Water quality exploiting PRISMA hyperspectral data: algorithm and first validation results

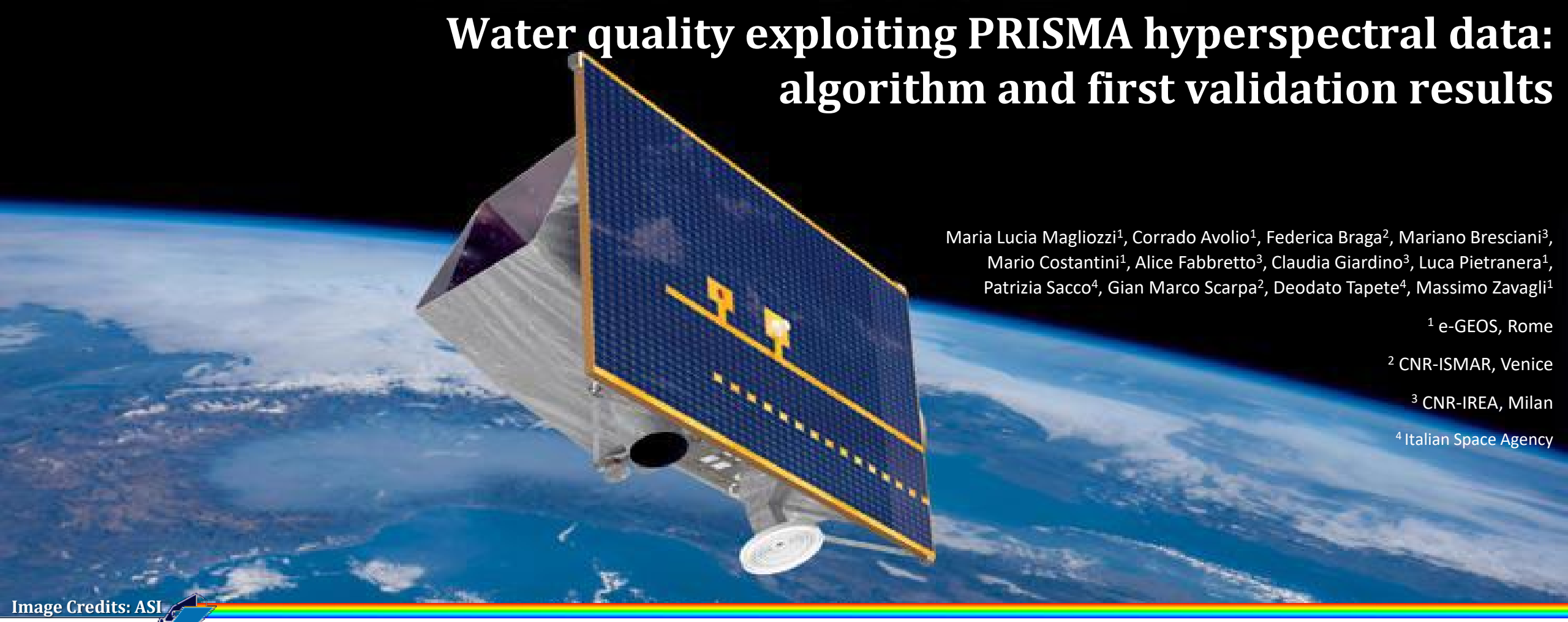

Image Credits: ASI

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istituto per il rilevamento elettromagnetico dell'ambiente

ISMAR

Objectives of the Project

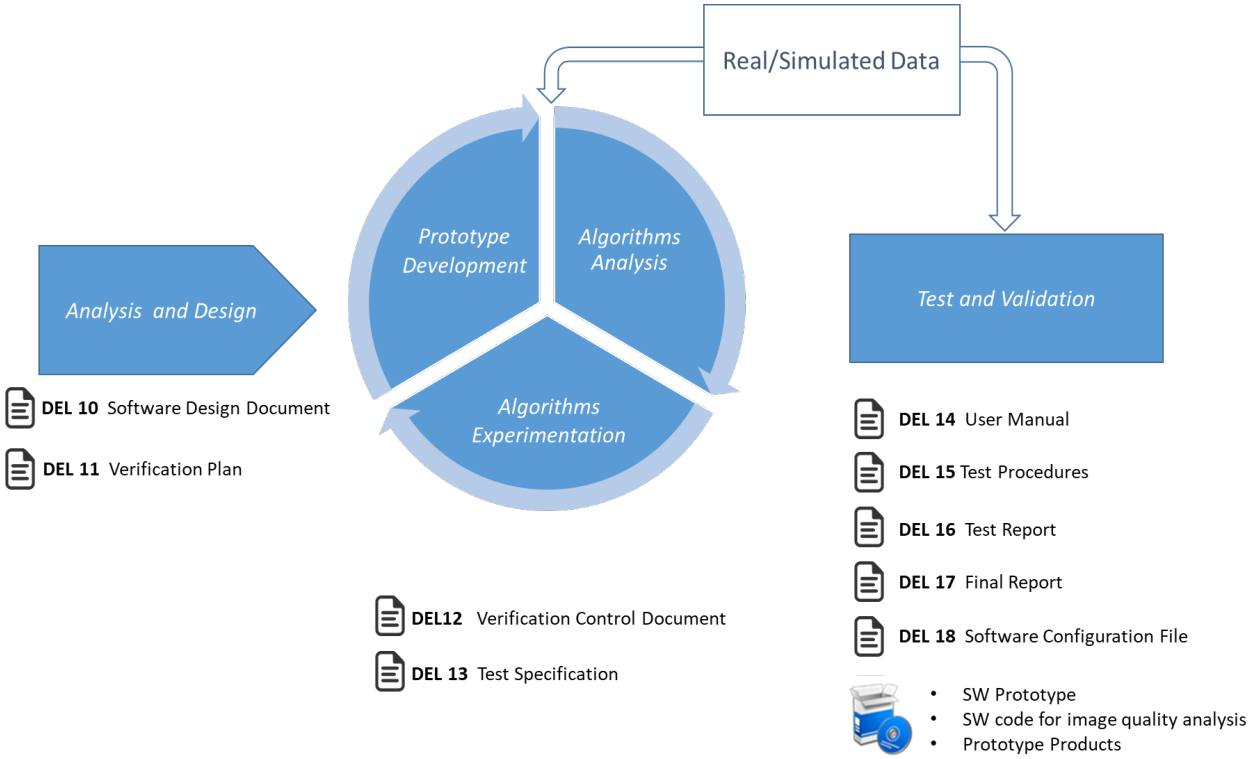
«Progetto per Sviluppo di Prodotti Iperspettrali Prototipali Evoluti»

- **Prototype development of value-added products exploiting PRISMA hyperspectral imagery** and state-of-the-art algorithms, with associated analysis of image quality and algorithm performance
- Definition of the **Development Plan** for Level 3 / Level 4 value-added products and their processing chains, starting from Level 1/Level 2 hyperspectral data.
- **Prototype processors** could be integrated in the PRISMA and SHALOM processing systems, after adequate engineering

Project Overview

Design, development, test and validation of the following software product prototype

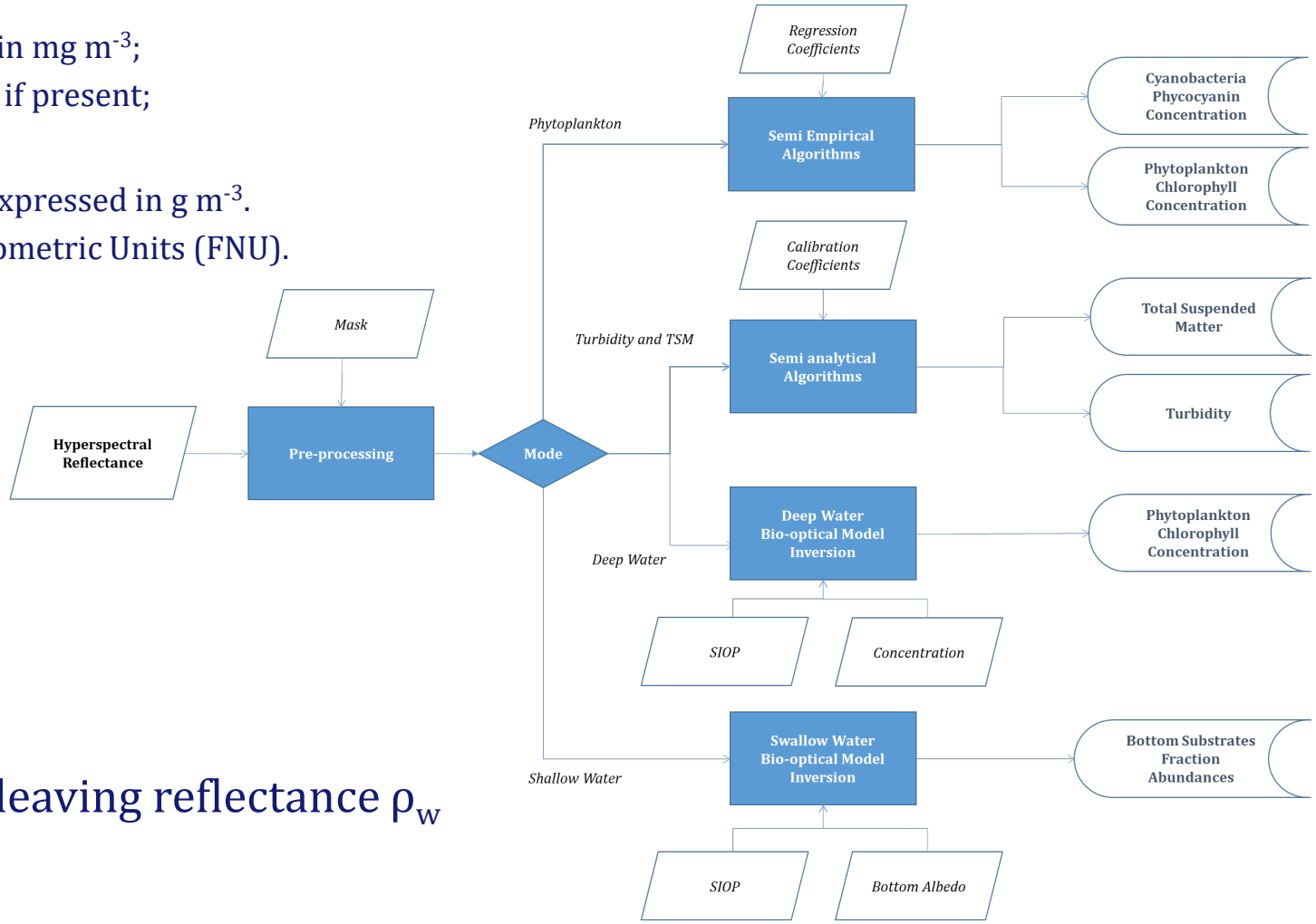
Product Prototype	Layer
Vegetation Indicators	- Leaf area index - Fraction of absobed phosynthetically active radiation - Fractional vegetation cover - Leaf chlorophyll content
Water Quality	- Phytoplankton - Total Suspended Matter - Bottom Substrate
Fire severity map	- Burnt Area Map - Fire Severity Map
Fire Fuel Map	- Fuel Type Map
Forest fire front	- Fire front map
Volcanic parameters products	- Water vapour columnar content - Carbon dioxide columnar content - Active lava flow thermal map
Urban and Industrial Functional area map & Urban growth map	- Urban land cover map - Building coverage map - Artificial change layer - Material change layer - Building Coverage change map
Material Detection	- Soft detection map - Hard detection map



Water Quality Product Description & Flow Diagram

The **Water Quality Prototype** provides the following parameters:

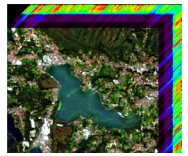
- **Phytoplankton**:
  - Chlorophyll-a (Chl-a) concentration, expressed in mg m^{-3};
  - Cyano-phycocyanin (CPC), measured in mg m^{-3}, if present;
- **Total Suspended Matter**:
  - Total Suspended Matter (TSM) concentration, expressed in g m^{-3}.
  - Water turbidity, measured in Formazin Nephelometric Units (FNU).
- **Bottom Substrates**:
  - Fraction of Substrates type.



Product Level Level 3

Input Data PRISMA L2D water leaving reflectance ρ_w

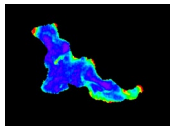
Water Quality Prototype: Product Generation



Regression Coefficients

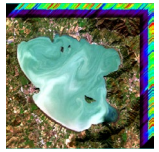
$$Pigment\ Concentration = a_1 + a_2 \cdot \frac{\rho_w(\lambda_{b\_max})}{\rho_w(\lambda_{a\_max})}$$

Adaptive Band Ratio



Chlorophyll-a and Cyano-phycocyanin Concentration

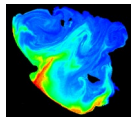
Hestir et al. 2015. Remote Sens. Env., 197
Bresciani et al. 2013. Mar. Freshw. Res., 64



Calibration Coefficients

$$TSM = \frac{A_\lambda \cdot \rho_w(\lambda)}{1 - \rho_w(\lambda)/C_\lambda}$$

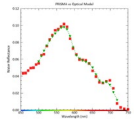
Semi Empirical Model



Turbidity and Total Suspended Solids

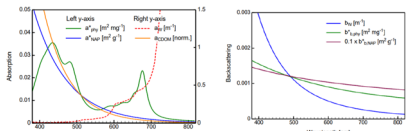
Nechad et al., 2009. Remote Sens. Ocean., 7473
Nechad et al., 2010. Remote Sens. Environ., 114

$$\rho_w(\lambda) = f(CCHL)$$



Bio-optical model for optically deep water and associated inversion techniques

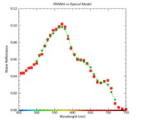
Chlorophyll-a Concentration



Site Specific Inherent Optical Properties

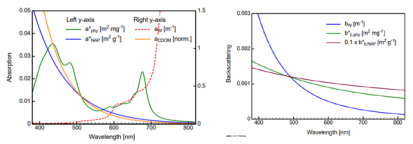
Giardino et al. 2012. Comput. Geosci., 45

$$\rho_w(\lambda) = f(q_i)$$

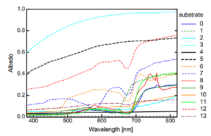


Bio-optical model for optically shallow water and associated inversion techniques

Bottom Substrates



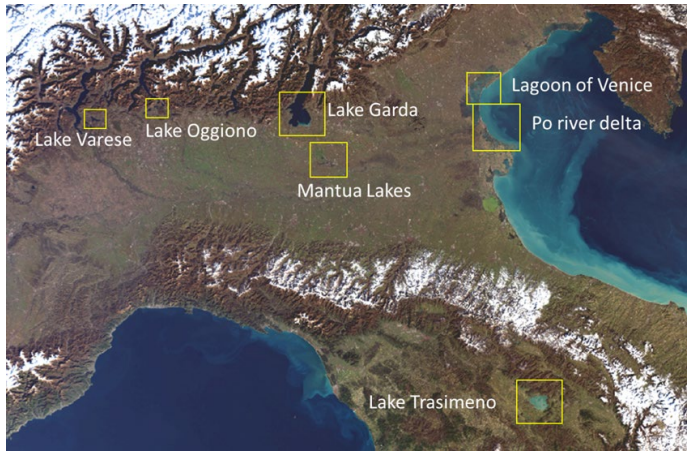
Site Specific Inherent Optical Properties



Substrates Albedo

Brando et al., 2009 Remote Sens. Env., 113

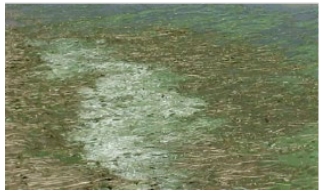
Case Studies



Site	Phytoplankton	TSM	Bottom Substrate
Lake Garda	✓		✓
Lake Mantova	✓		
Lake Oggiono	✓		
Lake Varese	✓		
Lake Trasimeno		✓	
Lagoon of Venice		✓	✓
Po river delta		✓	

Different phytoplankton composition and blooms

Sporadic homogeneous blooms with vertical migration in oligo-meso trophic lakes

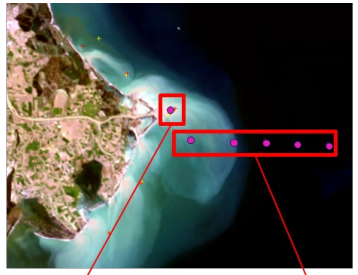


Frequent and intense homogeneous bloom in hypertrophic lakes with scums

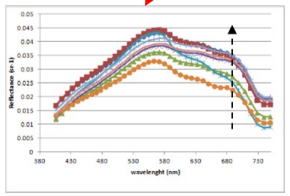
Frequent and intense heterogeneous bloom in hypertrophic lakes

Frequent homogeneous bloom in meso-eurtrophic lakes without scums

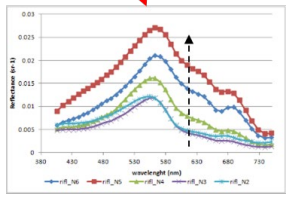
High variability of suspended material



Rrs in situ

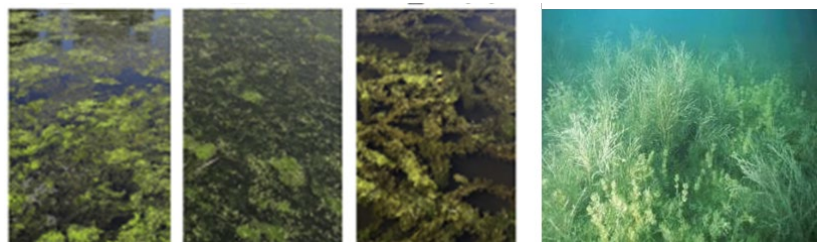


Temporal variability

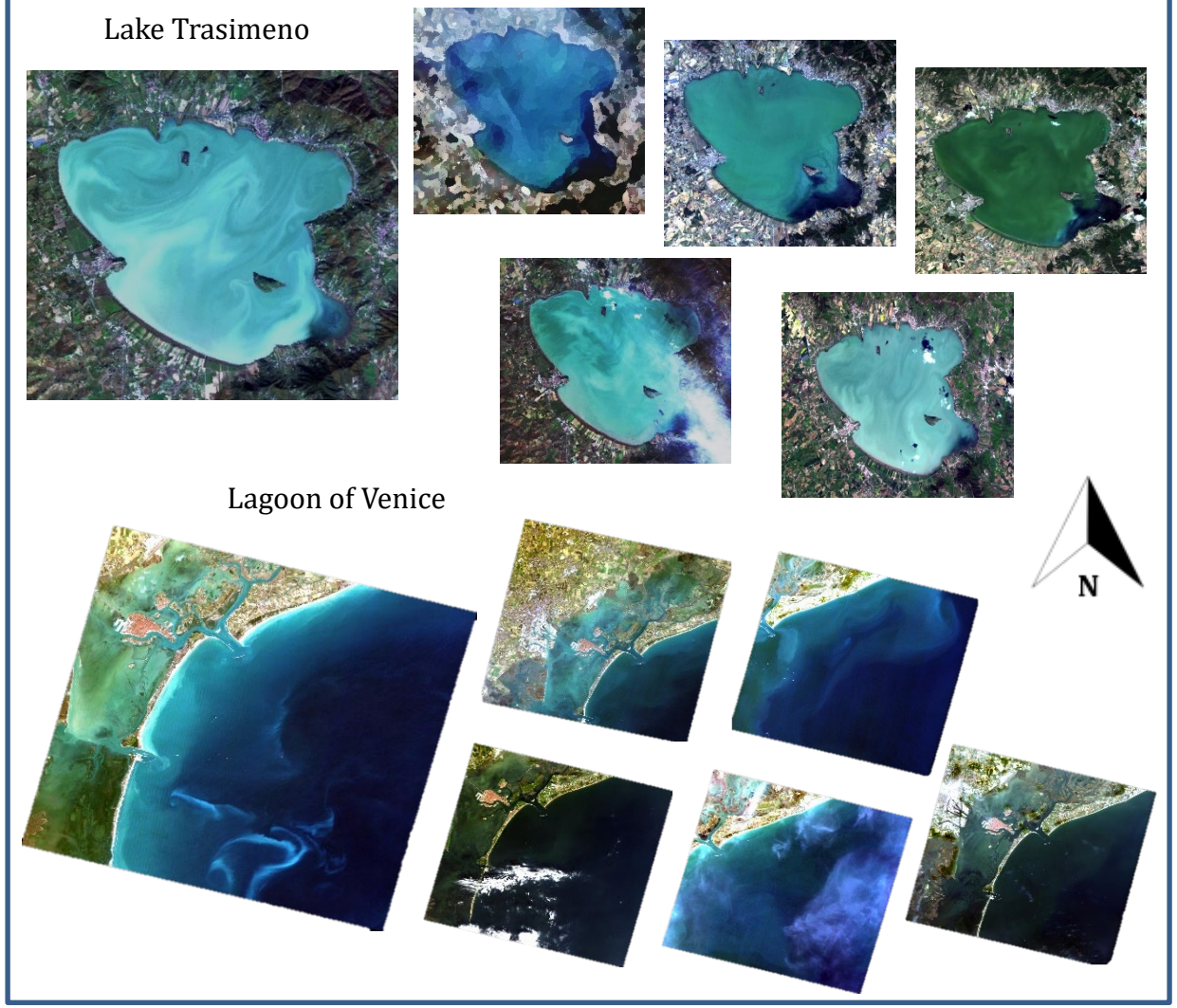


Spatial variability

Different types of submerged aquatic vegetation



Data Set



Site	Acquisition date	In situ Data
Lake Trasimeno	26/07/19	Autonomous system
Lagoon of Venice	08/02/20	Autonomous system
Lake Trasimeno	23/04/20	Autonomous system
Lake Trasimeno	03/06/20	Fieldwork + Autonomous system
Lagoon of Venice	02/07/20	Fieldwork + Autonomous system
Lagoon of Venice	14/07/20	Fieldwork + Autonomous system
Lake Trasimeno	25/07/20	Autonomous system
Lagoon of Venice	25/07/20	Autonomous system
Lake Garda	10/09/20	Fieldwork
Lake Trasimeno	30/11/20	Autonomous system
Lagoon of Venice	09/03/21	Fieldwork + Autonomous system
Lake Trasimeno	09/06/21	Fieldwork + Autonomous system
Lagoon of Venice	09/06/21	Fieldwork + Autonomous system
Lagoon of Venice	20/07/21	Autonomous system
Lagoon of Venice	06/08/21	Autonomous system
Lake Oggiono	31/08/21	Fieldwork + ARPA Lombardia
Lake Trasimeno	10/09/21	Fieldwork + Autonomous system
Lagoon of Venice	10/09/21	Autonomous system
Lagoon of Venice + Po river delta	15/10/21	Fieldwork + Autonomous system
Lake Varese	16/10/21	Fieldwork + ARPA Lombardia
Lake Mantova	27/10/21	Fieldwork
Lake Trasimeno	06/12/21	Fieldwork + Autonomous system

Validation Approach

The products assessment and validation activity were primarily based on dedicated in situ measurements, synchronous to PRISMA acquisition.

Two validation approaches were used according to the spatial and temporal variability of the investigated parameters:

→ **Water quality parameters (phytoplankton and total suspended matter)**

- Targeted *in situ* campaigns for key relevant sites at the time of PRISMA overpass (± 2-3 h)
- Data acquired by continuous monitoring system
- The validation results between PRISMA-generated products and *in situ* data were made by common descriptive statistical metrics such as root mean square difference (RMSD), mean absolute difference (MAD), bias and coefficient of determination (R^2).

→ **Bottom substrate**

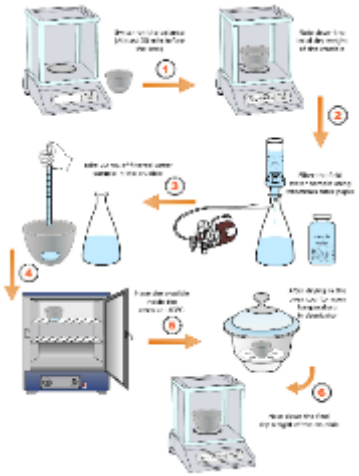
- *In situ* data and/or thematic maps of substrate type distribution. Control points were used to compare *in situ* and satellite-derived bottom coverage.
- The product accuracy was quantified using a confusion matrix.

Water Quality Product Validation

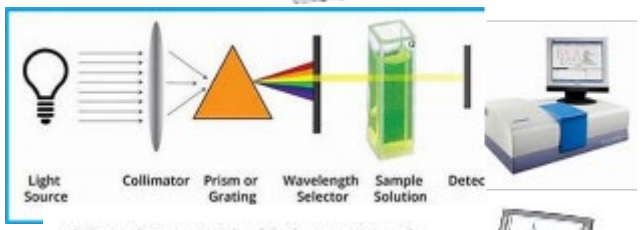

Collection of water samples

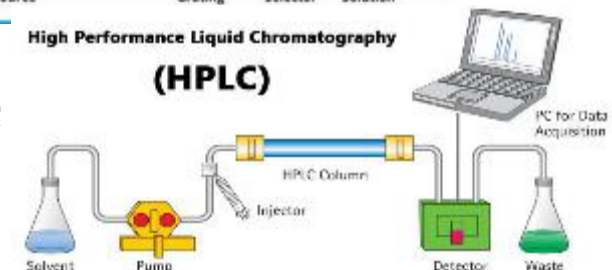
In situ and laboratory filtration with Whatman filterpads (GF/F o GF/C)


Gravimetric



Laboratory analysis with standard methodologies





Spectrophotometric

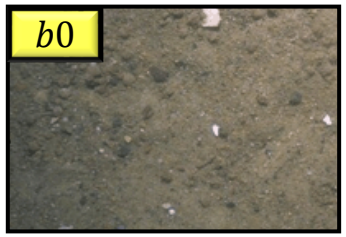
Continuous autonomous WISP-Station (lake Trasimeno)

Continuous autonomous Floating RoX (subalpine lakes)

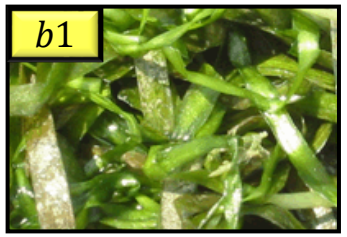
Fixed stations for radiometric, fluorimetric and turbidity measurements

Water turbidity and fluorimetric measurements of phytoplankton pigments during fieldworks

Substrate Product Validation

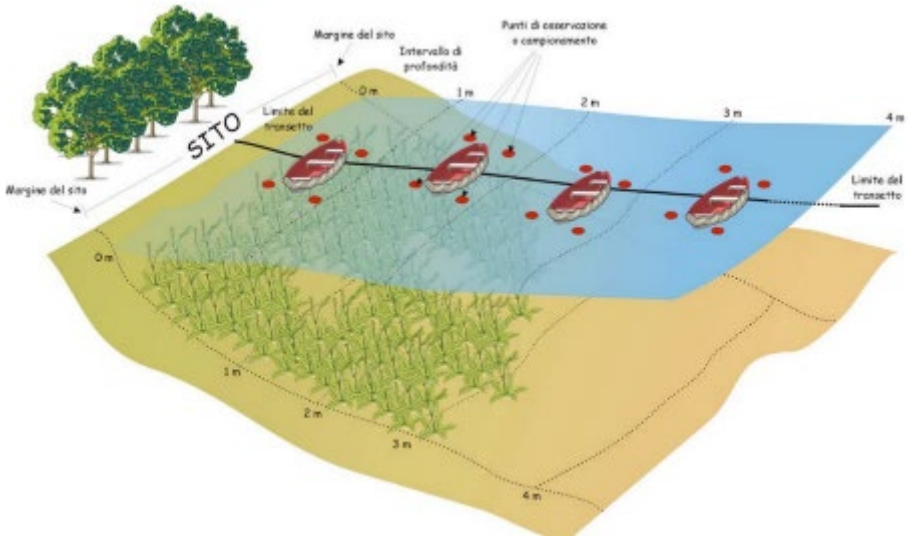


Bare substrate



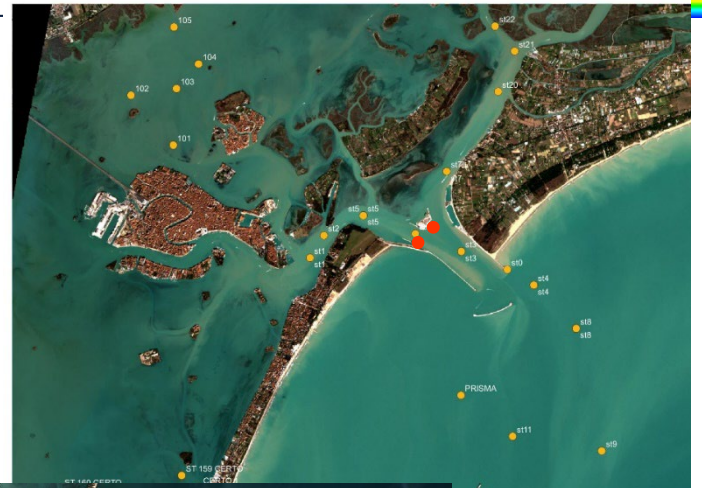
Dense macrophyte

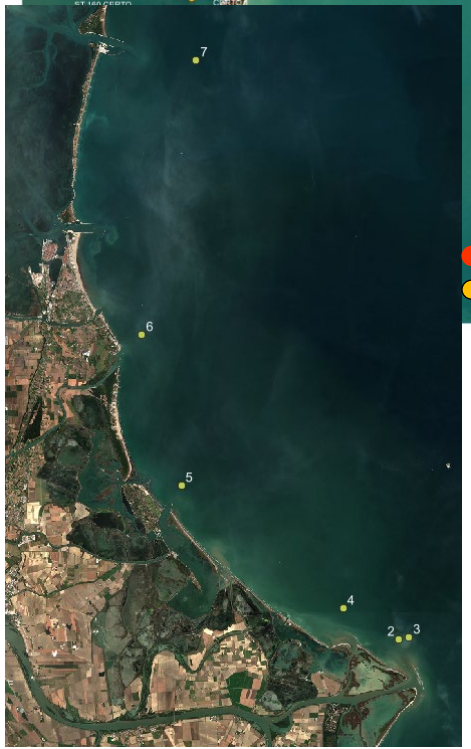
Sparse macrophyte



Single points and transects according to WFD methodology

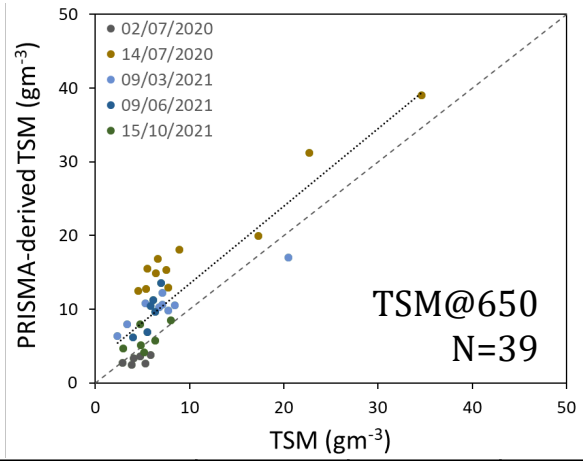
Validation Results

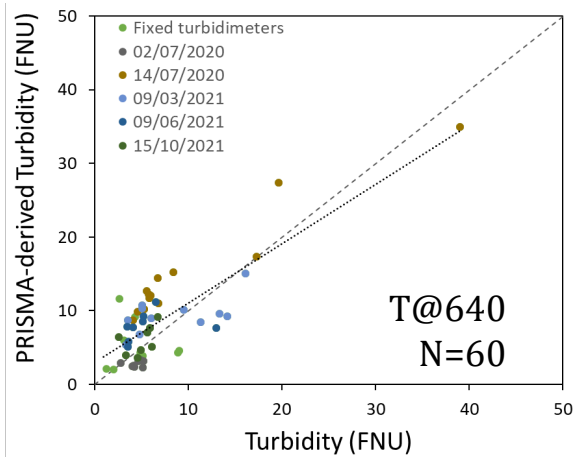




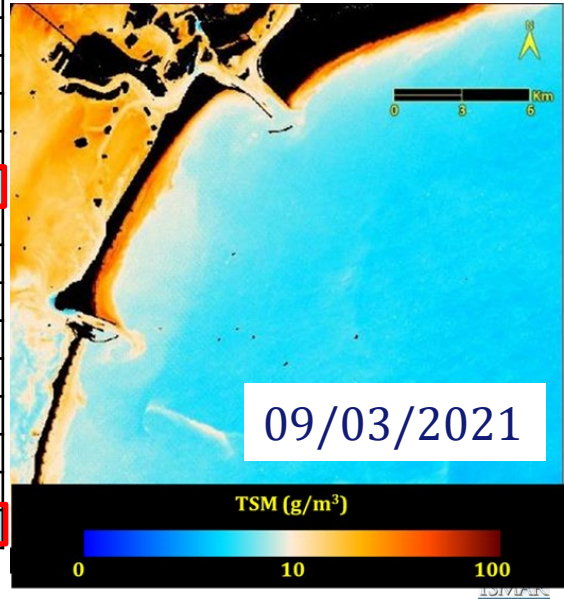
Fixed turbidimeter
In situ field

Lagoon of Venice and Po river delta



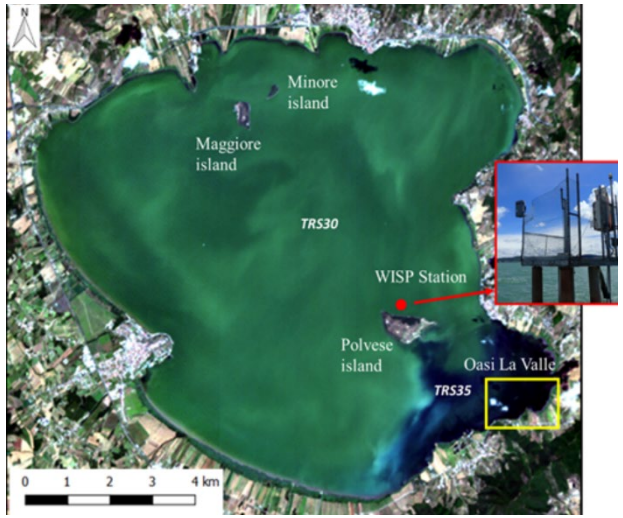


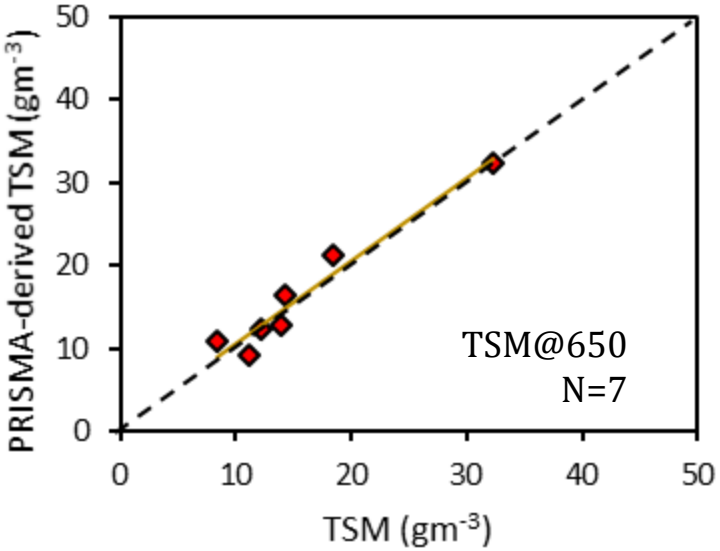
	r	R^2	RMSD	MAD	Bias	Intercept	Slope
TSM@700	0.77	0.59	8.88	7.20	6.59	5.4	1.15
TSM@690	0.82	0.67	7.56	6.15	5.65	4.6	1.14
TSM@680	0.84	0.71	7.92	6.43	6.25	4.7	1.21
TSM@670	0.85	0.73	7.50	6.16	5.93	4.4	1.18
TSM@660	0.86	0.74	6.17	5.05	4.59	3.7	1.12
TSM@650	0.87	0.76	4.98	4.06	3.36	3.0	1.05
TSM@640	0.89	0.80	5.43	4.40	3.94	2.7	1.16
T@700	0.72	0.51	6.28	4.72	1.96	5.7	0.54
T@690	0.76	0.58	5.76	4.21	1.26	5.1	0.53
T@680	0.78	0.62	5.67	4.18	1.86	5.3	0.57
T@670	0.79	0.63	5.66	4.22	2.18	5.5	0.60
T@660	0.80	0.64	5.37	3.96	1.64	5.0	0.59
T@650	0.81	0.65	5.24	3.71	0.81	4.4	0.56
T@640	0.84	0.70	4.93	3.59	0.97	4.3	0.63



Validation Results

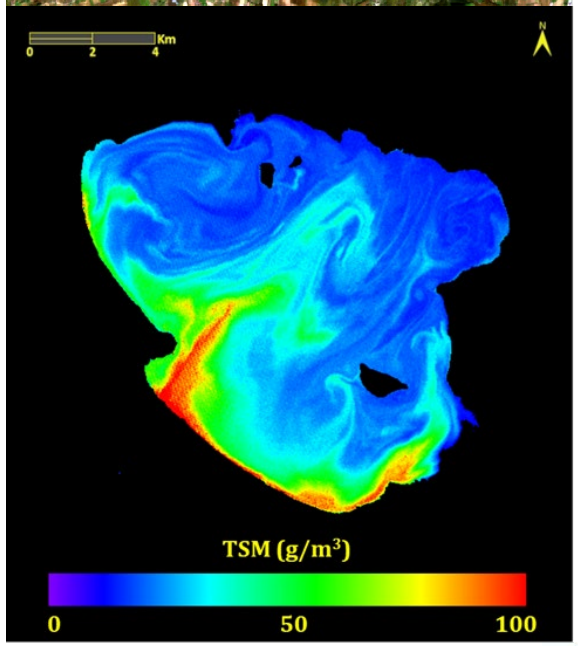
Lago Trasimeno





26/07/2019
03/06/2020
25/07/2020
30/11/2020
09/06/2021
10/09/2021
06/12/2021

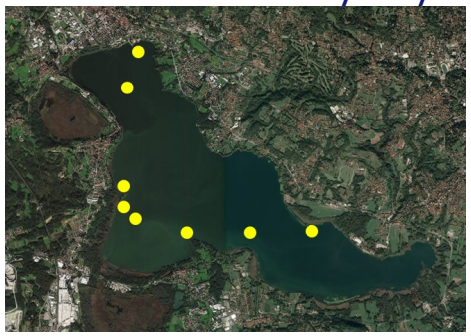
	R^2	RMSD	MAD	Bias	Intercept	Slope
TSM@700	0.86	4.28	3.59	3.16	0.09	0.83
TSM@690	0.93	3.41	2.99	2.38	0.94	0.82
TSM@680	0.89	2.93	2.71	1.70	0.84	0.85
TSM@670	0.88	2.83	2.51	1.43	0.98	0.86
TSM@660	0.90	2.38	2.03	1.01	0.28	0.92
TSM@650	0.94	1.88	1.58	0.63	0.21	0.95
TSM@640	0.91	4.06	3.36	2.92	1.25	0.78



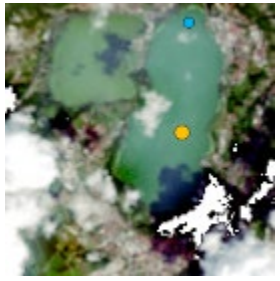
30/11/2020

Validation Results

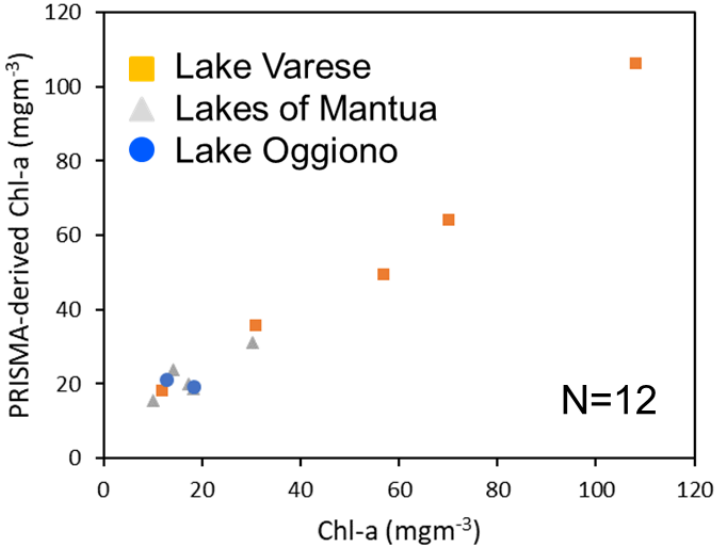
Lake Varese - 16/10/2021



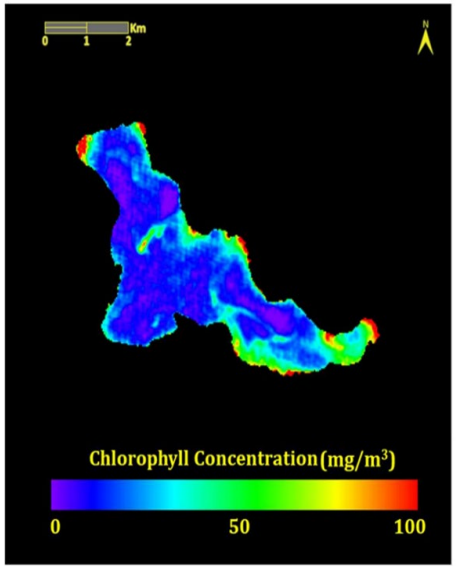
Lake Oggiono - 31/08/2021

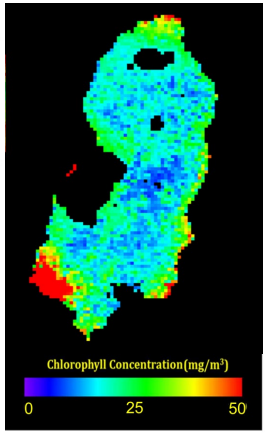


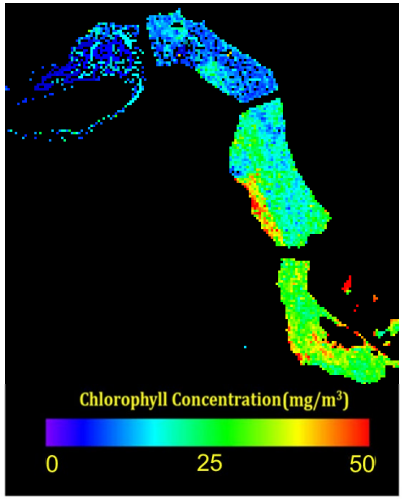
Lake Mantua - 27/10/2021



	R^2	RMSD	MAD	Bias	Intercept	Slope
Chl-a	0.93	5.48	4.61	1.96	-6.20	1.12





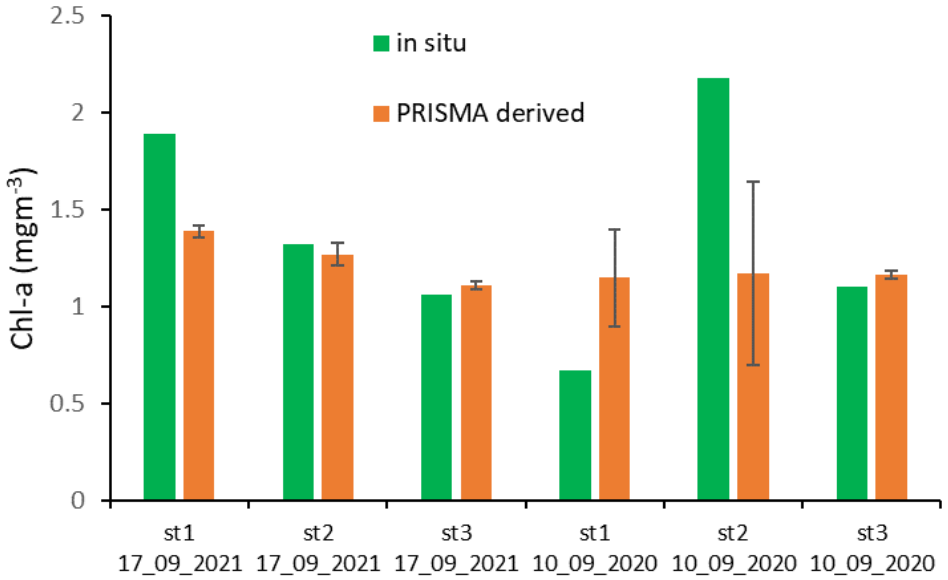


Validation Results

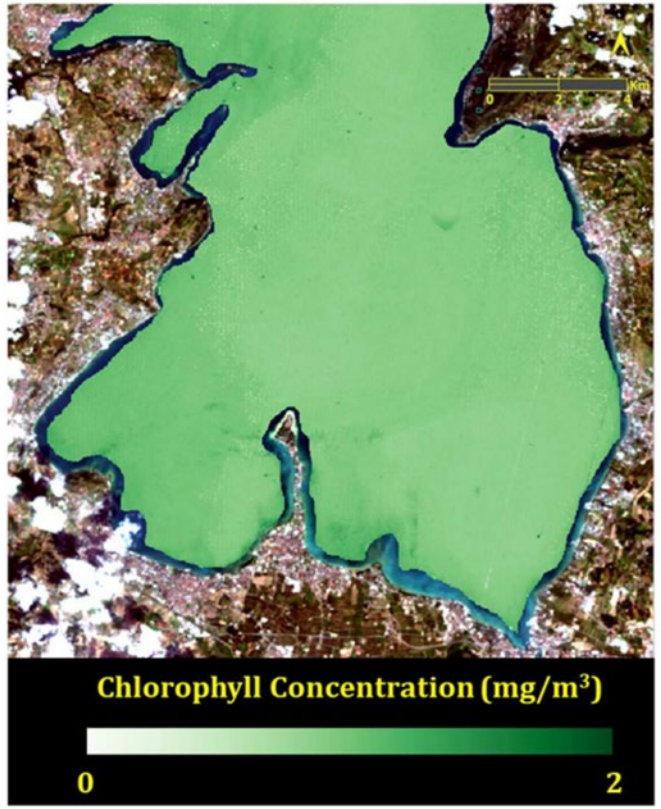
Lake Garda

10/09/2020

17/09/2021



	R^2	RMSD	MAD	Bias	Intercept	Slope
Chl-a	0.31	0.35	0.36	0.16	-2.02	2.69



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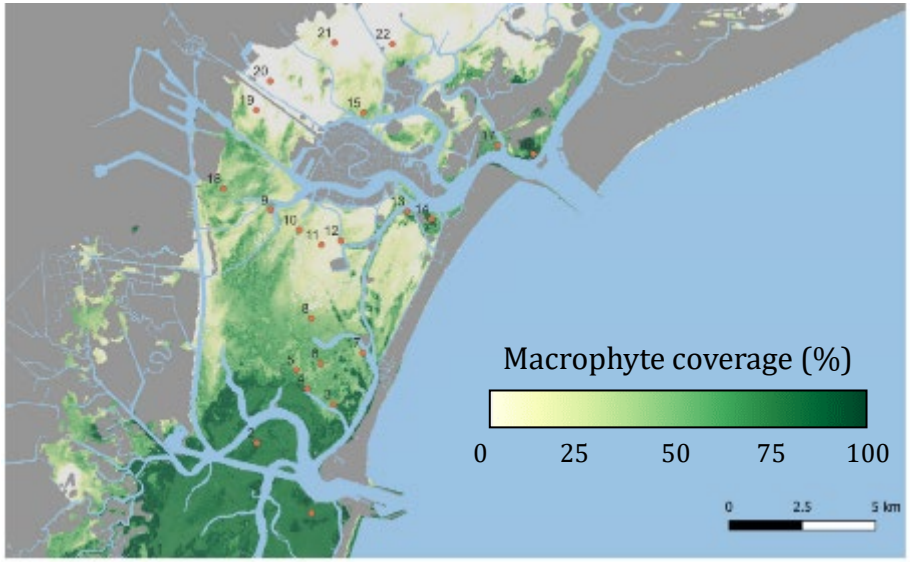
Validation Results

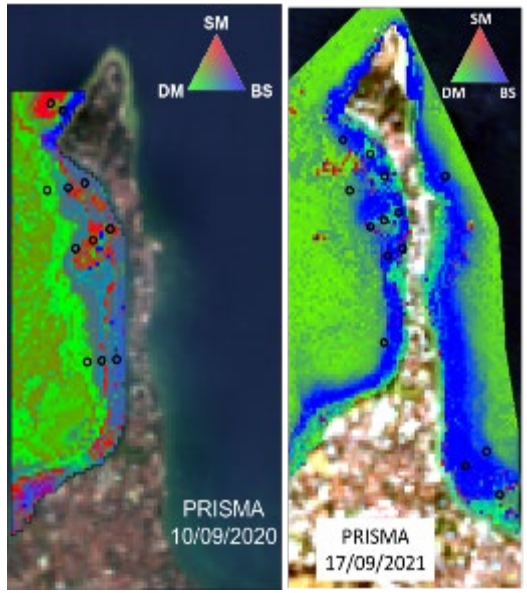
Lagoon of Venice



		In situ			
		BS	SM	DM	User's Accuracy
Classified	BS	5	0	0	100%
	SM	2	5	1	62.5%
	DM	0	1	8	88.9%
	Producer's Accuracy	71.4%	83.3%	88.9%	81.8%

BS = Bare Sediment, SM = Sparse Macrophyte, and DM= Dense Macrophyte

Lake Garda



		In situ			
		BS	SM	DM	User's Accuracy
Classified	BS	7	1	0	88.0%
	SM	1	7	1	80.0%
	DM	0	2	6	75.0%
	Producer's Accuracy	87.5%	70.0%	85.7%	80.0%

Stakeholder & End User

- Users feedbacks were positive both during public meeting and questionnaires.
- Some users have identified the added value of hyperspectral data, due to the capability to obtain innovative products (e.g. phycocyanin) and / or more accurate estimates.
- Other remarks were related to the technological characteristics of the PRISMA mission (e.g. spatial, spectral, temporal and radiometric resolution), probably because users compare them with Copernicus data (especially Sentinel-2).

Bathing

Monitoring inland and coastal waters

Climate Change

Public Health

Water Quality

Prototype Products

Aquaculture

Ecological analysis

Conclusions and Further Developments

- Water quality products were validated in inland and coastal waters characterised by different optical properties. The results are encouraging, confirming that these products are reliable and useful for aquatic ecosystem mapping.
- The results highlight the hyperspectral relevant contribution in the retrieval of adequate water quality products.
- In some environmental conditions (i.e. oligotrophic waters), the low signal of water-leaving reflectance (low SNR) influenced the accuracy of the retrieved products.
- Trasferability to other aquatic sites with specific algorithm parametrization.
- Further validation activities are needed to extend performance analysis to other water bodies, characterised by a wider range of water optical properties.
- Further code optimization / parallel processing and development of a toolbox (GUI).

Thanks for your attention