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Multiscale Observation Networks for Optical monitoring of Coastal waters, Lakes and Estuaries

Deliverable 2.6

MONOCLE reference sensor collection

Project Description

Funded by EU H2020 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.

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1. Executive Summary

This document summarizes the availability and market readiness of the MONOCLE reference sensor collection, which consists of high-end radiometry sensors and supporting platforms for field deployment to register hyperspectral reflectance (water colour) and atmospheric conditions. The original targets for each of the three sensor systems were met in two cases (HSP-1 and So-Rad) whereas the WISP-M is still under development, with a timeline to completion provided for marketing purposes.

The demonstration of this deliverable is provided through the project website, which provides user guidance, cost/pricing (where available) or information on the pathway to market. Additional materials targeted at specific user groups, such as instructional videos, build guides, manuals and software tools, are also collected there, either as part of this deliverable or the associated D8.5 "Set of MONOCLE documentation per stakeholder audience" and D6.3 "Software library for data inspection and statistical information extraction".

Despite some production issues, often related to the 2020/2021 COVID-19 pandemic, prototypes of each of the three systems (the WISPStation representing the WISP family of sensor systems) has had long-term field exposure, generating data sets and supporting the development of operational, standardardized data flows. This has resulted in the achievement of TRLs near, at or beyond the initially planned targets. All sensor systems now move forward into the last phase of the project which is focussed on demonstrating new and improved capabilities in the in situ segment of Copernicus, with and for selected end-user communities.

2. Scope

This document documents the availability of project deliverable D2.6, which consists of (advanced) prototypes and/or market-ready reference sensor systems to support the calibration and validation of optical satellite imagery. The availability and usage of the systems is demonstrated through links to materials on the project website: https://monocle-h2020.eu/Sensors_and_services, as specified in the next section of this document.

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3. MONOCLE reference sensors overview

Three MONOCLE reference sensor systems have been under development, as listed in Table 1. The requirements for the sensor systems are described in D4.1 “Report on performance criteria for field testing” (Riddick et al. 2018) and will be evaluated in D4.3 “Final Report Sensor Performance in the Lab and Field”.

Table 1. List of MONOCLE reference sensors

System	Developer	Measurand	Technological Readiness Level		
			Initial	Original target	Current
HSP-1	Peak Design Ltd	Global and diffuse spectral irradiance	< 4	9	7
So-Rad	PML	Water-leaving reflectance under optimal viewing angles	< 4	6	7
WISP-M	Water Insight	Water-leaving reflectance in modular (static/mobile) configuration	n/a	8	7

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3.1. Hyperspectral pyranometer HSP-1 by Peak Design

The HSP-1 (Figure 1) measures the spectrum of downwelling solar radiation, and how this is partitioned between Direct, Diffuse and Global Irradiance. This sensor provides a reference for the colour or spectral distribution of sunlight near the water's surface. The HSP-1 is designed for long-term unattended use outdoors including marine environments.

HSP-1 can be used to improve the accuracy of other sensors making direct measurements of the reflected light from the water body.

Applying HSP-1 data

- Measurements can be used to improve satellite water quality products by removing or correcting for atmospheric effects, especially in coastal or inland waters.
- Improving data products from other surface-based instruments (such as other MONOCLE instruments) where a reference is normally too expensive.
- In situations where existing equipment is difficult or impossible to use such as moving platforms, boats, buoys or aircraft.
- HSP-1 spectral measurements can be used to measure Global, Diffuse and Direct irradiances with arbitrary spectral sensitivity curves, e.g. Broadband energy, PAR, Lux, RGB etc.
- HSP-1 spectral measurements can be used to derive atmospheric parameters such as AOD, Cloud cover, precipitable water content.
- HSP-1 spectral measurements can be used to improve the extraction of water-leaving reflectance, and hence estimates of chlorophyll, sediments etc.

Figure 1 HSP-1 sensor

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Table 2. HSP-1 availability

	System	HSP1
Pathways to market	Is the sensor already available on the market?	Not yet. A limited number of prototypes are available for evaluation.
	Price	expected price range of the sensor – £12k - £15k
	Pathway to market (timeline and milestones)	Discussions are ongoing with a potential manufacturing licensee & distributor, expected to be finalised by end 2021.
	Contact:	Peak Design Ltd, john@peakdesign.co.uk
	Actual TRL	7
	Expected TRL by the end of the project	TRL Number 8 Steps needed to reach it: 1. Complete transfer of operating software from Windows PC to Single-board computer 2. Complete build of pre-production batch for sale & demonstration.
Documentation and support	Manual	Full details about the sensor are available at https://monocle-h2020.eu/Sensors_and_services/Hyperspectral_Radiometer_for_Global_Diffuse_Irra An updated manual will be available before the end of the project.
	Technical Specifications	• Spectral range 350nm – 950nm (1050nm potential) • Optical bandwidth ~3nm • Measurement – Global horizontal & Diffuse horizontal spectral irradiance, plus any additional channels • Field of View for Direct/Diffuse partition ~±5° • Measurement time ~1s • Power requirement ~10W @ 12V (reductions planned) • Internal diagnostics – enclosure RH%, Pressure, Temperature, GPS position & time, (Orientation optional) • Connectivity – Ethernet cable, (WiFi / GSM optional) • Data storage – >1 year at 1-min storage interval. • Dimensions: 230mm x 400mm x 110mm • Weight: 6kg

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	Instructions for deployment	Mounted on fixed mast, or on boat, buoy, or aircraft. The sensor should be level, with an unobstructed view of the sky. On moving platforms, an orientation sensor will be necessary for accurate correction of the measurements.
	Instructional Video	So-Rad and HSP-1 installation on MV Armorique

3.2. Solar-tracking radiometry platform (So-Rad) by PML

The So-Rad is a low-power, low cost autonomous system to obtain high-frequency water-leaving reflectance from non-stationary platforms such as ships and buoys. The So-Rad software is highly configurable and open-source. So-Rad optimizes the measurement geometry of commercially available sensors which increases the number of successful observations of water colour that can be obtained from moving platforms (Simis and Olsson 2013). It also provides full automation of sensor acquisition, data synchronization, local data buffering and upload to a remote server for downstream processing.

Hyperspectral water-leaving reflectance is used to determine diagnostic features in water colour that can be associated with phytoplankton biomass, suspended solids and dissolved organic matter concentration.

Observing in situ reflectance with sensors on the So-Rad is used to validate satellite observations, particularly the performance of algorithms that separate atmospheric and water-leaving radiance, which have high uncertainty in optically complex waters such as coastal seas and inland waters. High-quality reference measurements are required, collected under optimal observation conditions (solar and viewing azimuth, sun elevation).

Figure 2 So-Rad on a car ferry

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Added Value of So-Rad

- Off-shore satellite validation is currently limited to research vessels and fixed moorings that are costly to operate. The So-Rad can be installed on non-stationary platforms and is ideally suited to be included on merchant vessels. Ferry routes are recommended because of predictable routes and schedules. Periodic sensor maintenance (cleaning) can be easily carried out by non-expert crew.
- A high degree of automation and low-power components means the platform can be installed in remote locations for autonomous operation.
- Data processing using state-of-the-art algorithms for quality control and reflectance calculations happens within minutes after an internet connection is established, and results are available to operators and users through OGC compliant web services.

Table 3. So-Rad availability

	System	So-Rad
Pathways to the Market	Is the sensor available on the market?	Yes. PML has established a supply chain to build So-Rad units, with a lead time of 2-3 months depending on order volumes. The supply chain and cost costs stated below are for expected volumes up to 10 units per year.
	Price	• Dependant on the options included, quotes provided by PML. • The self-build cost (ex labour) is approximately €5000 Future orders (after completion of the MONOCLE project) will be considered through PML's commercial subsidiary.
	Self-build	For those interested to build their own So-Rad platform: • Refer to the open source build guide and technical drawings at Construction of the Solar-tracking Radiometry platform (So-Rad) doi: 10.5281/zenodo.4485805 • Further information available at https://monocle-h2020.eu/Sensors_and_services/Solar_tracking_radiometry_platform • PML can supply part of the solution, such as the control unit or the motor enclosure. • End-brackets (between the So-Rad and the deployment platform) are always provided by the end user, although some generic designs are available and can be supplied on request. • All software related to the So-Rad is openly available under a non-commercial license: https://github.com/monocle-h2020/so-rad

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	Contact:	Stefan Simis, stsi@pml.ac.uk
	Actual TRL	7
	Expected TRL by the end of the project	7 (planned) or 8 (series-2 production and operation)
Documentation Support	Online Resources	monocle-h2020.eu/Sensors_and_services/Solar_tracking_radiometry_platform
	Manual	User guide: So-Rad-Solar-Tracking Radiometry Platform: Deployment and Operation
	Technical Specifications	**Observed properties** (when equipped with compatible radiometers) Water-leaving radiance, sky radiance, downwelling irradiance, platform tilt, internal temperature and humidity, viewing angle, solar geometry, location and heading. **Supported sensors** TriOS RAMSES G1 (contact us to discuss other solutions) **Power consumption** Typical use: 15W Configurable for AC or DC (12/24V) power supply. Internal fuse. **Control Unit** Weight 13kg. Dimensions 400x400x150mm. Vertical mounting (tilt sensor enclosed). **Motor enclosure** Weight (without sensors): 6kg Dimensions: 560 mm H, 175 mm diameter **Intrusion protection** Enclosures have been tested in-house to withstand water intrusion equivalent to IP6.
	Instructions for deployment	Mount on a ship or buoy with a wide unobstructed view of the sea. The downwelling irradiance sensor should have a clear view of the sky in all upward directions. Installation consists of attaching the deck box, motor enclosure, and two GPS antennas.
	CE certification	The assembly meets all relevant CE certification requirements.

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3.3. WISP-M

The family of WISP (Water Insight SPectrometer) instruments (WISP-3 and WISPstation) is in MONOCLE extended with a new portable instrument with the working title 'WISP-M'. The 'M' stands for 'Mobile' and 'Modular'.

The instrument is designed and built around the proven components of the WISPstation architecture (https://doi.org/10.5281/zenodo.2533079). Prior to starting development of the final handheld WISP-M instrument, several important improvements were implemented and field tested in the WISPstation, mainly focussed at significantly lowering power consumption and improving and speeding up calibration procedures.

The WISP family of instrument all measure the light that is transmitted out of the water. The measurement is a quantitative hyperspectral measurement of the colour of the water. The new portable instrument WISP-M will share the measurement principle of the WISPstation but with the following new features: the interface of the instrument will be designed around the capabilities of a mobile phone, initiating measurements, sending and receiving data and visualisation of the results. Our current philosophy for the orientation of the instrument is that it will be kept in the correct position either by hand, by servo controlled platforms such as the So-Rad or by putting the fore-optics on a servo controlled hand-held stabilizer as used by professional photographers so the instrument can be operated manually in challenging dynamic situations such as on small boats.

While the integration of components and software is still work in progress some new capabilities can be demonstrated already such as our new visualisation app that can be used to download and visualise quality controlled calibrated measurements in real time from WISPcloud.

Optical measurements of water reflectance are used to derive water quality parameters mainly associated with ecological water quality. The WISP-3 and WISPstation instruments have been used in very clear to very turbid waters to derive Chl-a as proxy for the concentration of green algae and derived properties such as tropic state, SPM as proxy for the concentration of suspended particles and derived parameters such as turbidity/transparency. In addition, the optical measurements have been used to derive the concentration of the cyanobacterial pigment phycocyanin and to convert this into an estimate of cyanobacterial biovolume used for early warning in bathing waters. Using Machine Learning, the observed spectra are useful to derive new relationships with variables observed in the field and as a basis for predictions based on time-series extrapolation.

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Table 4. WISP-M availability

	System	WISP-M
Pathways to the Market	Is the sensor available on the market?	WISP-M is not yet on the market, the other members of the WISPfamily are available
	Price	Depending on a set of options to be chosen by the user the price will vary but will centre around €25k.
	Foreseen pathway to market:	1) Minimum viable product construction based on WISPstation- and WISP-M specific components. Updata of input- and output API's. Milestone: ready for lab testing end-September 2021 2) Proof of concept testing and updates. Milestone: approved proof of concept, unit ready for integration with mobile phone control unit (end November 2021) 3) Mobile phone control unit v0.5 (work is already in progress) (basic functionality) Milestone: instrument responds to Bluetooth triggers, takes a measurement and sends the data back to the database; data is accepted and processed (end December 2021) 4) First version of a physical design and prototype. Milestone: the instrument is successfully used in a MONOCLE campaign in spring 2022. 5) After validation of the prototype, the WISP-M will be made market ready in subsequent steps during 2022. Contact for further information: peters@waterinsight.nl

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	Contact:	pre-market inquiries can be directed to laanen@waterinsight.nl
	Actual TRL	7: Based on reusability of WISPstation components and concepts
	Expected TRL by the end of the project	8
Documentation Support	Manual	The manual of the WISP-M will be issued in first version around February 2022.
	Technical Specifications	The WISP-M shares many components with the WISPstation instrument leading to similar specifications: • Two radiance channels to measure sky and water leaving radiance. • One irradiance channel to measure downwelling irradiance • Wavelength range: 220-1100 nm • Calibrated range: 400-850 nm • Spectral resolution: approx 0.45 nm • FWHM spectral resolution: 4.65 nm • Measurement frequency: depending on user settings
	Instructions for deployment	The instructions for deployment will be issued around February 2022

4. Future activities/recommendations

This deliverable summarizes the information of the current MONOCLE reference sensor collection. Full details on the WISP-M could not yet be provided at this time, therefore plans for completion are included.

5. References

Riddick, C.A.L., et al. (2018). D4.1 Report on performance criteria for field testing. Deliverable report of project H2020 MONOCLE (grant 776480), doi: 10.5281/zenodo.1492178