedicated calibration session on 26 May 2025. The installation, conditioning, and measurement protocols followed standard best practices for the Autosal 8400B. Results confirmed the instrument's reliability, with stability better than ± 0.002 PSU and successful standardization using IAPSO-certified seawater. These tests validated the instrument's readiness for use in operational cruises and its suitability as a reference system for shipboard salinity calibrations.

Future developments

While no automation or real-time transmission is planned for the salinometer itself, future developments will focus on: (i) developing a standardized calibration-reporting template linked to the Marine Data Store, (ii) integrating calibration metadata into the cruise QA/QC framework, (iii) evaluating potential software solutions for semi-automated logging and formatting of calibration outputs to streamline documentation.

These enhancements will aim to improve the traceability and accessibility of calibration procedures, ensuring their integration into the broader shipboard data management ecosystem.

3.7 Testing data transmission: LIDAR

Interface with the Marine Data Store

The integrated industrial computer within the LIDAR control unit (described in Section 2.1) is responsible for data storage, measurement scheduling, and remote control. A second computer, the Lidar Workstation, running Linux Ubuntu 22.04, is dedicated to analyzing and displaying LIDAR data, providing near-real-time data products, and archiving older data for filtering and visualization. The workstation periodically checks for new data and automatically processes them. It is also equipped with measurement scheduling software, allowing complex measurement configurations (e.g., day/night cycles, weekly campaigns, continuous 24/7 monitoring).

Data transmission plan

LIDAR data processing involves two main steps:

1. Pre-processing of raw LIDAR signals;

2. Application of LIDAR inversion algorithms to retrieve vertical profiles.

The LIDAR device is fully remotely controllable. Any user within the local network can access the LIDAR computer running Windows 10 via Remote Desktop. Additionally, if the network has internet access, external connections to the LIDAR system can be established through the Linux workstation, which has a valid IP address on the same local area network.

Raw data are converted into NetCDF format and can be automatically uploaded to one or multiple FTP servers.

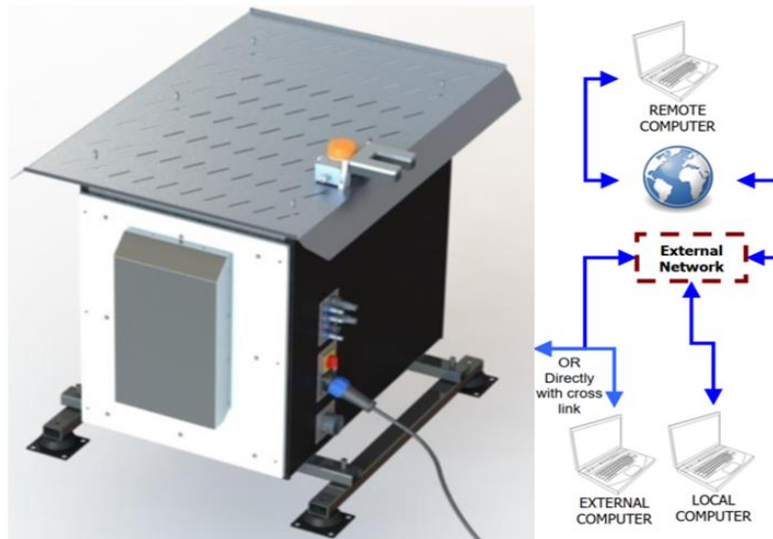


Figure 15. Schematic of the connections between the LIDAR control unit and the local network.

Testing and validation procedures

Site acceptance tests were conducted between May 14 and 16, 2025, with a follow-up visit on May 26 onboard *Gaia Blu*. Quality assurance tests complied with the guidelines set by the pan-European research infrastructure ACTRIS for Aerosol Remote Sensing Observational Platforms.

Final installation of the LIDAR on R/V *Gaia Blu* is scheduled for July 7–8, 2025.

Future developments

The LIDAR system will be configured to automatically transfer raw data from the Windows computer to the Ubuntu workstation at the end of each measurement. This ensures complete datasets are received, analyzed, converted to NetCDF format, and uploaded to FTP servers.

These developments will strengthen ITINERIS's capacity to provide innovative atmospheric–marine LIDAR observations and enhance CNR's capabilities in studying optical properties across marine and atmospheric domains, contributing to the integration and harmonization of national research infrastructures.

4. METADATA MANAGEMENT FOR ERDDAP INGESTION

The ingestion of RV Gaia Blu data streams into the ERDDAP platform requires a rigorous and standardized metadata management pipeline. As ITINERIS aims to ensure FAIR data principles (Findable, Accessible, Interoperable, Reusable), metadata structuring is critical for enabling downstream users to interpret, access, and integrate the datasets with broader marine data infrastructures.

4.1 Metadata and ERDDAP integration workflow

The metadata framework adopted for ERDDAP ingestion is aligned with both the SeaDataNet and Copernicus Marine Environment Monitoring Service (CMEMS) conventions, with progressive adoption of Climate and Forecast (CF) conventions and the ISO 19115 standard. This guarantees cross-platform compatibility and supports machine-readable metadata harvesting by catalogues such as EMODnet and the Marine Data Store.

Each dataset is accompanied by two metadata layers:

- Static metadata (platform name, instrument type, calibration references, geospatial coverage, etc.) maintained in a Metadata Model x ITINERIS * * * .xlsx masterfile using controlled vocabularies (P01, P06, L22, BODC codes).
- Dynamic metadata (start/end time, geographical positions) generated automatically from the daily acquired files via Python scripts.

The output is harmonized into NetCDF files containing embedded CF-compliant global attributes and variable-level metadata. The NetCDF files are structured following the requirements for ERDDAP ingestion, including:

- Dimension naming and structure (time, latitude, longitude, and depth if applicable)
- Time encoding in ISO-8601 format (units = "seconds since 1970-01-01T00:00:00Z")
- Complete global attributes such as title, institution, source, history, summary, keywords, license, and geospatial* entries.

Each instrument or data stream (e.g., FerryBox, LIDAR, etc...) will be assigned a distinct dataset ID on ERDDAP, with consistent file naming, versioning, and update frequency.

4.2 Metadata structure and challenges for multi-parameter instruments

The metadata structure required for ERDDAP ingestion consists of a combination of global attributes and variable-level descriptors, including associated quality control (QC) variables, defined in the master Metadata Model x ITINERIS.xlsx. In the current metadata model adopted for RV Gaia Blu, each NetCDF file will include, aside from the data:

~89 global attributes: describing the dataset context (title, institution, platform, geospatial_*, time_coverage_*, source, license, etc.)

~30 variables for each measured parameter: each with attributes such as standard_name, long_name, units, valid_range, ancillary_variables, and coordinates

~6 variables associated QC flag variable per parameter, following SeaDataNet or CF quality flag conventions.

This means that for a multi-parameter instrument such as the FerryBox, which currently includes measurements of temperature, salinity, dissolved oxygen, pH, total alkalinity, chlorophyll, turbidity,

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and pCO₂, a single NetCDF file may contain as much primary variables and QC flag variables than original raw data, in addition to their shared coordinate variables (time, latitude, longitude). Such complexity significantly increases the metadata management effort, especially considering that each parameter must be fully described and compliant with controlled vocabularies, and that the ship's platform is mobile, requiring all time series to be georeferenced.

At the time of reporting, the full set of metadata is being compiled. Metadata entries are currently being incrementally integrated, as each instrument is brought onboard, tested, and validated. This approach ensures that metadata accurately reflects operational conditions, calibration status, and instrument configurations.

4.3 Metadata merged in Netcdf files

A key milestone has already been achieved: we have successfully tested the automated generation of NetCDF files that consolidate, within a single structure,

- all time series from a given instrument,
- their associated spatial and temporal coordinates (following the mobile platform logic),
- and the complete metadata fields required for ERDDAP ingestion.

This process, described below, demonstrates that our system is capable of producing compliant, comprehensive, and dynamic datasets from the instrumentation suite aboard R/V *Gaia Blu*. The workflow for metadata integration and NetCDF generation remains flexible and adaptable to different implementation needs. Two scenarios are currently under evaluation:

- Onboard metadata integration, performed within the Virtual Machine environment, producing fully formed NetCDF files directly during the mission. This approach is preferred as it streamlines the overall workflow and reduces the processing load on the shore-based data center.
- Post-transmission metadata integration, where raw data and preliminary metadata are transmitted to the shore-based data center and metadata integration is completed there.

At present, we favor the first approach—integrating metadata and generating NetCDF files directly onboard—but final decisions will depend on technical constraints and operational conditions encountered during sea missions. This pragmatic flexibility ensures data continuity and robustness across diverse deployment scenarios.

The system is implemented within the directory `/GaiaBLU/EUROFLEETS_DATA/`, where each instrument is clearly identified using a standardized prefix:

- EF_FBX – FerryBox
- EF_HSR – Hyperspectral Radiometers
- EF_LID – LIDAR
- EF_ROV – Remotely Operated Vehicle
- EF_SAS – Spectral Absorption System
- EF_SLN – Salinometer

Each instrument directory follows a harmonized internal structure:

EF_<instrument>/

├── raw/ # Raw incoming data (e.g. .txt, .csv)

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- └─ metadata/ # XLS metadata definition files
- └─ nc/ # Output NetCDF files ready for ingestion

Once data has been put in raw/, a Python script can periodically triggers the processing chain as follows:

- **File detection:** The script scans the raw/ folder for new files not yet processed.
- **Data loading:** When a new file is found, it is parsed into memory.
- **QC flag creation:** A first-level quality flag is assigned to each variable. For now, this step does not include numerical validation (e.g., not checked) but provides a structural placeholder for QC workflows.
- **Metadata selection:** The script simultaneously scans the metadata/ folder to locate the latest valid metadata file, which includes updated information. Note that any instrument intervention (e.g., instrument cleaning or part replacement) should lead to the creation of a new metadata.xls file, that will be used then automatically.
- **Metadata generation:** Global attributes and static variable attributes are pulled directly from the XLS metadata reference as a namespace variable in the Python environment..
- **Dynamic metadata** attributes such as start/end time, and geographical position are computed from the raw data.
- **Variable matching:** An automatic association is made between the variable names in the raw data and their corresponding sheet in the xls file.
- **NetCDF writing:** The data, QC flags, and full metadata are compiled into a CF-compliant NetCDF file, which is then written to the nc/ directory, ready for ERDDAP ingestion.

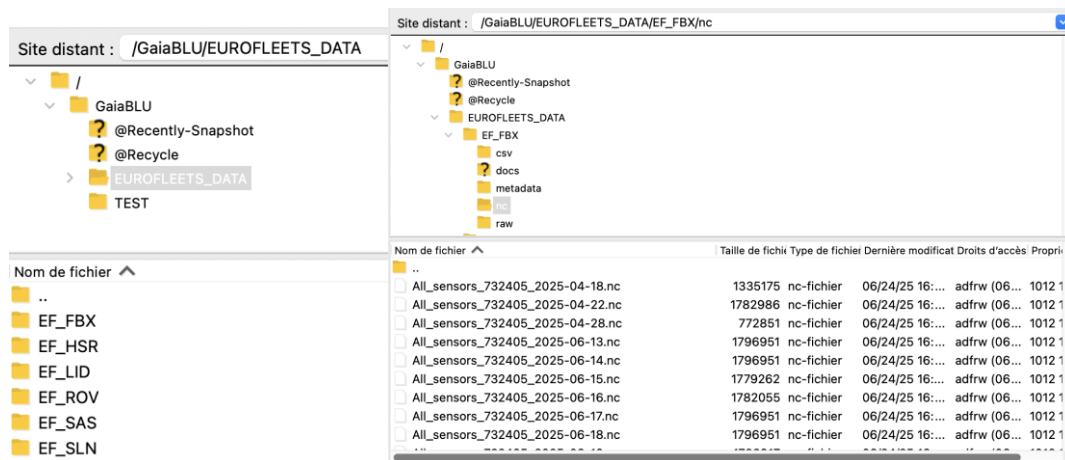


Figure 16. Directory structure of /GaiaBLU/EUROFLEETS_DATA as seen through the SFTP interface. Each instrument (e.g., EF_FBX for FerryBox) has dedicated subdirectories for raw data, metadata templates, and generated NetCDF files. This modular organization enhances traceability and scalability within the data ingestion pipeline.

4.4 Example of the Netcdf file

We present an example of the resulting content of All_sensors_732405_2025-06-22.nc (FerryBox data). Note that at this stage, the metadata fields are declared and nested but have yet to be fully populated:

```
import netCDF4 as nc
f = nc4.Dataset(netcdf_path, 'r')
```

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```
print(f.dimensions,'\n')
print(f.ncattrs())
```

Results:

```
{'TIME': <class 'netCDF4._netCDF4.Dimension'>: name = 'TIME', size = 1440, 'STRLEN': <class 'netCDF4._netCDF4.Dimension'>: name = 'STRLEN', size = 19}
```

```
['Conventions', 'Coordinates_reference_system', 'Project_DOI', 'RI_abstract', 'RI_coordin_organization', 'RI_coordin_organization_edmo_code', 'RI_coordin_organization_edmo_uri', 'RI_coordinating_person', 'RI_geographical_coverage', 'RI_name', 'RI_short_name', 'RI_start_date', 'acknowledgement', 'cdm_data_type', 'contributors_name', 'contributors_orcid', 'contributors_role', 'creator_name', 'creator_type', 'creator_url', 'data_best_practices_doi', 'data_creation', 'data_dataset', 'data_doi', 'data_filename', 'data_format_original', 'data_type', 'data_update', 'data_update_frequence', 'data_version', 'distributor_name', 'distributor_url', 'geospatial_lat_max', 'geospatial_lat_min', 'geospatial_lat_resolution', 'geospatial_lat_units', 'geospatial_lon_max', 'geospatial_lon_min', 'geospatial_lon_resolution', 'geospatial_lon_units', 'geospatial_vertical_max', 'geospatial_vertical_min', 'geospatial_vertical_positive', 'geospatial_vertical_units', 'infoUri', 'inspire', 'institution', 'institution_edmo_code', 'institution_edmo_uri', 'institution_ror_code', 'institution_ror_uri', 'keywords', 'keywords_vocabulary', 'license', 'license_url', 'metadata_dataset', 'metadata_filename', 'metadata_source', 'naming_authority', 'oceanographic_campaign', 'platform_name', 'platform_id_orig', 'platform_organization_managing', 'platform_organization_owning', 'platform_reference_person', 'platform_type_sdn_name', 'platform_type_sdn_uri', 'platform_type_sdn_urn', 'platform_wmo', 'project_code', 'project_edmerp', 'project_edmerp_uri', 'project_id', 'project_name', 'project_statement', 'publisher_name', 'publisher_type', 'publisher_url', 'references', 'ship_call_sign', 'ship_imo', 'ship_name', 'source', 'standard_name_vocabulary', 'summary', 'time_coverage_duration', 'time_coverage_end', 'time_coverage_resolution', 'time_coverage_start', 'title']
```

One variable (SBE45_temp):

```
f.variables['SBE45_Temp']
<class 'netCDF4._netCDF4.Variable'>
float64 SBE45_Temp(TIME)
  ebv: nan
  ebv_uri: nan
  ecv: Sea Surface Temperature
  eov: Sea Surface Temperature
  ecv_uri: https://gcos.wmo.int/site/global-climate-observing-system-gcos/essential-climate-variables/sea-surface-temperature
  eov_uri: https://goosoocean.org/document/17466
  discipline: SDN:P08::DS03
  device_sdn_name: non-separating flow-through data acquisition system
  device_sdn_uri: SDN:L05:133
  device_sdn_urn: urn:sdn:L05:13:133
  long_name: Sea Surface Temperature
  parameter_group: Temperature of the water column
  parameter_sdn_name: Temperature of the water body
  parameter_sdn_uri: https://vocab.nerc.ac.uk/collection/P01/current/TEMPPR01/
  parameter_sdn_urn: urn:sdn:P01:1:PSALST01
  sensor_accuracy: 999999
  sensor_last_calibration: 2025-01-01T00:00:00Z
  sensor_manufacturer_sdn_name: nan
  sensor_manufacturer_sdn_uri: nan
  sensor_manufacturer_sdn_urn: nan
  sensor_sdn_name: nan
  sensor_sdn_uri: nan
  sensor_sdn_urn: nan
  standard_name: sea_surface_temperature
  unit_sdn_name: Degrees Celsius
  unit_sdn_uri: https://vocab.nerc.ac.uk/collection/P06/current/UPAA/
  unit_sdn_urn: urn:sdn:P06:1:UPAA
  units: degree_Celsius
  units_url: https://docs.unidata.ucar.edu/udunits/current/udunits2-derived.xml
  variable_best_practices_doi: https://repository.oceanbestpractices.org/handle/11329/1502
unlimited dimensions:
current shape = (1440,)
filling on, default _FillValue of 9.969209968386869e+36 used
```

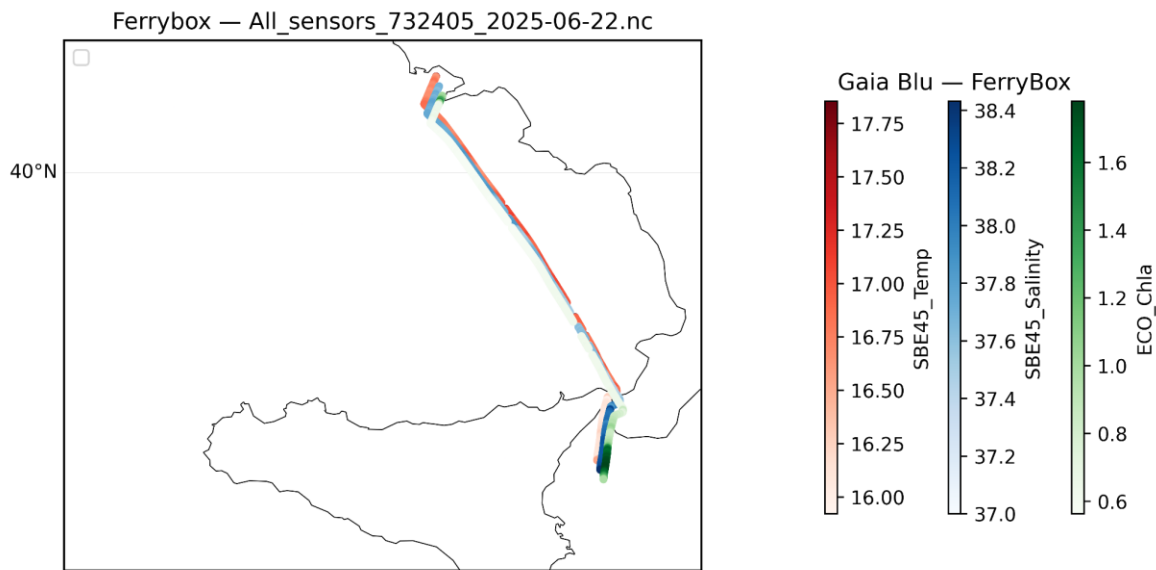


Figure 17. Example of temperature, salinity, and fluorescence data extracted from the FerryBox daily data file.

5. WEB-BASED ACCESS, VISUALIZATION AND VIRTUAL TOOLS

5.1. Development of the web-based access platform

The development of the Web-Based Access (WBA) platform remains a core activity within Task 5.16.3, aiming to deliver a user-friendly digital interface designed to serve both the scientific community and the general public. The platform will provide access to near real-time underway data, ship track information, live interactive maps, and multimedia content such as a virtual tour of R/V *Gaia Blu*. Additionally, it will enable users to explore derived data products generated during onboard scientific missions.

5.2. Progress on the virtual tour of the RV Gaia Blu

Significant progress has been made during the reporting period, particularly in establishing the foundation for the virtual tour component of the WBA. The team conducted dedicated field activities aboard R/V *Gaia Blu*, capturing video and photographic documentation of key onboard areas, including the Control Room, Library, and Dry Lab. These materials are being utilized to develop a prototype virtual tour currently under evaluation.

This activity has been carried out in close coordination with the Logistics, Investment, and Communication & Outreach Working Groups (GdL). Such collaboration ensures optimized resource use, avoidance of duplication, and alignment with broader ITINERIS outreach and dissemination goals. Regular exchanges between technical developers and communication specialists support harmonized progress, particularly in relation to public engagement and ocean literacy.

The virtual tour also incorporates audiovisual materials collected during the TREMOR oceanographic campaign, including footage of seabed sampling operations (e.g., box corer and

SW104) and scientific instruments in action. These contributions will enrich the content and scientific relevance of the final WBA platform.

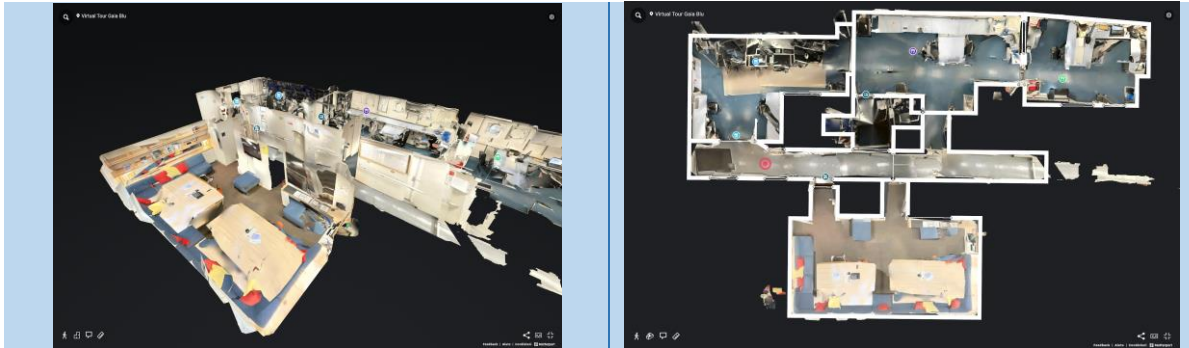


Figure 18. Rendering of the virtual tour of R/V Gaia Blu. Interactive tour available at: <https://my.matterport.com/show/?m=NeXKsA6h99r>.

Development of a Virtual Tour using a 360° camera and the Matterport application – Tremor Campaign

During the TREMOR Campaign, a project concept was developed and implemented to create a virtual tour of the *Gaia Blu* infrastructure, consistent with Task 5.16.3 requirements. The approach combined the use of a 360° camera (brand and model to be specified) with the Matterport application for 3D data acquisition and processing. The operational procedure included:

1. **Preliminary area scan:** A preliminary scan of the Control Room was conducted using an iPad Pro equipped with a LiDAR sensor. This device enabled acquisition of high-precision 3D spatial data, necessary for defining the project area within the Matterport app.
2. **Acquisition of 360° images:** Spherical 360° photospheres were captured using a 360° camera mounted on a tripod. Careful positioning of the tripod within the room ensured proper alignment of the images with the 3D spatial data.
3. **Processing within the Matterport application:** Following data acquisition, a workspace was created in Matterport, allowing: a. Upload of the 360° images to enhance the resolution and detail of the 3D model; b. Integration of the photo spheres with the 3D spatial survey to produce an interactive virtual tour, enabling users to navigate the environment through predefined viewpoints.

The integration of 3D scanning with 360° imagery, supported by the Matterport platform, has proven highly effective in generating a detailed, navigable virtual environment. This represents an advanced technological solution that fully meets the objectives outlined in Task 5.16.3.

Planned improvements and next steps

In the upcoming months, the team will finalize and present the virtual tour prototype to the relevant Working Groups (GdL) for review and feedback. Adjustments will be made accordingly before proceeding to full deployment. Concurrently, efforts will continue to define the broader technical architecture of the WBA platform, including the integration of underway data streams and visualization tools for both raw and processed datasets.

The overarching objective remains to deliver a comprehensive, accessible, and informative platform that supports scientific dissemination, facilitates education, and promotes engagement with oceanographic research conducted aboard R/V *Gaia Blu*.

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6. LESSONS LEARNED AND NEXT STEPS

6.1 Summary of what worked well

The procurement and installation process of most planned instrumentation on the RV *Gaia Blu* progressed efficiently and according to the expected timeline. Several critical systems—such as the automatic underway acquisition suite (Ferrybox), hyperspectral radiometers, and the semi-portable salinometer—have been successfully installed, tested, and integrated into the shipboard environment. The close collaboration between technical staff, scientific teams, and onboard personnel was key in facilitating smooth installation, initial calibration, and interface with the ship's data infrastructure.

Positive outcomes also include the early testing of real-time data transmission systems, notably for the Ferrybox, and the initial implementation of procedures for interfacing with the Marine Data Store. These efforts demonstrated the feasibility of near-real-time environmental data flow from ship to shore.

The progress made in developing the web-based access tools and virtual ship tour also marks an important step toward enhancing the accessibility and visibility of onboard systems for both scientific and outreach purposes.

6.2 Key bottlenecks and delays

While most systems progressed as planned, some delays and limitations were encountered. The delivery of the deep-sea ROV remains pending, representing the most significant bottleneck. Its integration into the onboard infrastructure requires careful planning, including power supply, cargo deck reinforcement, and safety protocols—all of which are currently in progress but cannot be finalized until the system is physically delivered and tested.

Additionally, the heterogeneous nature of the onboard instrumentation, provided by different partners and contractors (across six procurement lots), introduced coordination challenges in terms of timeline alignment, compatibility checks, and data interface harmonization.

6.3 Recommendations for future operations and finalization

- Early coordination across suppliers and installation teams should be prioritized, especially for large and complex systems like the ROV, to avoid integration delays and ensure that supporting infrastructure is ready in advance.
- Standardize data flow procedures across instruments as early as possible, using the Ferrybox workflow as a reference for expanding real-time capabilities to other systems.
- Ensure flexibility in onboard infrastructure (power supply, data ports, mounting solutions) to accommodate ongoing and future upgrades, particularly for scientific missions with evolving technical requirements.
- Continue developing virtual tools and documentation to support remote access, shipboard training, and outreach, especially for cruise participants not physically present during system testing phases.

The final phase of the work will focus on completing remaining installations, validating system interoperability during operational cruises, and delivering a consolidated handbook for onboard data acquisition and transmission protocols.

7. ANNEX

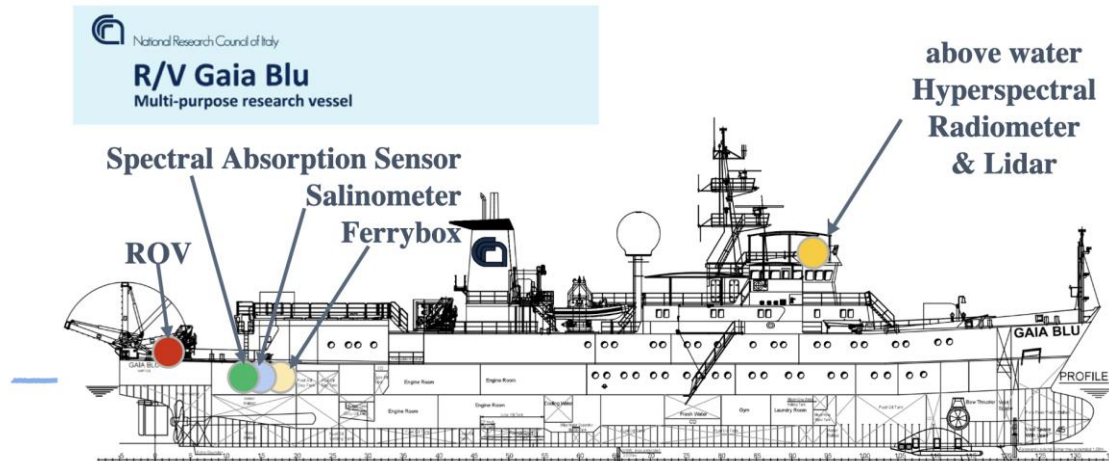


Figure 19. Locations of the various instruments installed onboard Gaia Blu, indicated by color-coded markers.