7th LAKES 2024 Workshop

istituto per il rilevamento elettromagnetico dell'ambiente

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climate change initiative

→ LAKES

New insights from the Lakes_cci project on satellite-derived lake variables for climate studies

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lakes cci

CLS National Research Council of Italy LEGOS Brockmann Consult Sertit icube University of Reading PML Plymouth Marine Laboratory HYGEOS H2O Geomatics University of Stirling

Outline

Background: Lakes & climate change

Remote sensing & lakes

Lakes_cci project: satellite-derived lakes variables for climate studies

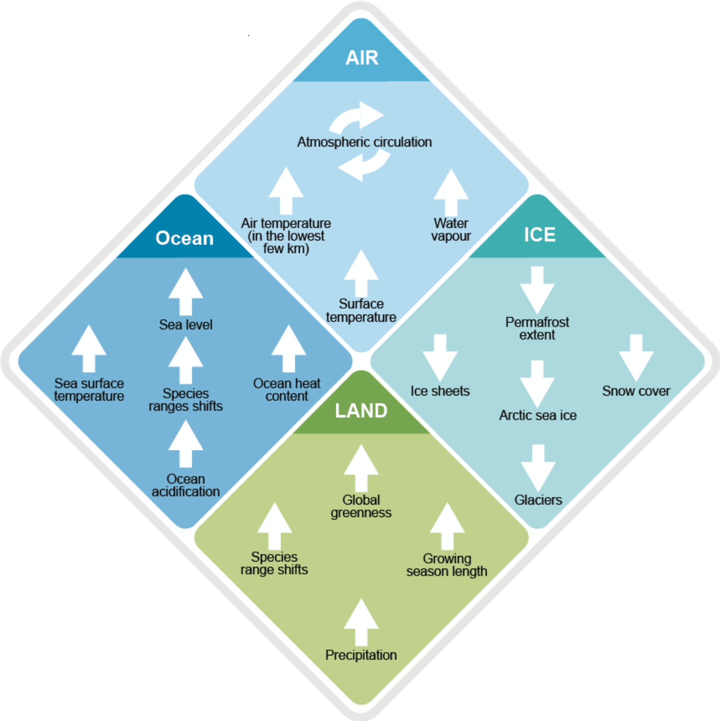
Use cases:

- Estimation of the attenuation coefficient (Kd) and the Secchi disk depth (Z_SD) on two reference lakes in Italy (Trasimeno and Garda) and African lakes
- Analysis of the impact of heatwaves and monsoon on chlorophyll-a and turbidity in Indian lakes

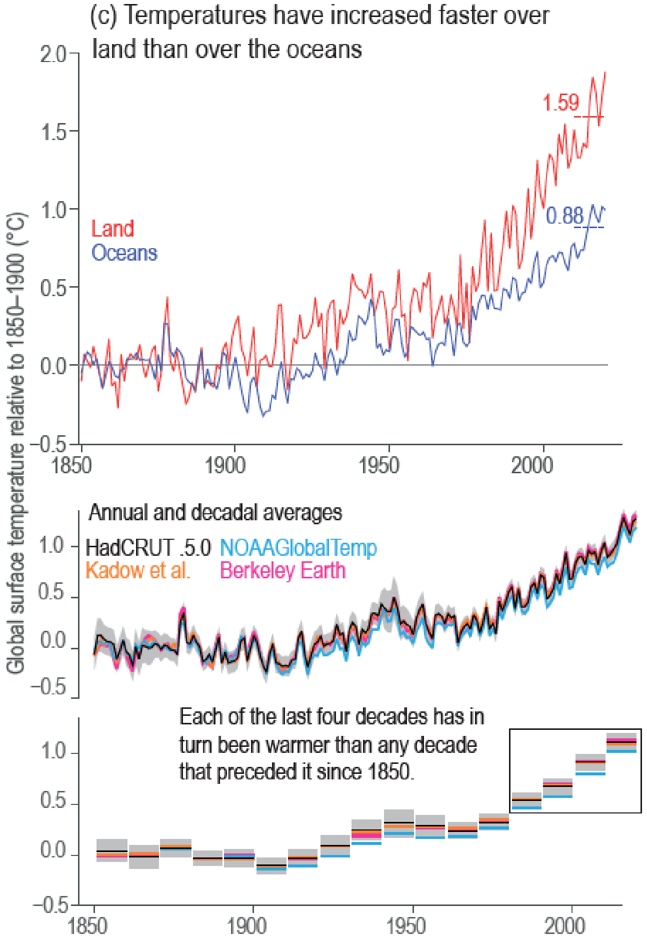
What Is the Evidence for Climate Change?

- A wide range of indicators lead to the conclusion that we are witnessing **rapid changes in many aspects of our global climate**: changes in the **atmosphere, ocean, cryosphere and biosphere**.
- Our scientific understanding depicts a coherent picture of a **warming world**.
- Global **surface temperature over land** has **increased since the late 19th century**.
- Since the mid-1950s the troposphere has warmed, and **precipitation and water vapour over land have increased**.

(IPCC, 2021)



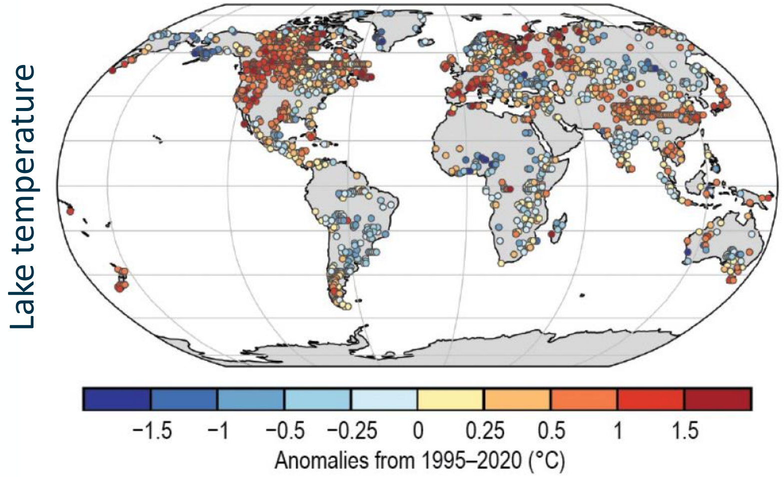
Synthesis of significant changes observed in the climate system over the past several decades.
Upwards, downwards and circling arrows indicate increases, decreases and changes.



IPCC Climate change 2021. The Physical Science Basis. Chapter 2. Changing State of the Climate System

Lakes in a Changing Climate

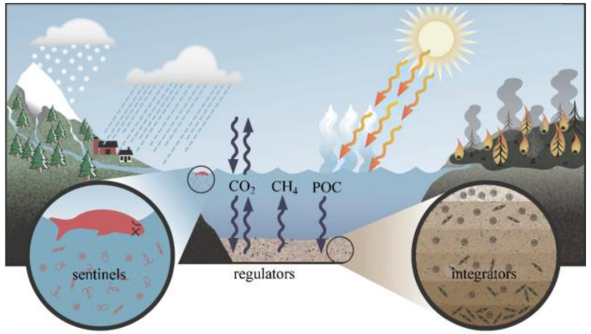
- **Lakes** > 100 million globally (Verpoorter et al. 2014)
- Large majority of Earth's liquid freshwater (87%)
- Support enormous biodiversity
- Provide key provisioning and cultural ecosystem services



BAMS, 2022

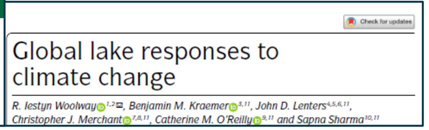
Lakes are sentinels, regulators and integrators of climate change

(Adrian et al., 2009)




Article
Lake heatwaves under climate change
https://doi.org/10.1038/s41586-020-03119-1
Received: 15 April 2020
R. Iestyn Woolway, Eleanor Jennings, Tom Shatwell, Malgorzata Golub, Don C. Pierson & Stephen C. Maberly


nature geoscience ARTICLES
https://doi.org/10.1038/s41561-019-0322-x
Worldwide alteration of lake mixing regimes in response to climate change
R. Iestyn Woolway and Christopher J. Merchant


Global lake responses to climate change
R. Iestyn Woolway, Benjamin M. Kraemer, John D. Lenters, Christopher J. Merchant, Catherine M. O'Reilly and Sapna Sharma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ELSEVIER
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Maciej Bartosiewicz, Anna Przytulska, Bethany N. Deshpande, Dermot Antoniades, Alicia Cortes, Sally MacIntyre, Moritz F. Lehmann, Isabelle Laurion

Climate change is one of the most **severe threats** to global lake ecosystems

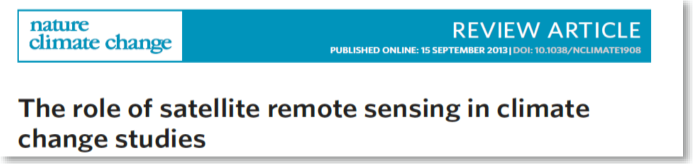
Observed **global in**

events

What are the linkages between lakes and climate?
Are these linkages measurable from satellites?

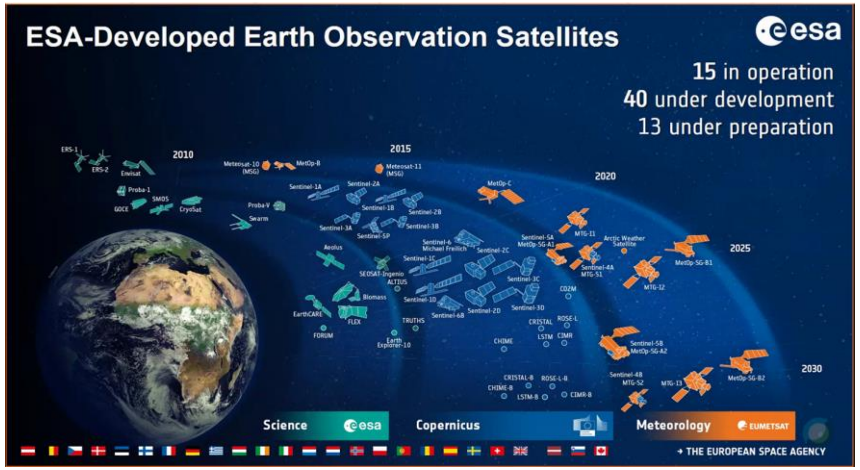
Remote Sensing & Climate Change

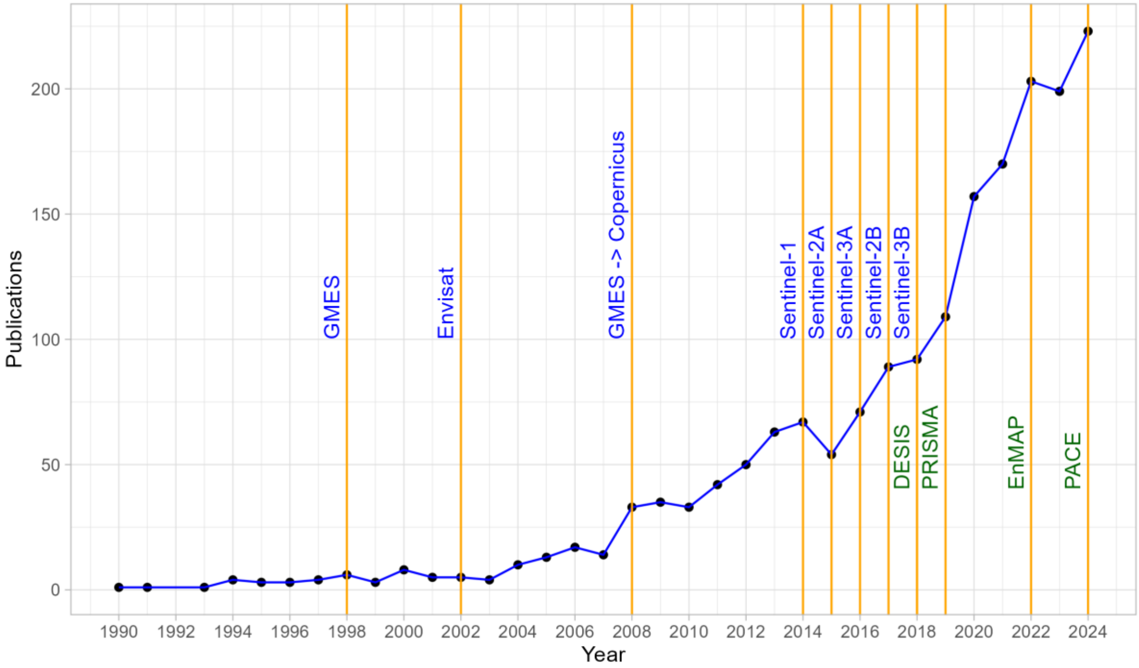
In the last 50 years the remote sensing (RS) discipline has substantially contributed to the furthering of research and understanding of climate change effects on ecosystems (Yang et al., 2013).


nature climate change | REVIEW ARTICLE
PUBLISHED ONLINE: 15 SEPTEMBER 2013 | DOI: 10.1038/NCLIMATE1908

The role of satellite remote sensing in climate change studies

(Yang et al., 2013. *Nature Climate Change*)

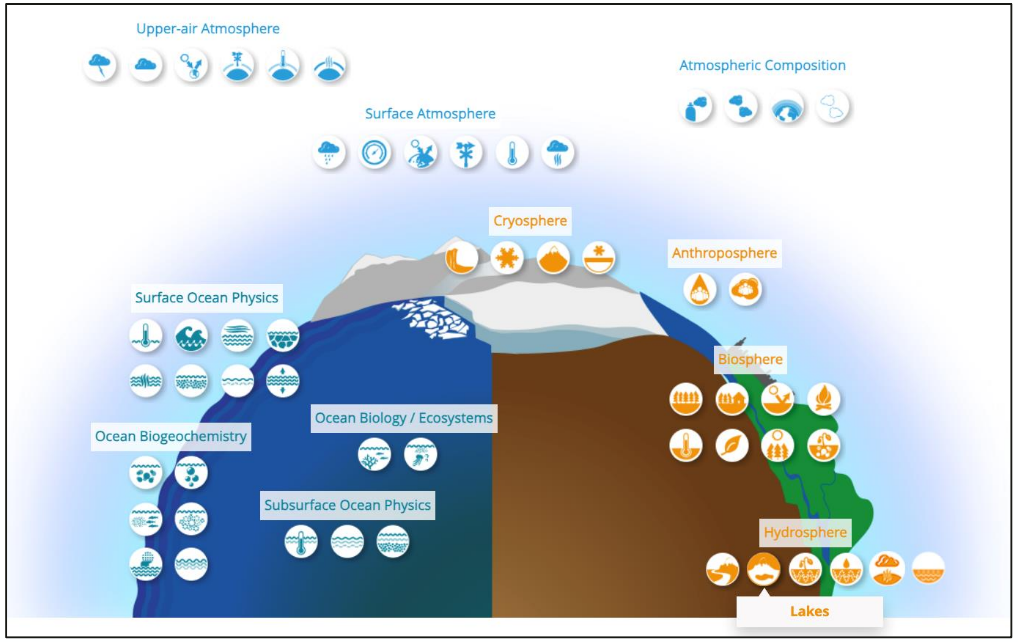




Keywords: Lake + climate change + remote sensing

The Lakes_cci mission

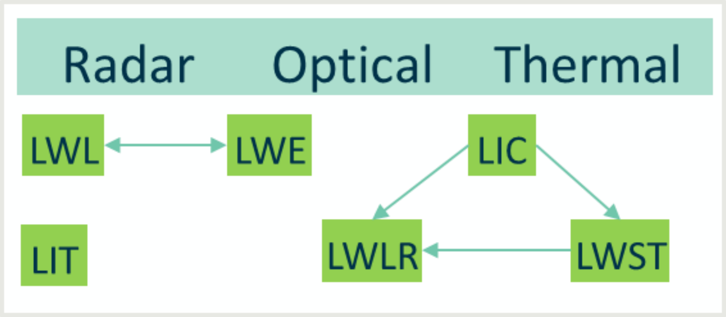
The European Space Agency (**ESA**) Climate Change Initiative (**CCI**) answers the Global Climate Observing System (**GCOS**) objectives to observe the Essential Climate Variables (**ECV**) at the global scale



Credits: modified from GCOS

- **Lake Water Extent** (LWE) & Lake **Water Level** (LWL)
- **Lake Ice Cover** (LIC) & Lake Ice **Thickness** (LIT)
- **Lake Surface Water Temperature** (LSWT)
- **Lake Water-Leaving Reflectance** (LWLR; chlorophyll *a*, turbidity)

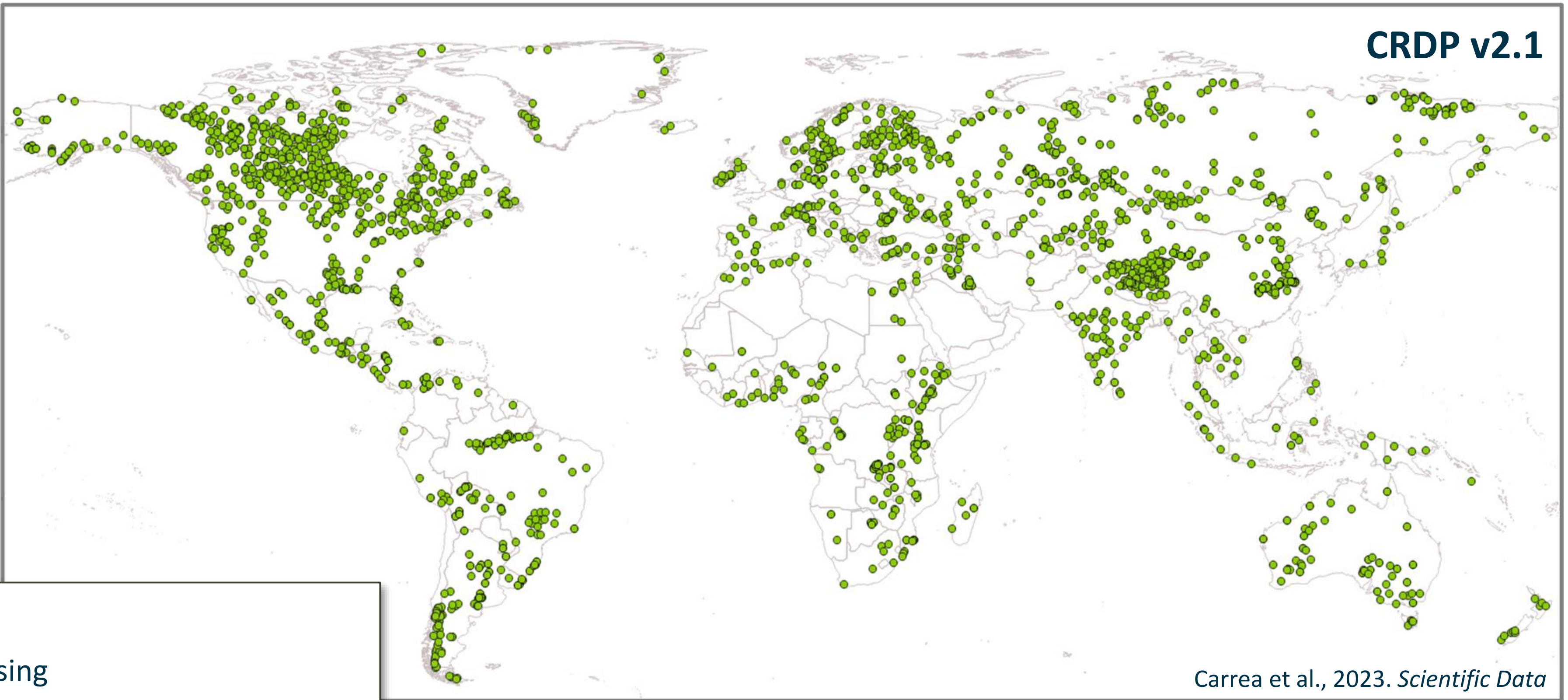
The **Lakes_cci** aims to provide global, stable, consistent, and long-term satellite-based products of the Lakes (ECV) for six products



The Lakes_cci dataset

The latest **Climate Research Data Package v2.1.0** has the following characteristics:

- Spatial coverage: **2024 globally distributed lakes**
- Spatial resolution: **1/120 degree global grid (near 1 km at the equator).**
- Temporal resolution: **daily**
- Temporal coverage: **from 1992 up to 2022**



Carrea et al., 2023. *Scientific Data*

Coverage varies per product:

- LWL/LWE steadily increasing
- LWST full coverage
- LIC full coverage for lakes which may form ice
- LWLR from 2002, limited coverage in 2013-2015

'Coverage' means that observation is *attempted* –quality control may remove some output

Future improvements

CRDP v3.0.0 is expected **mid-2025** with several major improvements:

- Temporal coverage extended to **2023**
- Additional **gap-filled temperature and ice cover** data set
- **LWLR** extended with **light attenuation, CDOM** and new atmospheric processing, improved accuracy of chlorophyll a and suspended matter concentration. A separate **cyanobacteria indicator** dataset and **phenology product** will also be released.
- **Product flags** to indicate reduced accuracy risk **due to atmospheric plumes**
- **Extended spatial coverage for LWL, LWE and LIT**
- New product providing insight into **Lake Storage Change**

USE CASE
Estimation of water transparency

Water transparency was estimated as:

- **Attenuation coefficient** (Kd) and
- **Secchi disk depth** (Z_SD) derived from Kd_{min}

This effort was carried out on a band basis on two reference lakes in Italy (Trasimeno and Garda).

Methodology Kd and Z_SD estimation

1. Inspection of LWLR bands data to find lowest uncertainty bands
2. Selection of bands
   → selection for clear and turbid conditions with bands overlapping between sensors
3. Quasi-Analytical Algorithm - QAA: extract Kd, Kd_min and Z_SD

(1) $$K_d = a + m_1\left(1 - \gamma\frac{b_{bw}}{b_b}\right)(1 - m_2 e^{-m_3 a})b_b$$ (Pitarch & Vanhellemont, 2021)

(2) $$Z_{SD} = \frac{1}{2.5\ \mathrm{Min}(K_d^{tr})}\ln\left(\frac{|0.14 - R_{rs}^{tr}|}{0.013}\right)$$ (Lee et al., 2016)

Methodology Kd and Z_SD estimation

1. Inspection of LWLR bands data to find lowest uncertainty bands
2. Selection of bands (at least one per R G B)

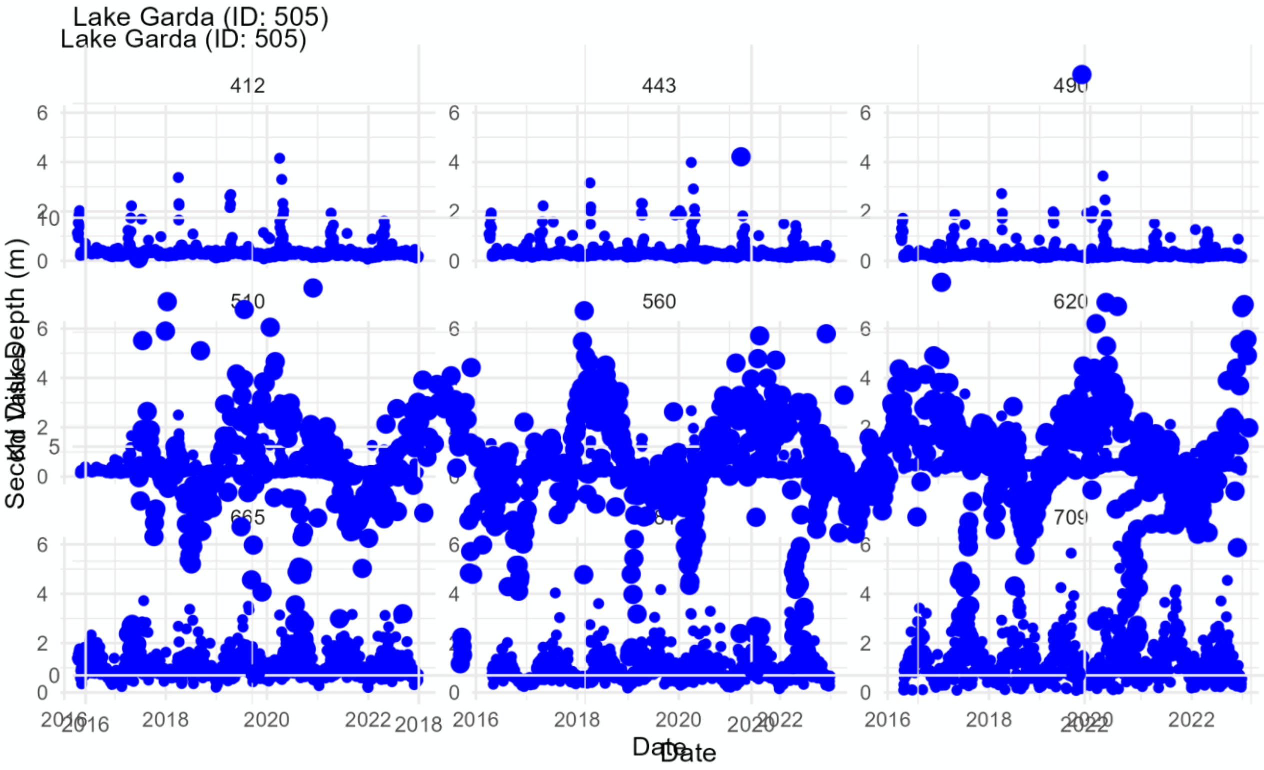
→ selection for clear and turbid conditions with bands overlapping between sensors

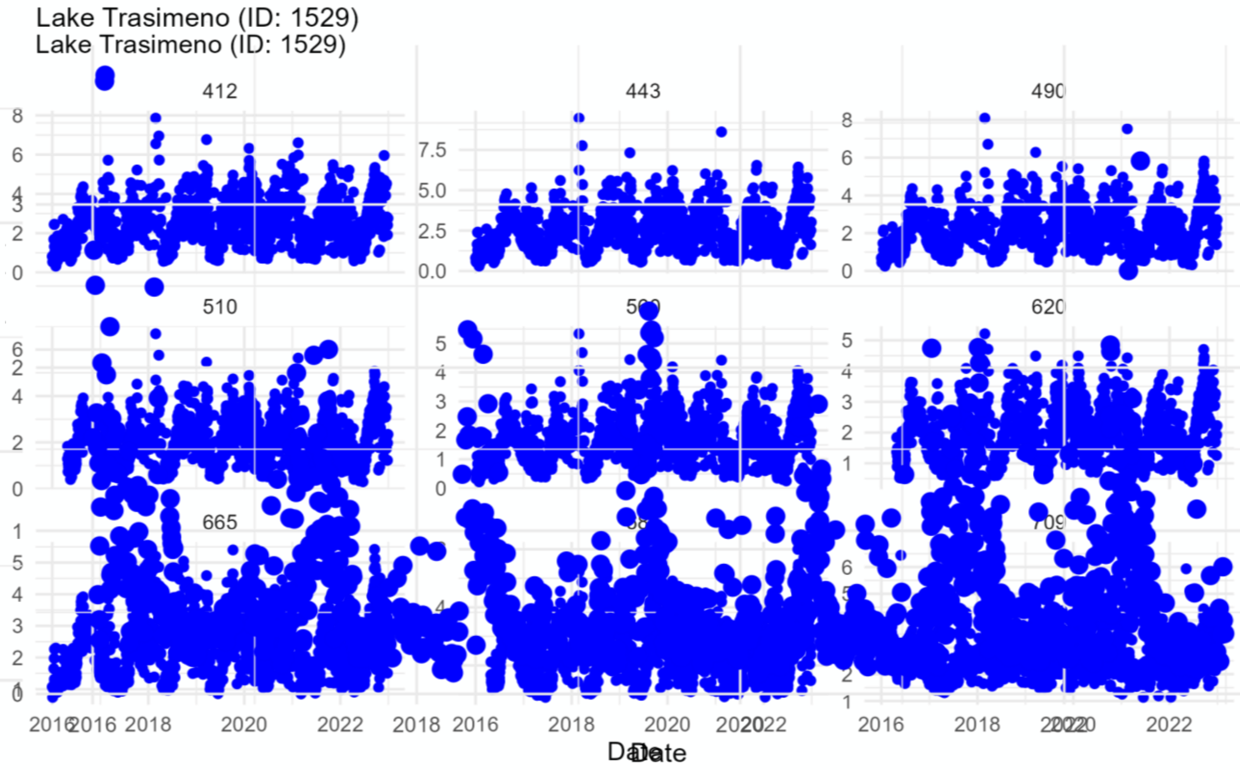
← clear:
490, 510, 560, 620, 665, 681

turbid:→
443, **490**, **510, 560, 620**, **665, 681**, 709, 754

Kd and Z_SD estimation

1. Inspection of LWLR bands data to find lowest uncertainty bands
2. Selection of bands
3. Kd and Z_SD from QAA





Water color & Kd assessment: Sub-sahelian African lakes

Clustering based on dominant wavelength

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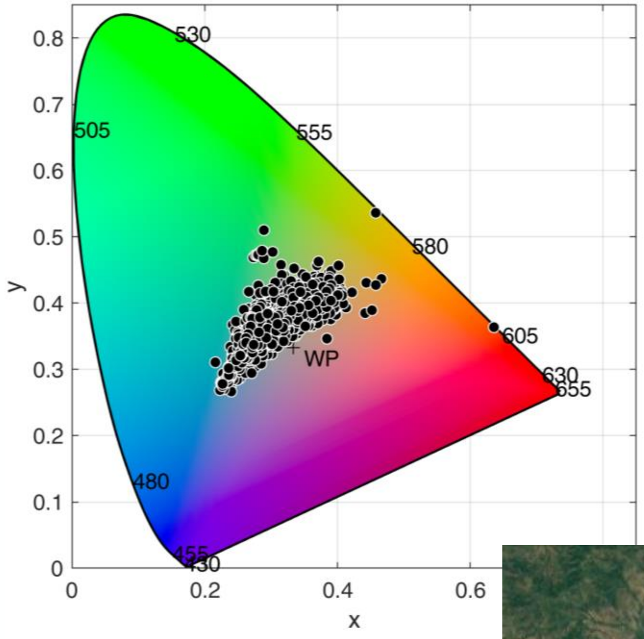


Kampe Oyi, Nigeria

Derived from reflectances

$$x = \frac{X}{X+Y+Z} \qquad y = \frac{Y}{X+Y+Z}$$

Where

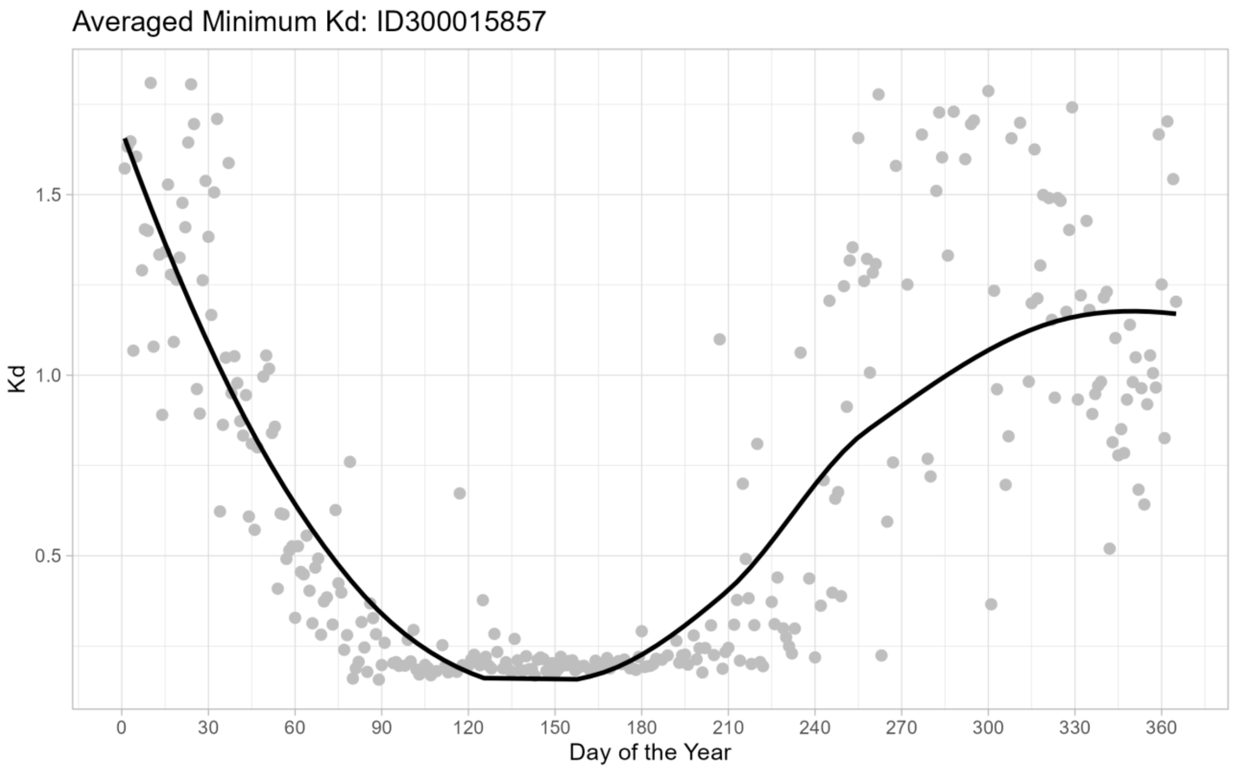
$$X = \sum_{i=1}^{N} a_i \cdot \lambda_i$$

$$Y = \sum_{i=1}^{N} b_i \cdot \lambda_i$$

$$Z = \sum_{i=1}^{N} c_i \cdot \lambda_i$$

Calculated after van der Woerd and Wernand (2018) and Ye and Sun (2021)

Clustering based on dominant wavelength



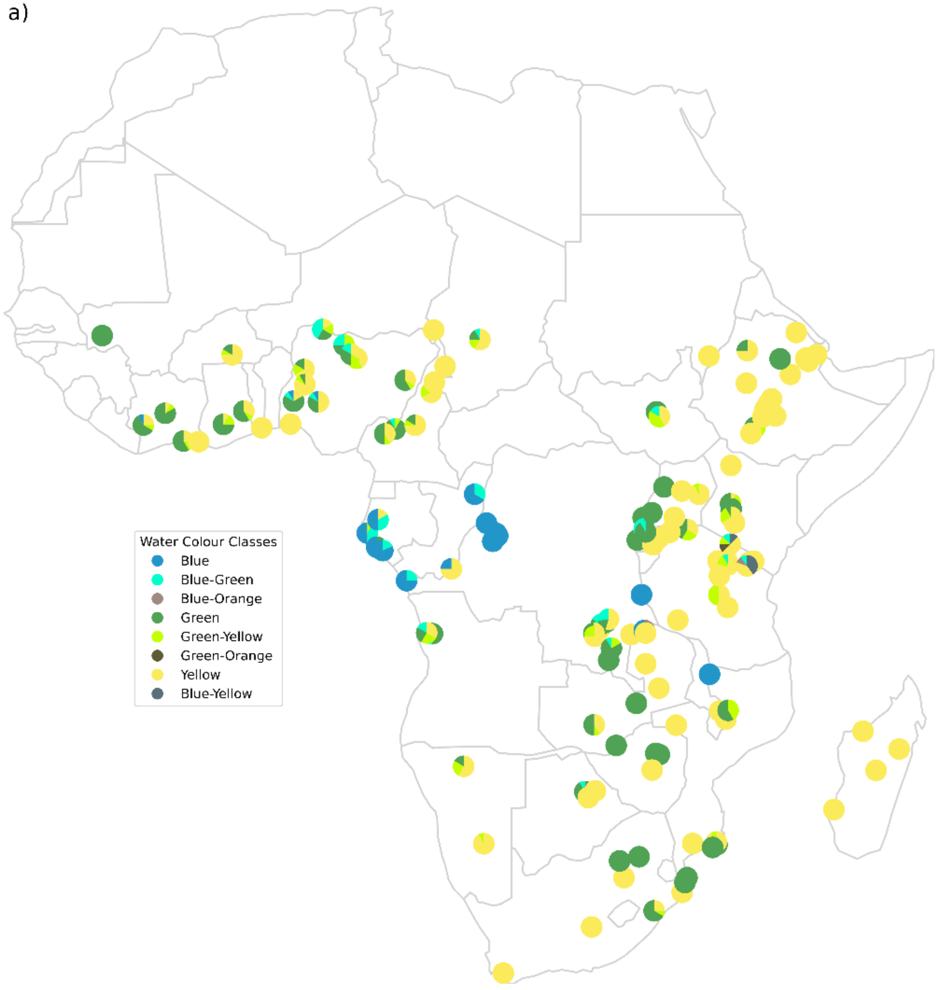
Two conditions
→ clear: 443, 490, 560 & 665
→ turbid: 443, 490, 510, 560, 620, 665, 681, 709 & 754

Calculated after Lee et al., 2011

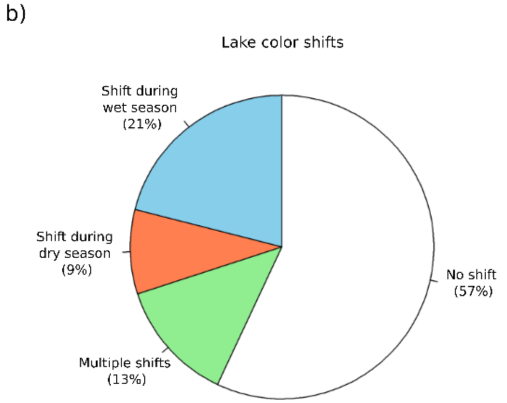
Water color & Kd assessment: Sub-sahelian African lakes

Clustering based on dominant wavelength

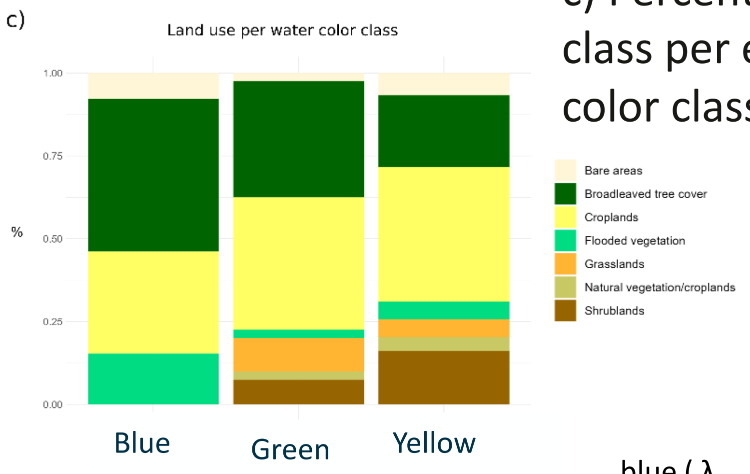
a) Overview of the unique colors expressed throughout the year by each lake.



Amadori et al., in prep



b) Percentage of lakes that shift color during the average year and the main season during which the shift occurs.



c) Percentage of land cover class per each lake water color class

blue (λ_{dom} < 495 nm)
green (495 nm ≤ λ_{dom} < 560 nm)
yellow (560 nm ≤ λ_{dom} < 590nm)

Option CCN9- WP2.2 Water transparency and attenuation coefficient

Objectives:

- Develop a physics or optical water type (OWT) based framework to estimate Kd (optionally Secchi disk depth).
- Produce match-up results for calibration and validation assessment
- Deliver final algorithms to LWLR ECV team – ideally in time for inclusion with CRDP v3.0

Current status/updates :

- Created online survey to understand user requirements
- Compiled some of the in situ remote sensing reflectance and Secchi disk depth data from existing database, e.g., GLORIA.
- Compile in situ remote sensing reflectance, Secchi disk depth and Kd data Code and assess existing Semi-analytical algorithms for estimating water transparency

Secchi disk

Credits: University of Stirling

USE CASE
Heatwave and storm events impacts on lakes

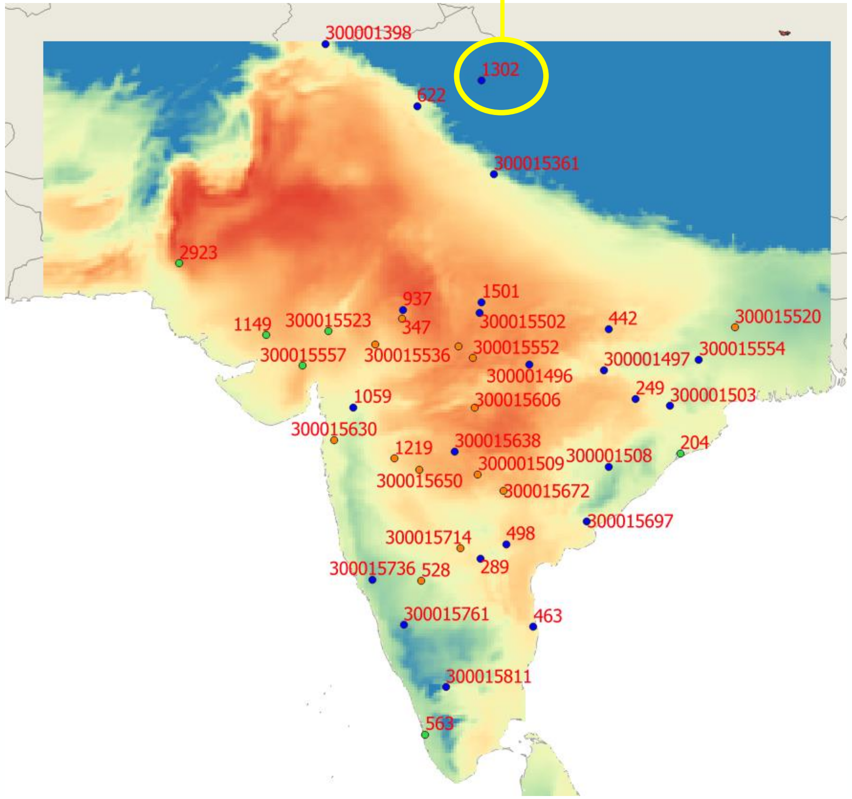
Heatwave 2019 in Indian lakes

Focus on India because of the combination of two extreme events in 2019:

- a strong and prolonged heatwave during May-June,
- a delayed arrival of monsoon season, with exceptional monsoon rainfall

- Indian lakes are an excellent test across Lakes_cci variables as monsoon dynamics require that lake turbidity, chlorophyll-a, LWL and climatic variables are considered together at seasonal and annual scale.

Lake Tso Moriri, Ladakh



Map of airT° during June 2019 heatwave and CCI lakes

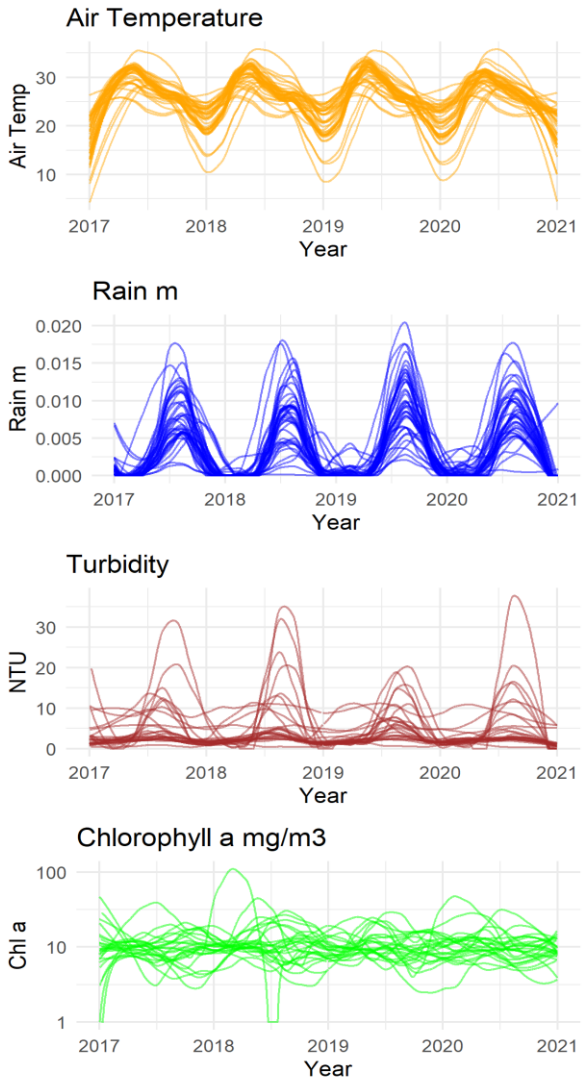
CCI lakes in India/Pakistan

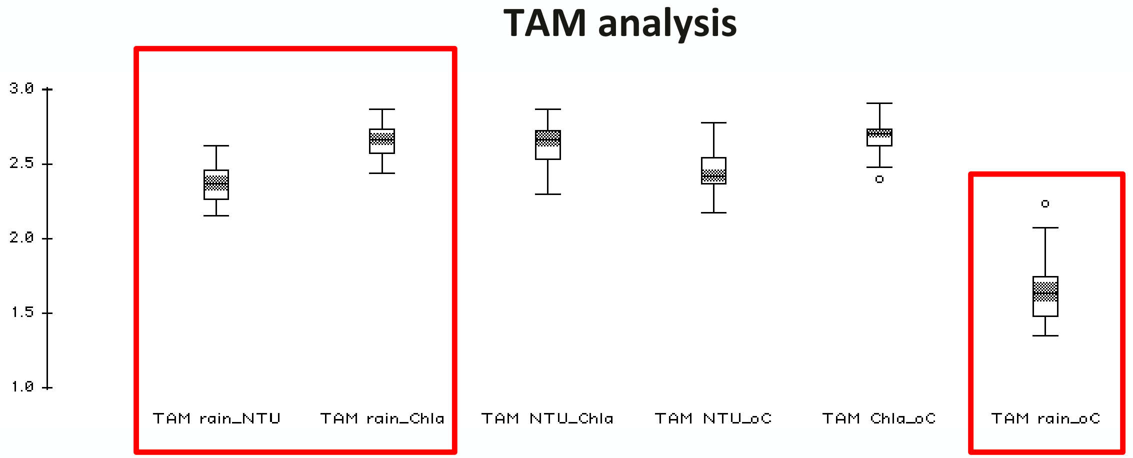
- 42 lakes (mainly reservoirs), different in hydro-morphology and trophic conditions
- data: Chl-a, turbidity, LWL (Lakes_cci); total precipitation, 2m airT° (ERA5)
- data analysis :
  - Timeseries and TAM (Time Alignment Measurement) analysis
  - Cluster analysis of Chl-a and turbidity patterns

Caroni et al., in prep

Timeseries and TAM

Interannual patterns of Air Temperature (C°), Precipitation (total rain m), turbidity (NTU) and Chlorophyll-a (Chl_a, mg m^3) for the studied Indian lakes during the period 2017-2020.





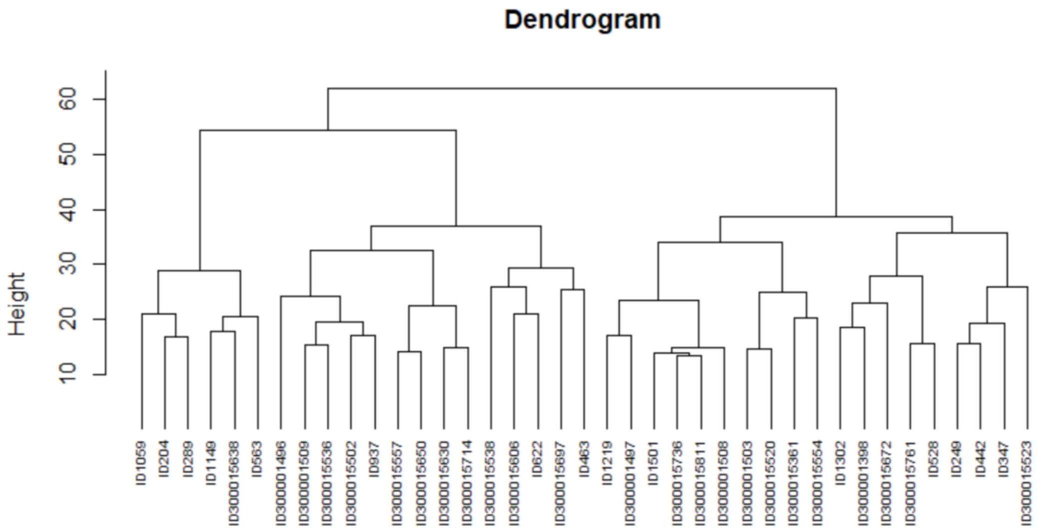
Timeseries of **precipitation was closer** in phase **with timeseries of turbidity** (mean value=2.3), while **less in phase with Chl-a** (mean value=2.7)

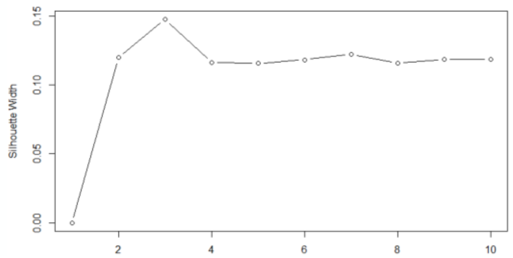
Timeseries of **air temperature has the best fit with precipitation** (mean value=1.6)

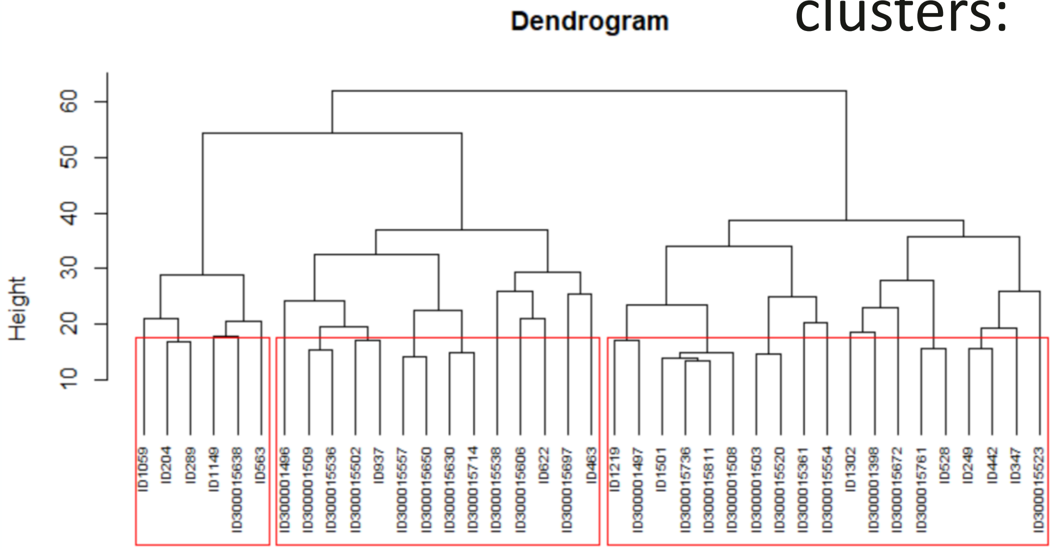
significant difference t-test p <0.001

Cluster analysis

Chlorophyll-a

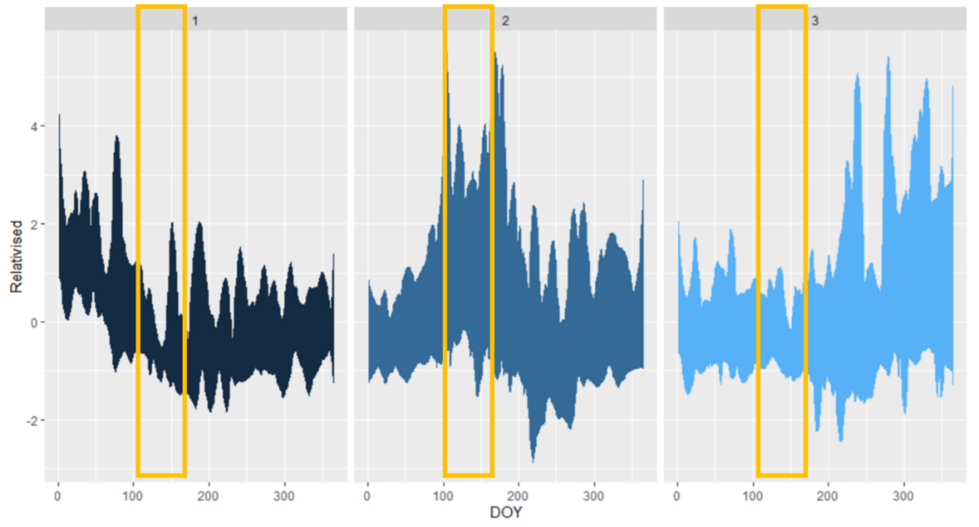






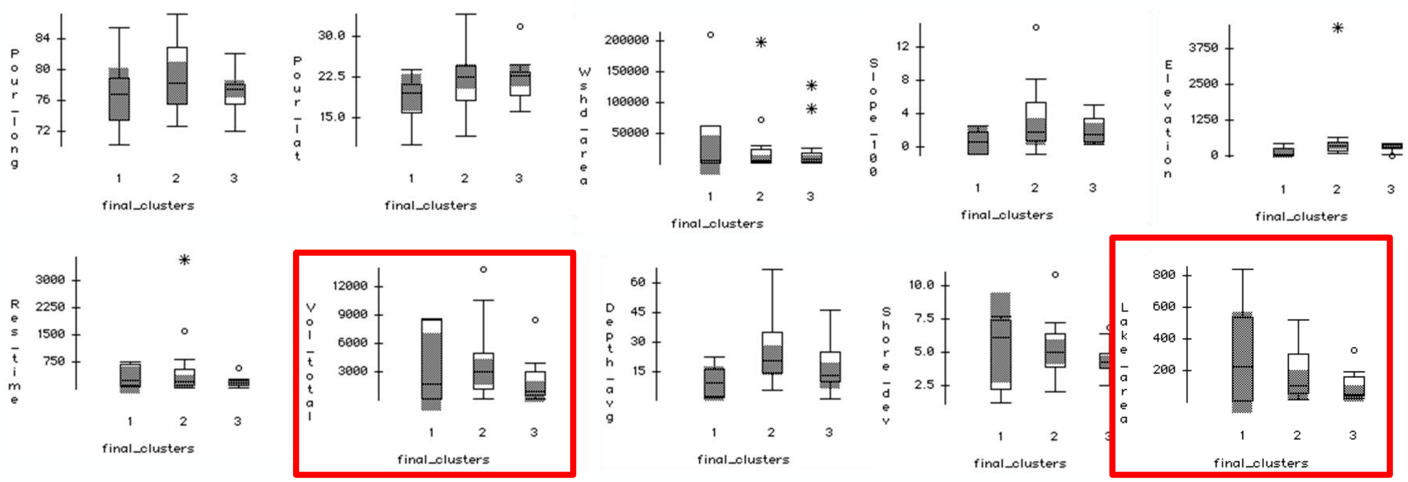
Three main clusters:

1 2 3



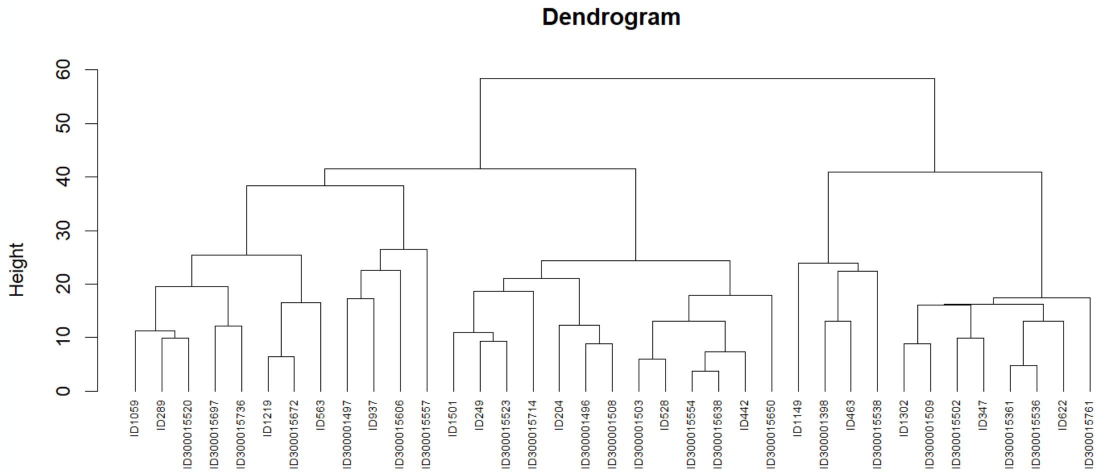
Lake chlorophyll-a (relativized) patterns by cluster

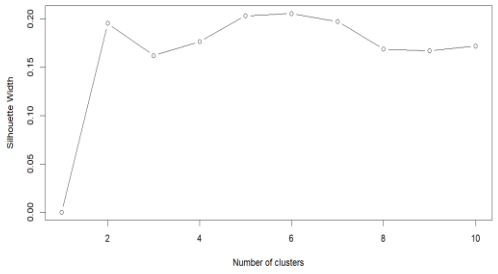
Chlorophyll-a clusters and hydro-morphological variables (HYDROLAKES)



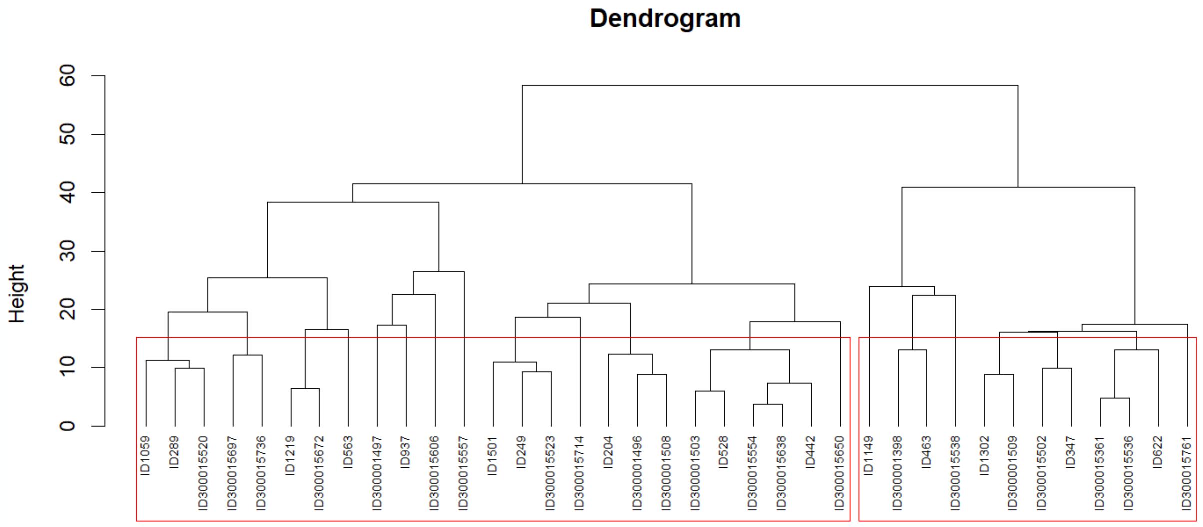
Difference in clusters were revealed for lake volume and extension, although not statistically significant.

Turbidity



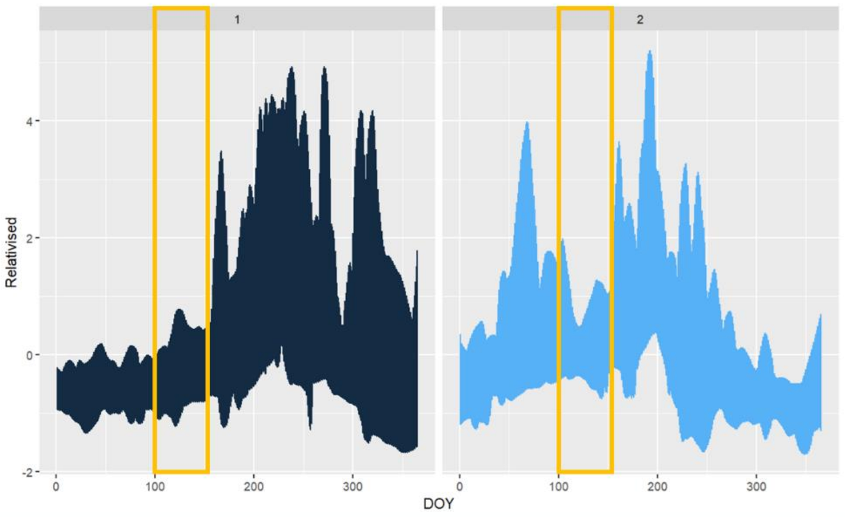


Two main clusters:

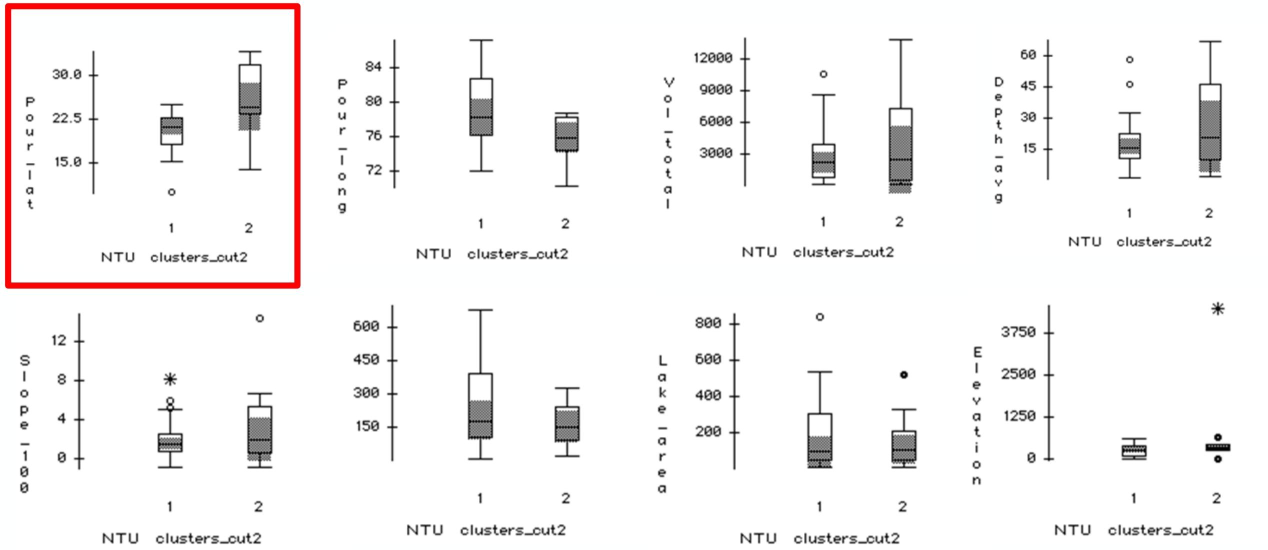


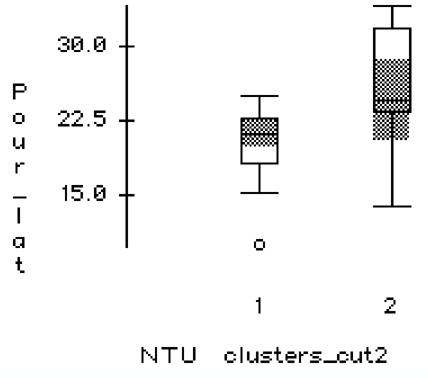
Turbidity clusters and hydro-morphological variables (HYDROLAKES)

1 2



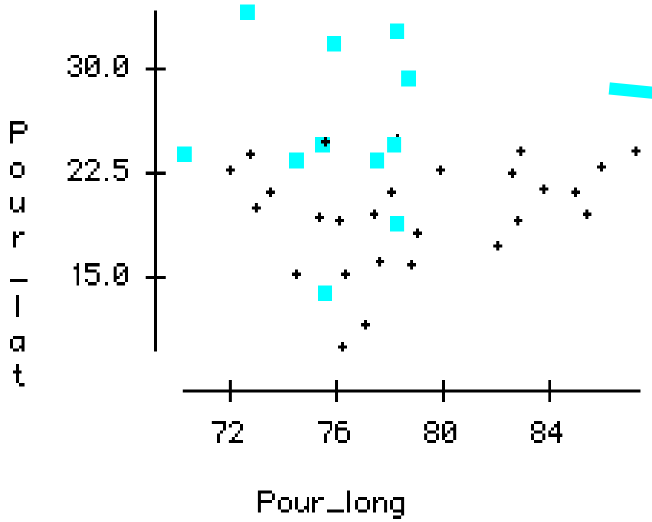
Lake turbidity (relativized) patterns by cluster





Lake Maharana Prataph (507 m asl), Himalayan foothills

Lake Tso Moriri (4522 m asl), Ladakh, India



Cluster 2 is at a significantly higher latitude

Hypothesis: the first turbidity peak is due to **snow/ice melting processes** followed by a peak due to **monsoon**

- northern lakes show increases driven by spring snowmelt
- southern lakes were mainly dominated by peaks driven by the summer monsoon.

Conclusions

Lakes_cci dataset

- ✓ the characteristics of the latest satellite sensors products, provide accurate, frequent, spatially distributed, and at fine scale information
- ✓ useful tool to investigate pattern, trend and changes in lake bio-geophysical conditions

Use case: water transparency estimation

- ✓ Good results and promising improvements in Kd and secchi disk depth assessement

Use Case: Indian Lakes

- ✓ influence of rainfall (monsoon) with turbidity
- ✓ Chl-a patterns are more complex to explain and less related to hydro-morphological

lakes cci

http://climate.esa.int/projects/lakes