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MONOCLE

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

Deliverable 2.1

Report on analysis of the requirements for MONOCLE sensors including projection of cost-savings and stakeholder feedback

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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TABLE OF CONTENTS

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

1. Executive Summary

Requirements for MONOCLE sensors were analysed at the start of sensor development, particularly with regard to projected cost-savings in monitoring and specific stakeholder feedback. The main inputs from stakeholders were obtained from the MONOCLE water quality monitoring survey (D9.1) and are used here to define sensor-specific development priorities, particularly with respect to purpose, performance, cost and interoperability. This document guides both the initial development of new sensors and evolution of existing prototypes to higher technological readiness levels.

2. Scope

The data and conclusions in this report will be primarily used by MONOCLE sensor developers to ensure that sensors are fit-for-purpose and bring added value to the sensor network developed in the project. The wider audience for this report comprises sensor developers and manufacturers and practitioners taking water quality measurements or those interested in combining in situ and remote observations.

3. Introduction

One of the main goals in MONOCLE is to improve in situ components of the GEOSS and Copernicus programmes in optically complex waters, with new sensor technological developments across a range of innovative platforms. The range of MONOCLE sensors includes systems that are focussed on reaching the highest accuracy, to determine correspondence between remote (satellite) observations and in situ reference sties, and systems focussed on increasing the spatial coverage of the network at the lowest possible cost. The latter framework includes novel deployment techniques and the potential added value of sensors developed for citizen scientists. The two directions for development are not mutually exclusive.

4. Overview of MONOCLE sensors

Eight MONOCLE sensor systems will be developed during the project. Their main features are summarized in Table 1. The sensor systems are fully described in D4.1 “Performance criteria for field testing ” (Riddick et al. 2018).

Table 1. List of MONOCLE sensors and systems

System	Developer	Priority Type (Accuracy / Spatial Coverage / low cost)	Measurement
HSP1	Peak Design Ltd	Accuracy	Global and diffuse spectral irradiance
CLAM	PML	Accuracy / low cost	Chl-*a*
Sun tracking radiance platform	PML	Accuracy / spatial coverage	Water-leaving reflectance under optimal viewing angles
WISPStation	Water Insight	Accuracy	Remote sensing reflectance (R_{rs})
Prosumer RPAS drone systems	VITO / Sitemark	Accuracy and detailed spatial coverage. Low-cost cameras also considered	Water-leaving reflectance, Total Suspended Matter (TSM) and Chlorophyll-*a* (Chl-*a*)
iSPEX	University of Leiden/DDQ	Spatial coverage at low cost	Aerosol optical thickness (AOT) and water colour (TBD)
KdUino	CSIC	Low cost / spatial coverage	Light attenuation coefficient (K_d)
FreshWater Watch	Earthwatch	Spatial coverage (microscale)	Water colour, turbidity and phosphate

5. Requirements for MONOCLE sensor systems

5.1. User requirements

Professional users (e.g. researchers and monitoring agencies) will pay particular attention to sensor performance in terms of measurement accuracy. While sensor cost versus functionality will in most cases ultimately determine the choice of sensor, the price bracket for sensors in this category is one or two orders of magnitude higher than for other users. The same principle generally applies to operational (deployment and maintenance) cost.

On the other end of the user spectrum are individuals and organisations seeking to maximize spatial cover at the lowest sensor acquisition, deployment and maintenance cost.

The following sections consider the optimization criteria for accuracy-oriented systems and cost/coverage oriented systems, respectively.

5.1.1. Measurement requirements for systems focussed on accuracy

The main measurement accuracy and precision parameters to target in 'high-end' MONOCLE systems targeting are summarized in Table 2. Target precision and accuracy for selected MONOCLE systems.

Table 2. Target precision and accuracy for selected MONOCLE systems

System	Developer	Measurement variable	Target precision	Target accuracy
HSP1	Peak Design Ltd	Global and diffuse spectral irradiance	3% - 5%	5%
CLAM	PML	Chl-a	TBD	<10%
Sun tracking radiance platform	PML	Water-leaving reflectance under optimal viewing angles	Optimal viewing angles: 1° or better	<2°
WISPStation	Water Insight	Remote sensing reflectance (Rrs)	2% (depending on illumination and wave conditions)	TBD
Prosumer RPAS	VITO / Sitemark	Water-leaving reflectance, total suspended matter and Chlorophyll-a	TBD	TBD

5.1.2. Costs considerations in systems focussed on measurement accuracy

A prominent goal in MONOCLE is to optimize the cost-efficiency of in situ sensors. Stakeholders were consulted about this aspect. The results collated from > 140 responses, mainly from practitioners in water quality monitoring, are detailed in Figure 1.

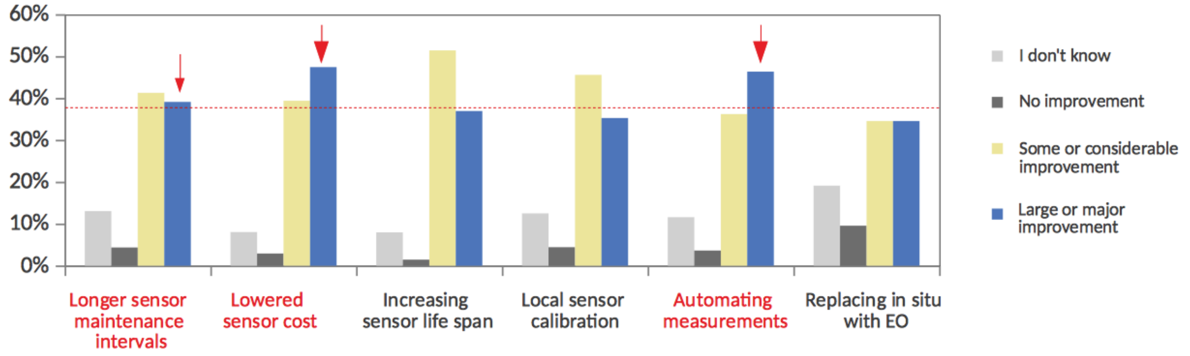

Figure 1 Results from the questionnaire (Q4): "Increasing cost-efficiency in water quality monitoring can likely be achieved through:". The most important aspects from the stakeholders has been highlighted in red

The three most important factors to increase the cost-efficiency are: (a) reducing the cost of the sensor, (b) automate measurements and (c) increase maintenance intervals (which could be translated also as reducing the operational cost). Table 3 summarizes the target reduction costs, both for acquisition and operation, for sensors developed for high accuracy.

Table 3. Acquisition and operational costs for highly accurate sensor systems

System	Acquisition cost bracket	Operational costs	Scope for cost-savings
HSP1	€10k – €15k	Minimal Annual: periodic cleaning & desiccant replacement. Calibration: €500 at 2 years. Insure for value of €10k – €15k.	The HSP1 delivers the same information as robotic sun photometers at 25% of the cost.
CLAM	€1 - €10k, depending on sensitivity options	No calibration required. Regular maintenance will include cleaning. Drift/fouling detection algorithms are intended to be developed to prompt maintenance.	The CLAM delivers the same information as laboratory analysis of chlorophyll-a extracts without the need for an analytical lab.
Sun tracking radiance platform	€5k (potentially €2k using printable parts)	TBD (negligible)	One set of radiometers is sufficient to continually collect reference radiometric measurements at optimal viewing angles. Cost-savings through higher data volumes of usable data and no need for duplicate sensors.

WISPStation	€40k	€1,500 excluding shipping, every 12 months (expected)	Cost-savings through fully automated production chain of radiometric reference measurements under favourable viewing angles, deployable at remote locations.
Prosumer RPAS drone systems	€1300 + €5000 (camera + irradiance sensor)	€125-150 / year	Cost-savings through involvement of non-experts in data collection covering micro- to mesoscale.

5.1.3. Requirements for systems focussed on wide spatial cover and low cost

The development priority for these systems is to ensure maximum participation from volunteers to cover large areas over long period of times at low cost.

As an example of previous experience within the consortium, EarthWatch demonstrates the case of the Freshwater Watch (FWW) programme with a total of 20,208 Data sets collected around the world to date (Figure 2). The FWW programme relies primarily on low-technology test kits and reporting through a mobile app. Adding low-cost sensors such as KdUINO or iSPEX to the activities fo established and new citizen scientist groups is explored during MONOCLE. Here, purchase cost for sensors is a major consideration, as well as ease of use and overcoming any cultural, age or language obstacles in the implementation of the sensor. Other factors that came out of the stakeholder analysis include the requirement to offer immediate feedback and results when measurements are contributed, and support for direct (including face-to-face) contact with the scientist in charge.

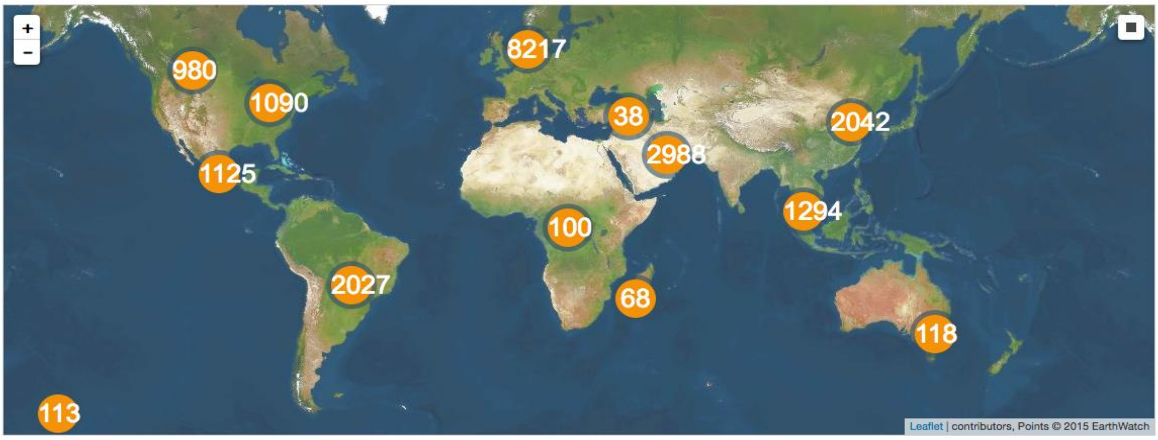

Figure 2. Contributions around the world for the Freshwater Watch program https://freshwaterwatch.thewaterhub.org/content/data-map, consulted on July 15th 2018.

To ensure wide and global participation from volunteers, opinions were gathered on the optimal sensor cost, both in terms of acquisition and maintenance. The analysis of the acquisition and maintenance cost was based on the results from two questions of the MONOCLE water quality monitoring survey (D9.1):

Q9: "Please consider your main water quality variable of interest. If a hobbyist (volunteer) were to collect complementary observations in your region, what would be a reasonable purchase price (in Euro) for a sensor they operate in this monitoring network to measure this variable"

Q10: "Thinking of the same variable and volunteer effort, what do you consider a reasonable annual cost for maintaining/calibrating (in Euro) that sensor"

The results shown in Figure 3 indicate that devices should cost no more than €100 or a fraction thereof if they have to be acquired / built by the volunteers, but could be more expensive if the instruments are provided by governing organizations. In this second case, there is no clear cost profile for a 'generic sensor'.

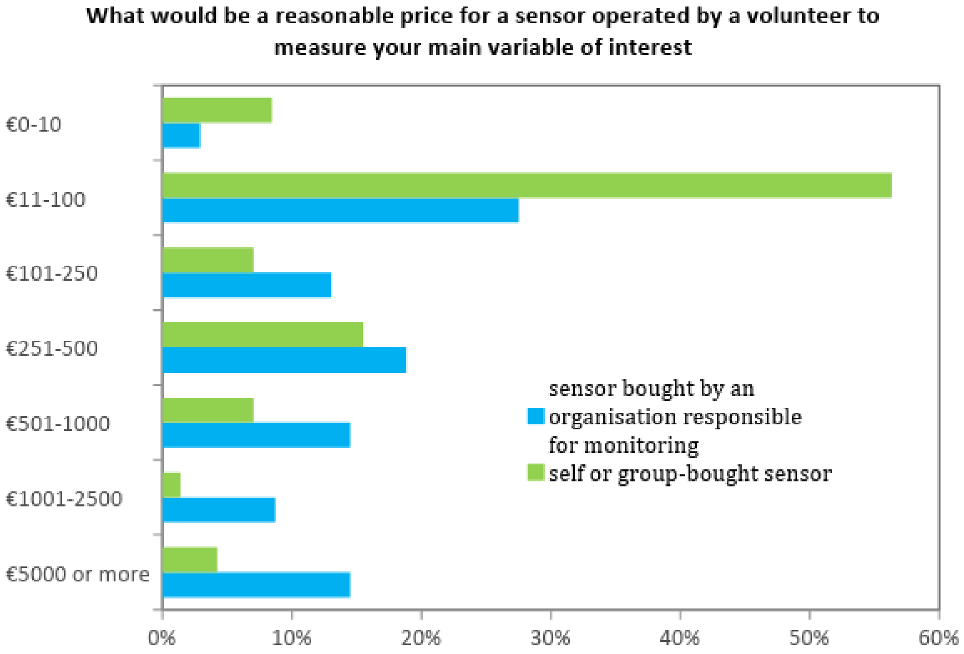

Figure 3. Results from the questionnaire (Q9): Please consider your main water quality variable of interest. If a hobbyist (volunteer) were to collect complementary observations in your region, what would be a reasonable purchase price (in Euro) for a sensor?

It is generally considered that the cost of annual sensor maintenance (Figure 4) should not exceed 10% of the purchase cost, regardless of who is responsible for covering the cost of maintenance.

From the results of the questionnaire and the expected cost of the iSPEX, FreshWater Watch and KdUino units (Table 4) we can extrapolate that KdUino is most likely to target monitoring organizations and other entities for which the purchase / building cost can be overcome. This could be the case for educational means in schools, for example, or when a unit is shared between users. The FWW and iSPEX kits are well within expected limitations for use by volunteers.

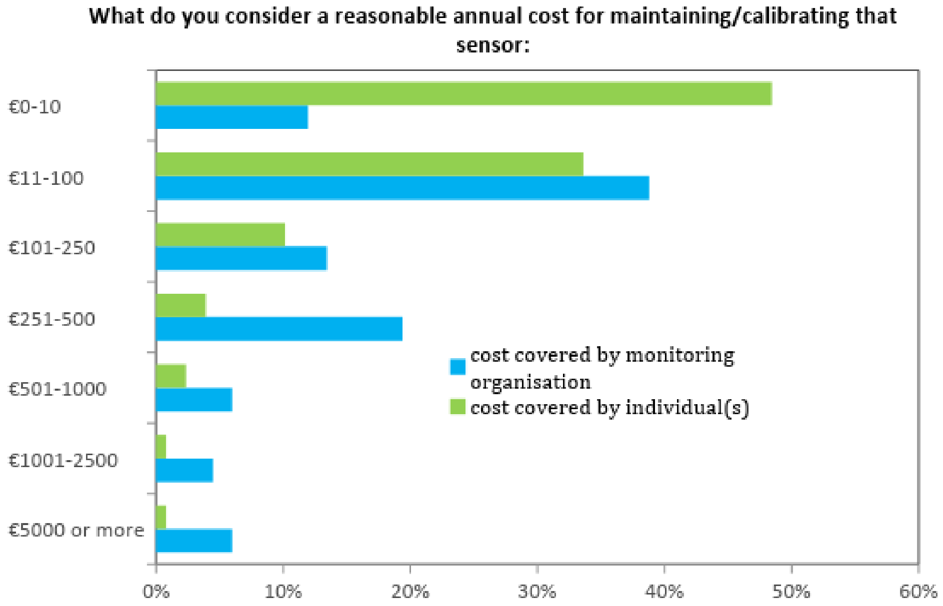

Figure 4. Results from the questionnaire (Q10): Thinking of the same variable and volunteer effort, what do you consider a reasonable annual cost for maintaining/calibrating (in Euro) that sensor?

Table 4. Acquisition and operational costs for SC-systems

System	Acquisition unit cost (indicative)	Operational cost
iSPEX	~10€	None
KdUino	< €150	Minimal (device cleaning, charging batteries)
FreshWater Watch	€30	None

5.1.4. Precision and Accuracy in the low cost / high coverage systems

Previous results with iSPEX (Snik et al. 2012) illustrate that it is necessary to average over several (~10-20) iSPEX measurements to obtain sufficient accuracy for the AOT (±0.1), because individual measurements are subject to significant errors (mostly related to using different smartphone cameras). The iSPEX add-on should therefore not *a priori* be considered a stand-alone instrument, but used in coordinated citizen science campaigns and / or within the context of multiple measurements, as shall be explored in Work Package 6. MONOCLE will enhance the existing iSPEX with spectropolarimetry to obtain quantitative and unbiased measures of water colour, and potentially spectral features related to specific constituents and pollutants, which can all be obtained in relatively simple and low-cost manners by citizen scientists.

The MONOCLE KdUINO version will work with a new sensor. The design of the KdUINO in MONOCLE has been conceived as an improvement of a previous version (Bardaji et al. 2016) developed in the framework of the FP7 CITCLOPS project (www.citclops.eu). One of the first requirements for the new instrument is to have the capability to provide the light extinction coefficient in three different colour bands (RGB). The new sensor selected provides four different measurements: the three color components (RGB) plus an integrated value. Preliminary laboratory test (Figure 5) show that the light extinction coefficient could be retrieved with similar accuracy to those reported for the first sensor (Bardaji et al. 2016).

The main challenge for the new KdUINO in MONOCLE is to engage enough volunteers to deploy units in a large number of locations. In this sense the major goals will be to optimize the prize, to use the most accessible materials (for the DIY version) and to improve usability aspects (for observation retrieval and maintenance). Weight and portability are further aspects to optimize, so that a unit can be carried to more remote locations.

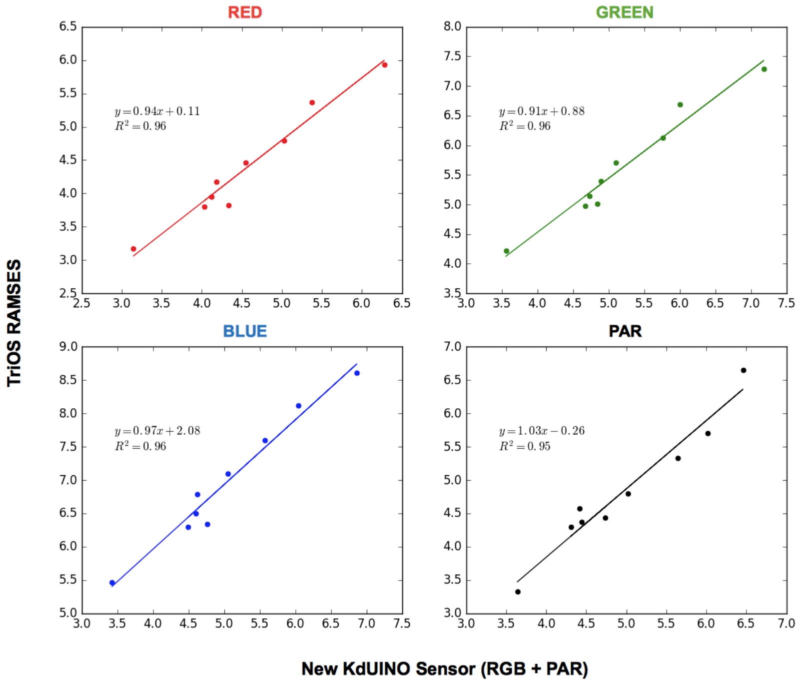

Figure 5. Preliminary tests to compare (RGB+PAR) light extinction coefficients of the new KdUINO sensor using TriOS RAMSES radiometers as reference

FreshWater Watch participants record the water quality of rivers, lakes and large stream using a field testing kit rather than sensors. Participants test for nutrients (phosphate and nitrate) and turbidity which are indicators of water quality, and record contextual observations like vegetation cover, surrounding land-use, presence or absence of pollution sources, litter, algal growth to identify potential drivers and causes of the observed water quality (detailed information in D4.1). The nitrate and phosphate methodology is based on standard colorimetric approaches and have been assessed for accuracy using traditional laboratory measurements (Skalar SAN++ auto-analyser) in laboratories at CEH (UK), Trent University (CA), University of Siena (IT) and FHT (UK). Quality control of individual lot numbers is performed by the manufacturer and by Earthwatch. Turbidity is measured using calibrated Secchi (turbidity) tubes with a measurement range between 14-240 NTU. Secondary observational data of water colour (categories), the presence of algae are used to validate reported turbidity measurements automatically (as automatic feedback to citizen scientists after uploading measurements) and manually by Earthwatch during the monthly QA/QC exercise.

5.1.5. Other operational requirements

Sampling frequency

Another set of survey questions addressed the required, desired, and current sampling frequency of in situ sensors. A clear difference in the responses was observed between the regulatory requirements (monthly to quarterly dominated the response), how often sampling actually takes place (monthly was most common), and the sampling frequency that would be most descriptive of the variability of the system (weekly to hourly). The results are detailed in Figure 6.

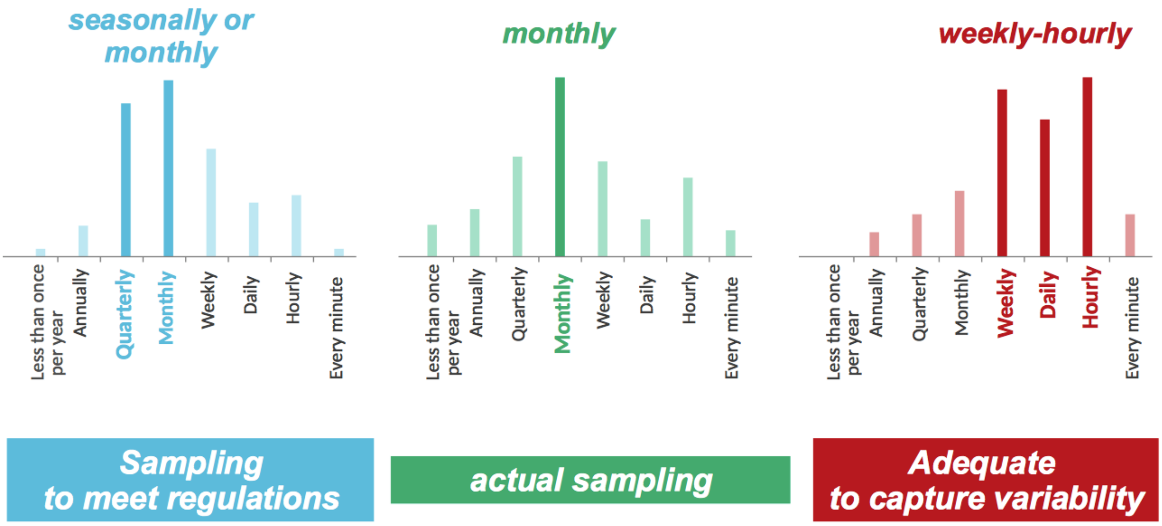

Figure 6. Survey response for questions regarding the regulatory requirement for sampling frequency, actual frequency, and adequate frequency

The major conclusion from stakeholder response is that we need to adapt the sampling frequency to the main objectives of the monitoring programs. Table 5 lists the expected capability of the different MONOCLE sensors to achieve the desired sampling frequencies.

The systems that ensure sampling at weekly-hourly frequencies over longer periods of time are those based on autonomous installations (HSP1, the Sun tracking radiance platform and the WISPStation). Instruments that are in contact with water, such as the CLAM or fluorometers and turbidity probes supported through a network interface for legacy sensors could also be included in these systems, once they reaches the intended TRL. However, considering their higher maintenance requirement, the observation sites will likely be limited to those that are easily accessible. Data from such sensors may capture the temporal variability at those selected sites, but they are less likely to capture regional spatial variability.

Thus, a clear opportunity exists to add systems focussed on increasing spatial coverage, notably by engaging volunteers to report microscale observations, even at high frequency. Such activities require an engagement strategy, particularly if daily observations are desired. This may be achieved in different scenarios: for example by incorporating observations in educational programs at schools, or supporting rewards systems (gamification, open rankings of participation, etc). Such engagement programmes are not a direct objective of the MONOCLE project but supporting them with a highly flexible user interface is. This will be achieved in part by providing open source solutions for the mobile apps and data integration algorithms, and by supporting near real-time data exchange between users and the MONOCLE data backbone (more details in D5.2, "System architecture and standards report"). It is therefore a clear requirement for all mobile and handheld MONOCLE solutions to support the interoperability standards and communication protocols for near real-time and buffered data transmission implemented in MONOCLE.

Table 5. Sampling capabilities of MONOCLE sensors and systems: (1) Achievable, (2) Only during certain periods, (3) Achievable, but with some operational constraints

Main R&D focus	System	Seasonally	Monthly	weekly-hourly
Accuracy	HSP1	1	1	1
	CLAM	1	1	1
	Sun tracking radiance platform	1	1	1
	WISPStation	1	1	1
	Prosumer RPAS drone systems	1	3 (In operational programs)	2 (during dedicated campaigns)
Spatial Cover	iSPEX	1	1	3 (volunteer engagement)
	KdUino	1	1	3 (volunteer engagement)
	FreshWater Watch	1	1	3 (volunteer engagement)

5.2. Planned instrument improvements

5.2.1. Improvement priorities per sensor

HSP1

Hyperspectral measurements. The MONOCLE instrument will be developed as a hyperspectral sensor based on a previous broadband radiometer, the SPN1 (Wood et al., 1999; Wood et al., 2017). The system will be developed to ensure the highest quality of hyperspectral data, e.g. by introducing stray light correction in data post-processing.

Interoperability. Since the HSP1 will also be used as a reference sensor for other instruments in the project, one of the goals is to improve the data interoperability with the rest of the MONOCLE sensors. This is linked to WP5 “Sensor Interoperability and Data Integration- activities”.

TRL & Cost. The current prototypes will be developed to final production readiness, with attention to reducing cost, where possible. Weatherproofing will also be further improved.

CLAM

Measurement Quality. Measurement range and precision are to be tested and will feed back into the development cycle, while target performance accuracy will be 10% uncertainty/offset. Reference concentrations of Chl-a with accredited laboratory analysis of (e.g. High Performance Liquid Chromatography (HPLC)) will be used to validate the measurements.

Field operation. At present the prototype is not waterproof nor splashproof and it requires mains power to be operated. Improvements will be made to ensure that the instrument can operate under the typical conditions of field measurements (e.g. from small boats).

Cost. The first prototype will aim at high accuracy allowing for higher cost. Further prototypes to lower cost will then be considered. Elements such as light source, detector and sampling capacity will be considered.

Interoperability. Full compatibility with MONOCLE back-end interfaces for sensor synchronization, remote triggering, and data logging will be pursued in partnership with a manufacturer.

Solar tracking radiance platform

Interoperability. The solar tracking radiance platform will be used to collect reference data sets in the project. Therefore one of the goals is to improve the data interoperability with the rest of the MONOCLE sensors as well as existing radiometers. This work links to WP5 – Sensor Interoperability and Data Integration activities.

TRL and cost. A major aim for this sensor system is to follow an open design concept, with blueprints and 3d-designs available for further development by the wider community. A pre-assembled kit may be made available at cost, depending on market demand and manufacturing agreements. A light-weight version based on 3d printed components is also intended, if this proves to be feasible and simultaneously reduces cost. Such designs will be brought to TRL 7.

WISPStation

Measurement Quality. Measurements will be validated against other high-end calibrated field spectroradiometers (e.g. TriOS Ramses). Measurement precision is 2%, depending on the ambient light and wave conditions) and target performance accuracy will be determined during the MONOCLE campaigns

Interoperability. Full compatibility with MONOCLE back-end interfaces will be implemented.

Prosumer Remotely Piloted Aircraft Systems

Cost reduction. Based on the questionnaire response, a hyperspectral camera is likely too expensive for operational use and will remain the domain of research for algorithm development and sensor design. With the evolution of technology, this might become affordable in the future. The development of a solution based on RGB cameras mounted under a commercial drone with self-made brackets (e.g. from 3D printing) fits the intended cost profile for 'prosumer' users and monitoring organisations alike.

Investigations are needed on the use of irradiance sensors or calibration panels, including lower-cost designs (e.g. painted panels using dedicated paint with known reflectance values). The primary goal for this development is to set up a multispectral camera in combination with an irradiance sensor mounted under/on a drone, which could be affordable for monitoring organisations together with an off-the-shelve calibration panel.

iSPEX

Observation uncertainty. The main source of uncertainty for iSPEX measurements is the behaviour of different smartphone cameras and associated operating software. A general assessment of performance for different popular (e.g. Apple, Samsung) smartphone cameras will therefore be made first, with specific focus on RGB profiles and white balance.

Information retrieval from water surface. To further assess the potential to retrieve water colour from iSPEX, the spectroscopy will be combined with RGB imaging to perform quantitative measurements of broadband spectral features (e.g. blackbody light sources with different temperatures). Next, we will investigate the fidelity of detecting spectral features (e.g. chlorophyll absorption) to further characterize water bodies based on the concentrations of optically active components.

KdUINO

Measurement robustness. One of the main challenges to retrieve water transparency near the surface is the light fluctuations generated by the effect of the surface waves. The field results obtained by Darecki et al. (2011) points out the potential high-frequency light fluctuations that could be induced by water surface waves, with changes of order of magnitude in the range of minute variations. This effect could be critical then for KdUINO sensors, and dedicated methodologies for data acquisition and post-processing will be developed to minimize the wave light focussing effect.

Usability, accessibility and interoperability. Improvements will be done to ensure that user requirements to acquire and transmit observations and to maintain the instrument will be minimal.

The DIY instrument version will be designed with low-cost components since price and unavailability will be the main barriers for makers, particularly in developing countries.

FreshWater Watch

Quality Control. The test and validation campaigns within MONOCLE WP4 allow to improve the precision and accuracy and evaluate the performance of the field kits in relation to various sensors using EO techniques. We aim to evaluate the accuracy and precision of all key parameters in a range of ecosystems during these campaigns. The integration of autonomous in situ water quality sensors within citizen observatory networks will allow a continued validation of the collected citizen science data at several key sites (e.g. Sweden and Tanzania). The collaboration with partners developing citizen science sensors to measure water colour (iSpex) and turbidity (KdUINO) provides data exchange opportunities (interoperability) but also the potential integration of automated water colour measurements to lower the subjectivity in the present data collection method. At the end of the project, we expect FreshWater Watch tools to be a (calibrated) and complementary approach to evaluate water quality of lakes, rivers and transitional waters by citizens alongside a network of low cost EO sensors to improve spatial and temporal coverage.

5.2.2. Improvements summary

Design improvement priorities from the previous section are summarized in Table 6. Sensor interoperatibility and cost are commonly taken onboard as the main development priorities, reflecting the scoping of user requirements and overarching aims of the MONOCLE project.

Table 6. Summary of the aspects to improve during MONOCLE for each instrument

Systems	Acquisition cost	Operational cost	Data quality	Field operability	Power requirements	User friendliness	Engagement	Interoperability	Spectral resolution	Accessibility (DIY)
HSP1	x							x	x	
CLAM	x		x	x				x		
Sun tracking radiance platform	x	x		x	x	x		x		
WISPStation			x					x		
Prosumer RPAS drone systems	x	x	x					x		

iSPEX			x				x	x		
KdUino	x		x		x	x	x	x	x	x
FreshWater Watch							x	x		

6. Exploitation and dissemination

This report will be advertised on the MONOCLE website and disseminated with a communication package towards relevant (H2020) projects, agencies and service operators. The relevant improvements of the developed instruments will be communicated internally and externally for potential benchmarking of new commercial instrumentation.

7. Complementary actions

This section includes a number of complementary actions which may be considered in the first MONOCLE sensor development and testing phase.

7.1. Modelling sensor response to evaluate sensor requirements and designs

One way to further evaluate the requirements of individual sensors is to use numerical simulations to create different theoretical (and fully controlled) measuring scenarios to obtain measurements of reference that can be compared later with simulated measurements from the different sensor configurations.

a) Generation of theoretical measuring scenarios. The theoretical measurement scenarios could be generated by simulating the optical properties of the different bodies of water according to the concentrations of optically active components (OAC: chlorophyll, coloured dissolved organic matter (CDOM) and sediments) in the water, environmental conditions (sun position, cloud cover, wind speed) and properties of the water column (depth, bottom type). The simulations will be carried out with the radiative transfer numerical model HydroLight (Mobley, 1989), which calculates distributions of optical properties (radiances) and related quantities (irradiance, reflectance, diffuse attenuation functions, etc.) in any body of water.

Users can specify the water absorption and scattering properties, the sky conditions, and the bottom boundary conditions in various ways, e.g., by selection of built-in bio-optical and sky models, by reading in user-supplied data, or by writing their own Fortran subroutines to define their input. HydroLight then solves the scalar radiative transfer equation (RTE) to compute the in-water radiance as a function of depth, direction, and wavelength. Other quantities of interest to optical oceanographers, such as the water-leaving radiance and remote-sensing reflectance, are also obtained from the computed radiances (Mobley, 1999). The output is presented as text files that can be incorporated later into their own routines. HydroLight can serve as a controlled environment to predict what the light field received by a sensor would be under a wide range of conditions. Such control of the environment and of simulated noise cannot be obtained in the field, which is best used for final testing and evaluation of sensors that were first designed using numerical simulations.

b) Modeling the response of the sensor. The output of the Hydrolight simulations will provide the reference optical properties. The outputs from Hydrolight are transformed to the measurements that we expect from the sensors based on their modelled response. The sensor response model will be designed considering different technical specifications such as spectral response, sensitivity, signal noise ratio, stability, temperature dependence, etc. ...

The result of this model will provide us the optical measurements we can obtain with the sensors and evaluate its performance. In Figure 7 we show the outputs of simulating two water bodies with different compositions (dominated in each case by phytoplankton or sediments), the result (Apparent Optical properties, AOP) that would be obtained in the first simulation and two possible outputs of the models of sensors: one for a multispectral sensor - of 6 bands - and the other with a commercial sensor of color (RGB)

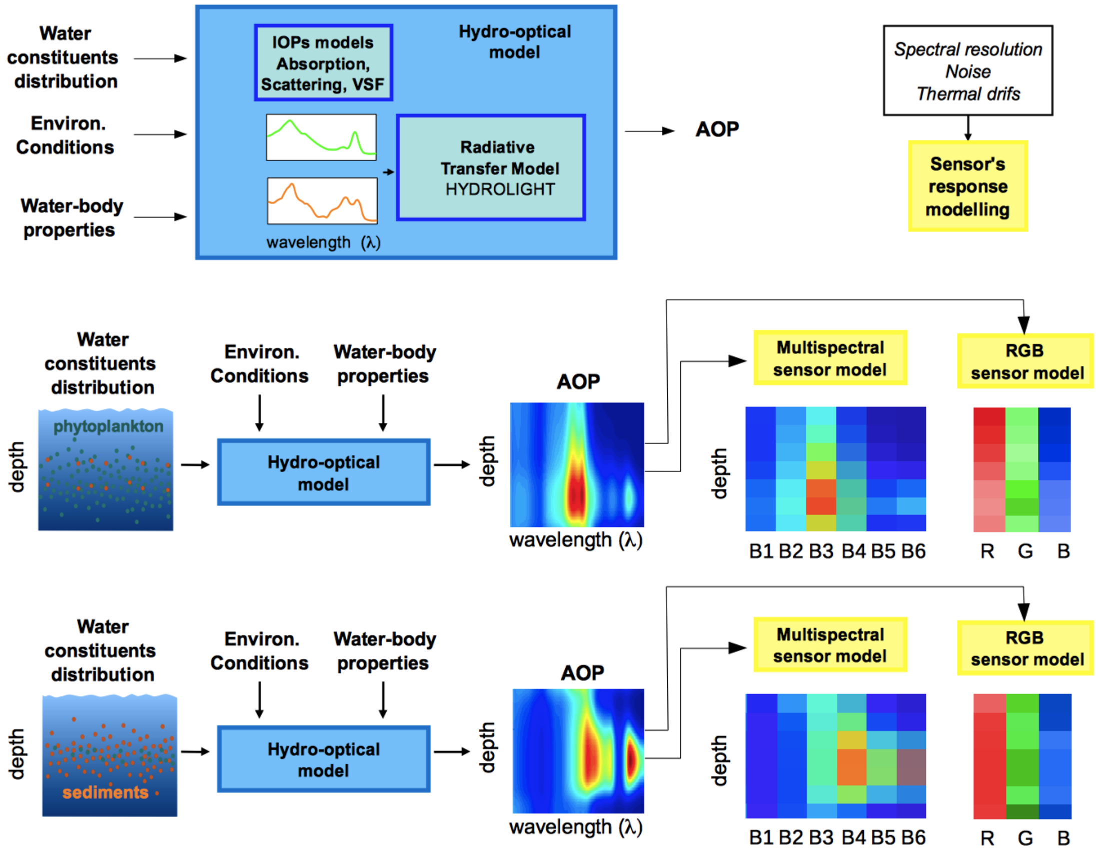

Figure 7 Schematic diagram of how we could obtain the final simulated optical measurements of different devices. In these examples there are the comparison between a multispectral sensor and another with only RGB channels

A modelling case example: Redesigning KdUINO

In order to evaluate the performance of the new sensor, a first test has been developed and summarized in Figure 6. The outputs to compare are the results from PCA analysis of theoretical measurements in different water bodies with different concentrations of chlorophyll and colour dissolved organic matter (CDOM). Top and bottom plots provide the same information, but on the top (green background) dots are coloured according the chlorophyll concentration in each case and bottom (light orange background) dots are coloured according to the CDOM concentration. The plots on the left (red axes) shows the result of the reference classification, obtained with the analysis of the outputs provided by the Hydrolight simulation in each case. In this case we assume the measurements were obtained with the highest spectral resolution possible (hyperspectral), with the highest vertical resolution (measurements every 2 cm) and error free. Three different groups can be distinguished (marked in dotted lines) that corresponds to (high levels of chlorophyll, low levels of CDOM) at the top, (low levels of chlorophyll, low levels of CDOM) bottom left, and (low levels of chlorophyll, high levels of CDOM) bottom right. We could consider that our new device should be designed to identify, at least this three different groups of water bodies.

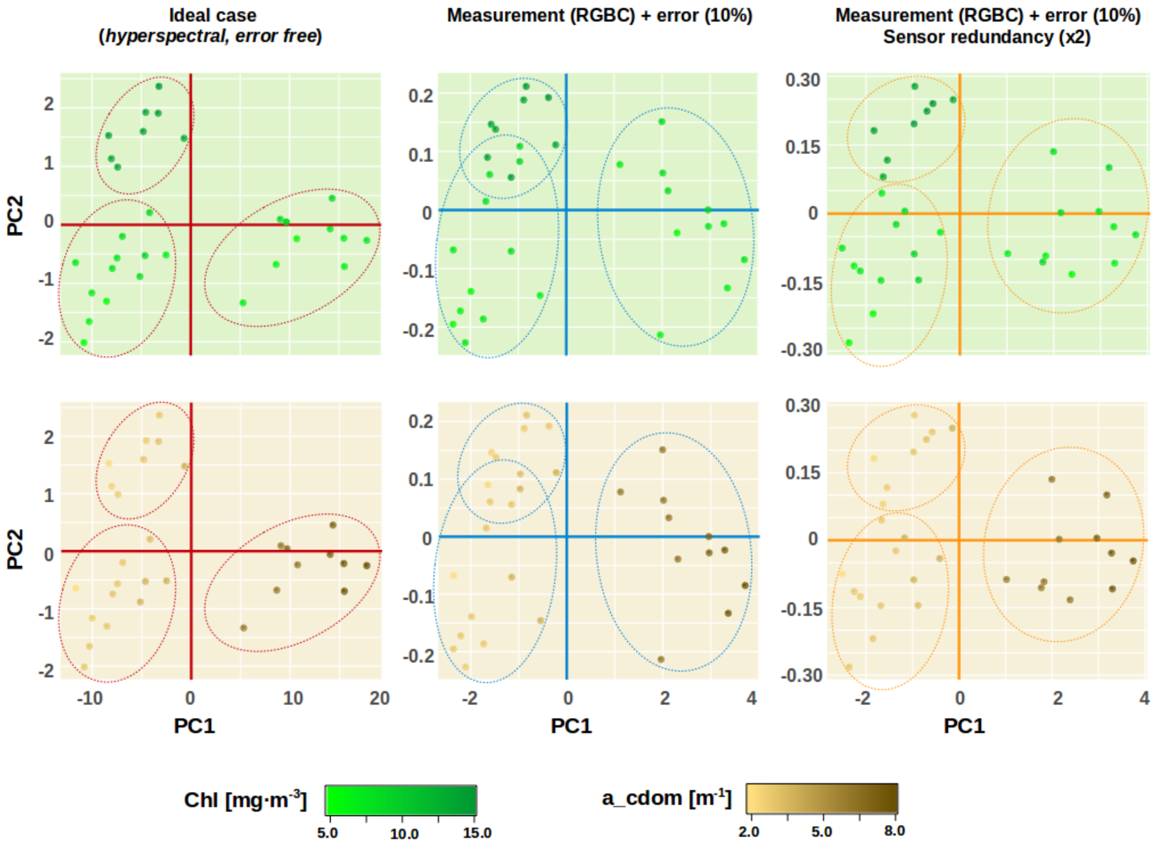

Figure 8 Example of the requirements evaluation for the new version of KdUINO using the outputs from the numerical models. The simulations provide the data for classifying different water bodies based on the PCA analysis of the Kd measurements obtained

The middle plots (blue axes) corresponds to the classification obtained with the first proposed configuration for the new instrument: four sensors at different depth. The sensors provide four different channels (RGB + TOTAL), and the spectral response has been modelled based on provider specifications. The sensor uncertainties have been modelled adding a random signal that generates errors up to 10% of the original measurement. According to the results, we could discard this configuration since it would not be able to separate the three groups as in the reference case.

The right plots (orange axes) provide the results for the second proposed implementation, very similar to the first proposal but adding sensors redundancy (two sensors at each depth), which will reduce measurement uncertainty. This solution could be accepted since it would be possible to identify the three different groups of water bodies.

This example shows the potential of numerical simulations on deciding the design of the new instruments to find the optimal solution between technical challenges and stakeholder requirements.

7.2. Volunteer engagement strategies for wide spatial coverage systems

The potential complementarity of systems focussed on low-cost, wide spatial coverage has been already pointed out in previous sections of the document, but it worthwhile to consider the role of volunteers and the way to support long-term engagement in instrument design.

Stakeholders were consulted (Q30) on eight different aspects of monitoring in which citizen science could play a potential role. Figure 9 shows the responses. There is a global agreement of the potential role of citizen science, on five aspects (above red dotted line in Figure 9) more than 65% of the stakeholders consider that citizen science could be suitable and in two of them (above blue dotted line in Figure 9) the agreement was higher than 80%: (a) expanding spatiotemporal coverage and (b) large-scale campaigns.

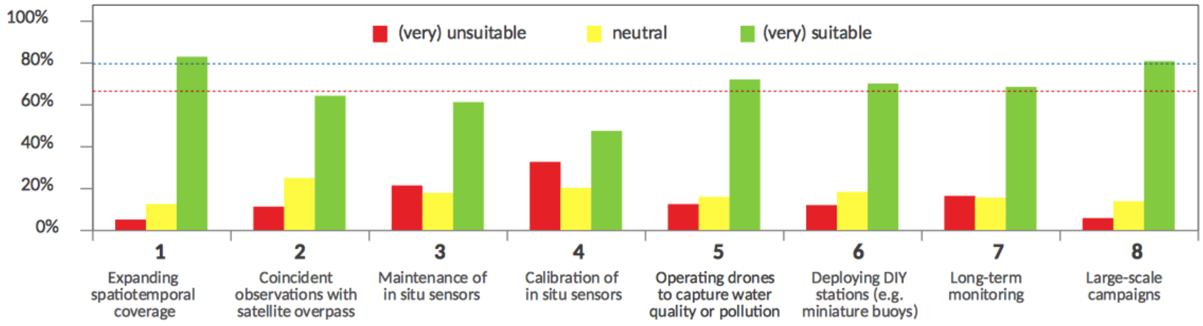

Figure 9 Results of the questionaire (Q30) "How suitable do you consider citizen science in water quality monitoring in the following situations?"

One of the goals should be then to think on promoting the consolidation of a community of volunteers that will collaborate in providing (and/or validating when possible) observations with MONOCLE tools. This links closely to a growing understanding of the importance of managing citizen scientist communities in environmental monitoring (e.g. Conrad and Hilchey 2011 and references therein). In MONOCLE only the FreshWater Watch programme maintains such communities. There has been some large-scale events using iSPEX (Light2015) and some school participation for KdUINO

(Bardaji et al. 2016) in previous projects. Ideally, these experiences are consolidated within the tools for community engagement provided with MONOCLE systems.

Stakeholders were also consulted to define the best methods to communicate with the community of volunteers. Figure 10 shows the results, in which there is a clear preference for choosing existing social networks and tools. These channels could be very effective to establish links among the volunteers, but it could be very challenging to develop collaborative validation systems using them, since there is little control of the offered services given that there are external tools. It is recommendable to evaluate existing social platforms in citizen science that could be adapted to MONOCLE objectives and goals.

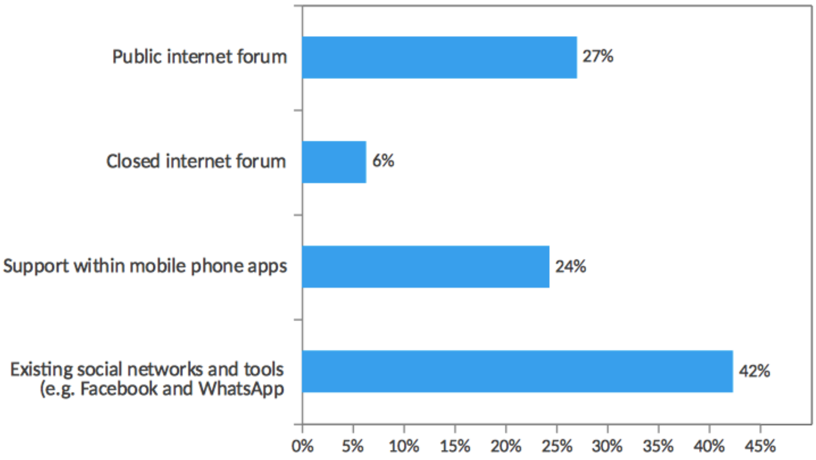

Figure 10 Results from (Q32) of the survey: What is the optimal way to support communication between participants in Citizen Science projects? (select the most representative option)

8. References

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