Global Observatory of Lake Response to Environmental Change

JNCC/Copernicus Workshop:
Using Earth Observation for Water Quality Monitoring

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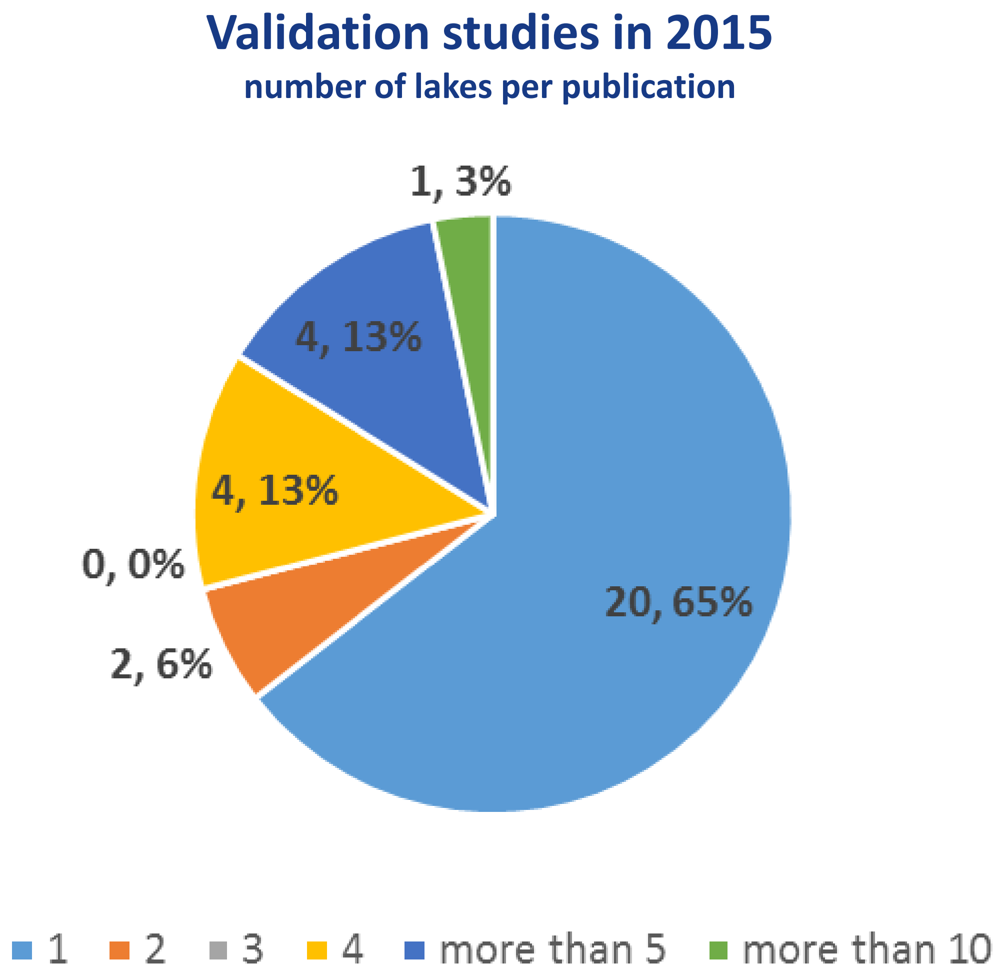
UKRI Natural Environment Research Council
esa ARC Lake diversity inland waters GLaSS INFORM
Centre for Ecology & Hydrology NATURAL ENVIRONMENT RESEARCH COUNCIL
University of Dundee
University of Glasgow
PML Plymouth Marine Laboratory
University of Reading
UNIVERSITY of STIRLING

The Context

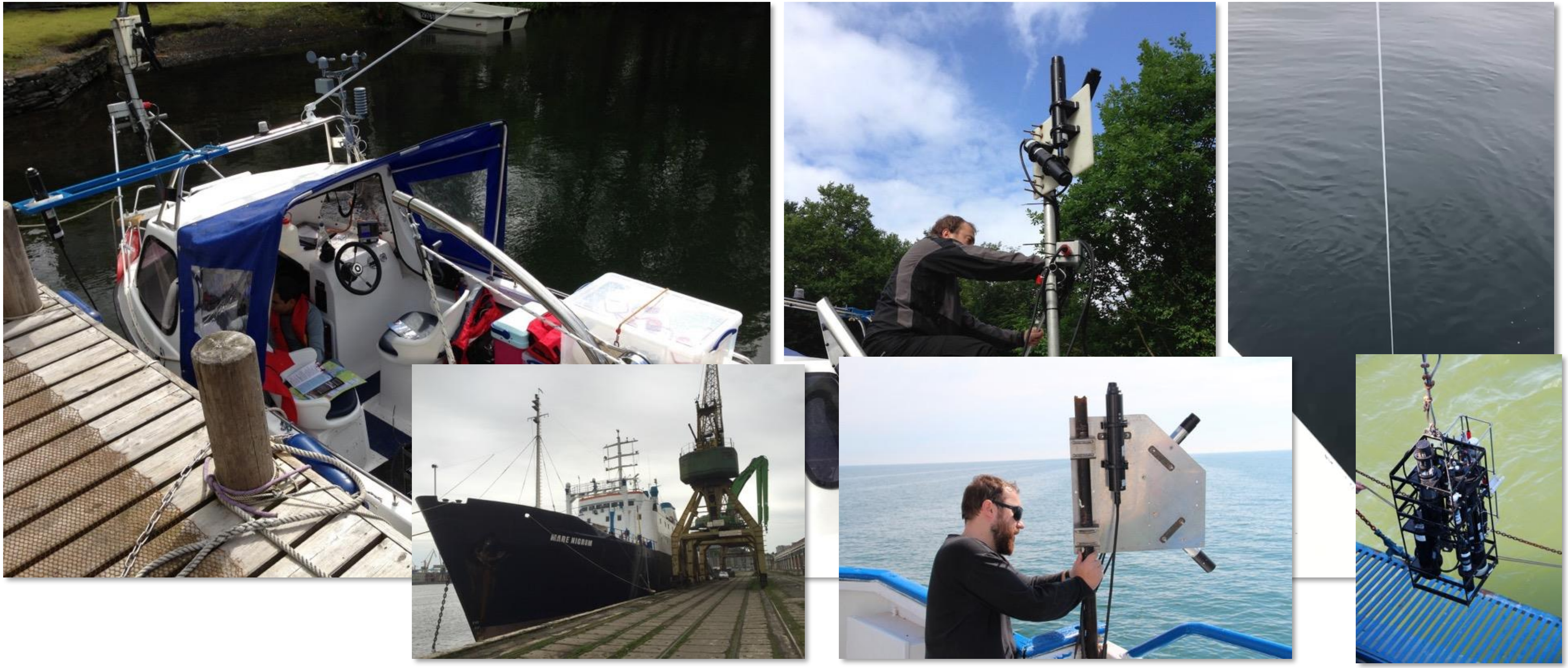
- ~117 million lakes globally: 3% of land area but 85% of fresh surface water
- Important to global biogeochemical cycles (e.g. Bastviken et al. 2011, *Science*) and biodiversity
- Global concerns over water security and provision of critical ecosystem goods and services
- Very small proportion routinely monitored in a consistent manner
- Increasing regulatory demands for status assessment (e.g. EU Water Framework Directive)

The Challenge

- High diversity in lake optical properties
- No single in-water algorithm parameterisation expected to have global applicability
- Dynamic parameterisation and/or selection of atmospheric and in-water algorithms
- Candidate algorithms must be openly available (e.g. formula, code)

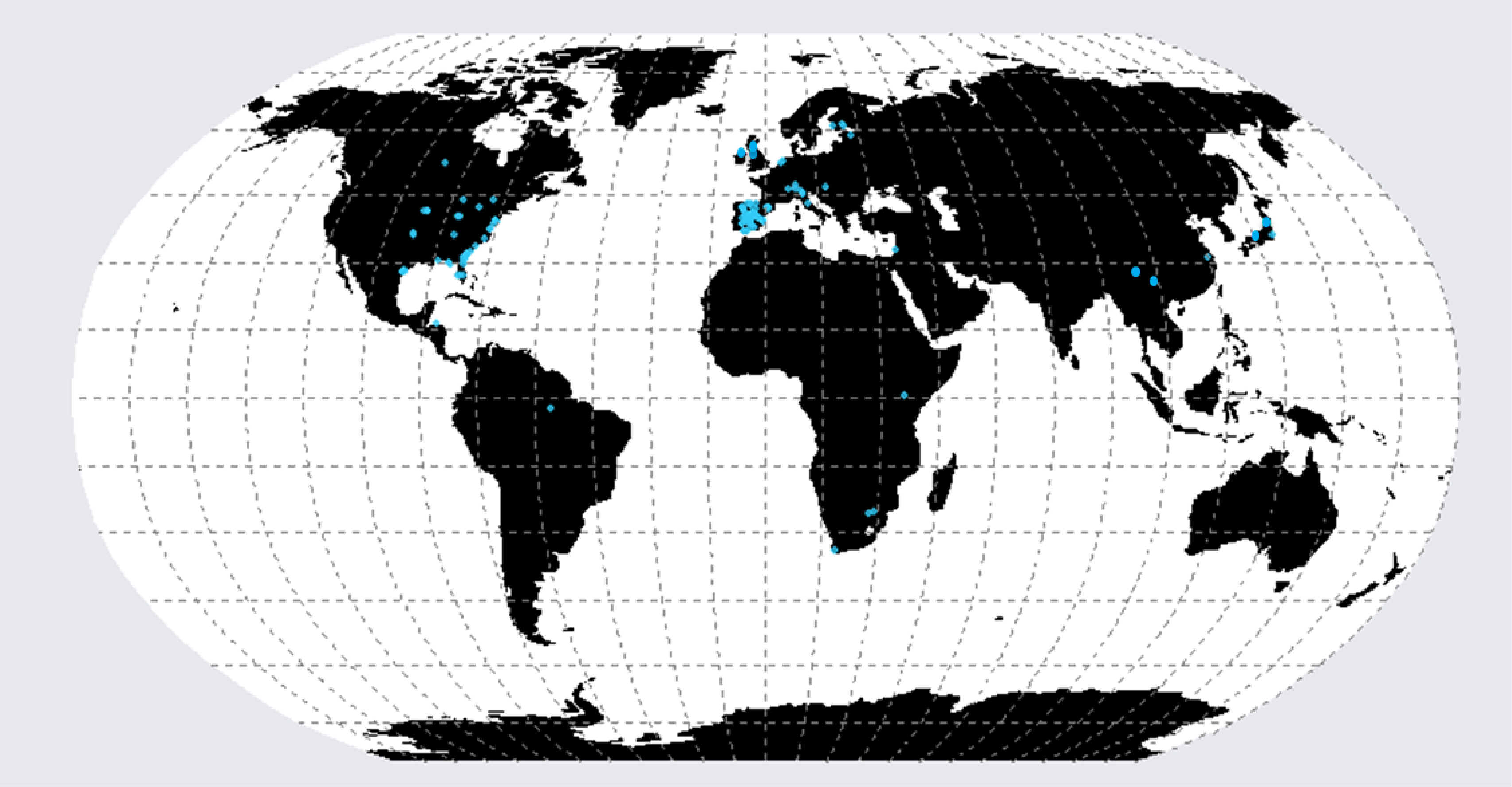


Instrument deployment

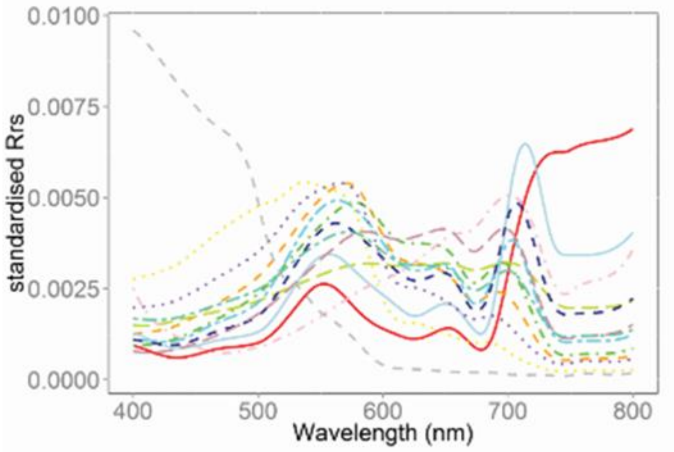


LIMNADES **Lake Bio-optical Measurements and Matchup Data for Remote Sensing**

https://limnades.stir.ac.uk



Parameter	Units	Range
Chla	mg m^{-3}	0.03-13297
PC	mg m^{-3}	0 – 24677
TSM	mg L^{-1}	0.09-2533
ISM	mg L^{-1}	0.01-359
$a_{CDOM}(442)$	m^{-1}	0.004-43
$a_{ph}(442)$	m^{-1}	0.036-455
$a_{NAP}(442)$	m^{-1}	0.004-12.5



60,000 measurements incl. Chl-a data for >1,500 waterbodies & radiometric data for >250 waterbodies

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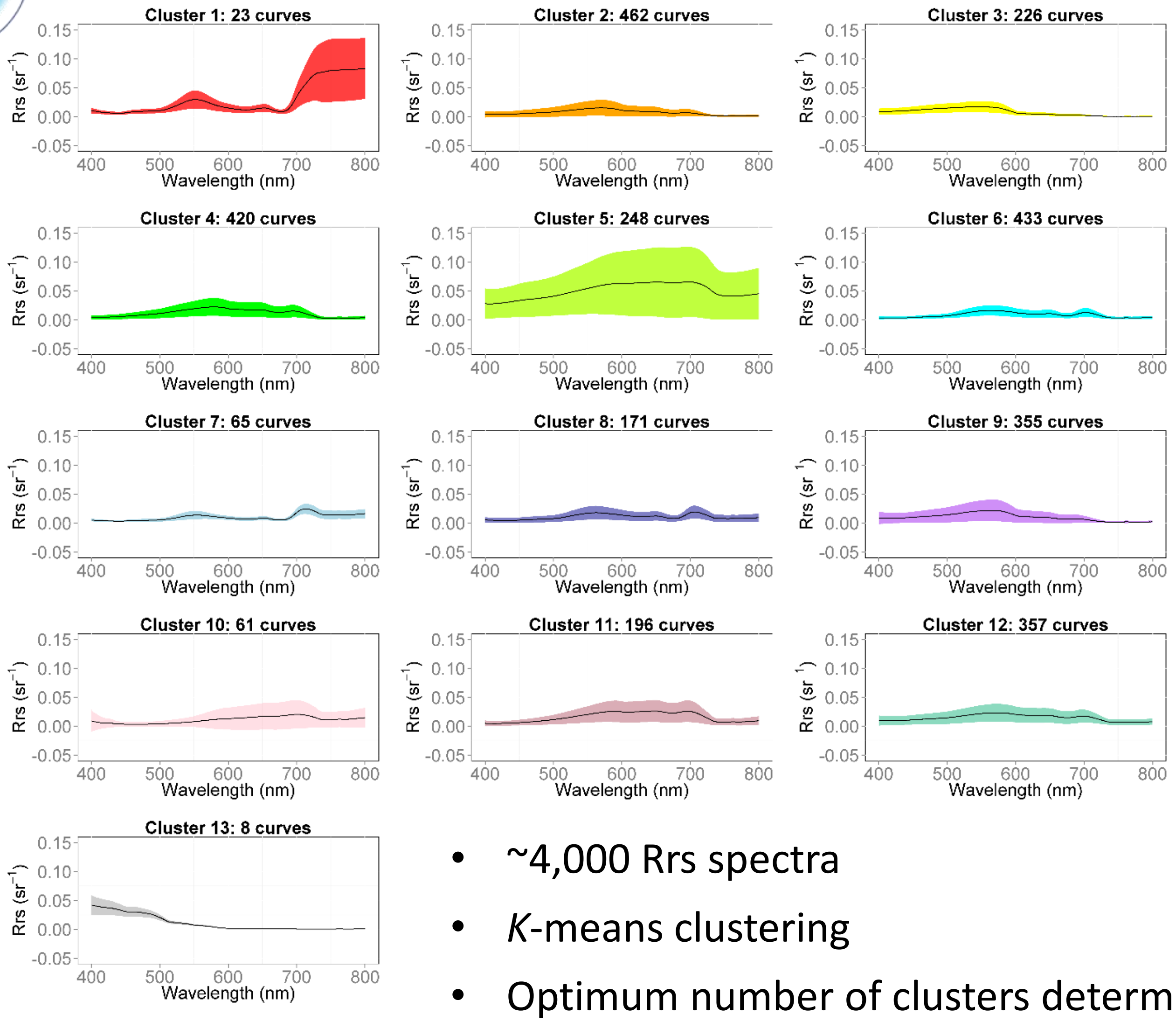
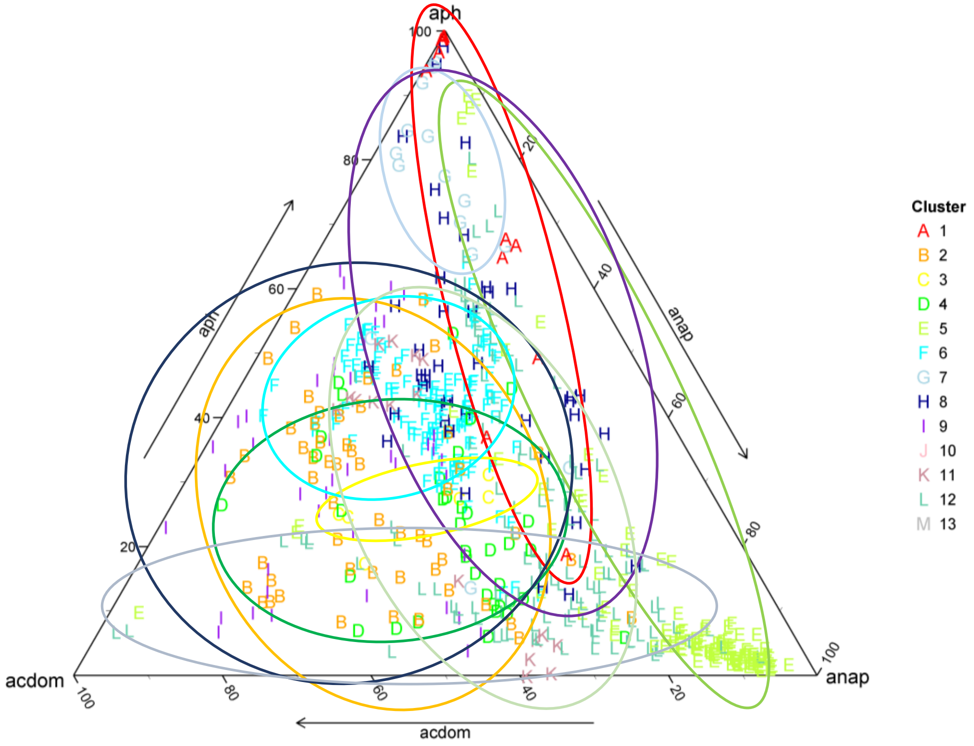
Optical Water Types



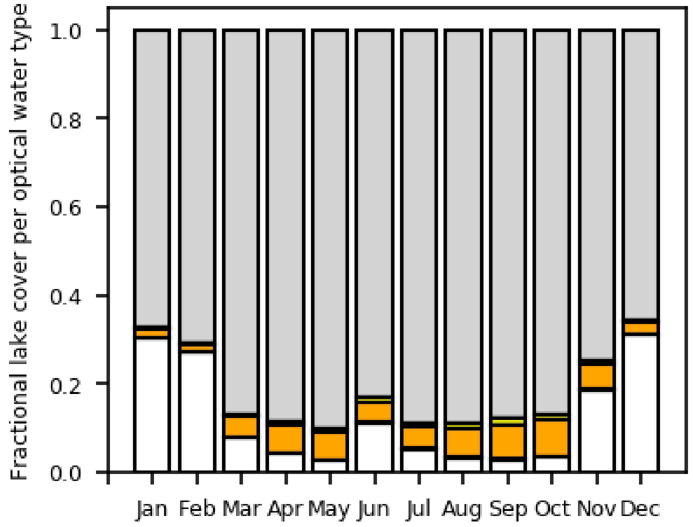


- ~4,000 Rrs spectra
- *K*-means clustering
- Optimum number of clusters determined statistically

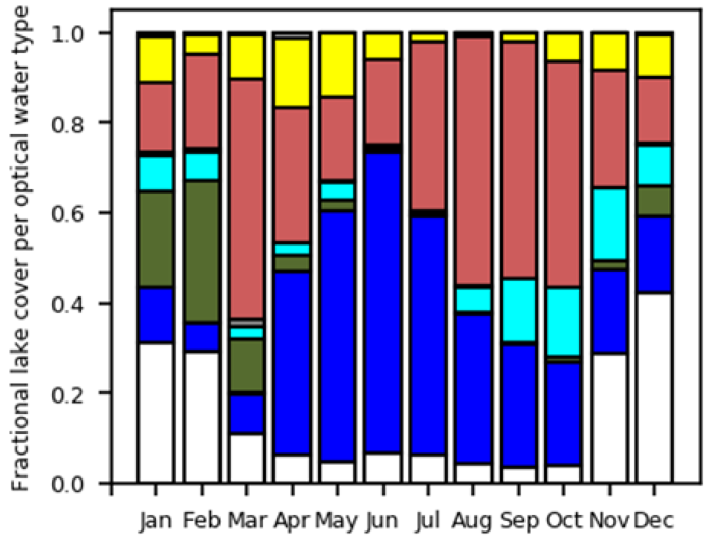
Spyrakos et al., 2018

Optical Water Types

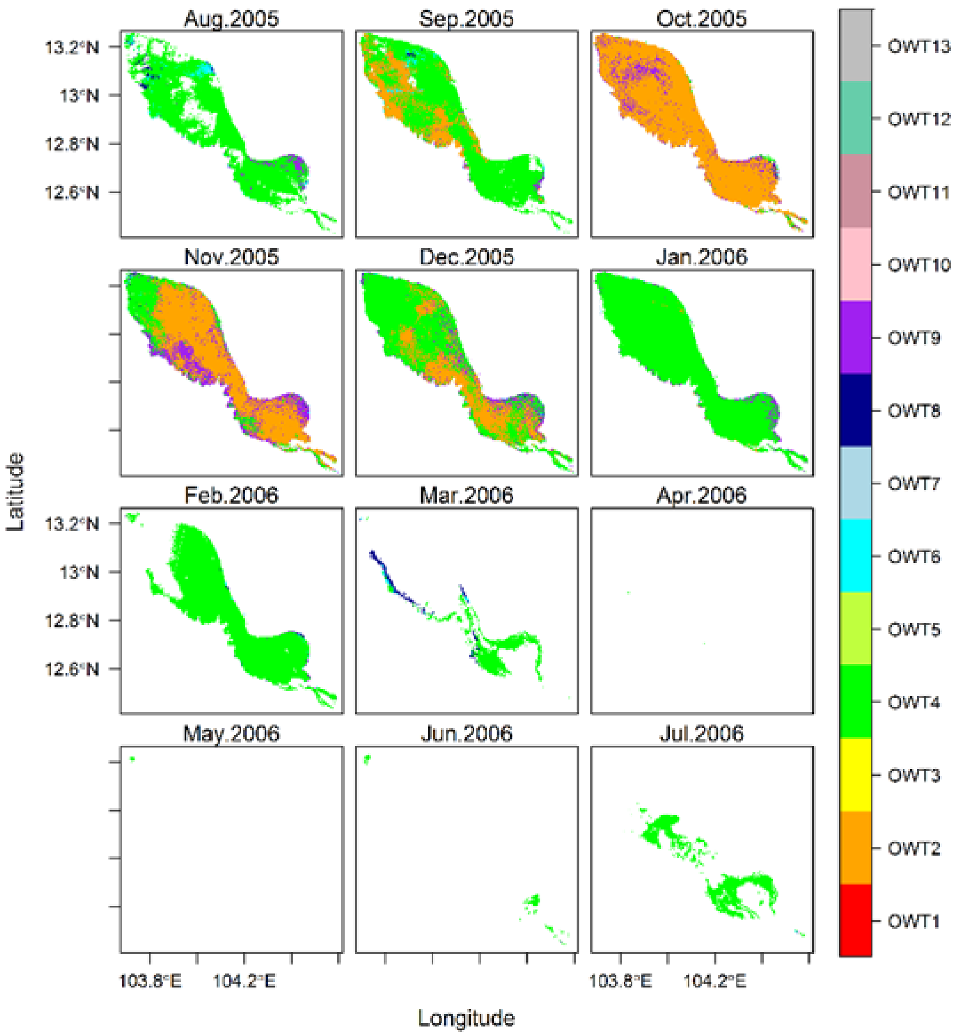
ISSUK KUL, Kyrgyzstan



IJsselmeer, Netherlands



TONLÉ SAP Lake, Cambodia



Overview of algorithm validation

- Validation using *in situ* and MERIS reflectances
- Six atmospheric correction processors
  - MEGS
  - CoastColour C2R
  - C2R Lakes
  - FuB NN
  - Scape-M
  - Polymer
- Suite of in-water algorithms for biogeochemical variables
  - **Chlorophyll**
  - Phycocyanin
  - Total Suspended Matter
  - Coloured Dissolved Organic Matter

Constituent	Type	Model	Reference
Chlorophyll	Empirical NIR-red BR	MERIS 2-Band 708/665	Gilerson et al., 2010, Gurlin et al., 2011, Gons et al., 2005.
		MERIS 2-Band 753/665	Gilerson et al., 2010, Gitelson et al., 2011, Moses et al., 2009.
		MERIS 3-Band	Gitelson et al. 2008, Gitelson et al. 2011, Gurlin et al., 2011, Moses et al., 2009.
		MERIS NDCI	Mishra et al. 2012.
	Empirical OC	MERIS OC2E MERIS OC3E MERIS OC4E	O'Reilly et al. 2000.
	Neural Network	NN_Chl NN_IOP	Ioannou et al., 2013.
	Analytical	MERIS QAA [Turbid]	Mishra et al., 2013.
		MERIS GSM	Maritorena et al., 2002.
		MERIS Matrix Inversion	Boss & Roesler, 2006.
	Peak Height Method	MPH	Matthews et al., 2012.

Overview of algorithm validation

Optical Water Types → Step 1: Validation of original algorithms

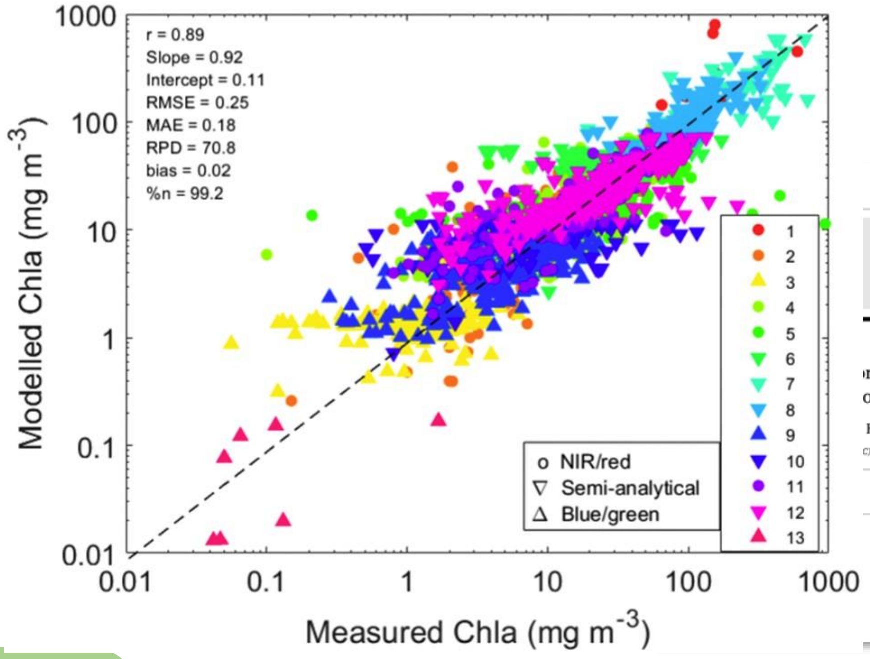
LIMNADES *in situ* → Step 1

MERIS matchups → Step 1

Step 1 → Step 2: OWT cluster-wise algorithm tuning

Step 2 → Step 3: Algorithm selection per cluster or cluster family

- Retuning per cluster reduced uncertainty compare to original model
- 6 algorithms selected to cover 13 OWTs
- Further improvements evident when using the best performing algorithm per cluster

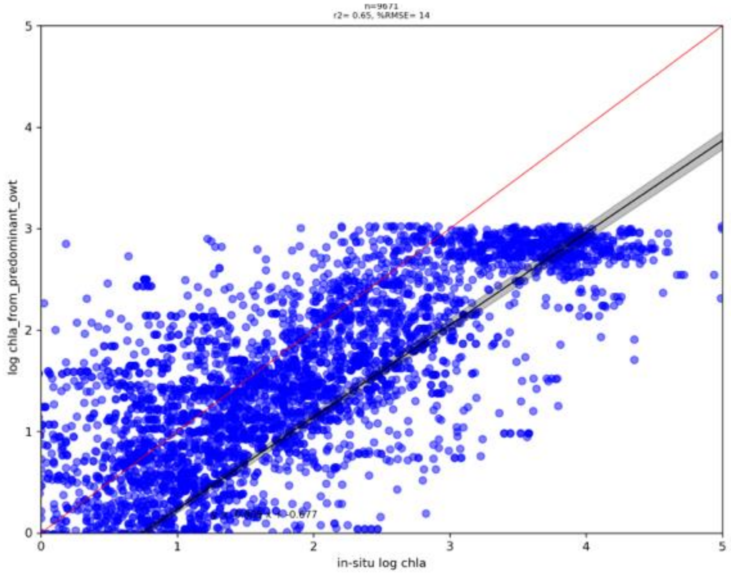


Neil et al., 2019

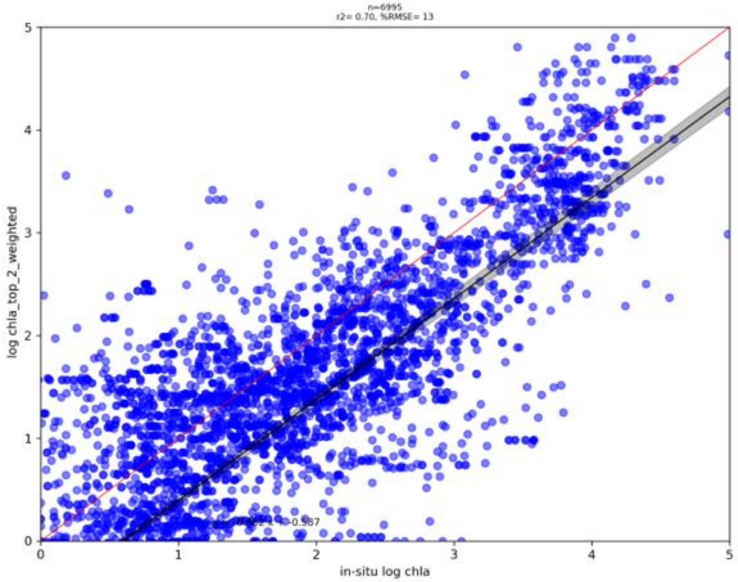
Chlorophyll-a retrieval validation

Per-pixel dynamic algorithm selection and blending outperforms lake-wide application of most suitable algorithm for each observation day.

Most suitable algorithm applied lake-wide
R^2=0.65, RMSE=14%



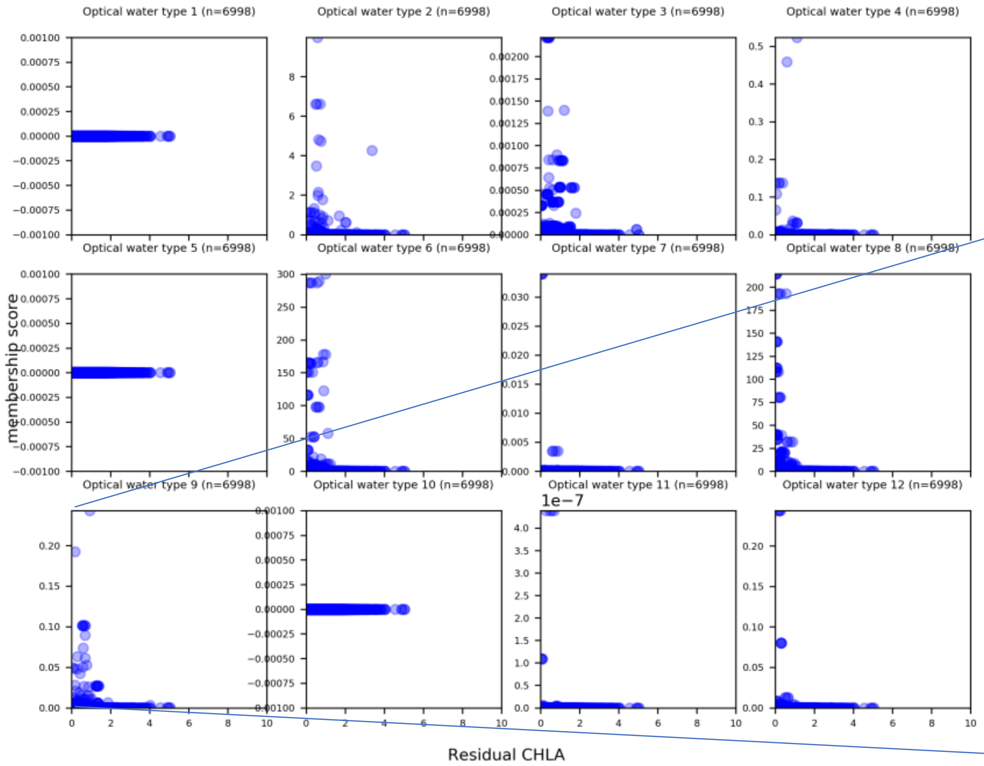
Per-pixel algorithm selection and blending (top-2 classes)
R^2=0.70, RMSE=13%



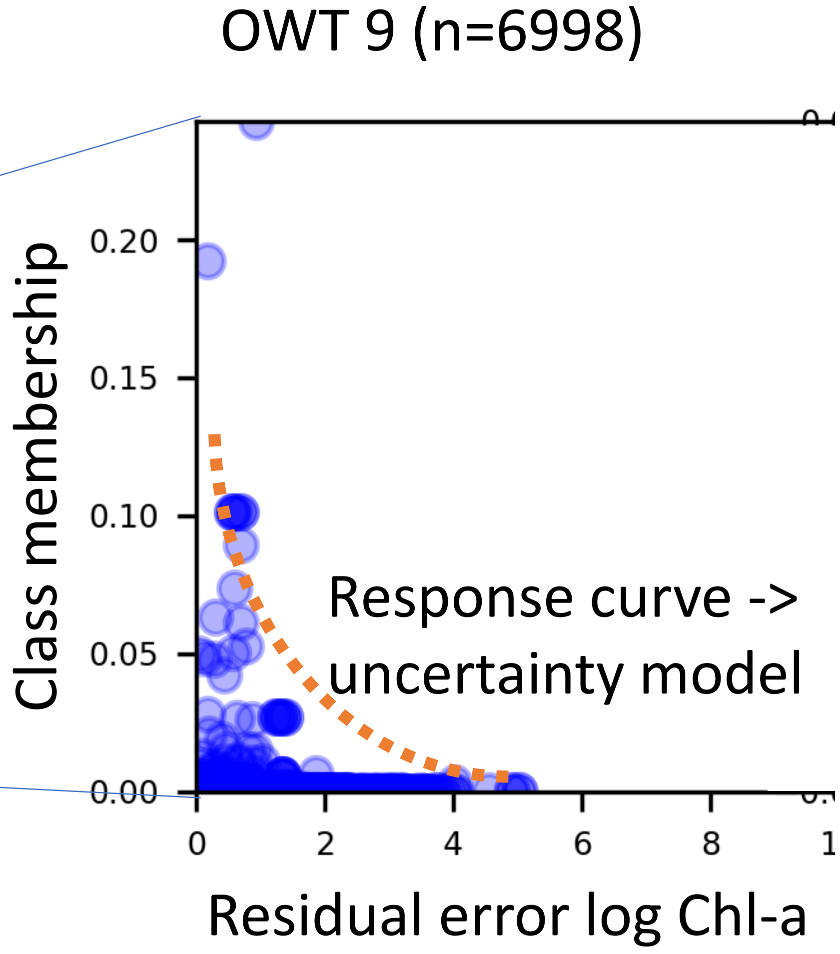
Optical water family	Optical water type	Selected algorithm
1	3; 9; 10; 13	OC2Ev6
2	2; 8; 11; 12	Rrs708:Rrs665
3	1; 4; 5; 6	Gons, 2005
4	7	QAA (Mishra et al., 2013)

Assessing product uncertainty

Optical water type membership can be used to predict residual error per algorithm, allowing uncertainty propagation to the blended product based on global data available per optical water type.



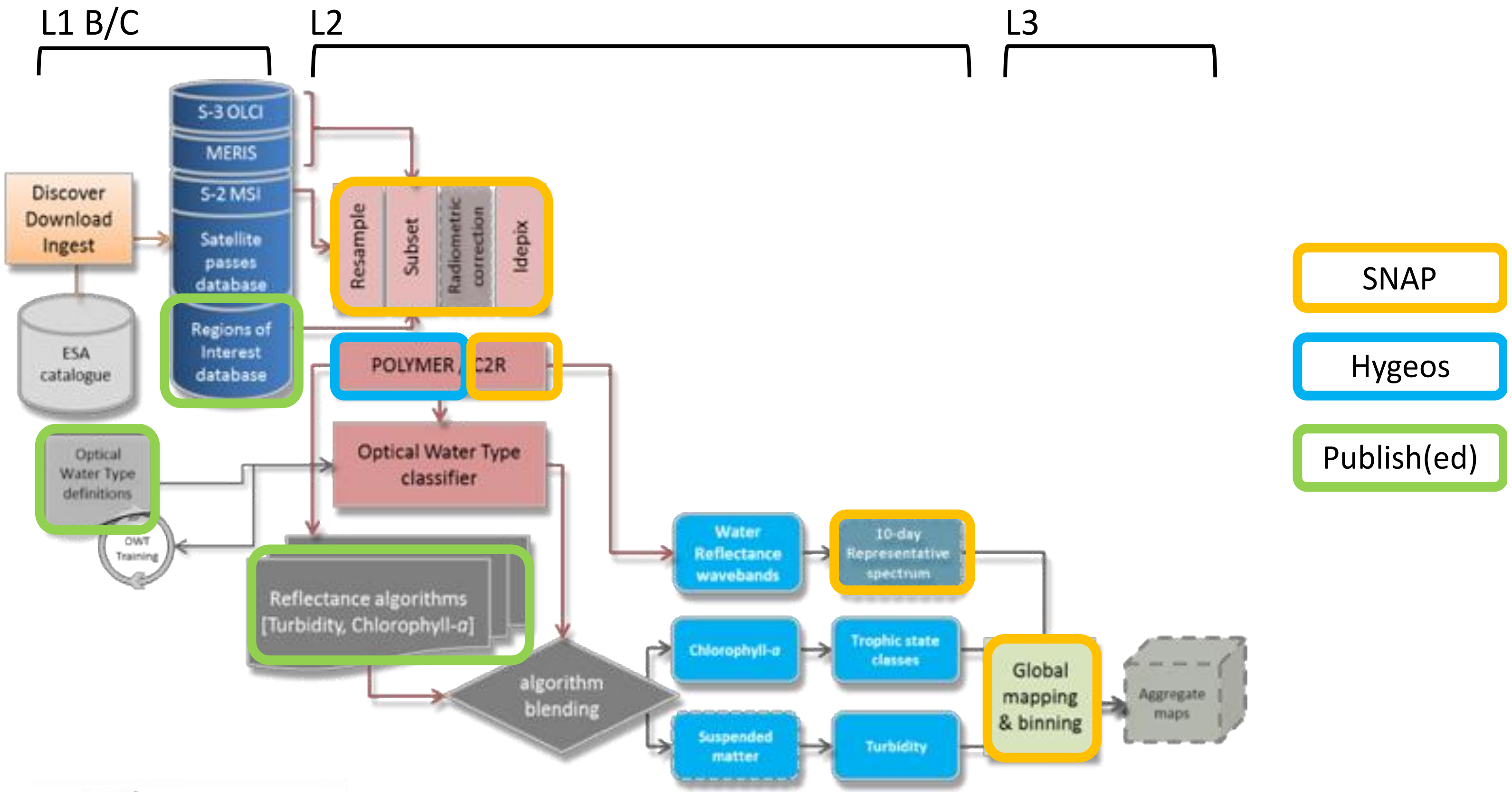
Error functions per water type



PML Plymouth Marine Laboratory

Calimnos Processor

- 10 year time-series from MERIS
- NRT/NTC operational processing for S2 MSI & S3 OLCI

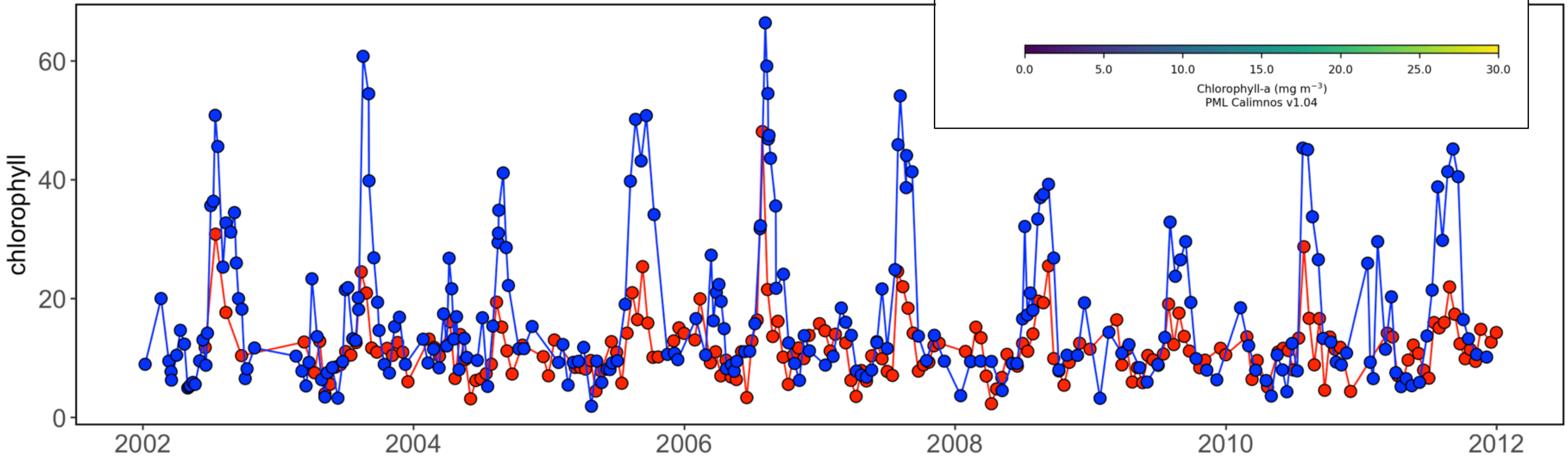


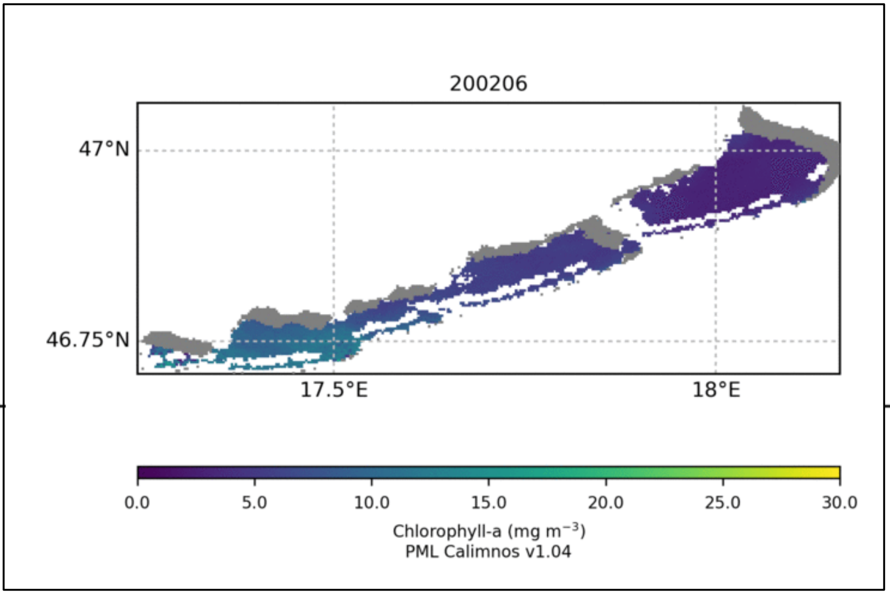
Validation

Lake Balaton [HU]

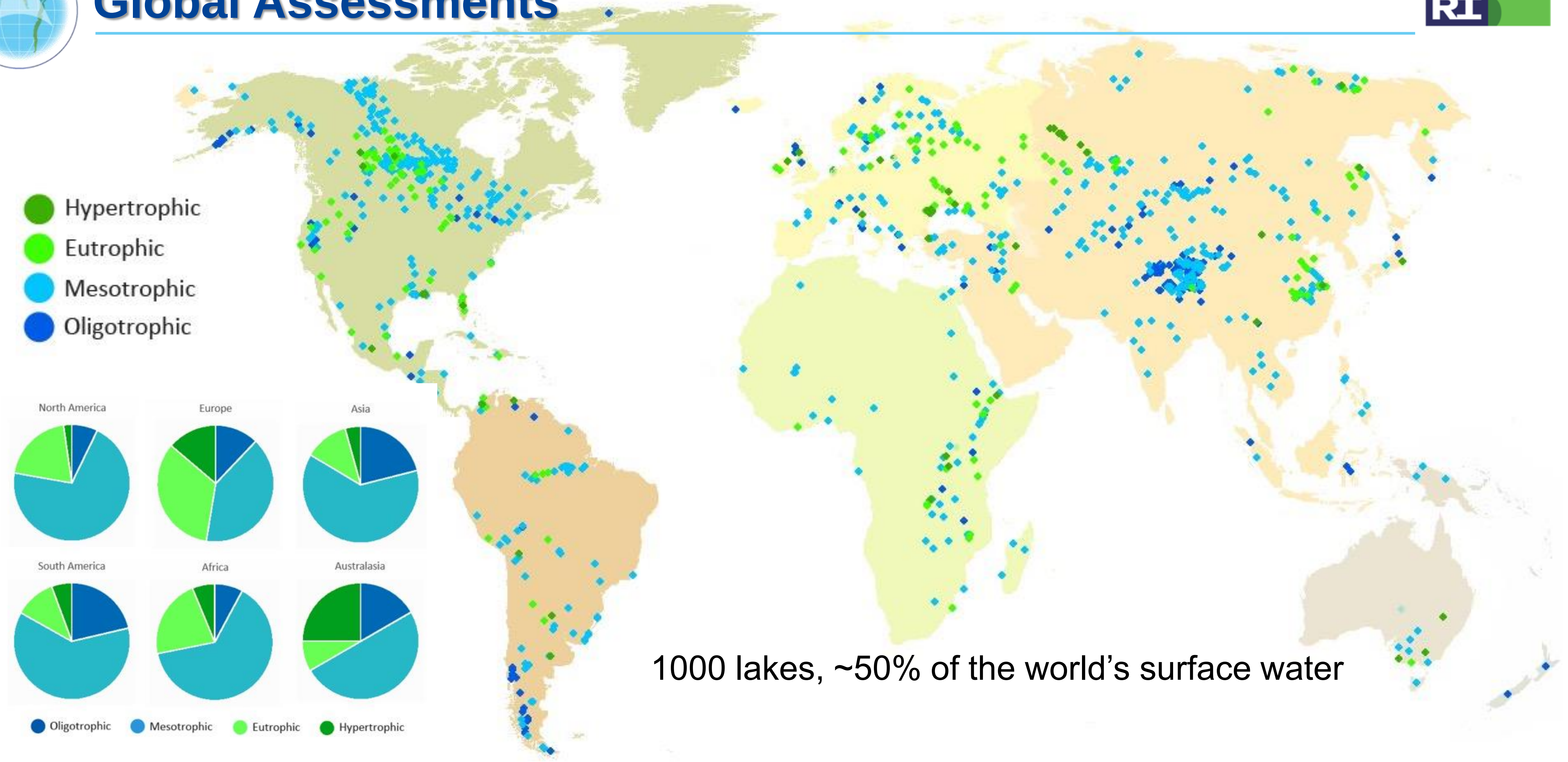
In-situ

Satellite



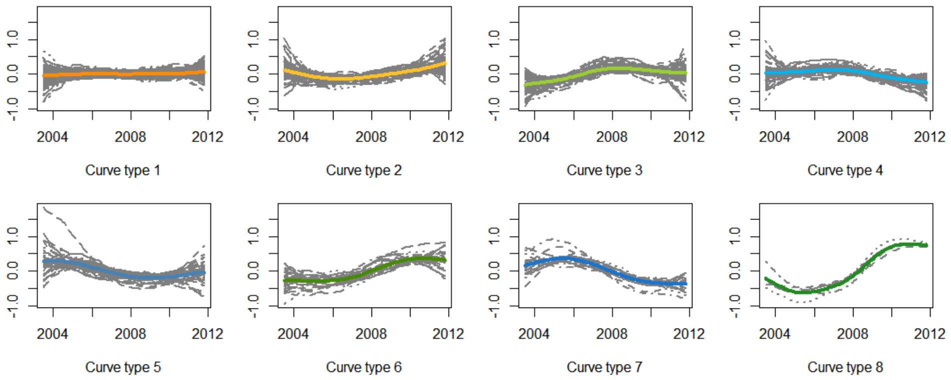


Global Assessments

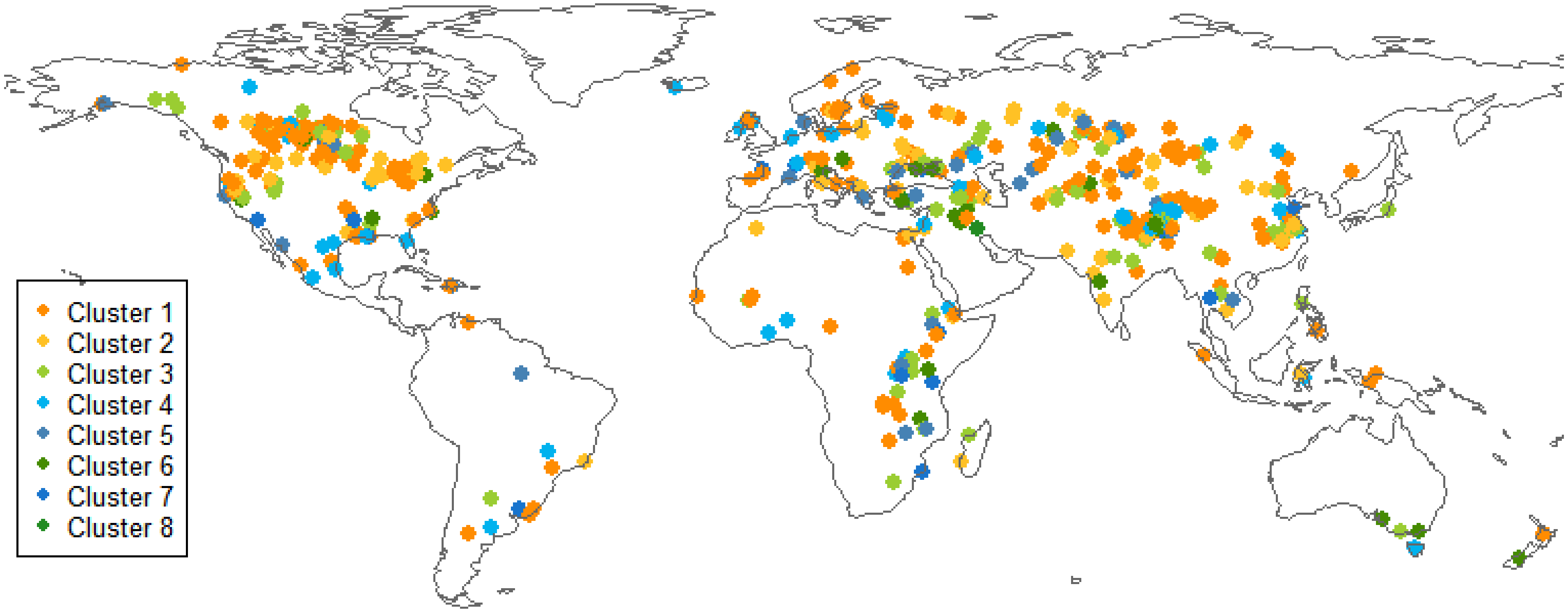


1000 lakes, ~50% of the world's surface water

Global Trends on Water Quality Status

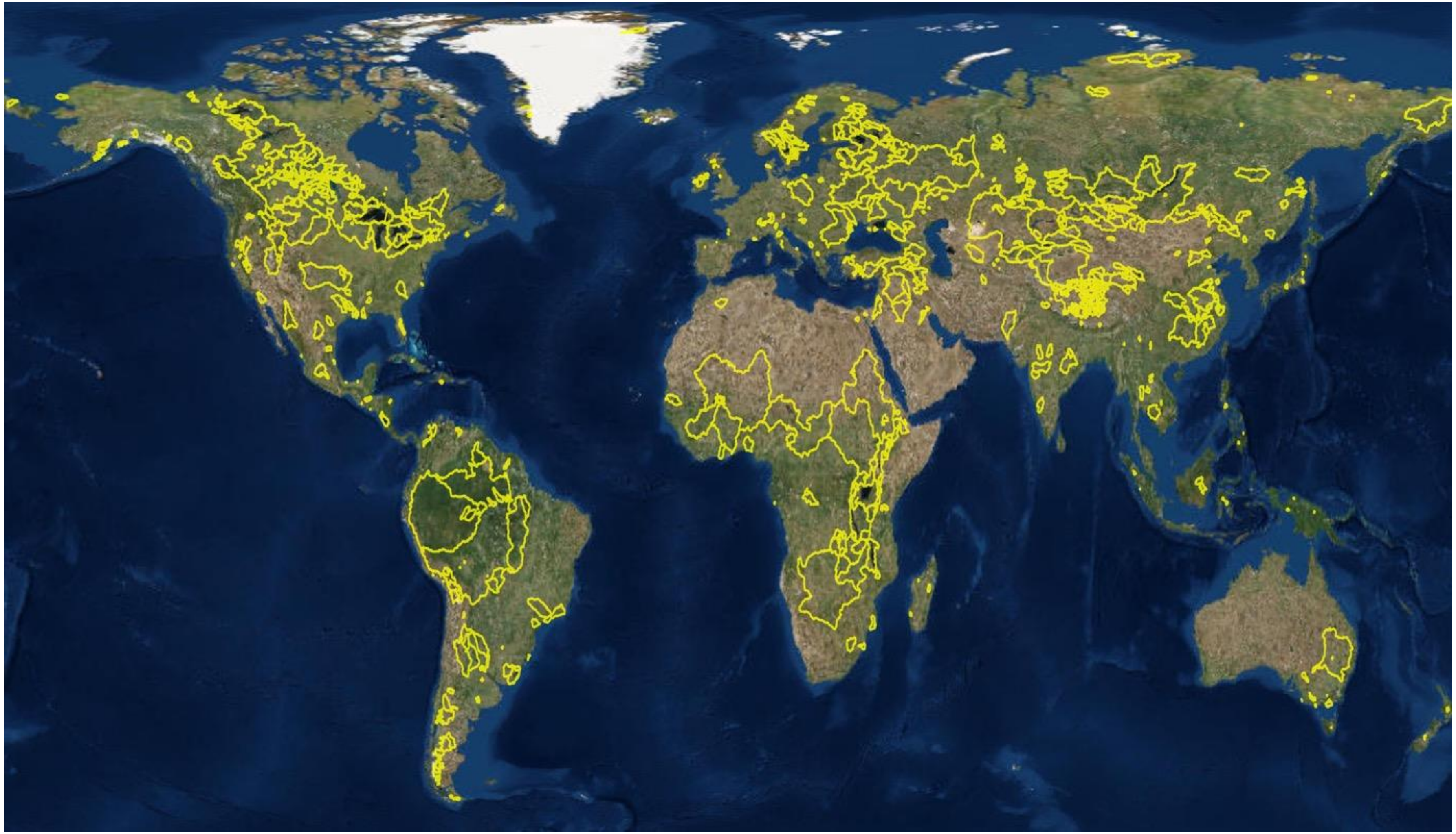


Smoothed Chl-a trend signals and cluster mean curves



little change
generally decreasing
generally increasing

Lake Catchments



- Total GloboLakes Catchment Area (cumulative) 131,180,824 km^2
- 25.7 % of the land mass
- Sensitivity factors
- Spatio-temporal variable drivers

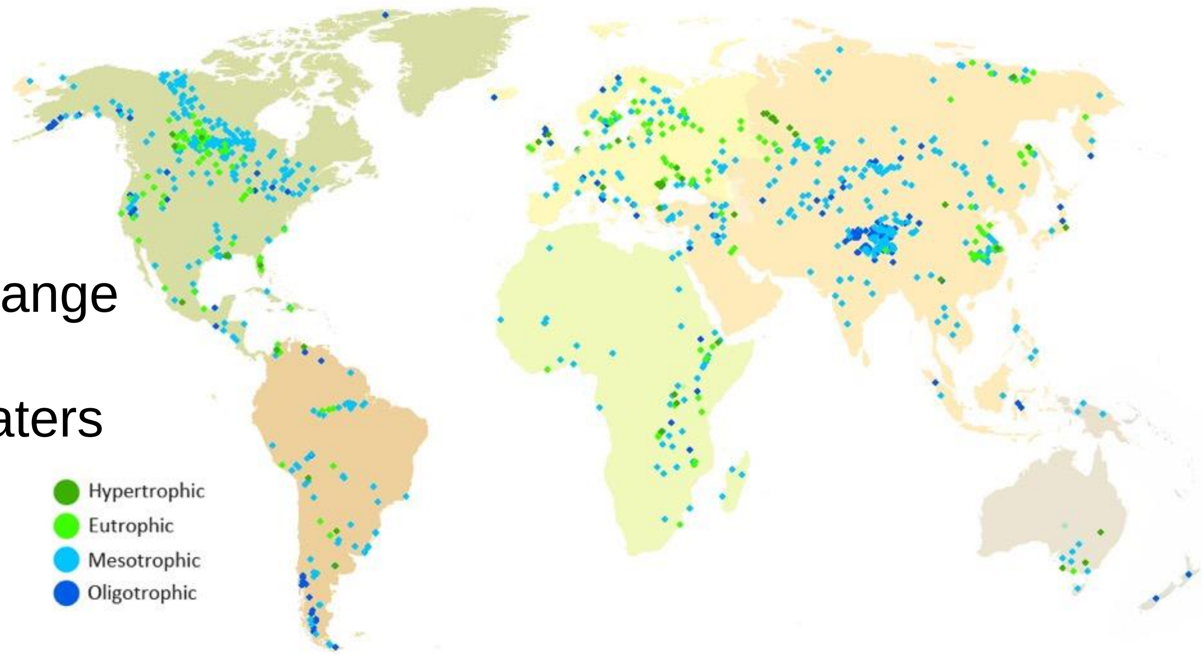
Results – lake types

Lake Types				Model coefficients											
Region	Elevation	Depth	Residence Time	Longitude	Latitude	Elevation	Lake Area	Mean Depth	Temperature	Rainfall	Annual NPP	% Agriculture	%Urban	DF	Adj. R^5
All Lakes					0.005	-0.0002	-0.115	-0.383	0.011	-0.006	0.328	0.005	0.021	781	0.49
					***	***	***	***	*	***	***	***			
All	<500 m			0.002	0.007		-0.118	-0.359	0.020	-0.006	0.431	0.004	0.038	506	0.42
				**	***		***	***	**	***	***	*	*		
All	<500 m	Shallow		0.002	0.005		-0.269			-0.004	0.323		0.038	201	0.31
				**	*		***			**	**		*		
All	<500 m	Deep		0.002	0.006		-0.053	-0.541	0.023	-0.008	0.468	0.004	0.049	297	0.42
				*	**			***	**	***	***		*		
All	<500 m		Short		0.003	-0.001	-0.089	-0.166		-0.006	0.344		0.070	199	0.28
						**	*	**		***	**		**		
All	<500 m		Long	0.002	0.006		-0.113	-0.417	0.023	-0.007	0.326	0.005	0.036	297	0.50
				**	**		**	***	*	***	**	*	.		

- Increase Chl-a: Latitude, Temperature, **NPP**, % Agricultural land, % Urban land
- Decrease Chl-a: Area, **Depth**, **Rainfall**
- **Temperature** has greater influence in deep lakes
- **% Urban land** has greater influence in short residence time lakes

Key highlights & further developments

- EO optically tuned data sets – leading to new understandings of trends in lake water quality
- Understanding lake responses to environmental change
- New monitoring paradigms for optically complex waters
- H2020 CSA Water-ForCE (2021-2024)
  - Tiit Kutser (University of Tartu)
  - Address disconnects between remote sensing and in situ observation
  - Identifying needs and expectations from public & private sector
  - Roadmap for Copernicus Inland Services



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Thank you

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