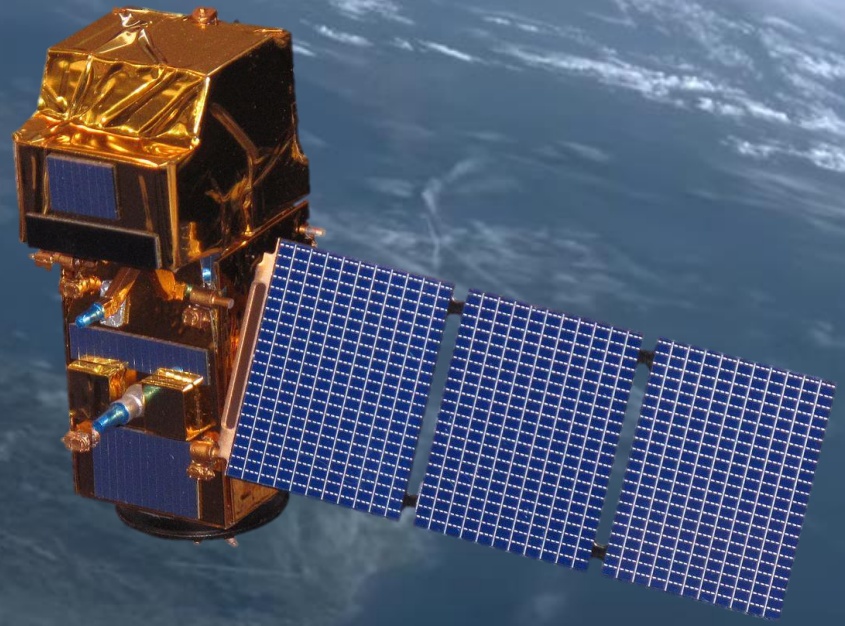
Monitoring eutrophication using a chlorophyll-a product derived from Sentinel-2



Claire Neil, Willie Duncan & Jan Krokowski | Scottish Environment Protection Agency
Matthew Blake | University of Stirling
Sian Davies & Joanne Pitt | Environment Agency
Fraser Leith | Scottish Water
Stuart Knott | Anglian Water

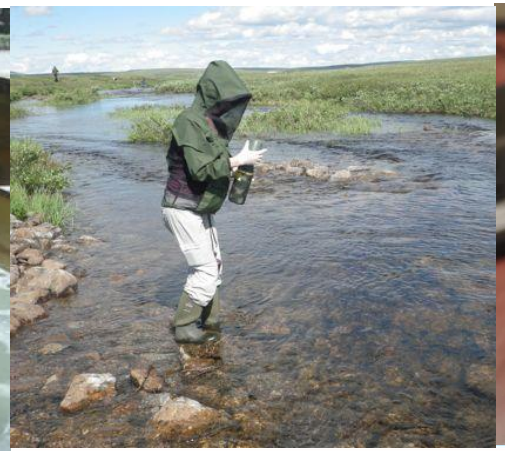
JNCC Workshop Earth Observation for Water Quality Monitoring, 13th & 14th October 2020

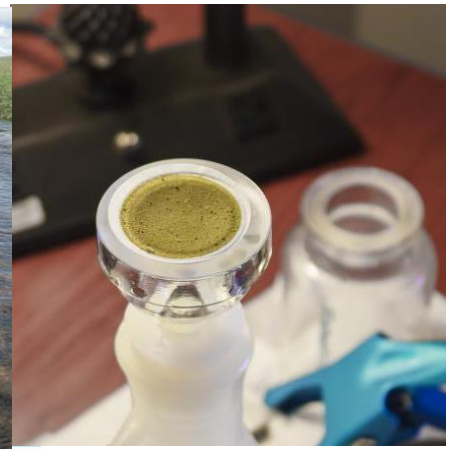
Challenges for water quality regulation

EU legislated Water Framework Directive (WFD), Marine Strategy Framework Directive (MSFD) & Drinking Water Directive (DWD) require routine monitoring and assessment of inland and transitional water quality.

- Typical ground-based measurement approaches fail to meet directive requirements

1. Current samples are not representative
2. Limited lakes monitored per year
3. Measurements are not standardised





UKTAG Guide to Lake Phytoplankton

2 Data collection

2.1 Sample collection – location, frequency, sampling period and sample volume

Samples need to be collected for analysis of chlorophyll *a* content and measurement of species composition and bio-volume. If not already known, information should also be obtained on the alkalinity and water colour of the lake which is needed to derive reference conditions (see section 2.3).

The following section defines the way the samples should be collected and subsequently analysed to obtain data on both chlorophyll *a* and phytoplankton species composition.

2.1.1 Location

Samples must be representative of open water conditions in the lake being studied.

1 **Samples must be representative of open water conditions**

Care must be taken to ensure samples are not contaminated with benthic material. Samples taken from a boat on the open water should be taken sub-surface (30cm below the surface) or from an integrated sample of the epilimnion.

2.1.2 Frequency

The frequency and total number of samples required differs according to the parameter being assessed.

Chlorophyll *a* – samples for chlorophyll *a* analysis should be collected at monthly intervals from January to December, giving a total of 12 samples per year. This encompasses the full

2 **January to December, giving a total of 12 samples per year**

It is important to take samples at even intervals throughout the year to ensure proper representation of the natural seasonal variation in phytoplankton biomass.

Ideally, the monitoring should be continued over three full years, such that 36 chlorophyll samples are collected in total.

1.4 Intercalibration

This is a process whereby all European Member States were required to compare WFD

3 **whereby all European Member States were required to compare WFD class**

assessment and reporting.

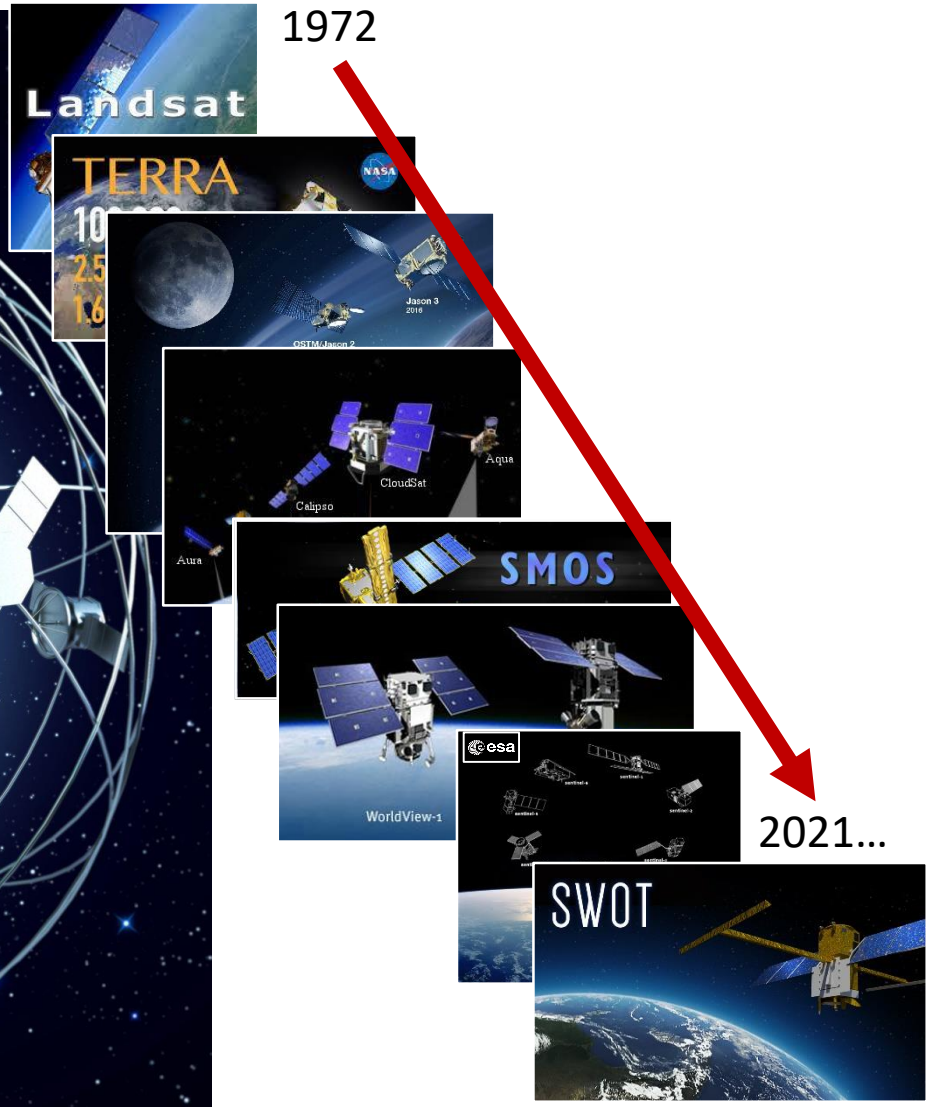
WFD-UKTAG Lake Assessment Method Phytoplankton

An opportunity for monitoring using Earth observing satellites

SEPA Scottish Environment Protection Agency
Buidheann Dion Àrainneachd na h-Alba

Why use satellites?

- Number of environmental parameters,
- Spatial and temporal scales
- Consistent measurements (NRT)
- Comparable across catchments, countries, agencies, industries.



ESA Sentinel-2 improved monitoring capabilities

Sentinel-2a & -2b

Multi Spectral Imager (MSI)

13 spectral bands (7 visible)

10-60 m spatial resolution

5 day global revisit (2a & 2b)

1-3 day UK revisit (2a & 2b)

Sentinel-2c & -2d

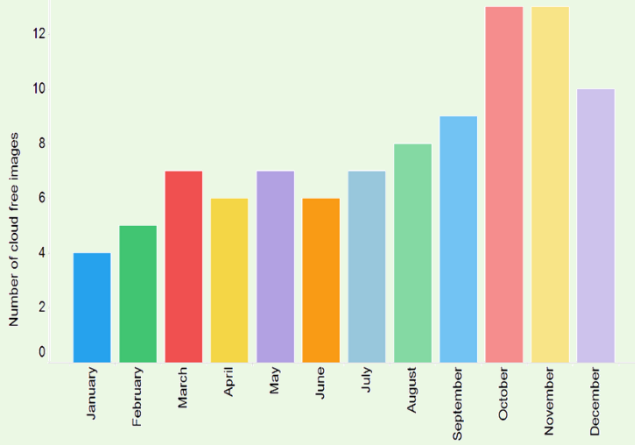
Planned for 2021-2030

Satellite remote sensing provides an opportunity for consistent monitoring of inland waters.

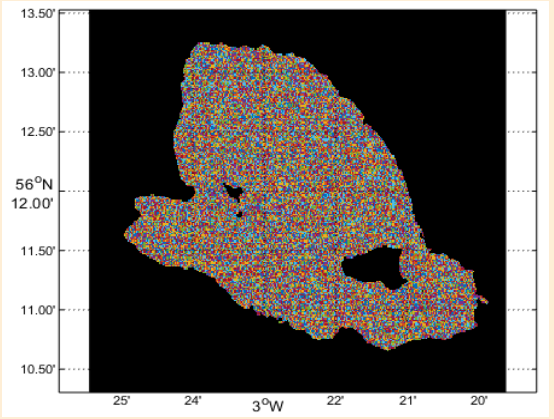
Bottom left:
300 m Envisat-MERIS

Bottom right:
10 m Sentinel-2 MSI

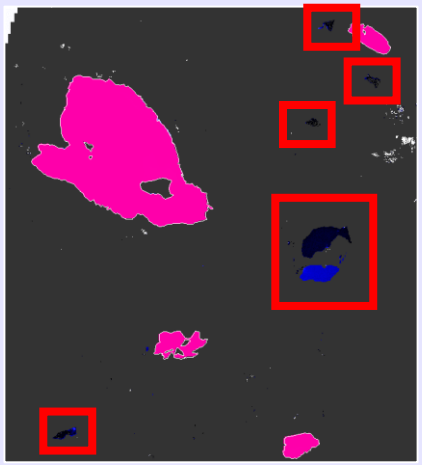
Routine monitoring capability in numbers



1) Number of cloud free days: **95** cloud free (>30% pixels) images collected over Loch Leven in **1 year**



2) Number of pixels per lake: Surface area of Loch Leven corresponds to ~**35000** pixels



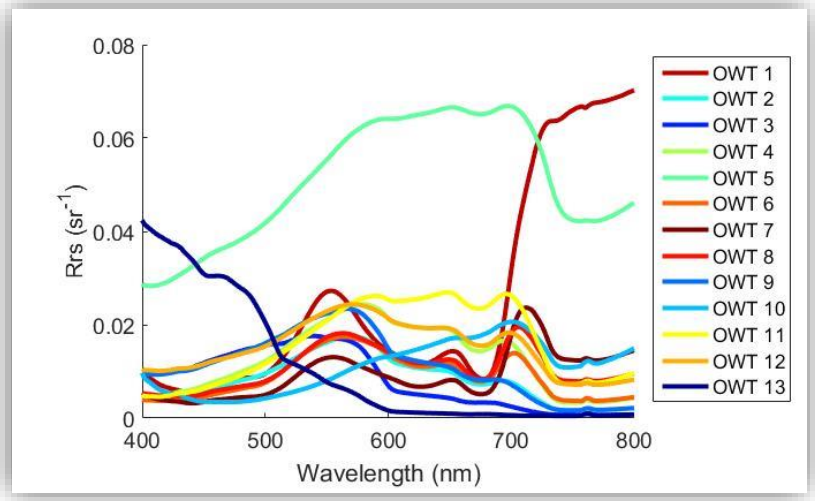
Sentinel-2 + WFD waterbodies (pink)

3) Number of observable lakes: Many more observable by S-2, particularly useful in areas inaccessible for ground-sampling.

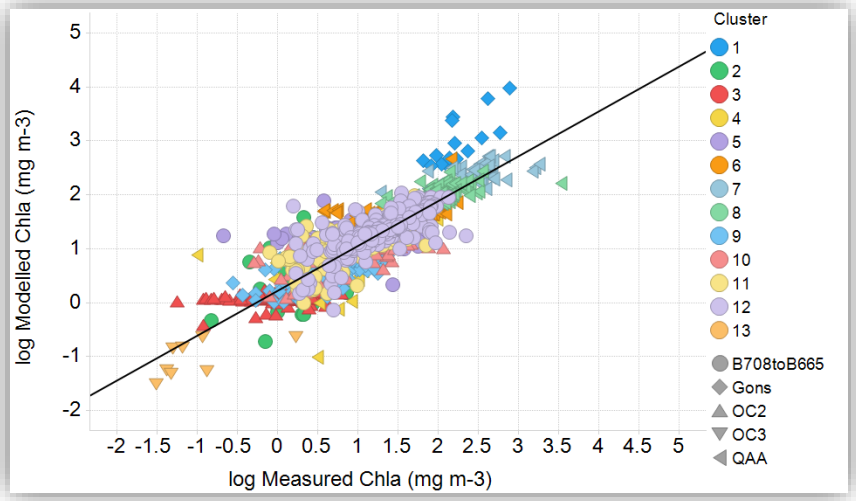
Factor	SEPA ground sample	Sentinel-2
Number of samples per year per lake	~12	~95
Number of lakes sampled per year	60	>1000s
Spatial representation	1 sample location	>10000s pixels
Number of equivalent samples	**720**	**950 x 10^6**

GloboLakes scientific breakthrough

1. Optical water type (OWT) classification



2. Algorithm selection

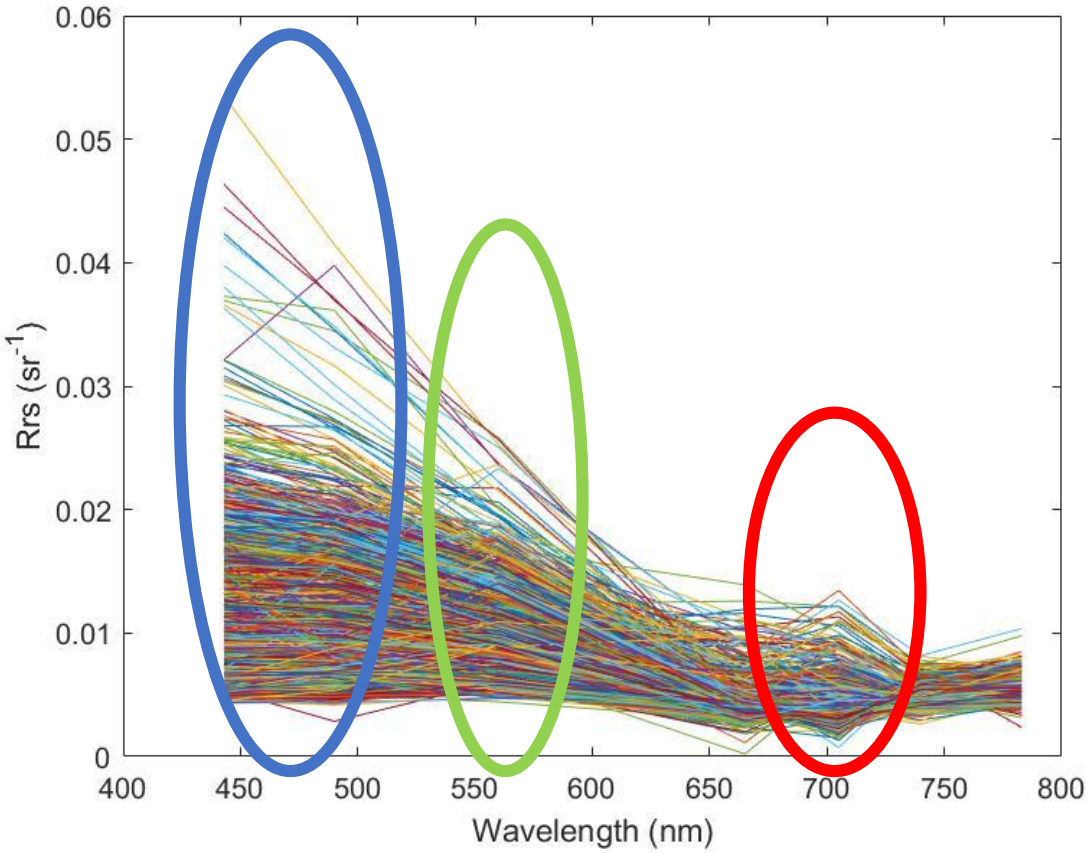


1. Remote sensing reflectance (Rrs) assigned an OWT - 13 distinct optical water types identified globally.
2. Best performing algorithms per OWT combined for Earth observation processing chain for global environment.

Neil, C., Spyrakos, E., Hunter, P.D., Tyler, A.N. A global approach for chlorophyll-a retrieval across optically complex inland waters based on optical water types. *Remote Sens. Environ.* **2019**, *229*, 159–178.

E. Spyrakos, R.O. Donnell, P.D. Hunter, C. Miller, M. Scott, S.G.H. Simis, C. Neil, C.C.F. Barbosa, C.E. Binding, S. Bradt, M. Bresciani, G.D. Olmo, C. Giardino, A.A. Gitelson, T. Kutser, L. Li, B. Matsushita, V. Martinez-vicente, M.W. Matthews, I. Ogashawara, A. Ruiz-Verdu, J.F. Schalles, E. Tebbs, Y. Zhang, A.N. Tyler
Optical types of inland and coastal waters Limnol. Oceanogr. **2018**, 10.1002/lno.10674

A simplified case for POLYMER corrected Sentinel-2



Two simple conditions;

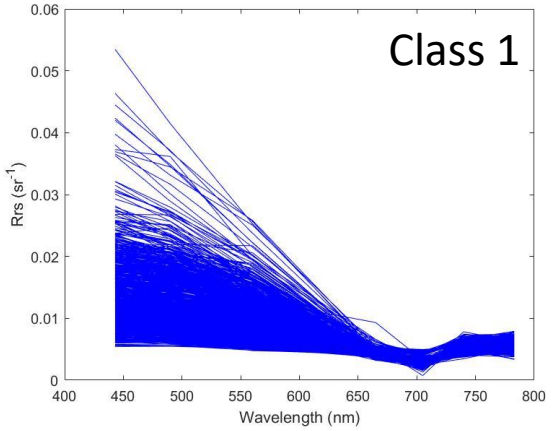
1. Blue or green waveband peak?
2. Is there a peak in the red wavebands?

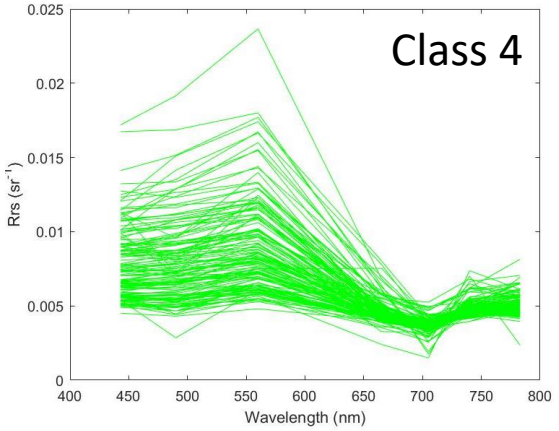
Algorithms per class

Scottish Environment Protection Agency
Buidheann Dion Àrainneachd na h-Alba

Class 1 & 4

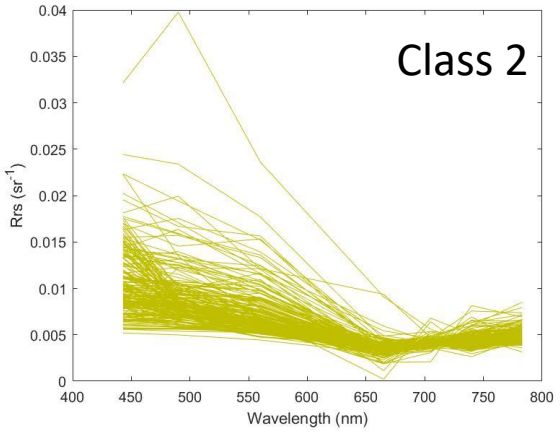
No red peak, algorithm based on **blue/green waveband ratio** as per NASA Ocean Color algorithms (O'Reilly *et al*, 2000)

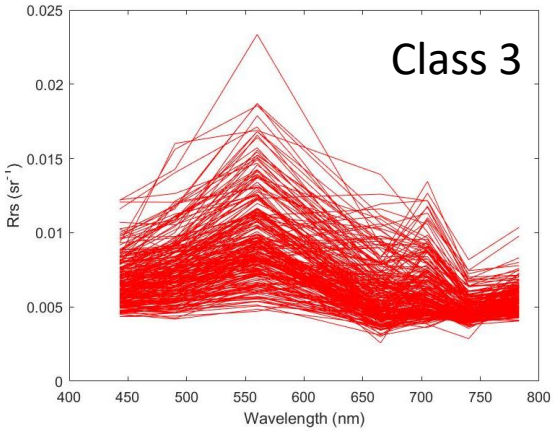




Class 2 & 3

Red peaks, algorithm based on **near-infrared/red waveband ratio** as per Gitelson (1993)



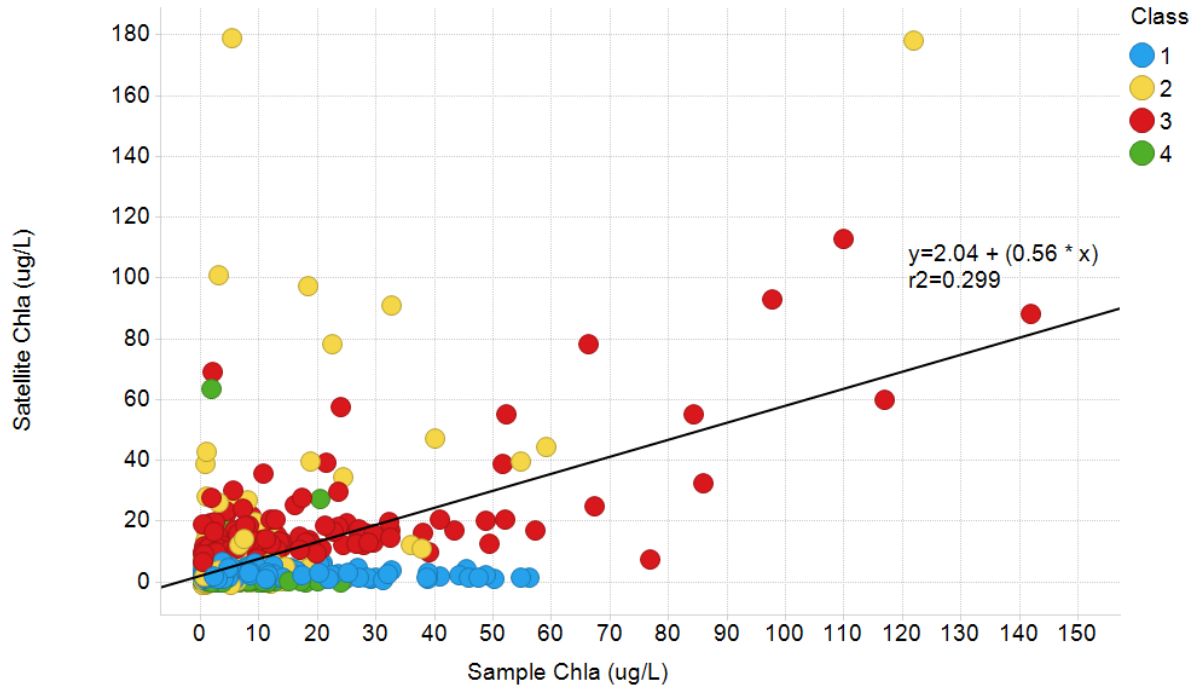


UK Sentinel-2 chlorophyll-a dataset

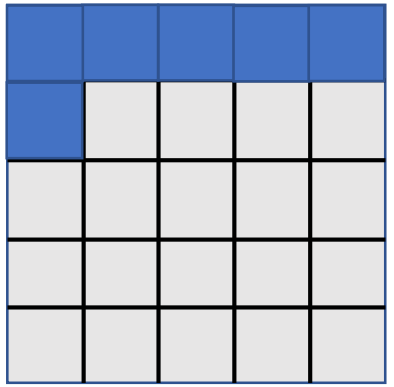
- Full Sentinel-2 period from 2015 until present
- 81608 Sentinel-2 images processed so far
- Incorporates (in the first iteration) 933 inland water bodies
- 135309 individual lake outputs

Point by point match-up comparison (or is it?)

Extremely difficult to validate results when we don't know exactly where a sample is taken



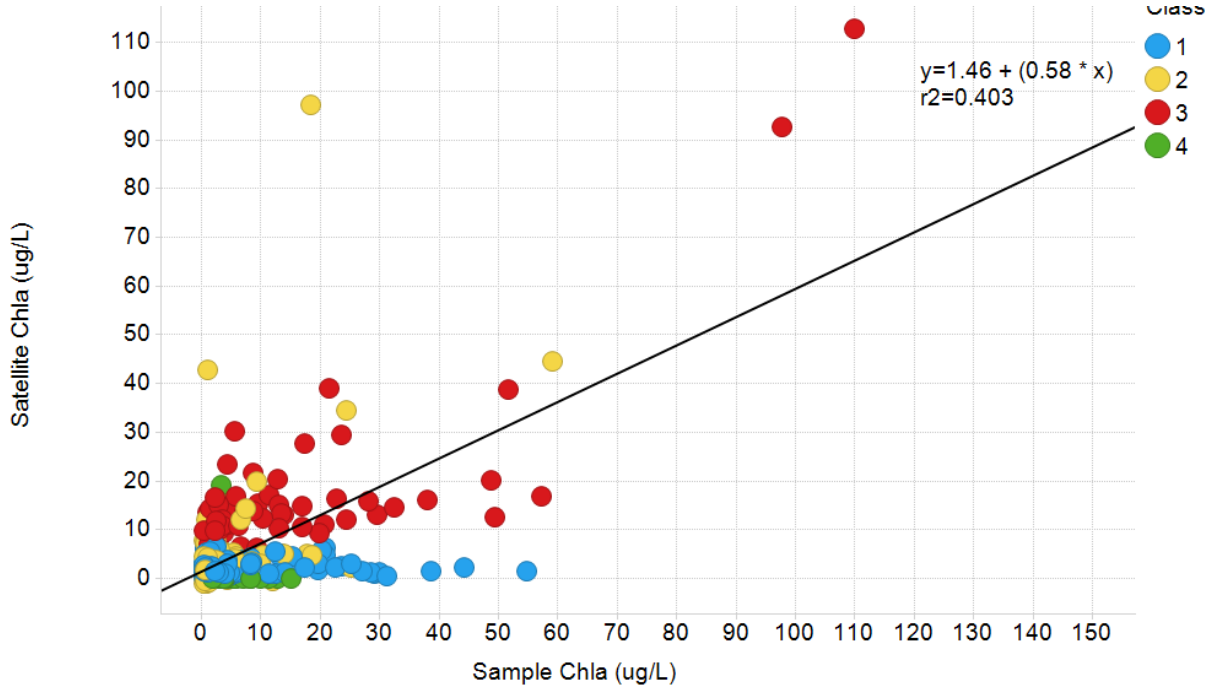
5 x 5 pixel boundary around sample



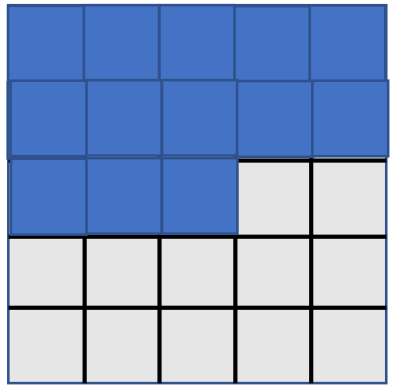
At least 25% class homogeneity in sample boundary

Point by point match-up comparison (or is it?)

Extremely difficult to validate results when we don't know exactly where a sample is taken



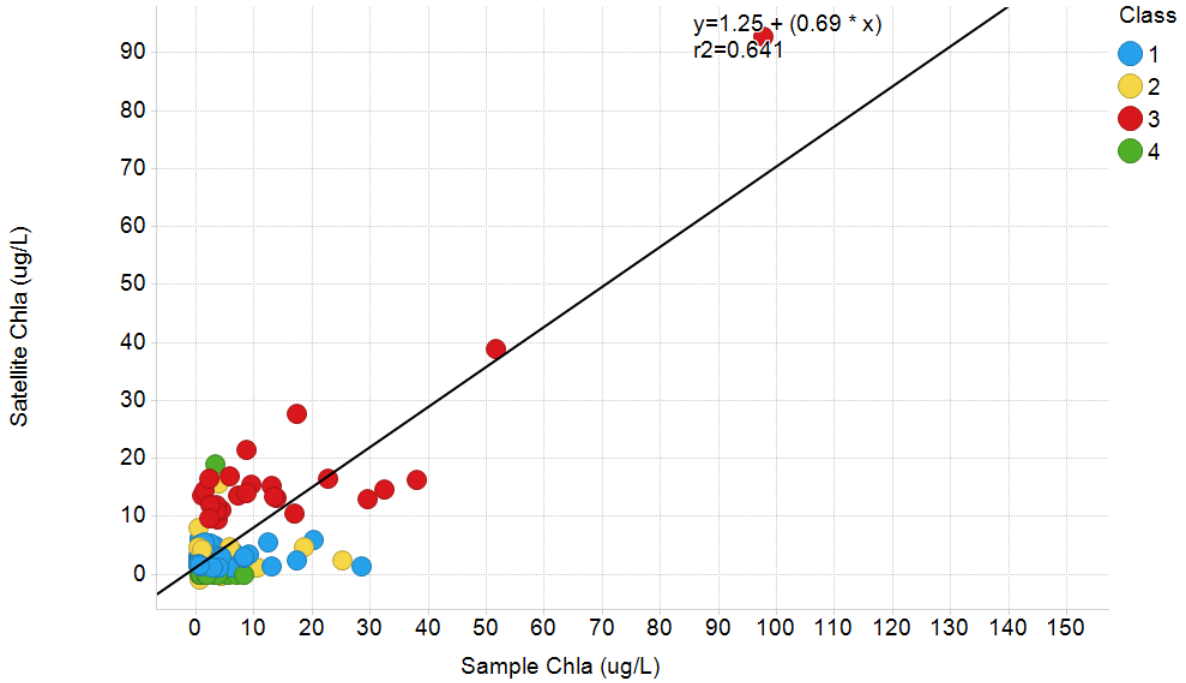
5 x 5 pixel boundary around sample



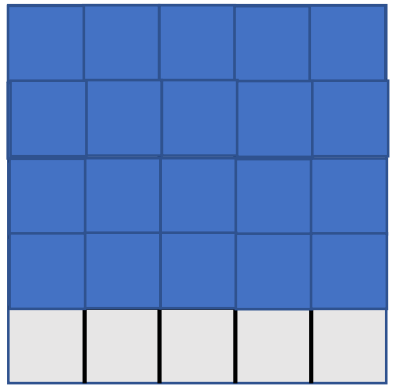
At least 50% class homogeneity in 5 x 5 pixel sample boundary

Point by point match-up comparison (or is it?)

Extremely difficult to validate results when we don't know exactly where a sample is taken



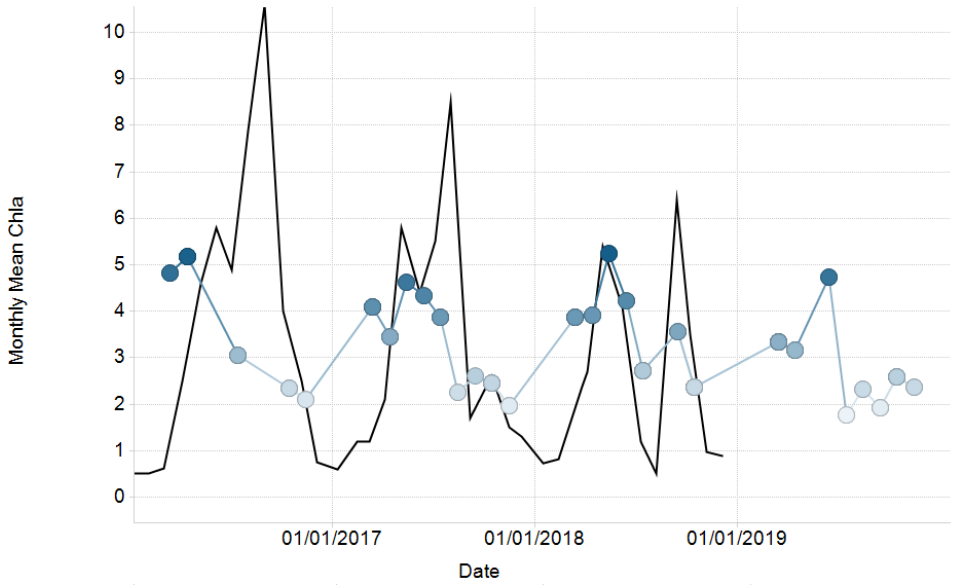
5 x 5 pixel boundary around sample

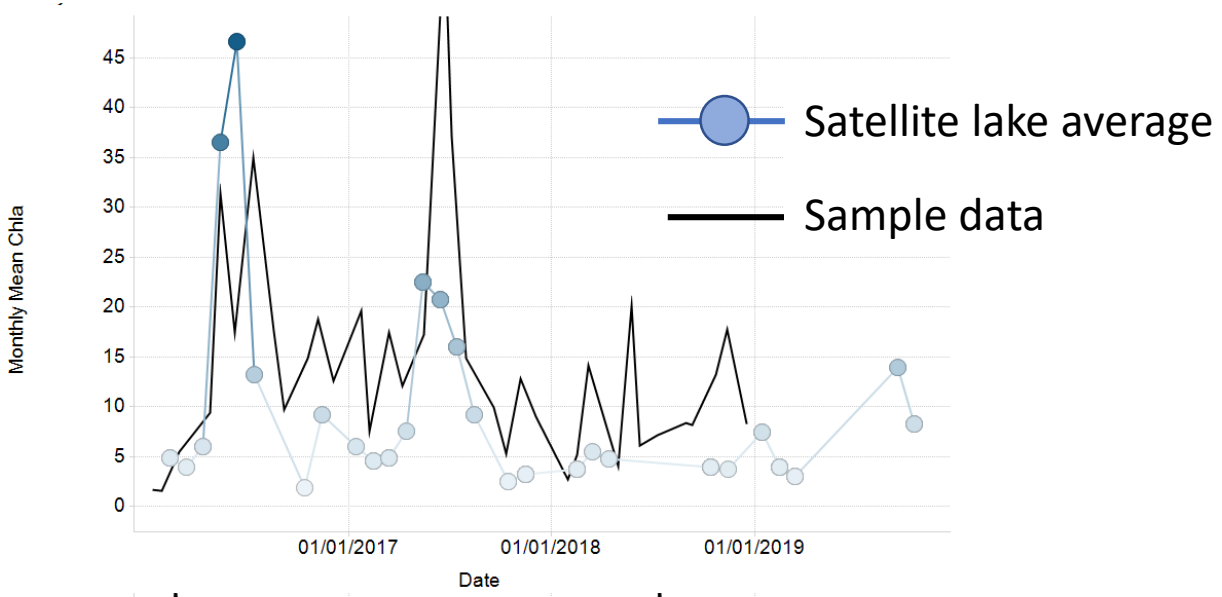


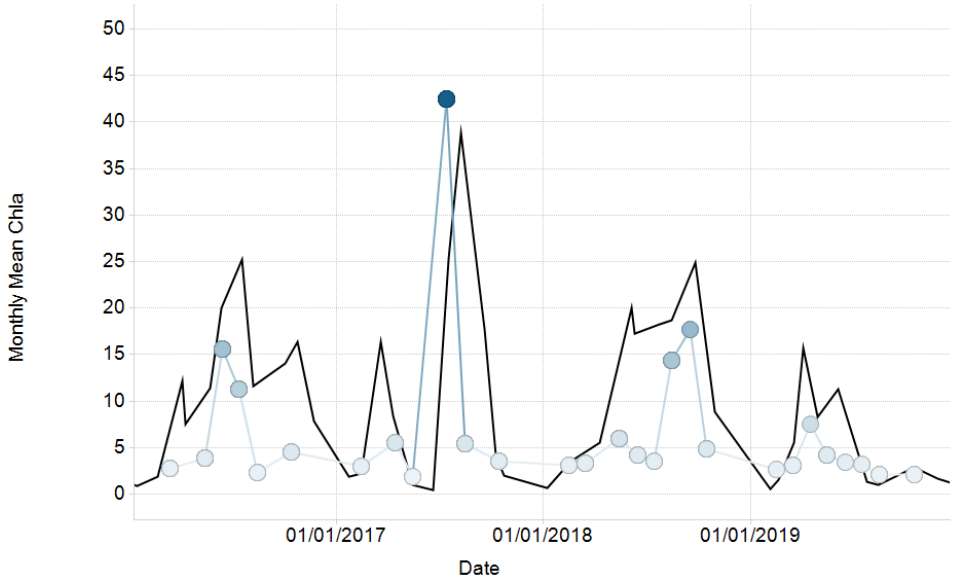
At least 80% class homogeneity in 5 x 5 pixel sample boundary

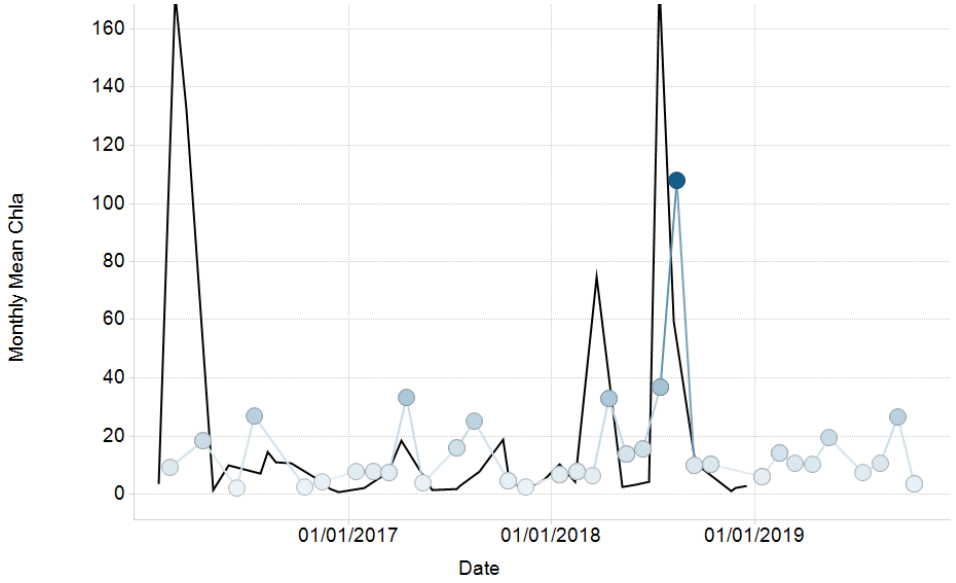
This demonstrates how the normal variability of S-2 pixels affects point by point comparisons

Lake average time series



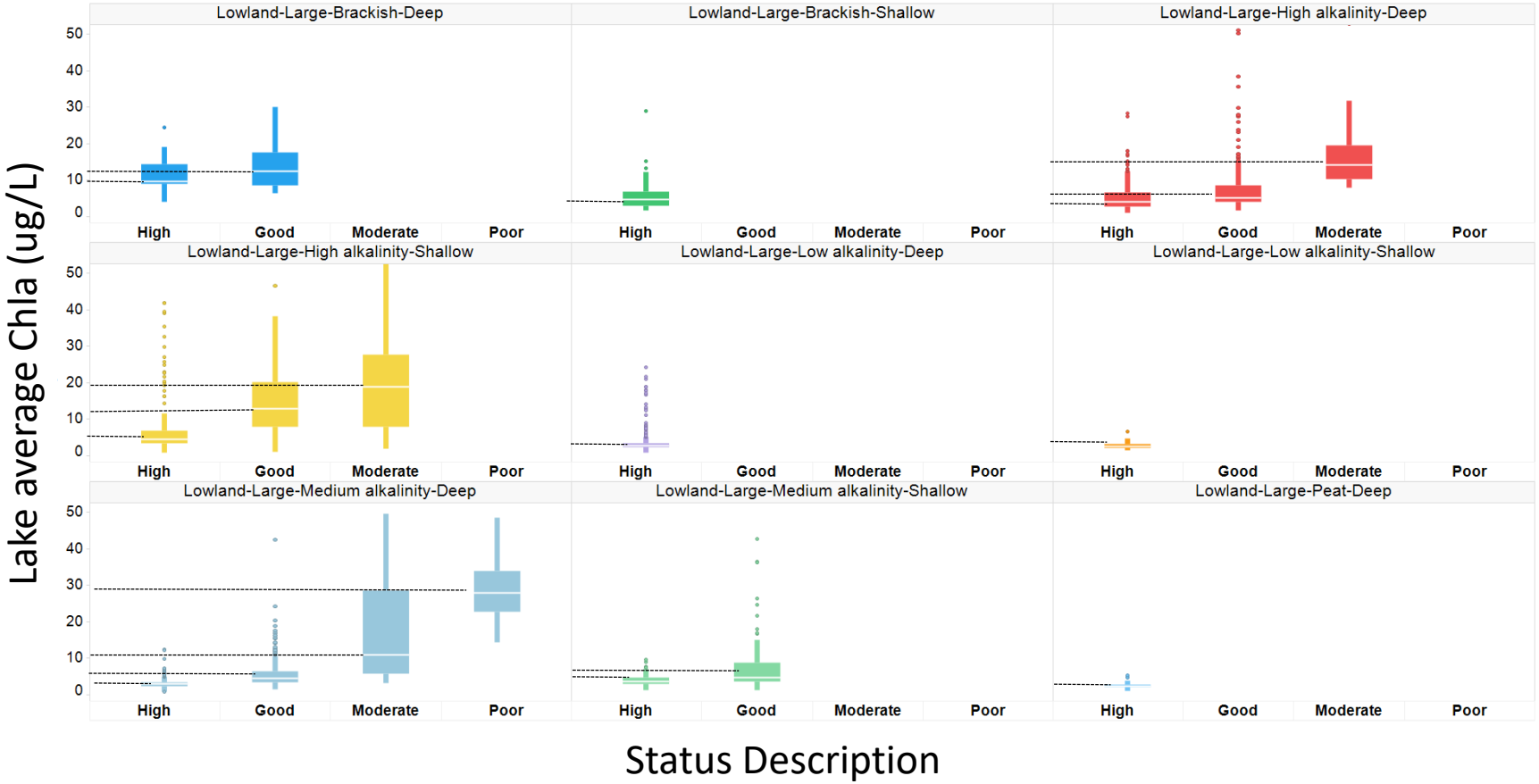






Application: satellite data to quantify change

Satellite chlorophyll concentration statistics for lake type and class status can be used to define common characteristics.

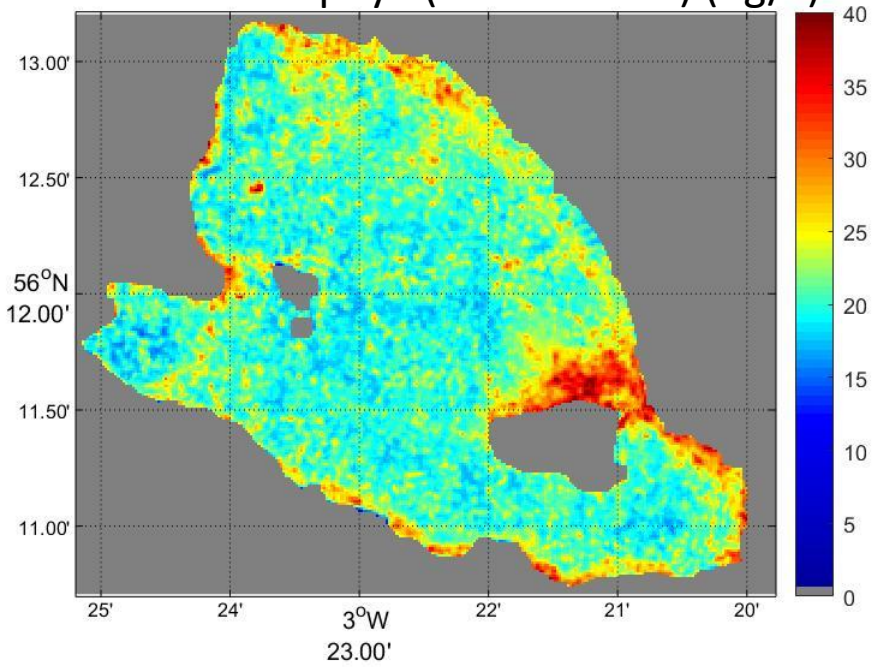


= Opportunity for additional evidence (or confidence) in classification or filling data gaps.

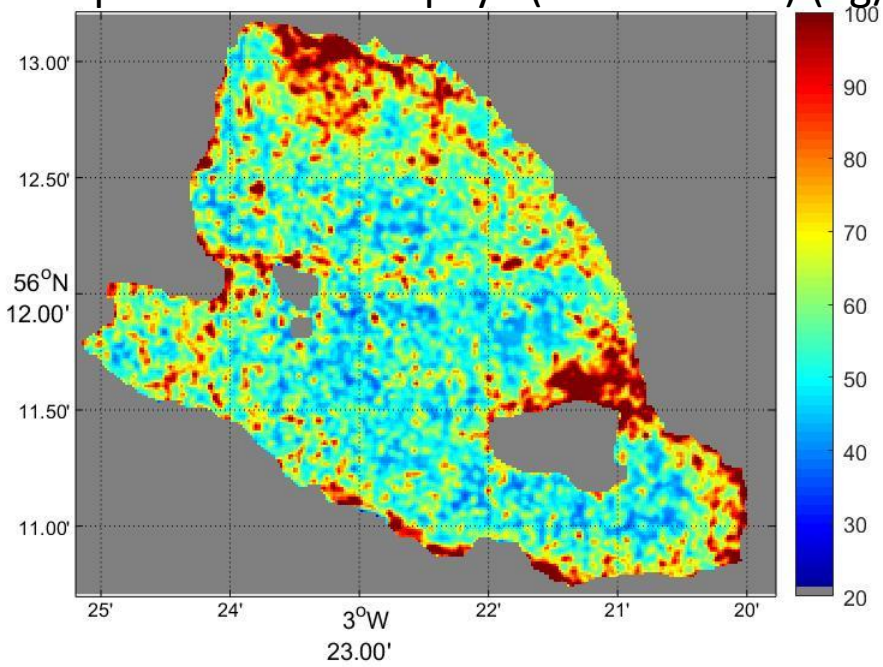
Application: satellite data to assess potential risk

Average chlorophyll concentration (“baseline”) maps can be used to identify “hotspots” of environmental risk whilst percentile maps indicate potential extent of eutrophication events.

Mean chlorophyll (2016 – 2019) (ug/L)



95th percentile chlorophyll (2016 – 2019) (ug/L)



= An opportunity for targeted treatment or timely intervention (e.g. nutrient reduction measures).

Innovation through Knowledge Exchange

- NERC Knowledge Exchange Fellowship with the aim of promoting and facilitating the use of **satellite remote sensing** for improved **regulatory monitoring** of inland and TRAC water quality.
- Special thanks to KE coordination group: Willie Duncan & Jan Krokowski from SEPA, Sian Davies & Joanne Pitt from EA, Stuart Knott from Anglian Water and Fraser Leith from Scottish Water.

Thank you

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SEPA
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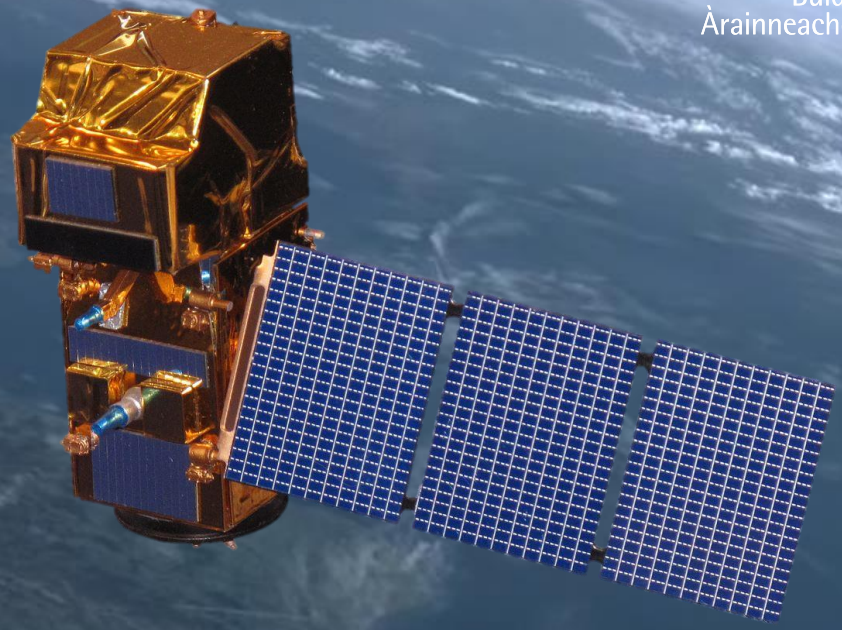

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