Mapping the spatial variability of optical properties in Mantua lakes with the APEX sensor

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istituto per il rilevamento elettromagnetico dell'ambiente

Research framework (1/3)

In the past **20 years** freshwater harmful algal blooms (**FHAB**) have increased in **frequency**, **intensity** and **geographic** extent in inland waters

Algal blooms strongly condition water quality. Some algal groups (**cyanobacteria**) can produce **toxic** substances, which are **dangerous** for the aquatic **fauna** and **human health**

Spectral characterization of harmful algal blooms in Mantua lakes (Italy)

EUFAR European Facility For Airborne Research
HABLakes

Projects	Times	Funds
Cyanobacteria assessment in Italian and Swedish waters from space	2010-13	MIUR
Coasts and Lake Assessment and Monitoring by PRISMA HYperspectral Mission	2010-2014	ASI
Monitoring European Lakes by means of an Integrated Earth Observation System	2003-on going	ESA cat-1 (AO553)

cyan-IS-wes

CLAM-PHYM

MELINOS

Research framework (2/3)

Spectral characterization of harmful algal blooms in Mantua lakes (Italy)

The aims of this proposal are:

- to calibrate and validate algorithms based on remote sensing techniques for monitoring cyanobacteria blooms in the Mantua lakes;
- to improve the knowledge of instrumentation currently available for monitoring activities;
- to assess the feasibility of separating and estimating the potentially harmful cyanobacteria blooms from blooms of algae using in situ and remotely hyperspectral measurements;
- to deepen ecological knowledge of the correlation between the occurrence of algal blooms (and their abundance) and both water physico-chemical and hydrodynamic parameters.

Two acquisitions of APEX data are necessary: one in the **morning** (9:30-10:30 am UTC) and another in the **afternoon** (1:00-2:30 pm UTC) in order to evaluate the effects of buoyancy of some species of cyanobacteria

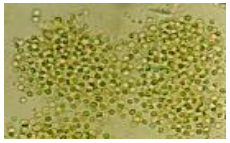
Season: between late July and the end of September

Research framework (3/3)

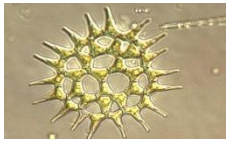
Mantua Lakes represent an ideal experimental site to investigate eutrophication phenomena, algal blooms and degenerative processes

up to the mid-1970s Mantua Lakes displayed a clear water state that rapidly turned into a phytoplankton dominated state (**up to 100 µg Chl-a L^{-1}**);


CYANOPHYTA: *Oscillatoria* sp.


CYANOPHYTA: *Microcystis* sp.


CYANOPHYTA: *Aphanizomenon* sp.


CHLOROPHYTA: *Pediastrum simplex*


BACILLARIO-PHYCEAE: *Synedra* sp.

although, **several life-growth forms of aquatic plants are still present** and locally well-represented;


Trapa natans


Nuphar luteum


Nymphea alba

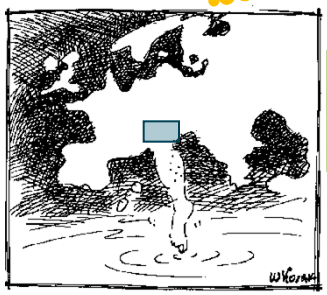

Acorus calamus


Nelumbo nucifera

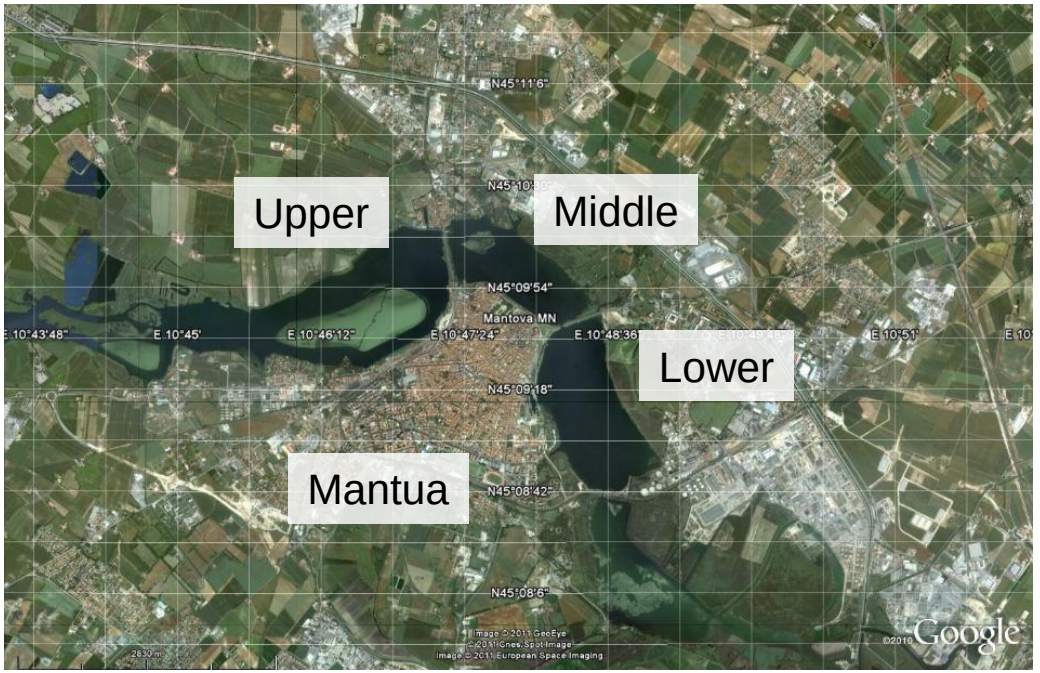
since mid 2000s Mantua lakes are widely-characterized with the aim to evaluate its trophic state and metabolism;

in 2007 we began to study Mantua Lakes with spectroradiometric measurements and remote sensing data.

Study area (1/2)



Northern Italy



- The lakes of Mantua (Upper, Middle and Lower) are three small and shallow basins surrounding the city of Mantua
- The lakes are fed by the Mincio River, which is the emissary of Lake Garda and the tributary of Po River, the longest Italian river, these lakes are regulated by dams

Lake	Lake area [km^2]	Perimeter [km]	Storage volume [×10^6 m^3]	Mean depth [m]	Residence time [days]
Upper	3.67	10	14.5	3.6	8.4
Middle	1.09	6	3.27	3.0	1.9
Lower	1.45	6	4.36	3.3	2.5

Study area (2/2)

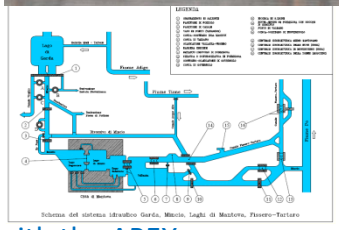
This wetland is precious for **wildlife habitat** and has aesthetic and **recreational** benefits for the entire region

… but

Anoxic waters and losses of endemic species and water clarity

Introduction of **exotic species**

High **anthropogenic pressure**



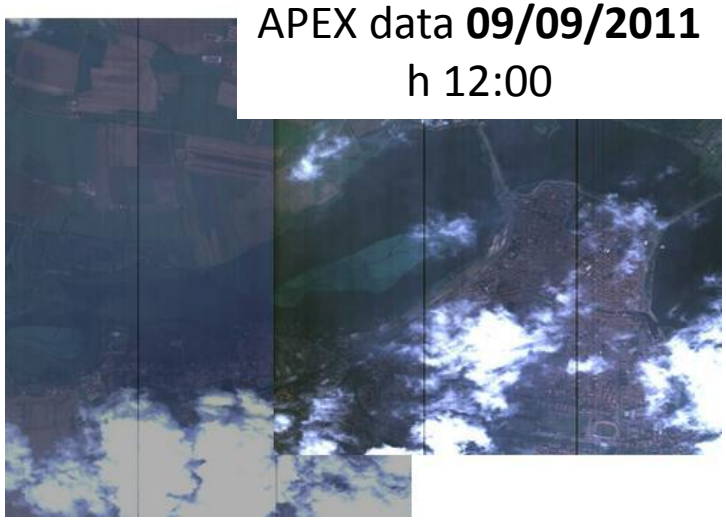
The **water treatment plant is insufficient**

APEX data

… unfortunately

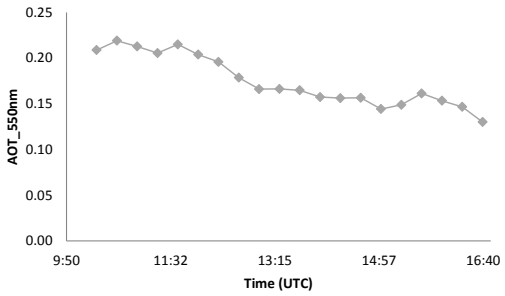
Clouds

APEX data **09/09/2011**
h 12:00



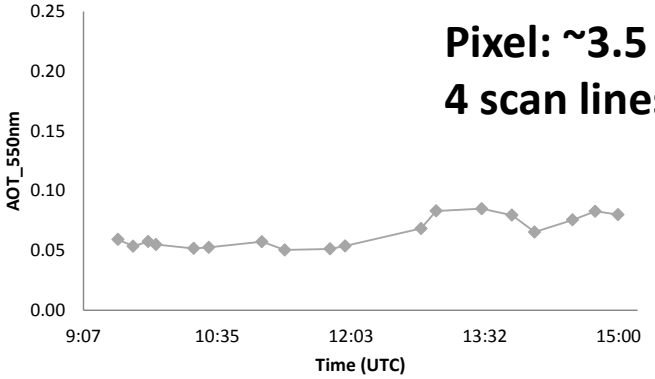
Diffuse light

APEX data 09/09/2011
h 16:30



APEX data **21/09/2011**
h 16:30

…but



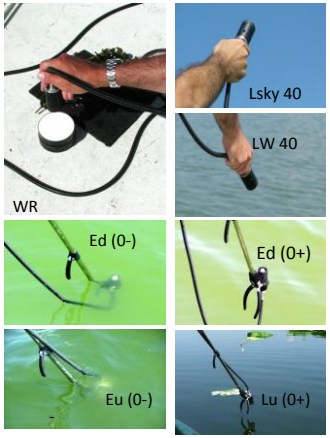
APEX data
300 bands: 400-2500 nm
Pixel: ~3.5 m
4 scan lines

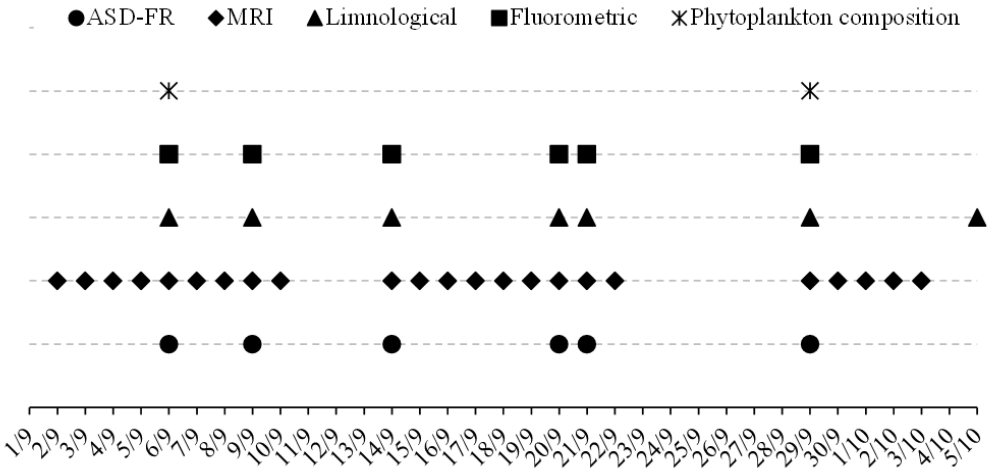
Field data acquisition



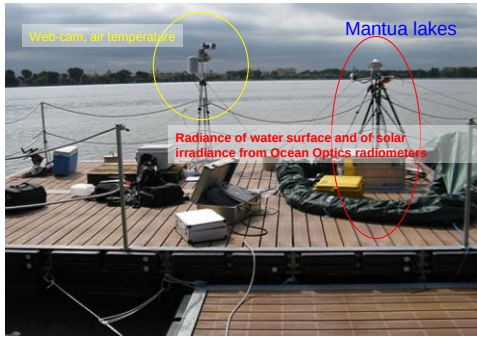

In September 2011 Mantua lakes were characterized by a **high variability of water conditions**

ASD-FR





MRI



Fluorometric

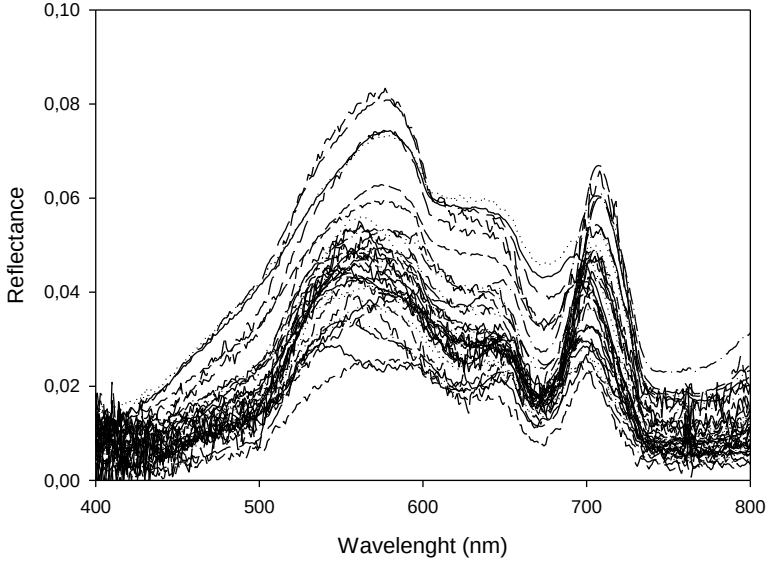
Secchi disk

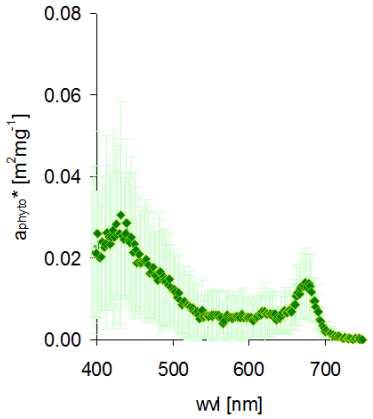
Water samples

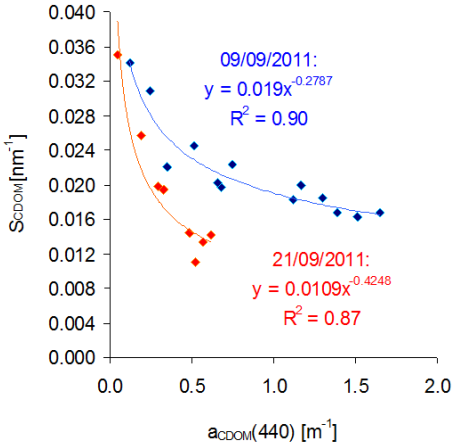
Hydroscat

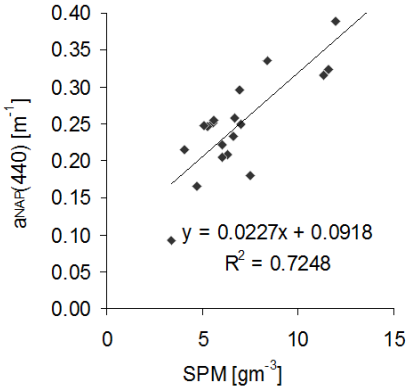
Field data results

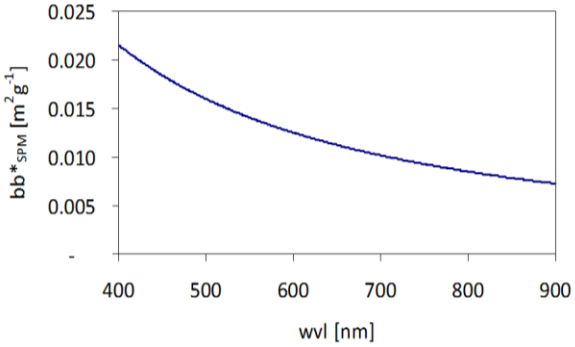
AOP and IOP











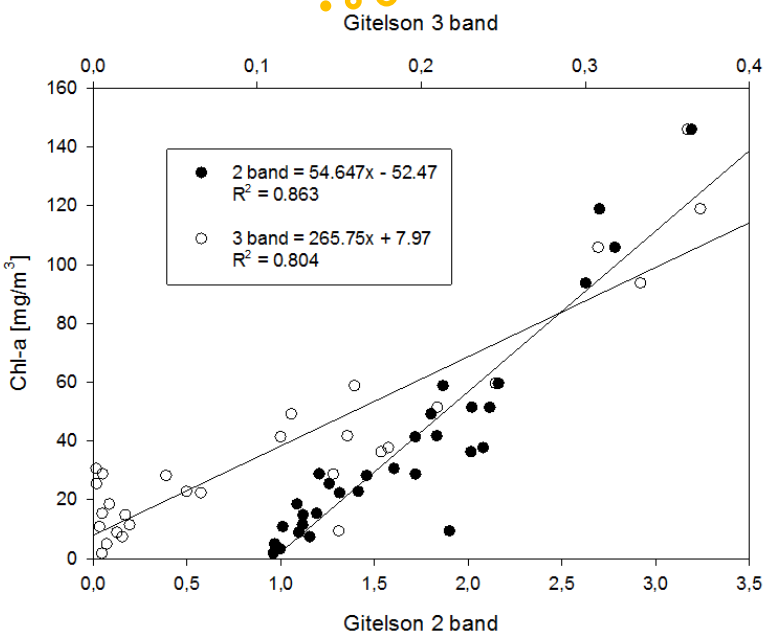
specific absorption spectra of phytoplankton

relation between slope and concentrations of CDOM

relation between SPM and the absorption of NAP at 440 nm.

specific backscattering spectra of particles

Field data for semi-empirical algorithms and temporal evolution



VALIDATION with MRI data

$r^2 = 0.92$ ($p < 0.0001$),

rRMSE = 16.3 %,

MAE of 3.61,

average in situ data of 36.8 mg/m^3

estimated average data of 34.3 mg/m^3

Figure 7. Correlation between Gitelson indexes values (two bands index in black and three bands index in white) and chl-a synchronous concentration measures obtained during 31 samples .

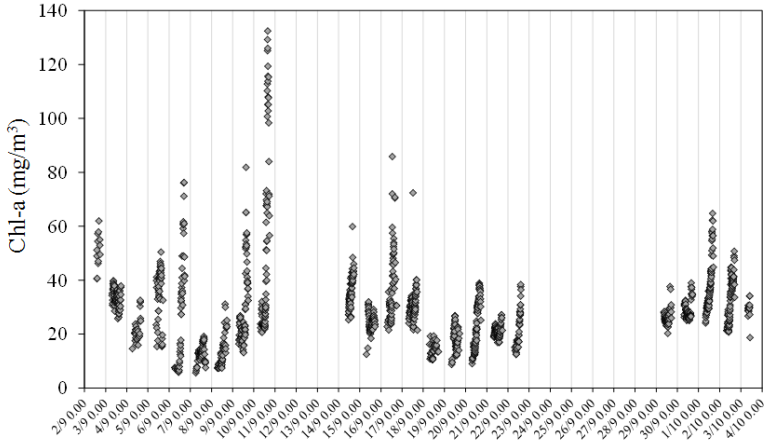
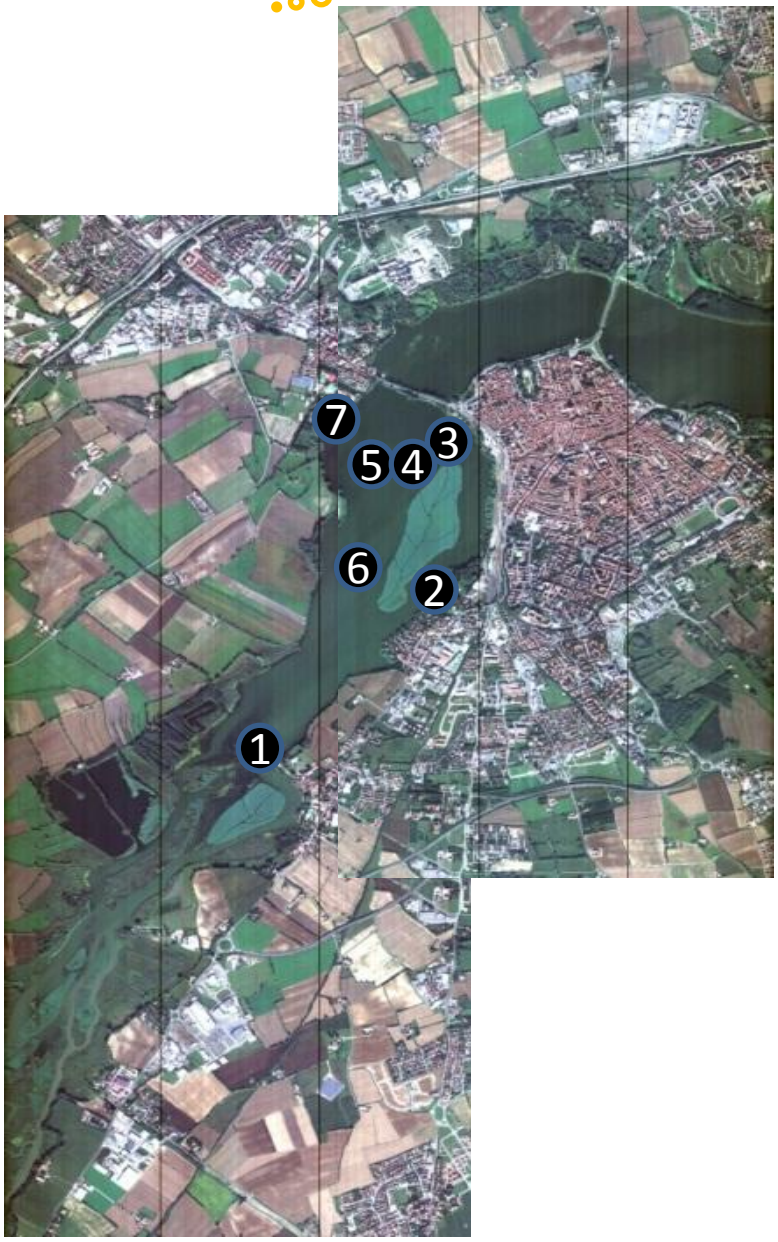
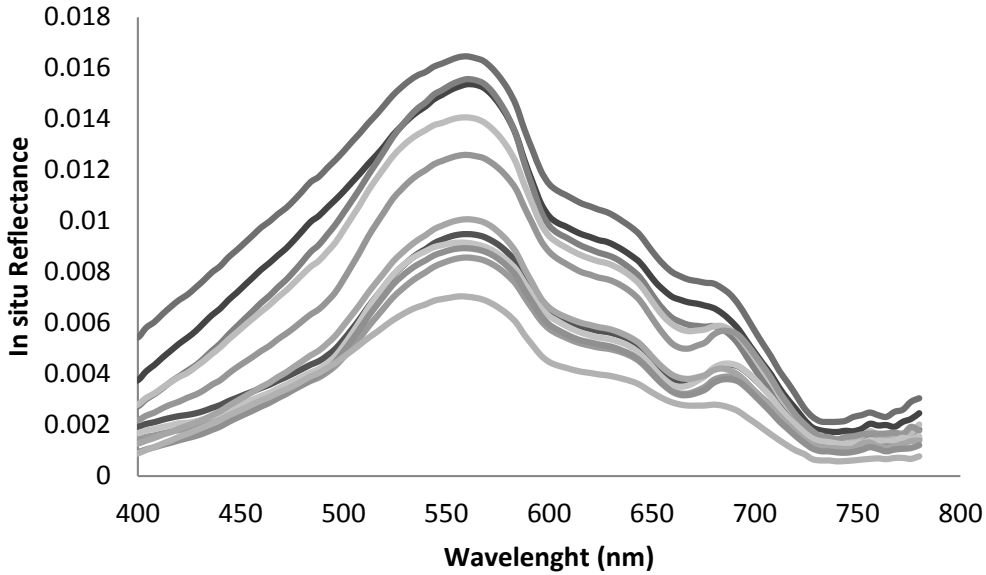


Figure 8. Intra- and inter-daily chl-a concentration trends derived from the application of the two bands Gitelson index to the MRI radiometric measures.

Field data during APEX acquisition

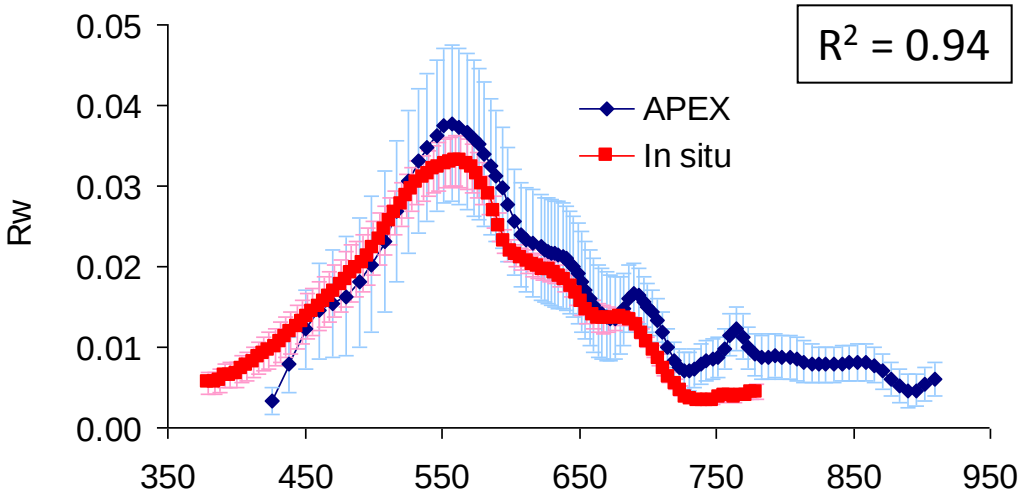




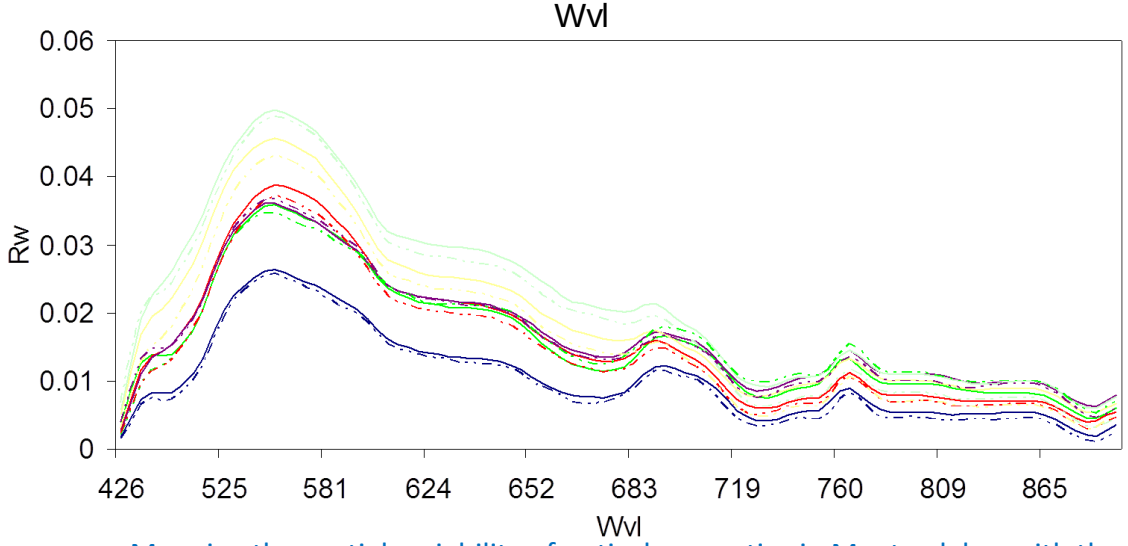
Chl-*a*:	16.0 10.6 µg L^{-1}
CDOM:	0.38 0.19 m^{-1}
TSM:	6.11 1.32 mg L^{-1}
SD:	1 0.1 m
Temp:	23.6 0.6 C

APEX pre-processing and radiometric validation

APEX images were corrected by VITO with the MODTRAN4 radioactive transfer code to remove atmospheric effects. The AOT value were provided by the sun photometric data acquired synchronously. We used Field Spectra data to validate water reflectance (Rw)



The good match suggests that the radiometric accuracy of the corrected APEX data is very high.



Comparison between two APEX runs for a number of stations that are common to both flight lines. APEX data are not affected by bidirectional effects that indeed are frequent in whisk broom scanners.

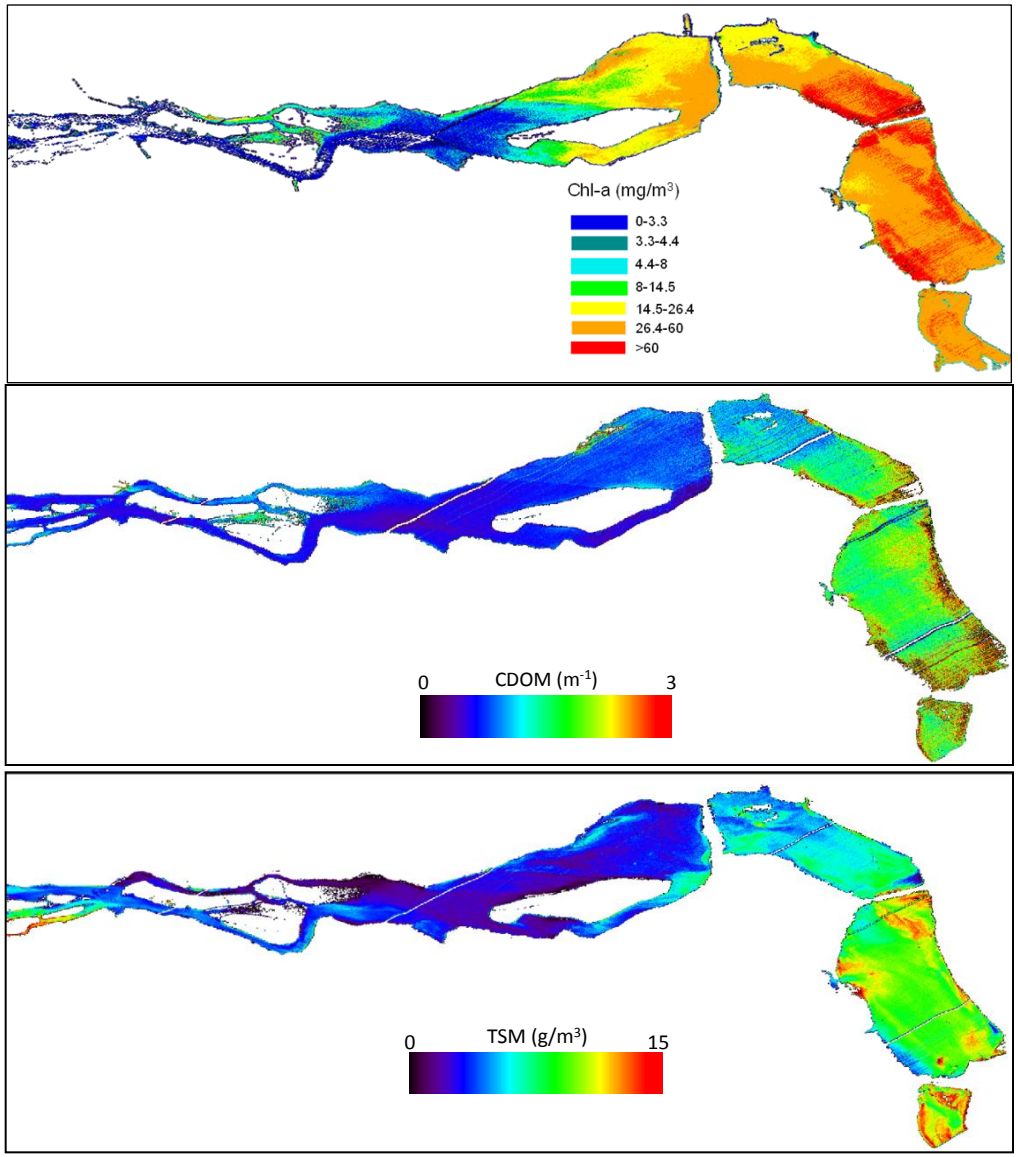
APEX processing and algorithms validation

For the estimation of water quality parameters we used 2 different approaches:

- semi-empirical algorithms (**Chl-a** Gitelson et al., 2008; **TSM** Bresciani et al., 2009) ***SEA***
- Bio-optical model BOMBER (*Bio-Optical Model Based tool for Estimating water quality and bottom properties from Remote sensing images*) (Giardino et al., 2011) ***BO***

	r2		RMSE		MAE		Average value	
	SEA	BO	SEA	BO	SEA	BO	SEA	BO
Chl-a	**0,86**	0,72	**27,9**	70,3	**3,81**	7,38	In situ 15,97 APEX 16.27	In situ 15,97 APEX 20.47
TSM	0,53	**0,63**	55,13	**23,8**	3,06	**1,32**	In situ 6,14 APEX 9,04	In situ 6,14 APEX 4.94
CDOM		0,79		12,2		0,04	In situ 0,47 APEX 0.49	In situ 0,47 APEX 0.49

Maps of water parameters



Chlorophyll-a

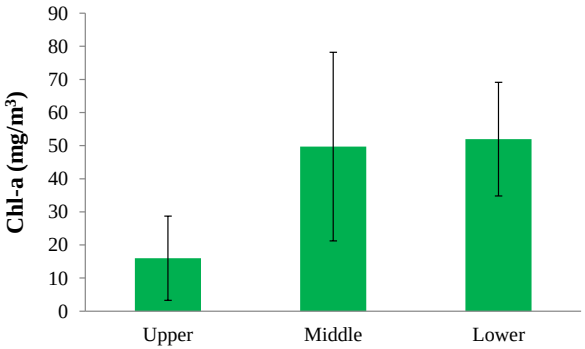
CDOM

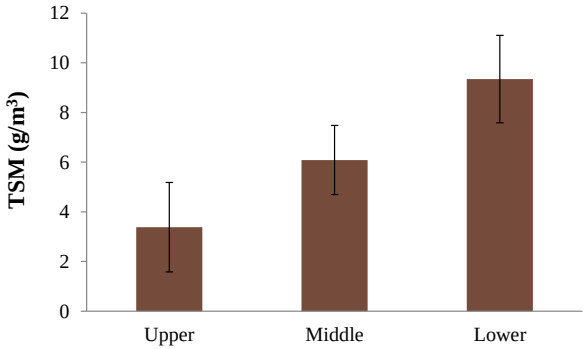
TSM

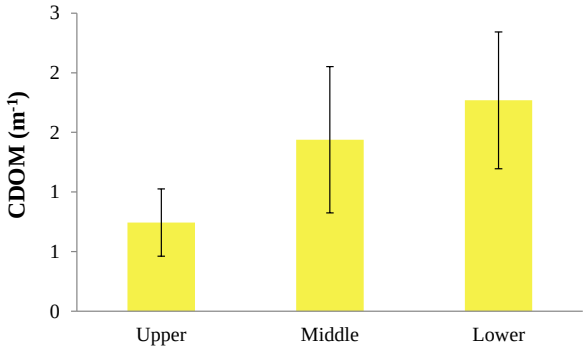
Maps obtained by the best algorithm

Spatial analysis (1/2)

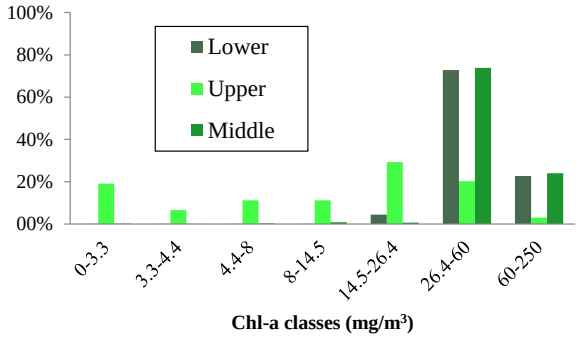
For all three estimated parameters concentration increases from Upper Lake to the Lower Lake

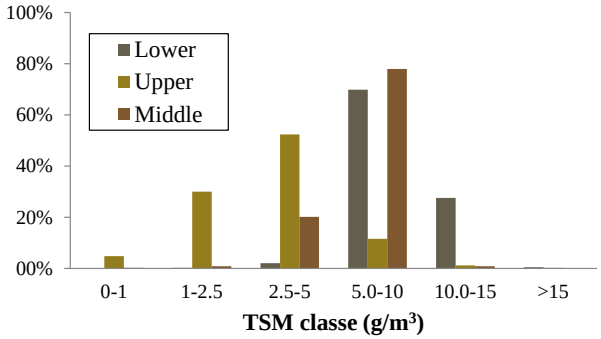


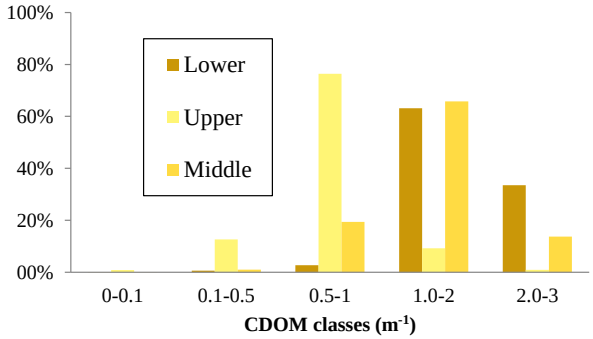




The statistics confirm the spatial variability of the chl-a, TSM and CDOM concentration

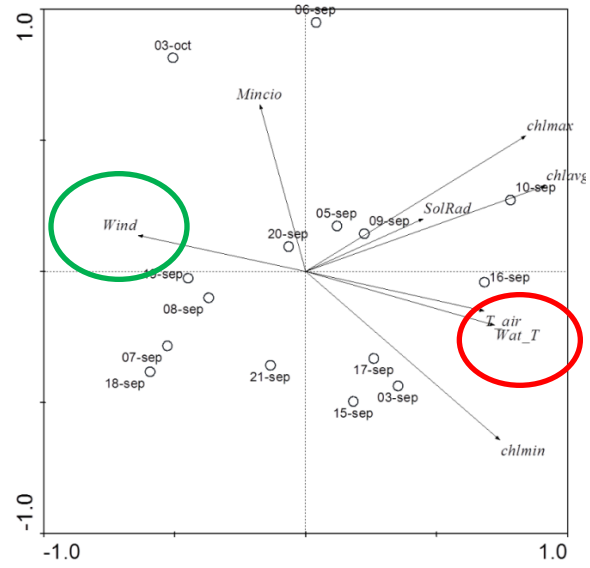






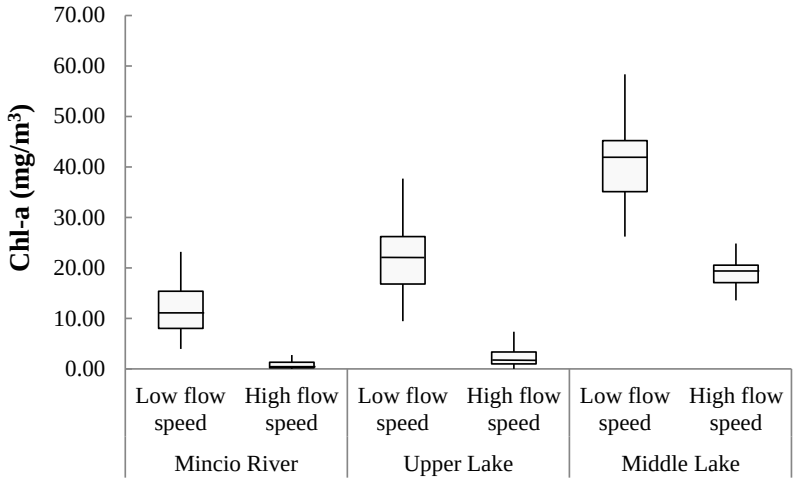
Spatial analysis (2/2)

We also analysed the correlation between estimates of the Chl-a and physico-chemical, meterological and hydrodynamic conditions of the water in the month of September

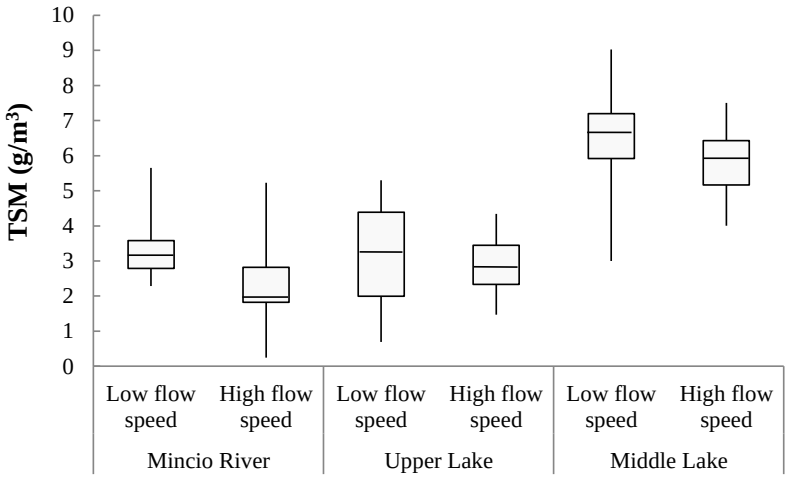


The first ordination axis is determined by most of the variables

Water and air temperature on the positive side, wind on the negative side



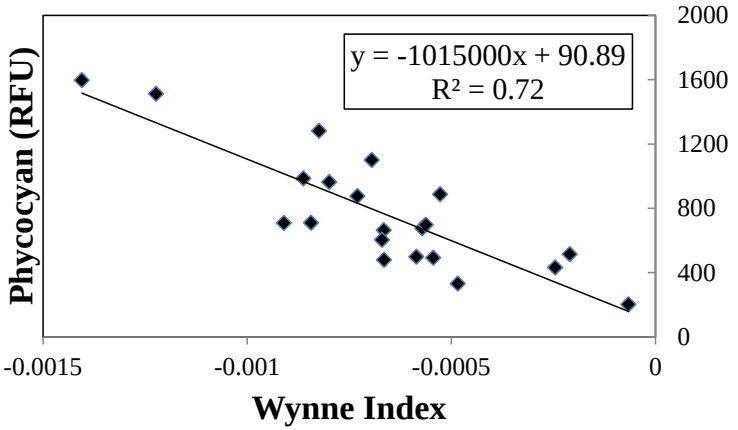
High chl-a concentration is high where water is stagnant



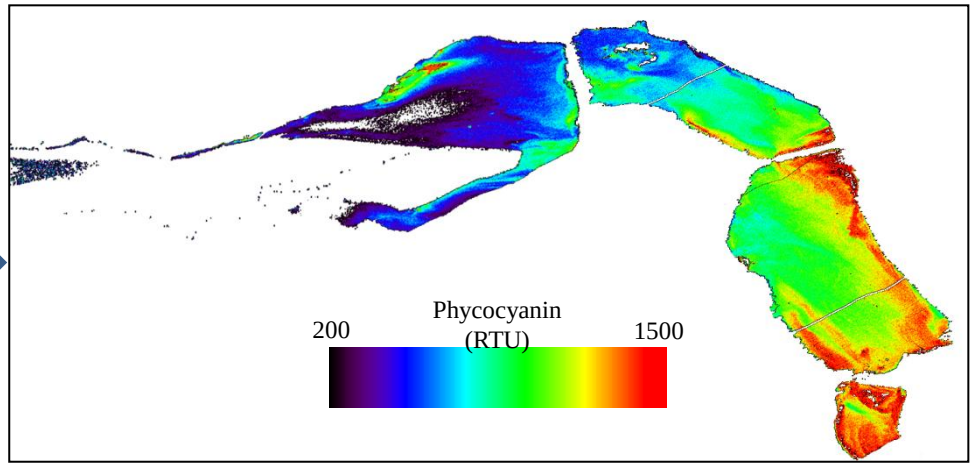
Differences are smaller in the case of TSM

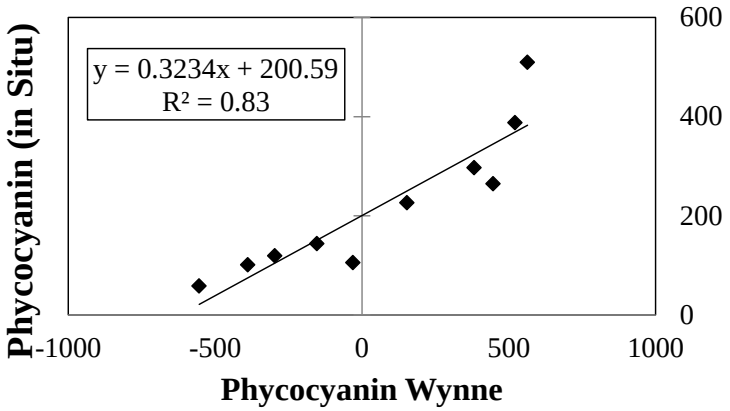
Cyanobacteria analysis (1/2)

To the spectral signatures of the field algorithms by Wynne 2008, Kutser 2006, Ruiz Verdù 2007 adapted to the in situ spectral characteristics, were applied. The Index fitting better with Phycocyanin fluorimetric data is Wynne (Rw670-Rw650)-(Rw702-Rw650)*(670-650)/(702-650).



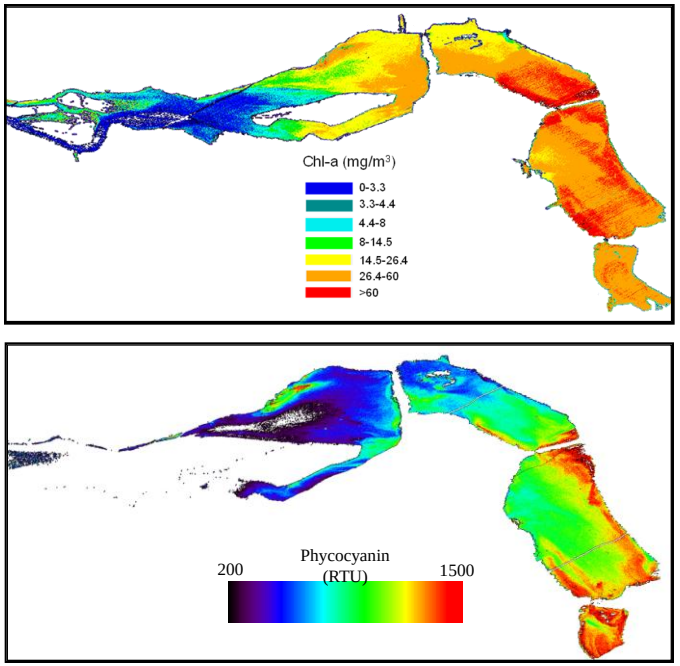
21/09

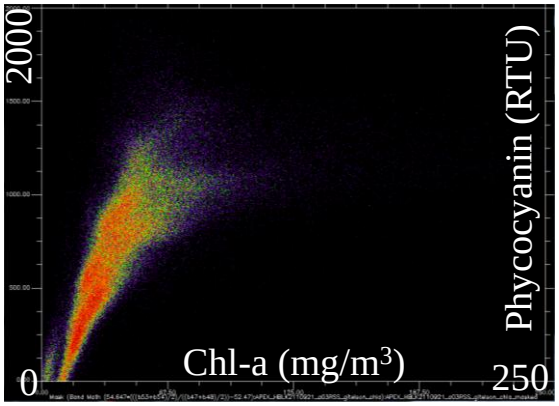




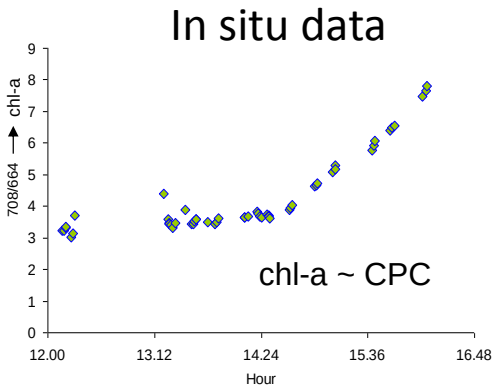
< ~ 200 RFU cyanobacteria are not present

Cyanobacteria analysis (2/2)

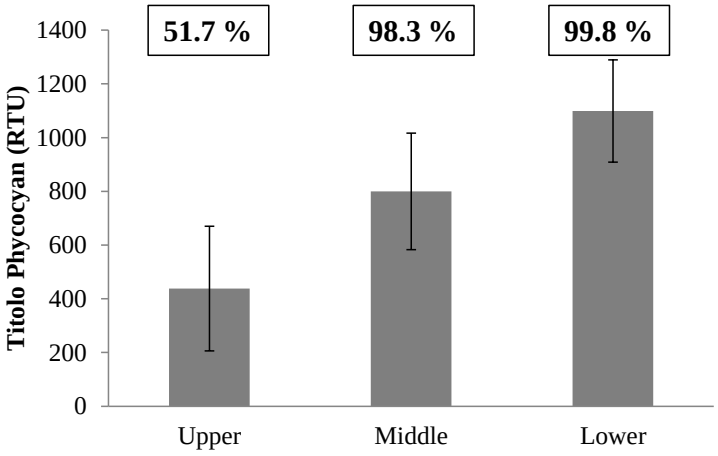


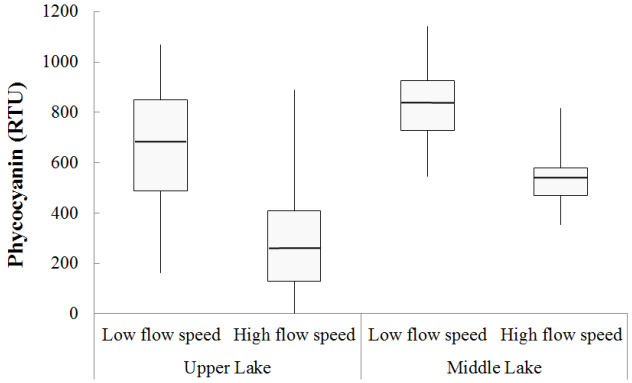


Correlation between Chl-a and Phycocyanin



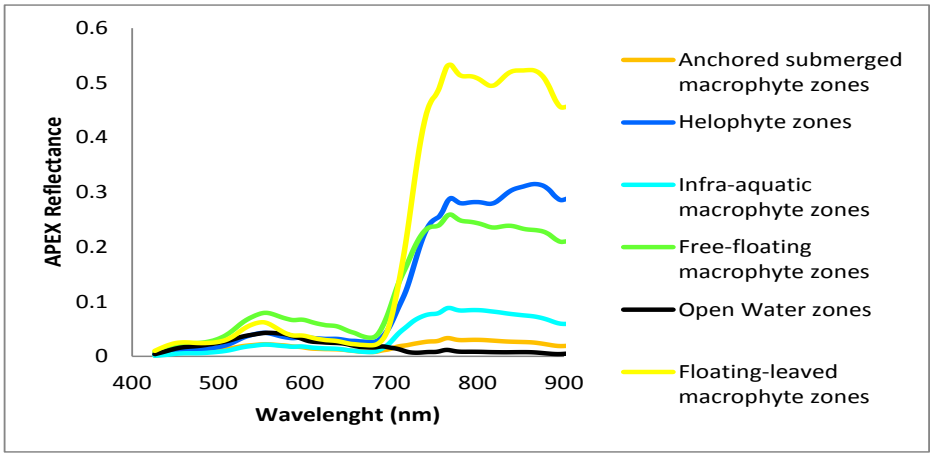
Spatial analysis of distribution of cyanobacteria



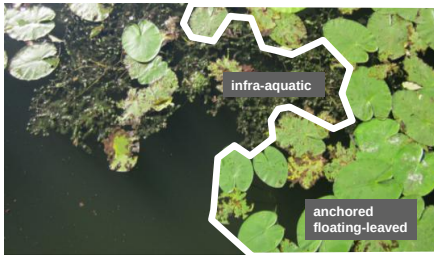


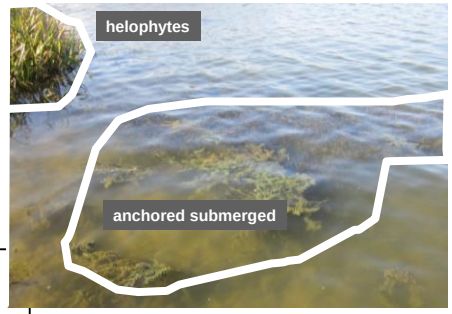
Macrophytes mapping

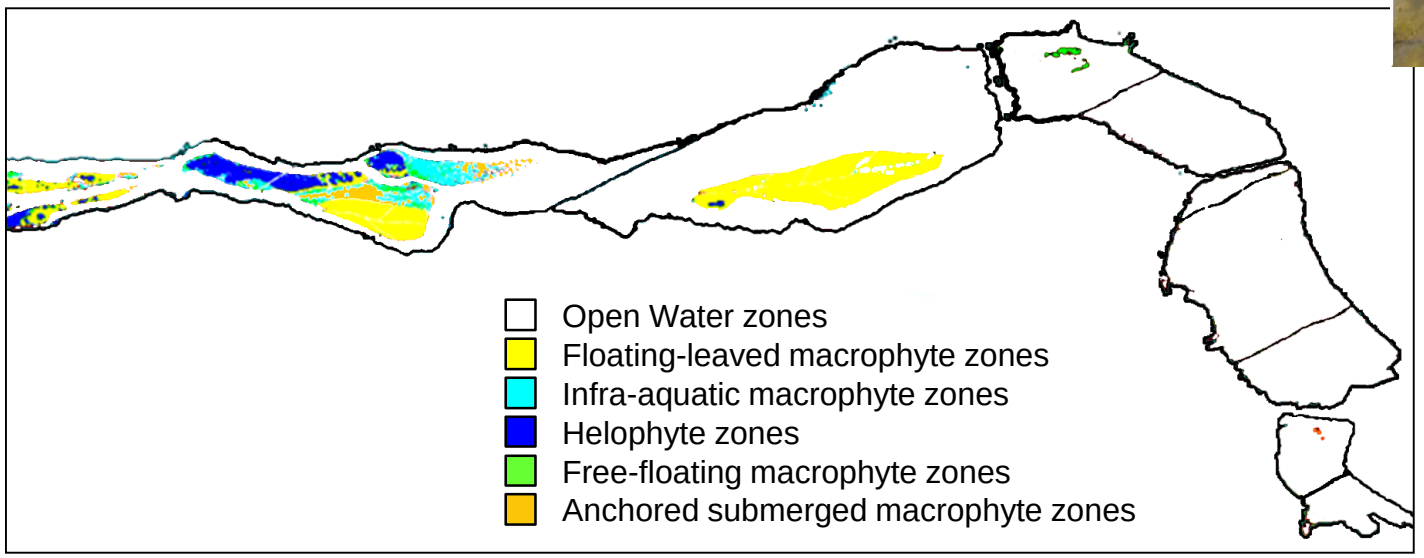
Macrophytes classification (map) was done by identifying in the field 5 classes based on **functional** and **structural** characteristics and by applying the Mahalanobis distance



Differences between classes are also highlighted by the **spectral signatures**



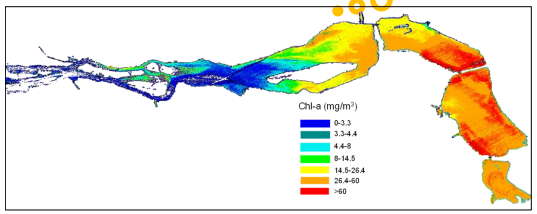


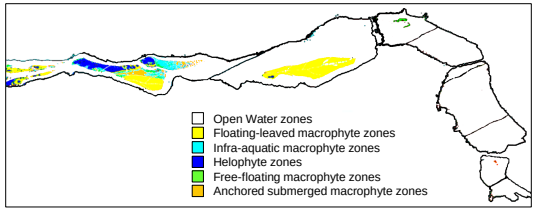


Good accuracy when compared to field data

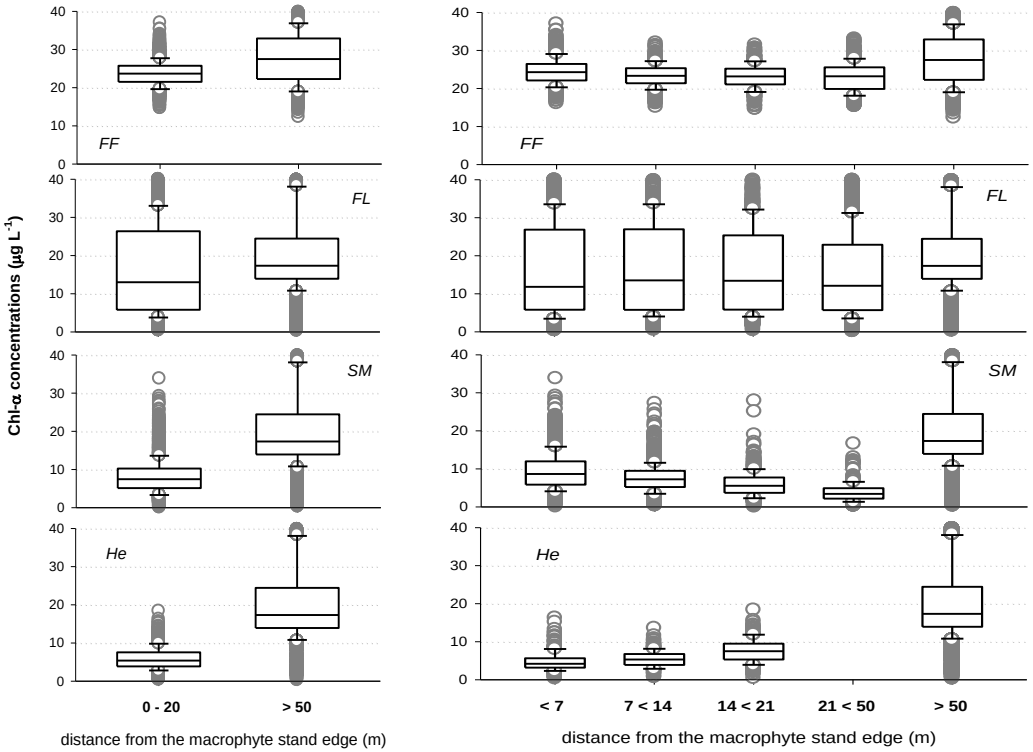
Total accuracy = 80-95%

Macrophyte-phytoplankton co-existance



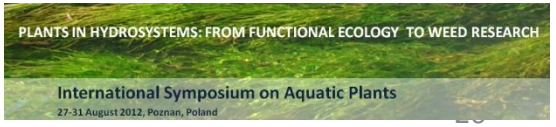


We created a 5 buffer with increasing distance from macrophyte islands



Results show that chl-a concentration increases with the distance from macrophytes because the two are competitors for resources such as light and nutrients. The increase of chl-a concentration is significant for distance greater than 50 m

Results are included in: *Macrophytes and phytoplankton co-existence: a spatial analysis in a shallow, hypereutrophic fluvial-lake system* by Bolpagni, Bresciani, Pinardi, Giardino, Bartoli presented at:



Conclusions

Remote sensing is a useful technique for investigating water quality and macrophytes;

The results of radiometric validation highlight the good radiometric quality of the APEX data; the APEX images allowed us to identify and to quantify the spatial gradients of optical properties of Mantua Lakes;

Semi-empirical algorithm provided better results with respect to the BOMBER for mapping Chl-a concentrations, while for TSM the products obtained with BOMBER are more accurate than the results obtained from the semi-empirical algorithms tested;

Our results confirm that the Mantua Lakes are characterized by high chl-a concentrations and a very high spatial variability. In particular, the Middle and Lower lakes, due to the presence of stagnant water, has a worse water quality (higher chl-a and cyanobacteria concentrations) than the Mincio river and Upper lake.

Future outlook

Testing new semi-empirical algorithms for the retrieval of TSM and CDOM concentrations;

increase the number of IOPs data to ensure a robust and accurate parameterization of the bio-optical modeling;

re-processing the APEX raw data acquired on afternoon 9 September to evaluate the possibility of using also this date;

Moreover, further investigations are needed to improve and refine present results in order to understand the complex mechanisms that modulate the co-existence of macrophytes, macro- and micro-algae and the relations between Chl-a and Phycocyanin.

Acknowledgements

I would like to thank to the Vito team for the possibility to carry out this work and in particular Koen Meuleman for support and Eva Ampe (Vrije Universiteit Brussel) for the help in macrophyte mapping.

Niklas Strombeck for the help in back-scattering data; Rossano Bolpagni (University of Parma) for the ecological data of the macrophytes; Micol Rossini-Roberto Colombo-Sergio Cogliati (University of Milan) for MRI data; Monica Pinardi (University of Parma) and Giuseppe Morabito (CNR-ISE) for scientific support.

This study was co-funded by **CYAN-IS-WAS** (Science and technological cooperation between Italy and the Kingdom of Sweden, Ministero dell'Istruzione, dell'Università e della Ricerca) and **CLAM-PHYM** (Contract ASI I/015/11/0) projects.