Integrating satellite remote sensing and in situ monitoring of water quality in Water Framework Directive waterbodies

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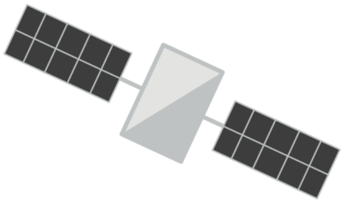
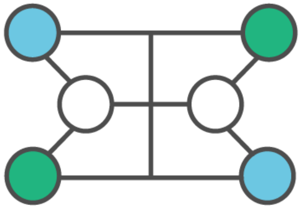
Key messages



In situ and satellite remote sensing strategies for water quality monitoring in coastal and inland waters are misaligned.



Cost-effectiveness and spatial coverage of in situ observation of water quality can and should improve in support of integration of remote and in situ observations.

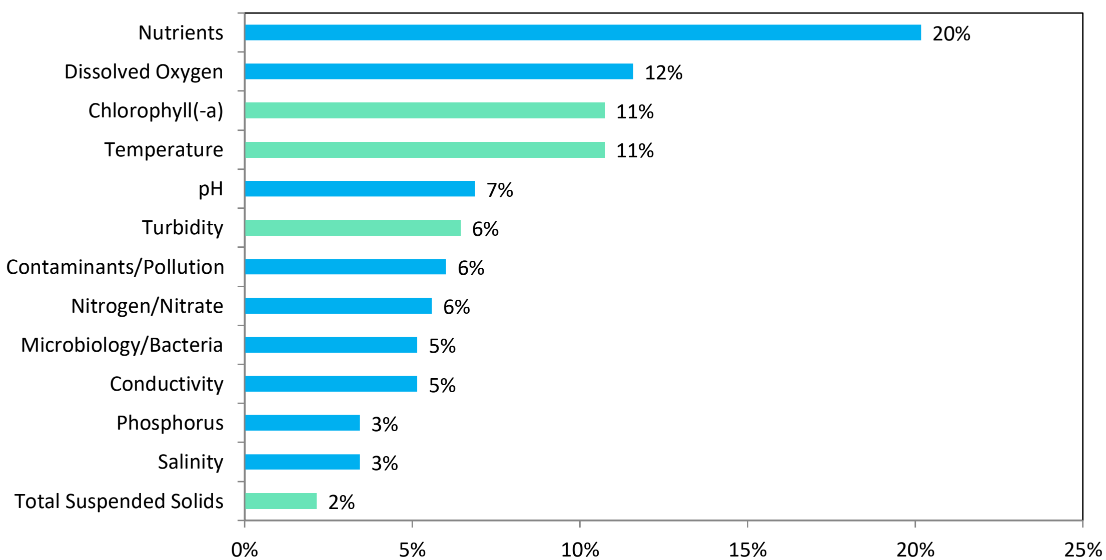
Helpful resources

- Stakeholder survey
- White Paper on satellite EO for Water Framework Directive
- MONOCLE sensors, demonstration activities

2018 Survey

Required Water Quality data

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



In situ observation essential

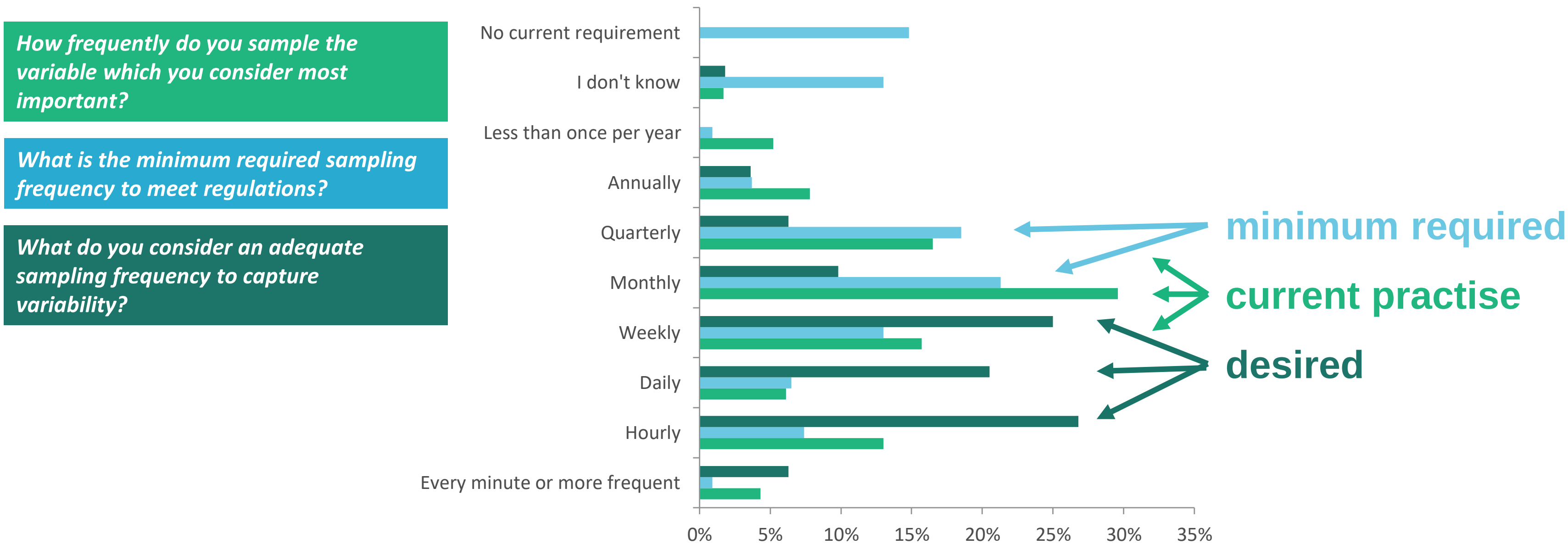
Remote observation possible

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.

2018 Survey

Survey results – water sampling

Sampling frequency



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.

Linking satellite EO solutions to policy?

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

Not trusted

Not our responsibility

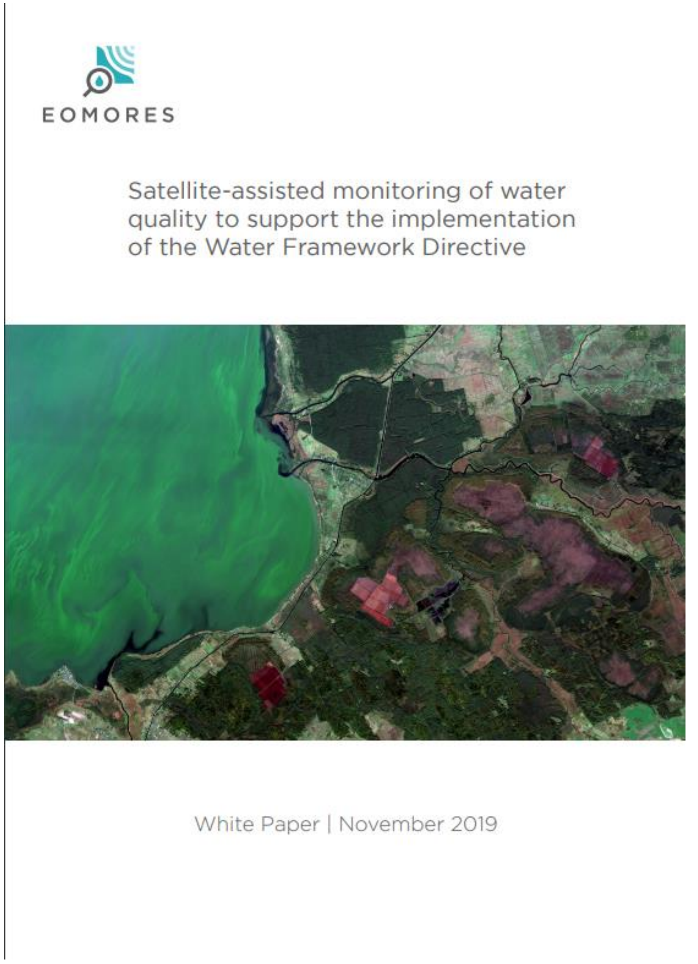
No baseline

No expertise

Not certified

No budget

It is not embedded in monitoring policy frameworks



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In situ observation for the WFD has gaps

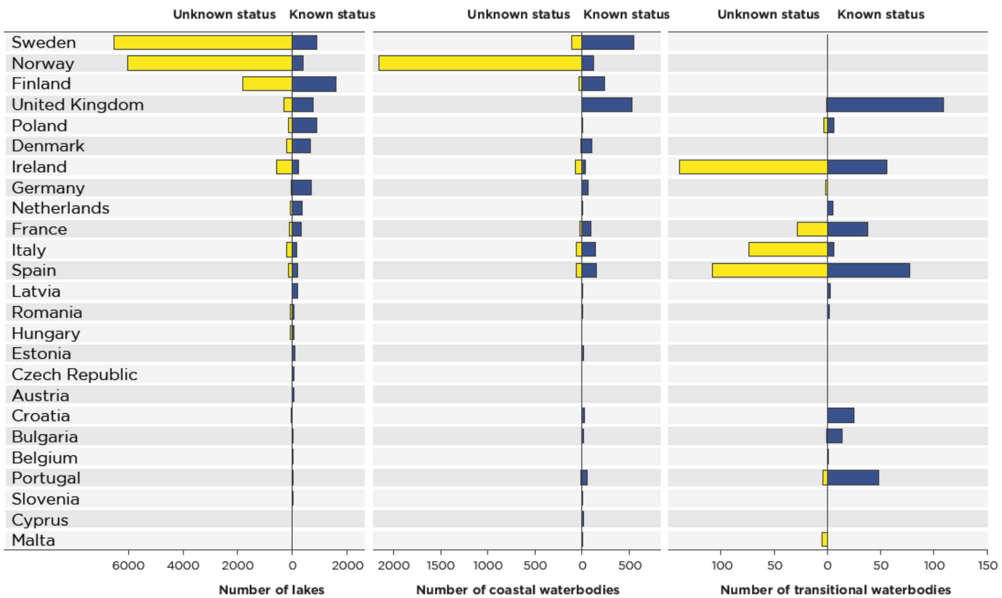

Figure 1: Known versus unknown status for BQE1-1 Phytoplankton in (left) lakes, (middle) coastal and (right) transitional waterbodies. Source of data: WISE-SoW database including data from 26 Member States and Norway (no data for Greece and Lithuania).

As far as the WFD water quality status of European waterbodies is known, our information tends to be based on relatively few site visits.

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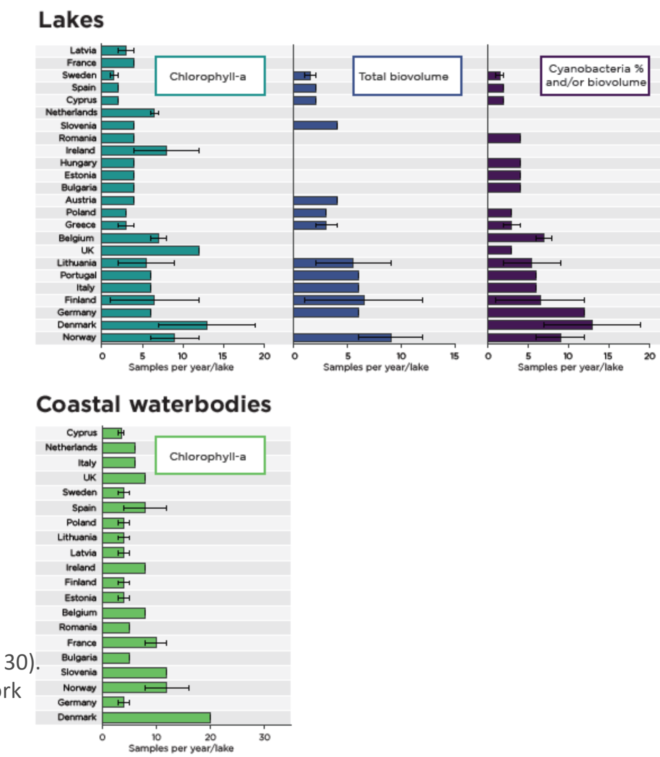

Figure 3: In situ sampling frequency for some Phytoplankton quality elements for lakes (top: left, middle and right) and coastal waterbodies (bottom). Coloured bars indicate the average, black error bars span the minimum and maximum frequency reported. Data collated from WFD Intercalibration technical reports, available on CIRCABC.

Remote sensing value for the WFD

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Table 1: Current in situ metrics and corresponding satellite-derived quality metrics to be considered

WFD requirements	National Systems	Satellite-derived proxies to be considered
QE1 Biological elements		
QE1-1. Phytoplankton		
Abundance and biomass	Extracted chlorophyll-a concentration[i] Biovolume of phytoplankton[i]	Chlorophyll-a concentration from in vivo pigment absorption[ii,iii] Trophic State Index derived from Chlorophyll-a
Composition	Biovolume of cyanobacteria[i] % of cyanobacteria of total biovolume[i] Various other metrics, trophic indices	Phycocyanin (cyanobacterial pigment) concentration[v] Functional size classes (only in oceanic waters)[iv]
Frequency and intensity of planktonic blooms	Not reported / not possible using conventional monitoring	Chlorophyll-a concentration[ii,iii] Phycocyanin (cyanobacterial pigment) concentration[v] Surface accumulations of cyanobacteria[vi]
QE1-2 Other aquatic flora		
Macrophyte abundance	Various trophic indices; Submerged vegetation cover[i] Total areal coverage[i]	Areal cover of floating vegetation
Macrophyte composition	Proportion of taxa	Not from current satellite sensors, but from airborne surveys[vii]
Macroalgal cover and angiosperm abundance	Combination of spatial extent and relative abundance (measured as density) of macrophytes Abundance of macrophytes[viii,ix]	Spatial extent In intertidal areas[x,xi,xii]: spatial distribution of seagrass density of sea grass, total surface area of seagrass beds
QE3. Chemical and physico-chemical elements		
QE3-1. General		
QE3-1-1. Transparency	Secchi disk depth (Dissolved organic carbon also used to characterise lake typology)	Satellite backscatter as turbidity, suspended particulate matter weight or vertical transparency (extinction or Secchi depth)[xiii,xiv]
QE3-1-2. Thermal conditions	Mean water temperature Water temperature range Air temperature	Surface water temperature[xv] (in open water >2 km from land)
QE3-1-4. Salinity	Electrical conductivity Refractometry	Only with regionally tuned models using Coloured Dissolved Organic Matter (CDOM) as freshwater proxy. In marine/ oceans: sea surface salinity
QE3-1-5. Acidification status	pH	Only in oceanic waters: from combining ocean colour, sea surface temperature, sea surface salinity[xvi]

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Added value for the WFD

Demonstrating:

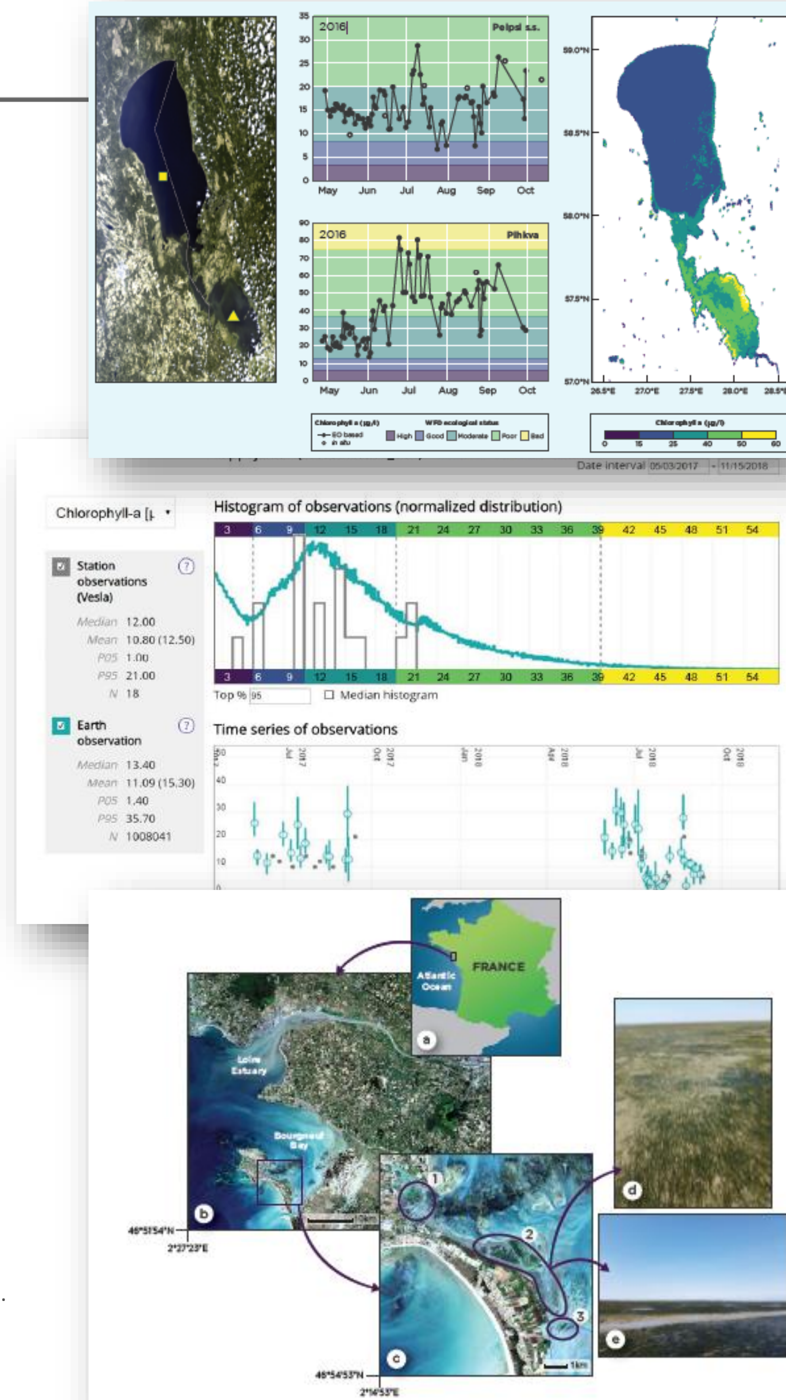
Current reporting gaps
Remote sensing use cases throughout Europe (6 countries)
Complementarity of satellite and in situ observation
Maturity of satellite observation science/industry

Aiming to convince:

National monitoring authorities – *as end-users*
Policymakers at national level – *as budget holders*
Policymakers at European level – *to agree roadmap*
Earth Observation community – *to work together*

Recommendations:

Recognise satellite observation as an assessment method
Harmonise metrics across countries,
advise member states on best practises
Reference the use of satellite-based Earth observation metrics in the WFD Reporting Guidance (Annex 5)
EC, Member States to **agree on recommendations of common practices** and reporting standards



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Remote sensing for the WFD?

EOMORES

Strengths

- Unprecedented observing capability
- More observations increase confidence in WFD status assessment
- Largely mature; uncertainties increasingly well described
- Science and EO service sectors ready

Opportunities

- Return on investment sought
- The surface water quality aims of the WFD are ambitious and not met
- Need for large-scale transparent, validated monitoring methods
- Increasing interest + R&D funding

Weaknesses

- Limited budgets for environmental monitoring, no statutory requirement.
- Remote sensing cannot observe all required biological and chemical indicators
- Lack of trust, harmonisation. Some claims unsupported by science
- Institutional capacity to take up satellite products lacking (?)

Threats: Product quality [capabilities], over-sell by industry [trust], evolving methods [methods maturity], skills gap [rapid growth]

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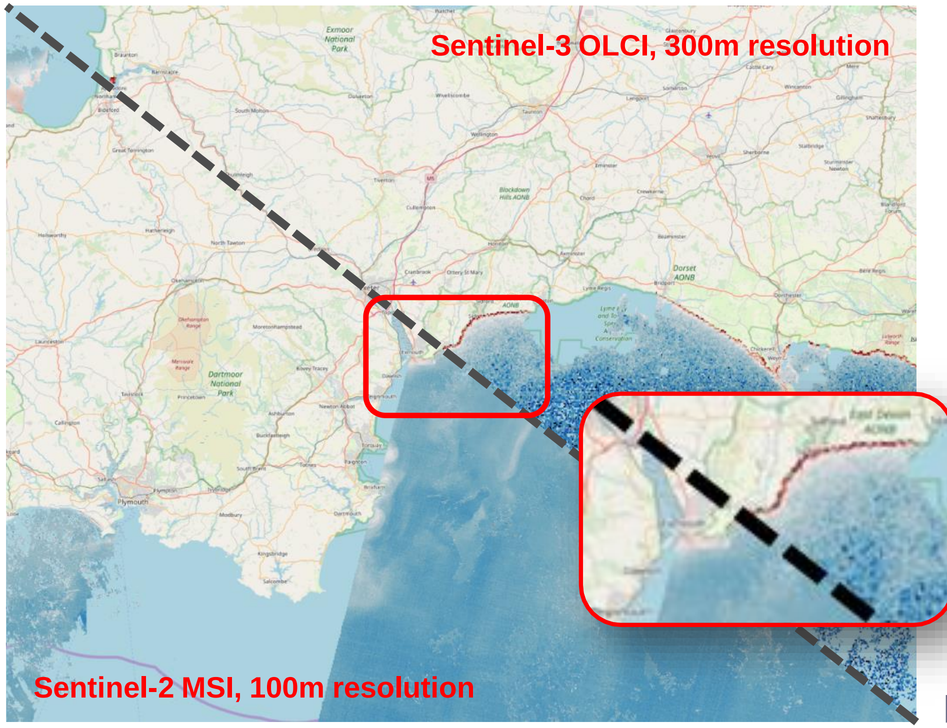
EO always delivers… something

Sentinel-2 MSI (launch 2016) vs Sentinel-3 OLCI (launch 2017)



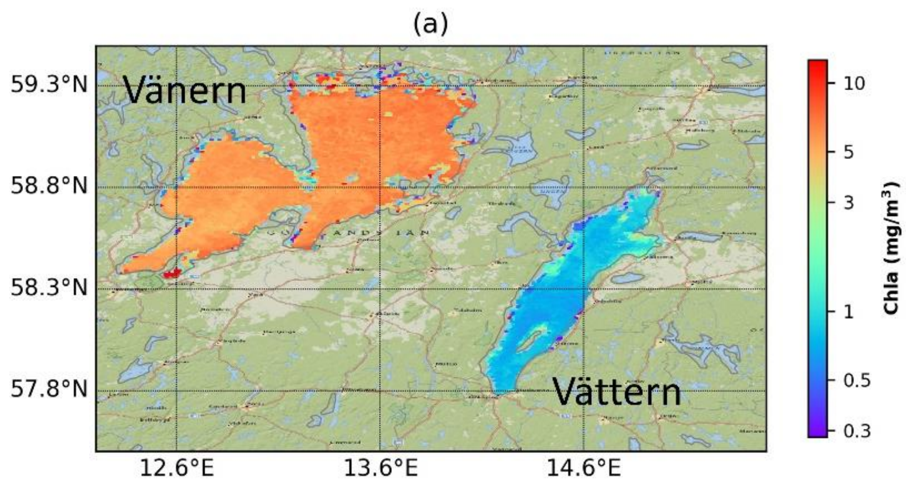
8 Aug 2018, Lyme Bay, UK. Turbidity (FNU).

Different sensor properties results in product inconsistencies, **particularly near land**. Dedicated and adaptive algorithms are needed to identify and handle these difficult environments -> see also H2020-CERTO

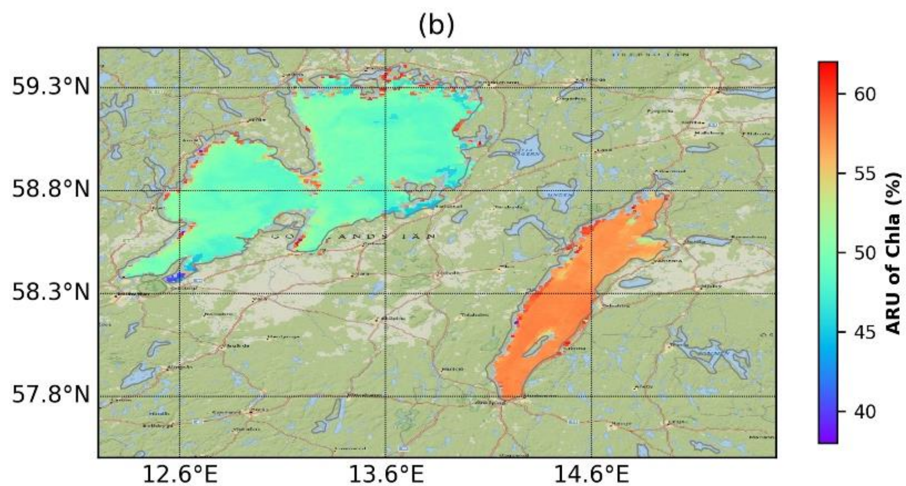
EO product uncertainty (lakes)

Chlorophyll-a modelled product uncertainty exceeds targets

Lakes Vänern and Vättern, Sweden, MERIS, 16 July 2006



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



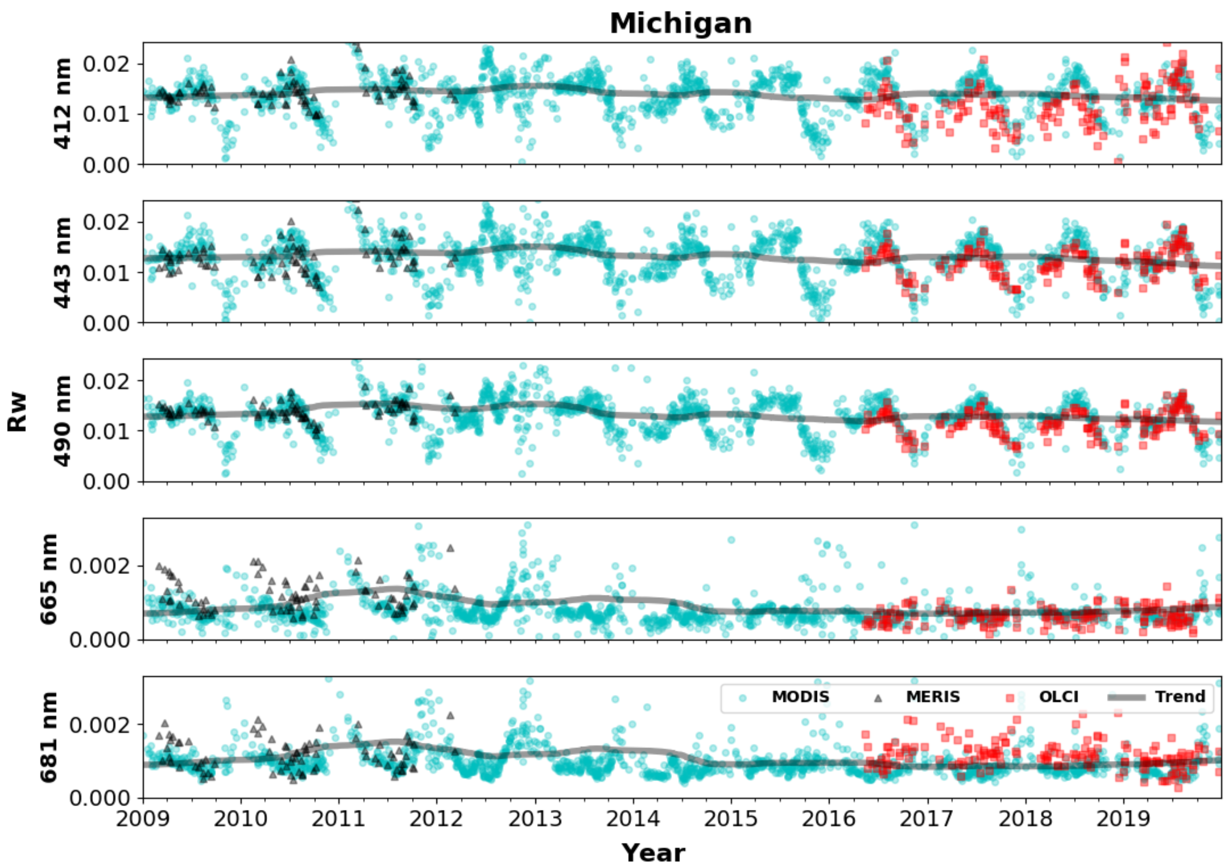
Modelled product uncertainty

(included in the ESA Lakes Climate Change Initiative and future releases of Copernicus Land Monitoring Service lake water quality)

Liu et al. *in prep*

EO product uncertainties (lakes)

Achieving long-term consistency in satellite retrieval



Retrieval of atmospherically corrected reflectance in 5 wavebands in common between MODIS, MERIS and OLCIA/B

Using POLYMER v4.12 for atmospheric correction.

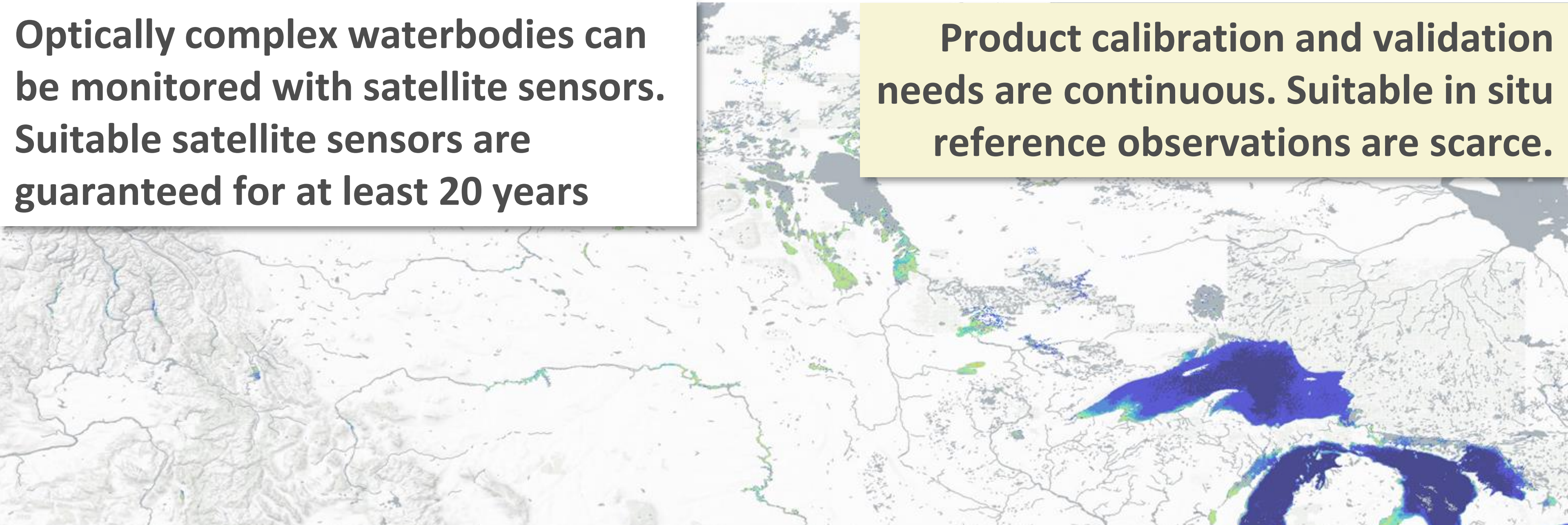
The trends and differences combine:

- Atmospheric correction
- Changes in water quality
- Sensor drift

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

Liu et al. *in prep*

Opportunities and Challenges



Optically complex waterbodies can be monitored with satellite sensors. Suitable satellite sensors are guaranteed for at least 20 years

Product calibration and validation needs are continuous. Suitable in situ reference observations are scarce.

Major product uncertainties from:

- **Removal of atmospheric effects**
- **optical diversity of water bodies**
- **land/water signal mixing near land**

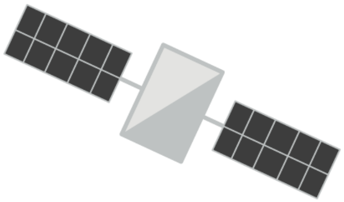
In situ data requirements:

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

Not typically covered with statutory monitoring!

Copernicus Land Monitoring Servce, Trophic State Index on 1 May 2018 from ESA OLCI

MONOCLE objectives

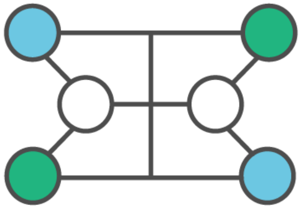


Addressing gaps in *in situ* monitoring

- New sensors and deployment strategies
- Water colour to link satellite and in situ water quality

Improve cost-effectiveness of *in situ* observations

- Automation and near-real time connectivity
- Sensors for non-experts
- In-field calibration and quality control aided by non-experts



Sustainability

- Push data interoperability and sharing policies
- Training and capacity building
- Facilitate uptake in regular monitoring practises

Solutions from MONOCLE

Increased automation of hyperspectral reference radiometry

- Lowers cost of reliable reflectance observations to validate current and future multi and hyperspectral satellites (VIS-NIR range)
- Dramatically increases satellite match-up data volume
- Supports studies into improving atmospheric corrections

Water-leaving reflectance

Water Insight
WISPstation
(all-in service)

PML Solar-tracking
Radiometry platform
(moving platforms, use
existing sensors, open-
source approac)

Atmospheric transmissivity

Peak Design HSR-1 diffuse/direct irradiance
(replacing robotic sun-photometer)

20-40k€ price bracket

Solutions from MONOCLE

Consumer and prosumer drone flights

Crowd-source water quality imagery: non-experts can observe micro-scale.
Reach open water easily, assess satellite product uncertainties near land.
Short flight time, not suitable to map large areas

Micasense RedEdge payload added to DJI drone Using 3D-printable mounts

vito remote sensing

MAPEO WATER

2-5k€ price bracket

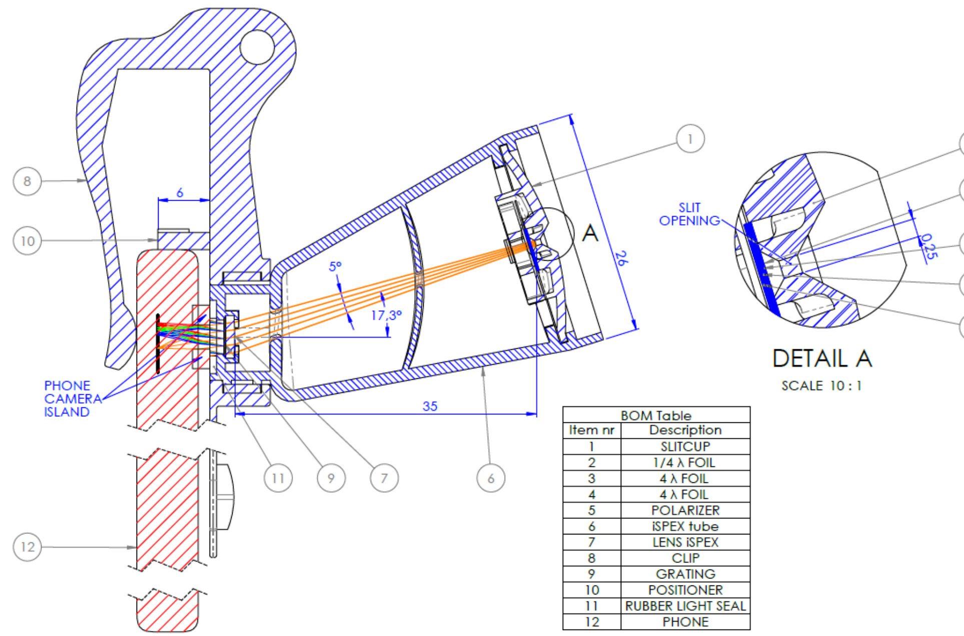
Solutions from MONOCLE

Citizen science radiometry: iSPEX 2

Miniature version of the SPEX instrument used by astronomers

Turns smartphone camera into spectropolarimeter

Use for atmospheric and water reflectance



10-20€ price bracket

Other solutions from MONOCLE

KdUINO

Low-cost (<100€) vertical transparency sensor chains

Read more

iSPEX 2

Take quick and easy ocean colour measurements using this the low-cost add-on for your smartphone

Read more

Solar tracking radiometry platform (So-Rad)

Control and automate underway radiometric measurements for satellite validation from ships and buoys

Read more

Hyperspectral Radiometer for Global & Diffuse Irradiance (HSR1)

A novel sensor to accurately measure the spectrum of sunlight near the water's surface

Read more

FreshWater Watch (FWW)

Nutrient and turbidity citizen science kits

Read more

MapEO Water

Using state-of-the art drone technology to monitor water quality. The MapEO Water service converts drone data into geo-referenced images providing information on the physical properties of water bodies.

Read more

Water Insight SPectrometer Station (WISPstation)

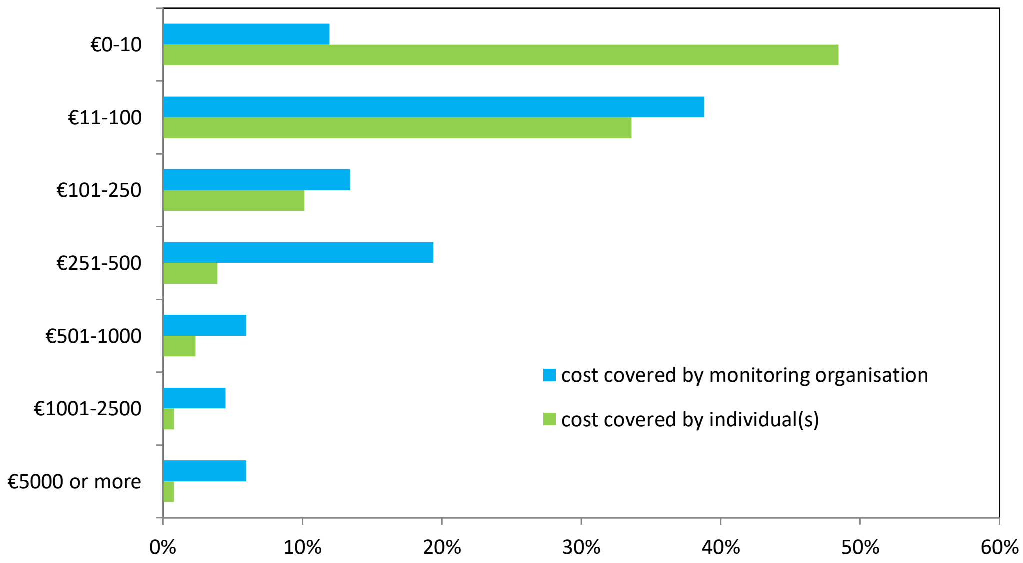
Measure water reflectance and key water quality parameters fully autonomously, emission-free, without any chemicals, at a high frequency and get results available near-real-time

Read more

More info https://monocle-h2020.eu/Sensors_and_services

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.

In the field

Lake Tanganyika: citizen scientists

30 participants per site recruited, 150 total

Started monitoring in May 2019: nutrients, transparency, land use

New technologies will be introduced in the coming year

Other test sites include:

- Loch Leven, Scotland
- Western Channel, UK/France
- Danube Delta
- Lake Balaton
- Periurban lakes in Sweden

Uptake & Sustainability

MONOCLE demonstrates data integration…

Satellite data: powerful in open water, uncertainty increases near coast

Automated sensors: more costly but continuous validation in open water

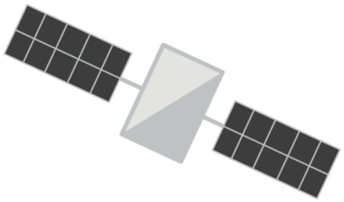
Citizens: contributing mostly shore based surveys – covering the microscale

Key research questions include *data redundancy requirements* and *quality assurance* methods.

… and gauging uptake potential

Chatham & Clarendon Grammar School building 3D printed mini-Secchi disks

Key messages



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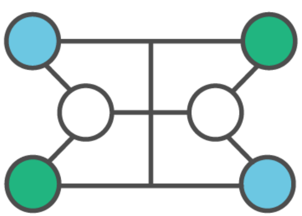

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- White Paper: satellite EO for Water Framework Directive
- MONOCLE sensors, demonstration activities

Contact: Stefan Simis
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White Paper: EOMORES, CoastObs consortia and all external experts

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