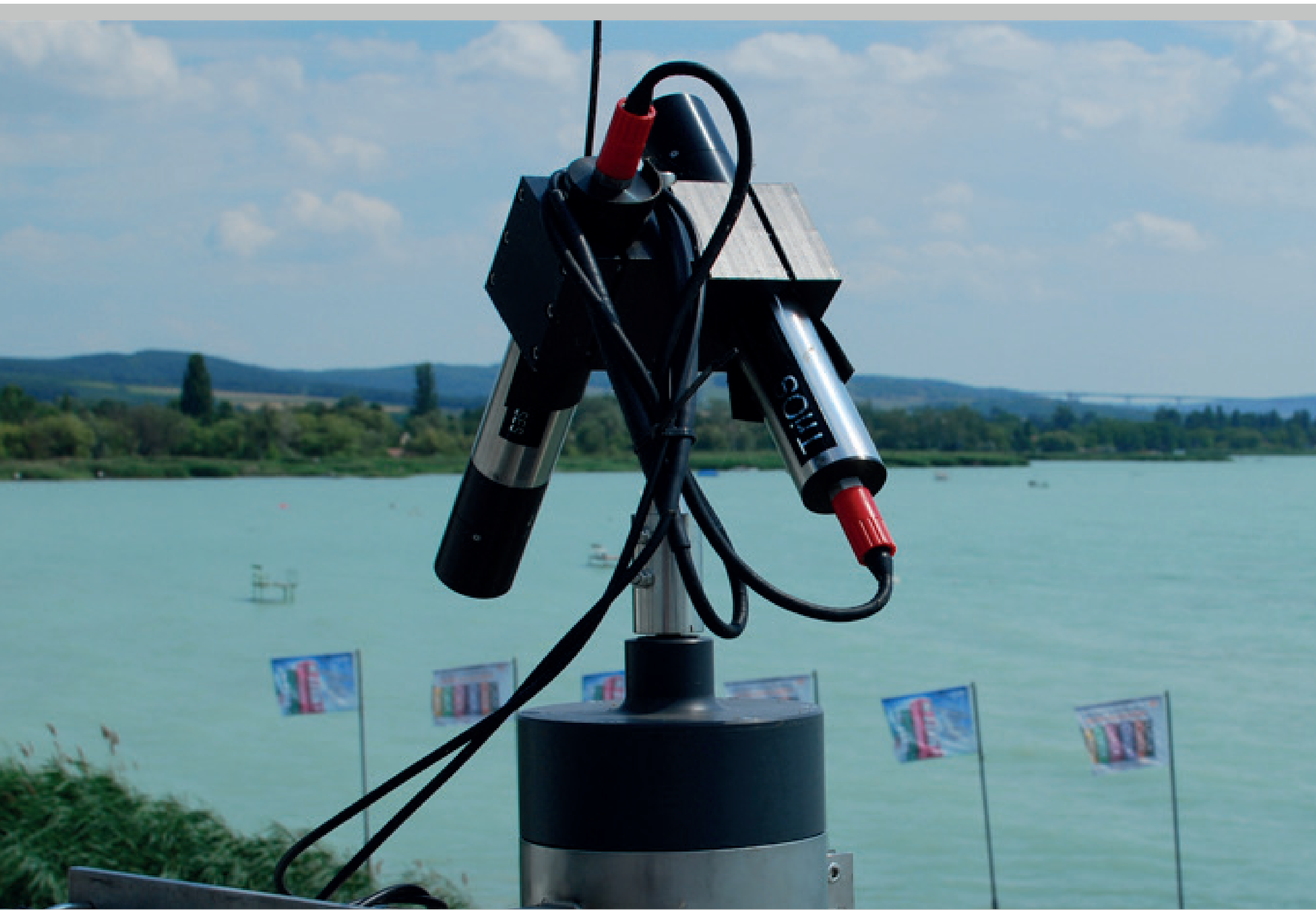
MONOCLE



So-Rad: Solar-Tracking Radiometry Platform

Deployment and Operation

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 776480.

PML Plymouth Marine Laboratory

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So-Rad

Contents

System description

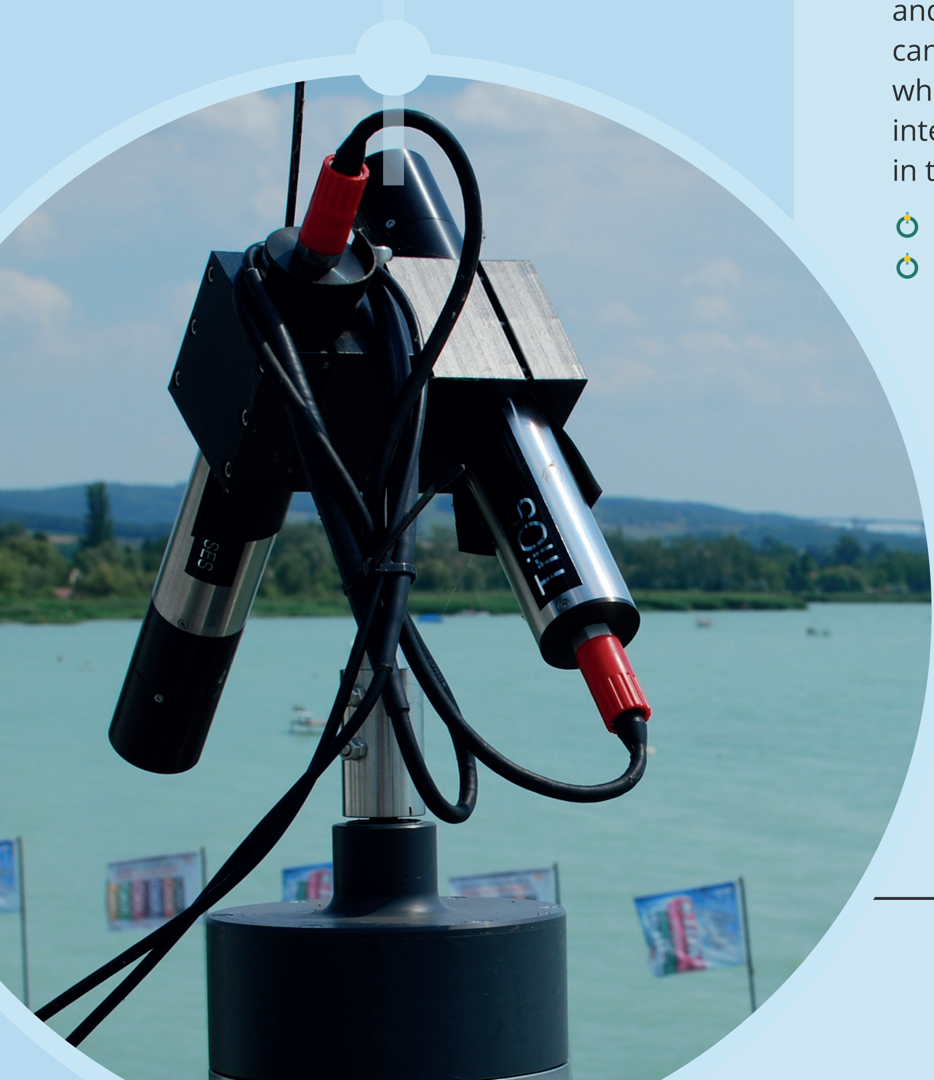
The purpose of the **So-Rad system** is to maintain optimal viewing angles of radiance sensors recording water-leaving reflectance to avoid sun glint and platform shading, even from moving platforms (ships, buoys).

The system is developed to operate autonomously, with low power consumption (15W), integrating existing radiometers and providing connectivity with the MONOCLE back-end.

The system combines off-the-shelf and purpose-built components. Two radiometers are mounted on a bracket which controls the horizontal (azimuth) sensor viewing angle, designed for this specific purpose.

The system is controlled from a single deck box. The open source software has a modular design. Currently it supports TriOS Ramses spectroradiometers (one irradiance and two radiance sensors), which can be extended to other sensors for which an application programming interface is available. Details are given in the following sections.

- Hardware components
- Software/data interfaces



The So-Rad system mounted on a car ferry on Lake Balaton showing the two radiance sensors attached to the motor enclosure.

Control unit

this includes the controller for the motor stack, Long-Term Evolution (LTE) modem, power supplies (24/12/5 V), solid-state relay, fuse, a Raspberry Pi to control the system and a tilt angle sensor.

Rotating sensor platform

An enclosure around a stack of geared stepper motor, encoder and brake, which is positioned over the side of a ship using stainless steel mounts, ideally with a wide unobstructed view of the water, such as the bow of a ship.

Power supply

the control unit can be built to work with 220–240 VAC, 12 VDC or 24 VDC power supply. Power consumption is only 15W so can also be provided from a battery or solar panel (for details see the construction guide[1]).

Bracket

Because every platform is different, only the bracket supporting the motor enclosure is provided with the So-Rad. A platform-specific bracket should be made to specifications and to match the mating plate of this support.

Cable conduit

this connects the control unit and the motor platform, default length is 2.5 m but up to 20 m is possible.

Location and heading sensing

two GNSS receivers are installed along the ship bow-stern or port-starboard axis (recommended 2–3 m apart), observing the same portion of unobstructed sky (to avoid GPS signal 'bounce'). These will provide accurate position and heading (<1°) information.

Sensor cables

not included

A complete guide to the construction and configuration of the So-Rad is available[1]. All elements of the So-Rad (hardware and software) are published under a Creative Commons Attribution-Non Commercial license.

1. Wright, A. and S.G.H. Simis. 2020. Construction of the Solar-tracking Radiometry platform (So-Rad). doi: 10.5281/zenodo.4485805

Technical specifications

The main technical specifications for the So-Rad system are listed below.

Intrusion protection: the electronics and motor enclosures have been tested to withstand water intrusion equivalent to IP66. Cable glands and seals should be checked for tightness and maintained to ensure continued protection.

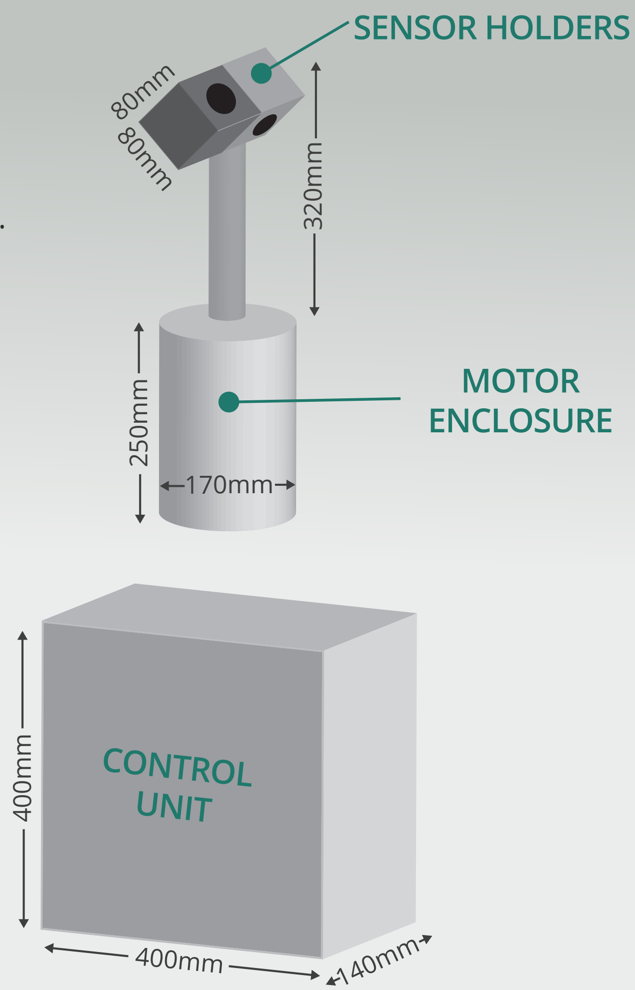
Allowable operating conditions: these are based on the specifications of the individual electronic components used in our recommended design. We recommend operation between 0–50°C and 20–85% relative humidity.

Dimensions and weight: the control unit measures 400 × 400 × 150 mm without cable glands and fixtures. 150 mm bottom clearance is recommended to accommodate cabling. The control unit weighs 13 kg.

Motor enclosure: this is manufactured in ABS plastic, including sensor holders, measures 560 mm in length, 175 mm in diameter and weighs ~6 kg (sensors not included).

Mounting brackets: these are platform-dependent and not specified here. Use of stainless steel is recommended for marine applications.

Power consumption: approximately 15 W in the default configuration.



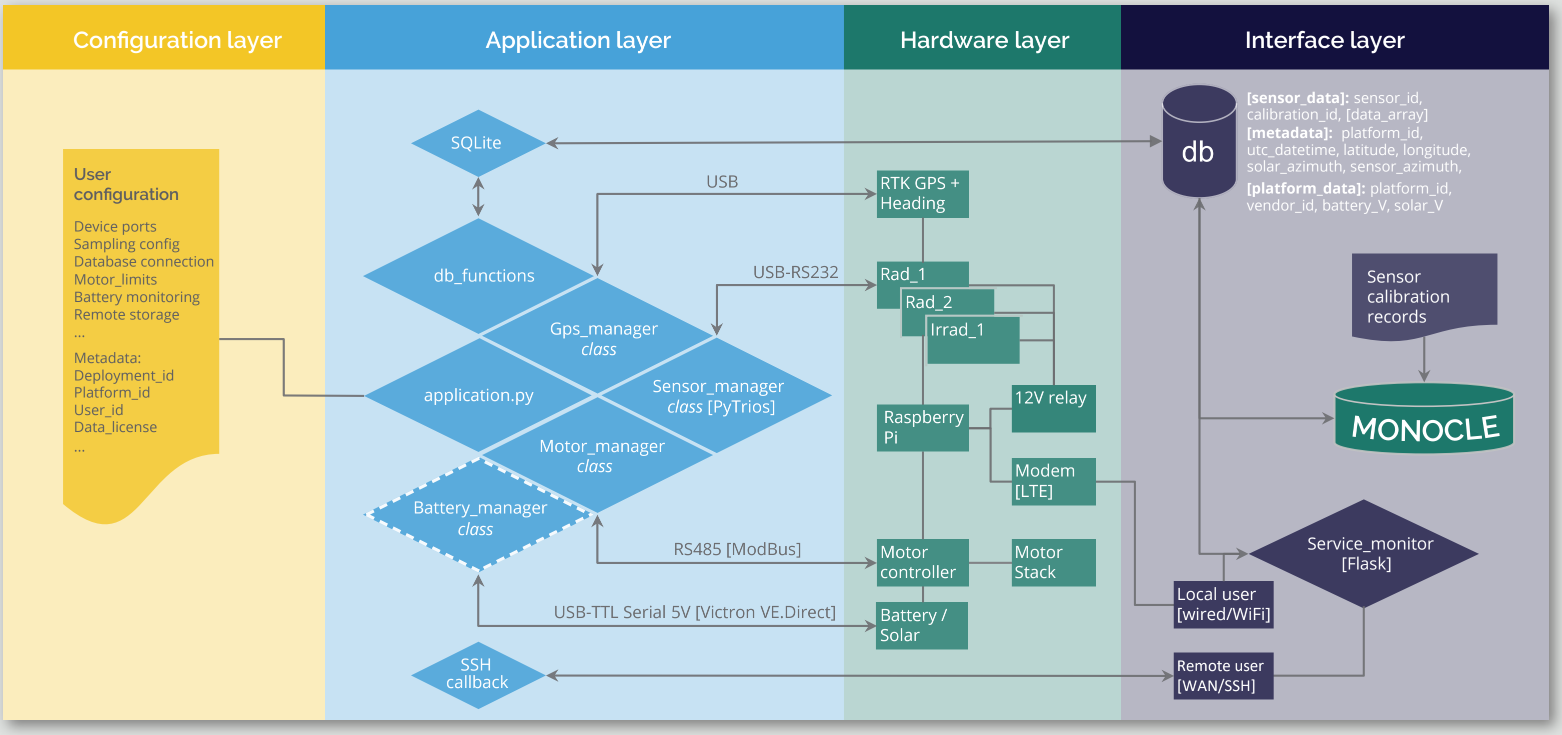
Dimensions of the So-Rad system

The controller software is implemented in Python and is published open-source under a non-commercial license[1]. The flow chart below provides a functional description of the various software components used to control the hardware, including:

User configuration files: provide metadata about the deployment platform and data ownership, connection properties for all sensors, deployment limits (e.g. to radial movement).

Main application: interface calling and instructing all sub-processes in parallel threads, as well as monitoring internet connectivity and solid-state relay to provide power to system components. The main application collects all required system state information to determine whether measurements should be made. The main application calls upon:

- **Gps_manager:** connects to RTK GPS units with two receivers to provide accurate heading information in addition to position and time information
- **Motor_manager:** calculates optimal heading of the motor depending on ship heading, longitude and time (from Gps_manager) as well as platform definitions (from user configuration, e.g. where is the sensor mounted on ship) and current motor viewing angle.
- **Log_db:** handles logging and requests to/from a local database, which acts as data buffer.
- **Sensor_manager:** connects to two radiance sensors and one irradiance sensor, triggering new measurements at user-configurable intervals when minimum measurement conditions are met.
- **Battery_manager:** (optional) when system operates on battery power and the battery or (solar) charger provides information on charge and load status, this information is logged and generates a status flag, indicating stable power supply (normal operation), low power (reduce consumption) or critical power (idle mode).

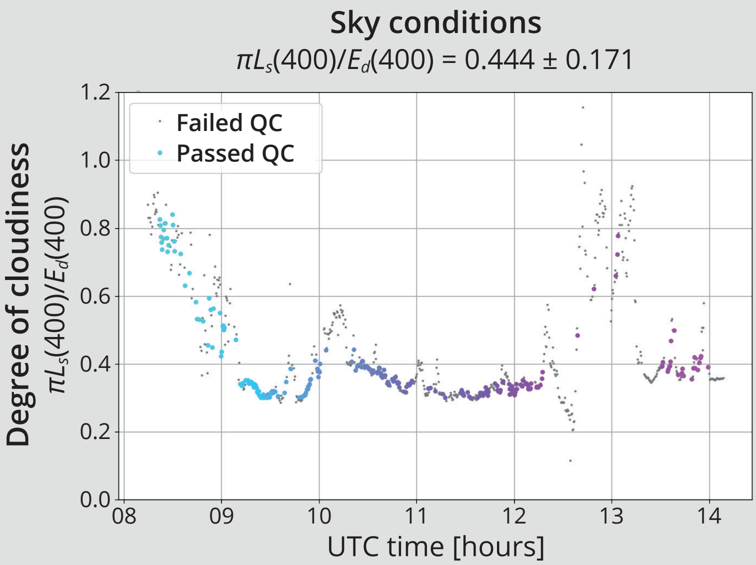


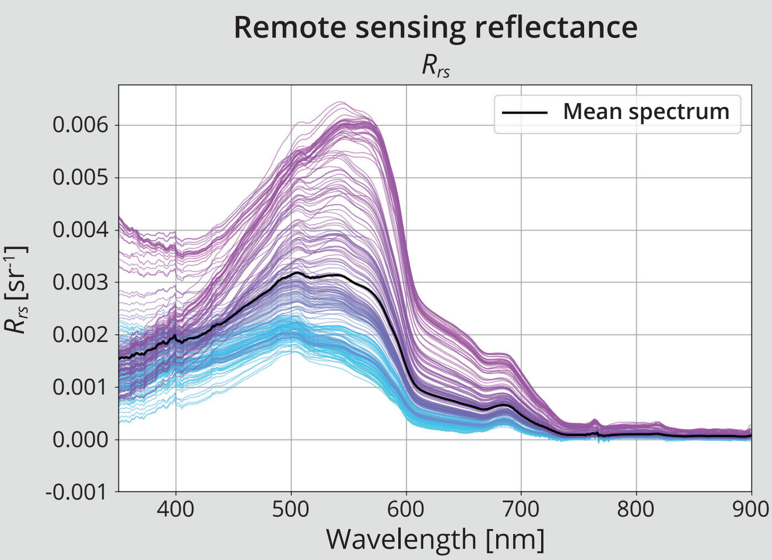
So-Rad system flow-chart.

1. https://github.com/monocle-h2020/so-rad

The system provides the following interfaces for operators to interact with the system:

- Automated Secure Shell (SSH) callback which periodically tries to connect to a central MONOCLE server or external dynamic Domain Name System (DNS), providing a reverse SSH tunnel to allow remote control and troubleshooting of the system, when an internet connection is available.
- An automated, efficient data transfer mechanism which packages observations and metadata, queries a remote database and uploads new observations. At the same time, data are buffered at the platform itself.
- A micro web service providing a status page, system logs and further routes to set operating mode (e.g. automated/manual/calibration – still under development), which can be reached by a local user connected to the router contained in the control box (cabled or WiFi), or by a remote user over SSH.
- A periodic check for updates to user configurations provided at a user-configured URL.





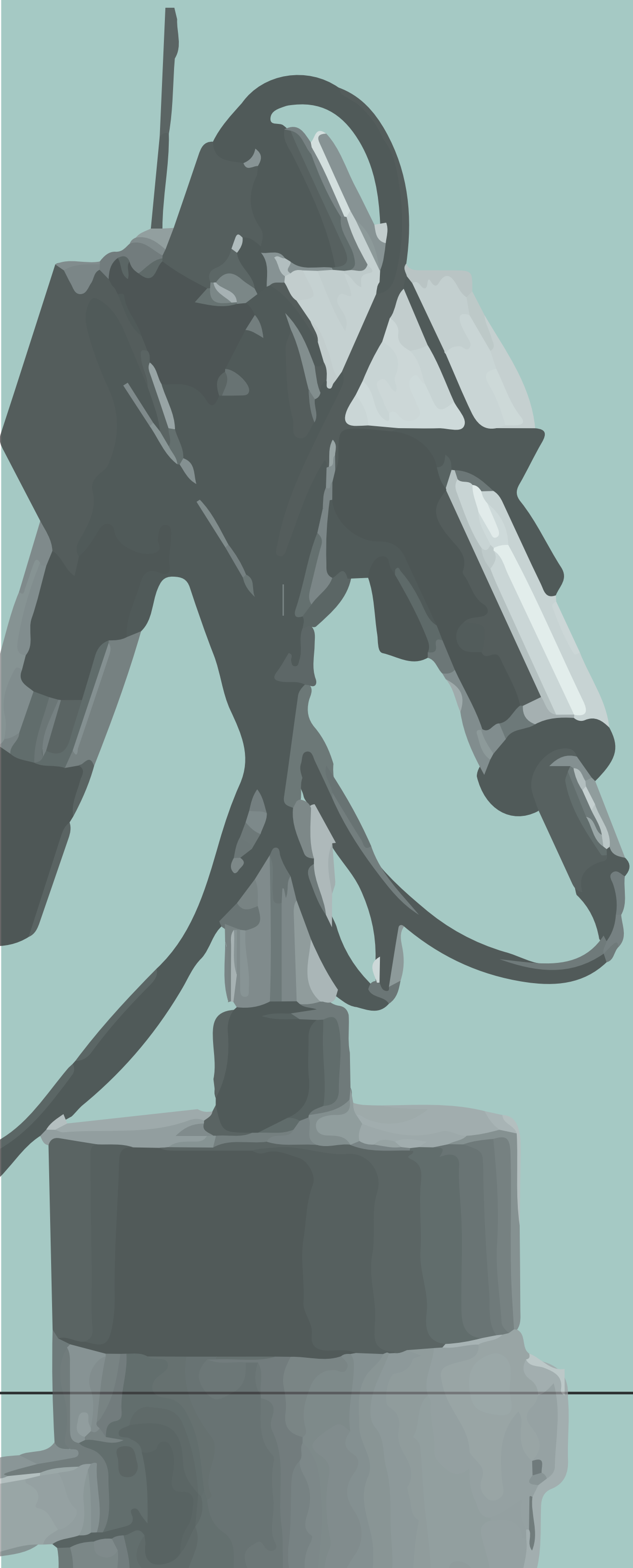
Remote-sensing reflectance data from a So-Rad system using TriOS radiometers, operated on a coastal transect from the open sea (cyan) to Plymouth harbour (pink).

Data records were automatically quality controlled resulting in removal of most observations collected under variable cloud cover around 13:00 UTC.

System installation

Installing the system components

The following instructions assume installation on a ship.



Tools required: Set of Allen keys, spanners and cable ties

1. Install the motor platform near the forward bow or along a front side of the ship, thus providing the largest unobstructed view of the water surface while avoiding the wake of the ship.
2. Align the 'home' position of the motor (marked on the motor housing) with the ship bow-stern axis so that sensors point in the forward direction (away from the ship) when the motor is in the home position. A rotational offset to the home position can also be configured in the software but the offset must then be recorded on installation.
3. Attach the radiance sensors to the motor platform. The sensor brackets point at 40 degrees forward angles (i.e. from vertical), one radiance sensor is to point up and the other to the water.
4. Secure cables to the ship to ensure free rotational movement of the sensors, but tight enough to prevent cables catching on moving parts.
5. Install the irradiance sensor at a high point on the ship where it is free from shading by any ship structure. This sensor must point straight up. The sensors and their cabling are interchangeable: when calculating reflectance, the lowest signal will be associated with water-leaving radiance, the highest signal to downwelling irradiance and the intermediate signal with sky radiance.

6. Mount the control unit and optional solar / battery box vertically so that all cable connections are at the bottom. The Tilt sensor of the system is included in the control unit, so this must be installed level. Additionally it is recommended to inspect the tilt reported by the unit after installation, making any required mounting adjustments to accurately record tilt. Recording data with tilt > 5° is not recommended.
7. Mount the GNSS receivers parallel to the bow-stern axis of the ship. The GPS receiver marked 'FRONT' should be positioned several metres ahead of the sensor marked 'REAR'. It is recommended that the sensors have an unobstructed view of the sky. If a bow-stern orientation is not possible, orient the receivers along the starboard-port axis instead. This will require editing the system configuration file.
8. Connect all data / communication cables (but not power cables).
9. Open the controller box (only in dry conditions) and ensure power connectors are switched off.
10. Connect power cables in the following order, as applicable: connect controller box to mains or battery box. If using solar, connect solar panel to battery box last. Always be aware that solar panels hold a voltage when exposed to light.
11. Secure all remaining loose cables to ship structure using cable ties.

Communication components

Setting up remote communication

Install a suitable full-sized SIM card in the modem. Use a laptop to set up the SIM Personal Identification Number (PIN) and access point (APN) by connecting to the modem via its WiFi network or by connecting to the available Ethernet port (marked WAN). Open a browser and navigate to 192.168.1.1 and logon using the name and password provided (see construction guide[1] for more detail on modem setup).

1. Wright, A. and S.G.H. Simis. 2020. Construction of the Solar-tracking Radiometry platform (So-Rad). doi: 10.5281/zenodo.4485805

Powering on the system

Only open the controller box when it is safe to do so. Before connecting to mains or battery power, switch the fused terminal switch to OFF. Alternatively, fit a switch on the power supply line feeding power to the control unit.

Mains power operation:

1. Connect mains power plug to a suitable electric outlet.
2. Power switch ON.
3. Ensure that indicator lights on the DC 24V, DC 12V and DC 5V supplies, motor controller, Raspberry Pi and USB hub are all ON. Within minutes, the solid-state relay will switch on and the motor should move first to its home position and then the optimal measurement position (if measurement conditions are met).
4. Close and lock the controller enclosure.

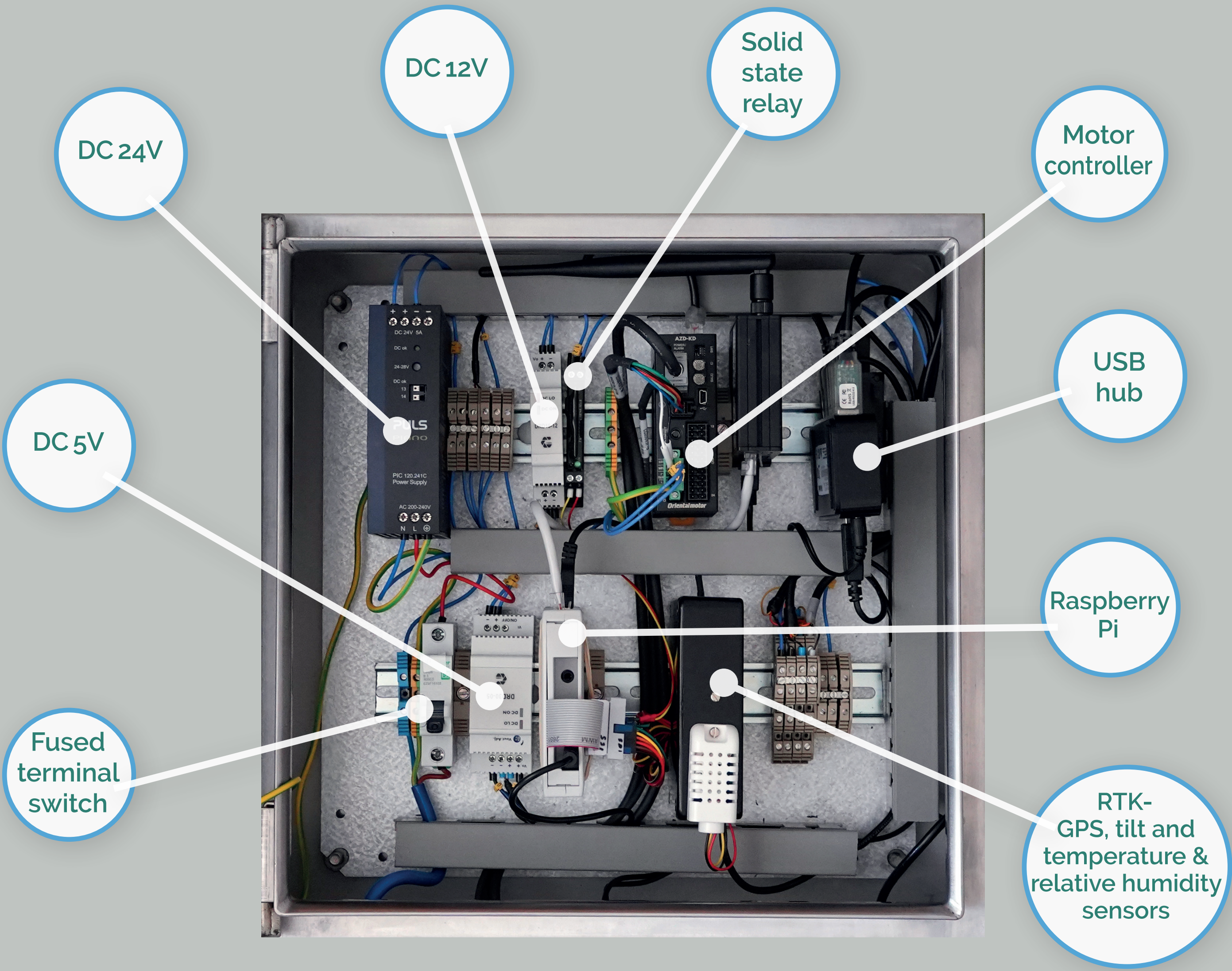


Figure 5 Control unit configured for mains power.

System check

Normally, if all systems are connected properly, soon after the Raspberry Pi has finished powering up it will switch on the sensor relay (green light) and some adjustment of the sensor viewing angle can be noted.

It may take a few minutes for the GPS sensors to obtain a position fix, before the system starts its operation.

- If all systems appear to work, it is possible to check data flow by connecting to the Raspberry Pi from a laptop, phone or tablet either over the local WiFi, cabled connection the modem, or via the internet (depending on whether remote configuration has been set – details on this configuration are provided in the construction guide[1]). The IP address for locally connecting to the system is indicated on the inside of the control unit or can be checked from the modem admin interface (Status -> Network -> LAN page). If remote monitoring has been enabled, a unique URL will have been provided. The status page should show which sensors are connected.
- Verify that the 24V, 12V and 5V power supplies show a green 'DC OK' light. If none show a light, there is a problem with power supply to or within the controller box. Verify that the correct power source has been chosen on the rotary connector and that the respective switchable fuse is ON. If some are on while others are not, there is an electrical problem that should be handled by a qualified engineer.
- If a motor failure is suspected because movement was blocked (e.g. a cable was caught, or someone was cleaning the sensors), first check the system logs which should identify a motor alarm. If a motor alarm is present, the motor controller will also show a blinking red light instead of green. First ensure that the sensor cables are not blocking motor movement and that the system is still mounted as intended. Never adjust any of the power/brake/encoder cables that connect the motor controller to the motor, unless the system is powered down first. Motor faults should be very rare and blocked movement will normally be the reason for the alarm. Once the underlying issue has been corrected, power-cycle the system and operation should resume normally.
- If a motor alarm is present and does not appear to be related to blocked movement, then to identify the motor alarm a PC can be connected over the Universal Serial Bus (USB) port of the motor controller, then using the MEXE02 software the alarm can be further identified. A motor alarm will also show in the system logs that can be viewed locally (WiFi/cable) or remotely (if enabled and connected). A motor issue should be investigated on-site, to prevent issues with cables getting caught from recurring. Once issues have been resolved follow the above steps to power cycle the system. Alternatively, a remote reset is possible using the scripts available in the So-Rad system tests folder (/home/pi/sorad-code/bin/tests) to detect and reset motor alarms.

1. Wright, A. and S.G.H. Simis. 2020. Construction of the Solar-tracking Radiometry platform (So-Rad). doi: 10.5281/zenodo.4485805

Sensor calibration

Procedures to support field calibration are still under development. We refer to MONOCLE Deliverable 6.2[1] for a methodology to detect drift of the downwelling irradiance sensor, achieved by comparison against modelled sky irradiance under clear-sky conditions.

Clear-sky conditions will be determined by inspecting the ratio of sky radiance over downwelling irradiance, which under clear sky conditions should resemble the spectral dependence of Rayleigh scatter[2]. This approach is expected to identify major fouling, and possibly long-term drift.

Prior to long deployments (a whole season or longer) we recommend that the sensors are calibrated in a dedicated laboratory. This way, data will be valid for satellite calibration and validation.

Intermediary, relative calibration is possible by recording the radiance of a diffuse reflectance target and downwelling irradiance simultaneously with all sensors. This allows sensor inter-calibration. While the reference target does not need to be of high calibre (such as e.g. spectralon), it does need to be characterized with the same set of sensors before initial sensor deployment, and then kept clean and stable. The field calibration should be carried out under a clear sky with sun at high elevation.

Under these conditions, the irradiance sensor will capture the full spectrum of sunlight arriving at the reflectance panel. The radiance sensors pointed at this panel should measure a signal equal to 1/π of the irradiance. These readings can then be used to produce a secondary calibration spectrum for each radiance sensor.

The secondary calibration is applied in data post-processing. Automation of this procedure using the So-Rad software and data backend is still underway. It is noted that secondary intercalibration of the sensors is a good way to prolong the interval between laboratory calibrations and will yield accurate Reflectance, since this is a relative measurement between the sensor signals. Over time, the sensors are expected to degrade and therefore their absolute values cannot be used without occasional laboratory re-calibration.

1. Jackson, T., S. Simis, L. De Keukelaere, J. Piera, C. Rodero and R. Bardaji. 2020. Demonstration of automated anomaly detection and data flagging. MONOCLE Deliverable 6.2. 9pp. doi: 10.5281/zenodo.4043552
2. Groetsch, P.M., P. Gege, S.G.H. Simis, M.A. Eleveld and S.W. Peters. 2017. Validation of a spectral correction procedure for sun and sky reflections in above-water reflectance measurements. Optics Express, 25: A742-A761. doi:10.1364/OE.25.00A742

Data

Data gathering

The So-Rad system will **automatically** prevent data collection if suitable conditions are not met. These settings and threshold criteria are user-configurable through the configuration file as indicated in **blue**, with recommended settings as shown:

- The regular sampling **interval** is set to 10–15 seconds when using TriOS G1 sensors.
- Sensor viewing azimuth angle should be >**90°**, <**145°** and as near as possible to 135° away from the solar azimuth.
- The GPS receiver should acquire a 3D fix and the latest information on latitude, longitude and heading may not be more than **2** seconds old.
- Solar elevation must be >**30°**.
- The sensor viewing angle is within **clockwise/counter-clockwise** limits defined by its position on the ship (to prevent looking at the ship itself) which must be defined in the user configuration file. The values are given in degrees relative to the ship bow-stern axis.
- The irradiance sensor can optionally be configured to continue measurements, even when conditions suitable for reflectance measurements are not met, to support e.g. primary production studies. The **interval** (in seconds) for downwelling irradiance (E_d) measurements outside the normal measurement interval can be specified.
- Sensor **timeout interval** (in seconds): if data are not returned within this interval from a measurement trigger, sensor connectivity may have been lost of an incomplete measurement returned, or serial data became corrupted. This setting is sensor specific. For TriOS sensors using the PyTrios protocol it is set to 12 seconds.
- Number of **timeouts allowed (3)**: if the number of consecutive timeouts is exceeded, power to the sensors is cycled to bring them back online.

MONOCLE observation solutions including the Hyperspectral Radiometer for Global and Diffuse Irradiance (HSP1; left) and So-Rad (right).

All user configurations are stored in two configuration files in the sorad-code folder on the Raspberry Pi. The file config.ini holds default settings. This file will be over-written when a firmware update is applied. The file config-local.ini is used to override any of the default settings, and it is recommended to make changes only to this file, and to backup its contents.

A procedure to periodically update the config-local.ini file from a remote location, is being implemented. This will allow the remote operator to change the sampling schedule of the So-Rad. When the platform is connected to the internet, new settings will be downloaded to override the system defaults. Only non-critical settings can be specified in this manner. A usage example is where the operator keeps a configuration file for each So-Rad platform in secure cloud storage (e.g. Dropbox). The remote link to the file is added to the config-local.ini settings along with a specified interval to check for updates. In another usage scenario, updates to the sampling schedule can be automated, by updating the remote configuration file held in cloud storage, e.g. to follow the schedule of satellite overpasses.

Data check

The first check of normal data throughput is to see whether all sensors return data. When viewing conditions are suitable for reflectance measurements, these should come through in sets of three (one record per sensor).

Further checks require calibration data to be applied to the raw data, and are out of scope of this document. Data anomalies and processing algorithms are discussed in MONOCLE Report 6.1[1].

Post-processing software tools developed in MONOCLE are maintained at https://github.com/monocle-h2020/

Data upload

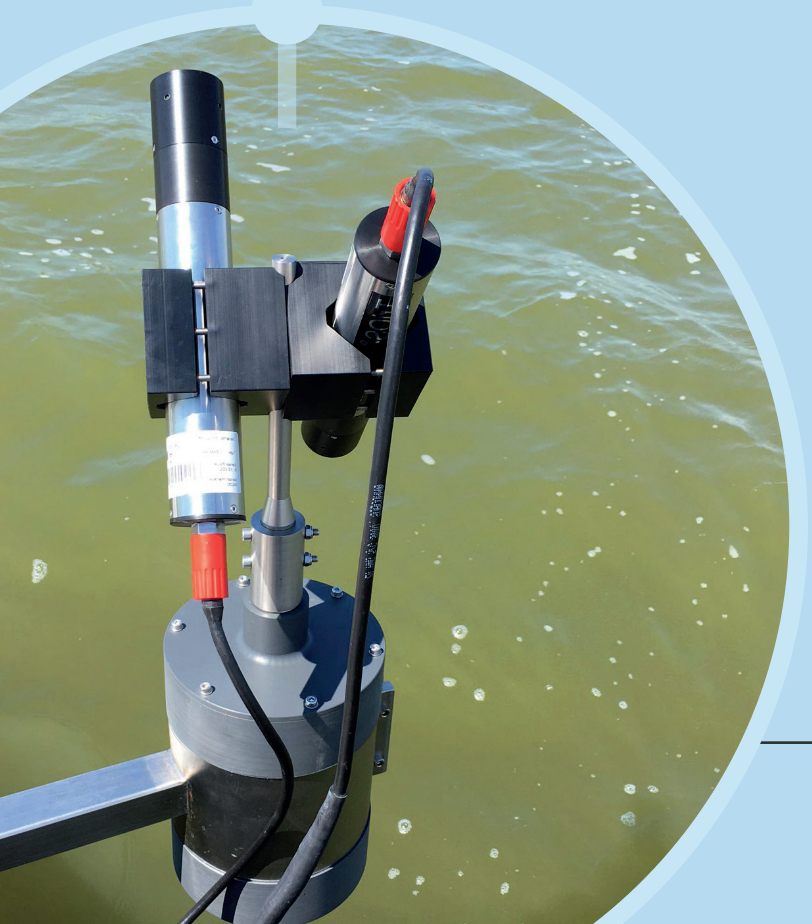
Data upload to the MONOCLE backend is user-configurable and activated by default. The So-Rad collects uncalibrated sensor data and calibration records are uploaded to the backend which provides access to calibrated (ir)radiance spectra at the native sensor resolution, and reflectance data interpolated to 1nm resolution.

Access to the data is provided within minutes after collection (if the So-Rad is connected to internet) through OGC compliant Web Map Service and Web Feature Services, which are compatible with modern geographic information systems. Python scripts demonstrating how to download and quality check the data are provided through the code repository linked on the left. Additionally, up to 9 million observations can be stored in a database on the internal memory of the So-Rad, which can be downloaded over a remote connection.

1. Jackson, T., L. De Keukelaere, S. Simis, S. Peters, O. Burggraaff, N. Schmidt, F. Snik, J. Wood, J. Piera, O. Julame, M. Ventura and R. Moelans. 2019. Report on value-adding approaches and algorithms for single sensor and inter-sensor data processing. MONOCLE Deliverable 6.1. 27pp. doi: 10.5281/zenodo.3258795

SYSTEM MAINTENANCE

Please follow the guidelines of the radiometer instrument manufacturer for sensor care and maintenance. Prior to long deployments (a whole season or longer) or when any degradation is suspected, we recommend that the sensors are calibrated in a dedicated laboratory. This way, data will be valid for satellite calibration and validation, and any drift in the sensors will be traceable.



We typically find that sensors degrade faster in their first year of deployment, and much slower thereafter. Conversion of the sensor output into calibrated (ir)radiance should use the latest calibration record created prior to deployment, rather than the nearest one in time (e.g. collected post deployment).

To assess the effects of gradual degradation or fouling during a deployment, some potential procedures are demonstrated in MONOCLE Report 6.2[1], looking at drift of the downwelling irradiance sensor, achieved by comparison against modelled sky irradiance under clear-sky conditions.

Intermediary, relative calibration is possible by recording the radiance of a diffuse reflectance target and downwelling irradiance simultaneously with all sensors. This allows sensor inter-calibration. While the reference target does not need to be of high calibre (such as e.g. spectralon), it does need to be characterized with the same set of sensors before initial sensor deployment, and then kept clean and stable.

1. Jackson, T., S. Simis, L. De Keukelaere, J. Piera, C. Rodero and R. Bardaji. 2020. Demonstration of automated anomaly detection and data flagging. MONOCLE Deliverable 6.2. 9pp. doi: 10.5281/zenodo.4043552

The field calibration should be carried out under a clear sky with sun at high elevation. Under these conditions, the irradiance sensor will capture the full spectrum of sunlight arriving at the reflectance panel. The radiance sensors pointed at this panel should measure a signal equal to 1/π of the irradiance. These readings can then be used to produce a secondary calibration spectrum for each radiance sensor.

The secondary calibration is optionally applied in data post-processing. It is noted that secondary intercalibration of the sensors is a good way to prolong the interval between laboratory calibrations and will yield accurate reflectance, because this is a relative measurement between the sensor signals rather than requiring absolute calibration against a reference lamp. Over time, the sensors are expected to degrade and therefore their absolute values cannot be used without occasional laboratory re-calibration.

So-Rad system (downwelling irradiance sensor not shown) mounted on a ferry.

MONOCLE

MONOCLE creates sustainable in situ observation solutions for Earth Observation (EO) of optical water quality in inland and transitional waters.

MONOCLE develops essential research and technology to lower the cost of acquisition, maintenance, and regular deployment of in situ sensors related to optical water quality. The MONOCLE sensor system includes handheld devices, smartphone applications, and piloted and autonomous drones, as well as automated observation systems for e.g. buoys and shipborne operation. The sensors are networked to establish interactive links between operational Earth Observation (EO) and essential environmental monitoring in inland and transitional water bodies, which are particularly vulnerable to environmental change.

Other MONOCLE observation solutions include:

FreshWater Watch

Hypersectral Radiometer (HSP1)

iSPEX2

KdUINO

MapEO Water

Mini-secchi disk

So-Rad

WISPstation

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