European Lakes Under Environmental Stressors
(Supporting lake governance to mitigate the impact of climate change)

EuLakes

Dati di input da immagini satellitari per la creazione di scenari della qualità delle acque dei laghi

Istituto per il Rilevamento Elettromagnetico dell'Ambiente

Mariano Bresciani, Claudia Giardino
CNR-IREA Milano

Gli effetti dei cambiamenti climatici sui grandi laghi europei.

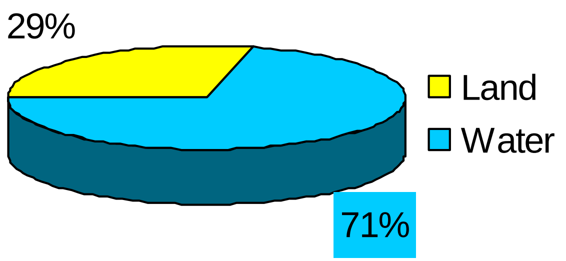
Riva del Garda- September 8, 2011

Presentation outline

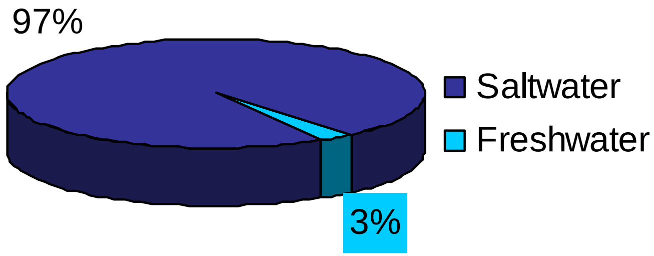
- **Introduction**
- **Applications of remote sensing**
- **EULAKES Project**
- **Focus Garda Lake**

Lake’s overview (cont.)

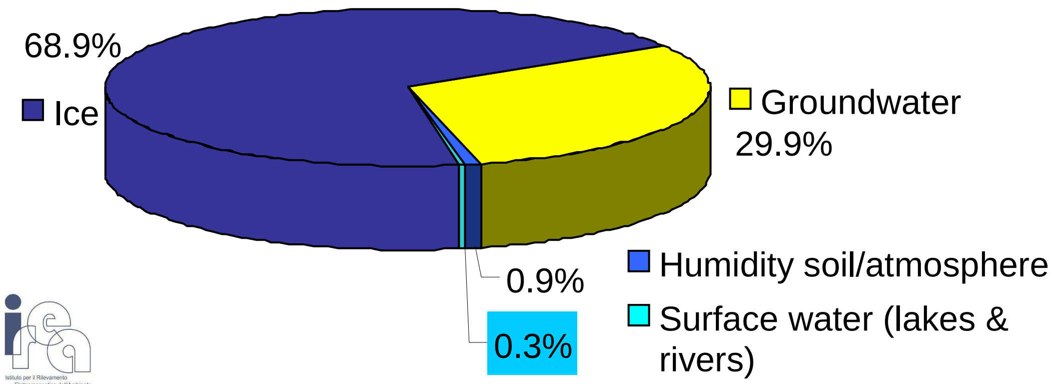
Earth

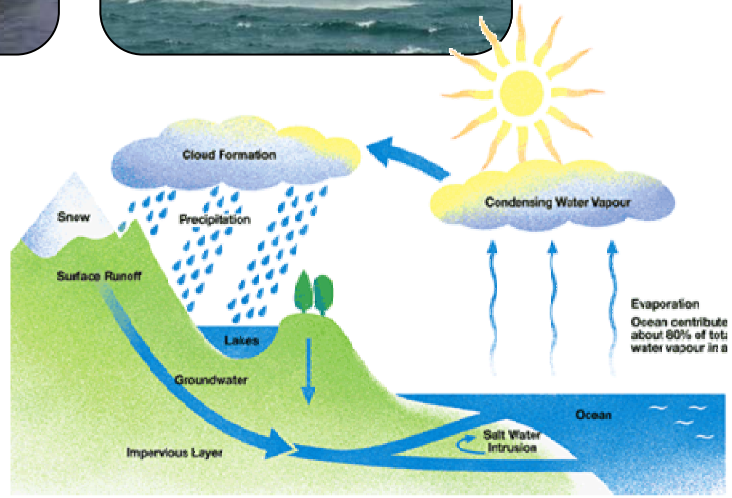


Hydrosphere

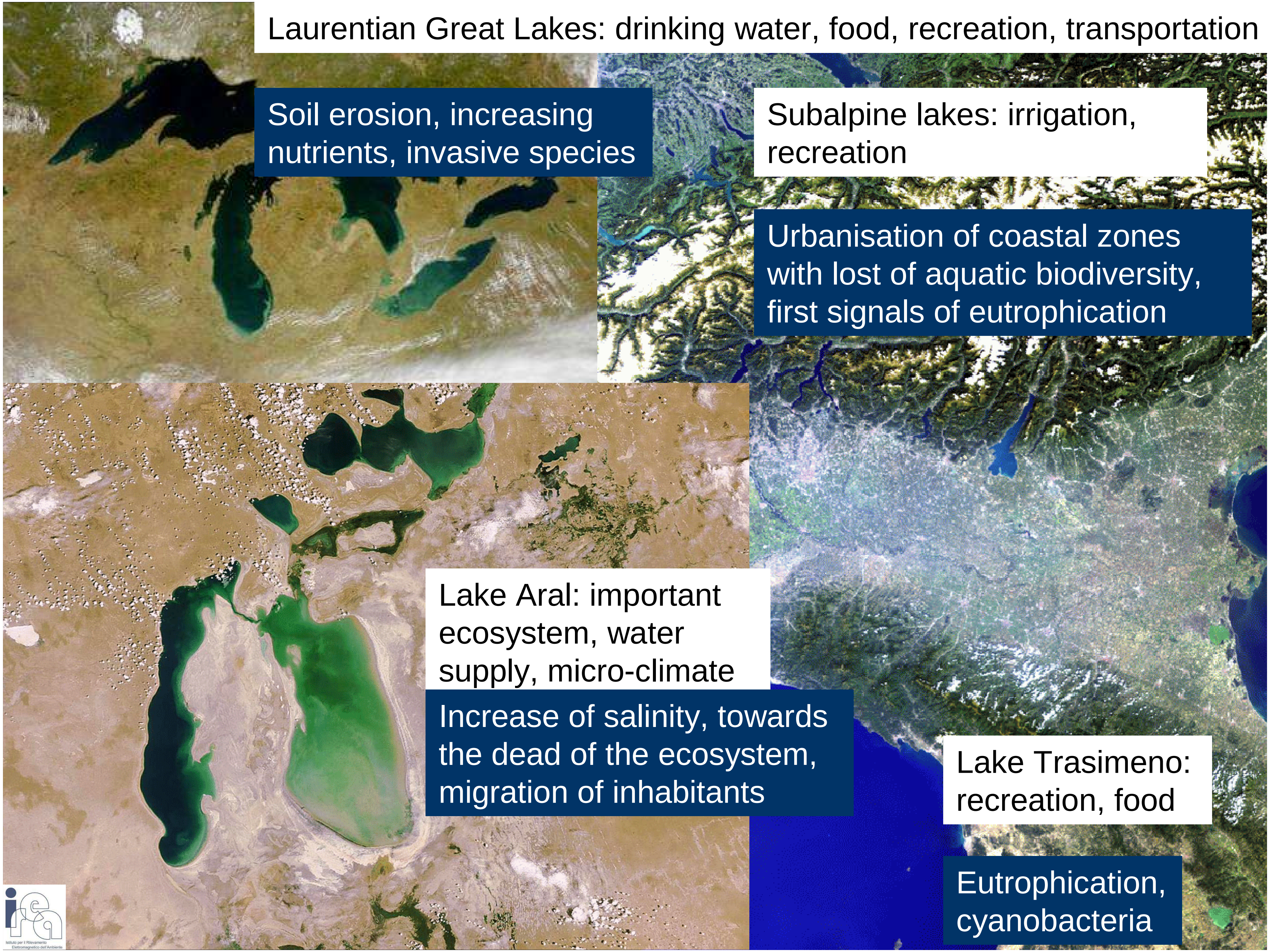


Freshwater

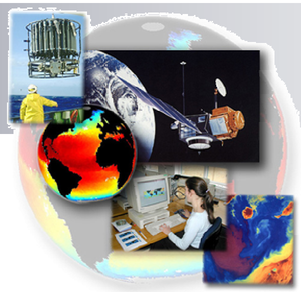




Lakes represent a small but a very important water volumes for the Earth's life

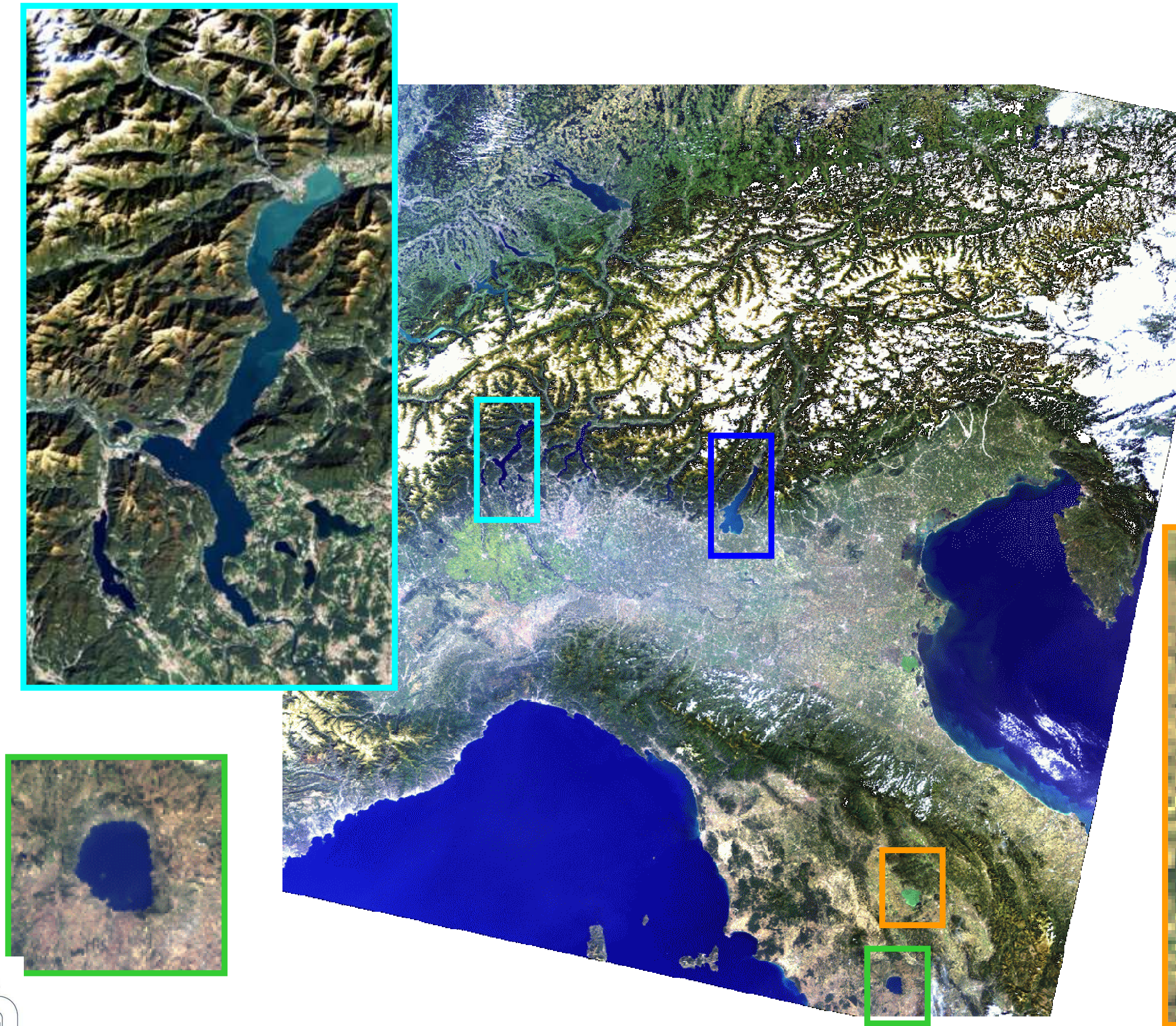

Laurentian Great Lakes: drinking water, food, recreation, transportation
Soil erosion, increasing nutrients, invasive species
Subalpine lakes: irrigation, recreation
Urbanisation of coastal zones with lost of aquatic biodiversity, first signals of eutrophication
Lake Aral: important ecosystem, water supply, micro-climate
Increase of salinity, towards the dead of the ecosystem, migration of inhabitants
Lake Trasimeno: recreation, food
Eutrophication, cyanobacteria

The colour of water

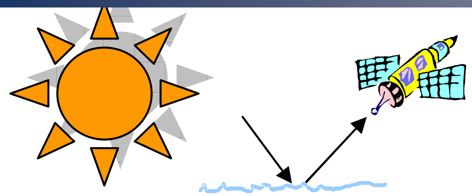


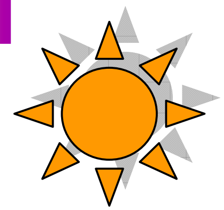
From **ocean colour** remote sensing…

…to **inland/coastal water quality** remote sensing



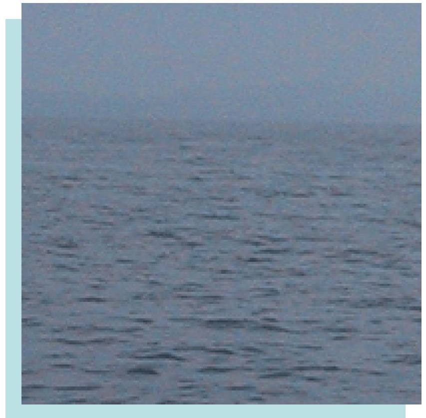
The colour of water



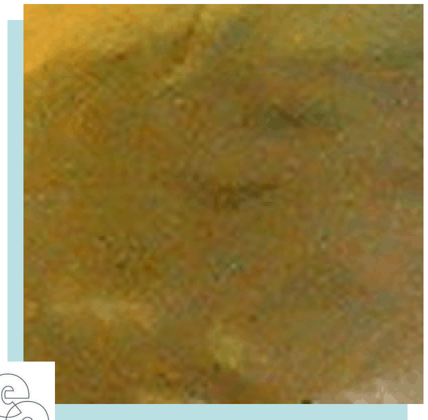


… sun-target-observation geometry

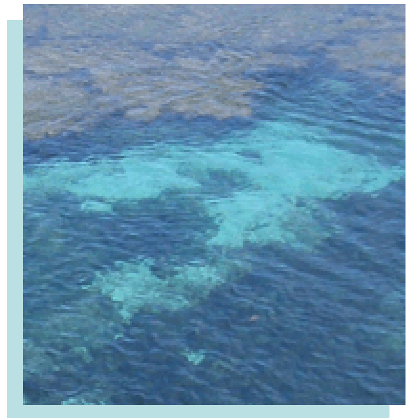
… color of the sky



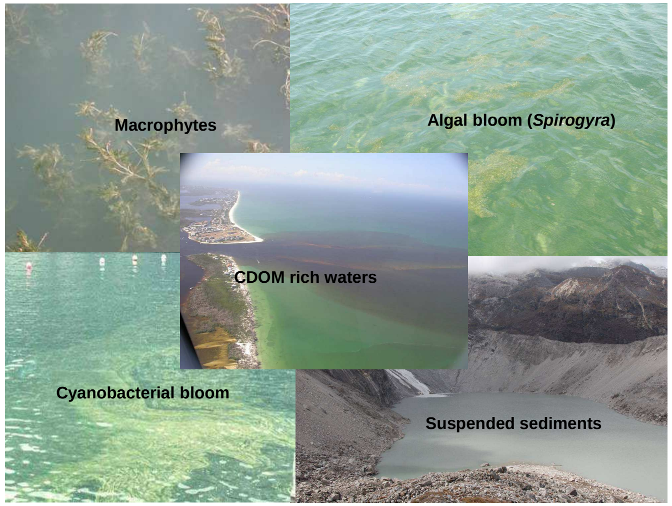
… substances suspended or dissolved into the water



… color of substrates



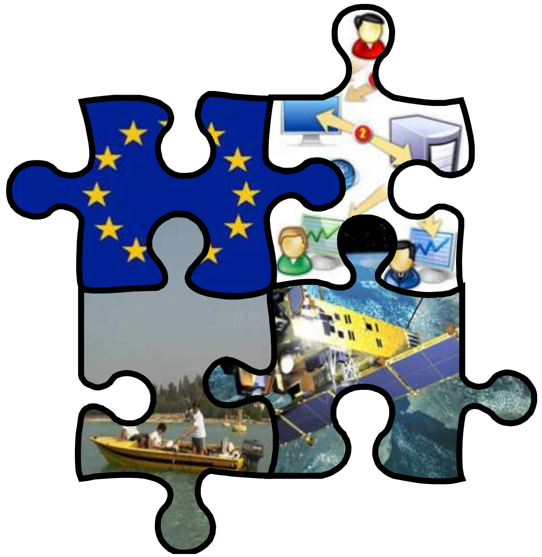
Contribution of remote sensing…



Parameters derivable from satellite imagery

- Green algae pigments mainly as Chlorophyll-a (Chl-a) used as a proxy of phytoplankton biomass.
- Total Suspended Matter (TSM) which is placed in suspension by wind-wave stirring of shallow waters and is a tracer for inflowing pollutants.
- Yellow Substance (YS) which protect the aquatic biota from ultraviolet solar radiation and influence on overall microbial activity in the water column.
- The diffused attenuation as measure for the water transparency in the euphotic zone (Ez) where most of the aquatic life occurs.
- The cyanobacterial pigment phycocyanin, potentially associated to harmful algal blooms.
- Macrophyte
- Temperature

High observation frequency in space and time
Basin Scale (synoptic observation)
High ratio cost/benefit



Remote sensing of lakes

Since the ‘80s, satellite remote sensing represents an opportunity for synoptic and multitemporal viewing of water quality of lakes.

Landsat/Airborne ...+ MODIS + MERIS + AVNIR2

the ’80s… ….beyond the 2000

High spatial resolution
Low temporal resolution

Data used to:

- perform **preliminary investigation** of **optical properties** of **lakes**
- **map water quality** (but not continuously, at that time Landsat data were very expansive!)

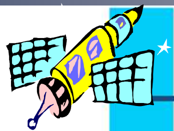
High spatial resolution
Low spatial resolution
High temporal resolution

Data used to:

- **investigate** of **optical properties** of **lakes**
- **mapping** and **monitoring** water quality
- perform **retrospective analysis** (with Landsat free archives!)

Sensors (cont)

ASTER 29/07/00

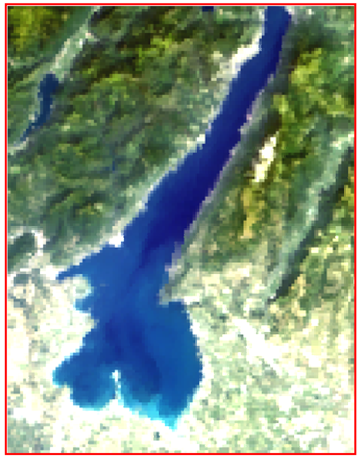


	Satellite - sensor	Pixel size (m)	Repetion rate	Channles VIS-NIR
Land	Quickbird	0.61/2.44	1-3.5	1/4
	Ikonos	1/4	2-3	1/4
	GeoEye	0.41/1.65	< 3 d	5
	SPOT HRG/HRS	2.5/10	> 2 w	1/4
	Terra ASTER	15	16 d	3
	Landsat	15/30	16 d	1/6
	EO1 ALI	30	4-16 d	6
	EO1 Hyperion	30	4-16	220
Water	Envisat MERIS	300	2 d	15
	IRS OCM-2	350	2 d	8
	Terra/Aqua MODIS	250/500/1000	1 d	13
	SeaWiFS	1000	2 d	8
Radar	Radarsat SAR	10-100	5-24 d	1
	ERS-1, 2 SAR	30	1-4 w	1
	Envisat ASAR	15-100	1-4 w	1

MIVIS 27/07/05

Airborne

MIVIS-CNR (102, 0.4-2.5+TIR)
HyMap-DLR (prog., 0.4-2.5)
APEX- BE, CH (300, 0.4-2.5)
AISA (prog., 0.4-2.4)
CASI (prog., 0.4-1.0)



MERIS 23/07/04

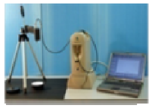
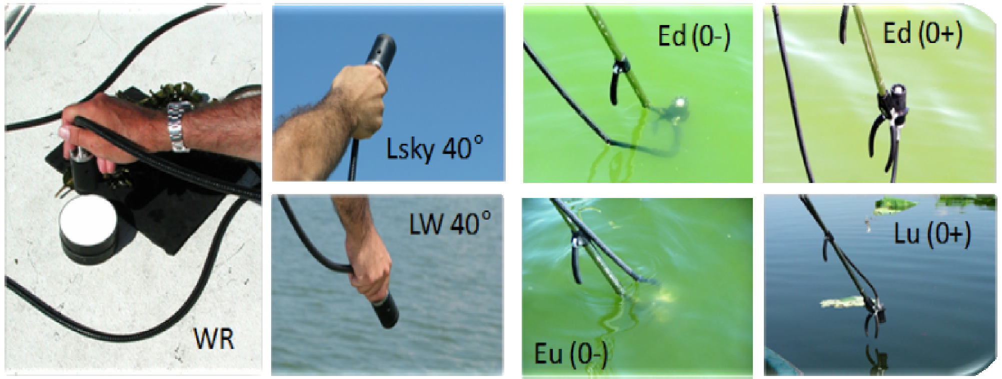
Hyperion 22/07/03

In situ measurements

- Limnological data
- Inherent optical properties
- Apparent optical properties

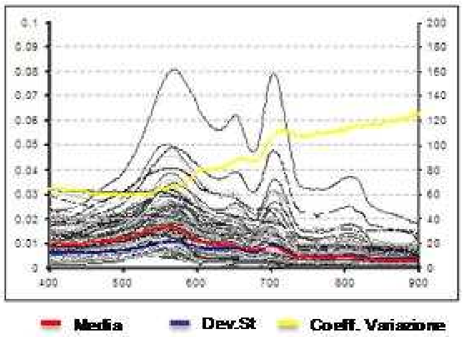




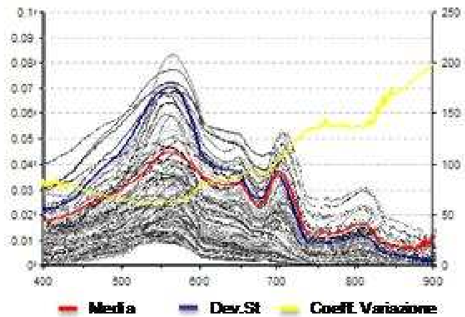
Remote sensing reflectance Rrs

$$R_{rs}(\vartheta,\phi,\lambda)=\frac{L_u(0^+,\vartheta,\phi,\lambda)}{E_d(0^+,\lambda)}$$



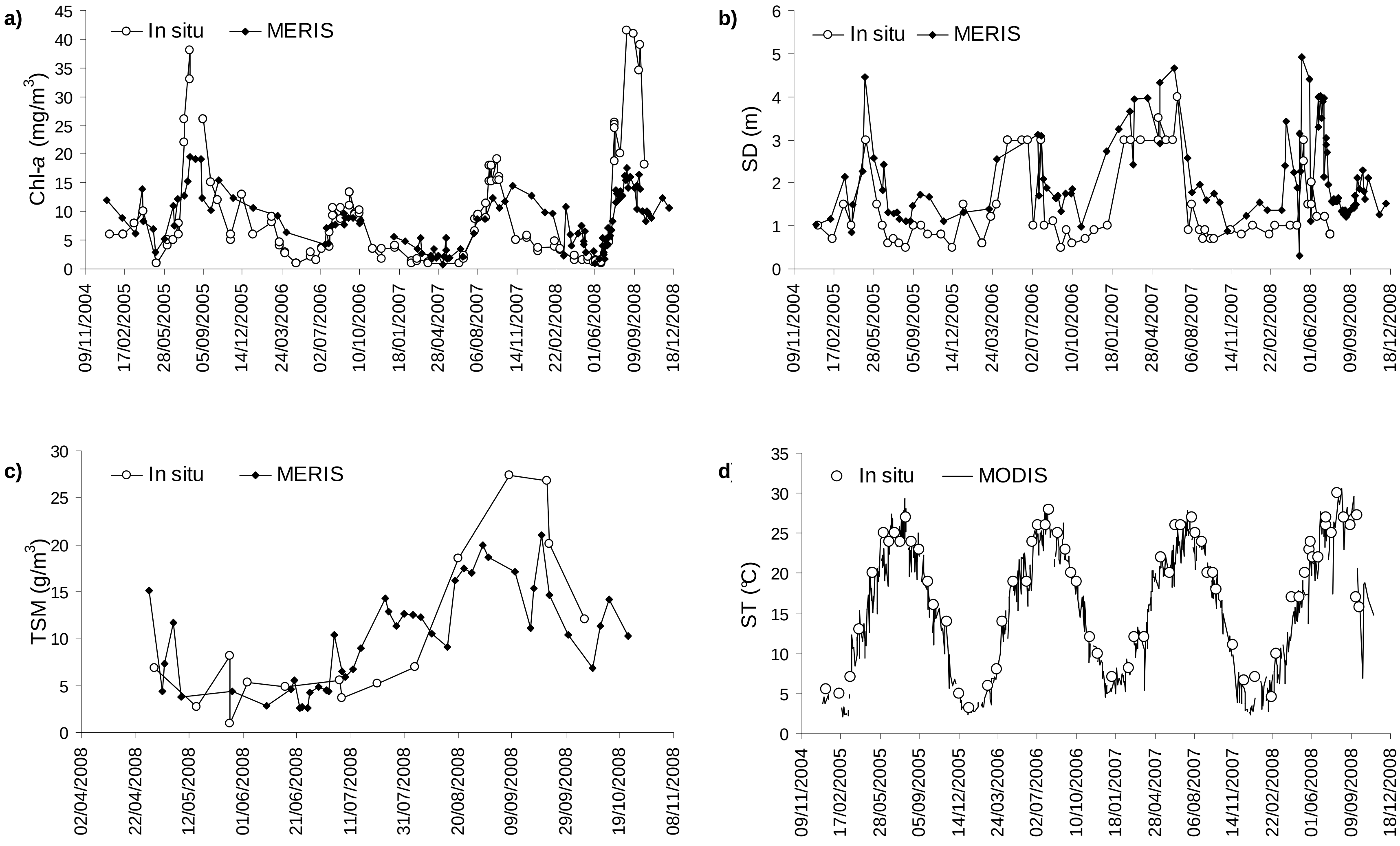
Subsurface irradiance reflectance R(0-)

$$R(0-,\lambda)=\frac{E_u(0^-,\lambda)}{E_d(0^-,\lambda)}$$

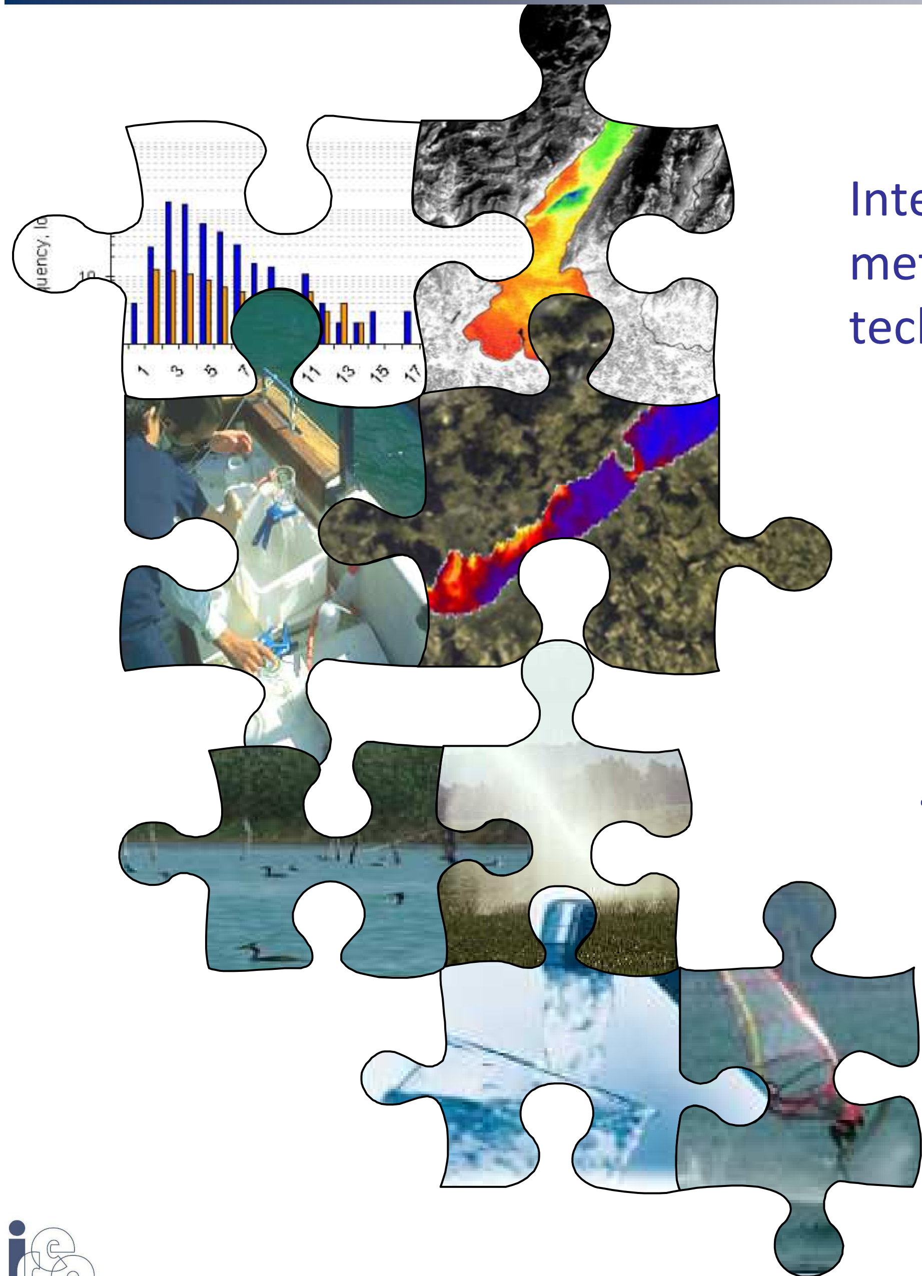


Validation

- Therefore it is a **significant result** when **satellite**-derived products **match** traditional **in situ** measurements **!!!**



Applications



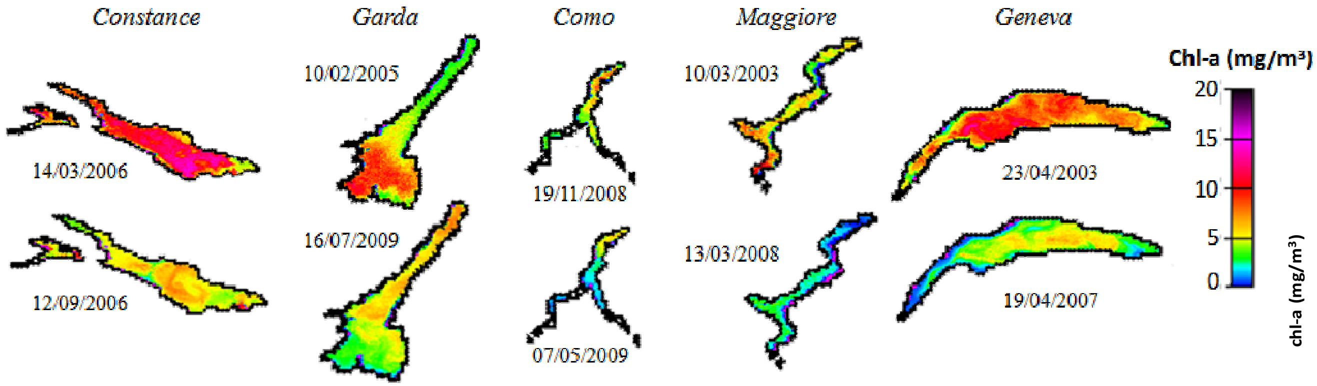
Integration of traditional methods with EO-related technologies…

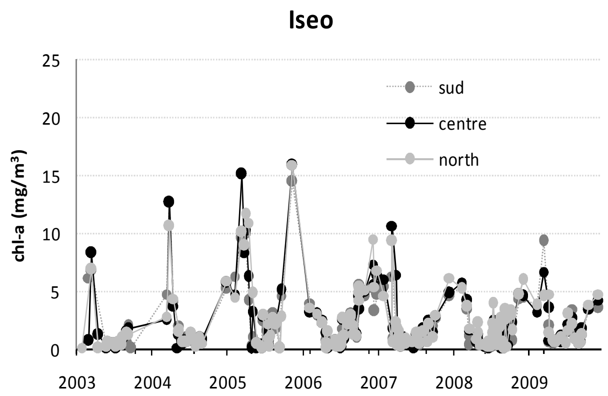
…to provide useful data for improving and preserving lake waters

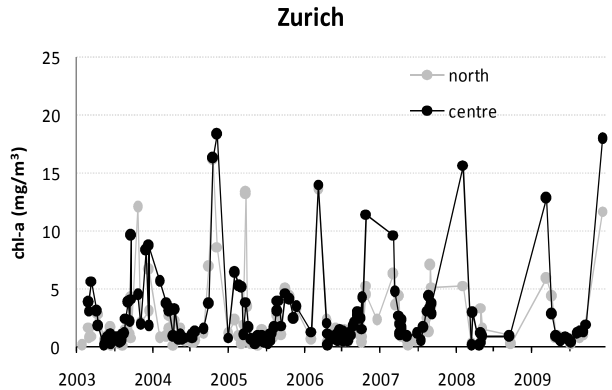
User needs

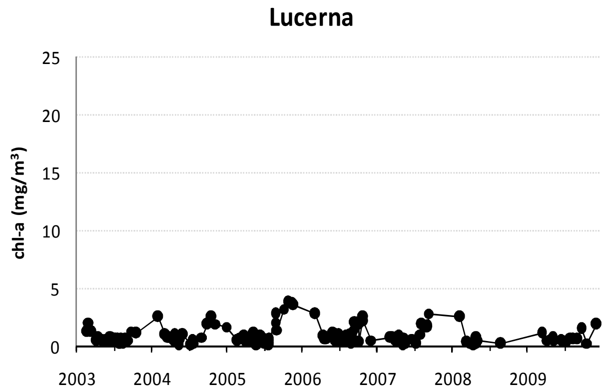
Riva del Garda- September 8, 2011

Monitoring water quality parameters in **cost effective** way with respect to traditional sampling



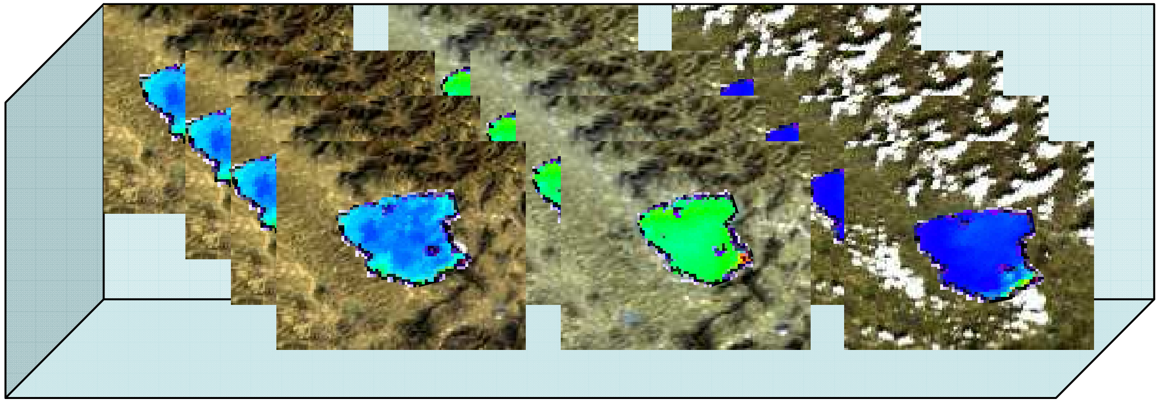


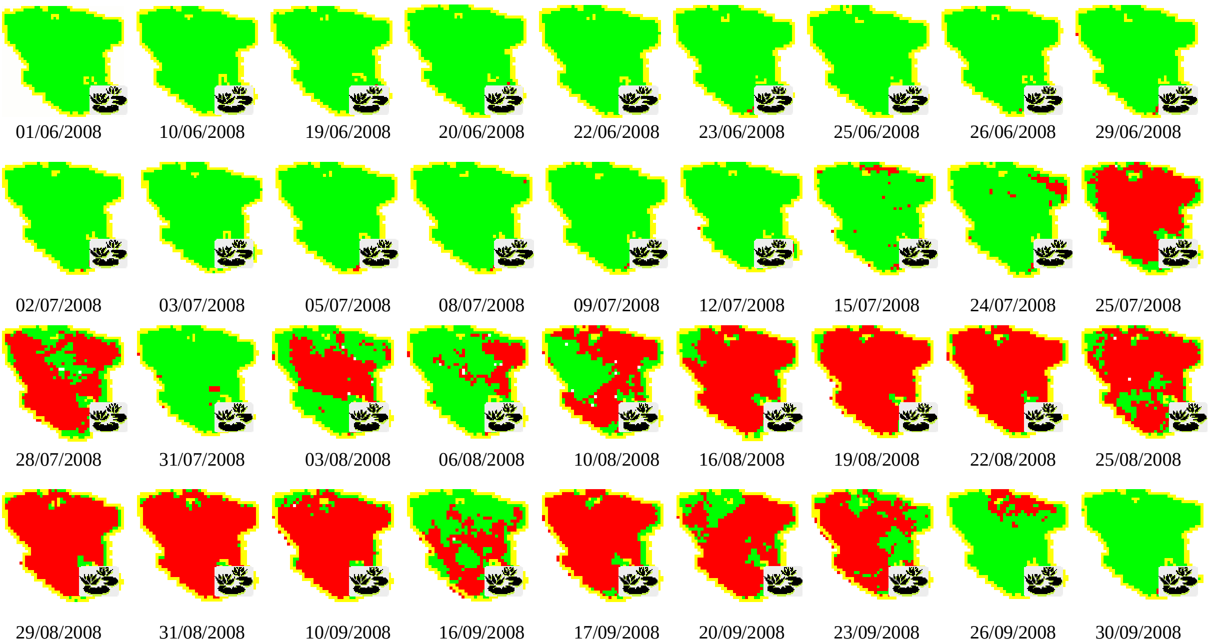




User needs

Generation of **handy information** about the **status of lake**





Chl-a < μ+σ (13 mg/m^3)   Chl-a > μ+σ (13 mg/m^3)

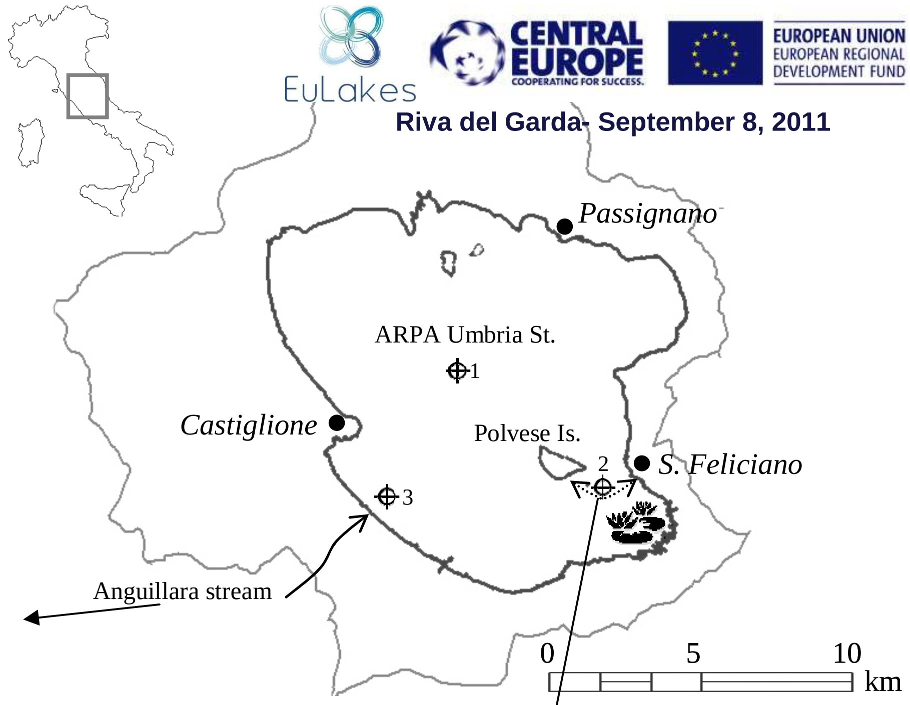
2005	2006	2007	2008
03/01/2005	10/01/2006	05/01/2007	25/01/2008
01/02/2005	15/03/2006	03/02/2007	13/02/2008
17/03/2005	04/04/2006	04/03/2007	13/03/2008
02/04/2005	14/07/2006	13/03/2007	19/03/2008
05/04/2005	17/07/2006	16/03/2007	29/03/2008
01/05/2005	23/07/2006	07/04/2007	01/04/2008
07/05/2005	30/07/2006	11/04/2007	20/04/2008
29/05/2005	08/08/2006	17/04/2007	27/04/2008
21/06/2005	30/08/2006	23/04/2007	02/05/2008
24/06/2005	31/08/2006	27/04/2007	03/05/2008
03/07/2005	03/09/2006	09/05/2007	06/05/2008
19/07/2005	12/09/2006	13/05/2007	09/05/2008
26/07/2005	22/09/2006	19/05/2007	28/05/2008
01/08/2005	08/10/2006	22/05/2007	01/06/2008
17/08/2005	11/10/2006	25/05/2007	10/06/2008
30/08/2005	02/11/2006	23/06/2007	19/06/2008
02/09/2005		29/06/2007	20/06/2008
24/09/2005		18/07/2007	22/06/2008
16/10/2005		25/07/2007	23/06/2008
20/11/2005		28/07/2007	25/06/2008
		06/08/2007	26/06/2008
		26/08/2007	29/06/2008
		13/09/2007	02/07/2008
		02/10/2007	03/07/2008
		15/10/2007	05/07/2008
		03/11/2007	09/07/2008
		21/12/2007	12/07/2008
			15/07/2008
			24/07/2008
			25/07/2008
			28/07/2008
			31/07/2008
			03/08/2008
			06/08/2008
			10/08/2008
			16/08/2008
			19/08/2008
			22/08/2008
			25/08/2008
			29/08/2008
			31/08/2008
			10/09/2008
			16/09/2008
			17/09/2008
			20/09/2008
			23/09/2008
			26/09/2008
			30/09/2008

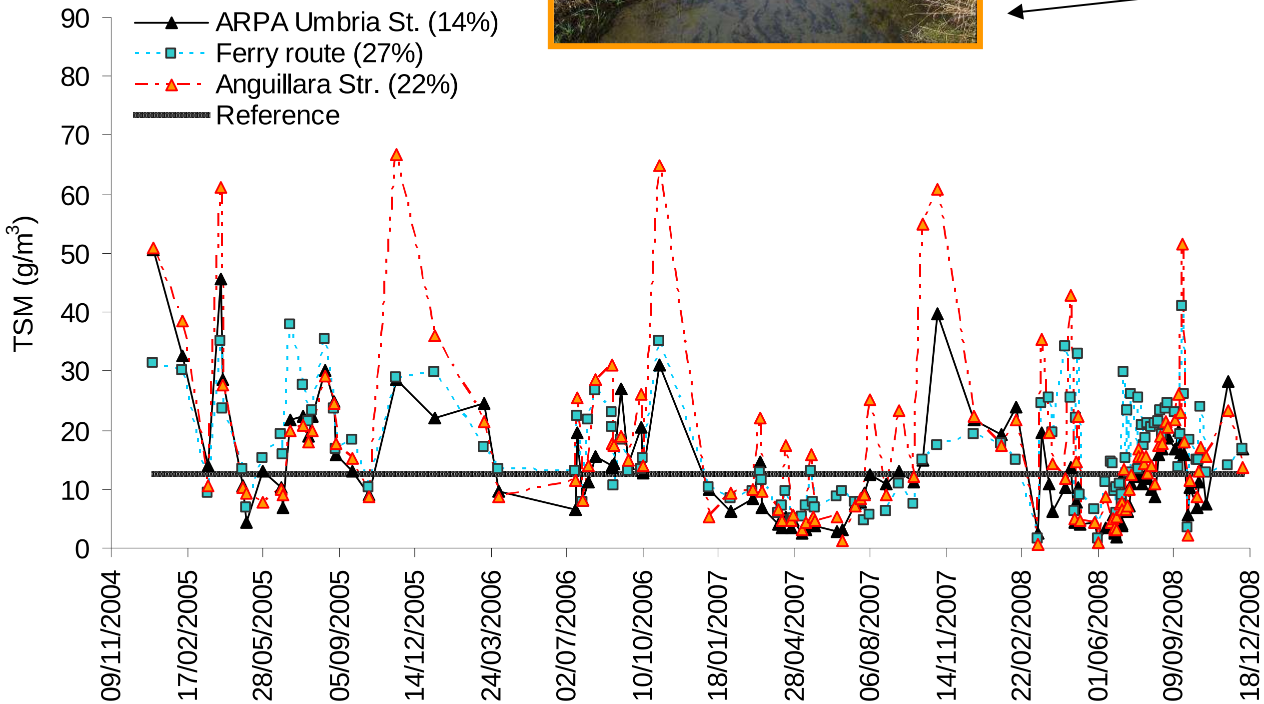
TSM < μ+σ (20 g/m^3)

TSM > μ+σ (20 g/m^3)

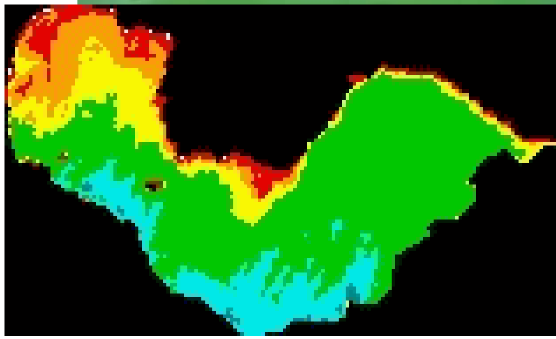
User needs

Supporting the **definition** of **strategic locations** of in situ stations

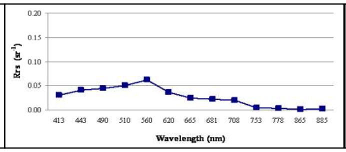
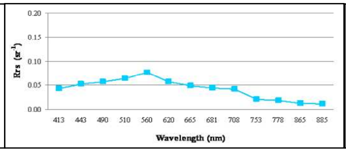
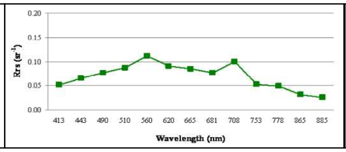
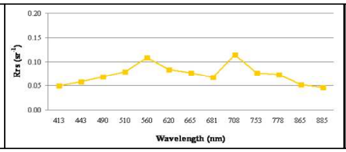
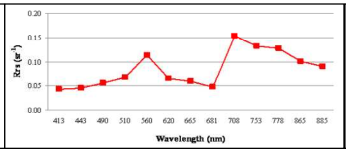




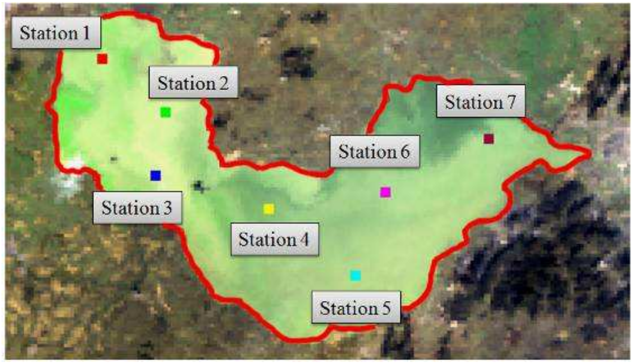
User needs - Water authority

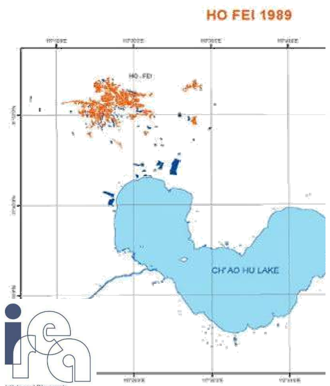


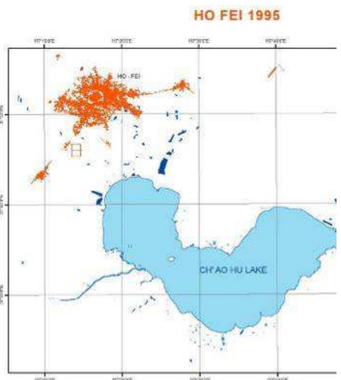
Assessing **spatial/temporal dynamics** of poor-quality waters

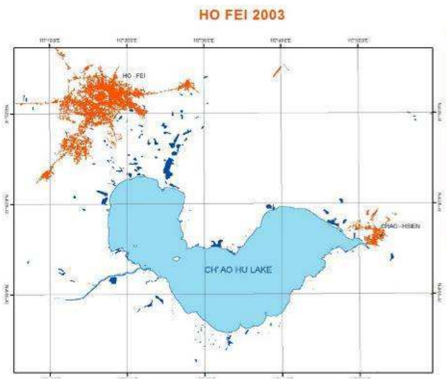
A		Rrs spectrum of clear waters	Water typical of oligo-mesotrophic status, with regard chlorophyll-a concentration. According to “Blue-Green Algae Bloom Emergency Preplan for Chaohu Urban Drinking Water Source” these waters could be used for drinking after the treatment.
B		Rrs spectrum associated to phytoplankton absorption. Nevertheless, the shape is still more typical of clear than turbid waters	Mesotrophic status with tendency to eutrophic conditions.
C		Rrs spectrum of productive waters, where the absorption due to phytoplankton is noticeable.	Water typical of meso-eutrophic status, with regard chlorophyll-a concentration. In this condition a elevated level of attention is suggested for drinking.
D		Rrs spectrum of productive turbid waters	Eutrophic status with tendency to ipertrophic conditions.
E		Rrs spectrum of productive and very turbid waters	Water typical of very productive waters in ipertrophic status, with regard chlorophyll-a concentration. In this condition a serious level of attention is suggested for any use of lake waters.

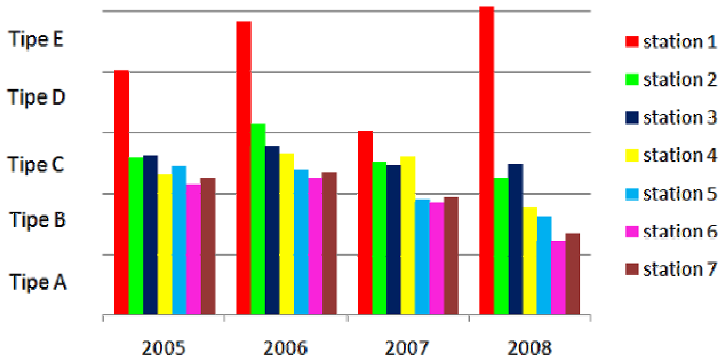
20040520







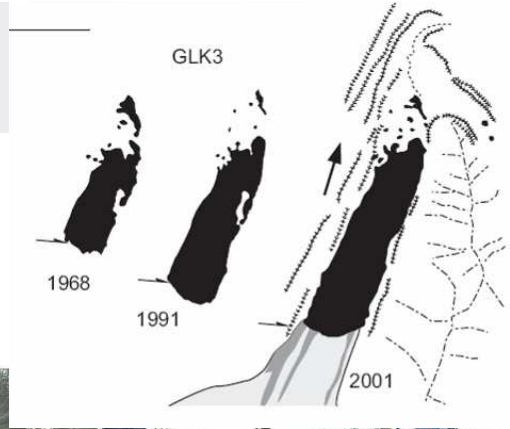


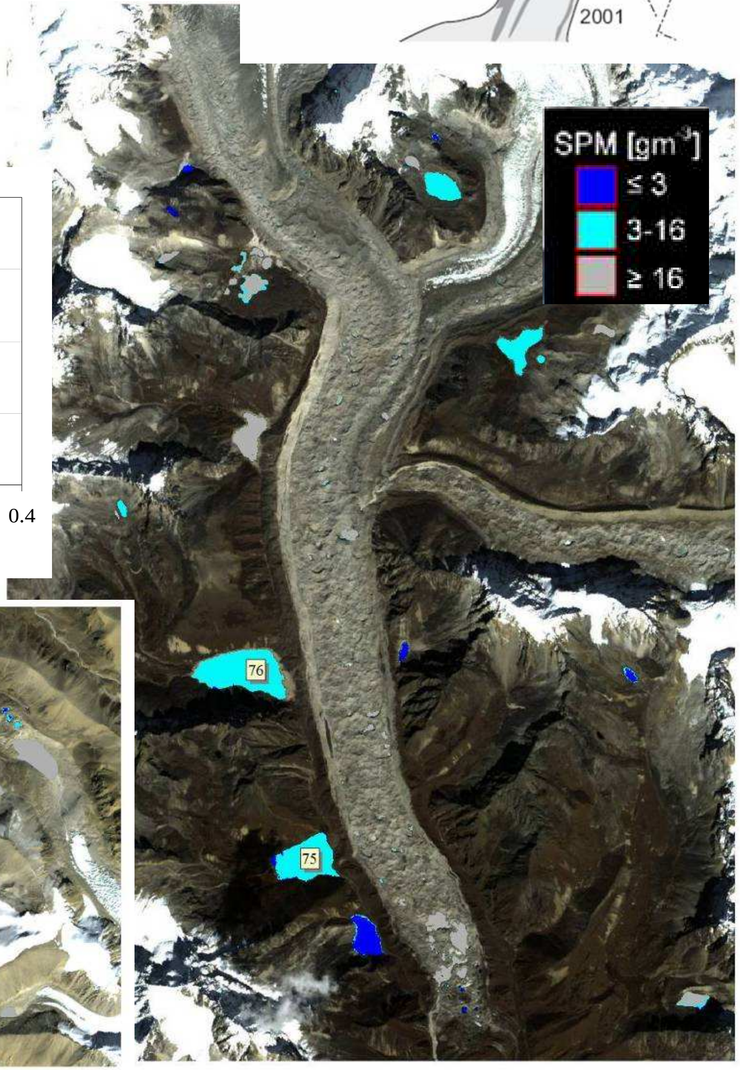


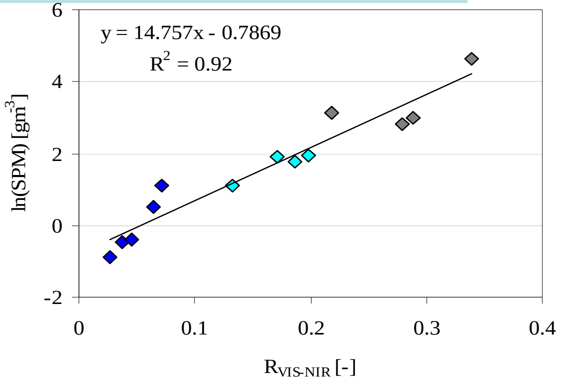
User needs – Glaciologist/climatologist

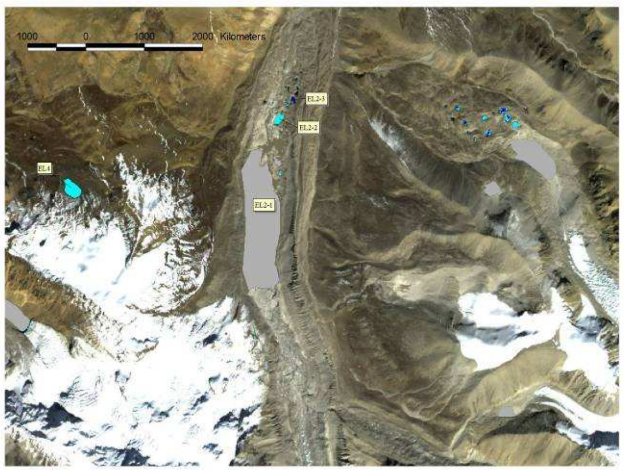
Detection of **moraine-dammed lakes**, whose morphological variations are essential indicators of **deglaciation processes**

Then, sudden discharge of large volumes of water with debris from some of these lakes may also cause **glacial lake outburst floods** (GLOFs) in valleys downstream

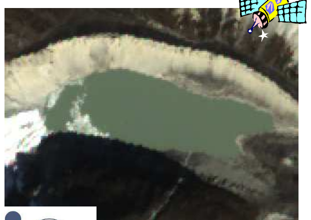








ALOS-AVNIR2 | **In situ**



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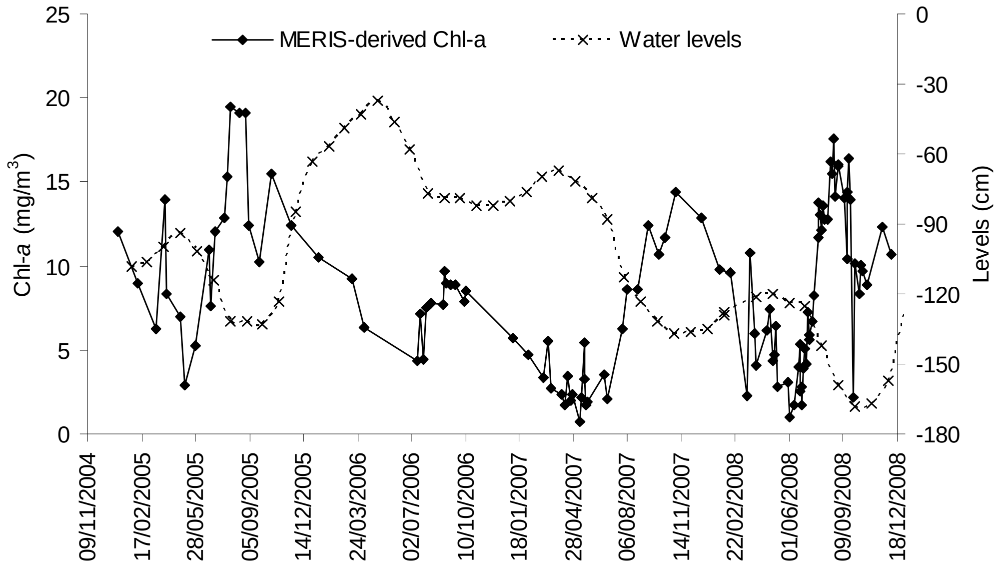
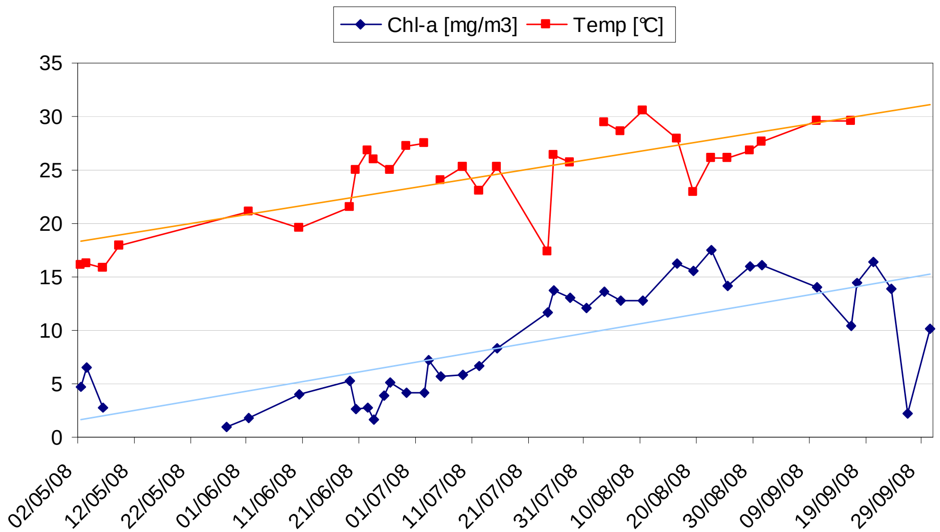
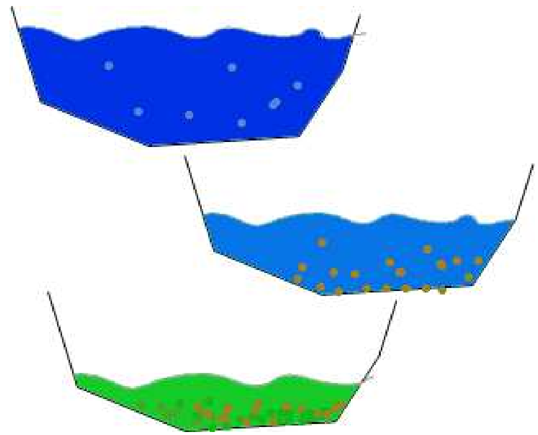
Providing some info to explain the **dynamics** of **natural phenomena**





Natural eutrophication

→ Increase of chlorophyll-a concentration for diminishing water levels



→ Increase of chlorophyll-a concentration with water temperature

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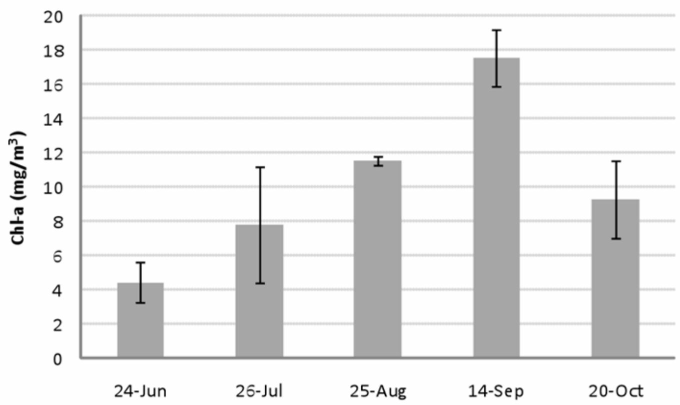
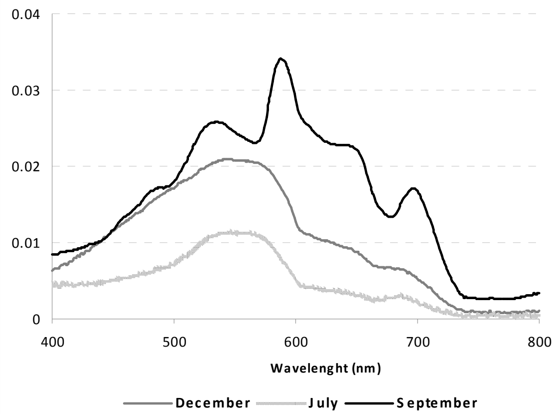
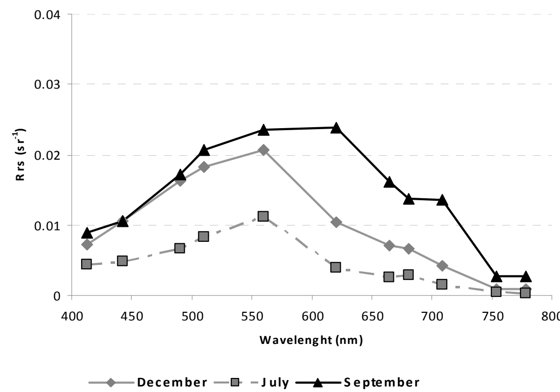
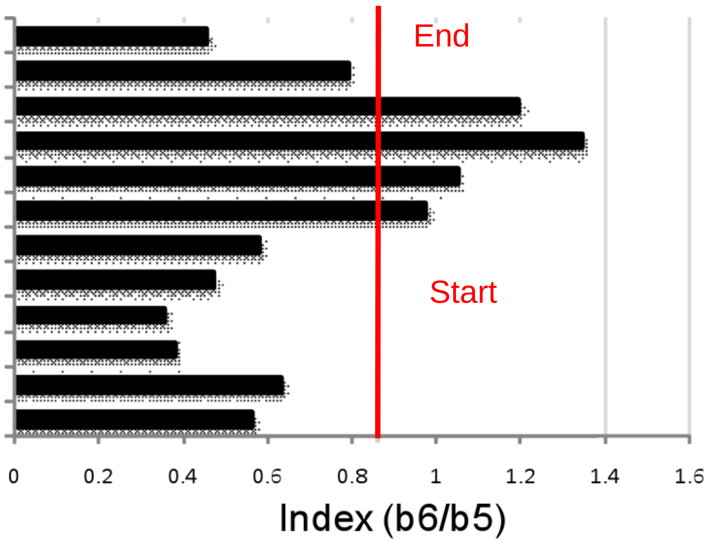
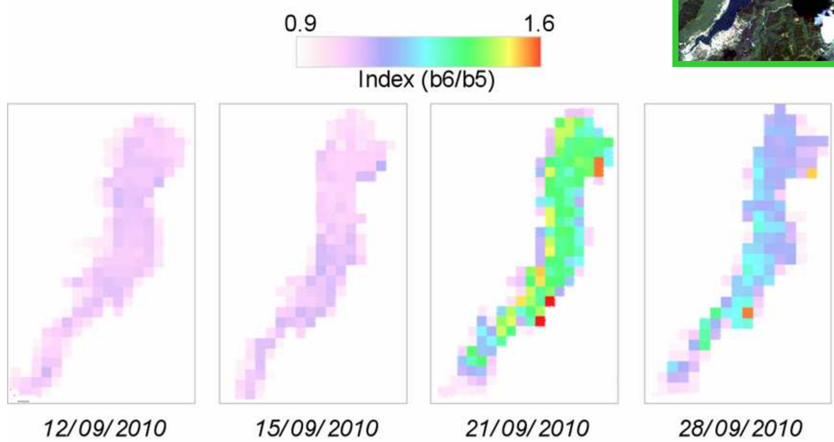
Detection of **starting/ending** phase of **algal bloom**











User needs - Citizen/tourist

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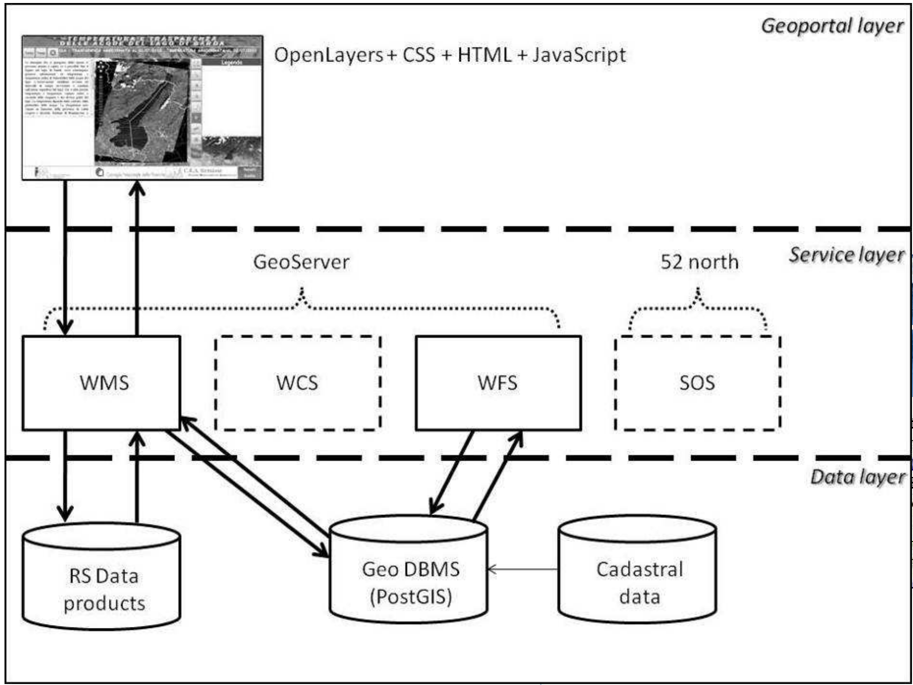
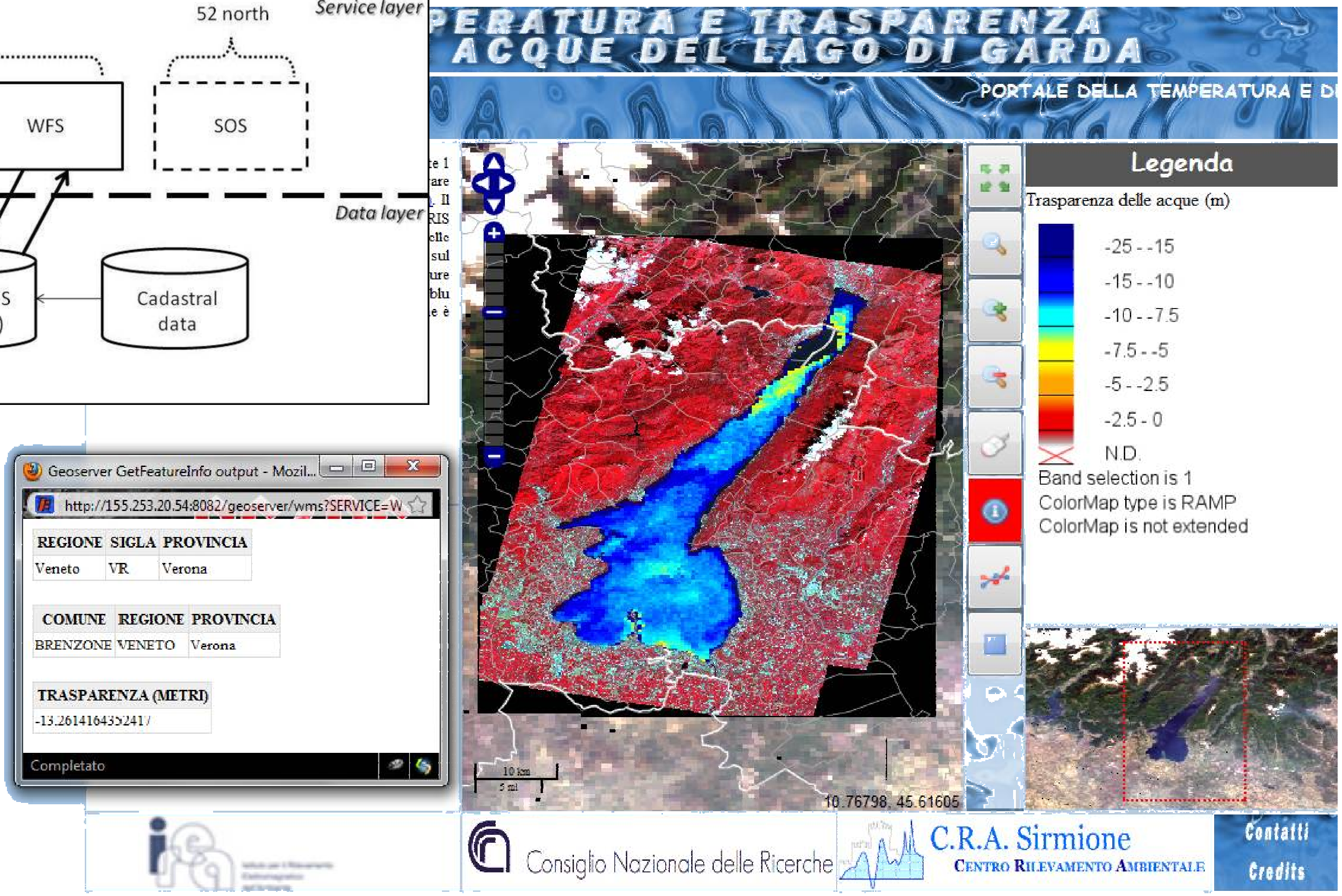
Dissemination of information for **recreational** uses of lakes



e.g. finding warmer and clearer waters



User needs – Multitemporal analysis

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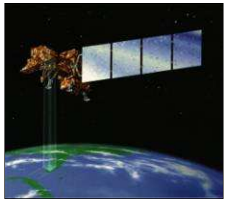
TERRA/ASTER

Tunisia,

LaKe Ichkeul.

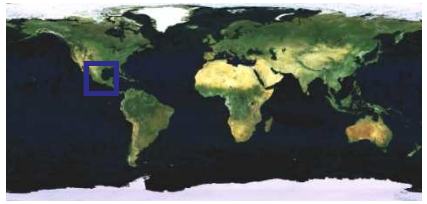
User needs – Multitemporal analysis



LANDSAT TM/ETM+

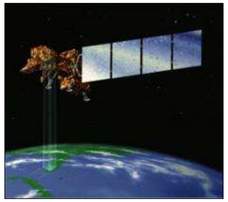
March 28, 1986

March 29, 2001



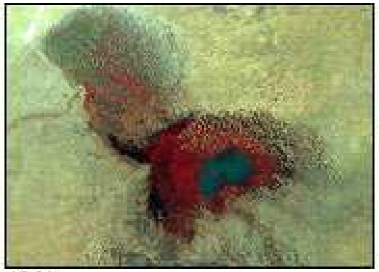
Messico,
Lake Chapala.

User needs – Multitemporal analysis



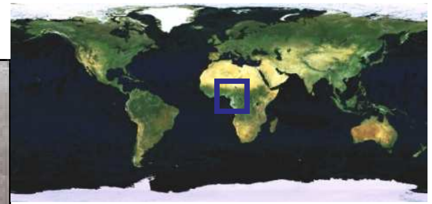
LANDSAT TM/ETM+

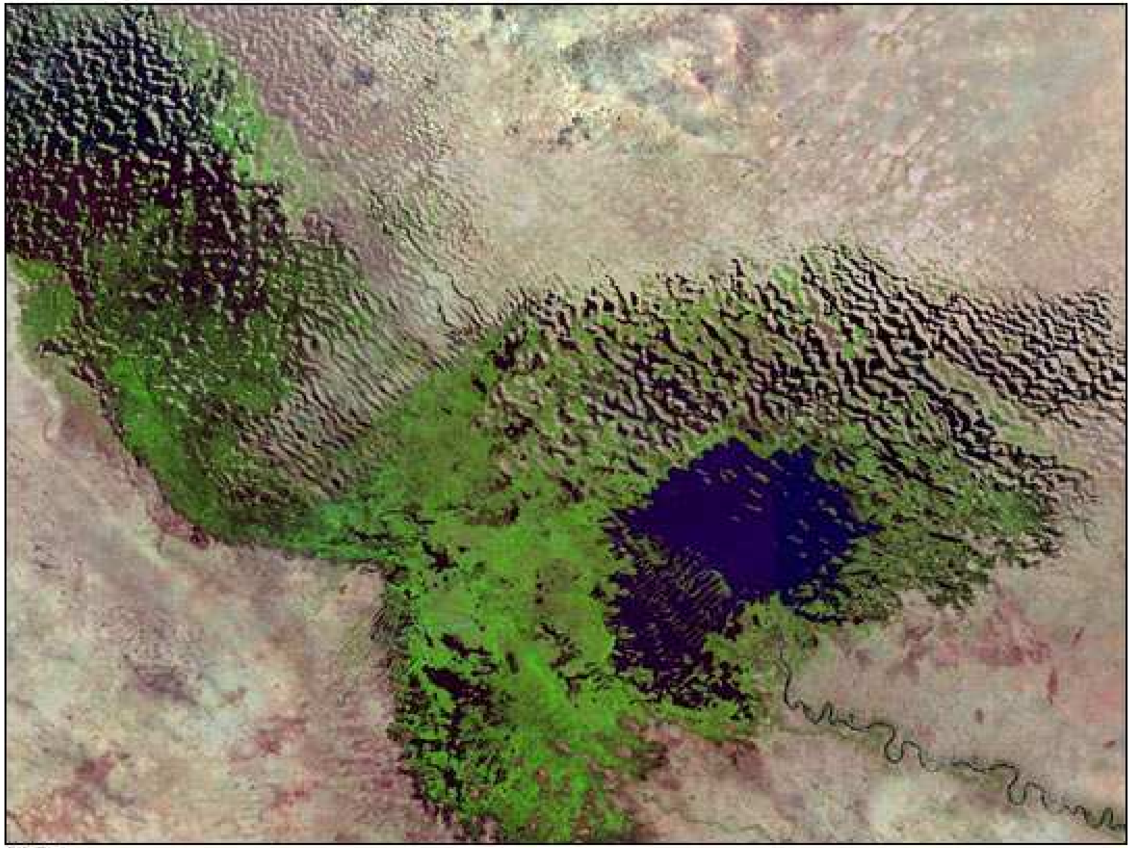
1973



1987

1997





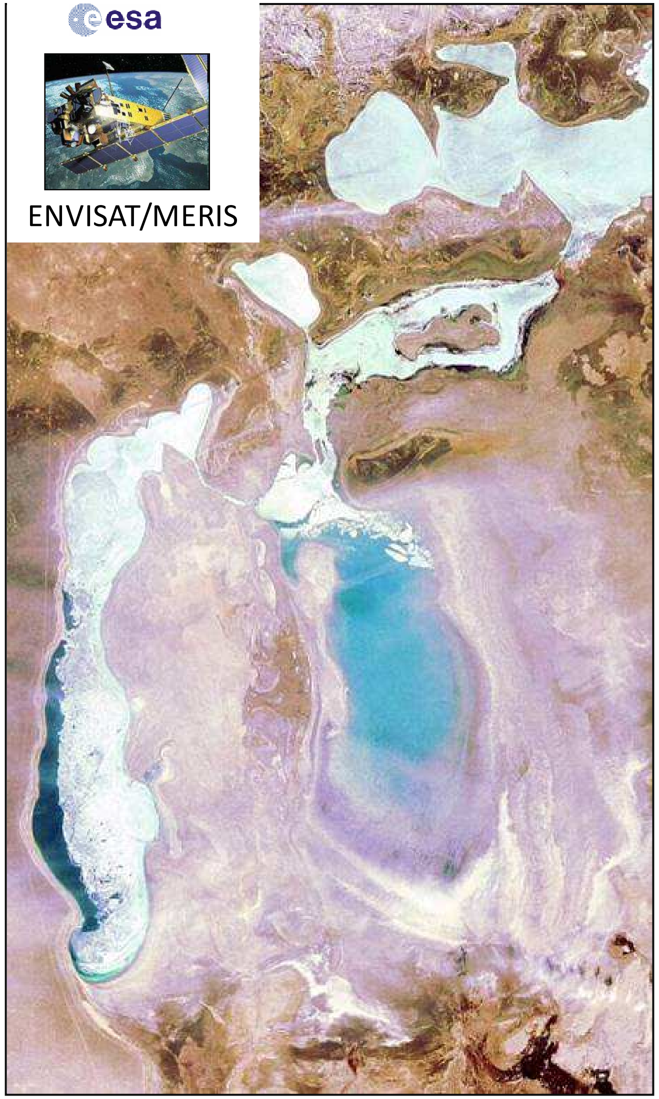
2001

Ciad,
Lake Ciad.

User needs – Multitemporal analysis

July - September, 1989

August 12, 2003

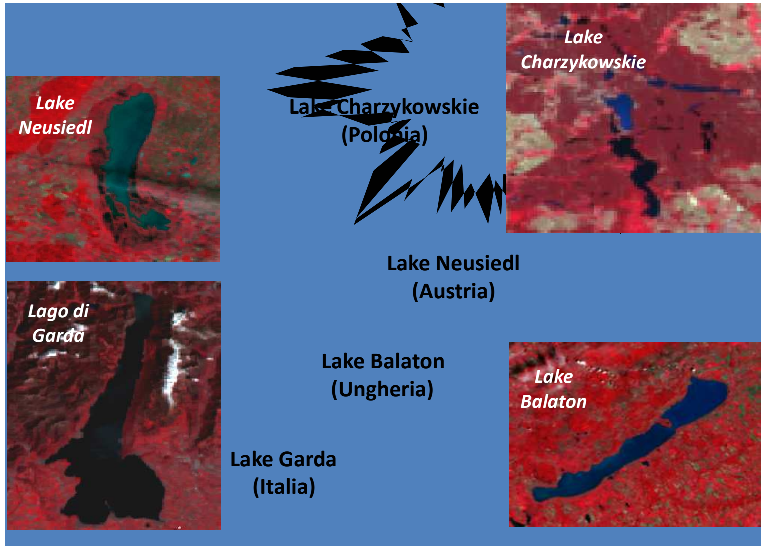


March 6, 2008

Lake Aral.

Eulakes Project

Riva del Garda- September 8, 2011

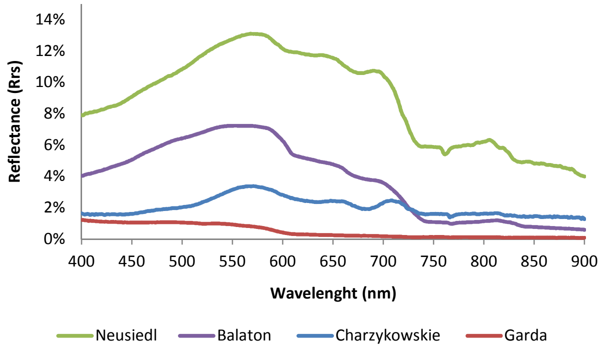


An integrated study merging satellite-derived products and in-situ data, to derive synoptic, transboundary and consistent information of water quality of targets lakes.

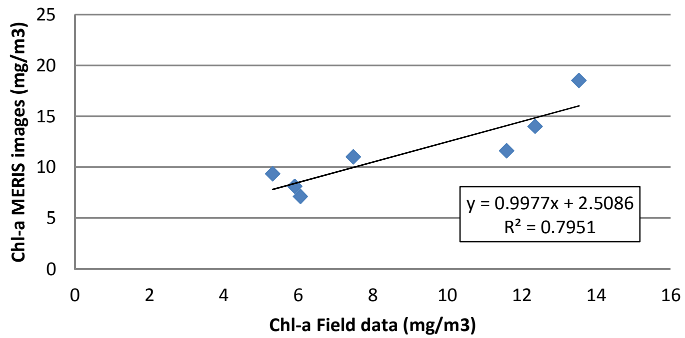
The analysis will be focused on the assessment of optical parameters in the euphotic layers, on the detection macrophyte and algal bloom events and on surface water temperature monitoring.

Field campaigns:

Radiometric
Limnological



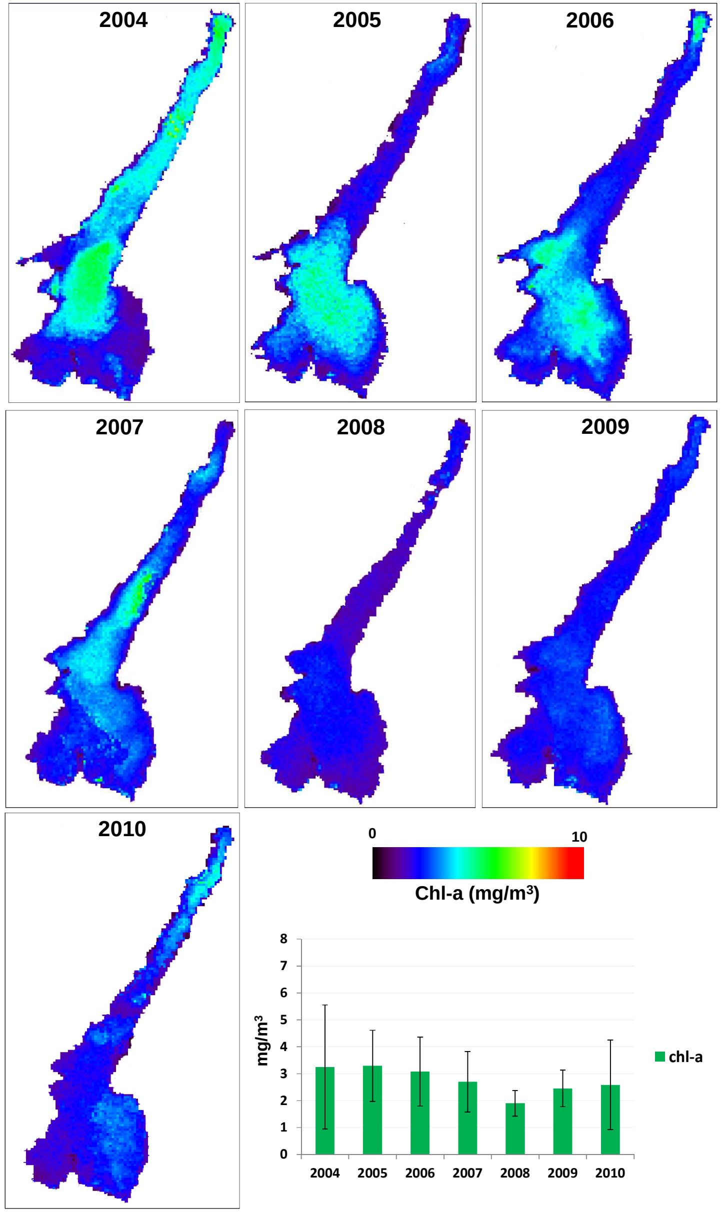
Calibration and validation

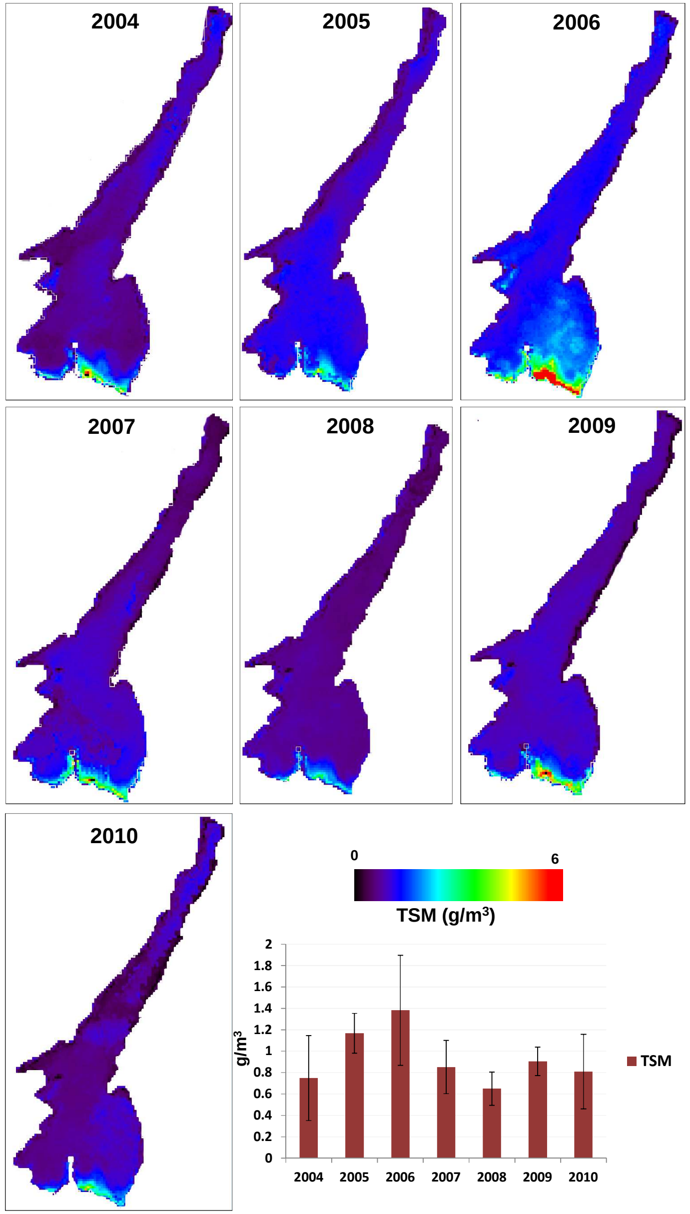


4800 MODIS 11A products, from 2004 to 2010, have been acquired to evaluate surface water temperature.

250 MERIS images, from 2004 to 2010, have been radiometric and atmospheric corrected and processed with bio-optical model for estimate Optical active parameters (Chlorophyll-a, Total Suspended Matter, Coloured Dissolved Organic Matter) and well as water transparency.

Lake Garda (Italy)

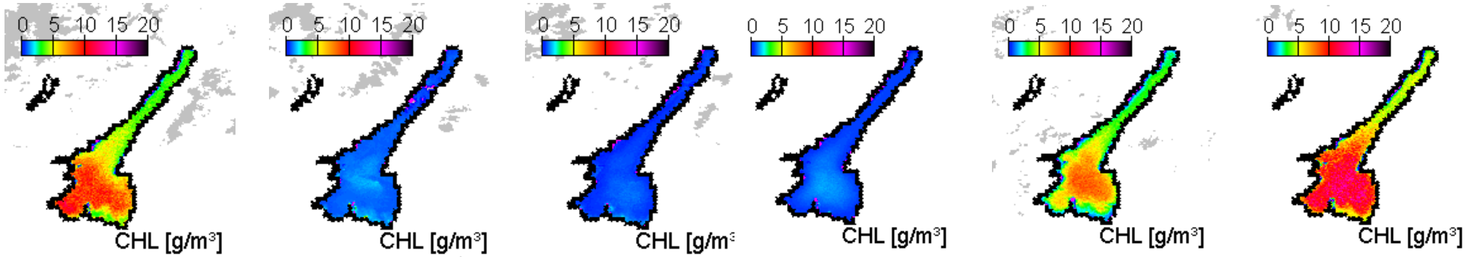




Eulakes Project: Results

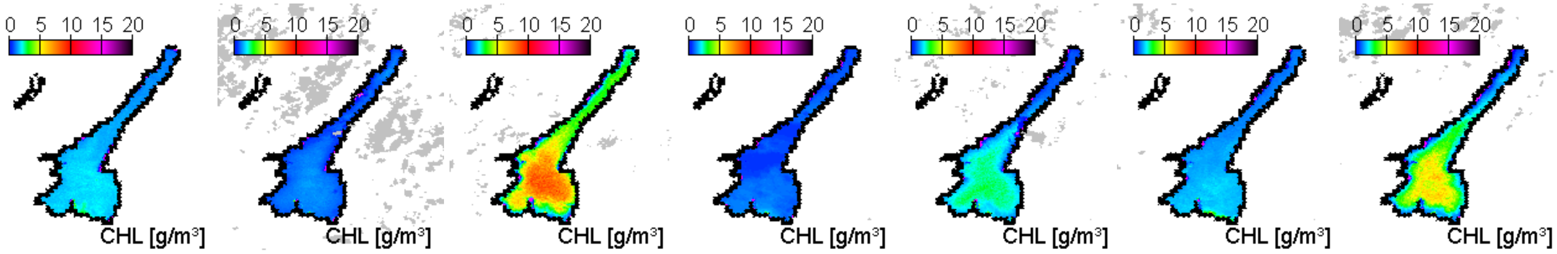
Lake Garda (Italy)

Changing of chl-a concentration during the year



10/02/2005 07/05/2005 29/05/2005 29/07/2005 24/09/2005 20/11/2005

Changing of chl-a concentration in different years

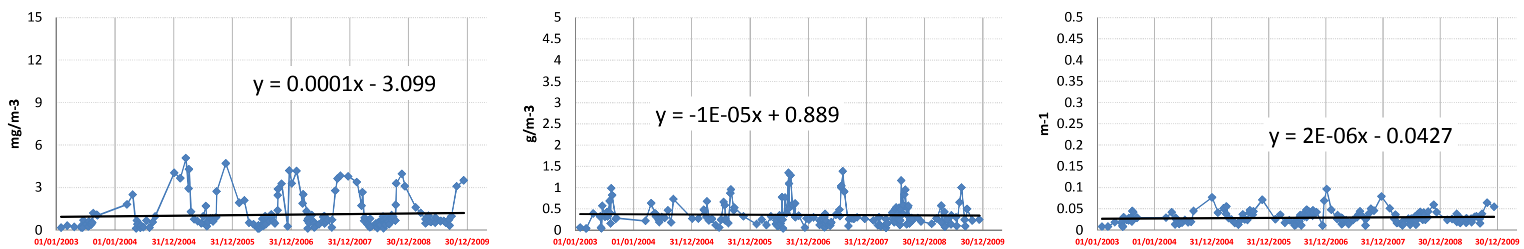


14/09/2003 07/09/2004 24/09/2005 12/09/2006 13/09/2007 16/09/2008 23/09/2009

Analysis of trends

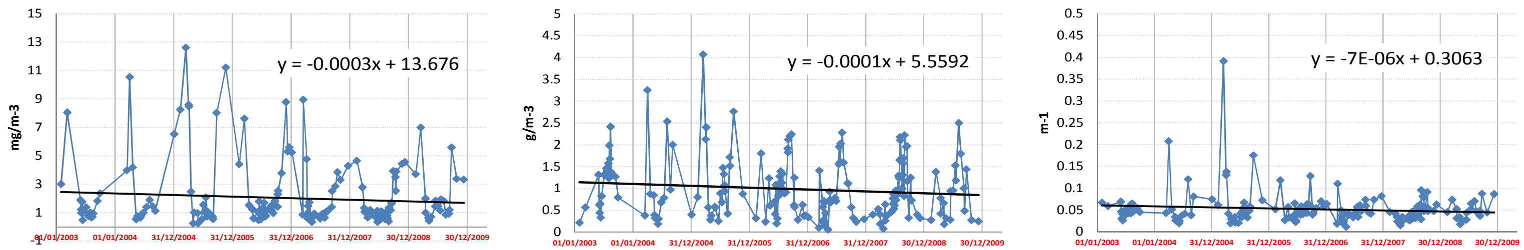
Chlorophyll-a TSM CDOM

North



Chlorophyll-a TSM CDOM

South-East



Eulakes Project: Results

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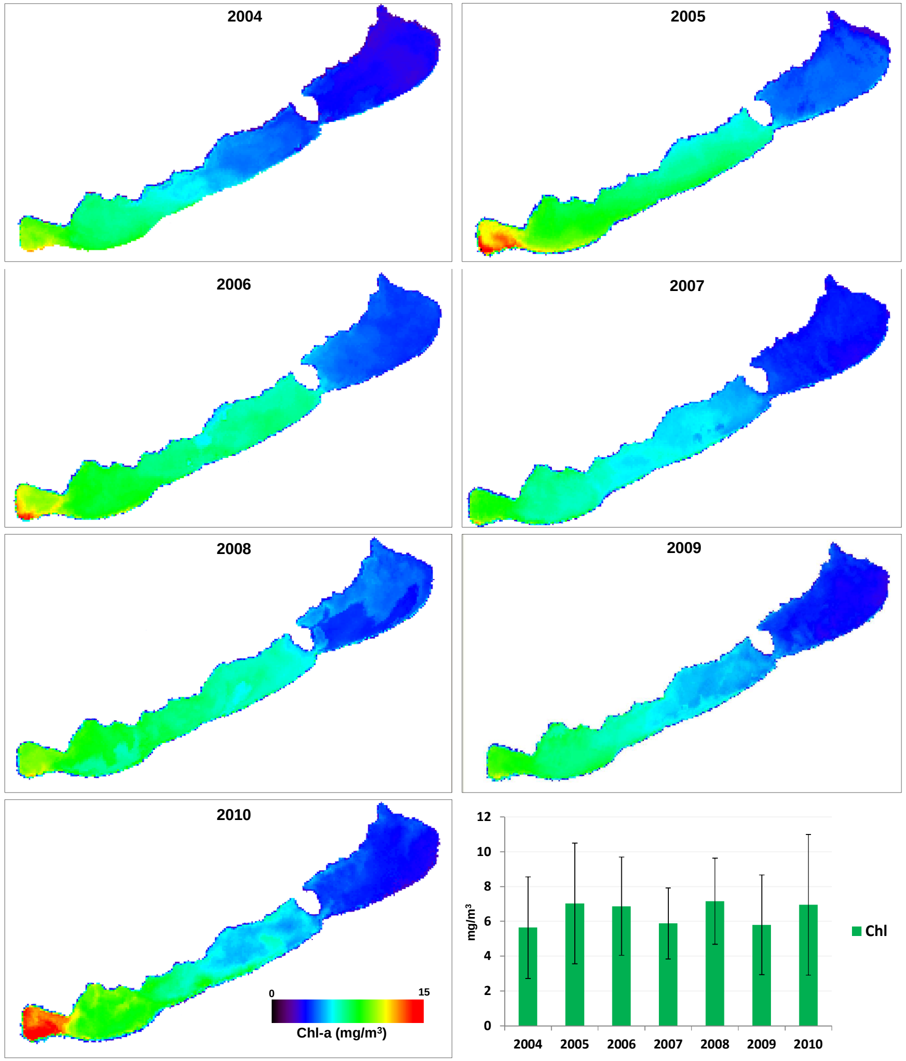
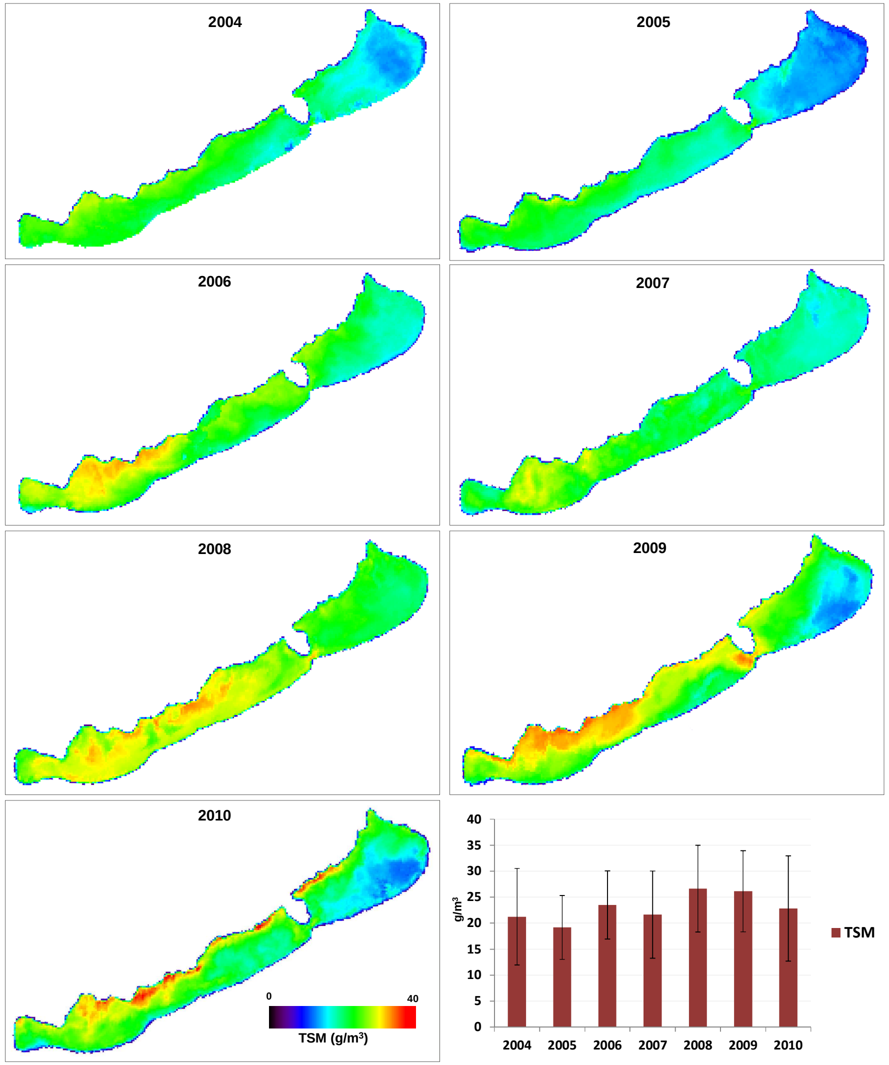
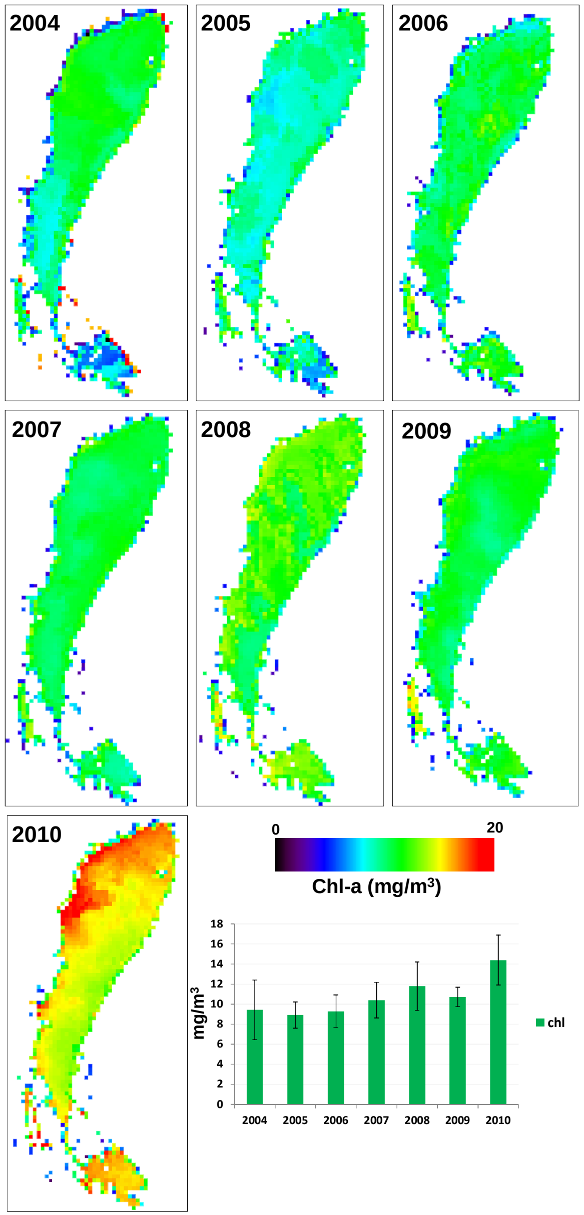
Lake Balaton (Hungary)

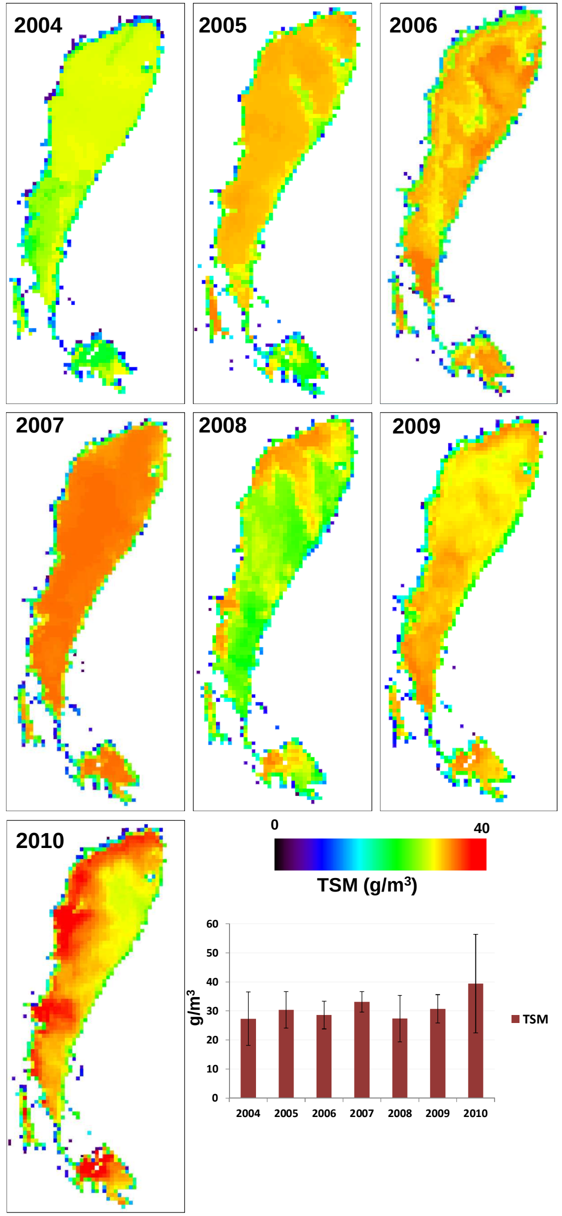




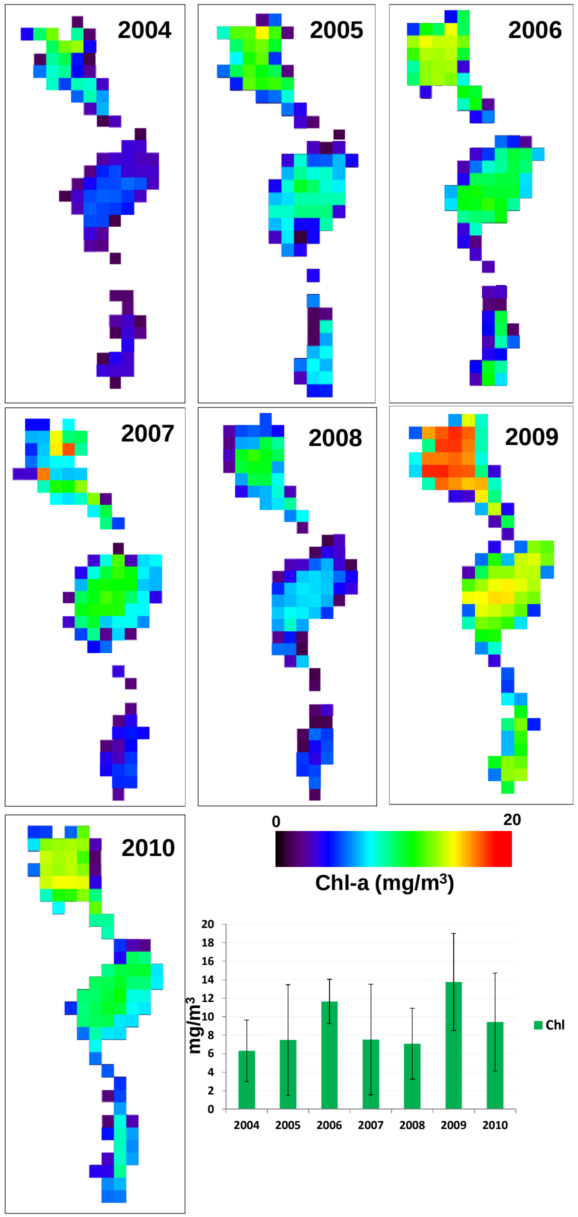
Istituto per il Rilevamento Elettromagnetico dell'Ambiente

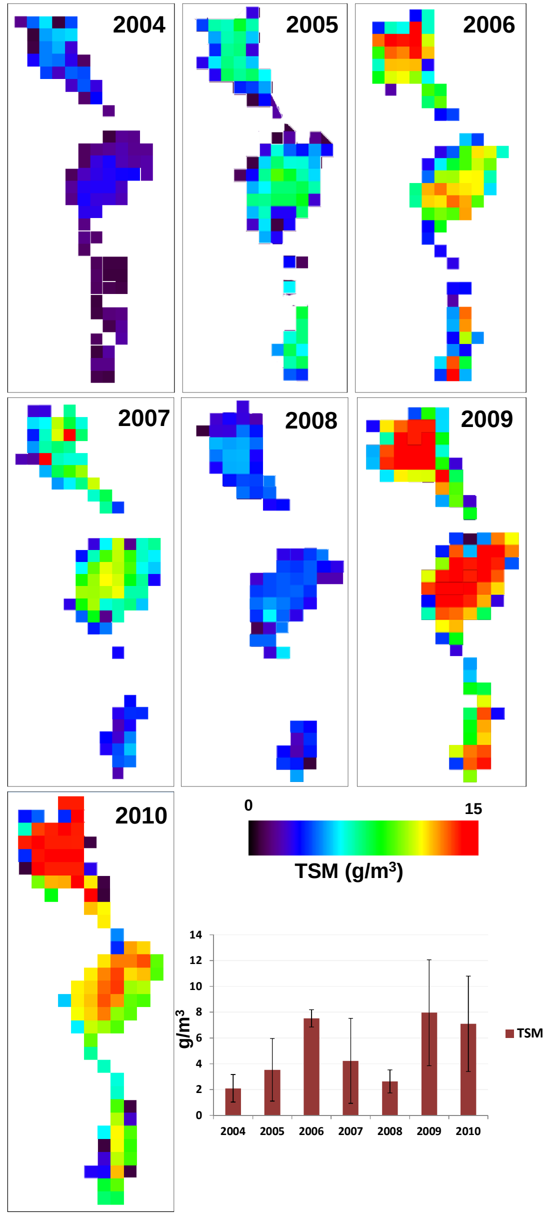
Lake Neusiedl (Austria)





Lake Charzykowskie (Poland)

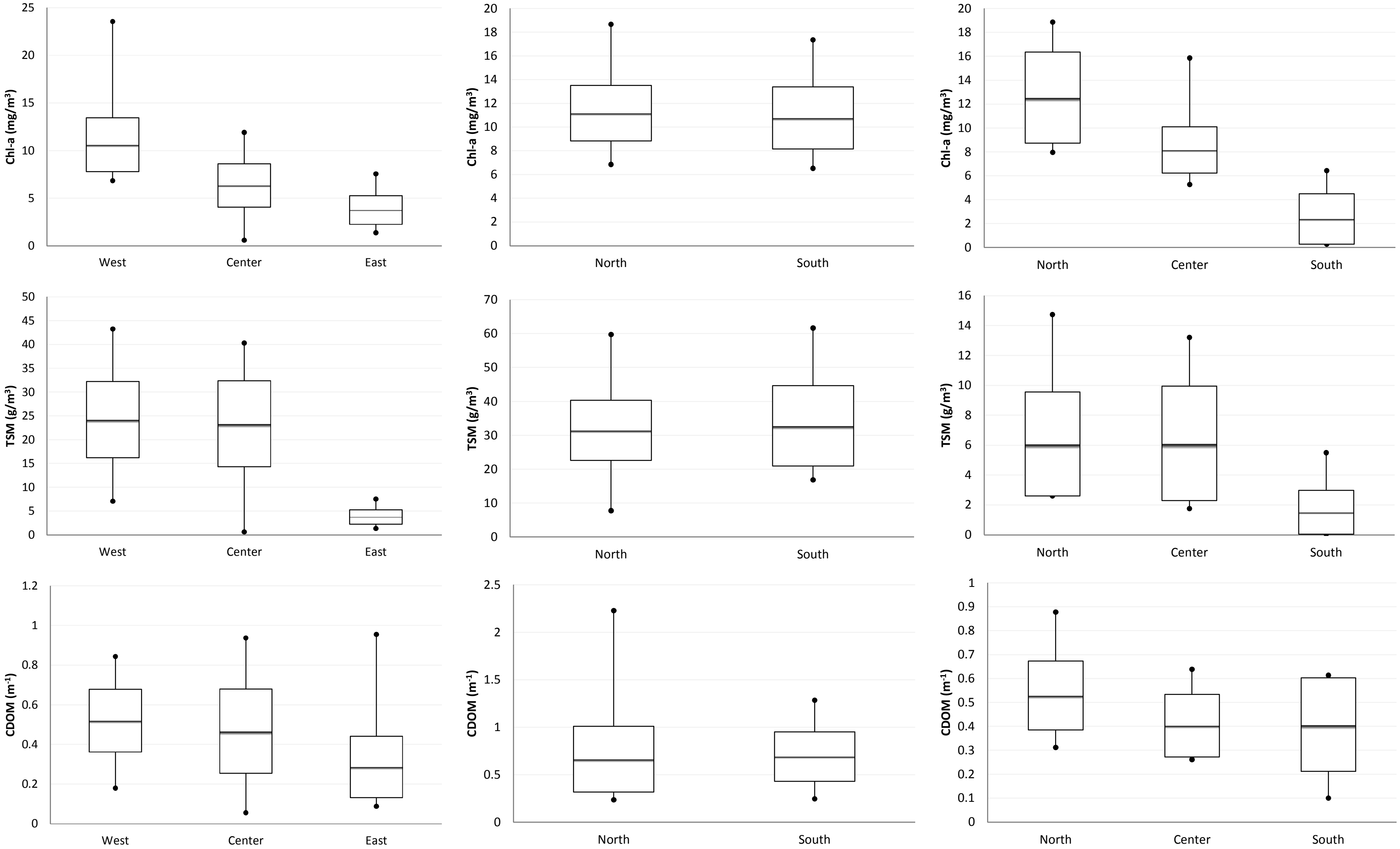




Eulakes Project: Results

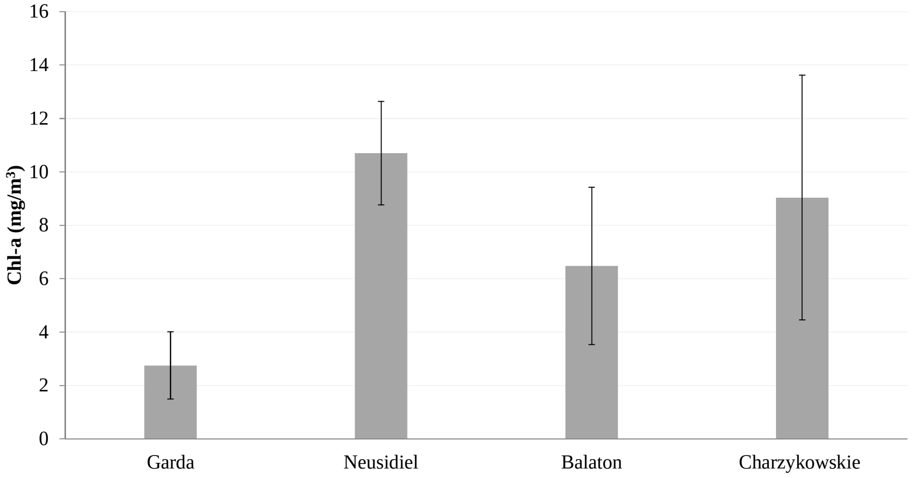
Riva del Garda- September 8, 2011

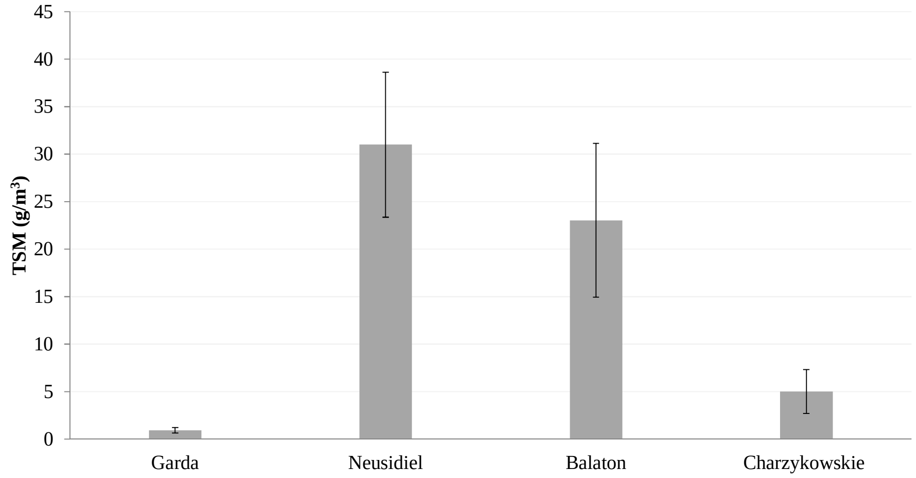
Spatial analysis

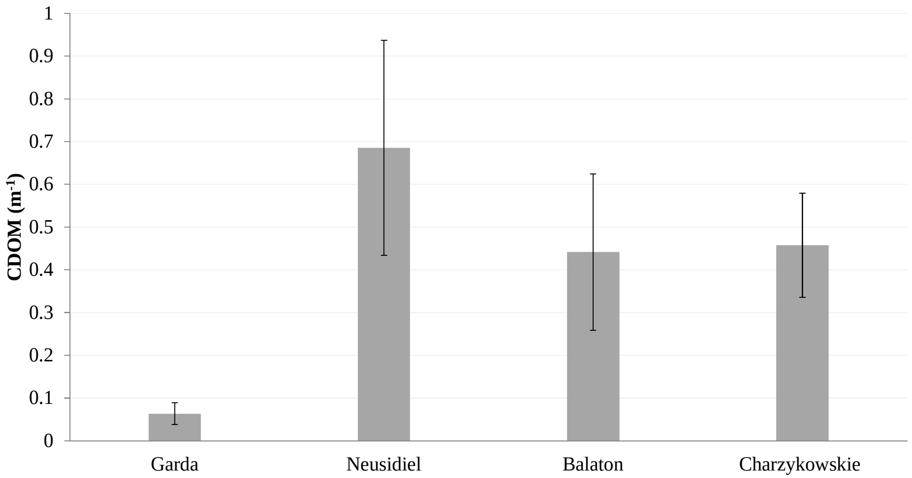


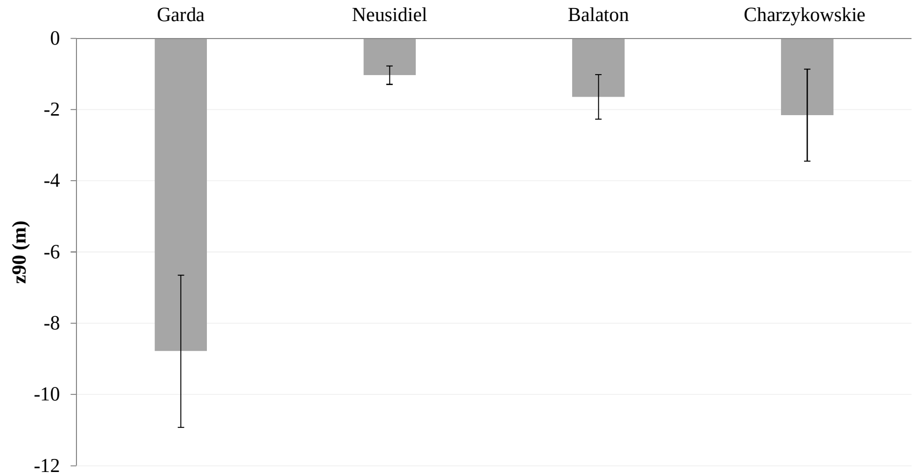
Lake Balaton **Lake Neusiedl** **Lake Charzykowskie**

Comparison lakes quality





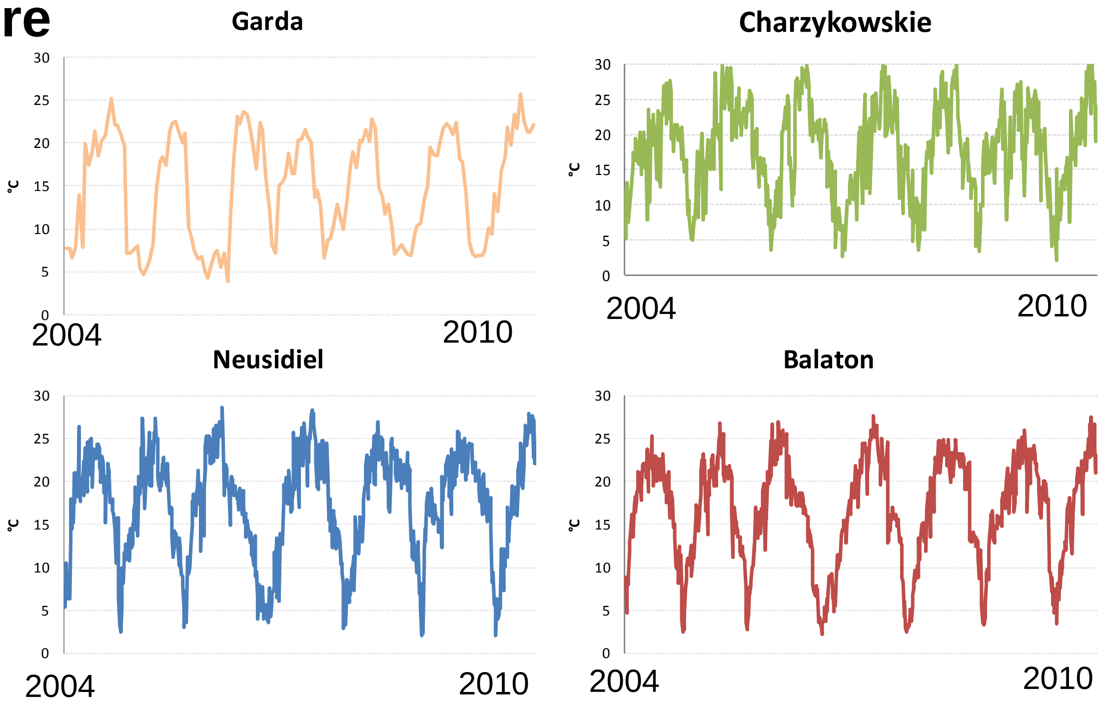




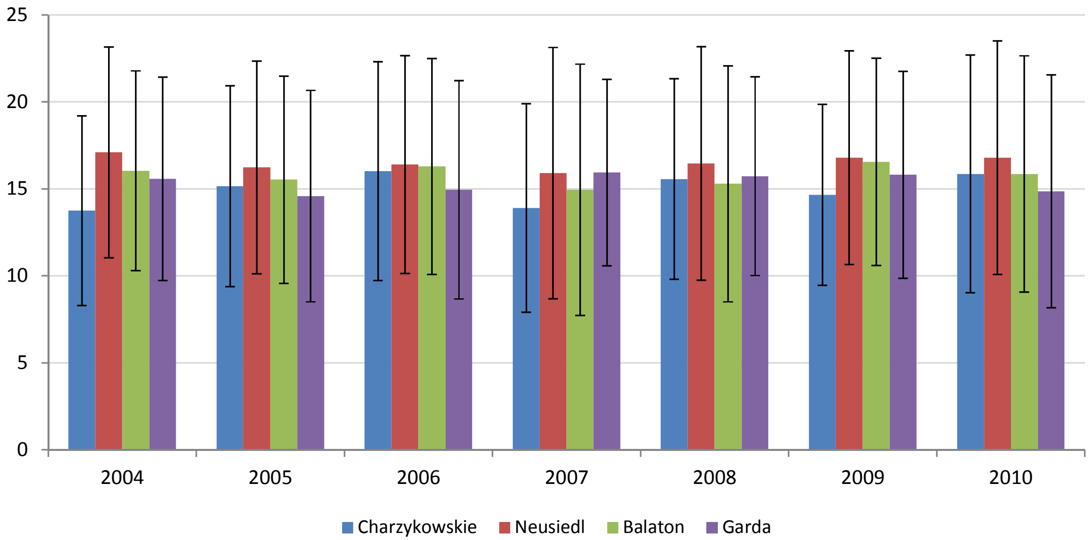
Average value 2004-2010 pelagic station of center of lakes

Lakes Surface temperature

Trend of lakes surface temperature (2004-2010) in the pelagic station of center of lakes

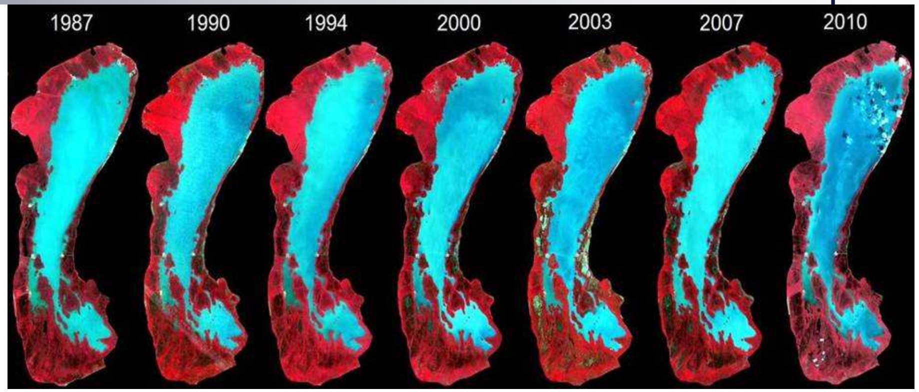


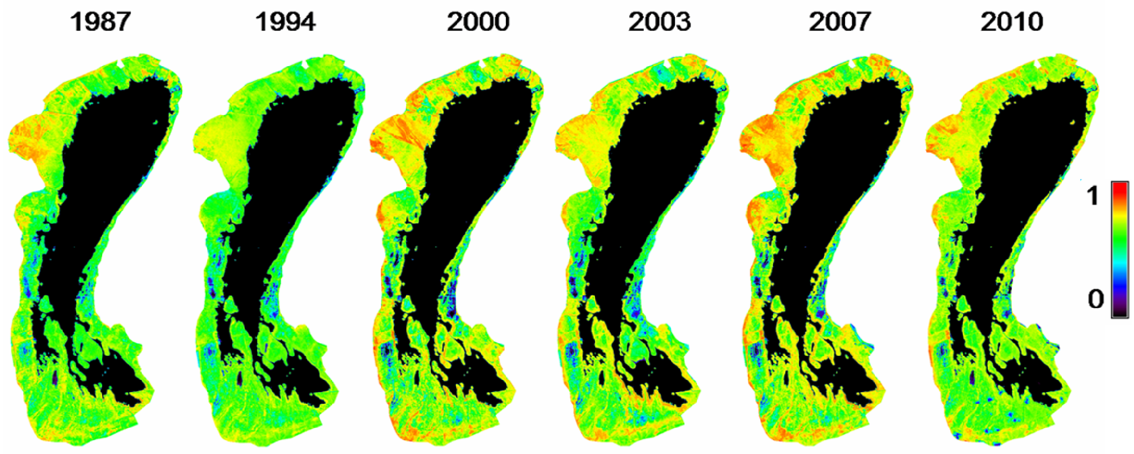
Annual average value of lakes surface temperature (2004-2010) extracted in different station of the lakes



Eulakes Project: Results

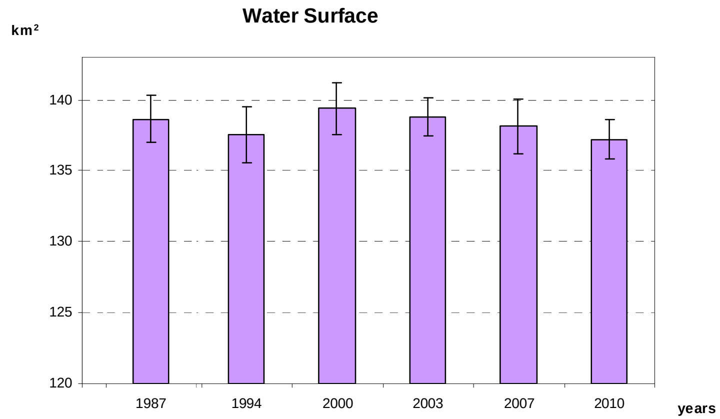
Multitemporal analysis of spatial variation and health state of the reeds in Neusiedl Lake





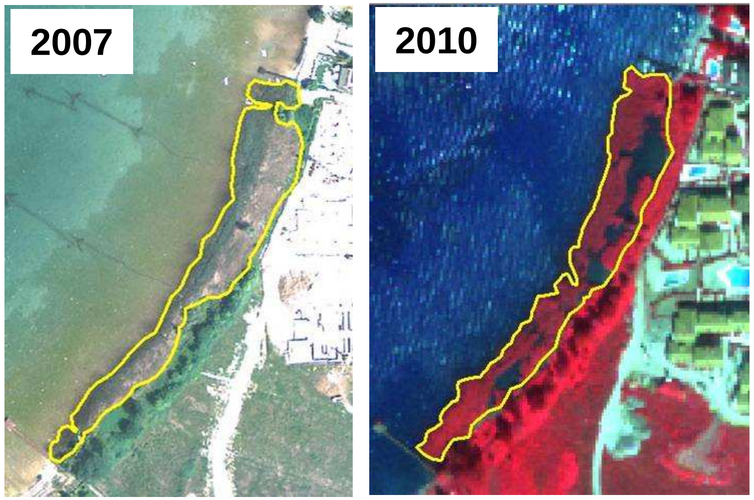
NDVI maps of Neusiedl reed belt scaled from blue (low) to red (high) values. Water is masked in black.

The lake water table surface is gradually decreasing from 2000 with higher growing rate every time interval of three years (0.968 km^2 from 2007 to 2010). This behaviour could suggest a progressive expansion of reed belt vegetation over the lake surface.

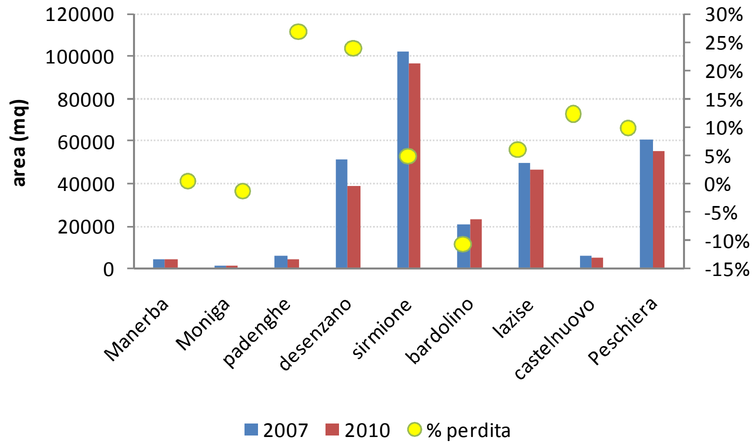


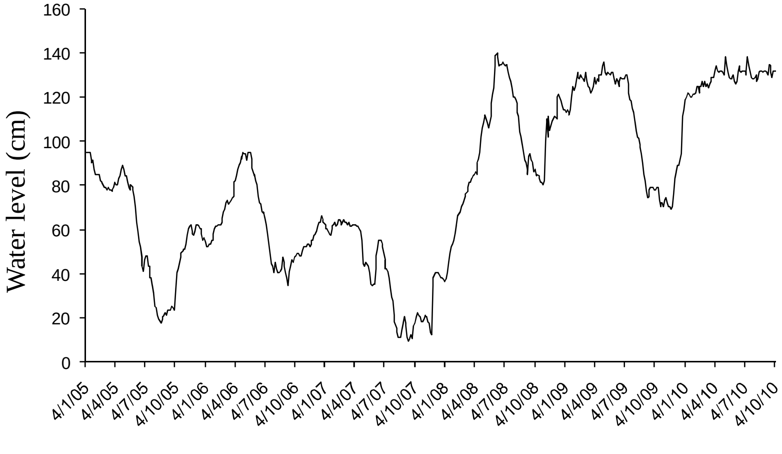
Riva del Garda- September 8, 2011

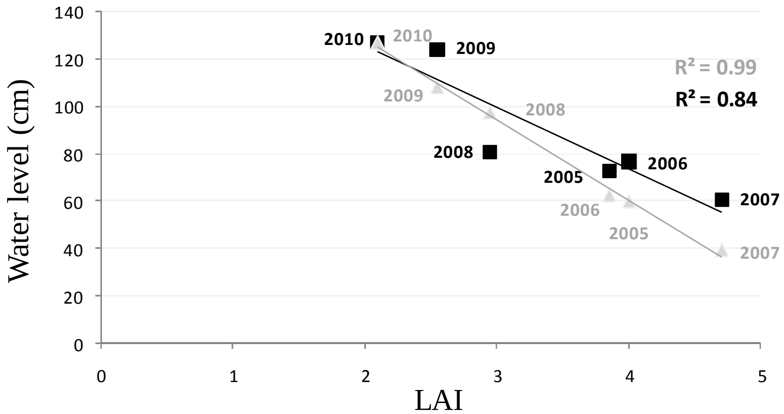
Multitemporal analysis of spatial variation and health state of the reeds



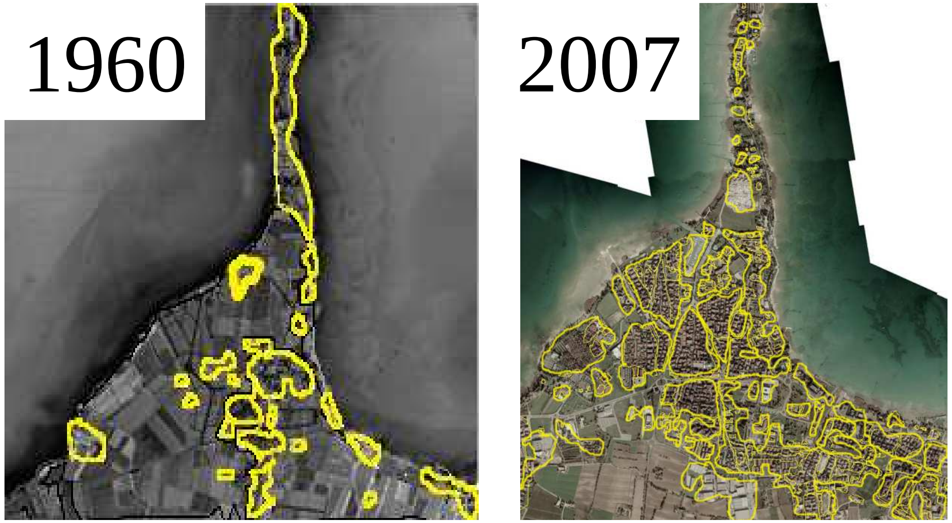
Lost 1500 m² (15%)



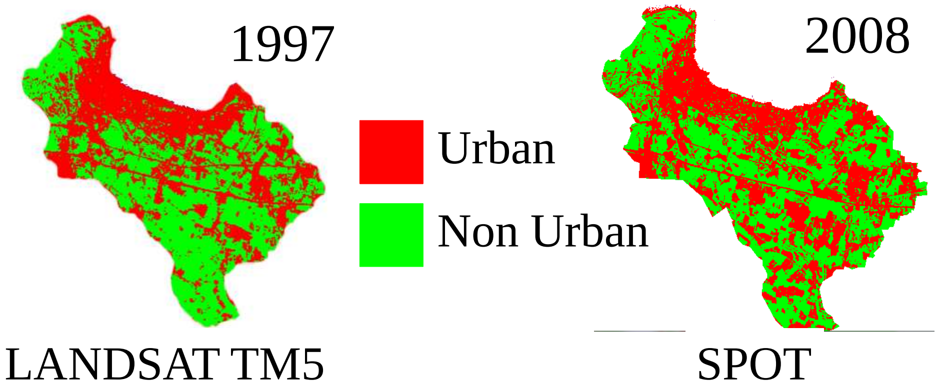




Multitemporal analysis of land cover changes



In yellow urban areas (Sirmione)



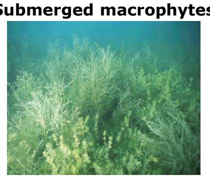
Town of Desenzano

1997 Surface Non Urbanized 249 ha

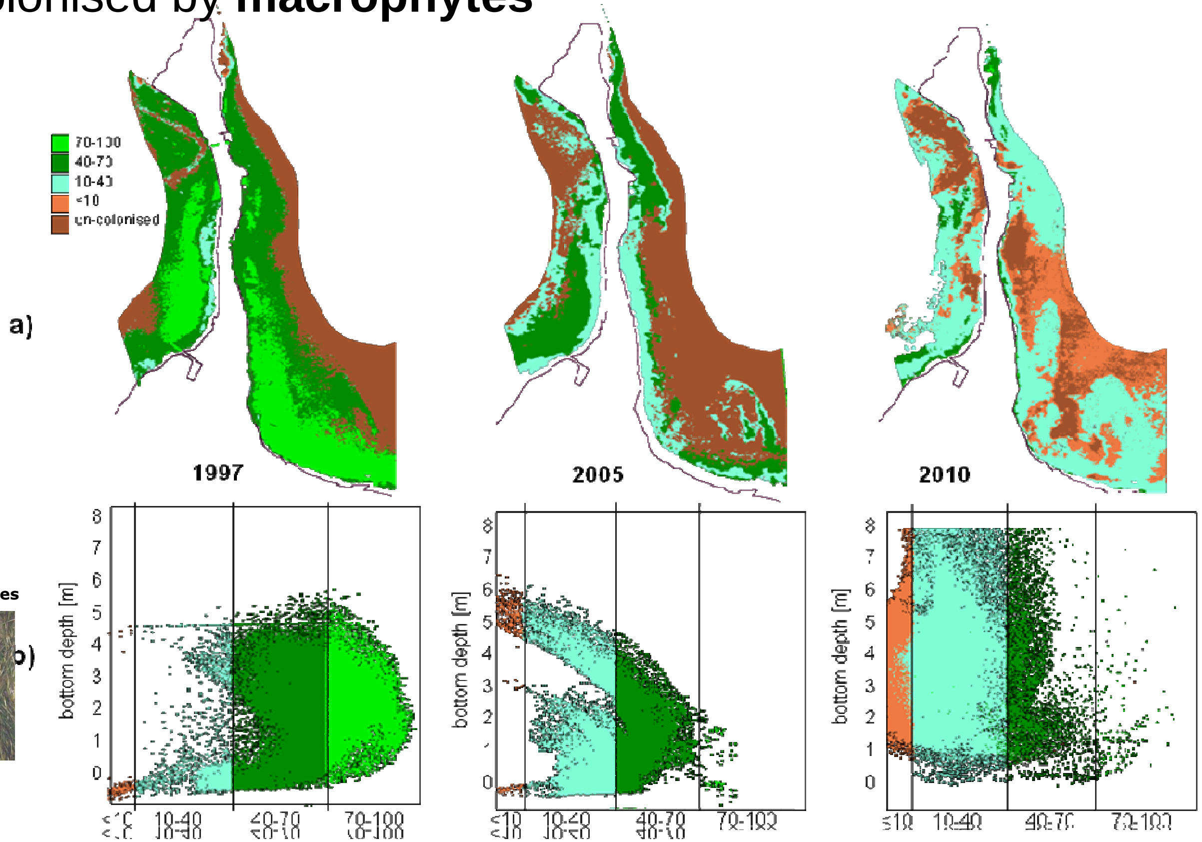
2008 Surface Non Urbanized 228 ha

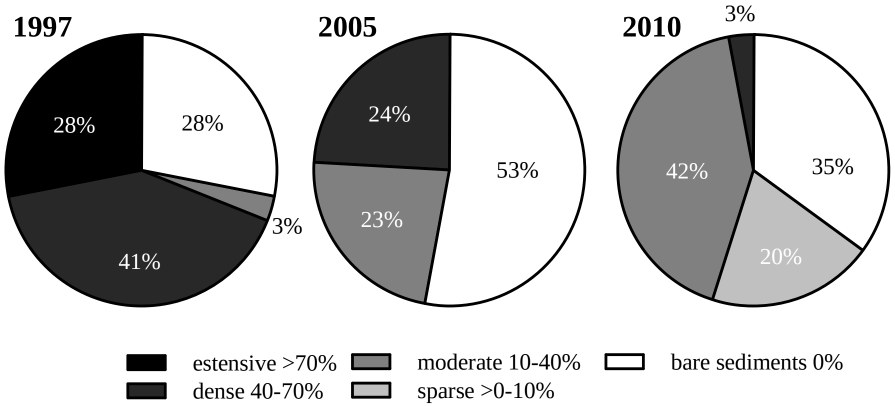
Detection of areas colonised by **macrophytes**

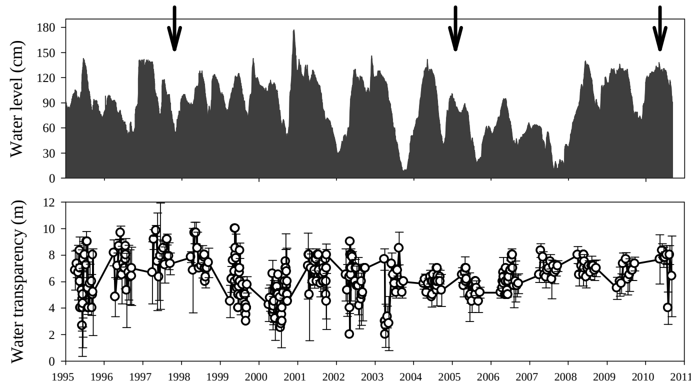
Submerged macrophytes



Floating macrophytes



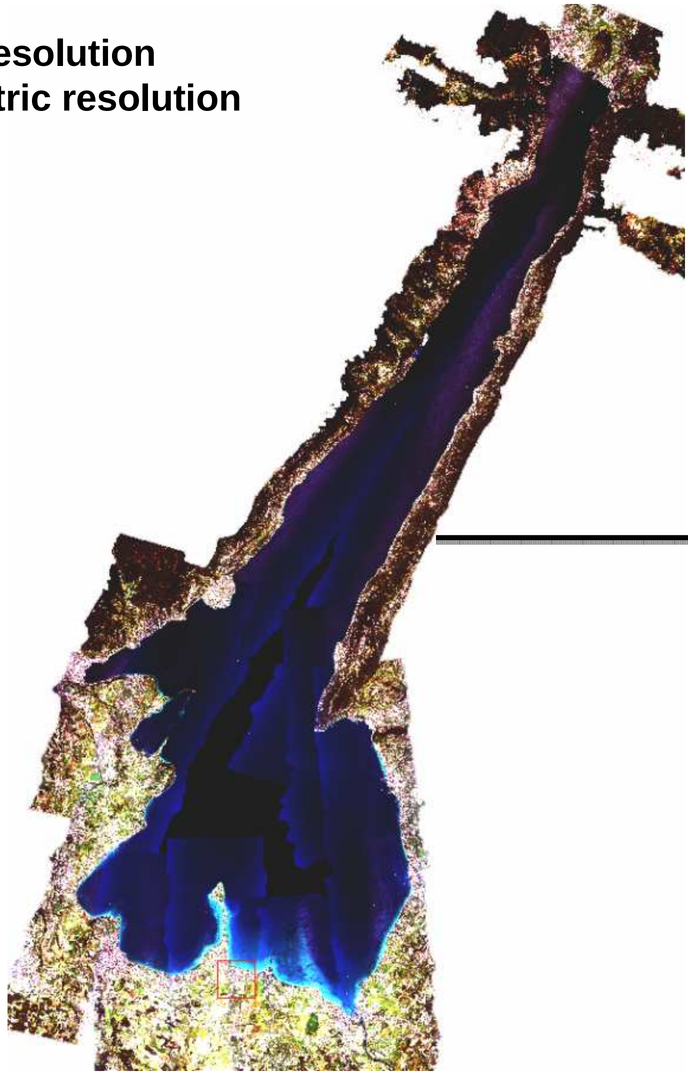




Eulakes Project: Focus Lake Garda

Airborne Hyperspectral Sensor (MIVIS) acquired by APPA Trento: 27-June-2011
Limnological, biological and radiometric campaign for calibration and validation the data (APPA Trento, ARPA Brescia, ARPAV, CNR-IREA, Università di Parma, CNR-ISE)

High spatial resolution
High radiometric resolution



Mapping macrophyte in all lakes in the region 0-8 meters of depth

Mapping water quality near of tributary (Sarca) and emissary (Mincio).

Mapping Lake Surface temperature.

Comparison for south Garda the change in 2011

First step for create a data base of comparison macrophyte colonized for all lakes in the time.

Thank you very much for your attention