UNIVERSITÉ PARIS-EST

ÉCOLE DOCTORALE UNIVERSITÉ PARIS-EST
Sciences, Ingénierie et Environnement

Monitoring cyanobacterial blooms using satellite remote sensing and modelling techniques: Application to Karaoun Reservoir, Lebanon

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INTRODUCTION

Cyanobacterial blooms deteriorate the water quality and impair the use of lakes and reservoirs. They also threaten human health through toxin production. Therefore, continuous monitoring of cyanobacterial biomass is critical for bloom detection and further development of early warning systems. Satellite remote sensing has been proven to be an effective tool for identifying and monitoring phytoplankton blooms across the whole lake surface. Recently, remote sensing algorithms have been developed based on phycocyanin (PC) absorption around 620 nm, a specific cyanobacteria pigment. This approach deals mostly with hyperspectral sensors harboring sufficient spectral bands to account for the phycocyanin absorption feature and rarely with multispectral sensors.

OBJECTIVE

Investigate the potential of Landsat 8 Operational Land Imager (OLI), a new generation sensor, to monitor cyanobacterial blooms.

MATERIALS AND METHODS

Study site: Karaoun Reservoir

- The largest freshwater body in Lebanon.
- Hydropower, irrigation, recreation, fisheries.
- Large fluctuations in water level (~25 m).
- Eutrophic (Average CTSI = 65.01 in 2013).
- Regular toxic cyanobacterial bloom events.
- Mainly *Microcystis aeruginosa* and *Aphanizomenon ovalisporum.*
- Anticipated drinking water supply for Beirut.

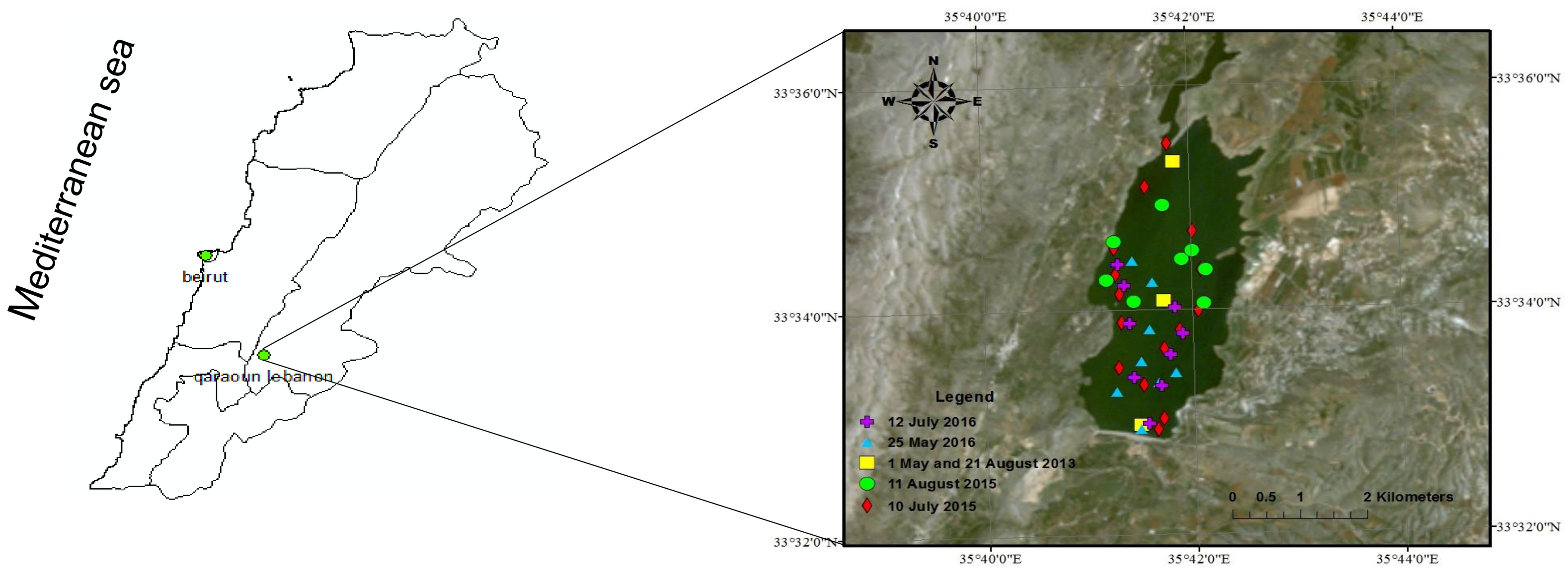


Figure 1: Karaoun Reservoir location with different sampling sites .

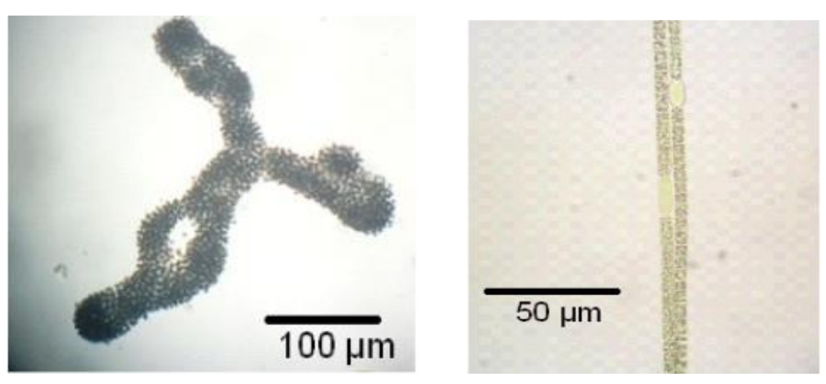
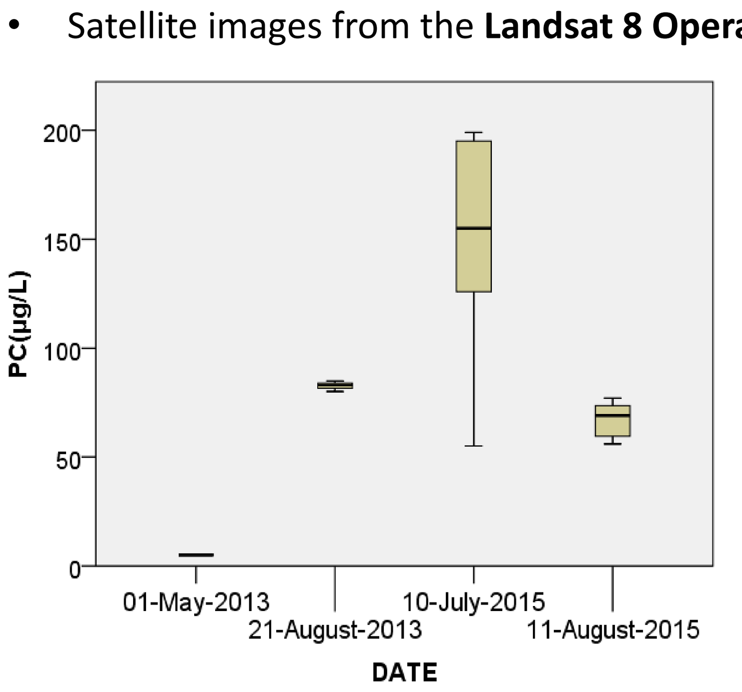


Figure 2: Microcystis aeruginosa (left) and Aphanizomenon ovalisporum (right) found at Karaoun Reservoir.

Morphometry and Hydrology	Values
Surface area at full capacity	12 km²
Maximum storage capacity	224 × 106 m³
Maximum depth	60 m
Mean depth at full capacity	19 m
Altitude at maximum level (m)	860 m
Catchment area	1600 km²
Mean residence time of water	9 months

Field work and data acquisition

- Surface phycocyanin concentrations with the **Trios micro Flu-blue probe** making use of fluorescent excitation. It has an excitation peak at 620 nm and reads the fluorescence emitted between 650 and 660 nm.
- Six field campaigns: four for calibration and two for validation on May 25th and July 12th 2016.
- Satellite images from the **Landsat 8 Operational Land Imager (OLI)** with a temporal resolution of 16 days.



Sensor	Bands	Wavelength (µm)	Spatial resolution (m)
OLI	Band1 - Coastal aerosol	0.43 - 0.45	30
	Band 2 - Blue	0.45 - 0.51	30
	Band 3 - Green	0.53 - 0.59	30
	Band 4 - Red	0.64 - 0.67	30
	Band 5 - Near Infrared (NIR)	0.85-0.88	30
	Band 6 - Shortwave Infrared (SWIR 1)	1.57 - 1.65	30
	Band 7 - Shortwave Infrared(SWIR 2)	2.11 - 2.29	30
	Band 8 - Panchromatic	0.50 - 0.68	15
	Band 9 - Cirrus	1.36 - 1.38	30
TIRS	Band 10 - Thermal Infrared (TIRS) 1	10.60 – 11.19	100 resampled to 30
	Band 11 - Thermal Infrared (TIRS) 2	11.5 - 12.51	100 resampled to 30

Table 1: Landsat 8 band designations (TIRS: Thermal Infrared Sensor)

Image processing

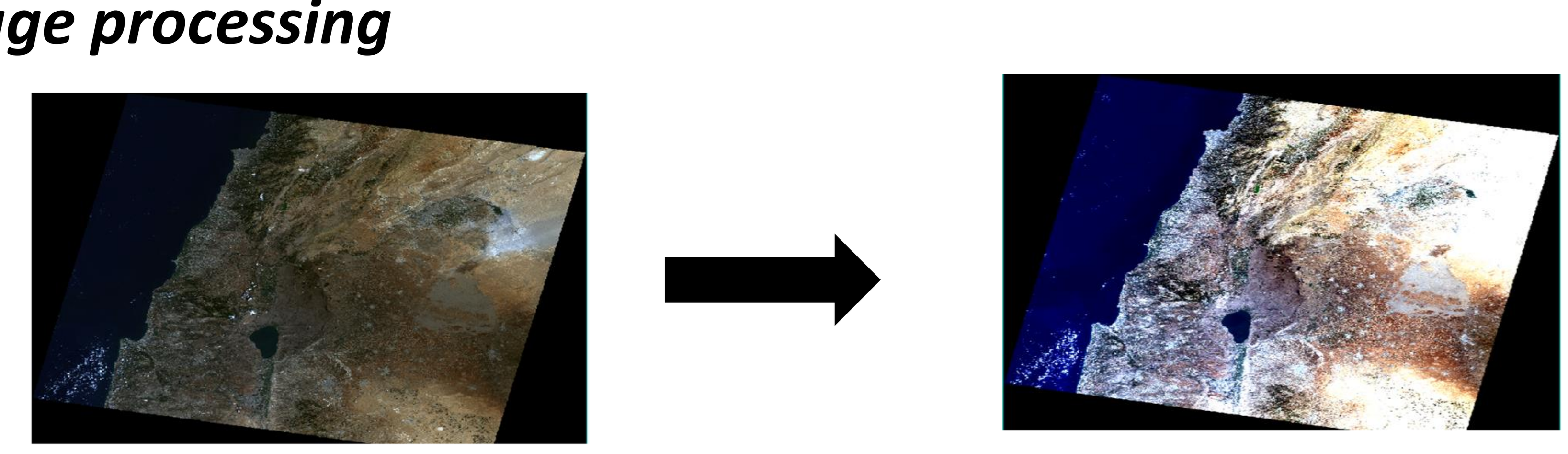


*Figure 3: Radiometric calibration and atmospheric correction (Dark Object Subtraction method) of Landsat 8 images using the **ENVI** software*

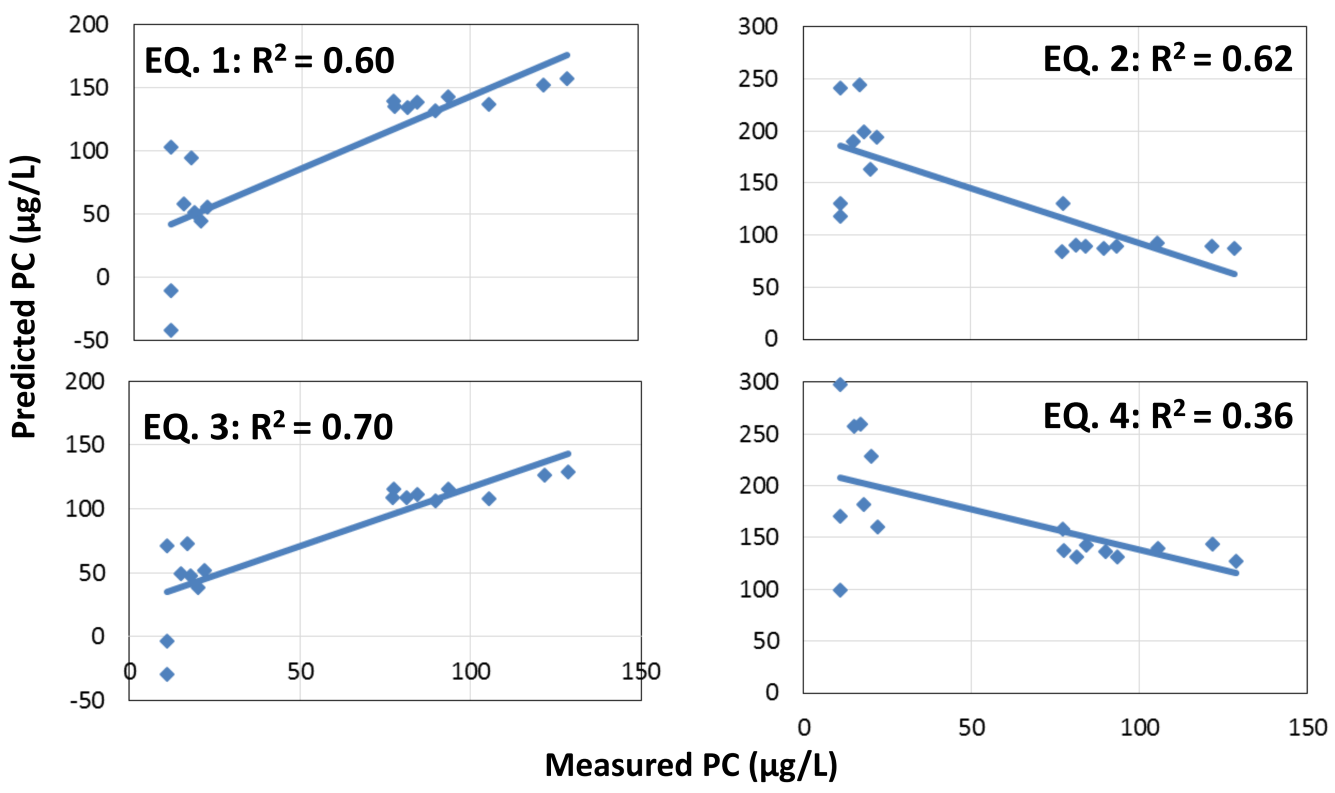
Development and testing of remote sensing algorithms

- On a single band level, reflectance values were extracted for each sampling point by means of the **ArcGIS** software.
- Empirical approach
- Previously proposed phycocyanin algorithms were tested with default parameters, calibrated and validated.

RESULTS

Insufficient performance of calibrated algorithms

- Unsatisfying performance and negative values with default algorithms.
- Low correlations and inaccurate estimates after validation of calibrated algorithms.



Equation 1: $[PC] = -\beta_0 + \beta_{42}\frac{B4}{B2} + \beta_{53}\frac{B5}{B3} - \beta_{64}\frac{B6}{B4} - \beta_{76}\frac{B7}{B6}$

Equation 2: $[PC] = \beta_1 - \beta_2 B2 + \beta_4 B4 - \beta_6 B6 + \beta_7 B7$

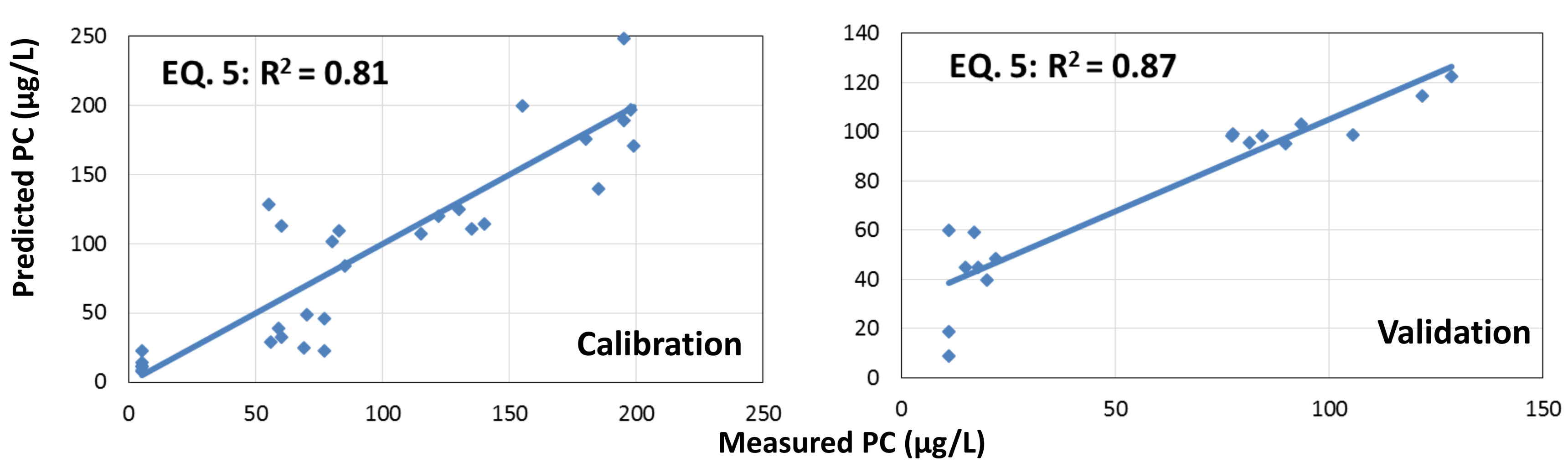
Equation 3: $[PC] = -\beta_2 + \beta_{42}\frac{B4}{B2} + \beta_{52}\frac{B5}{B2} + \beta_{54}\frac{B5}{B4} + \beta_{64}\frac{B6}{B4} - \beta_{74}\frac{B7}{B4} + \beta_{75}\frac{B7}{B5}$

Equation 4: $[PC] = -\beta_3 - \beta_2 B2 + \beta_3 B3 - \beta_4 B4 + \beta_5 B5 + \beta_{54}\frac{B5}{B4} - \beta_{53}\frac{B5}{B3} + \beta_{52}\frac{B5}{B2} + \beta_{43}\frac{B4}{B3} - \beta_{42}\frac{B4}{B2} + \beta_{32}\frac{B3}{B2}$

Outperformance of a band ratio algorithm targeting Landsat 8 OLI data

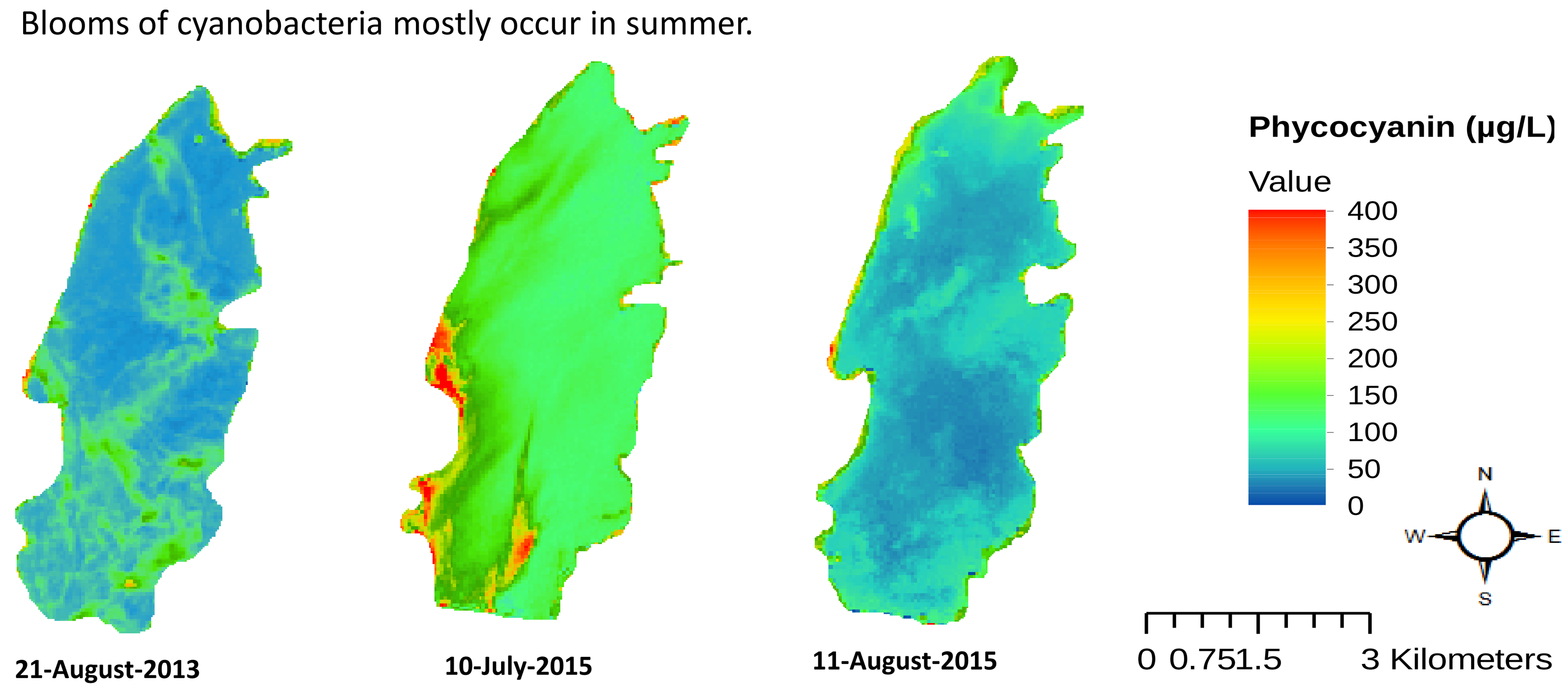
Equation 5: $[PC] = 59.3\left(\frac{B5}{B2}\right) - 8.02$

B5: Near –Infrared
B2: Blue



Maps of phycocyanin concentration

- Phycocyanin concentrations in agreement with those found during surveys.
- Blooms of cyanobacteria mostly occur in summer.



CONCLUSION AND PERSPECTIVES

- Multispectral sensors like Landsat OLI can be used effectively to determine the distribution of phycocyanin and detect cyanobacterial blooms . Being a time and cost effective approach, the near-infrared to blue band ratio algorithm derived in this study will help improve monitoring of cyanobacteria at Karaoun Reservoir
- The use of Sentinels, a recent family of satellites will enhance the quality of such studies as they offer images with higher spatial, spectral and temporal (overpass each 5 days) resolutions. Moreover, results will serve as basis for retrospective studies with use of the Landsat archive.
- Modelling can complement the analysis of satellite imagery and makes it possible to estimate depth profiles and to interpolate temporal gaps in data derived from satellite and traditional water quality monitoring. Therefore, the objective of our current research is to integrate remote sensing and coupled three dimensional hydrodynamic-ecological model (Delft3D suite, Deltares) in order to better monitor and understand the dynamics of cyanobacterial blooms in Karaoun Reservoir. This integration, rare for harmful algal blooms in freshwaters, will present a new perspective for water quality monitoring. It will also be implemented as a tool for building an early warning system.