Lakes and Climate: The Role of Remote Sensing

Claudia Giardino

National Research Council of Italy

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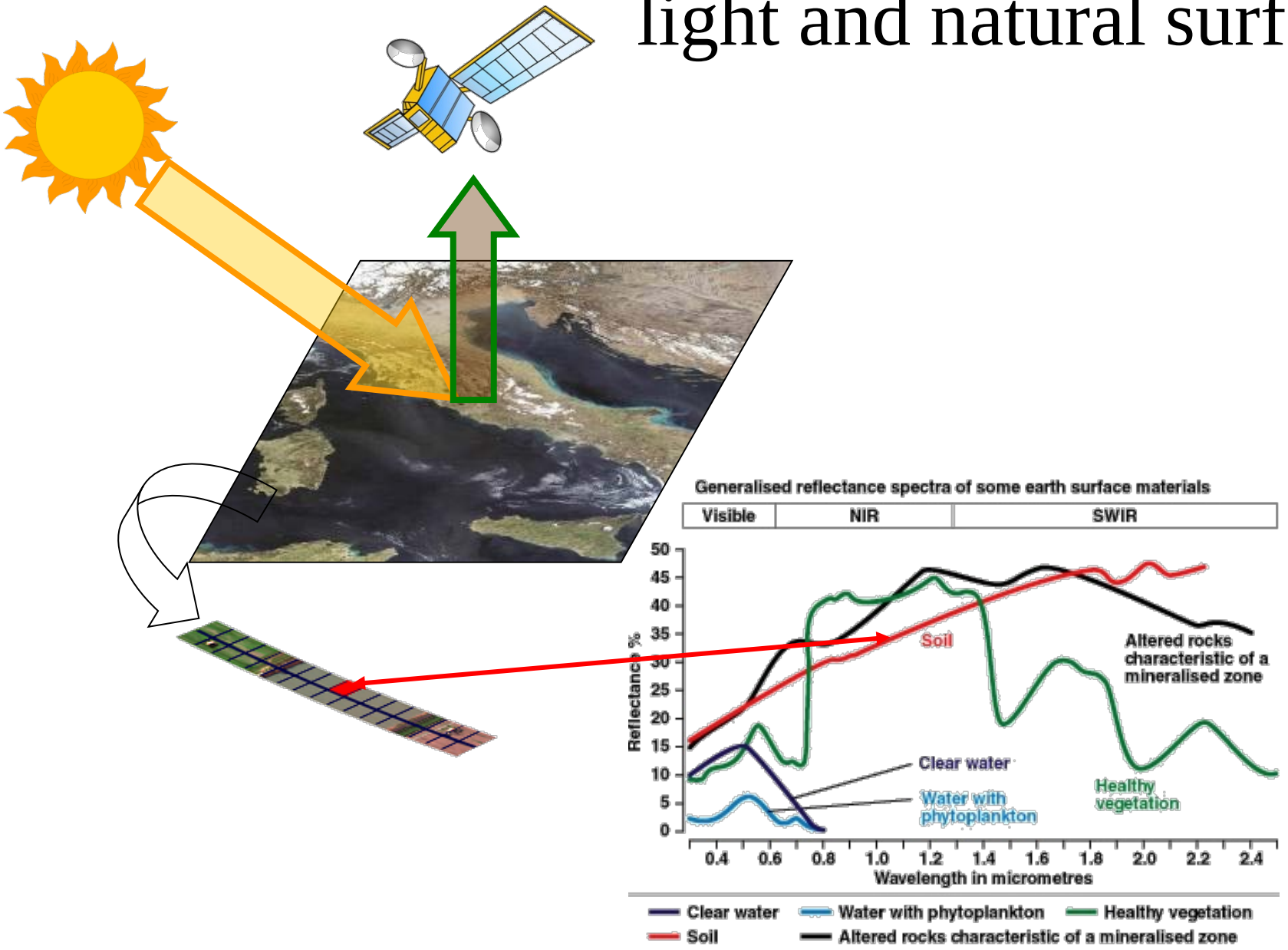
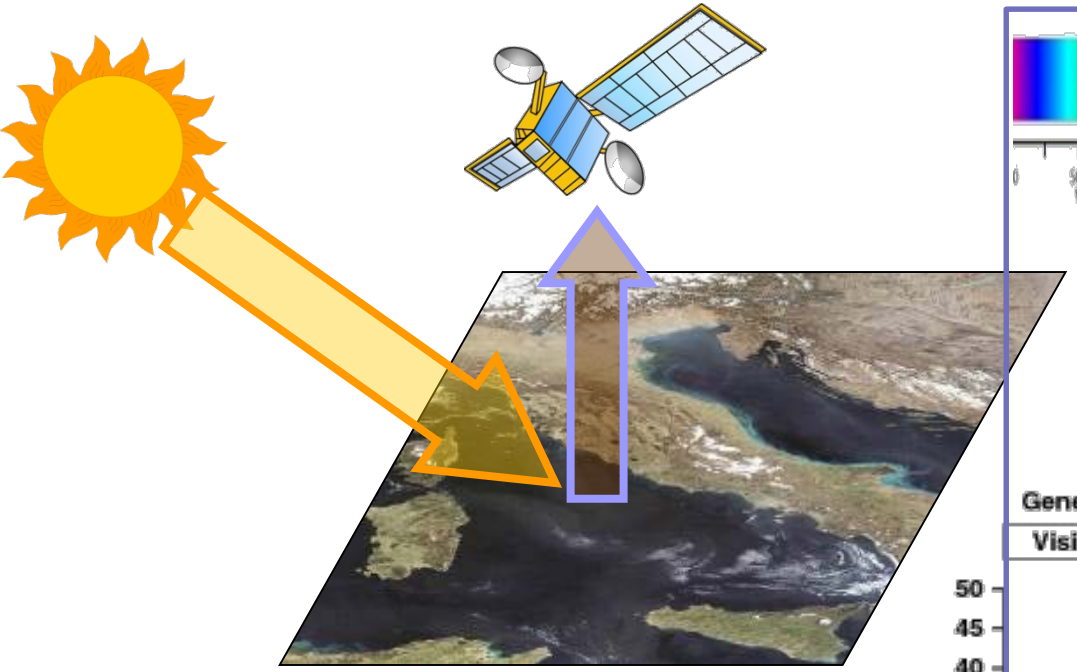
Presentation outline

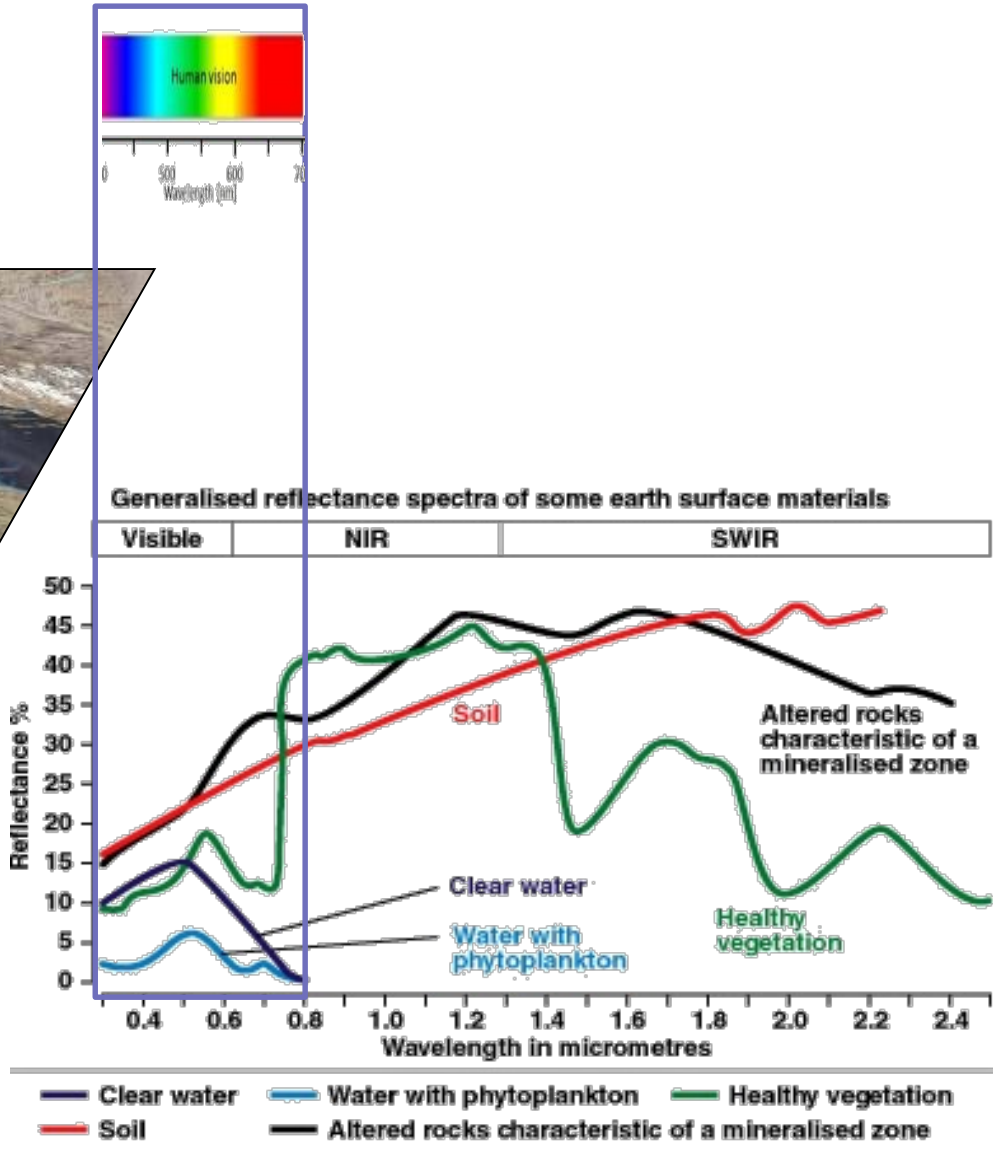
- General concepts
- The colour of water
- Methods
- Selected applications
- Conclusions

Measuring the interaction between Sun light and natural surfaces



The colour of water





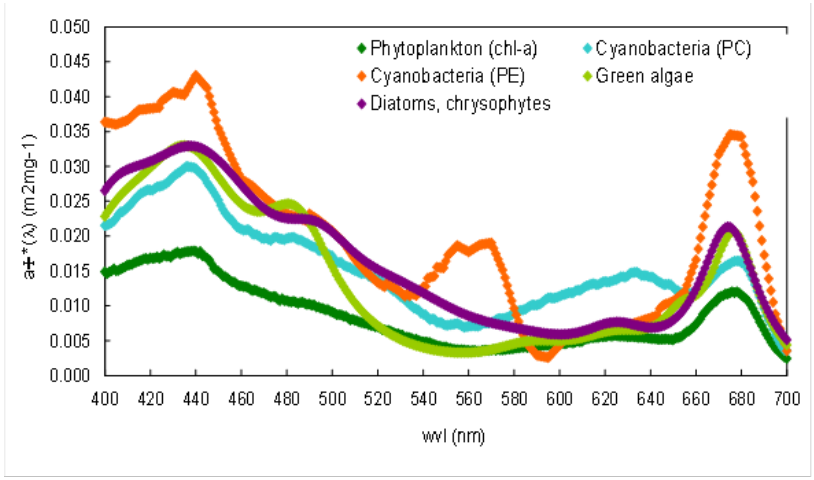
The colour of water reveals its contents

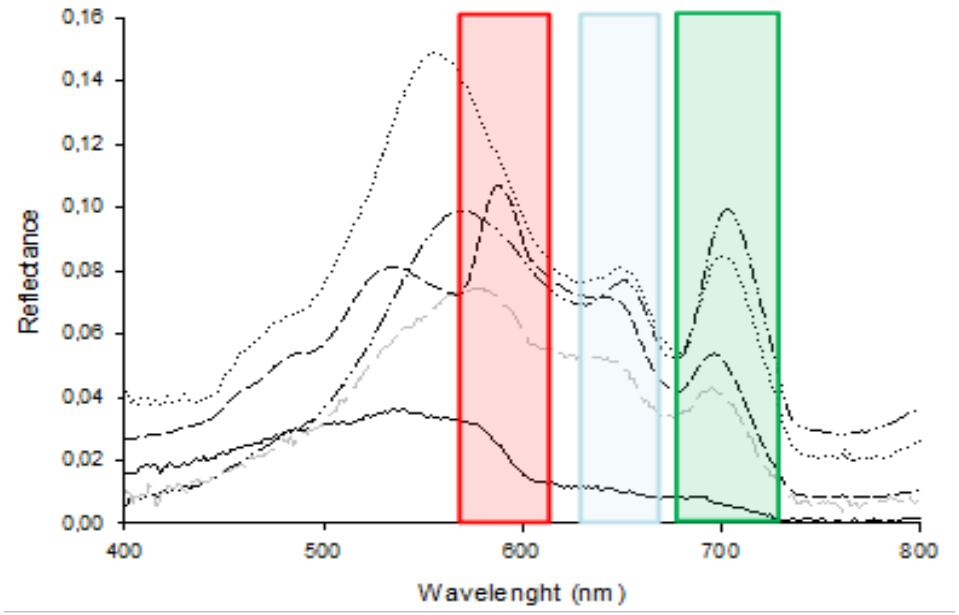
- A refreshing glass of water may appear **colourless**, but water is actually a faint **blue** colour

- The blue colour becomes visible when we look down into, or through, a large volume of water → Water itself has an **intrinsic blue colour** that is a result of **absorption** and **backscattering** of Sun light

- We see natural water in a variety of colours. It may be colored by the presence of **dissolved/particulate substances**

The colour of water reveals its contents



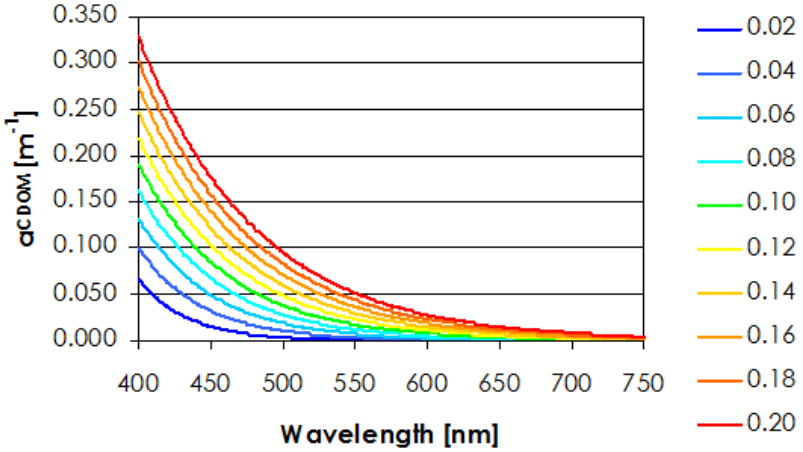


Phytoplankton - chlorophyll-a and important pigments: e.g. phycoyanin and phycoeritrine

The colour of water reveals its contents

Dissolved organic matter or Yellow Substances

Origin: fluvial transport, in situ phytoplankton degradation, agriculture

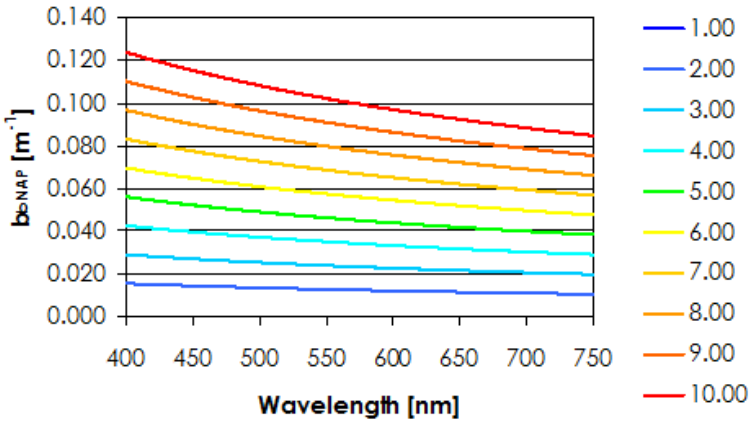


Absorbing a lot in the UV-Blue region

Suspended Particulate Matter (organic/inorganic)

Mineral particles suspended inside the water body (sand, clay, silt, detritus…)

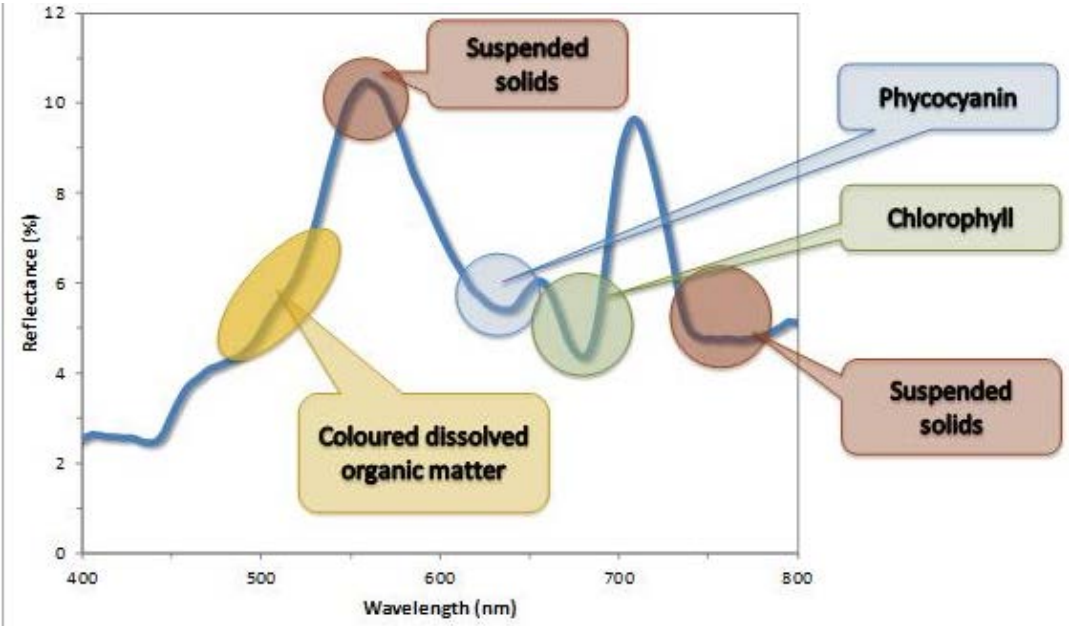
Origin: fluvial erosion, sediment re-suspention



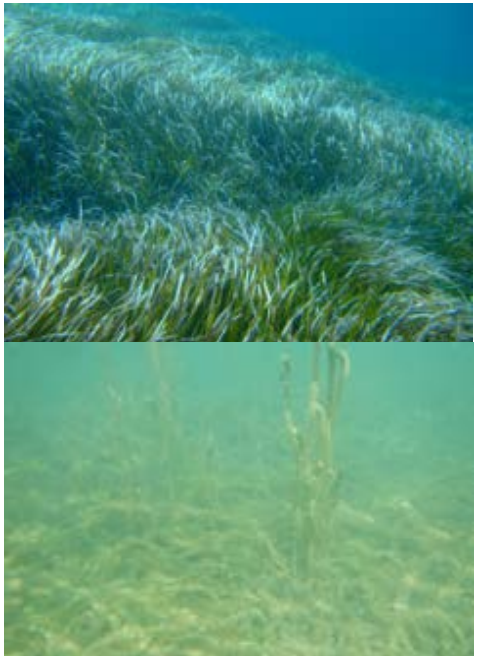
High backscattering if compared to absorption

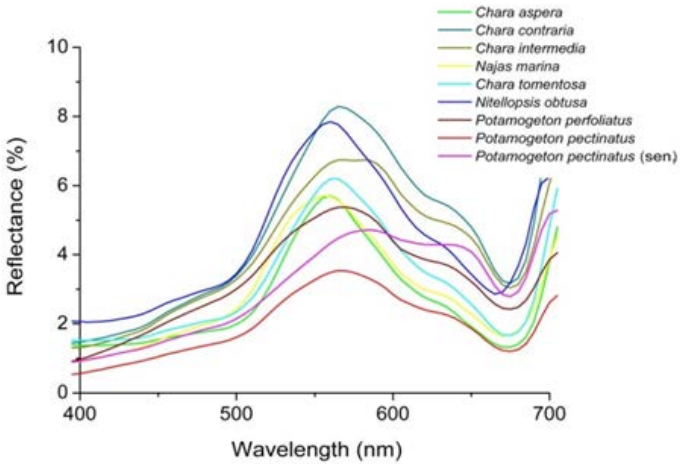
The colour of water reveals its contents

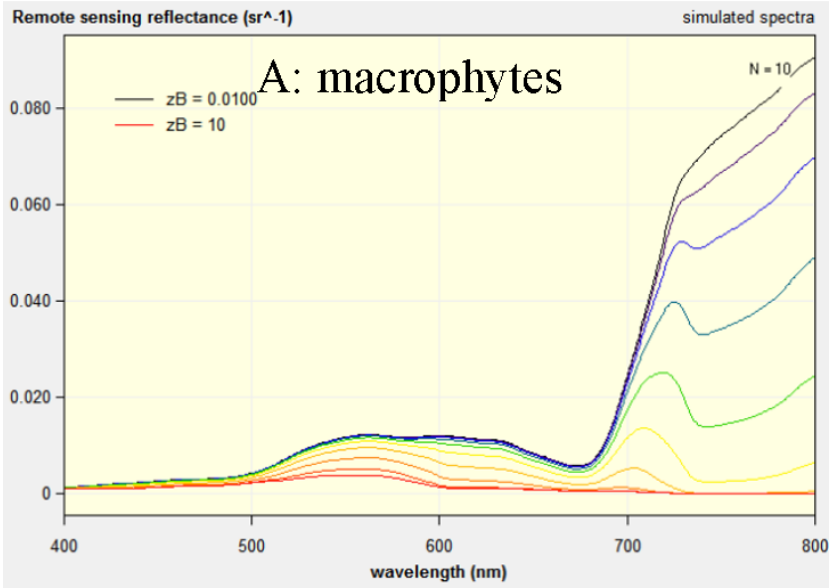
- Most algea appear green due to chlorophyll
- Sediment reflects and is therefore bright
- Toxic cyanobacteria look blue-green
- …and so on

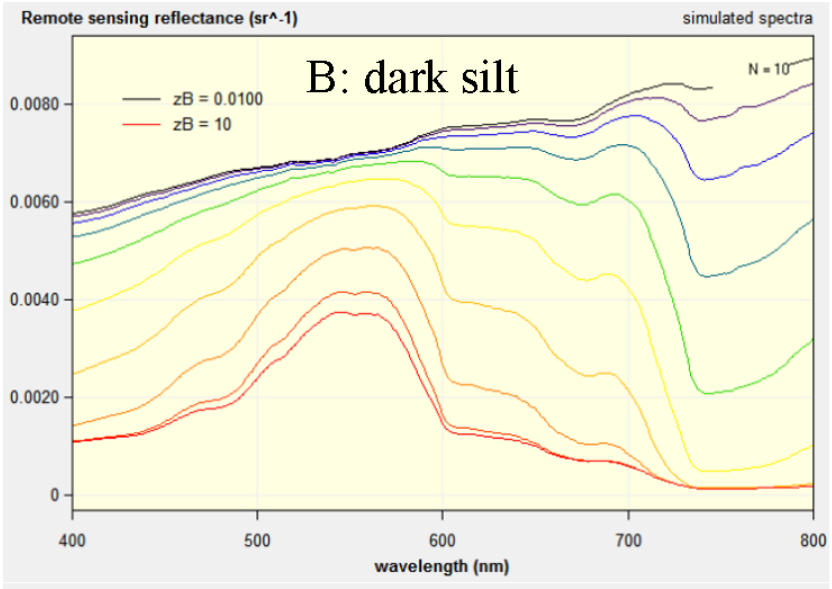


The colour of substrates



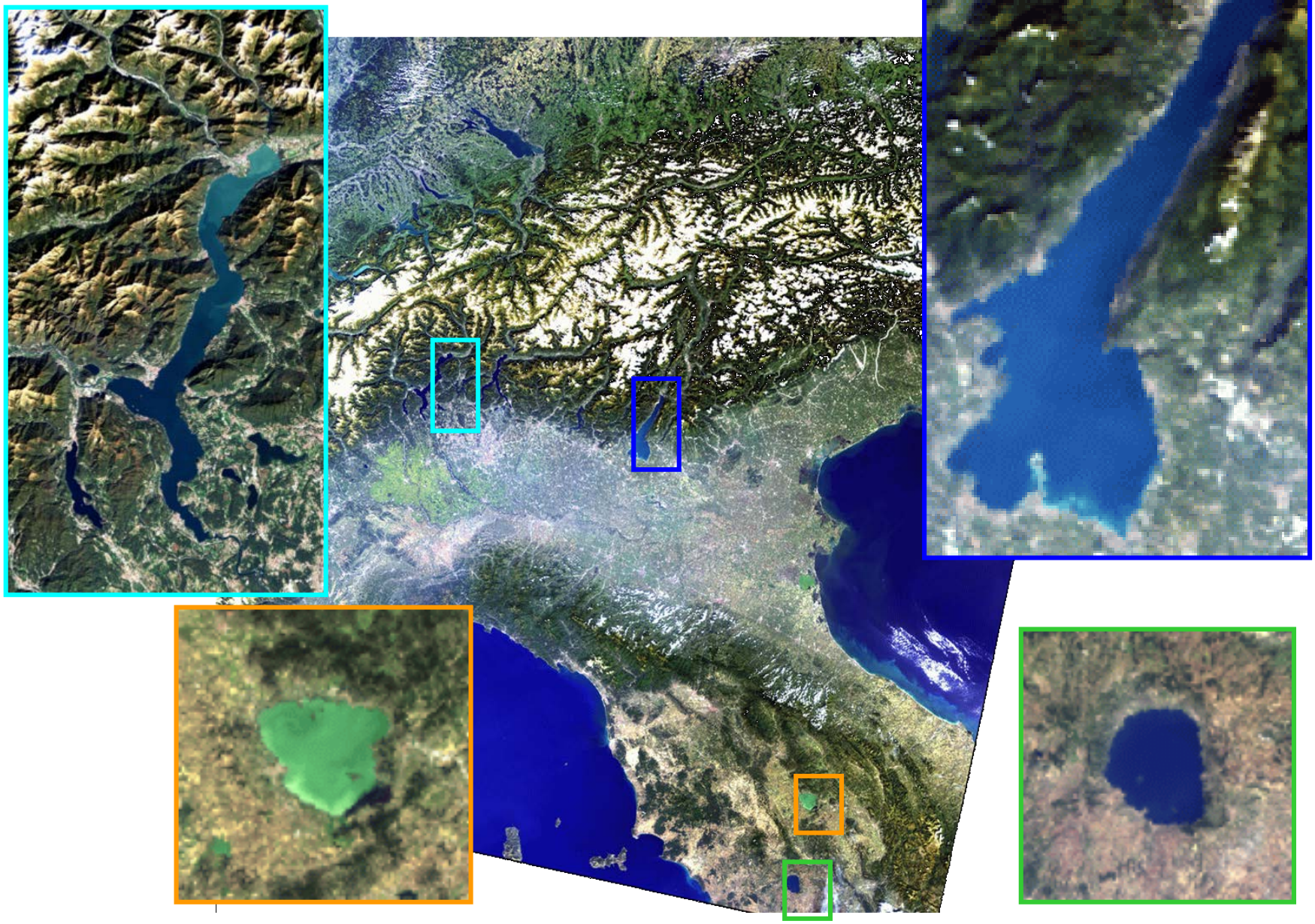




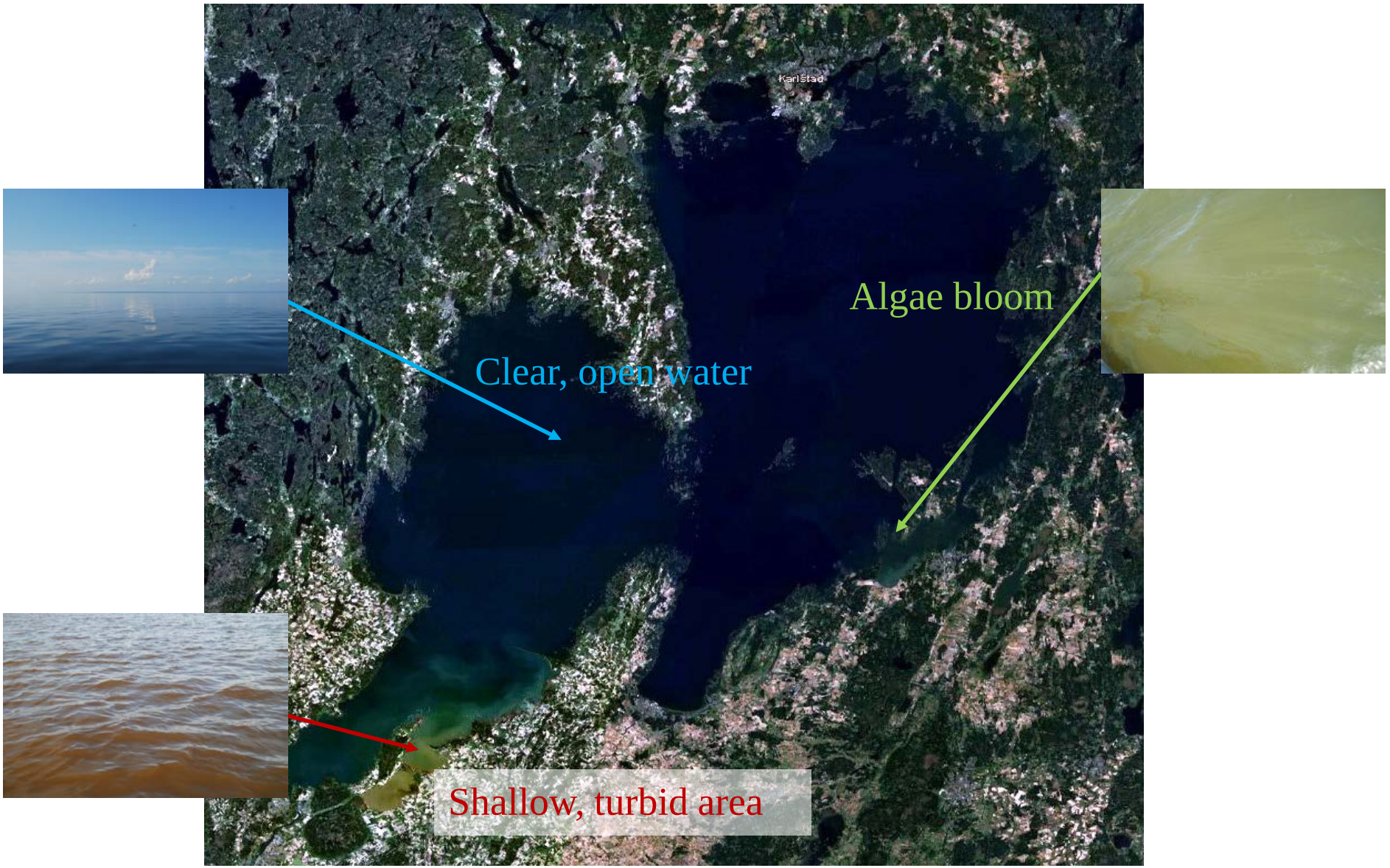


Gege, 2014 C&G

The colour of lakes in Italy



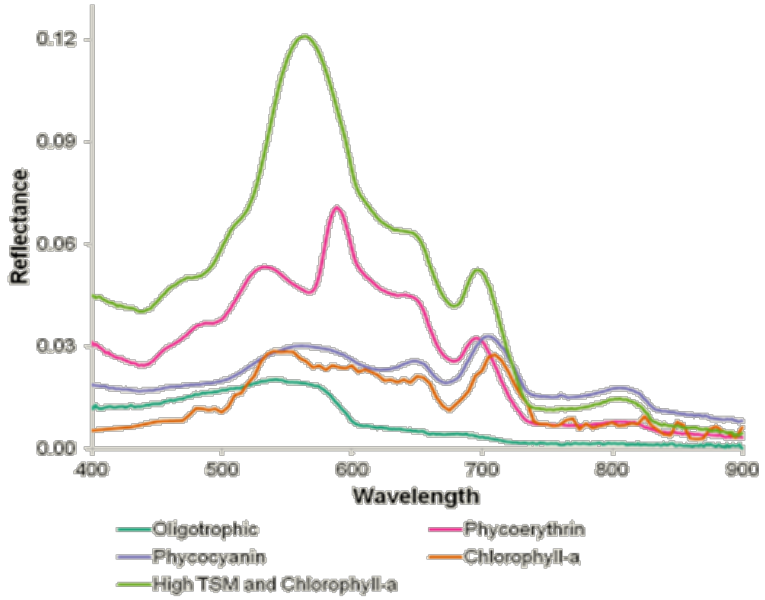
The colours of Lake Vänern, Sweden



Optically complex system

Challenge for EO in lakes is the mixture of:

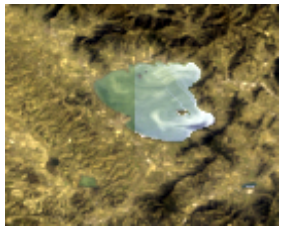
- optically shallow,
- and optically deep waters (gradients of clear, turbid and productive waters & varying bottom visibility)
- substrate visibility and optical complexity affects water quality parameters model retrievals
- atmosphere strongly impacts on the water signal



Hestir et al., 2015 RSE

….also spatially complex

….with a high degree of change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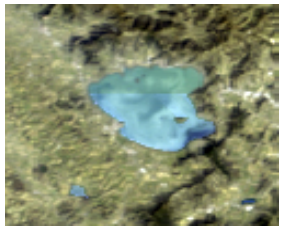
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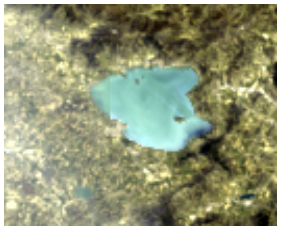
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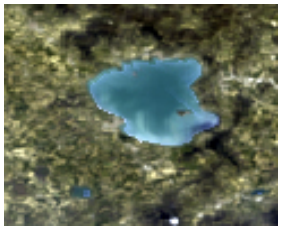
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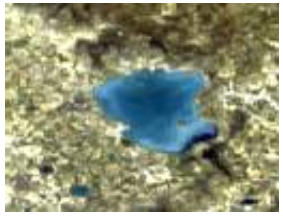
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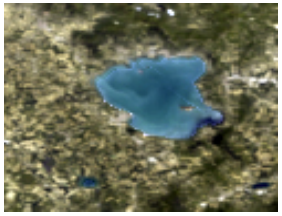
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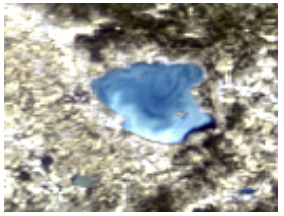
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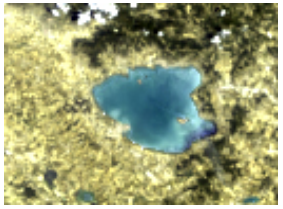
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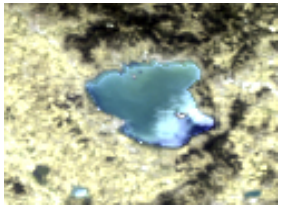
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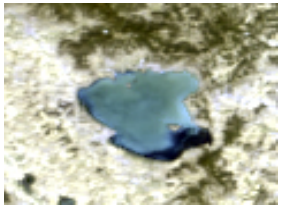
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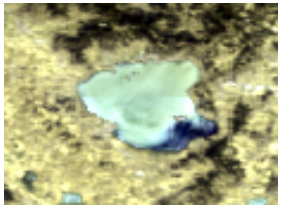
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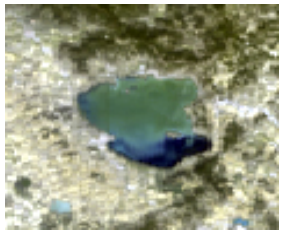
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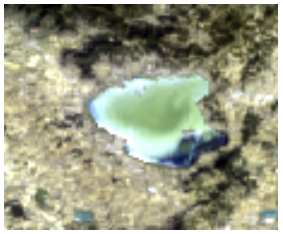
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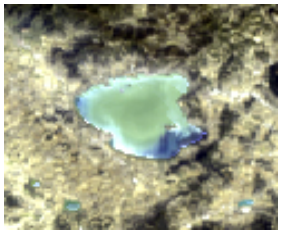
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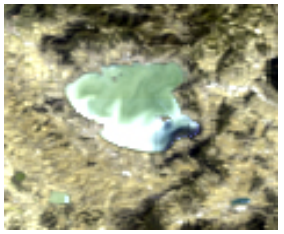
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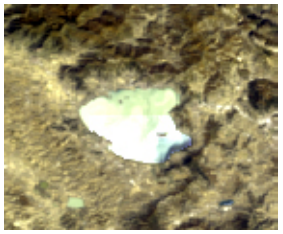
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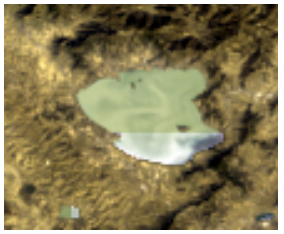
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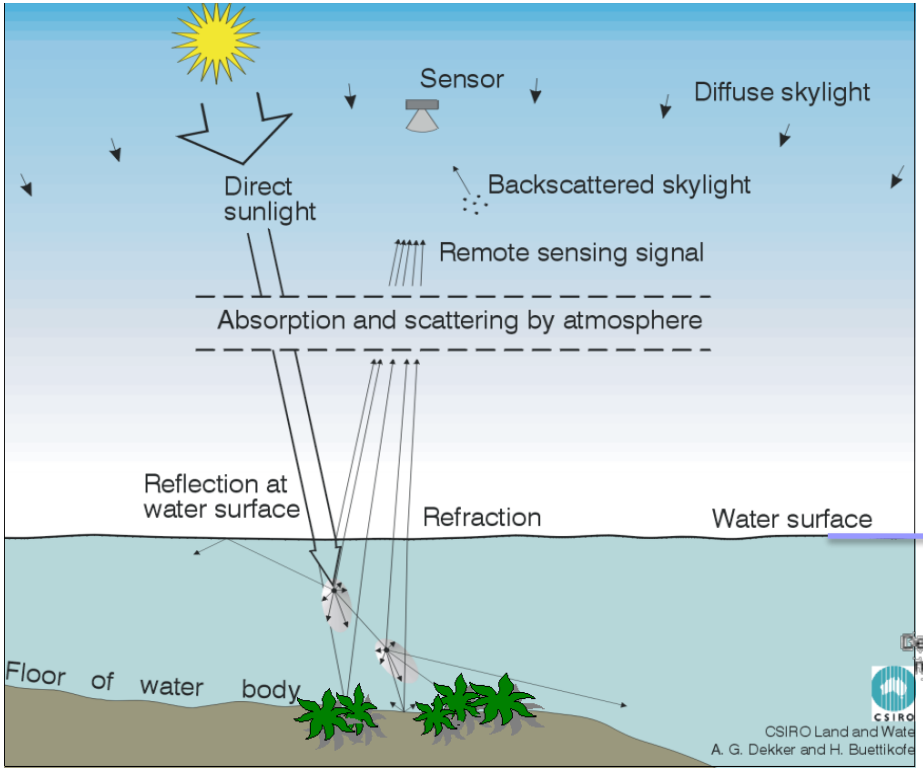
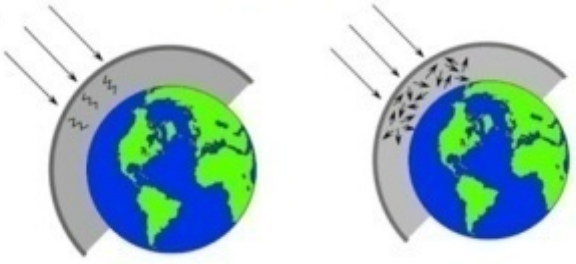
How does it work?

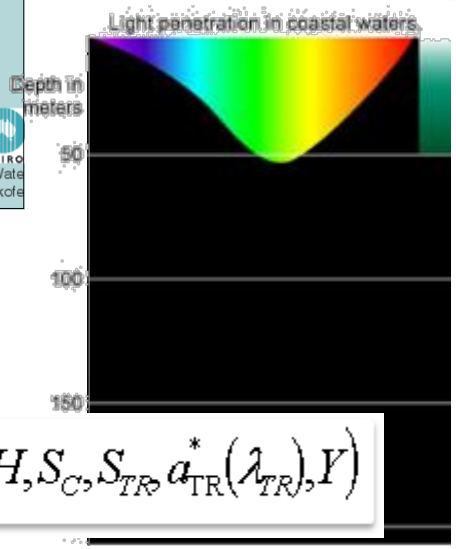
Radiative transfer in the atmosphere

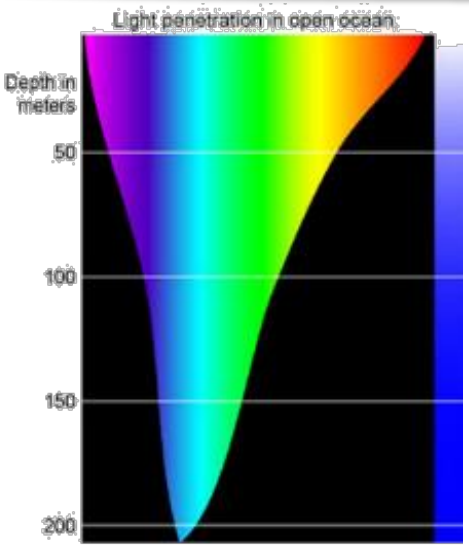




$$\rho_{app}(\lambda) \approx \frac{\pi\,[L_0(\lambda) - L_{d\uparrow}(\lambda)]}{T_{v\uparrow}(\lambda)[E_0(\lambda)\cos\theta_z\ T_{z\downarrow}(\lambda) + E_{d\downarrow}(\lambda)]}$$

Radiative transfer in the water column

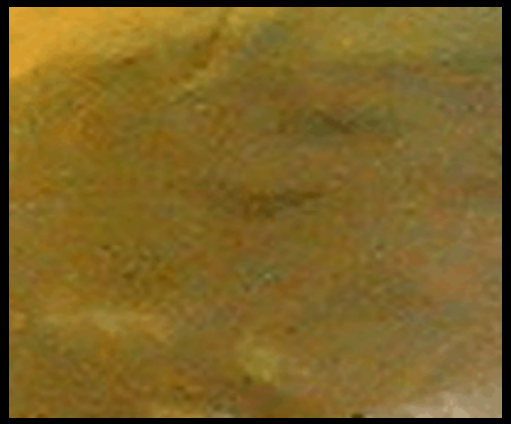




$$r_{rs}(\lambda)_{modelled} = f\left(C_{CHL}, C_{CDOM}, C_{TR}, X_{PHY}, X_{TR}, q_{ij}, A_i, A_j, H, S_C, S_{TR}, a^*_{TR}(\lambda_{TR}), Y\right)$$

Atmospheric/illuminating conditions

Dissolved or suspended substances



Sun-target-observer geometry

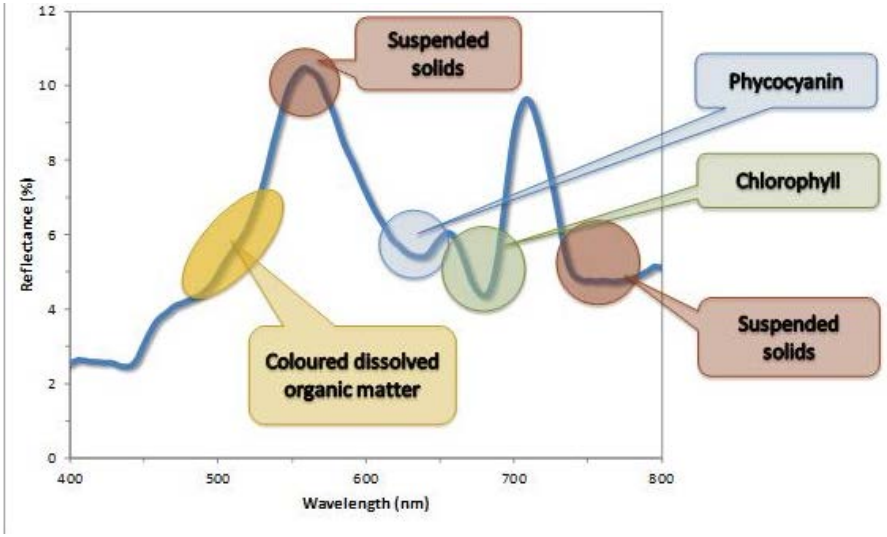
Water status

Bottom characteristics

Environmental conditions

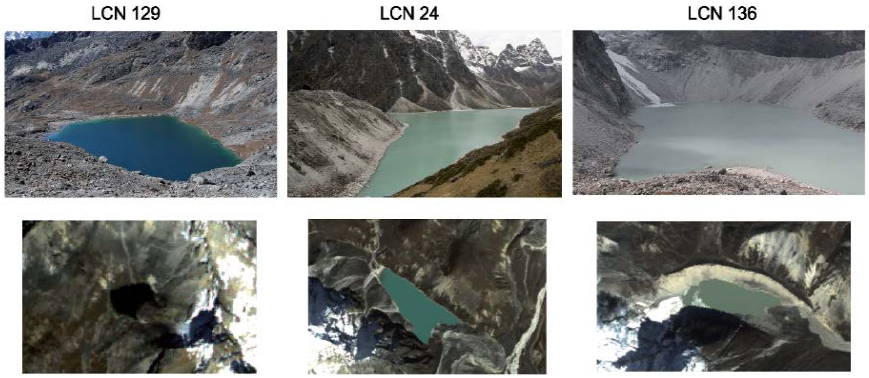
Main parameters derivable from optical satellite (VIS-NIR)

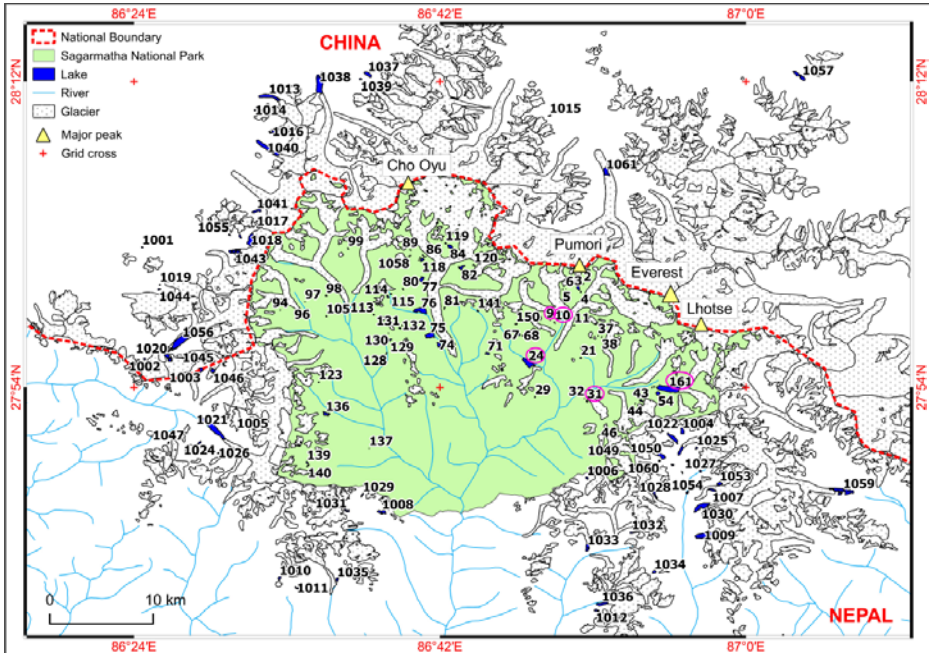
- Water leaving reflectance
- Abs coefficients
- Chlorophyll-a
- Total Suspended Matter
- Yellow Substances
- The diffused attenuation as measure for the water transparency
- Phytoplankton pigments
- Scum and floating matter
- Macrophytes
- Bottom properties and depth

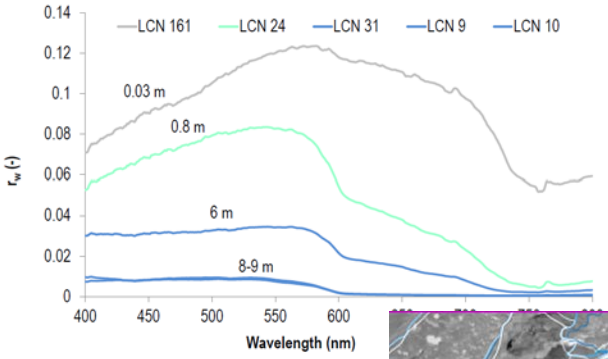


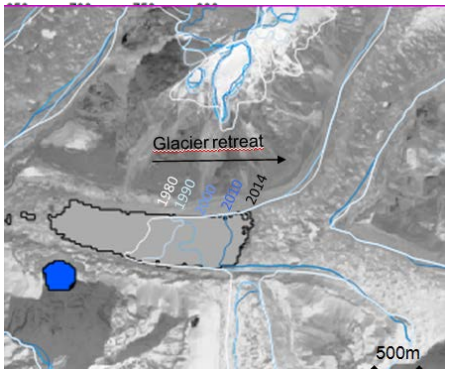
Selected Applications – Himalayan lakes

- Lake-glacier interaction as a response of climate change at regional scale
- Glacial retreat → transport of debris into glacial lakes → change turbidly and color
- Evaluation of lake colour and lake shapes / size from Landsat (few shot → possibility to have 40 years of records)



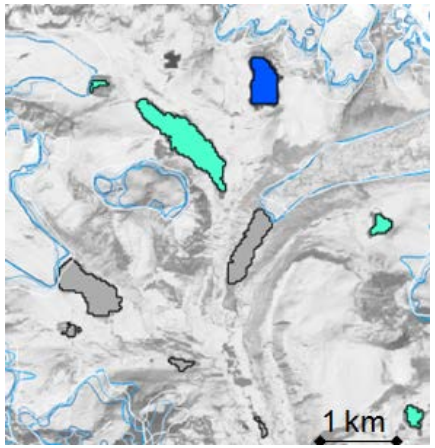


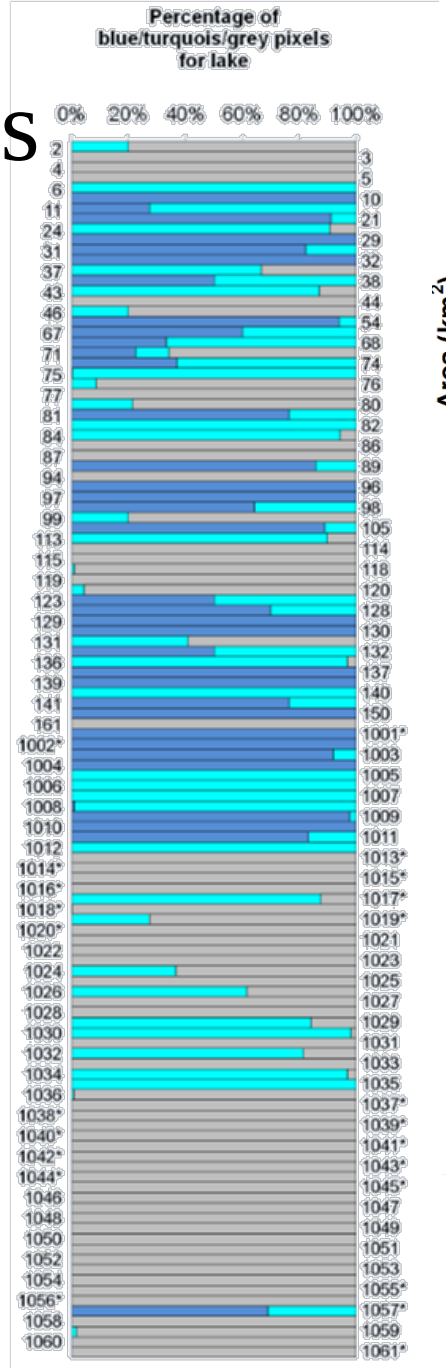


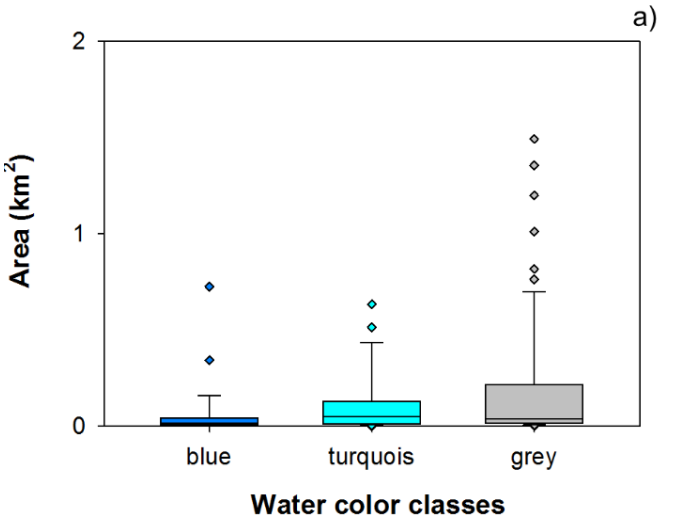


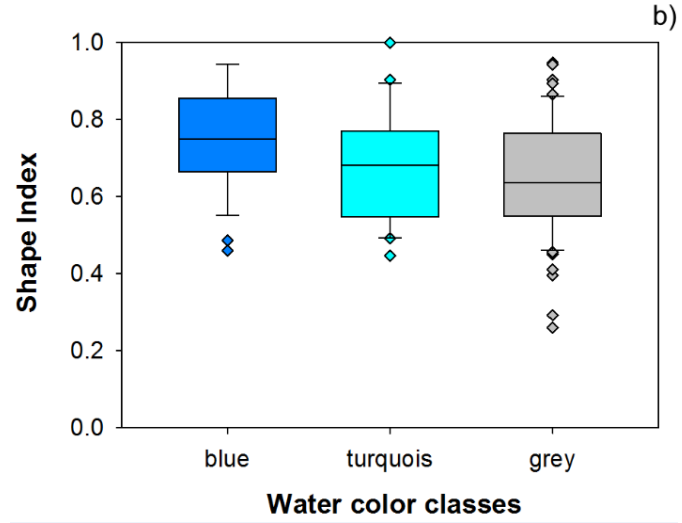
As Glaciers Melt, Imja lake (Nepal) increase in size (Bolch et al 2008) and turbidity (Giardino et al., 2010)

Himalayan lakes









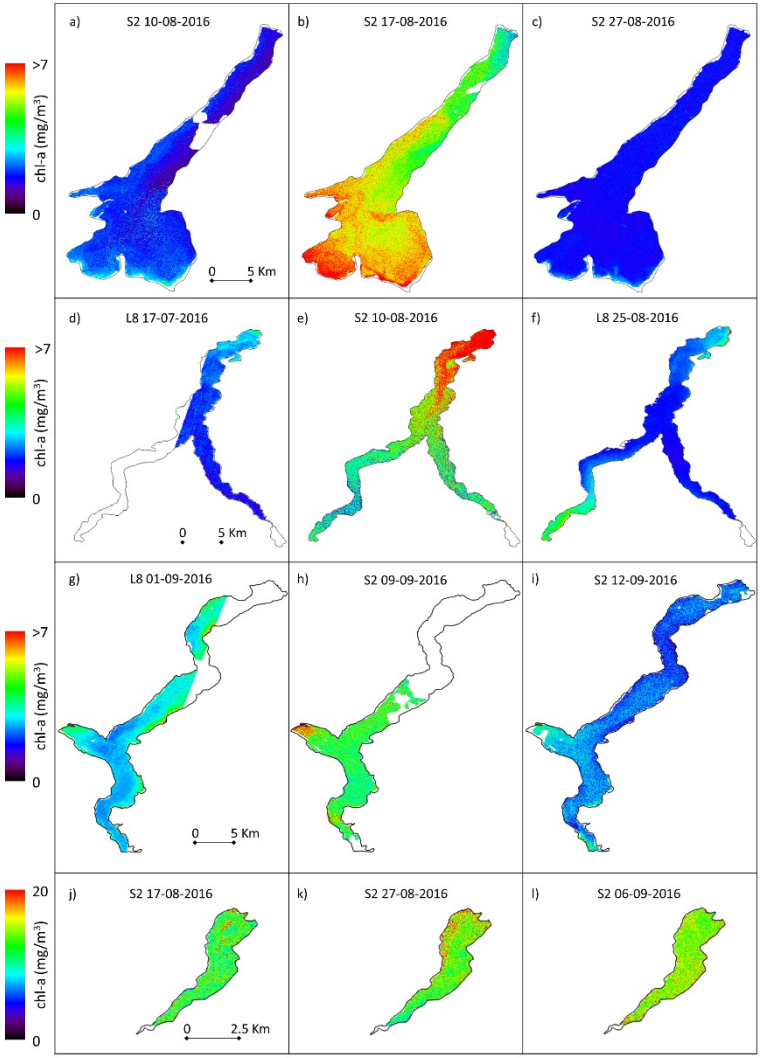
- Grey lakes are generally more elongated and larger than blue
- Change detection 2014 – 2010 on the 255 classified lakes showed a increase of grey lakes and a decrease of blue
- If these lakes are commonly elongated shapes and larger
- If these lakes are supraglacial they might be risky for outburst flow

Giardino et al. 2010 - MRD
Matta et al. 2014 - MRD

Selected Applications – deep clear lakes

- Impacts from climate change are not well understood in deep clear lakes, but are hypothesized to:
  - make increase primary production
  - change phenology
  - Increasing of harmful algal blooms
  - Variation of macrophytes densities and species
  - Changing in biodiversity

- Critical years have a strong impact on water quality (e.g. cold winters in subalpine lakes causes a complete circulation of water with consequence on bottom nutrients available for spring blooming)

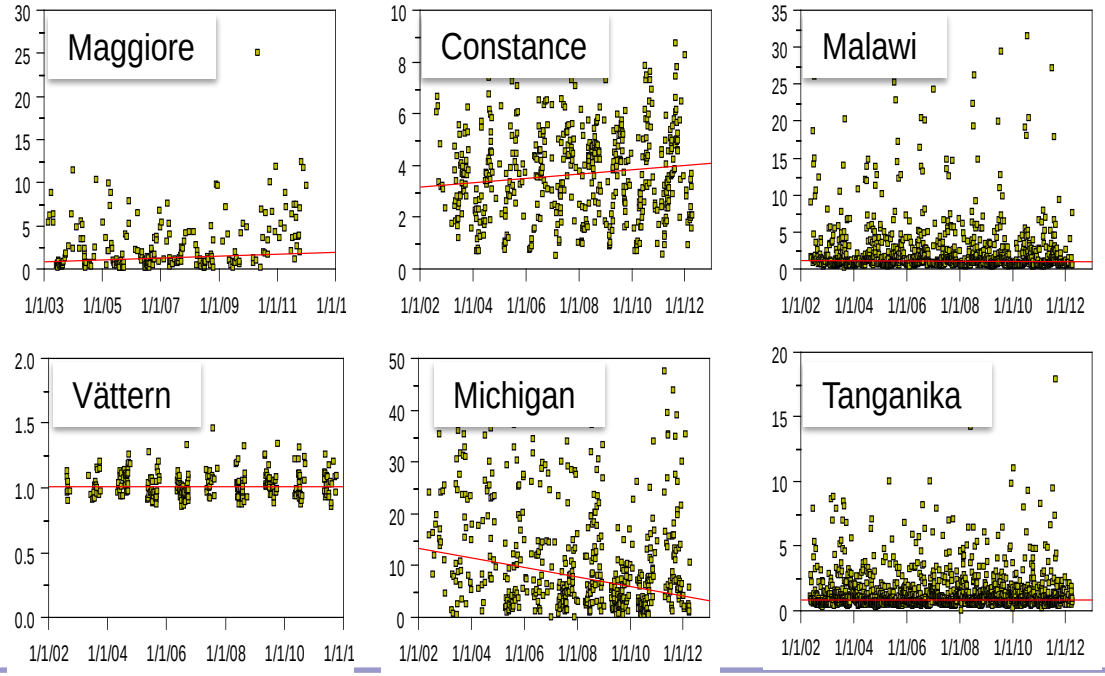


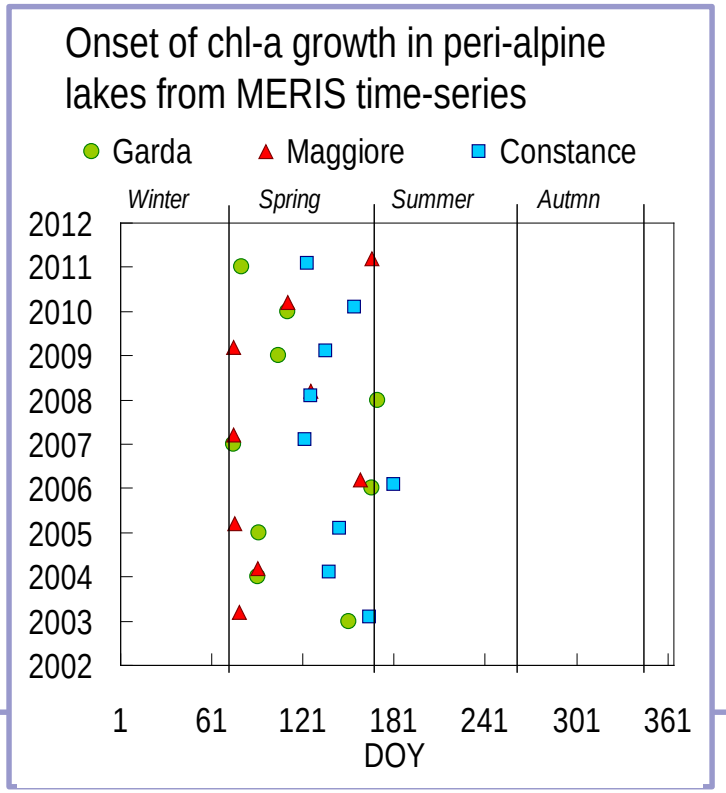
Chl-a concentration maps for the time windows of algal bloom events on each lake.

Giardino et al. 2014 - Sensors
Bresciani et al. – submitted

Deep clear lakes

- The results presented in this report showed the great capability of MERIS to perform trend tests analysis on trophic status with focus on chl-a concentration (possibility to extend with OLCI and MODIS/SeaWiFs (largest lakes)





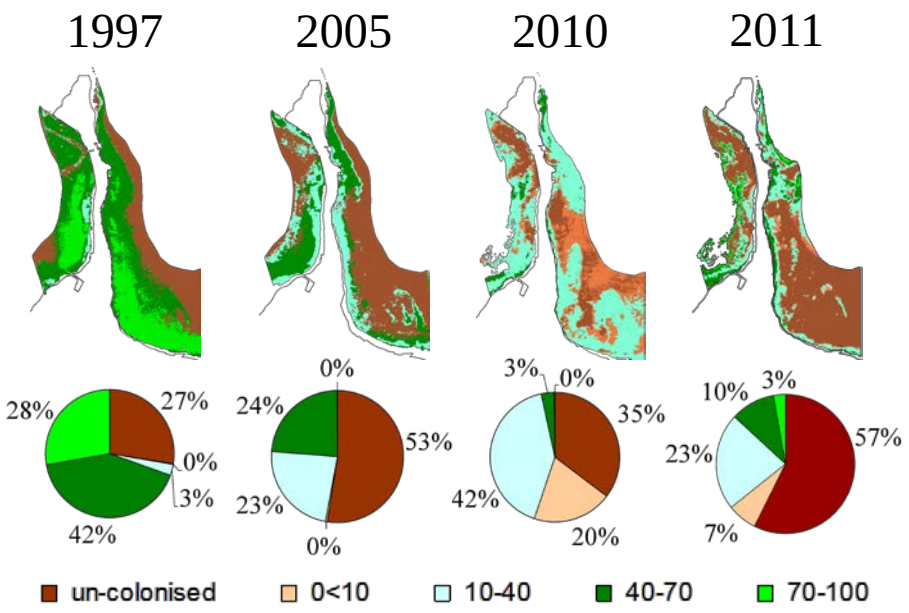
Tendency of chl-a from 12-years of MERIS imagery (Bresciani et al., 2011 STOT)

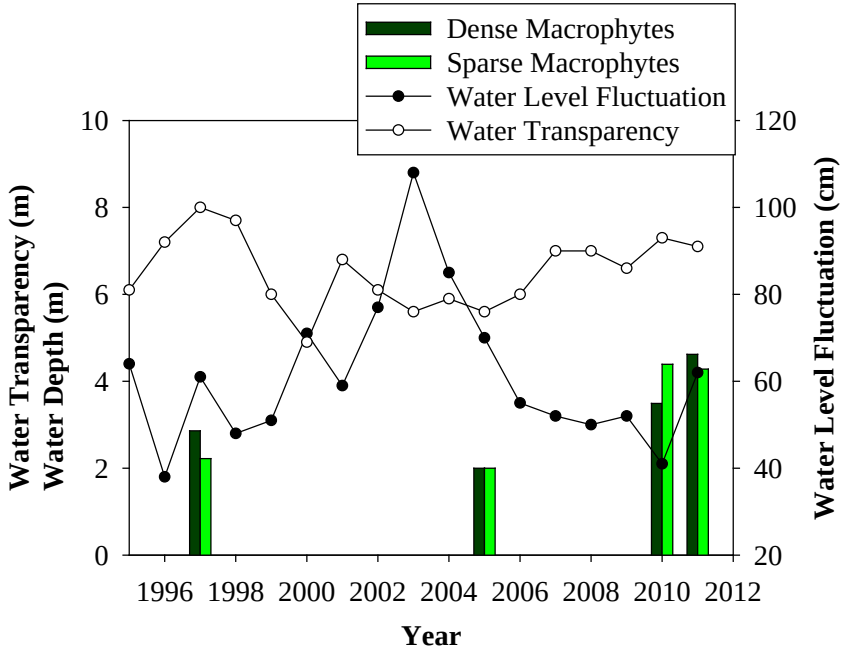
Lake	Median annual Sen Slope (min/max)	Tendency of trophic status
Maggiore	0.124/0.127	Slight increase
Constance	0.060/0.083	Slight increase
Vättern	No trend	Stable
Michigan	-1.877/0.02	Slight decrease*
Malawi	No trend	Stable
Tanganyika	-0.01/-0.02	Slight decrease

* a slight increase was obtained in some sub-basins

Deep clear lakes – coastal zones

- Variation of macrophytes densities and species

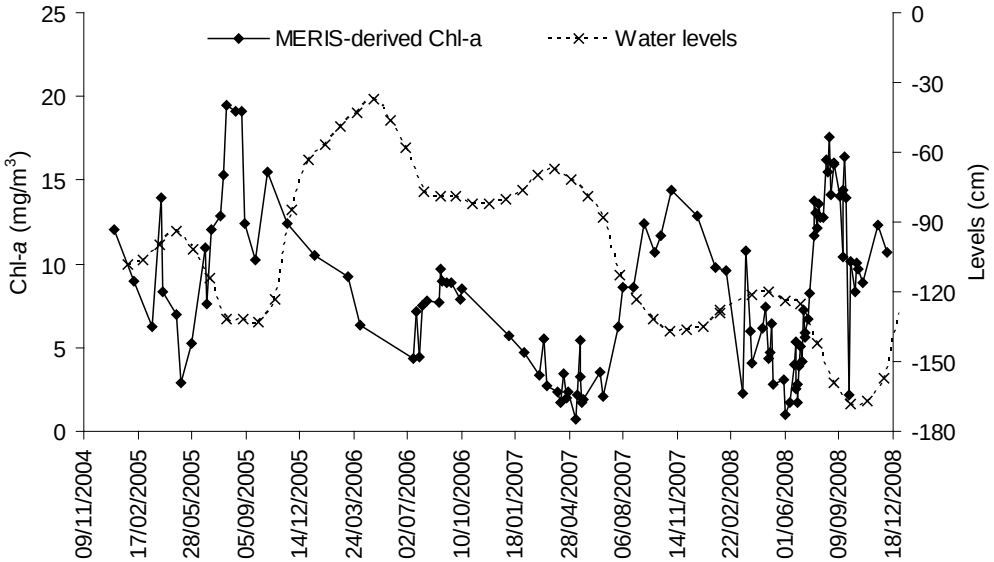


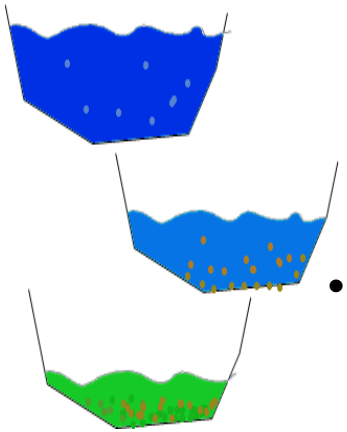


Giardino et al. 2010 - JARS
Bresciani et al. 2014 - JL

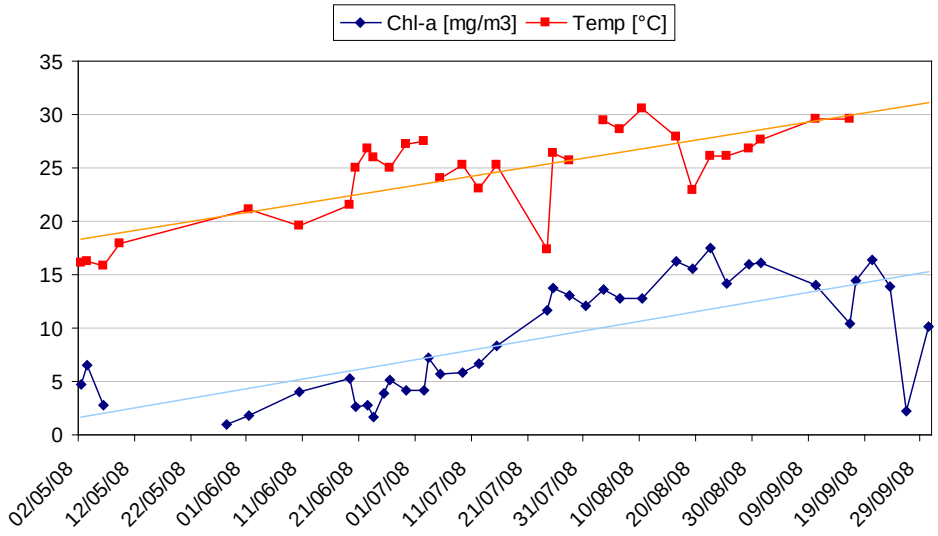
- The results show a considerable modification terms of macrophyte structural complexity and colonized area
- Well-established submerged macrophytes are replaced by de-structured communities characterized by moderate to scarce density
- Macrophyte distribution respond to water transparency and water level fluctuation.

Selected Applications – shallow lakes





- Increase of chlorophyll-a concentration for diminishing water levels
- Increase of chlorophyll-a concentration with water temperature



Giardino et al. 2010 - WRS
Giardino et al. 2014 - RSE

Selected Applications – HABs

Economic effects of HABs in the U.S. are at least $82 million/year*

Commercial Fisheries Impacts: **$38 million/year**

Public Health Costs of Illness: **$37 million/year**

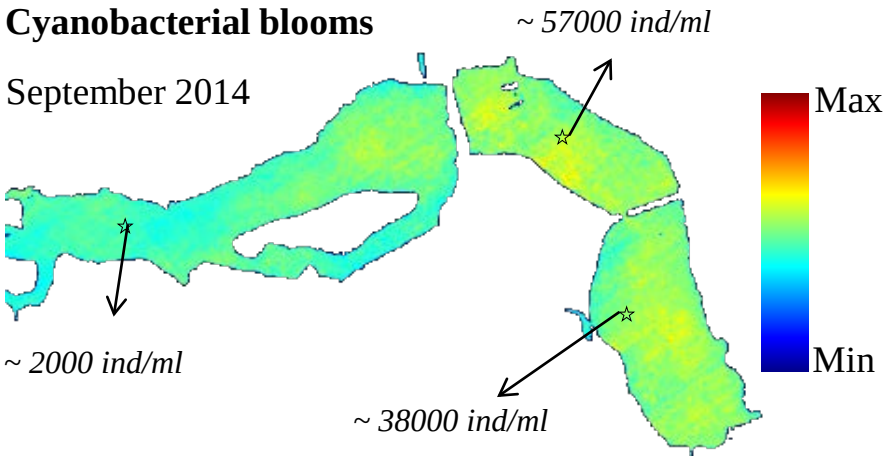
Recreation and Tourism Impacts: **$4 million/year**

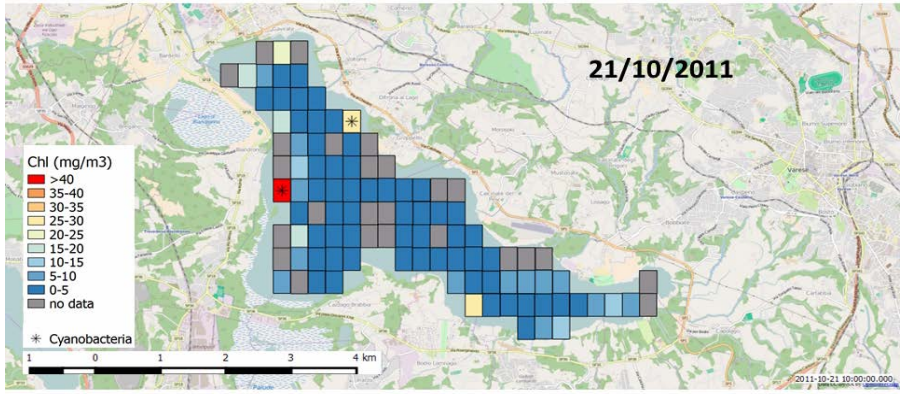
Coastal Monitoring and Management: **$3 million/year**

*2005 dollars, Hoagland and Scatasta (2006). Based on subset of outbreaks in 1987-2000.

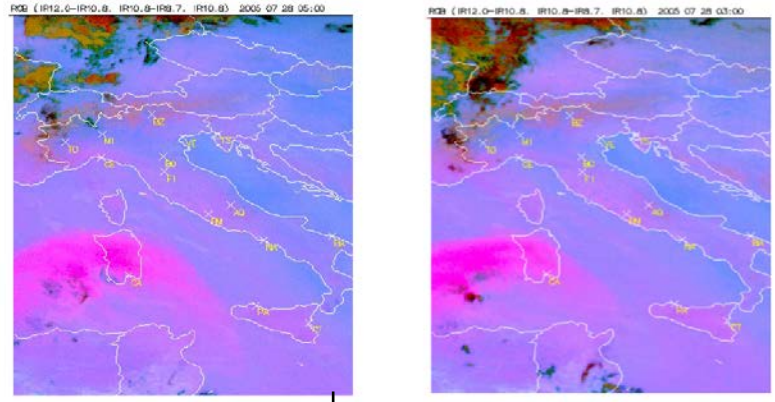
Cyanobacterial blooms

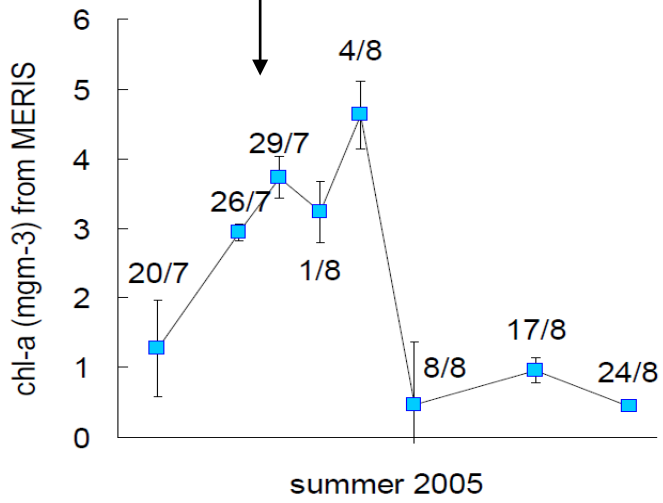
27 September 2014



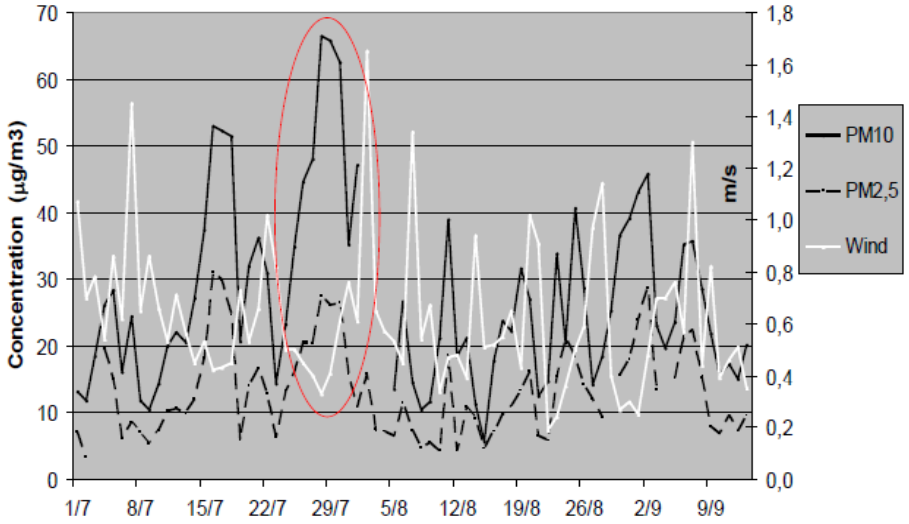


Selected Applications – dust





Water temperature and P data analysis revealed the chl-a increase was not due to those two factors



PM data measured in Bosco Fontana. The dust event is detected when PM10 is sensible higher than PM2.5 (red the circle)

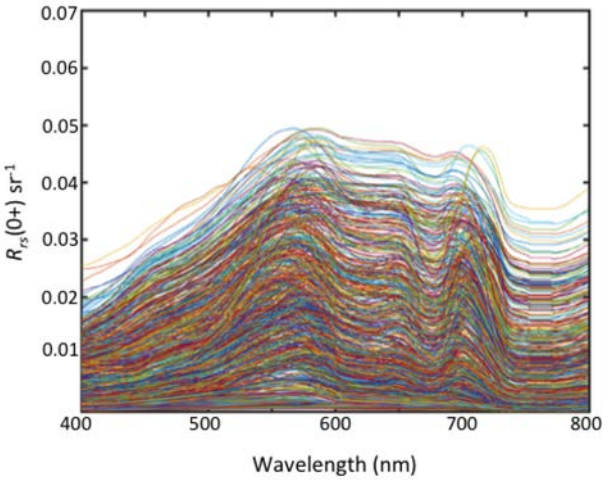
SUN PHOTOMETER CE 318

Dicolantonio et al., 2014

Summary and conclusions

- RS in inland and coastal water is challenging due to their optical complexity being a mixture of optically shallow and optically deep waters, with gradients of clear, turbid and productive waters and varying bottom visibility:

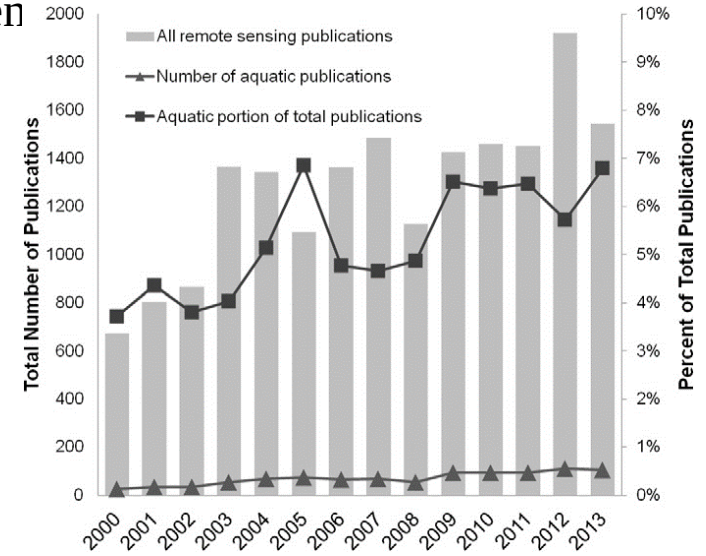
  Chl-a: 0.1 - 940 mgm-3
  TSM: 0.1 - 290 gm-3
  CDOM: 0.04 - 10 m-1



Eleveld et al. (2017)

- Most of the lakes are in the boreal region where illuminations, ice and CDOM rich waters makes even more complex the implementation of algorithms

- Nevertheless remote sensing community of lakes is increasing as S3, S2 and L8 are anyway providing improved data to assess water colour and bio-physical parameters at global scale



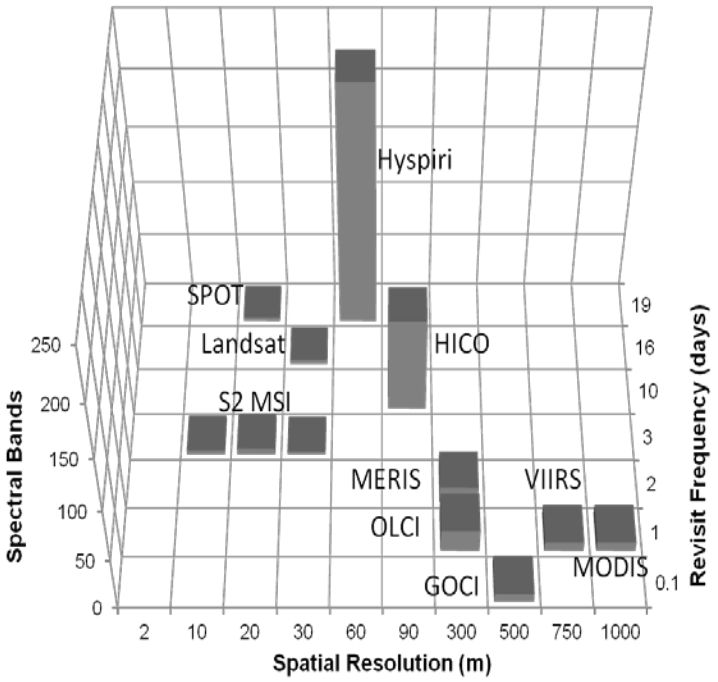
Hestir et al. (2015)

Summary and conclusions

- Continental to global studies are now possible (GLaSS, Copernicus land service Lot 2: ‘Operation of the Global Land component, thematic domain cryosphere and water’, Globolakes, NERC)

- Latest (L8, S2-3) and future missions (FLEX, PACE, Hyper: PRIMSA/EnMAP/Hyspiri) will provide further data to study the color of lakes

GloboLakes
Global Observatory of Lake Responses to Environmental Change
LIMNADES



Merci!