MONOCLE

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

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

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

Part 1: Challenges and opportunities in optical sensing of water quality

Stefan Simis, Xiaohan Liu, Mark Warren, Nick Selmes
(Plymouth Marine Laboratory)

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Requirements: observation frequency

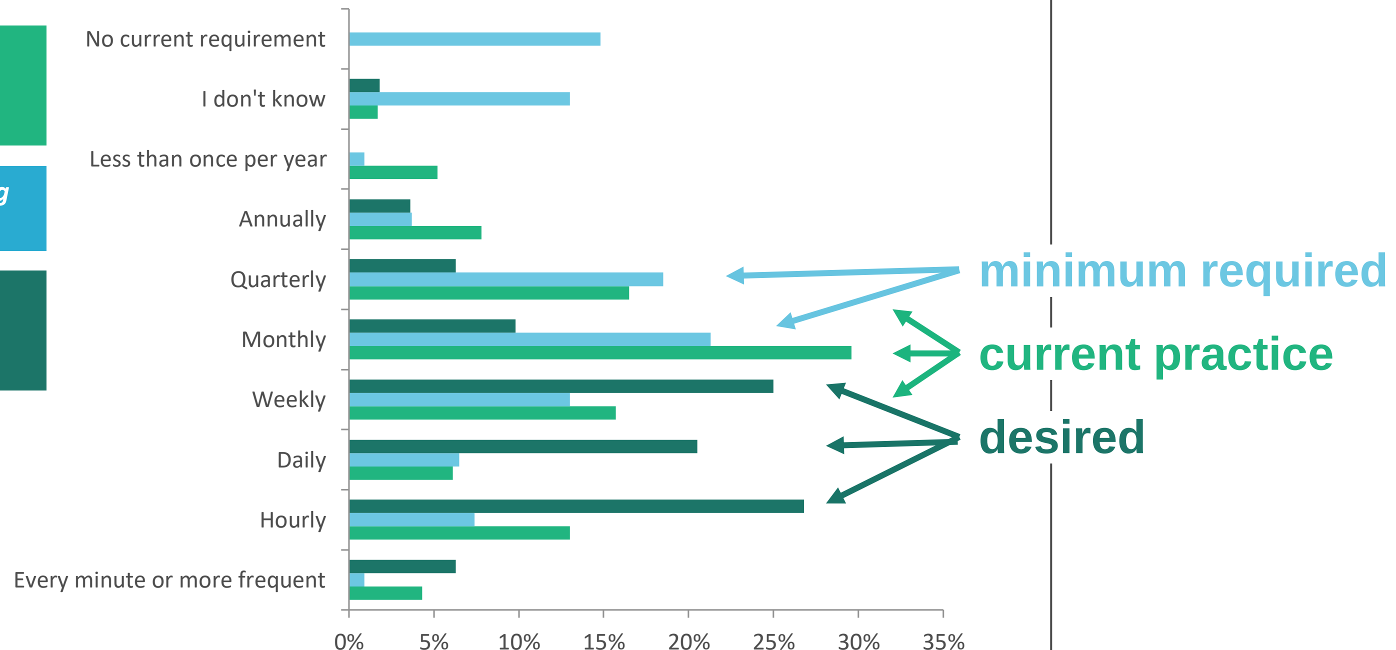
Survey results – water sampling

Sampling frequency

How frequently do you sample the variable which you consider most important?

What is the minimum required sampling frequency to meet regulations?

What do you consider an adequate sampling frequency to capture variability?

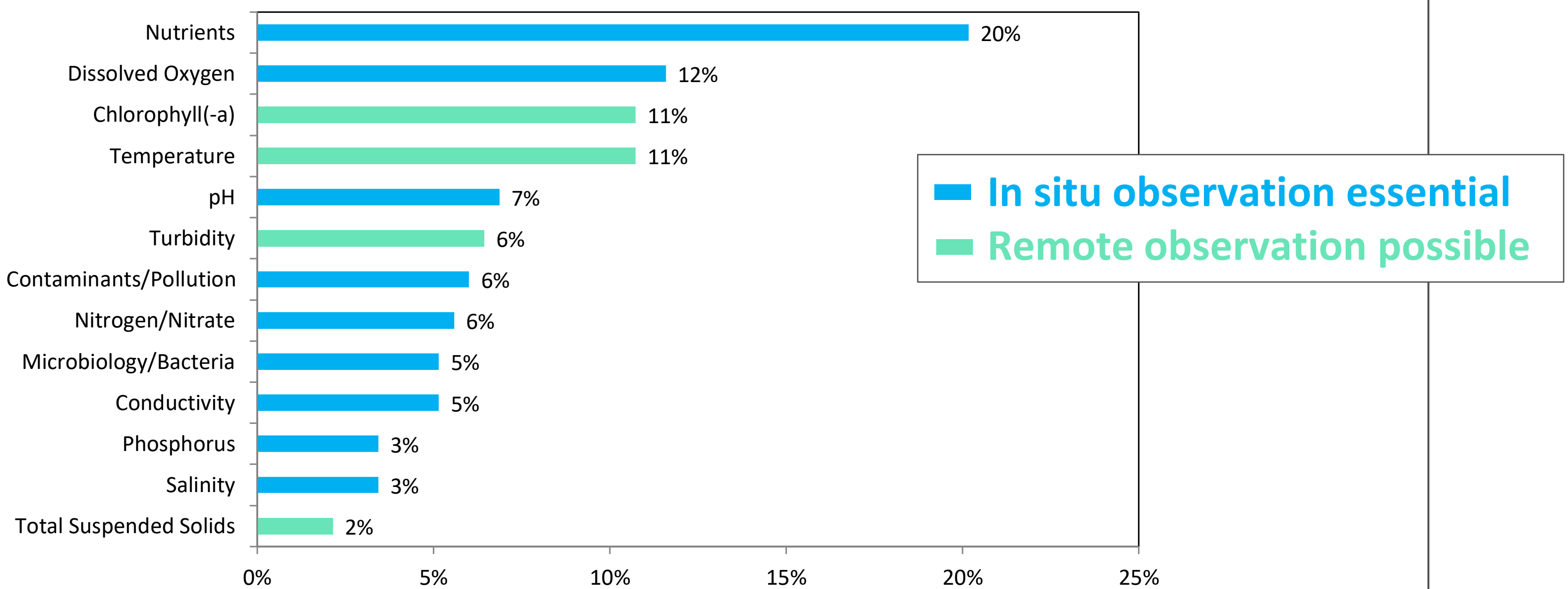


Monthly sampling is most common and corresponds to the sampling frequency required by regulations. However, hourly to weekly sampling is considered required to adequately capture natural variability.

Requirements: measurands

Required Water Quality data

Which of the water quality variables sampled in your region do you consider to be the most relevant?



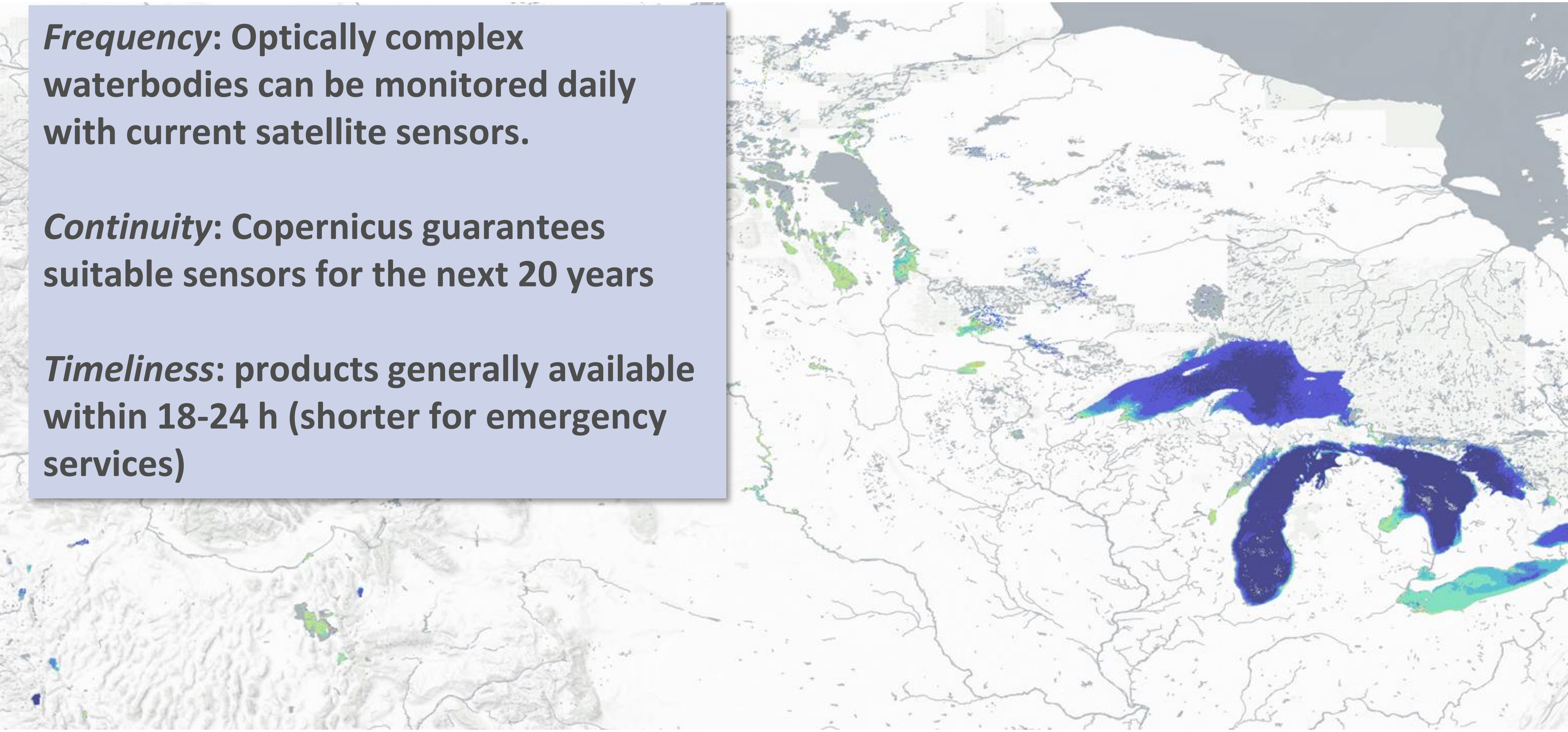
Nutrients are by far the most desired water quality variables, followed by other chemical and biological variables, of which some (in green) can also be derived from remote sensor observations.

Satellite observation solutions

Frequency: Optically complex waterbodies can be monitored daily with current satellite sensors.

Continuity: Copernicus guarantees suitable sensors for the next 20 years

Timeliness: products generally available within 18-24 h (shorter for emergency services)

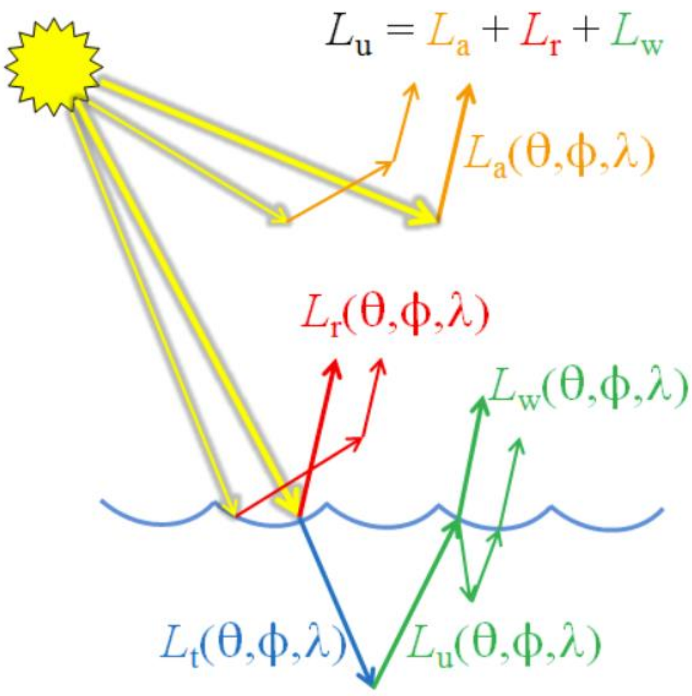


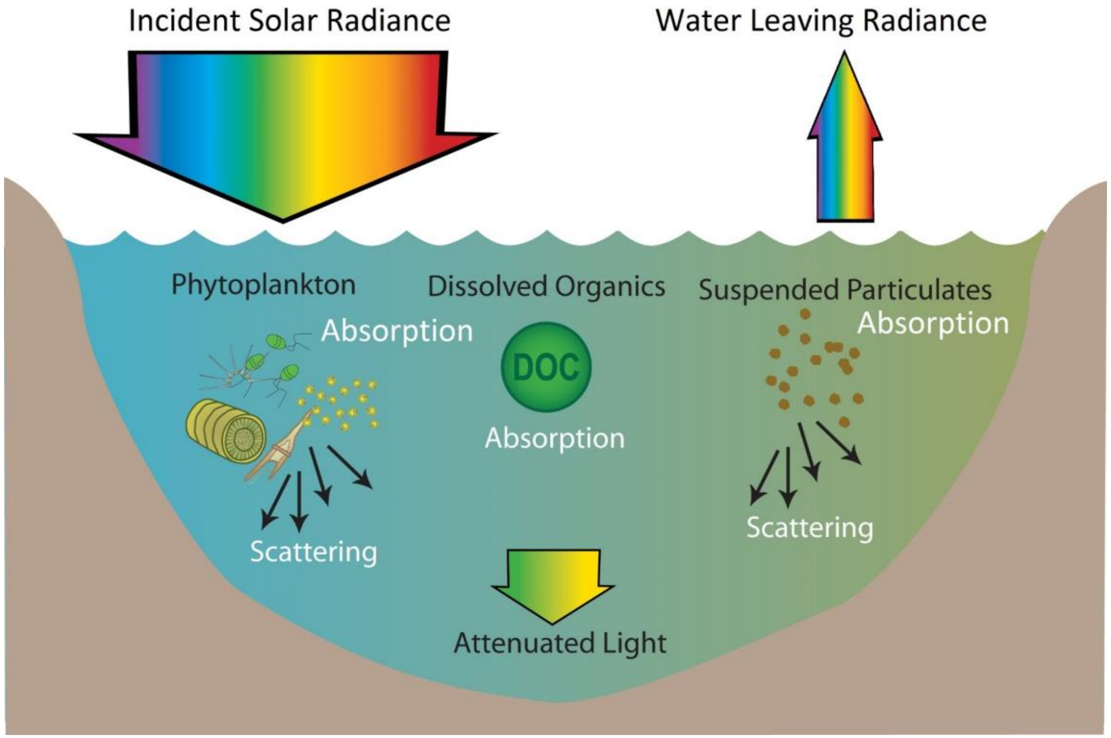
Background: Copernicus Land Monitoring Service, Trophic State Index on 1 May 2018 from ESA OLCI, generated at Plymouth Marine Laboratory

How does it work?

Radiance-reflectance is the fraction of downwelling sunlight that passes back through the water-air interface.

In the water column, absorption, scattering and fluorescence alter the *angular* and *spectral* structure of the light.





The *inverse problem* attributes absorption and scattering processes following the observation of radiance-reflectance.

The inverse problem becomes ambiguous when optical processed are not coupled – '**optically complex** waters'.

How do we do that?

Current state of the art

(As used in Copernicus Land services, ESA Climate Change Initiative)

Calimnos produces:

Essential Climate Variable:

Lake water-leaving reflectance

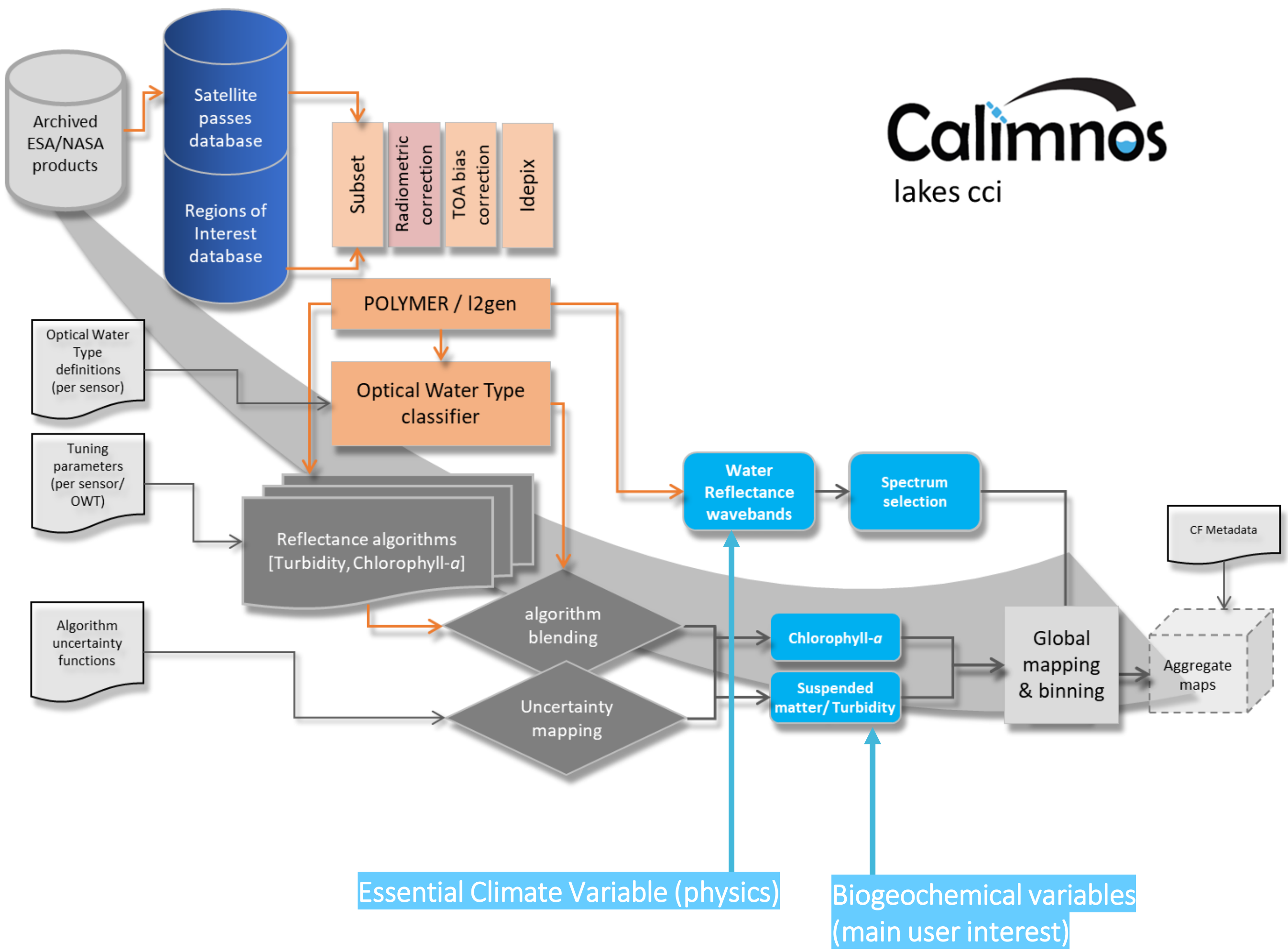
Derived products:

Optical Water Type membership

Chlorophyll-*a*

Turbidity

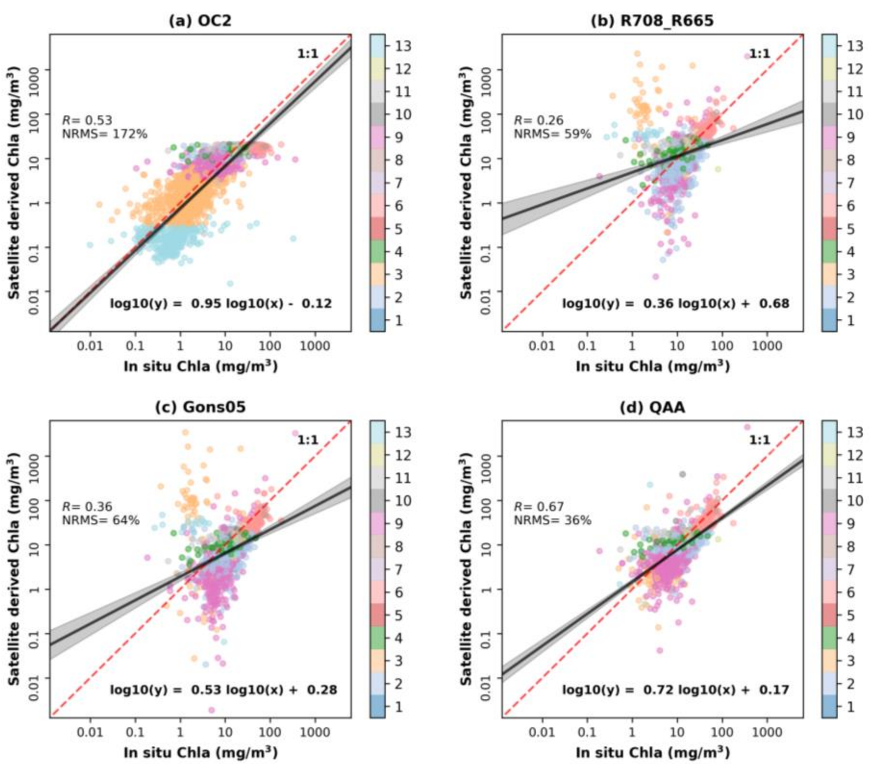
Uncertainties



How well does this work (globally)?

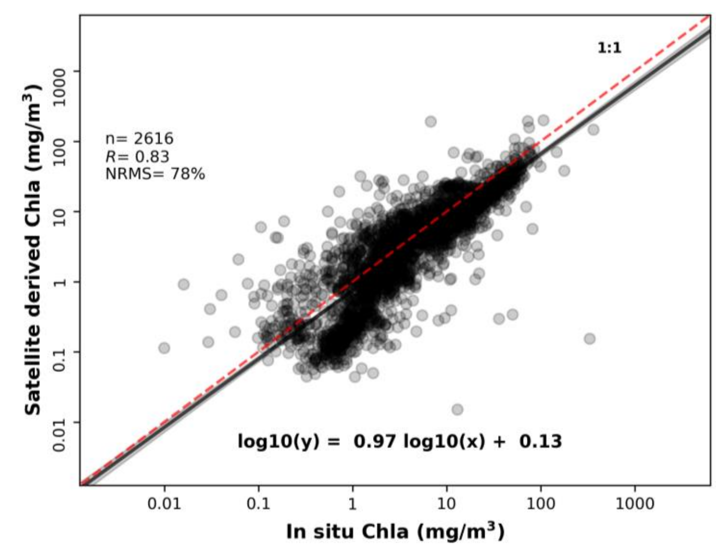
As used in Copernicus Land services, ESA Climate Change Initiative

Individual, globally optimised **Chlorophyll-*a*** algorithms across 13 Optical Water Types



Weighted-blending

Per-matchup blended result based on optical water type class membership

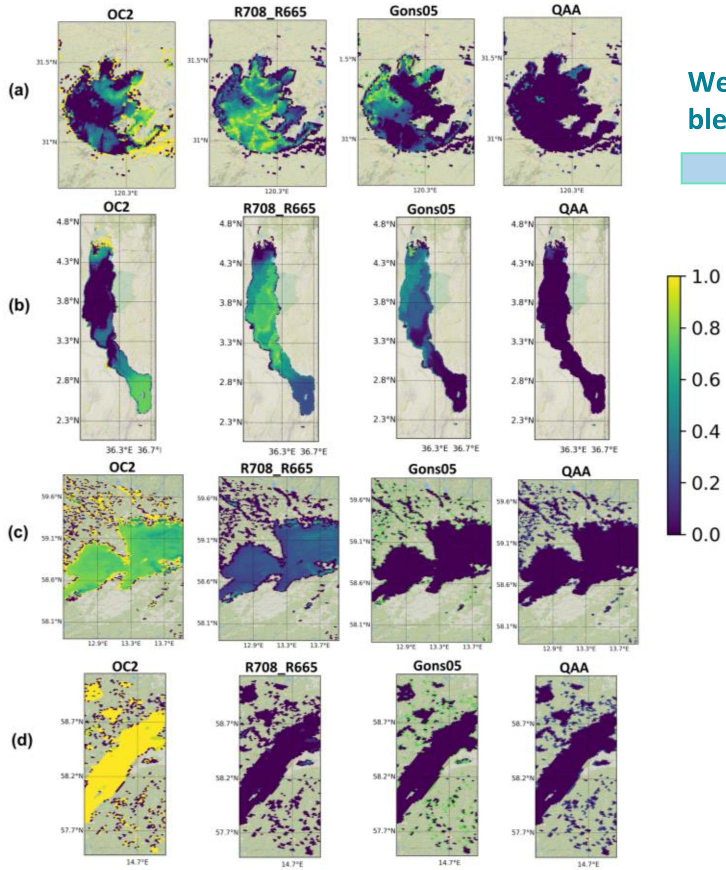


Global merged chlorophyll-*a* mapping provides reasonable linearity, 78% NRMS estimated error, over > 3 orders of magnitude. Low concentration range is problematic.

PML | Liu et al. *in press*
Remote Sensing of Environment

What does that look like?

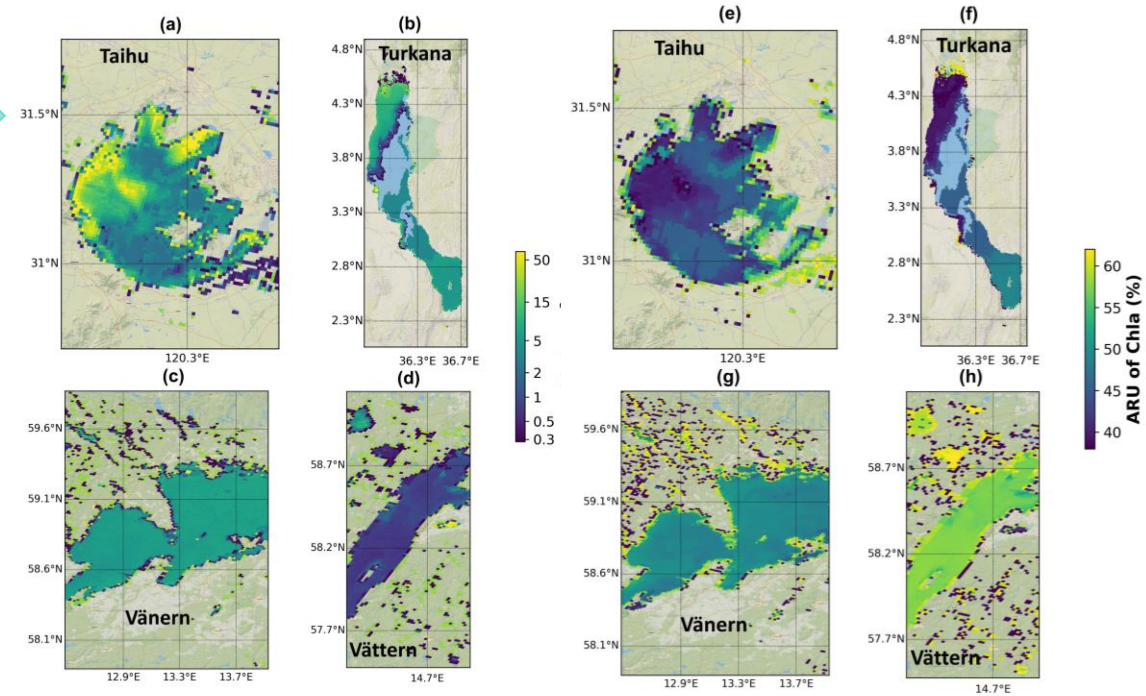
Weight assigned to each algorithm in the blended chlorophyll-a product



Weighted-blending

Multi-algorithm blended chlorophyll-*a* product from *Calimnos*-MERIS

Product Uncertainty



High product uncertainty may be caused by low availability (or quality) of in situ reference observations taken in 'average' conditions – But we cannot know this.

MERIS scenes over lakes

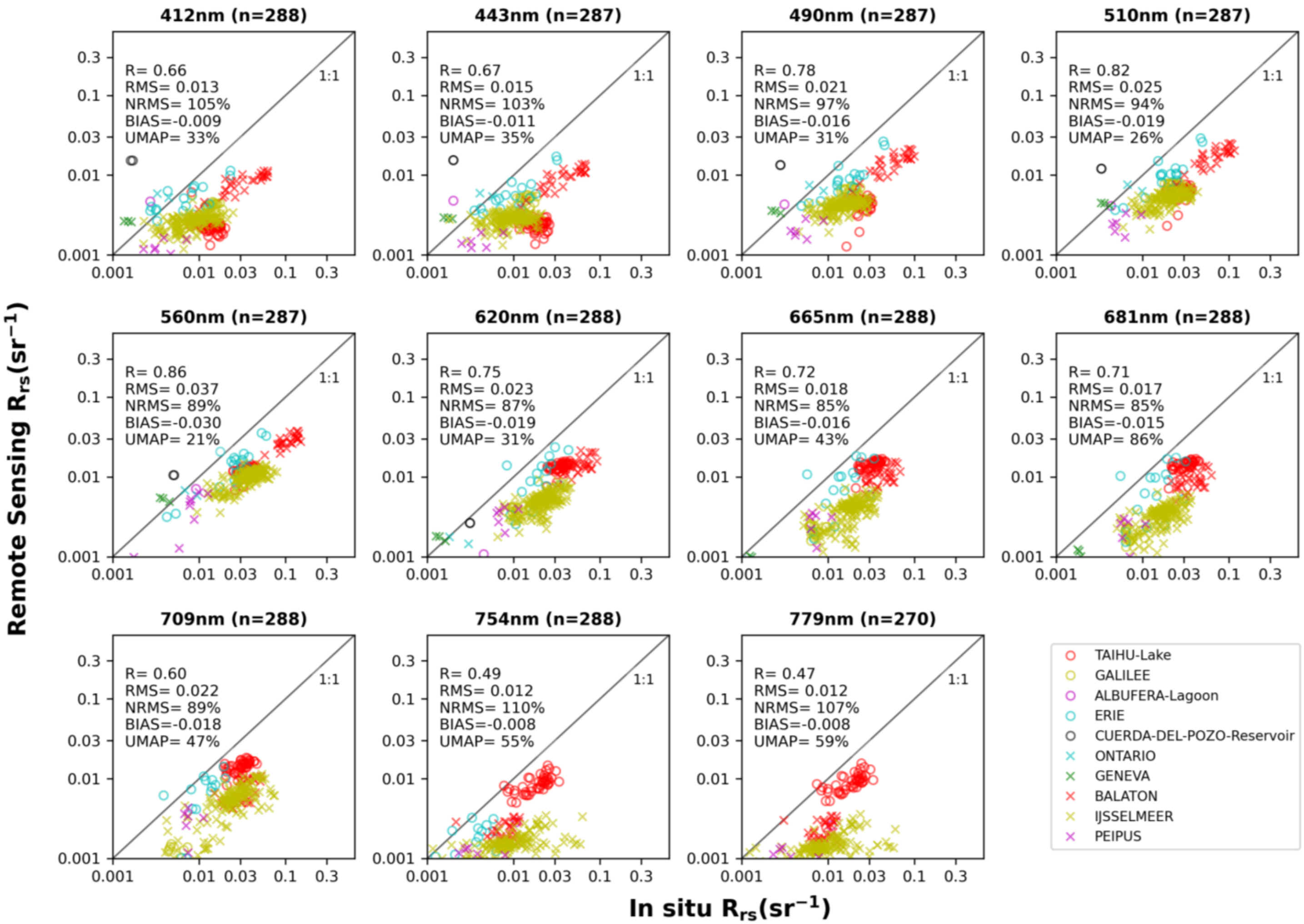
Taihu (31 July 2010)
Turkana (1 August 2011)
Vänern (16 July 2006)
Vättern (16 July 2006)

Product uncertainty challenge: radiometry

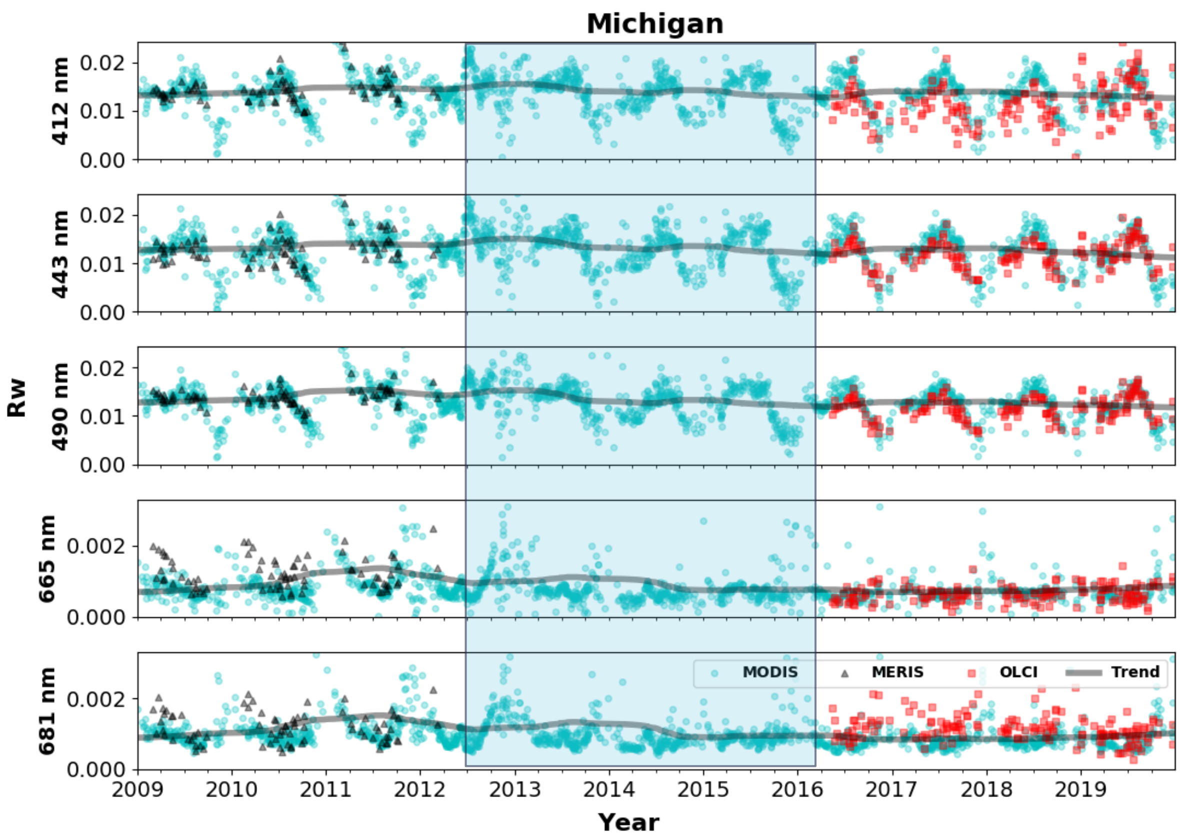
Lake Water Leaving Reflectance in situ validation **suggests systematic** biases in Reflectance.

They are systematic because the chlorophyll-a algorithms tuned to each Optical Water Types, largely remove these effects.

This is based on **very scarce** in situ data, so we have little means of improvement.



Product uncertainty challenge: radiometry

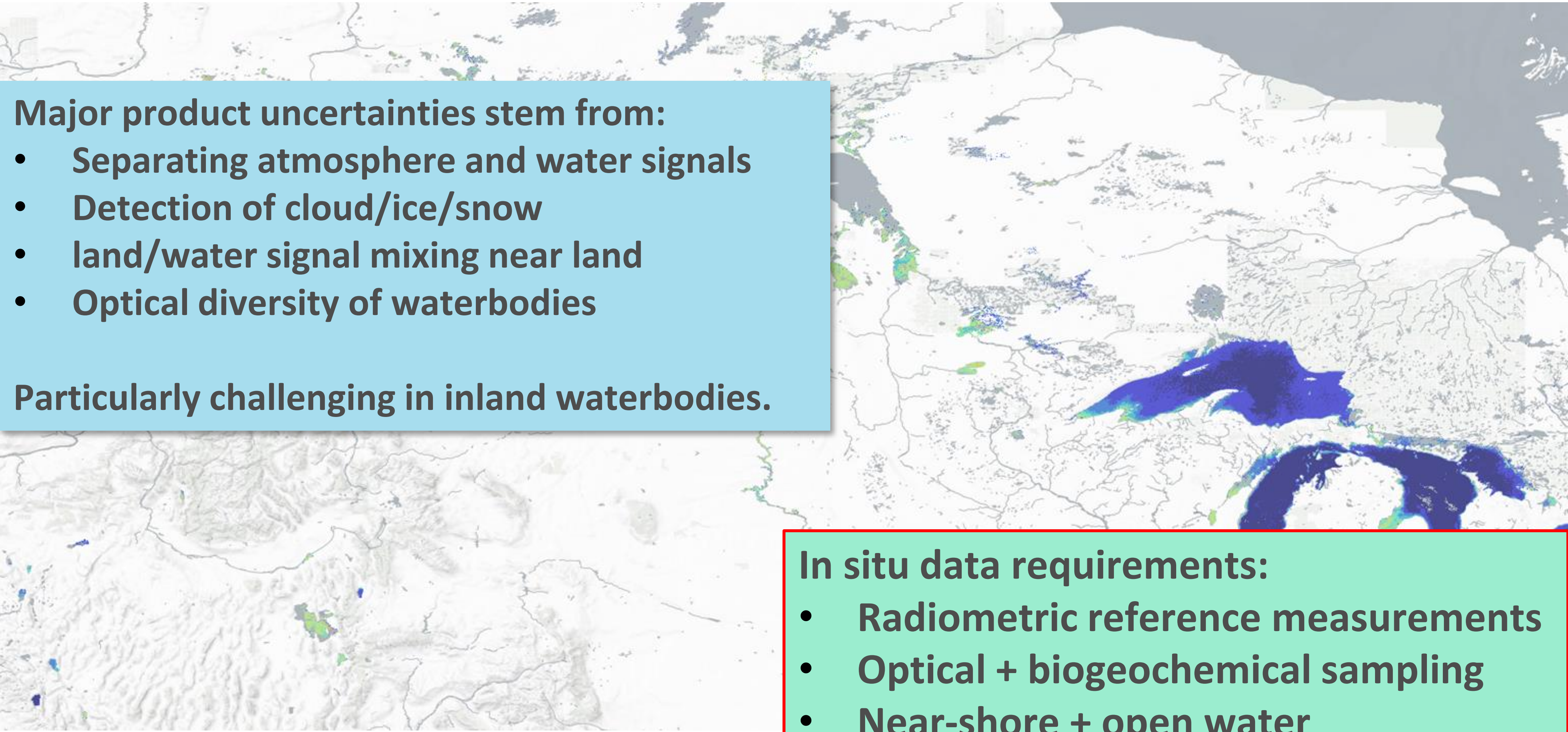


- Retrieval of atmospherically corrected reflectance in 5 wavebands in common between MODIS, MERIS and OLCI A/B
- Using POLYMER v4.12 for atmospheric correction.

The trends and differences combine:

Ultimately, reliable in situ reference data are needed from many different waterbodies to attribute sources of uncertainty.

Summary: satellite observation challenges



Major product uncertainties stem from:

- Separating atmosphere and water signals
- Detection of cloud/ice/snow
- land/water signal mixing near land
- Optical diversity of waterbodies

Particularly challenging in inland waterbodies.

In situ data requirements:

- Radiometric reference measurements
- Optical + biogeochemical sampling
- Near-shore + open water

Not typically covered with statutory monitoring!

Background: Copernicus Land Monitoring Service, Trophic State Index on 1 May 2018 from ESA OLCI, generated at Plymouth Marine Laboratory

Part 2: In situ observations to support Copernicus services

Stefan Simis (PML), Jaume Piera (CSIC), Liesbeth de Keukelaere (VITO),
John Wood (Peak Design), Steef Peters (Water Insight), Olivier Burggraaff (Leiden Uni),
Steven Loiselle, Sasha Woods (Earthwatch)

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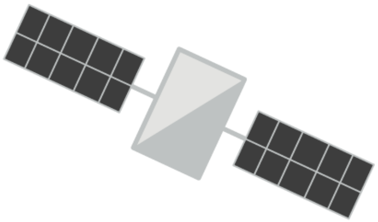
MONOCLE general objectives

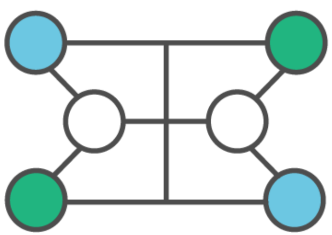


Addressing gaps in *in situ* monitoring

- New sensors or new deployment strategies
- **Focus**: **reflectance** to link satellite and in situ water quality
- Complementary observations: microscale, nutrients, vertical

Improve cost-effectiveness of *in situ* observations

- **Less work**: improve automation and connectivity
- **Larger networks**: operation by non-experts
- **Global scale**: leverage the potential of citizen science



Sustainability

- Improve data interoperability and sharing
- Training materials and capacity building
- Demonstrations to water management authorities

MONOCLE expected outcomes

More in situ observations to support satellite cal/val in optically complex waters and under a variable atmosphere.

- Better understanding of **uncertainties** (atmospheric & water sources) using coupled, reference hyperspectral radiometry systems

Lowered initial and operating cost: fill spatial data gaps

- Wider choice of **reference and low-cost** instruments
- Wider data accessibility through **automation** of observations, data flow, and quality control

Complementary fit-for-purpose sensors to capture:

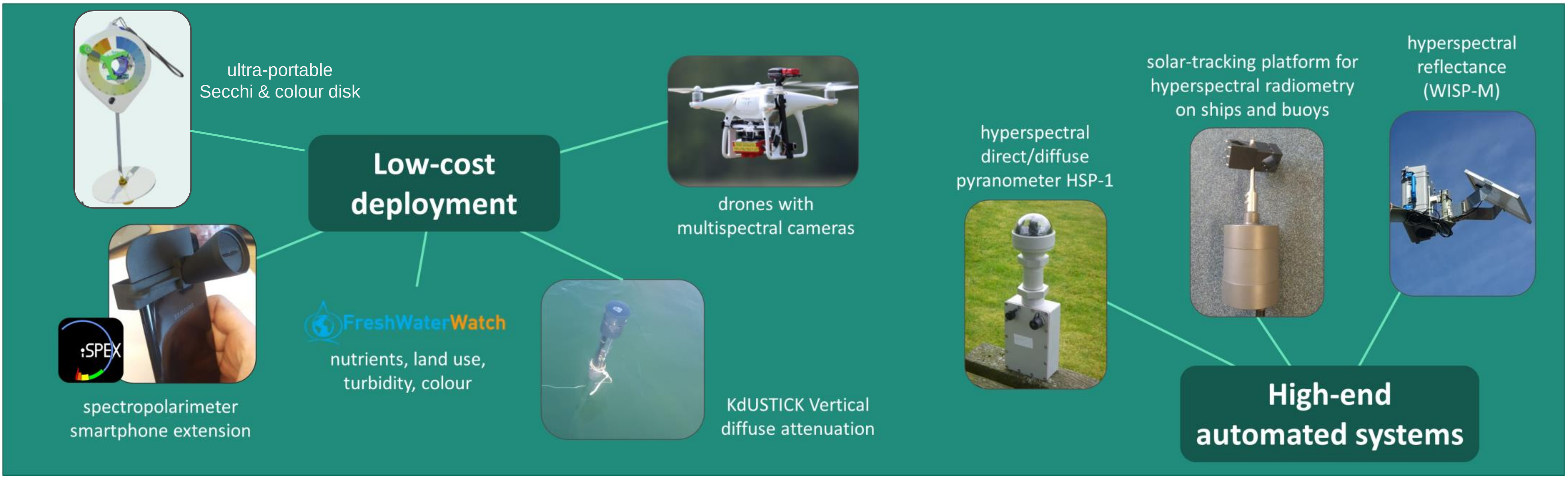
- **water** and **atmosphere** properties through radiometry
- **water column** structure (optical/temperature)
- **nutrients** and land-use context in the micro-scale

MONOCLE sensors and platforms

(Developed in years 1-3 of the project)

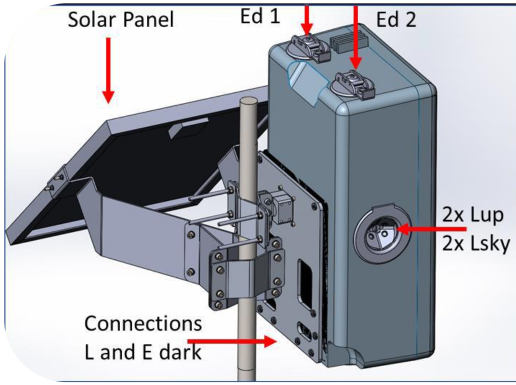
Participation

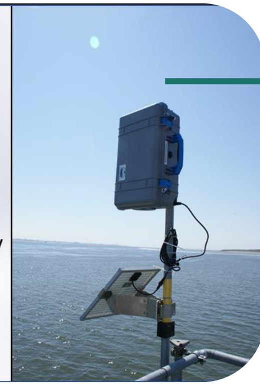
Automation



For the latest technical specs, videos and training materials, visit
monocle-h2020.eu/Sensors_and_services

Automated radiometry systems



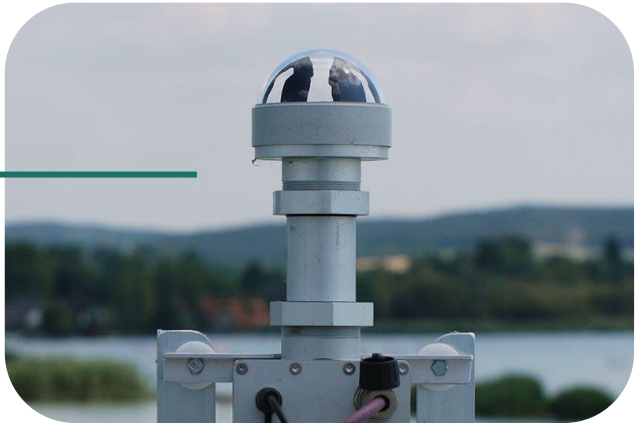


WISPstation by **Water Insight** provides water-leaving Reflectance from 6 channels, 2 azimuth angles, 350-1100 nm, sub-nm resolution. €25k (with tech support, data handling).

So-Rad (Solar-tracking radiometry platform) by **PML** providing water-leaving Reflectance (3 channels) integrating existing sensors, providing azimuth angle control. €2.5k component cost (excl. sensors). Fully open-source.

PML | Plymouth Marine Laboratory

The **Peak Design HSP-1** (Hyperspectral Pyranometer) provides global and diffuse downwelling irradiance, 3-nm resolution, 350-950*nm range, no motors. €11-17k target



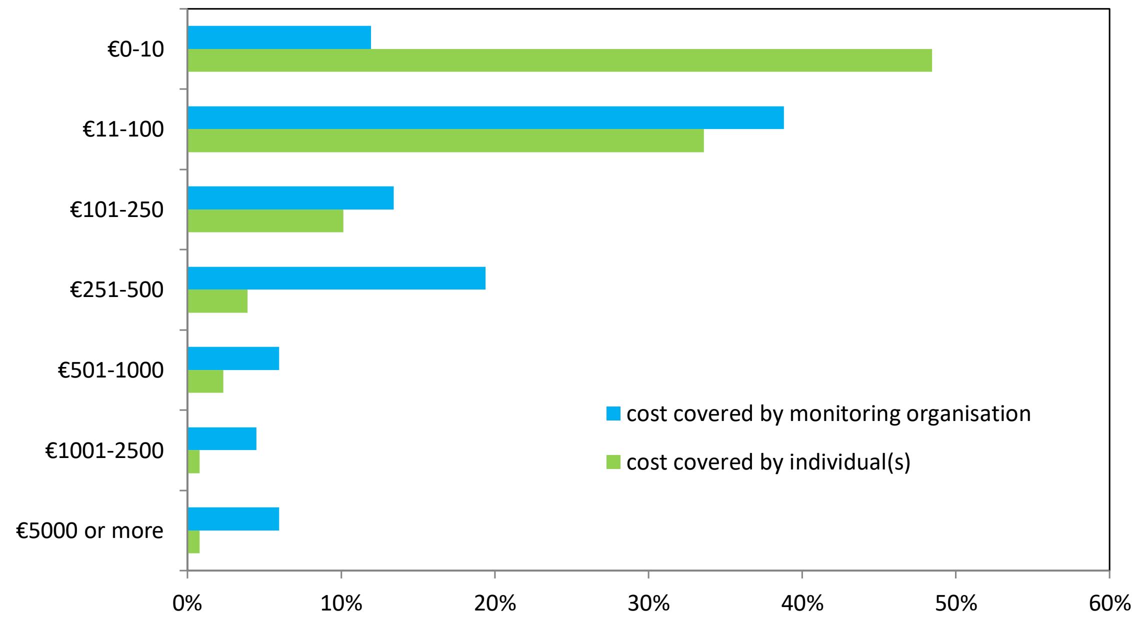
Peak Design

All instruments supports remote, low-power operation and monitoring, cellular data transfer and configuration, and OGC-compliant metadata.

Reducing operational cost

Survey results – sensor cost

What would be a reasonable price for a sensor operated by a volunteer to measure your main variable of interest?

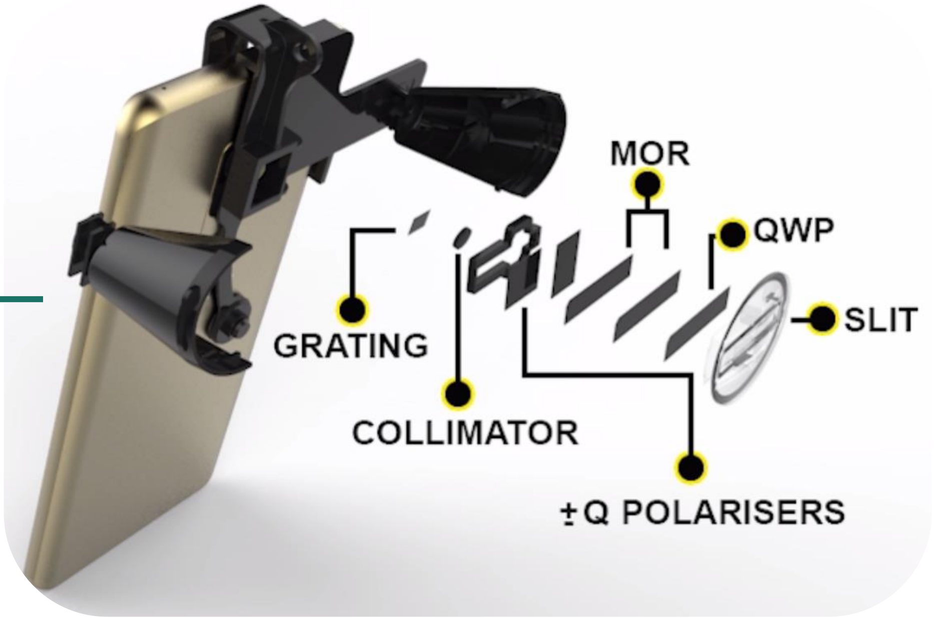


The optimal price point for volunteer-operated sensors is around €10-€100 according to most respondents, with some allowance if it is provided by a monitoring organisation.

Manually operated radiometry

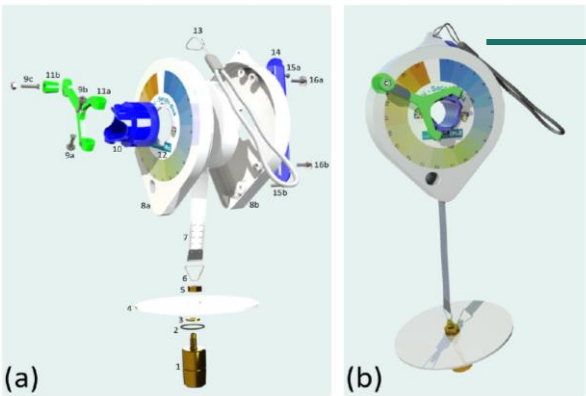
Drone-based solutions by VITO
target water-leaving Reflectance from multispectral add-on payload and on-board RGB cameras, supported by flight planning and data processing service. For 'pro-sumers'.

iSPEX 2 by Leiden University is
a clip-on spectropolarimeter that uses the smartphone camera (app by DDQ) and camera calibrations. €15-25



Universiteit Leiden

Transparency, vertical attenuation



Mini Secchi-disk by **Brewtek** & **PML**, portable disk with Forel-Ule colour index, pH paper attachment and supporting App (by **DDQ**). Open source, 3D-printable.

Vertical attenuation using **KdUStick** by **CSIC**: chained light sensors with integrated electronics and telemetry (<€500). **KdUMod** is a more capable, modular package including RGB and temperature profiling (€2k freshwater, €6k marine)

CSIC
CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS

EARTHWATCH INSTITUTE

FreshWater Watch by **Earthwatch**

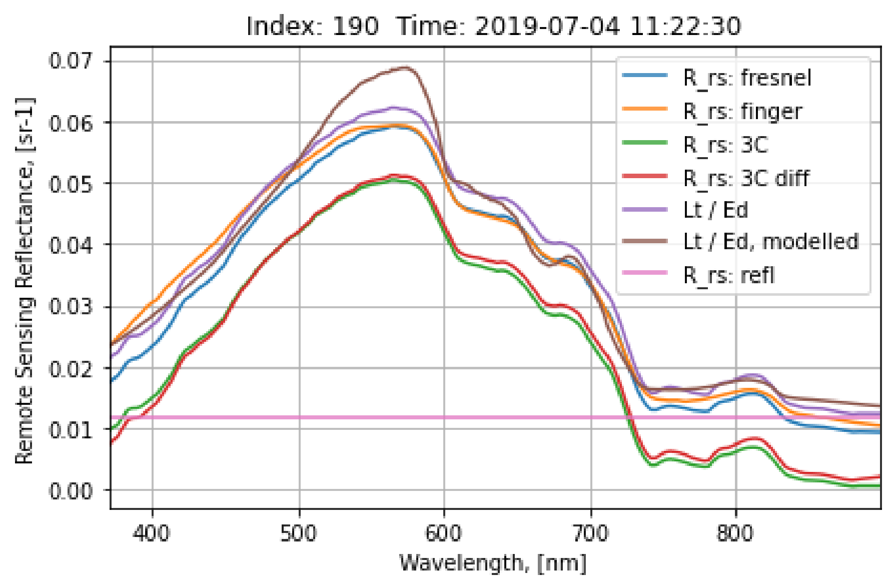
Includes Turbidity tube, nutrient kit.

Used globally in citizen science projects.

Ongoing R&D

So-Rad and HSP-1 deployed together

- HSP1 characterizes the atmosphere
- So-Rad characterizes the water reflectance
- Atmospheric modelling based on the HSP-1 diffuse and direct irradiance signals constrains the shape and amplitude of reflectance at the water surface.
- This lowers the uncertainty in correcting for reflected skylight at the water surface.
- Analysis code + paper coming soon



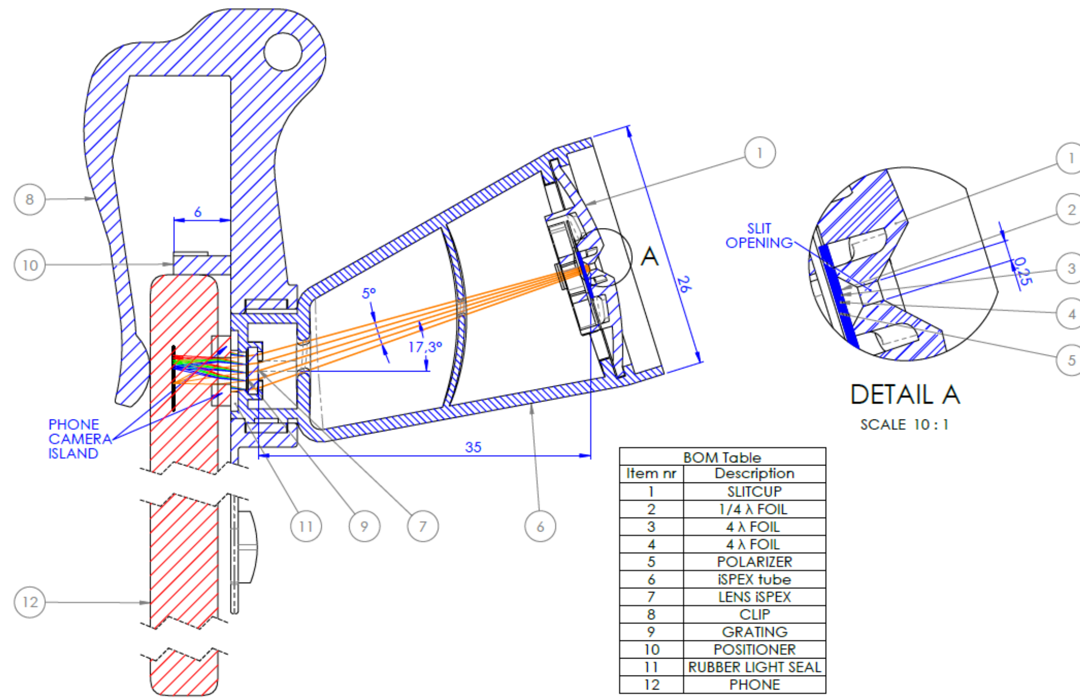
Ongoing R&D

Citizen science radiometry: iSPEX 2

Miniature version of the SPEX instrument used by astronomers

Turns smartphone camera into spectropolarimeter

Use for atmospheric transmissivity and water reflectance



BOM Table	
Item nr	Description
1	SLITCUP
2	1/4 λ FOIL
3	4 λ FOIL
4	4 λ FOIL
5	POLARIZER
6	iSPEX tube
7	LENS iSPEX
8	CLIP
9	GRATING
10	POSITIONER
11	RUBBER LIGHT SEAL
12	PHONE

Universiteit Leiden

iSPEX

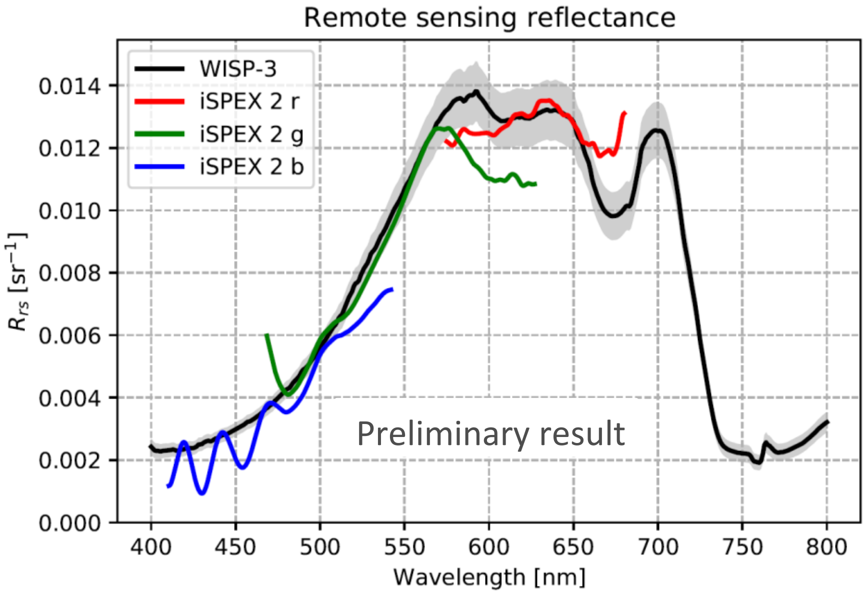
10-20€ price bracket

Ongoing R&D

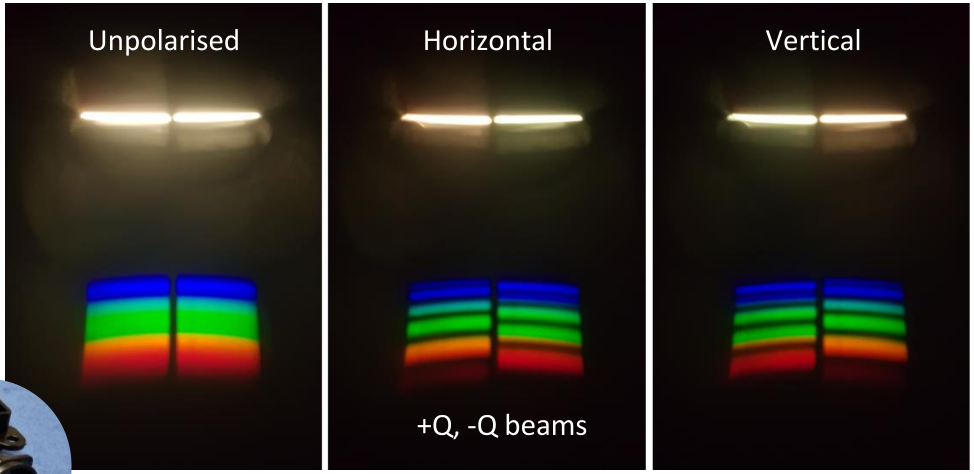
Universiteit Leiden

iSPEX 2: testing mass-production units

- Smartphone linear spectropolarimeter
- Universal smartphone support
- Camera calibration protocol & database
- Aerosol Optical Depth
- Remote-sensing Reflectance

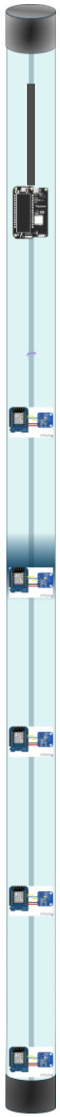


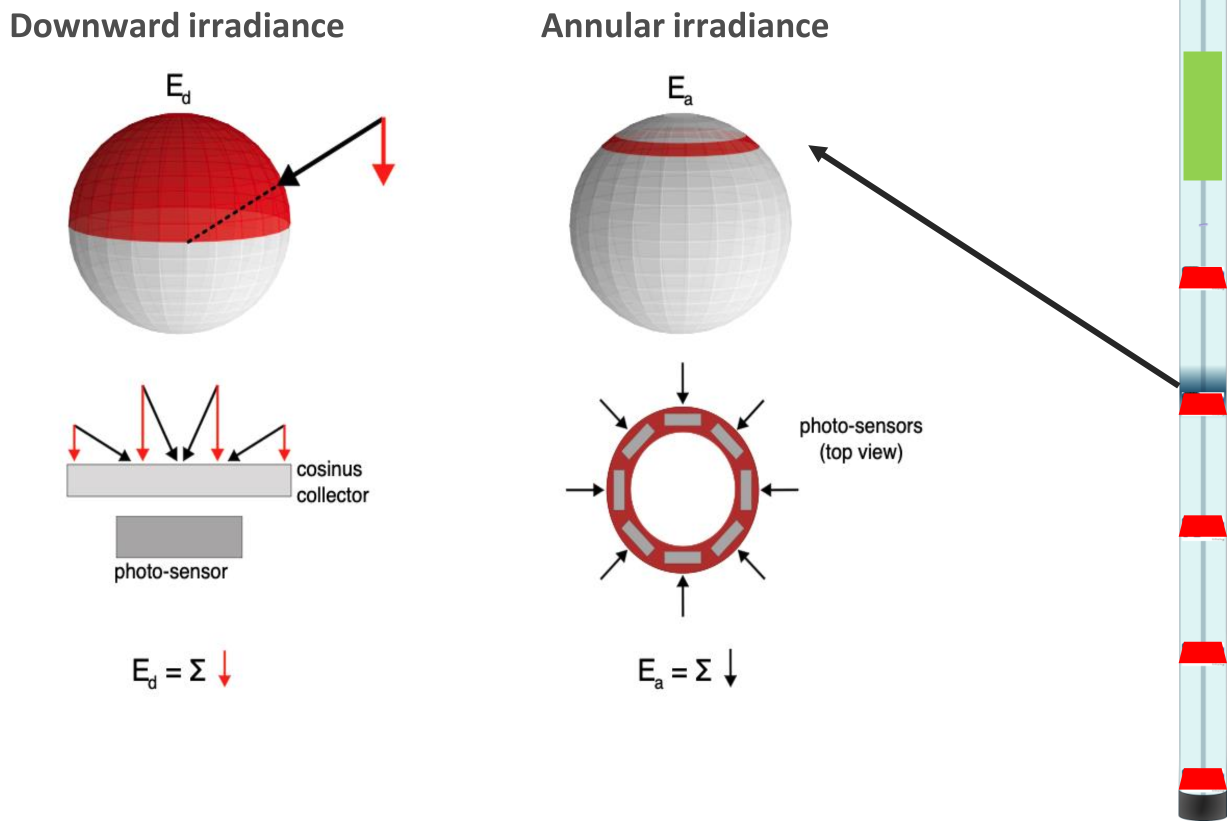
3D printed iSPEX 2 prototype vs WISP-3 (black) shows good agreement (5% RMSD). Sine wave in B-band, band edge effects currently being addressed. Camera filters out > 700nm.



Camera images recorded with smartphone and iSPEX, polarization on/off

Ongoing R&D



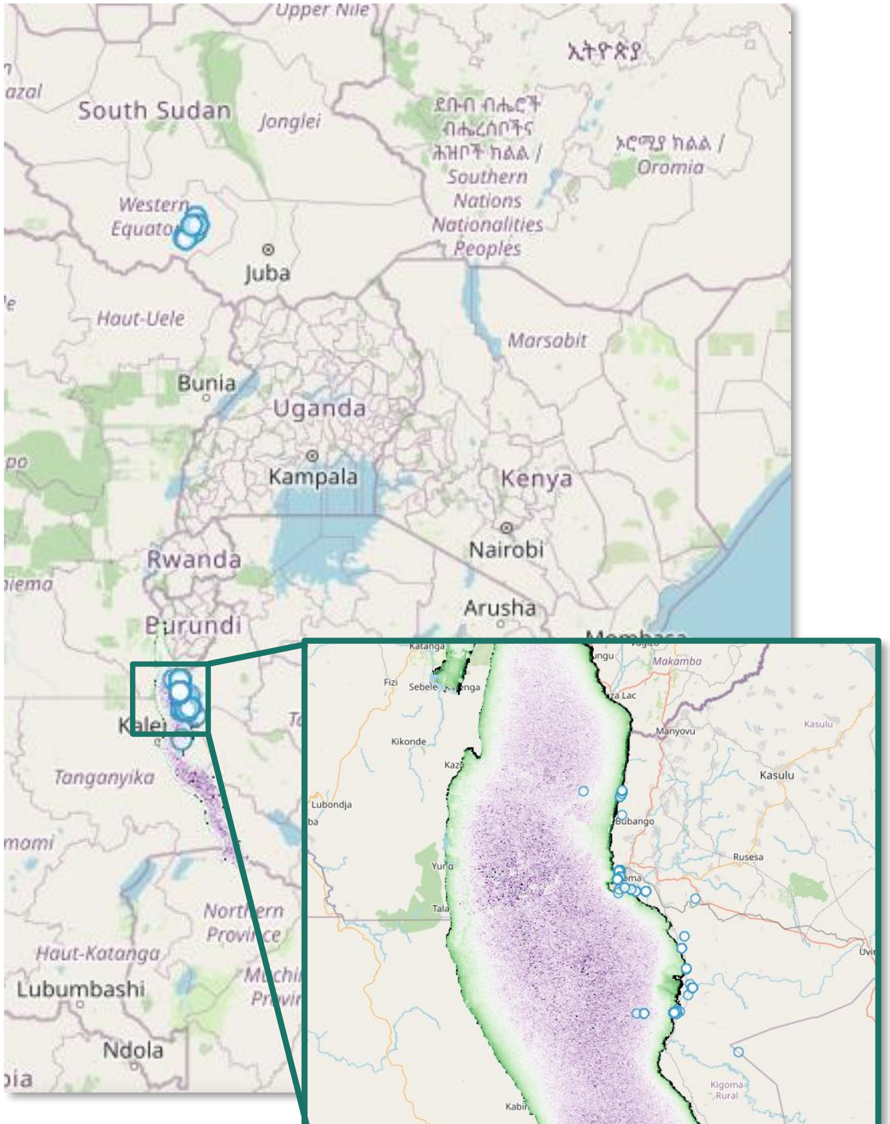


KdUStick

- Bespoke electronics board to control sensor integration time
- Sensors in annular arrangement (avoiding shading)
- Open hardware design
- Do-it-yourself build possibilities

CSIC
Consejo Superior de Investigaciones Científicas

Bringing multiscale observations together



Harmonized data flows

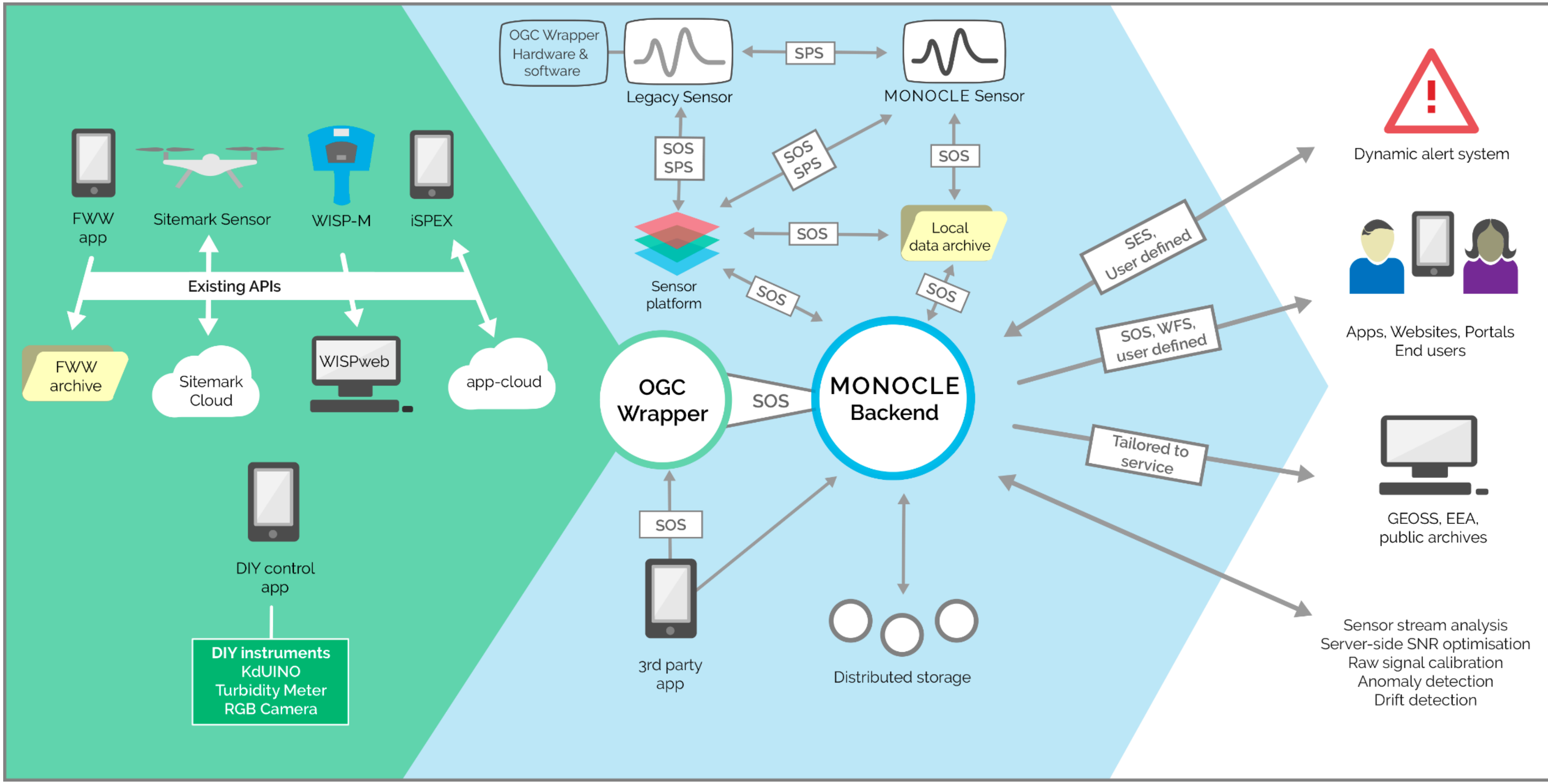
All instruments/platforms provide

- Essential metadata (See MONOCLE report D3.2)
  - Sensor/sample/operator/platform ID
  - Ownership & licensing info
  - Calibration information
- OGC-based data offering
  - [optional] Sensor-to-backend (SOS, SensorThings-API)
  - [optional] Backend-to-middleware
  - Frontend, e.g. Geoserver with WFS and WMS
- Public front-end (any GIS) can mix sources, conduct geospatial queries.

Sources currently connected

- LIMNADES (U Stirling)
- FreshWater Watch (Earthwatch)
- So-Rad systems (PML)
- MapEO drone imagery (VITO)
- …

The data vision..



All potential data streams and their standardized data interfaces – a work in progresss

Sustainability vision

Majority of project outcomes are open, supporting future development, do-it-yourself builds (e.g. school projects), uniform data formats & processing tools (including quality control).

Data flows use OGC standards where possible and very rich metadata, including license-for-use, ownership, calibration information.

Demonstration activities have started

https://remotesensing.vito.be/monocle-call-proposals-drone-demonstration-cases

Closes next week

Ultimately, buy-in from research, industry, agencies is needed to upscale the observation network. MONOCLE is only a vehicle for R&D and demonstration.

Satellite EO solutions vs current policy?

Why is the uptake of satellite-derived water quality products slow in Europe?

Not trusted

Not our responsibility

No baseline

No expertise

Not certified

No budget

It is not embedded in monitoring policy frameworks

Lowered cost **and** ***capacity building***
are key to success

E Papathanasopoulou, S Simis, K Alikas, A Ansper, S Anttila, J Attila, … M L Zoffoli. (2019, September 30). Satellite-assisted monitoring of water quality to support the implementation of the Water Framework Directive (Version 1.2). Zenodo. http://doi.org/10.5281/zenodo.3903776

Thank you

Optical water quality is complex but monitoring solutions don’t have to be

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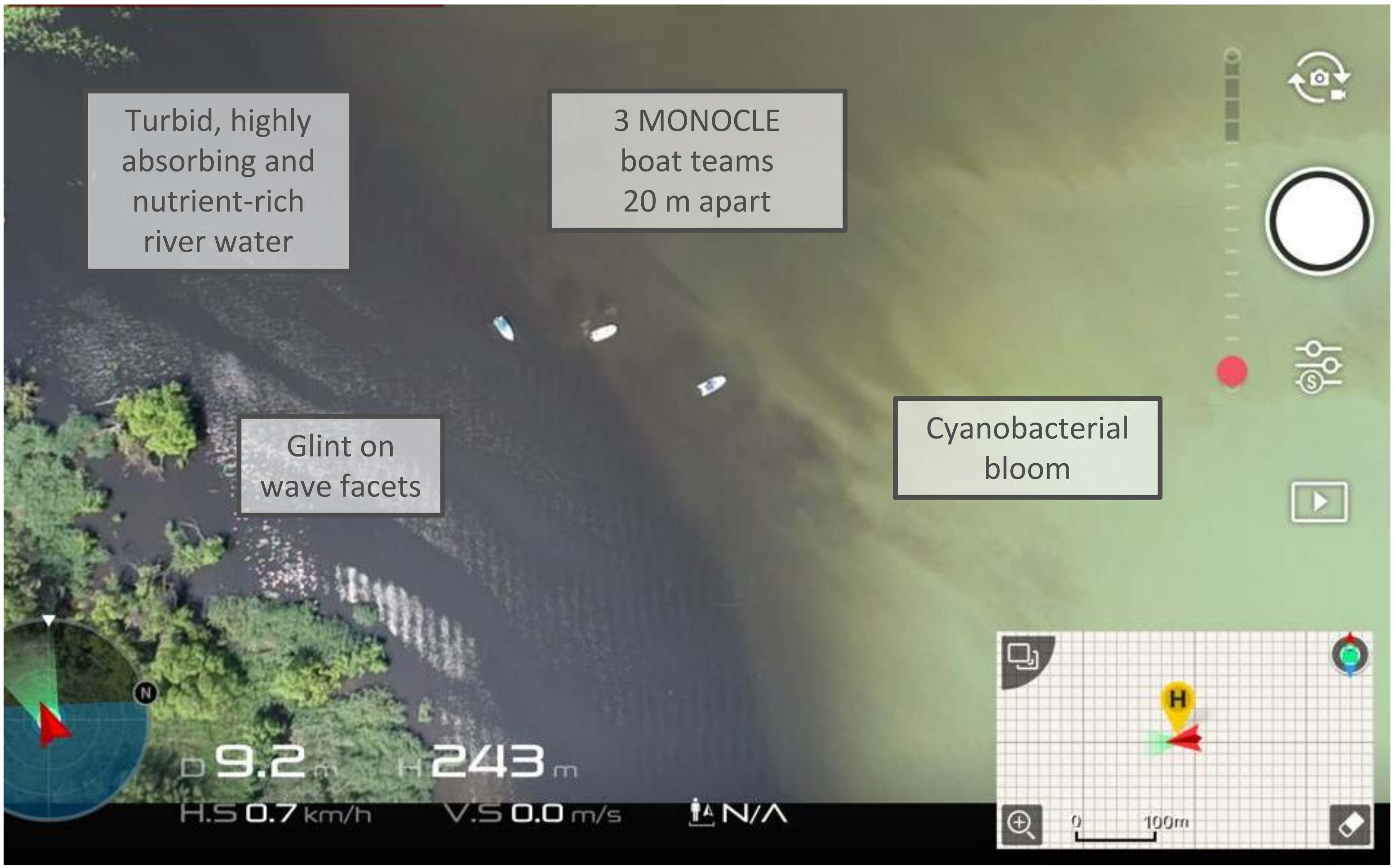

Lake Balaton, Hungary, 2019. The Zala river mouth seen by drone and 3 boats.