PROGRAMME OF THE
EUROPEAN UNION

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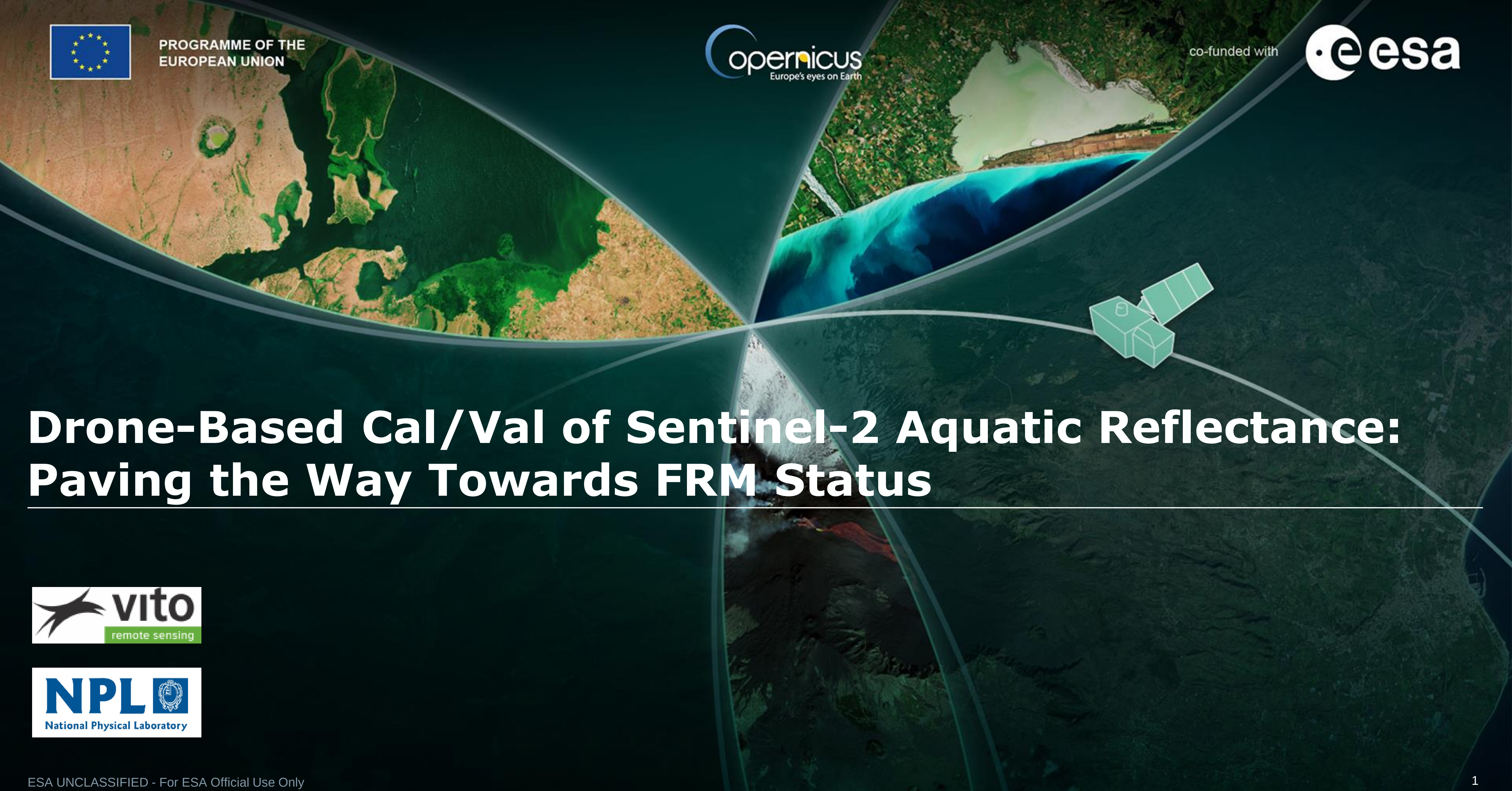


Drone-Based Cal/Val of Sentinel-2 Aquatic Reflectance: Paving the Way Towards FRM Status

Traditional in situ Cal/Val data from fixed stations like AERONET-OC or HYPERNET

Complemented by

Aerial drones **to assess the spatial variability surrounding fixed stations**, helping to determine the representativeness of point measurements for satellite pixel resolution and coverage

Aerial drones to conduct **transects** from the shoreline to the open sea, which in turn **enables the validation of atmospheric correction algorithms such as adjacency correction algorithms**

↓

Holistic approach utilizing aerial drones enhances the accuracy and reliability of satellite Cal/Val processes

Ruddick et al. (2019)

Cal/Val of satellite products requires high-quality in situ measurements, referred to as Fiducial Reference Measurements (FRM).

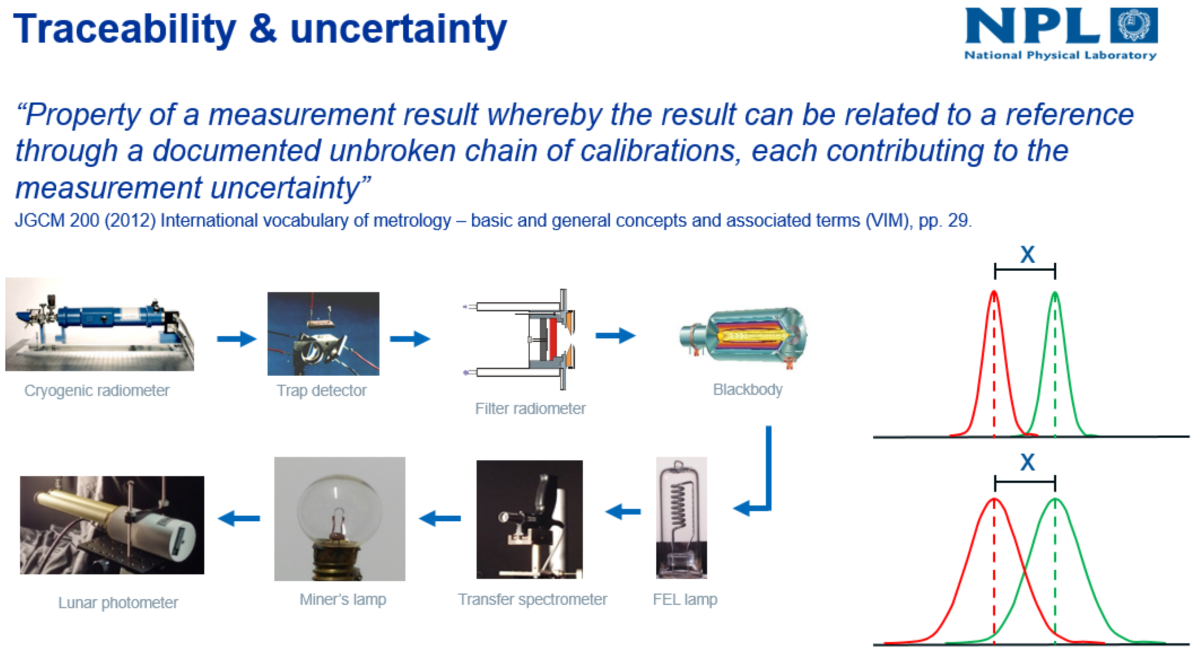
Before a measurement can be labelled as FRM, it should

(i) be accompanied by an uncertainty budget,

(ii) adhere to openly available measurement protocols and community-wide management practices,

(iii) have documented evidence of International System of Units (SI) traceability and

(iv) be independent of the satellite retrieval process.



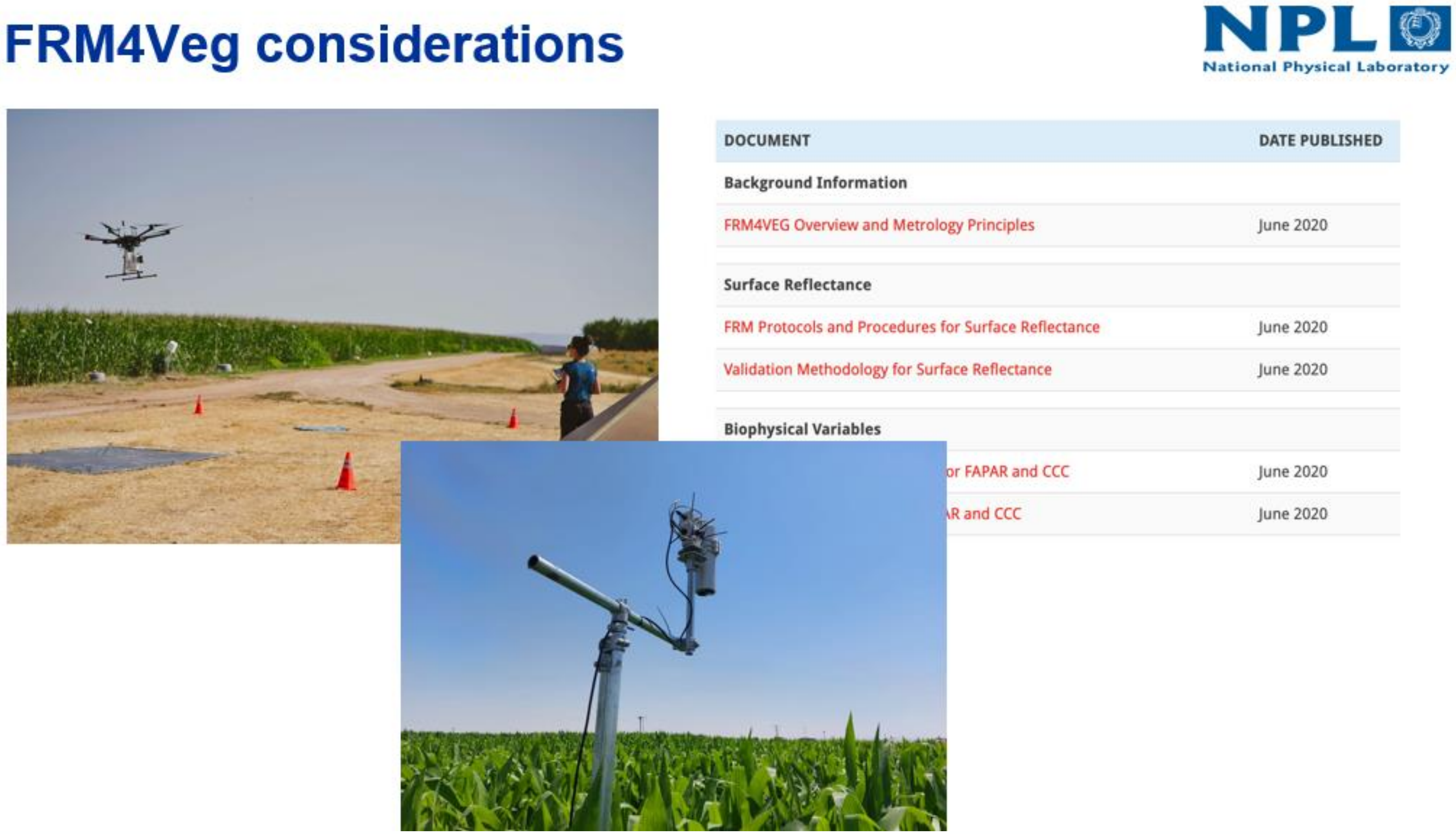
Traceability & uncertainty

NPL National Physical Laboratory

"Property of a measurement result whereby the result can be related to a reference through a documented unbroken chain of calibrations, each contributing to the measurement uncertainty"

JGCM 200 (2012) International vocabulary of metrology – basic and general concepts and associated terms (VIM), pp. 29.

Initial steps towards Fiducial Reference Measurements (FRM) for drones through the FRM4VEG project
SRIX4VEG exercise with focus on land vegetation



FRM4Veg considerations

DOCUMENT	DATE PUBLISHED
Background Information	
FRM4VEG Overview and Metrology Principles	June 2020
Surface Reflectance	
FRM Protocols and Procedures for Surface Reflectance	June 2020
Validation Methodology for Surface Reflectance	June 2020
Biophysical Variables	
or FAPAR and CCC	June 2020
AR and CCC	June 2020

Activities

- Campaign measurements (over a limited period of time but larger area)
- Instrumented sites (over a limited area but continuous in time)
- Protocols and procedures

BUT protocols and findings not always applicable to aquatic applications

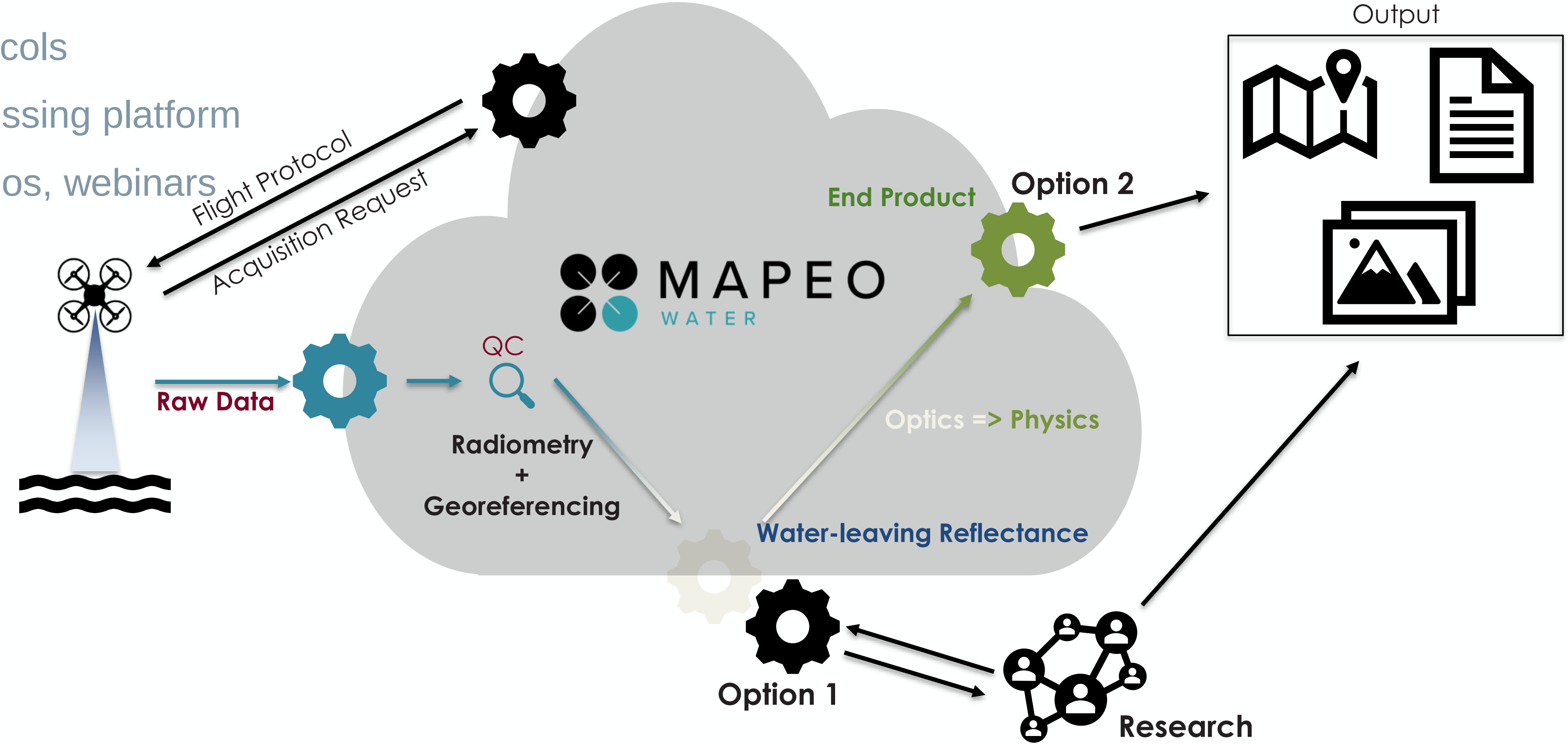
For obtaining **aquatic reflectance with aerial drones** facing challenges like

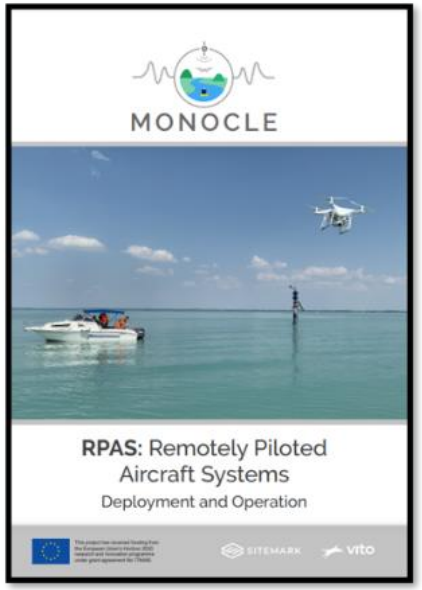
- Presence of sun glint
- Presence of sky glint
- Adjacency effect
- High temporal variability
- Lacking SI traceability
- Geometric accuracy (direct georeferencing)
- Lacking uncertainty estimates

Need to address these challenges to advance the effective utilization of aerial drones for Cal/Val purposes over water

First steps towards FRM: e.g. MapEO-Water co-developed within EU H2020 MONOCLE:

- Drone flight protocols
- Drone data processing platform
- User guides, videos, webinars





MONOCLE

RPAS: Remotely Piloted Aircraft Systems
Deployment and Operation

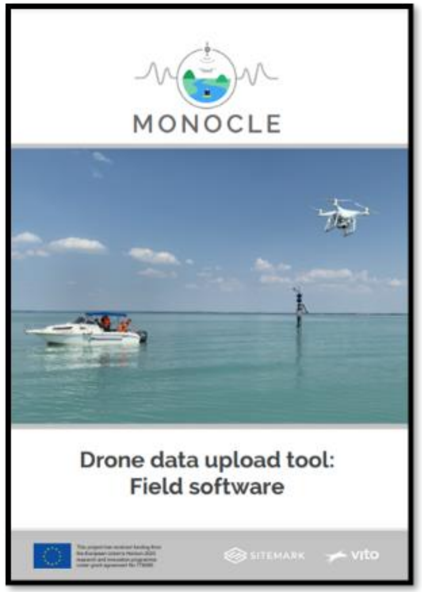
SITEMARK
vito

Avoid sun glint:

- Don’t look nadir
- Look away from the sun

Include calibration panels in absence of irradiance sensor (DLS)

Collect RAW data



MONOCLE

Drone data upload tool:
Field software

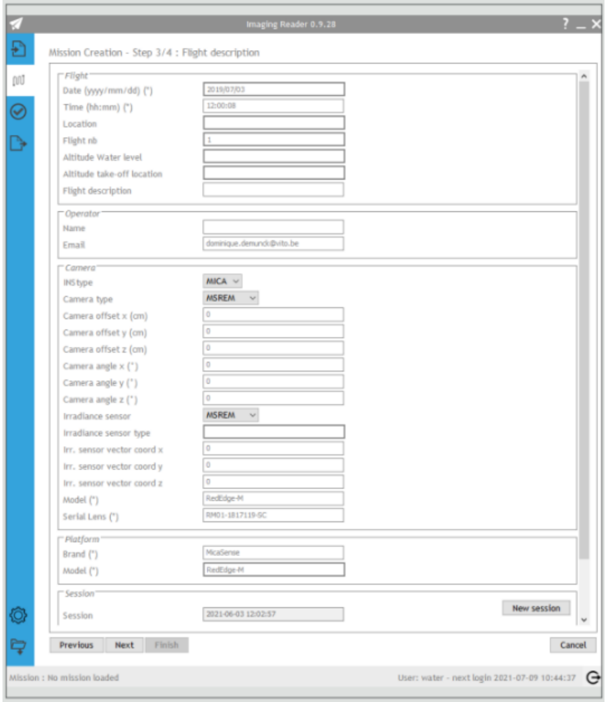
SITEMARK
vito

Data upload tool

+ Metadata (Location, name, relative height difference between take-off location and water level, camera sensor, …)

Aim: Guidelines for drone pilots

Extend: for Cal/Val



Imaging Reader 0.9.28

Mission Creation - Step 3/4 : Flight description

Flight
Date (yyyy/mm/dd) (*) 2019/07/03
Time (hh:mm) (*) 12:00:08
Location
Flight nb 1
Altitude Water level
Altitude take-off location
Flight description

Operator
Name
Email dominique.demunck@vito.be

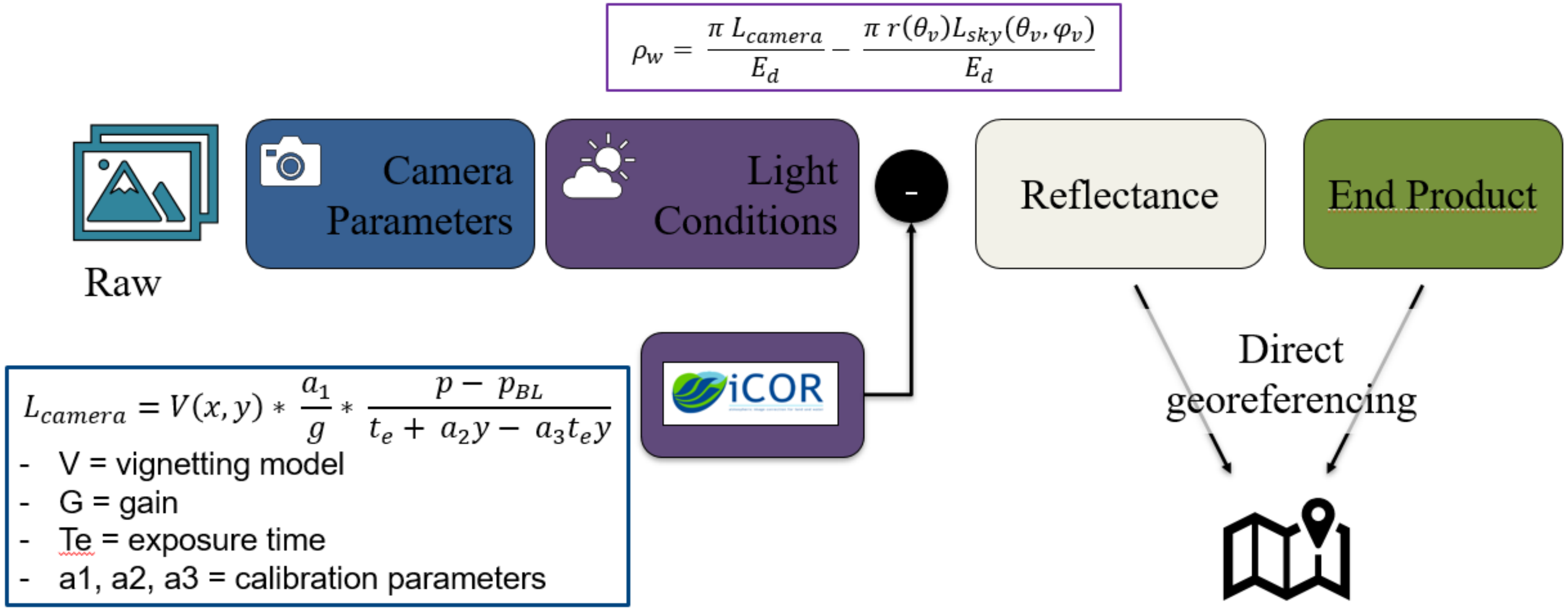
Camera
INS type MICA
Camera type MSREM
Camera offset x (cm) 0
Camera offset y (cm) 0
Camera offset z (cm) 0
Camera angle x (°) 0
Camera angle y (°) 0
Camera angle z (°) 0
Irradiance sensor MSREM
Irradiance sensor type
Irr. sensor vector coord x 0
Irr. sensor vector coord y 0
Irr. sensor vector coord z 0
Model (*) RedEdge-M
Serial Lens (*) RM01-1817119-SC

Platform
Brand (*) MicaSense
Model (*) RedEdge-M

Session
Session 2021-06-03 12:02:57

Mission : No mission loaded
User: water - next login 2021-07-09 10:44:37

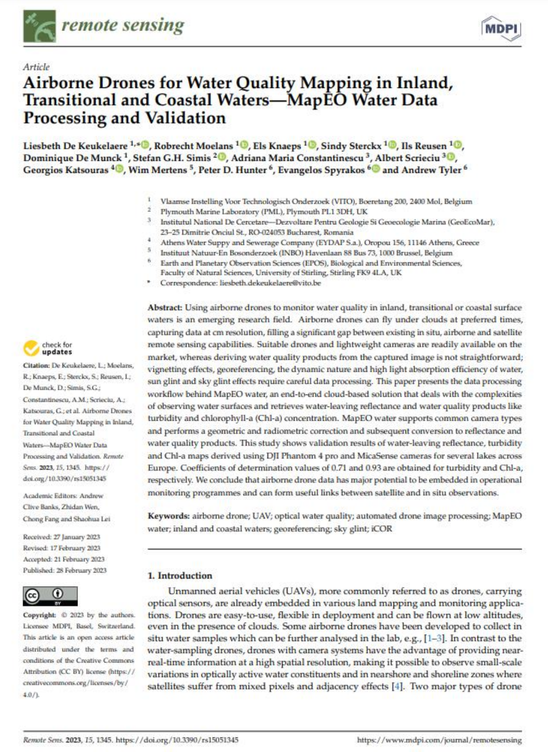
Data Processing



$$\rho_w = \frac{\pi\, L_{camera}}{E_d} - \frac{\pi\, r(\theta_v) L_{sky}(\theta_v, \varphi_v)}{E_d}$$

$$L_{camera} = V(x,y) * \frac{a_1}{g} * \frac{p - p_{BL}}{t_e + a_2 y - a_3 t_e y}$$

- V = vignetting model
- G = gain
- Te = exposure time
- a1, a2, a3 = calibration parameters



remote sensing
MDPI

Article

Airborne Drones for Water Quality Mapping in Inland, Transitional and Coastal Waters—MapEO Water Data Processing and Validation

Liesbeth De Keukelaere [1,*], Robrecht Moelans [1], Els Knaeps [1], Sindy Sterckx [1], Ils Reusen [1], Dominique De Munck [1], Stefan G.H. Simis [2], Adriana Maria Constantinescu [3], Albert Scrieciu [3], Georgios Katsouras [4], Wim Mertens [5], Peter D. Hunter [6], Evangelos Spyrakos [6] and Andrew Tyler [6]

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[3] Institutul National De Cercetare—Dezvoltare Pentru Geologie Si Geoecologie Marina (GeoEcoMar), 23–25 Dimitrie Onciul St., RO-024053 Bucharest, Romania
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[6] Earth and Planetary Observation Sciences (EPOS), Biological and Environmental Sciences, Faculty of Natural Sciences, University of Stirling, Stirling FK9 4LA, UK
* Correspondence: liesbeth.dekeukelaere@vito.be

check for updates

Citation: De Keukelaere, L.; Moelans, R.; Knaeps, E.; Sterckx, S.; Reusen, I.; De Munck, D.; Simis, S.G.; Constantinescu, A.M.; Scrieciu, A.; Katsouras, G.; et al. Airborne Drones for Water Quality Mapping in Inland, Transitional and Coastal Waters—MapEO Water Data Processing and Validation. *Remote Sens.* **2023**, *15*, 1345. https://doi.org/10.3390/rs15051345

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Abstract: Using airborne drones to monitor water quality in inland, transitional or coastal surface waters is an emerging research field. Airborne drones can fly under clouds at preferred times, capturing data at cm resolution, filling a significant gap between existing in situ, airborne and satellite remote sensing capabilities. Suitable drones and lightweight cameras are readily available on the market, whereas deriving water quality products from the captured image is not straightforward; vignetting effects, georeferencing, the dynamic nature and high light absorption efficiency of water, sun glint and sky glint effects require careful data processing. This paper presents the data processing workflow behind MapEO water, an end-to-end cloud-based solution that deals with the complexities of observing water surfaces and retrieves water-leaving reflectance and water quality products like turbidity and chlorophyll-a (Chl-a) concentration. MapEO water supports common camera types and performs a geometric and radiometric correction and subsequent conversion to reflectance and water quality products. This study shows validation results of water-leaving reflectance, turbidity and Chl-a maps derived using DJI Phantom 4 pro and MicaSense cameras for several lakes across Europe. Coefficients of determination values of 0.71 and 0.93 are obtained for turbidity and Chl-a, respectively. We conclude that airborne drone data has major potential to be embedded in operational monitoring programmes and can form useful links between satellite and in situ observations.

Keywords: airborne drone; UAV; optical water quality; automated drone image processing; MapEO water; inland and coastal waters; georeferencing; sky glint; iCOR

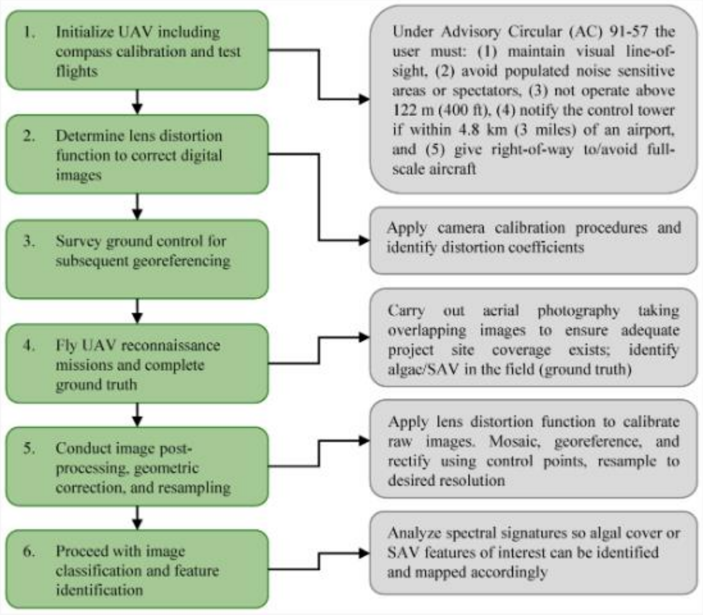
1. Introduction

Unmanned aerial vehicles (UAVs), more commonly referred to as drones, carrying optical sensors, are already embedded in various land mapping and monitoring applications. Drones are easy-to-use, flexible in deployment and can be flown at low altitudes, even in the presence of clouds. Some airborne drones have been developed to collect in situ water samples which can be further analysed in the lab, e.g., [1–3]. In contrast to the water-sampling drones, drones with camera systems have the advantage of providing near-real-time information at a high spatial resolution, making it possible to observe small-scale variations in optically active water constituents and in nearshore and shoreline zones where satellites suffer from mixed pixels and adjacency effects [4]. Two major types of drone

Remote Sens. **2023**, *15*, 1345. https://doi.org/10.3390/rs15051345 https://www.mdpi.com/journal/remotesensing

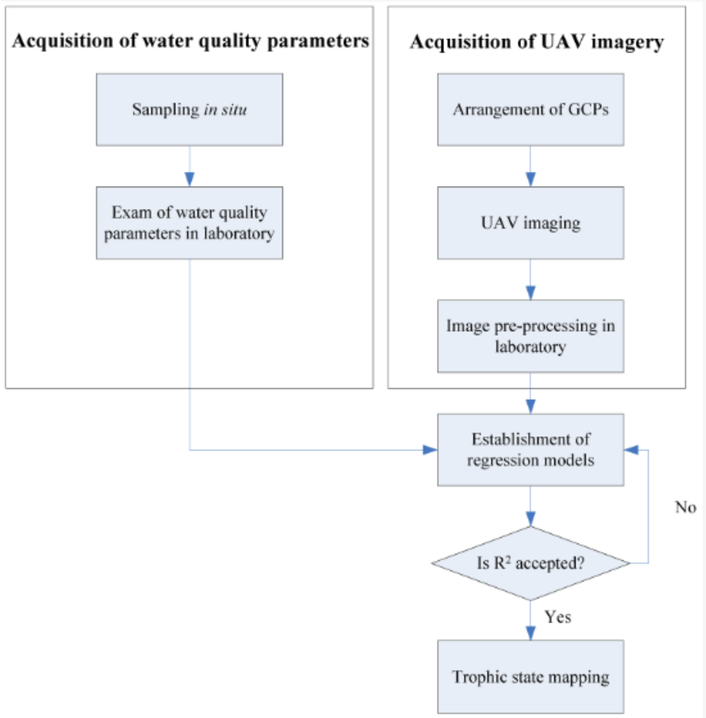
De Keukelaere et al. Remote Sens. ***2023****, 15, 1345. https://doi.org/10.3390/rs15051345*

Figure 2. Steps for unmanned aerial vehicle (UAV) use and subsequent algal cover mapping in shallow rivers.



*Flynn, K.F.; Chapra, S. Remote Sensing of Submerged Aquatic Vegetation in a Shallow Non-Turbid River Using an Unmanned Aerial Vehicle. Remote. Sens. **2014**, 6, 12815–12836.*

Figure 2. Flowchart of applying UAV multispectral imagery coupled with measurement, *in situ*, to trophic state mapping of small reservoirs.



*Su, T.-C.; Chou, H.-T. Application of Multispectral Sensors Carried on Unmanned Aerial Vehicle (UAV) to Trophic State Mapping of Small Reservoirs: A Case Study of Tain-Pu Reservoir in Kinmen, Taiwan. Remote Sens. **2015**, 7, 10078–10097.*

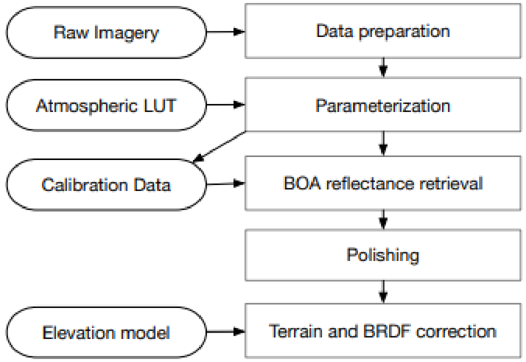


Figure 1. Processing flowchart of the DROACOR method

Schläpfer, Daniel, Christoph Popp, and Rudolf Richter. "Drone data atmospheric correction concept for multi-and hyperspectral imagery–the droacor model." The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences 43 (2020): 473-478.

Demonstration Cases

RGB

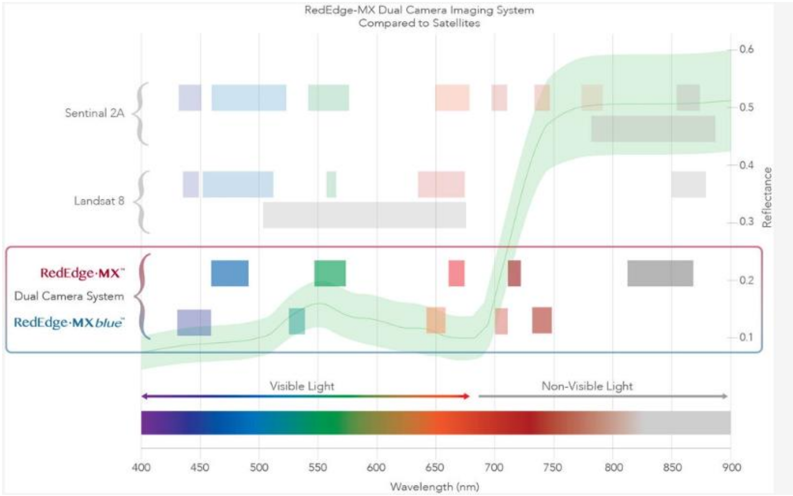
DJI Phantom 4pro

Multispectral

Micasense RedEdge-M

Micasense Dual

Belgium	North Sea Sibelco Lake Papelenvijver Lakes, Balen Rupelmondse Kreek Grote Laak
Greece	Lake Marathon
Hungary	Lake Balaton
Poland	Gdansk
Romania	Danube Delta
Sweden	Langvik
The Netherlands	Markermeer Wissenkerke Texel Breskens
United Kingdom	Loch Leven
Antarctica	*Punta Hannah*

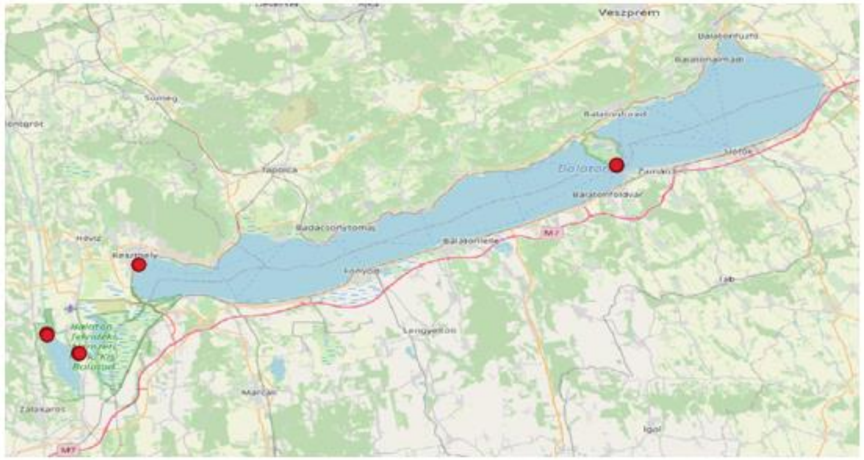


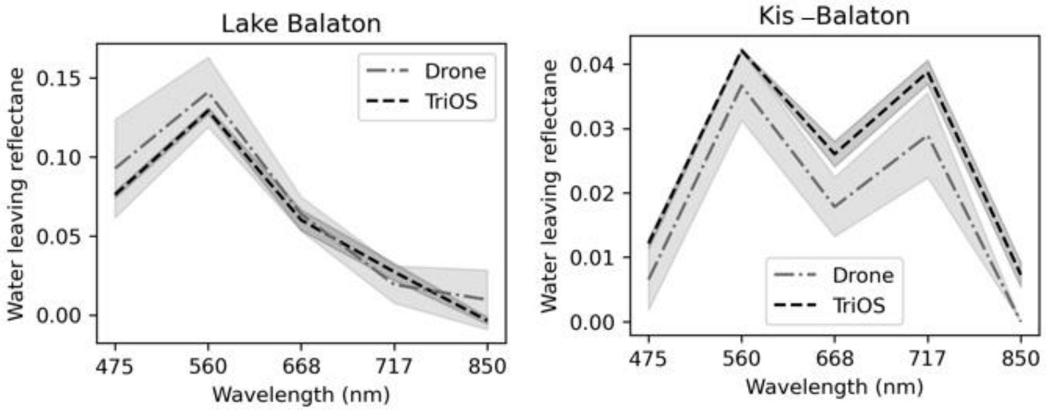
Source: Dronenerds.com

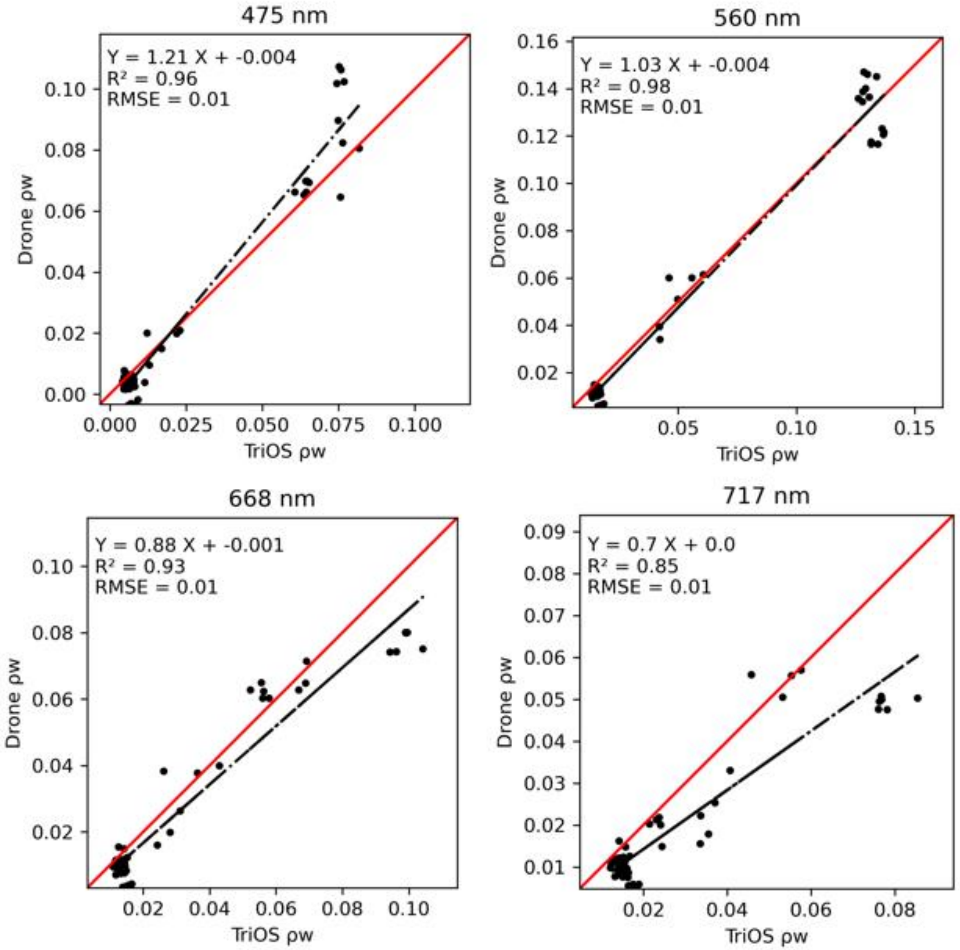
SRF measured at NERC Field Spectroscopy Facility

vito.be

Validation Drone-Based Aquatic Reflectance







De Keukelaere et al. Remote Sens. ***2023****, 15, 1345. https://doi.org/10.3390/rs15051345*

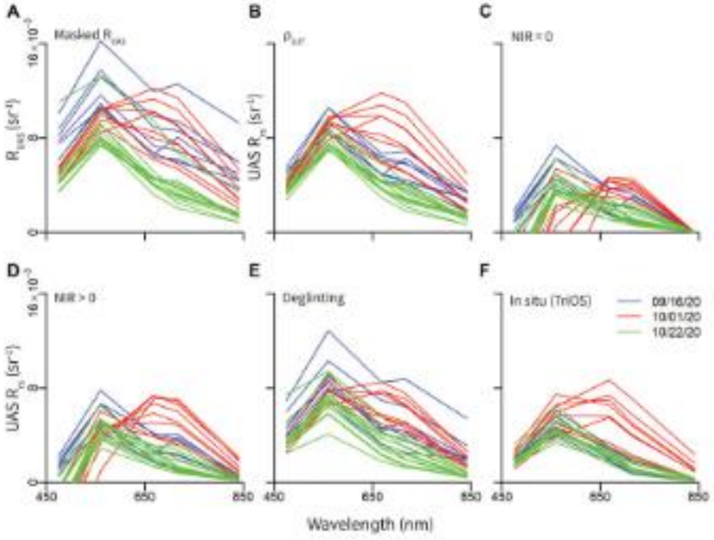


FIGURE 7. Total UAS reflectance (R_{UAS}) (A) and remote sensing reflectance (R_{rs}) spectra using various methods to remove surface reflected light: (B) ρ look-up table from HydroLight simulations, (C) Dark pixel assumption with NIR = 0, (D) Dark pixel assumption with NIR >0, (E) Deglinting methods following Hochberg et al. (2003), and (F) *In situ* R_{rs} spectra from TriOS sensors with MicaSense SRFs applied. Negative values are not shown in plots.

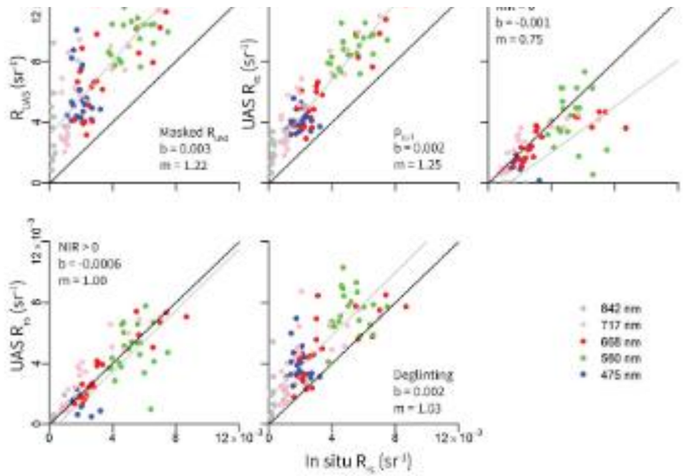
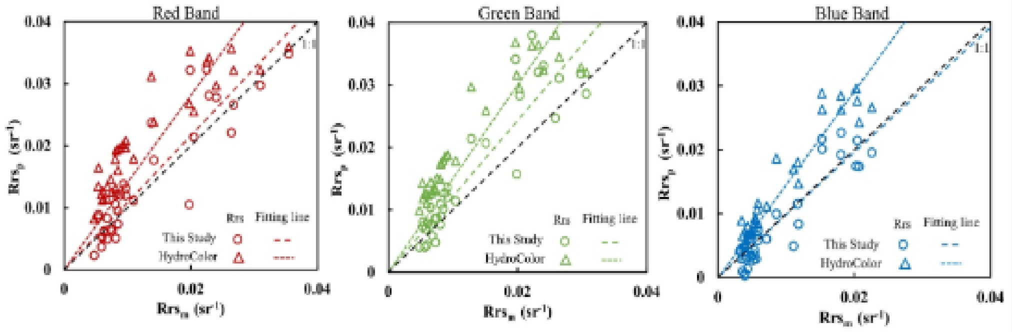


FIGURE 8. Comparison of UAS radiometry and *in situ* R_{rs} in all bands at each station (n = 28) using different methods to remove surface reflected light after initial sun glint masking. (A) Total UAS derived reflectance (R_{UAS}), (B) ρ look-up table from HydroLight simulations, (C) Dark pixel assumption with NIR = 0, (D) Dark pixel assumption with NIR >0, (E) Deglinting methods following Hochberg et al. (2003). Negative values are not shown in plots.

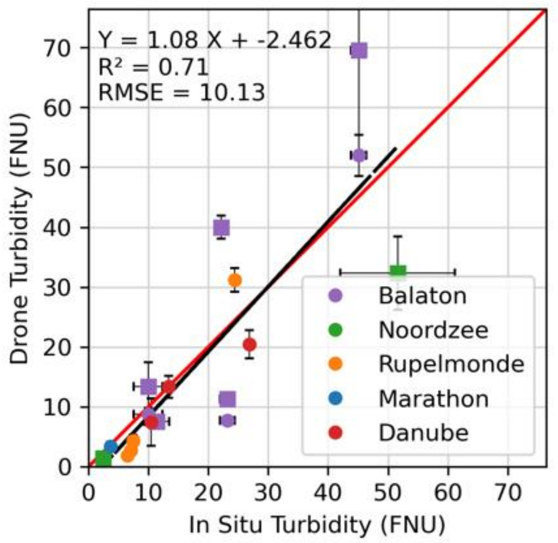
Windle, A. et al. Front. Environ. Sci. ***2021****, 9, 674247.*

Figure 6. Scatterplots of water leaving reflectance derived from digital images at 31 sampling stations (using the method in this Study vs. the method in HydroColor) and measured by the spectrometer in RGB (red, green, blue) bands.



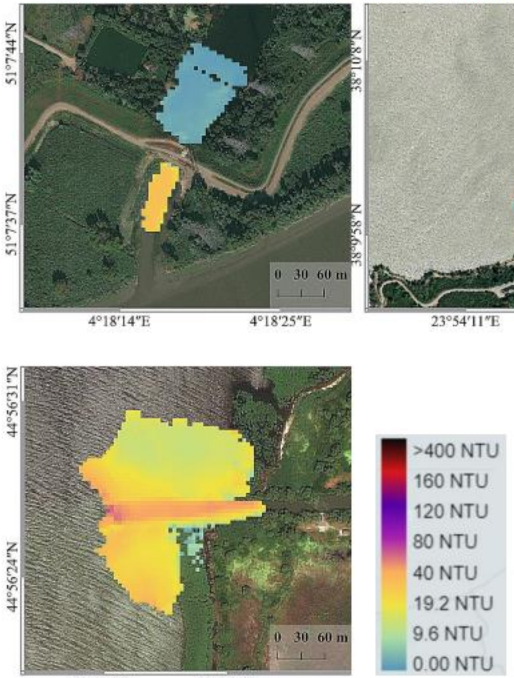
Gao, M. et al. . Cards. Sensors ***2020****, 20, 6580.*

Validation – Turbidity



Turbidity Mean

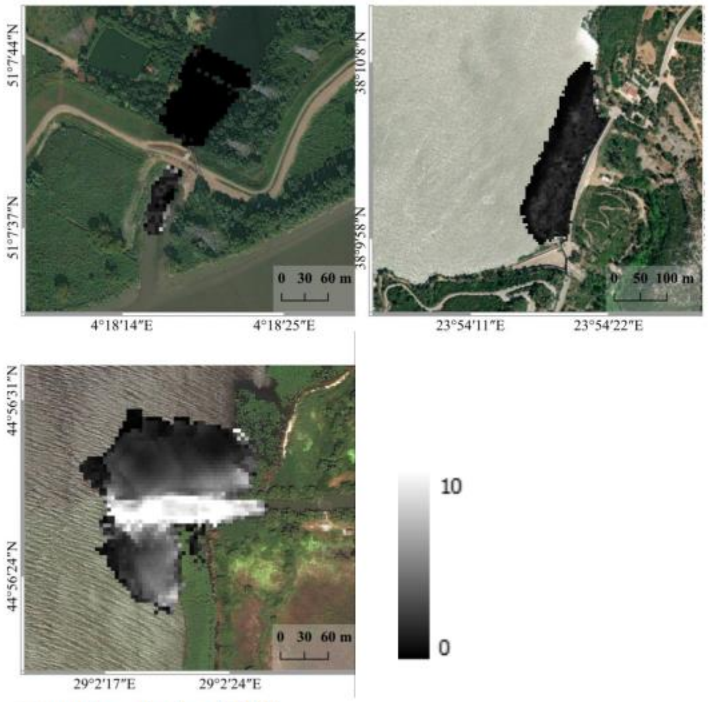
Rupelmondse Creek (BE) Lake Marathon (GR)



Danube Delta (RO)

Turbidity Std

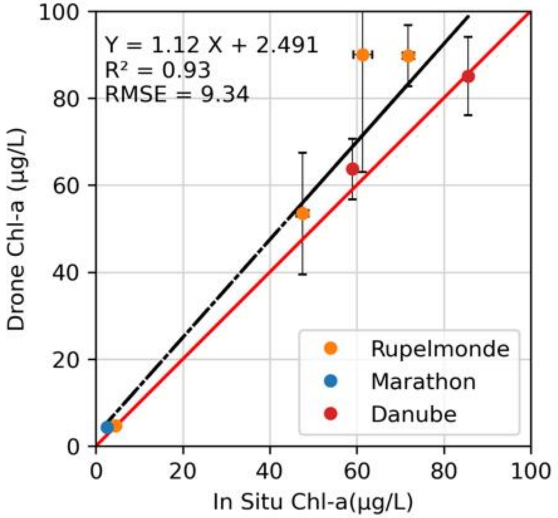
Rupelmondse Creek (BE) Lake Marathon (GR)



Danube Delta (RO)

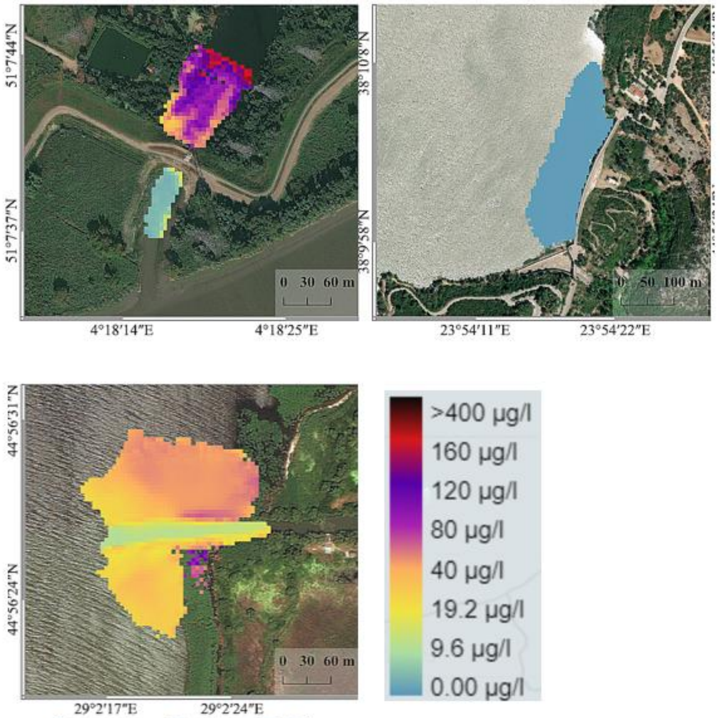
De Keukelaere et al. Remote Sens. ***2023****, 15, 1345.*
https://doi.org/10.3390/rs15051345

Validation – Chlorophyll-a



Rupelmonde Creek (BE)

Lake Marathon (GR)



Danube Delta (RO)

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De Keukelaere et al. Remote Sens. ***2023****, 15, 1345.*
https://doi.org/10.3390/rs15051345

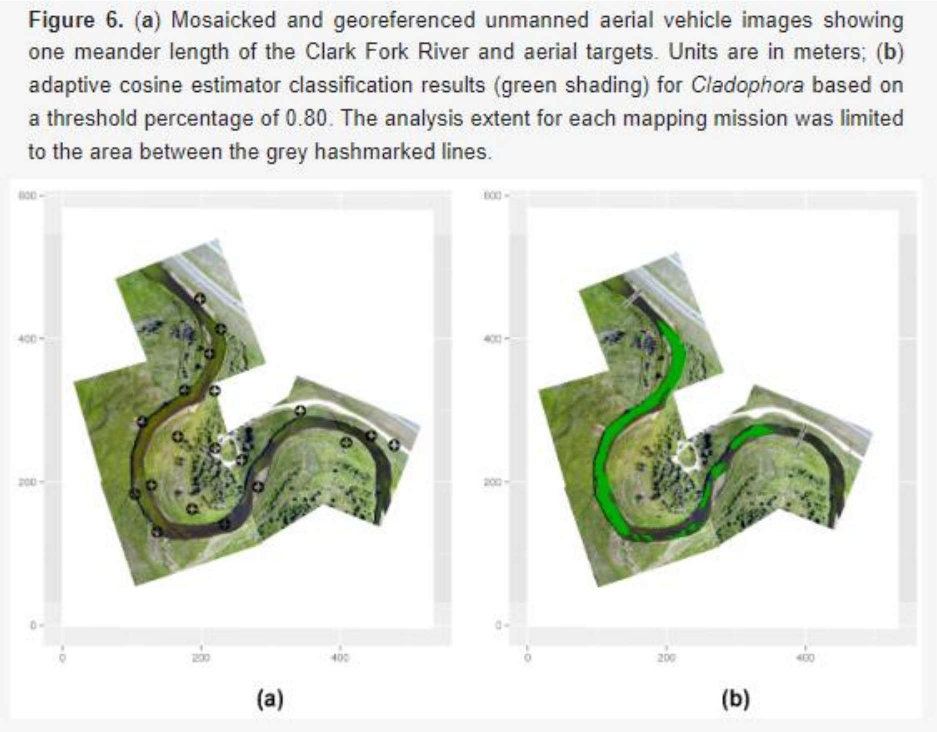
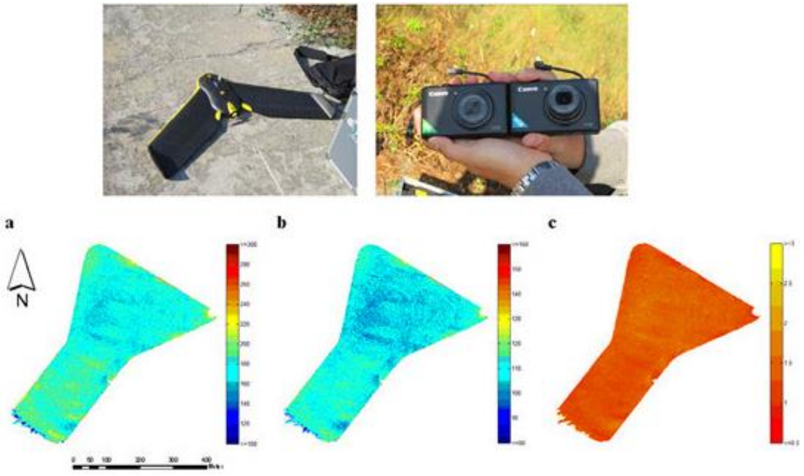


Figure 6. (**a**) Mosaicked and georeferenced unmanned aerial vehicle images showing one meander length of the Clark Fork River and aerial targets. Units are in meters; (**b**) adaptive cosine estimator classification results (green shading) for *Cladophora* based on a threshold percentage of 0.80. The analysis extent for each mapping mission was limited to the area between the grey hashmarked lines.

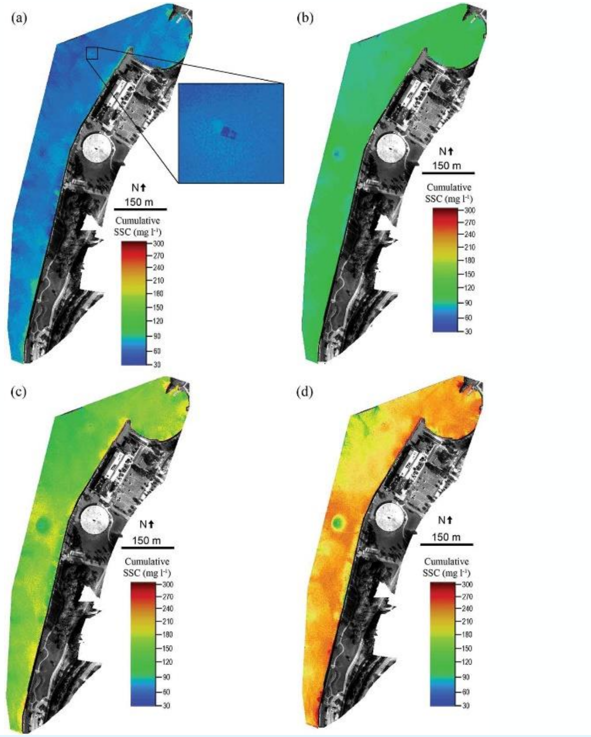
Flynn, K.F.; Chapra, S. Remote Sensing of Submerged Aquatic Vegetation in a Shallow Non-Turbid River Using an Unmanned Aerial Vehicle. Remote. Sens. ***2014****, 6, 12815–12836.*



An application of RGB (right) and NIR (left) sensors carried on fixed-wing UAV to concentration mapping of (**a**) chlorophyll-a (μg l^{-1}), (**b**) total phosphorous (μg l^{-1}), and (**c**) Secchi disk depth (m) for Tain-Pu reservoir in Kinmen, Taiwan on 24 Nov. 2014.

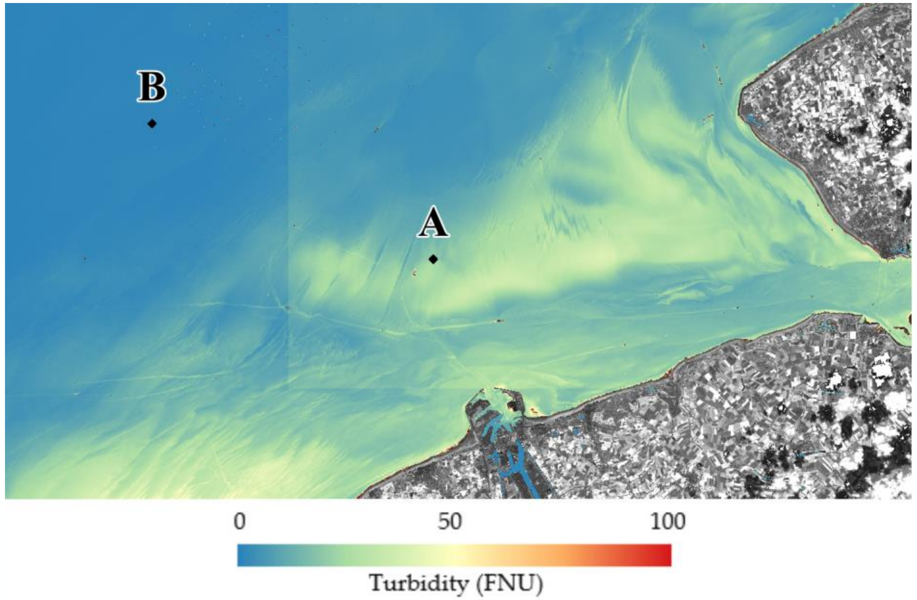
Su, T.-C.; Chou, H.-T. Application of Multispectral Sensors Carried on Unmanned Aerial Vehicle (UAV) to Trophic State Mapping of Small Reservoirs: A Case Study of Tain-Pu Reservoir in Kinmen, Taiwan. Remote Sens. ***2015****, 7, 10078–10097.*

Figure 6. UAV-based cumulative SSC maps of the Maumee River in downtown Toledo. (a) Cumulative SSC from 0 to 15 cm depth. Zoomed in section is of the boat used for water sampling. Increased SSC is detected behind the boat as the propeller is mixing up the water; (b) cumulative SSC from 0 to 61 cm depth; (c) cumulative SSC from 0 to 91 cm depth; (d) cumulative SSC from 0 to 182 cm depth.



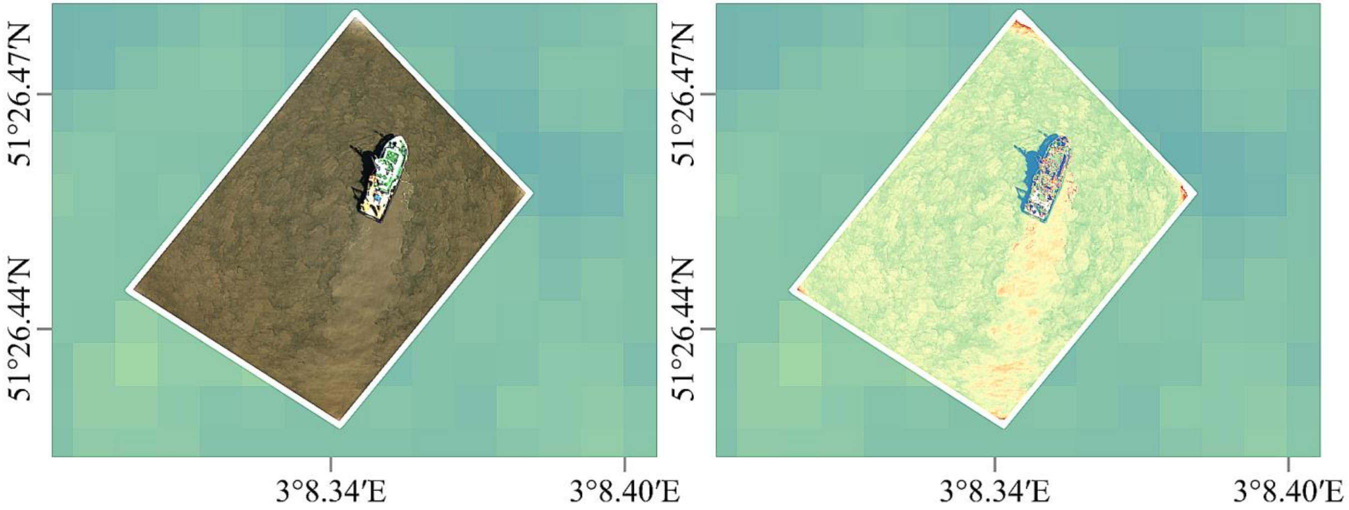
Larson, M.D.; Milas, A.S.; Vincent, R.K.; Evans, J.E. Multi-depth suspended sediment estimation using high-resolution remote-sensing UAV in Maumee River, Ohio. Int. J. Remote. Sens. ***2018****, 39, 5472–5489.*

Sentinel-2 10:59 UTC

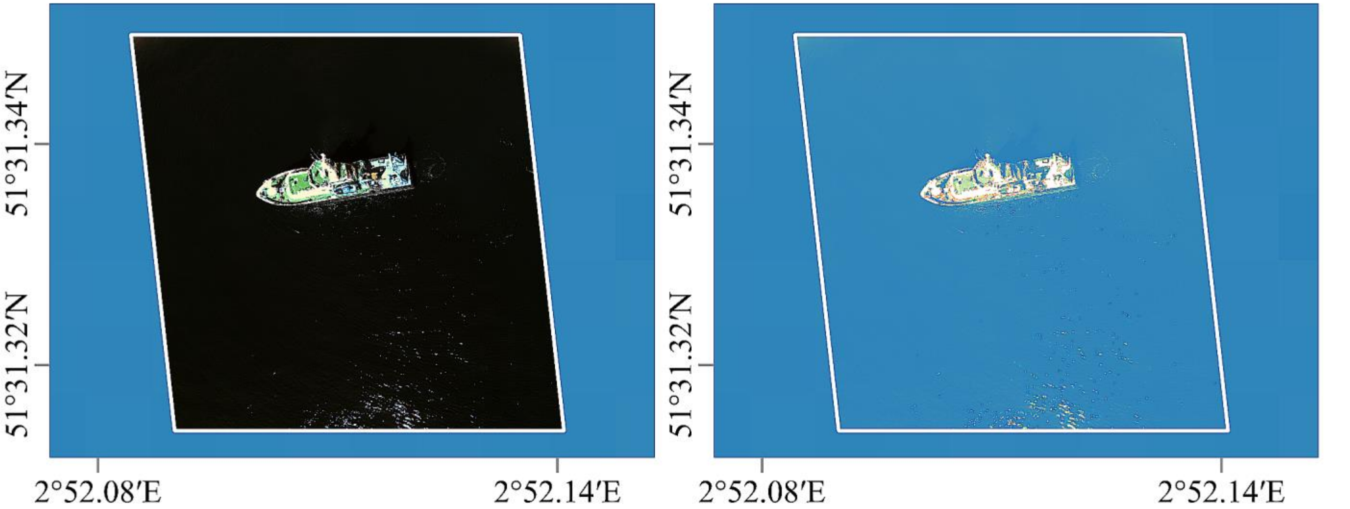


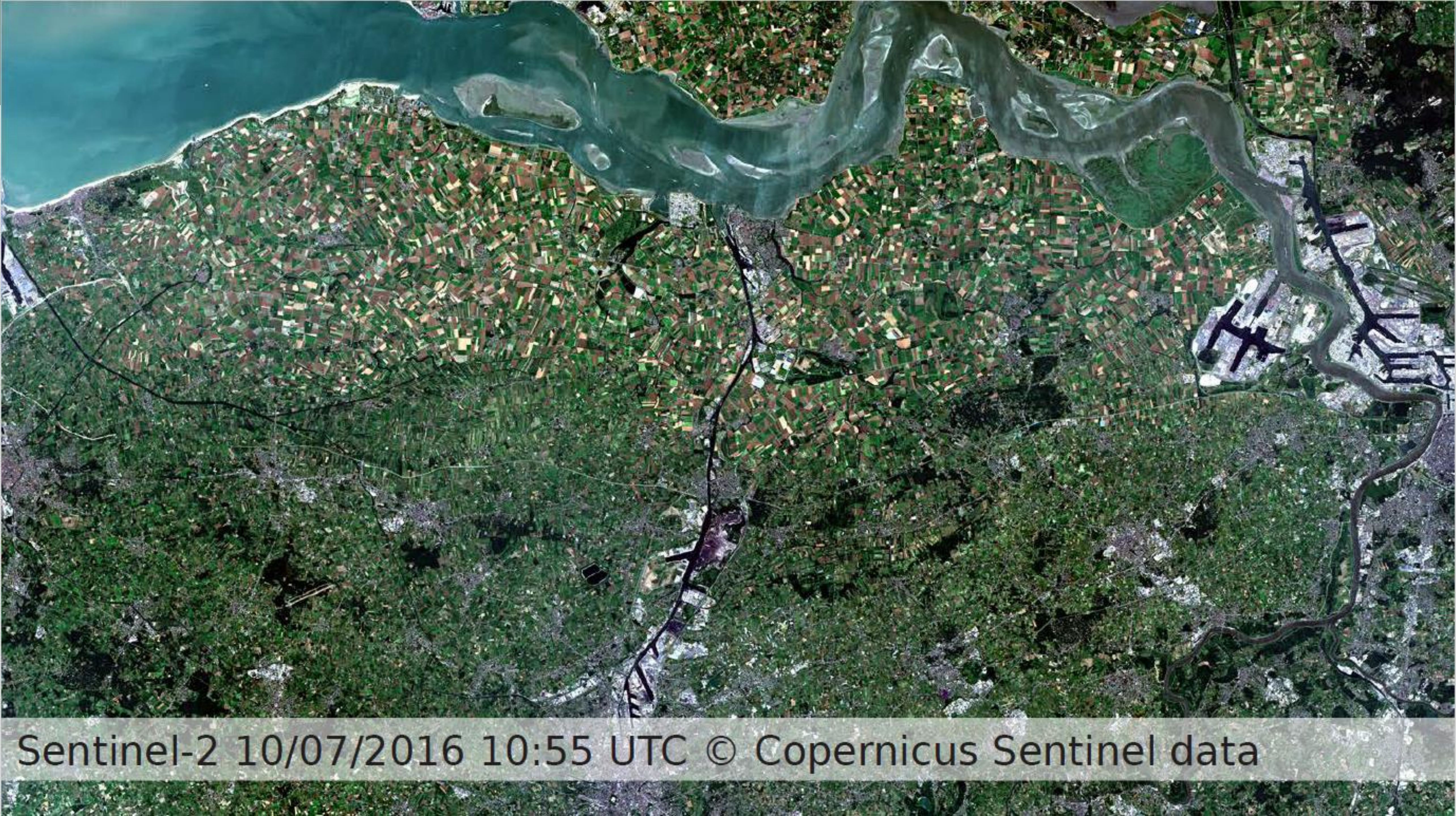
	Tur (FNU) - A	Tur (FNU) - B
S2	19–21	1.5
Drone	Plume: 40–60 Backgr: 30–40	0.5 – 5
IS	51.6 (40.7 – 58.6)	2.5

Location A - 10:05 UTC Drone

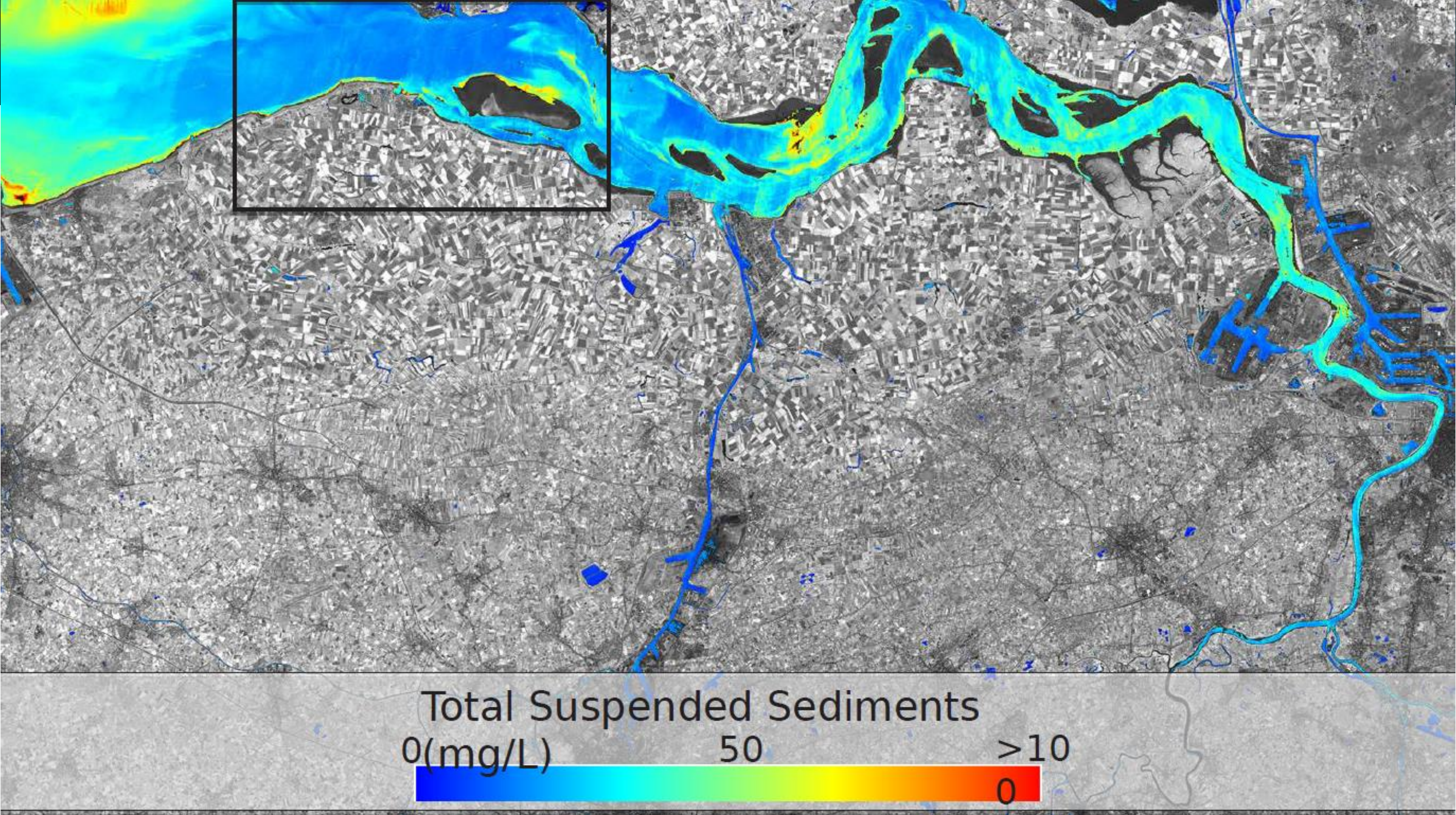


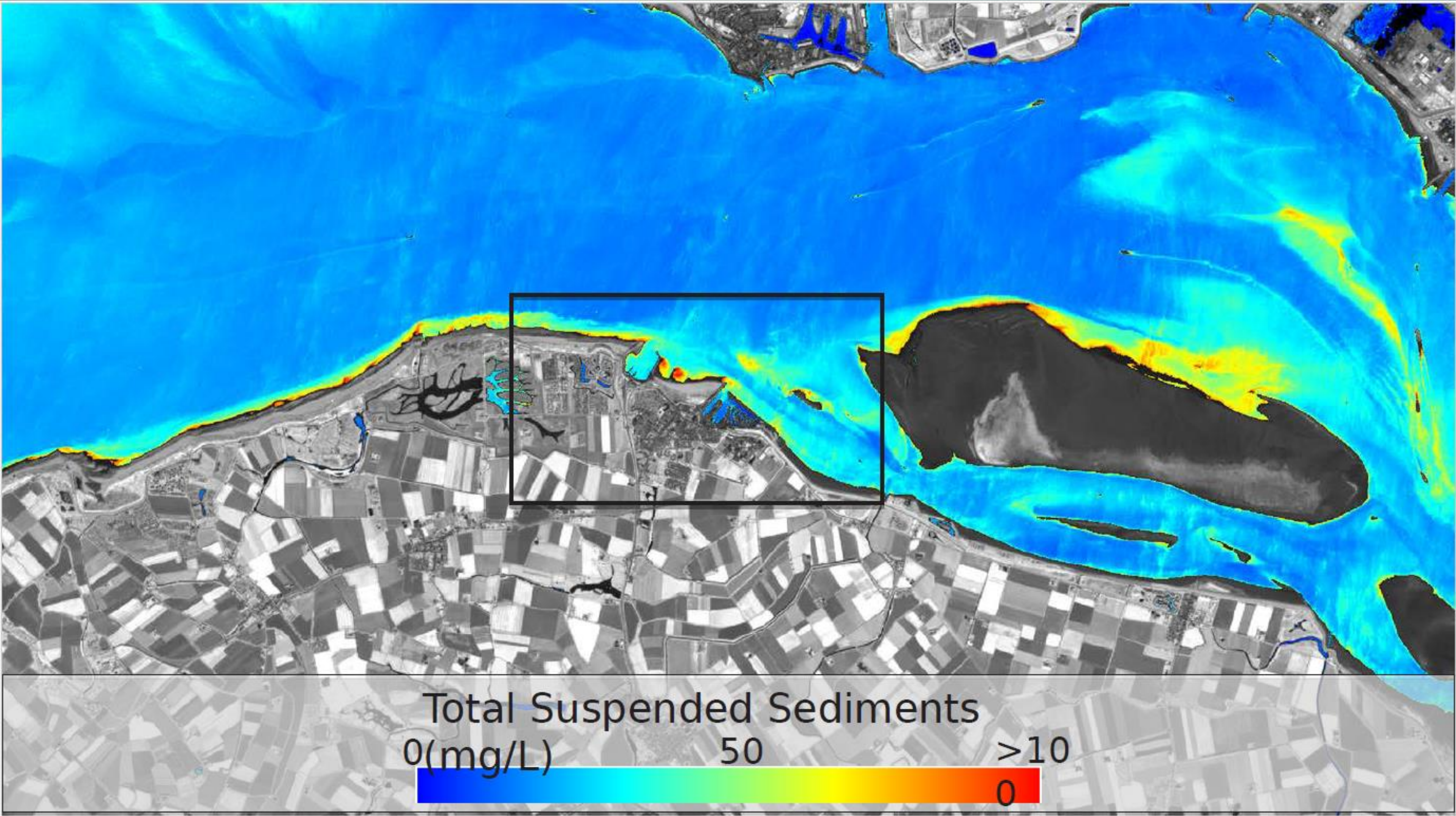
Location B - 12:32 UTC Drone

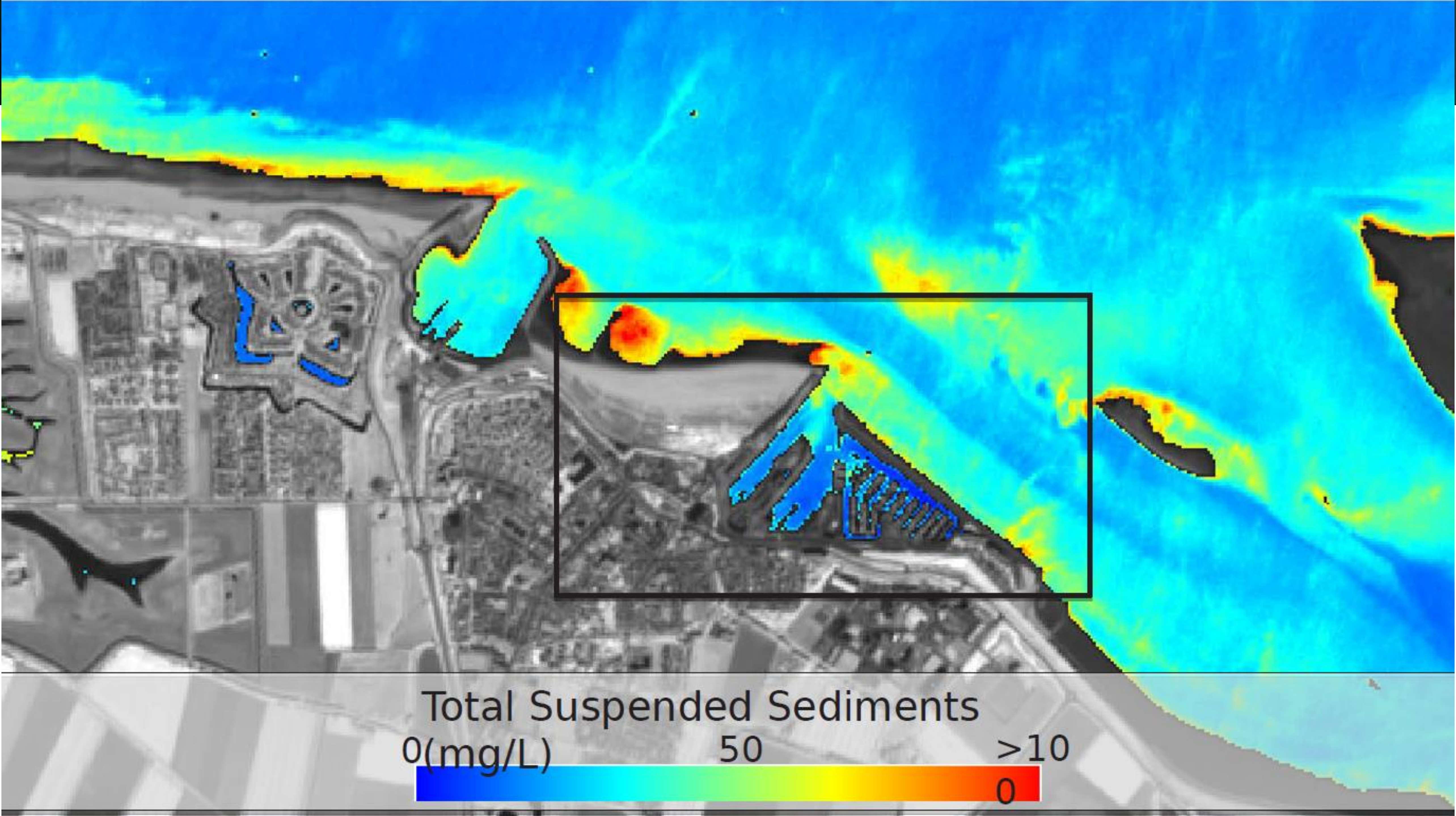


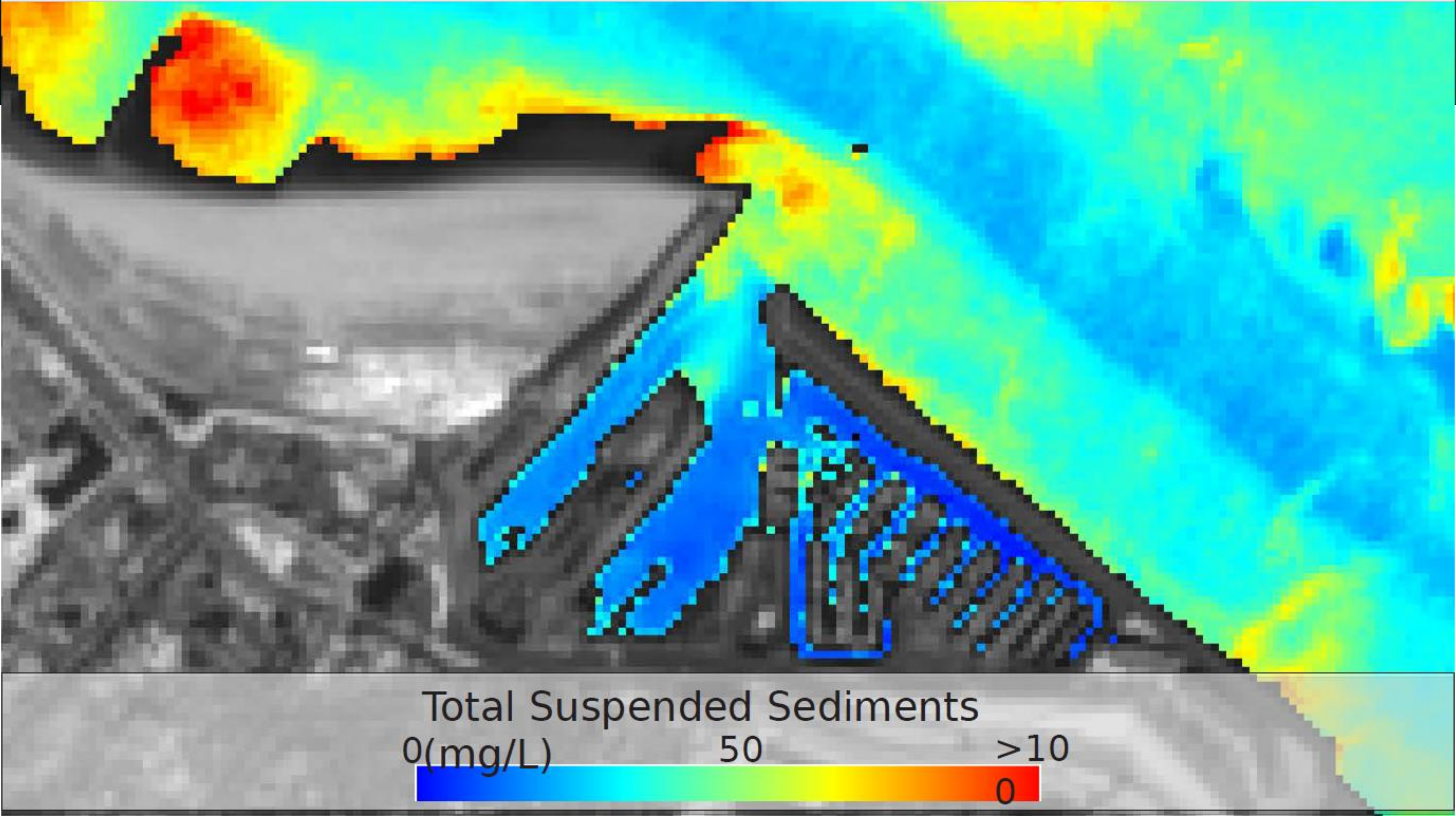


Sentinel-2 10/07/2016 10:55 UTC © Copernicus Sentinel data


Total Suspended Sediments
0(mg/L)
50
>10
0


Total Suspended Sediments
0(mg/L)
50
>10
0


Total Suspended Sediments
0(mg/L)
50
>10
0


Total Suspended Sediments
0(mg/L)
50
>10
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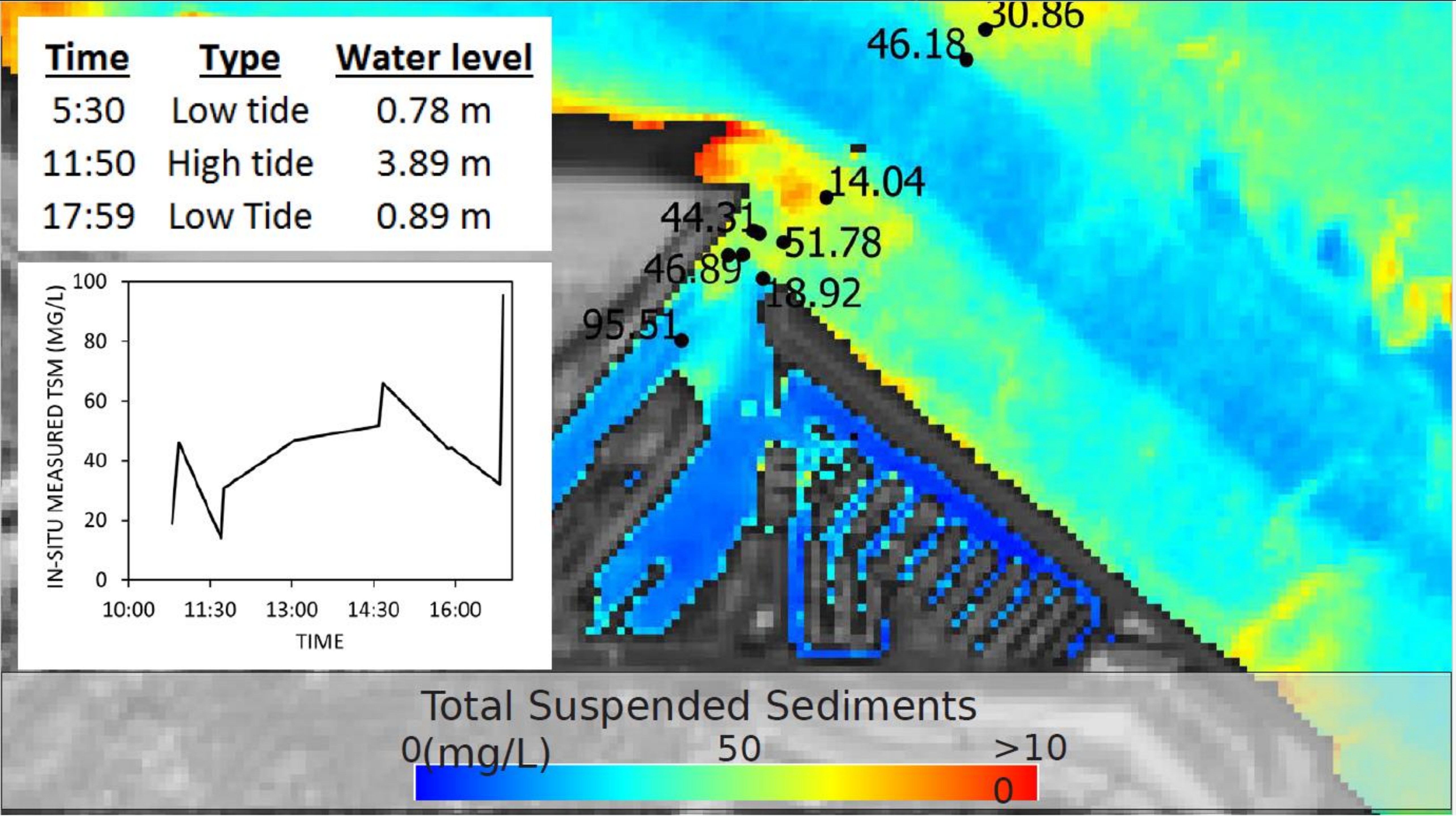
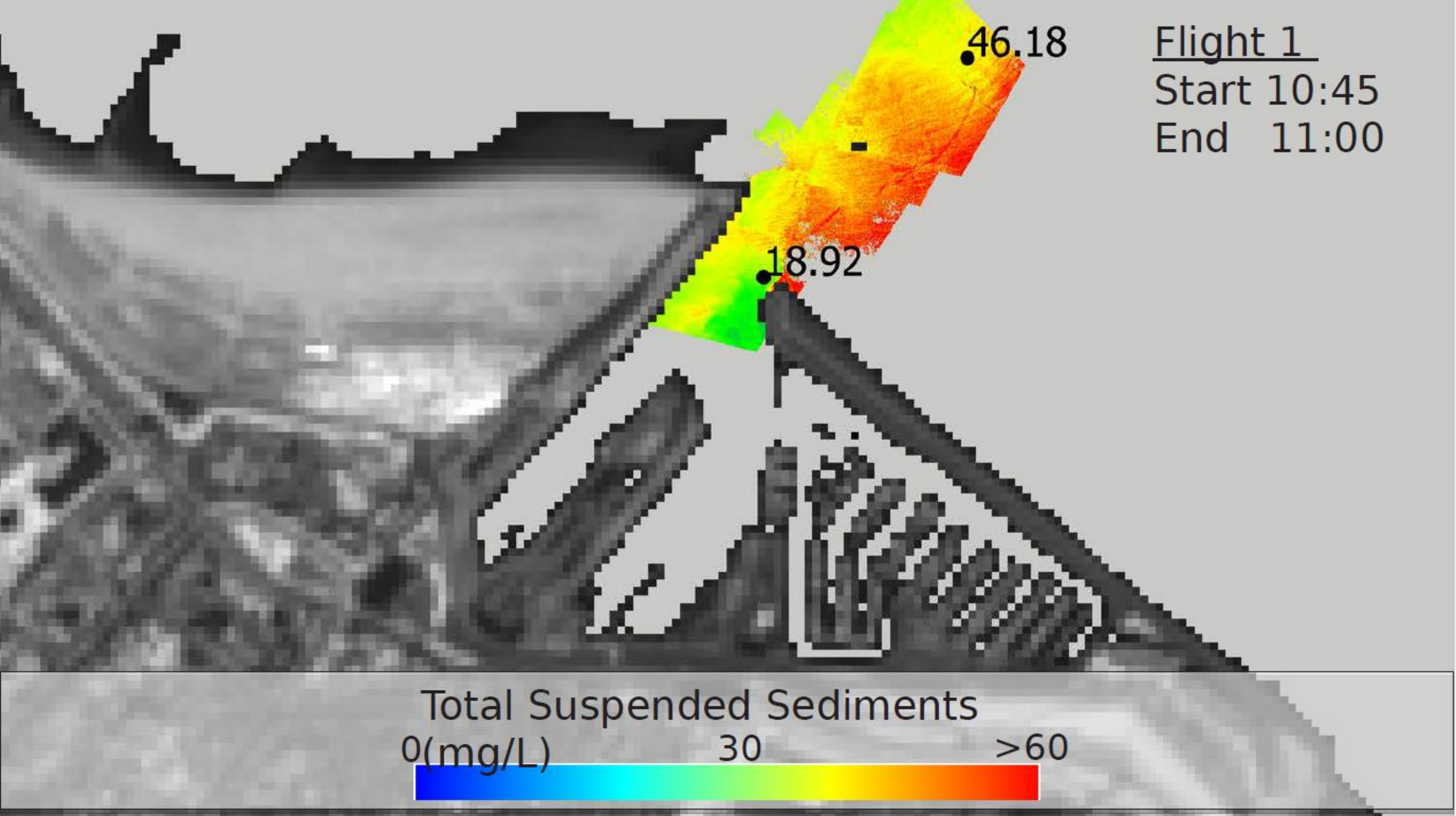
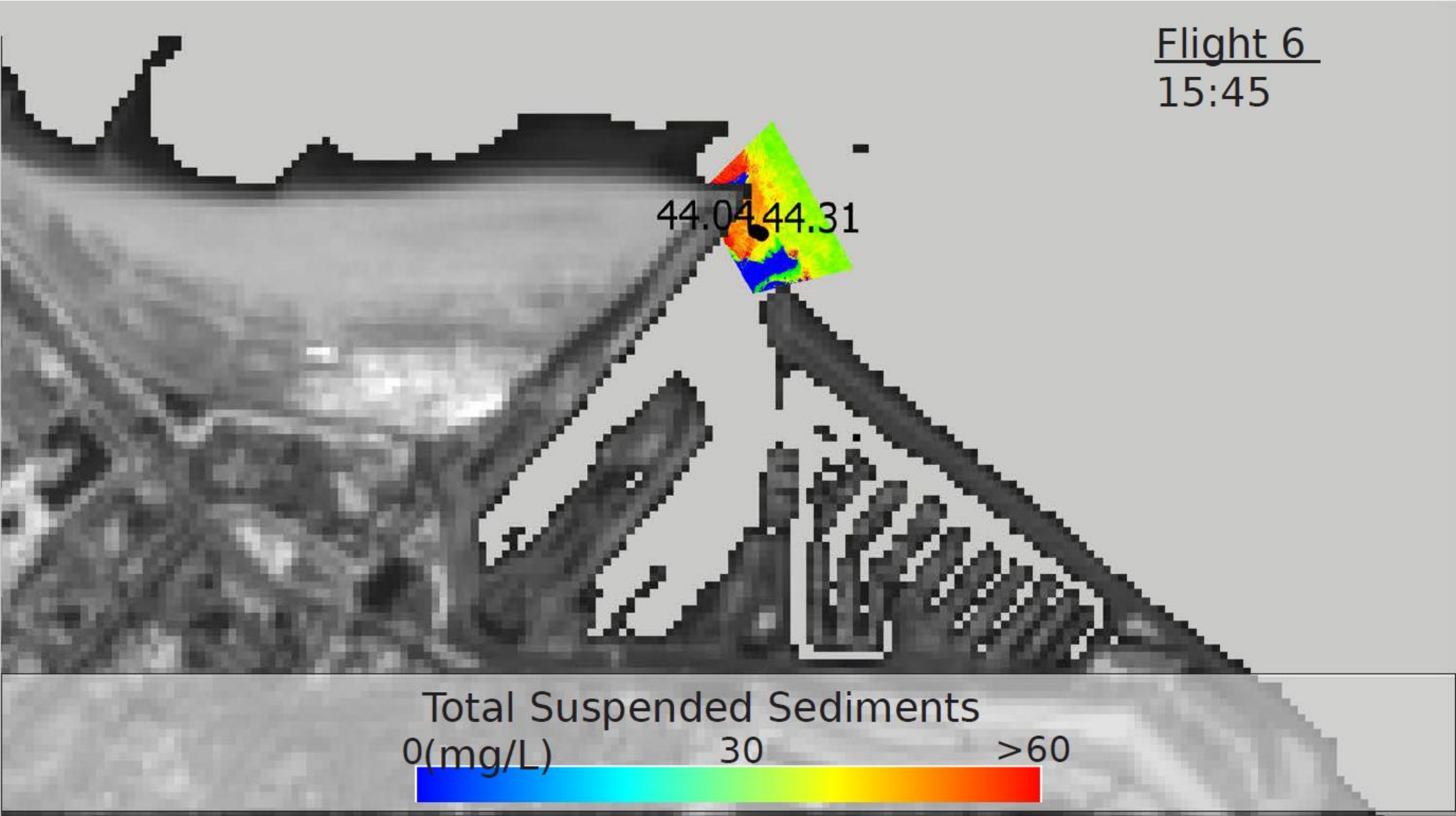
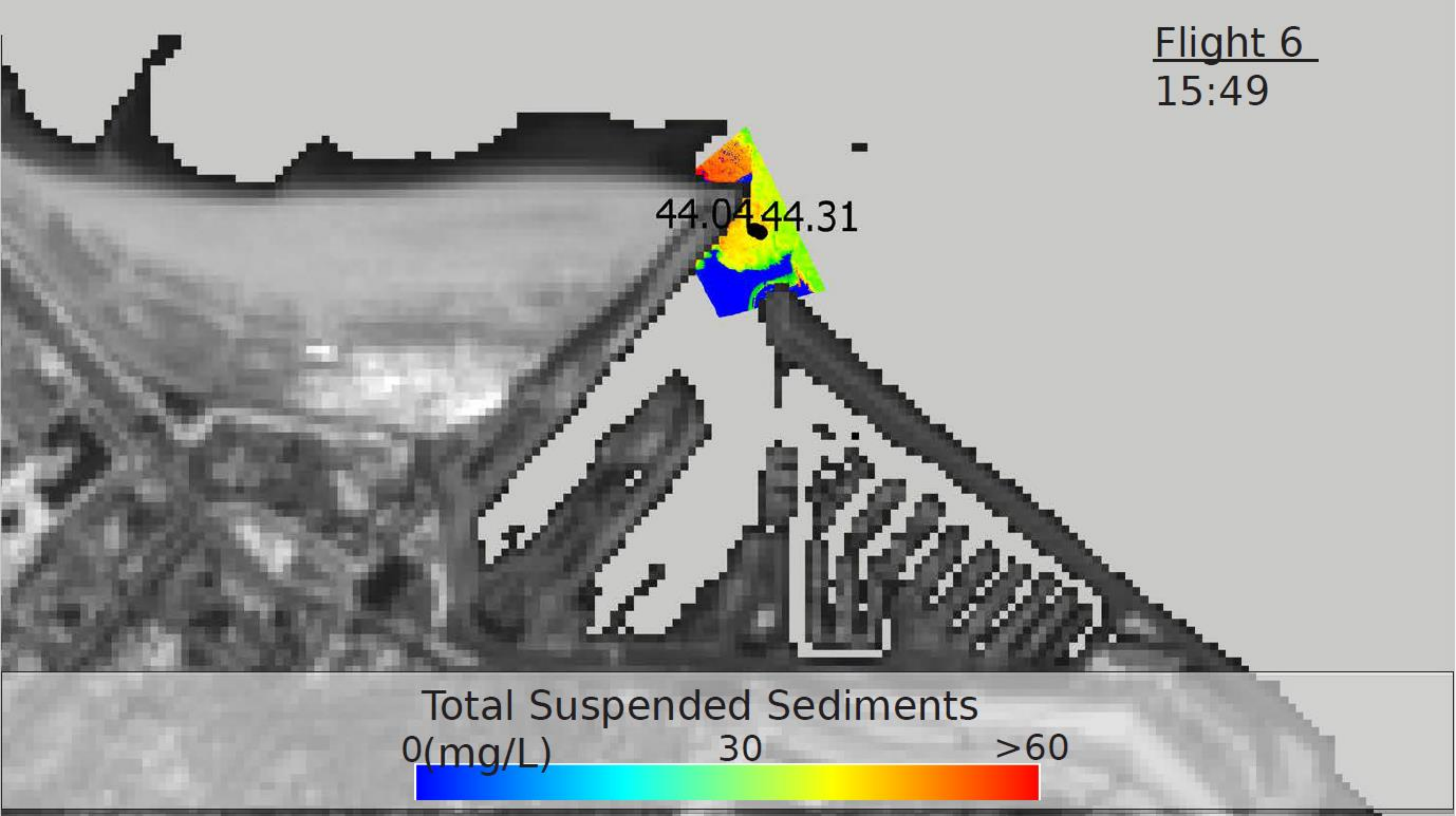


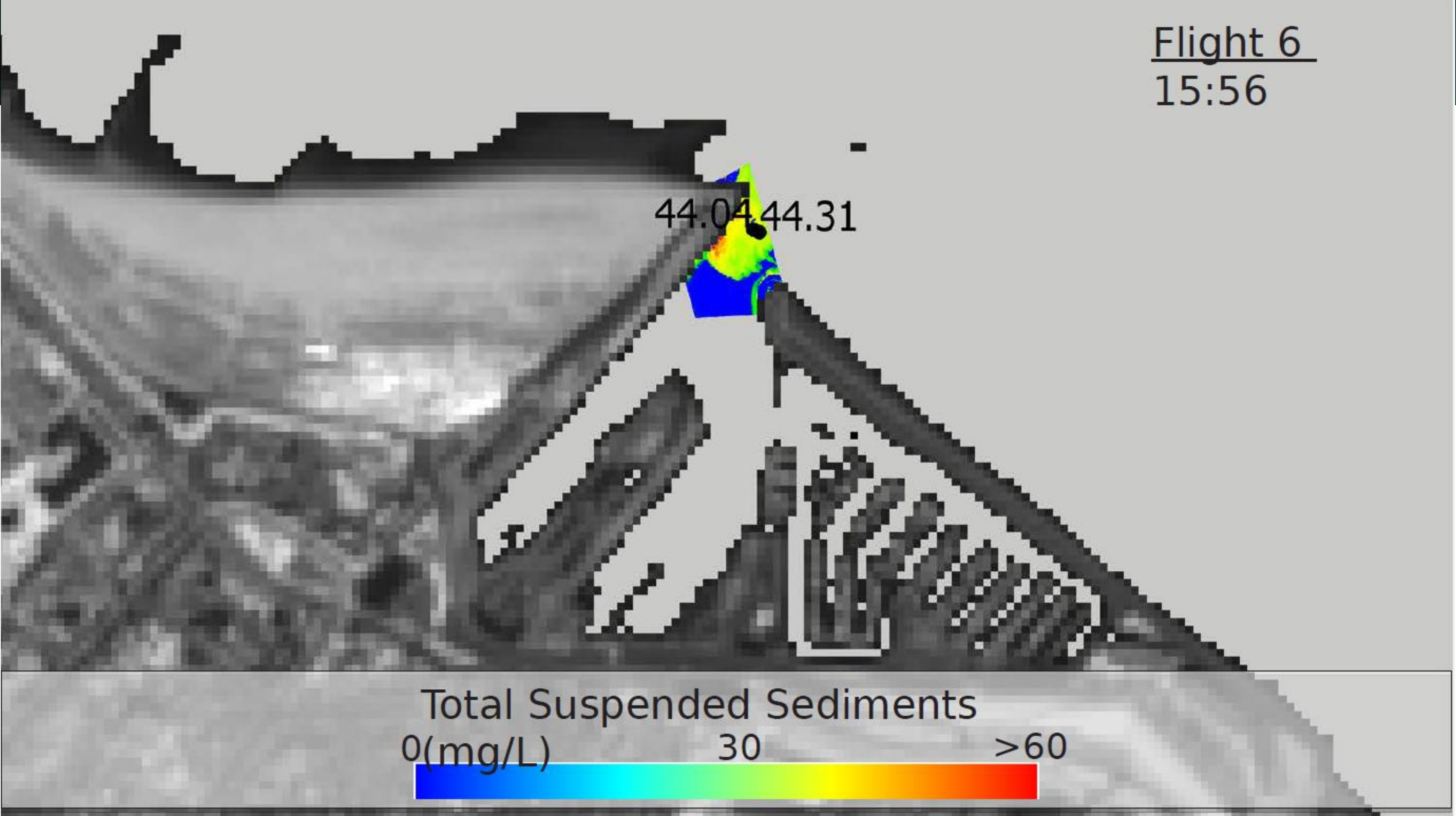
Time	Type	Water level
5:30	Low tide	0.78 m
11:50	High tide	3.89 m
17:59	Low Tide	0.89 m


46.18
Flight 1
Start 10:45
End 11:00
18.92
Total Suspended Sediments
0(mg/L)
30
>60



Flight 6
15:45


Flight 6
15:49
44.04
44.31
Total Suspended Sediments
0(mg/L)
30
>60


Flight 6
15:56
44.04
44.31
Total Suspended Sediments
0(mg/L)
30
>60

Cillero Castro, C. et al. Remote Sens. **2020**, 12, 1514. https://doi.org/10.3390/rs12091514

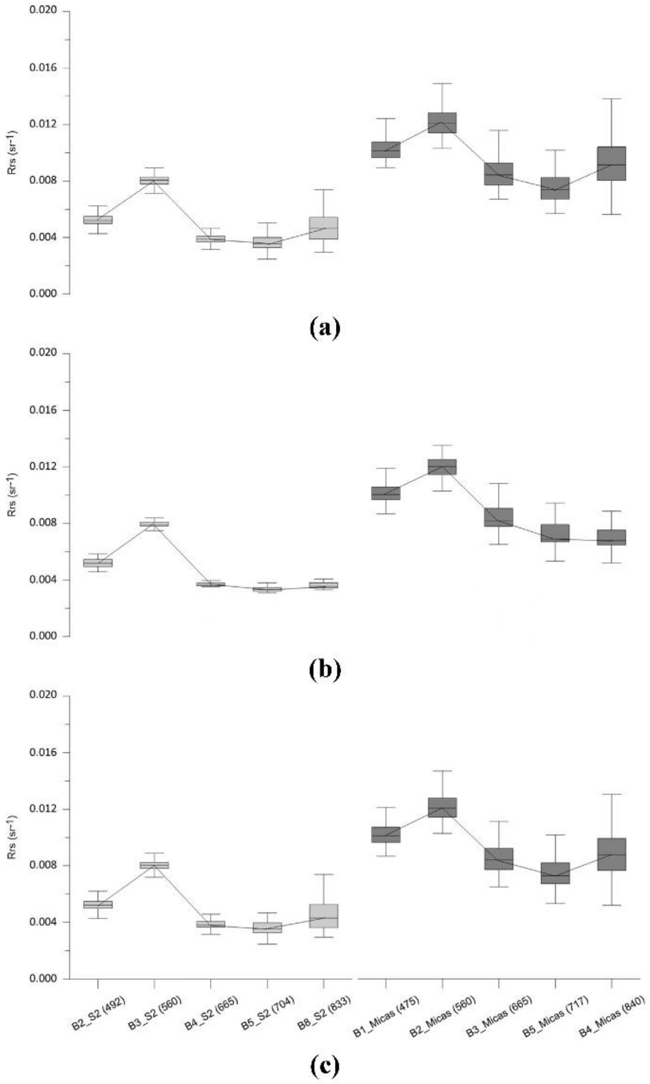
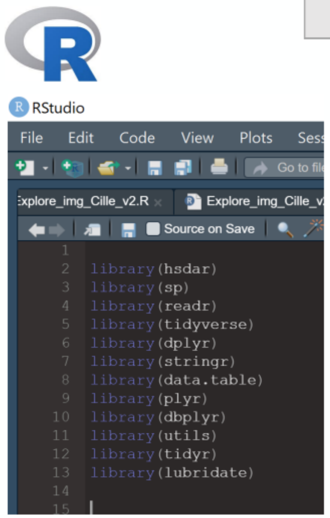


Figure 11. Box-whiskers plot comparing the spectral signature of Sentinel 2 MSI and Rededge Micasense sensors for the images acquired on 10/02/2018. Figure (**a**) shows the results for the outer pixels in the reservoir. Figure (**b**) shows the results for the central pixels in the reservoir, and Figure (**c**) shows the results for the entire reservoir.



```
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library(sp)
library(readr)
library(tidyverse)
library(dplyr)
library(stringr)
library(data.table)
library(plyr)
library(dbplyr)
library(utils)
library(tidyr)
library(lubridate)
```

STS on board Drone

Above water Rrs
Spectral Library STS

TriOS Ramses

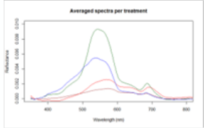
Above water Rrs
Spectral Library TriOS

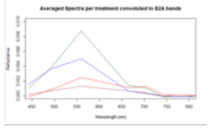
OWTs identificaction (Spyrakos et al. 2018) – Spectral Similarity

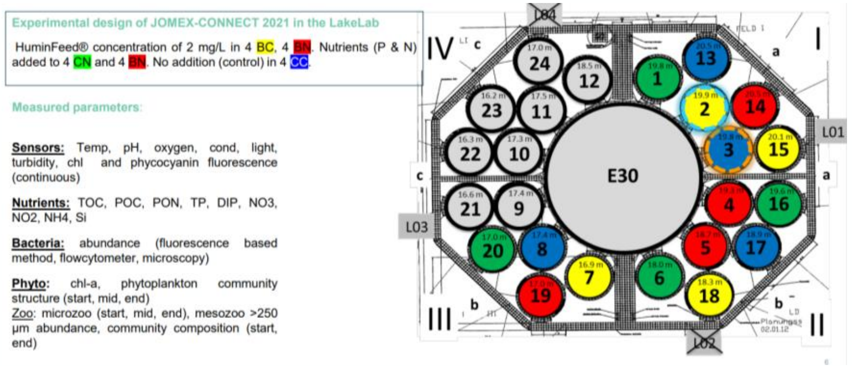
Fitting the spectral libraries to Sentinel 2A bands.
Spectral Response Function (hsdar R library)

Chl *a* Algorithm assessment
Entire dataset

Chl *a* Algorithm assessment for
each OWTs







Experimental design of JOMEX-CONNECT 2021 in the LakeLab

HuminFeed® concentration of 2 mg/L in 4 BC, 4 BN. Nutrients (P & N) added to 4 CN and 4 BN. No addition (control) in 4 CC.

Measured parameters:

Sensors: Temp, pH, oxygen, cond, light, turbidity, chl and phycocyanin fluorescence (continuous)

Nutrients: TOC, POC, PON, TP, DIP, NO3, NO2, NH4, Si

Bacteria: abundance (fluorescence based method, flowcytometer, microscopy)

Phyto: chl-a, phytoplankton community structure (start, mid, end)
Zoo: microzoo (start, mid, end), mesozoo >250 µm abundance, community composition (start, end)

Work in progress by Cillero et al.

FAIR data

Metadata provided to products generated with MapEO-water

- GEOJSON file format
- Defined at collection and product level

Data accessibility

- Geoserver: https://mapeo.be/geoserver/MONOCLE/wcs
- OpenEO

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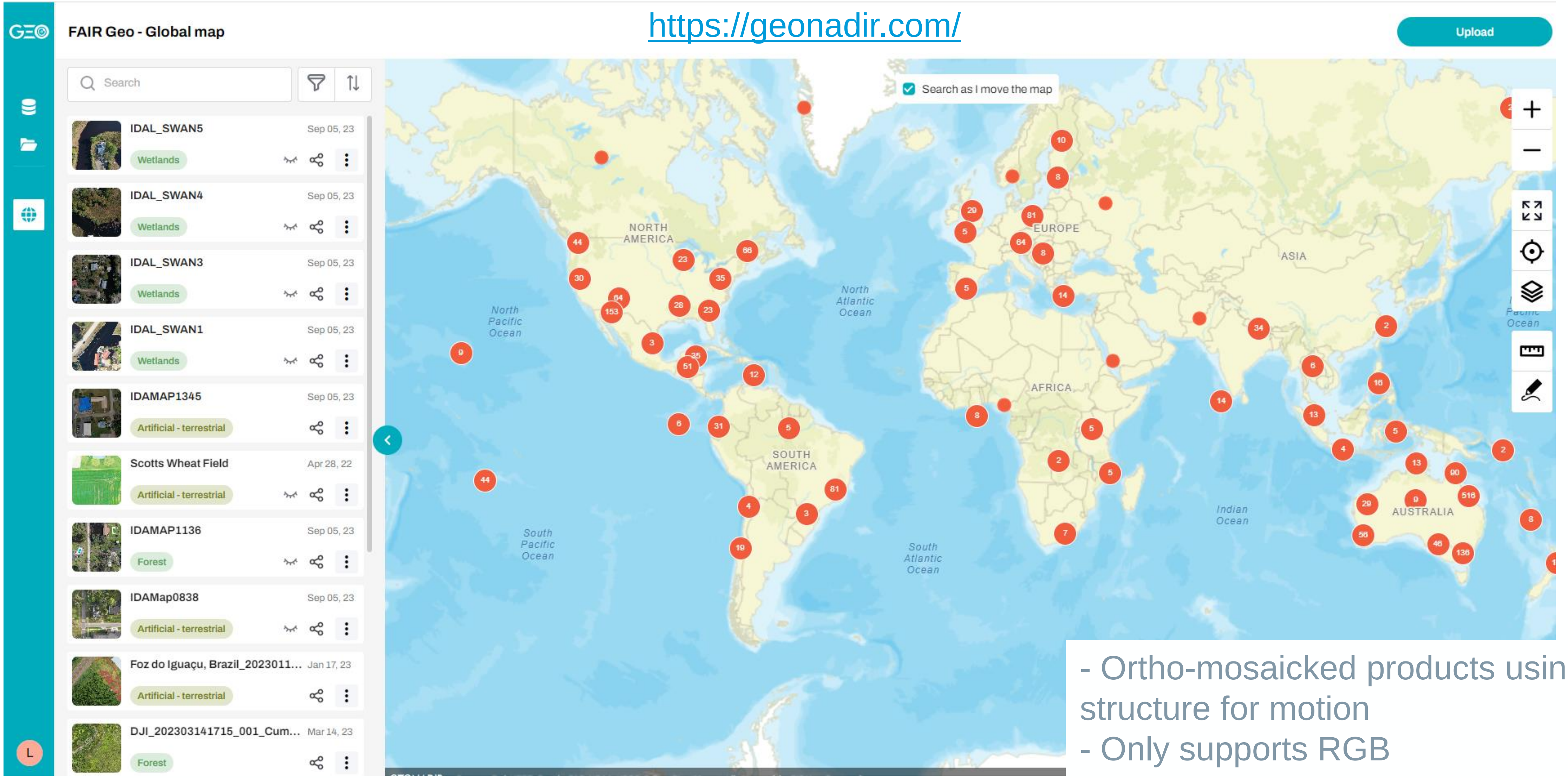
https://geonadir.com/



FAIR Geo - Global map

Upload

Search

IDAL_SWAN5	Sep 05, 23	Wetlands
IDAL_SWAN4	Sep 05, 23	Wetlands
IDAL_SWAN3	Sep 05, 23	Wetlands
IDAL_SWAN1	Sep 05, 23	Wetlands
IDAMAP1345	Sep 05, 23	Artificial - terrestrial
Scotts Wheat Field	Apr 28, 22	Artificial - terrestrial
IDAMAP1136	Sep 05, 23	Forest
IDAMap0838	Sep 05, 23	Artificial - terrestrial
Foz do Iguaçu, Brazil_2023011...	Jan 17, 23	Artificial - terrestrial
DJI_202303141715_001_Cum...	Mar 14, 23	Forest

☑ Search as I move the map

- Ortho-mosaicked products using structure for motion
- Only supports RGB

Need for dedicated drone campaigns (drone data acquisition during Sentinel-2 overpass)

Opportunity:

AQUARIUS

Horizon Europe AQUARIUS Transnational Access project (start 1 March 2024)

“Aqua Research Infrastructure Services for the health and protection of our unique, oceans, seas and freshwater ecosystems”

Concept: Towards drone-based aquatic reflectance fiducial reference measurements used for validation of aquatic reflectance satellite products

1) Identify the necessary steps to qualify drone measurements over water as FRM for Cal/Val purposes
2) Bring together the community to collect and discuss best practices
3) Develop Roadmap for achieving FRM status for drone-based water Cal/Val

Initiate an IOCCG Task Force/Working Group ‘FRM drones for Cal/Val Water’?

Propose dedicated session at conference?

Explore funding channels?

Ideas? Contact liesbeth.dekeukelaere@vito.be

International Ocean Colour Science Meeting 2023 | Advancing Global Ocean Colour Observations

2023 International Ocean Colour Science Meeting
St. Petersburg, FL, USA, 14-17 November 2023

The fifth International Ocean Colour Science (IOCS) meeting will be convened by the International Ocean Colour Coordinating Group (IOCCG) in partnership with the University of South Florida, NASA, and NOAA, and will take place from 14-17 November 2023 in St. Petersburg, Florida, USA

Important Dates

1 May – 30 Jun 2023
Early Registration

1 Jul – 14 Oct 2023
Regular Registration

15 Sep 2023
Deadline for travel support & poster abstracts

15 Oct – 12 Nov 2023
Late Registration

13 Nov 2023
Training courses & GEO AquaWatch Team Meeting

14 – 17 Nov 2023
IOCS Meeting

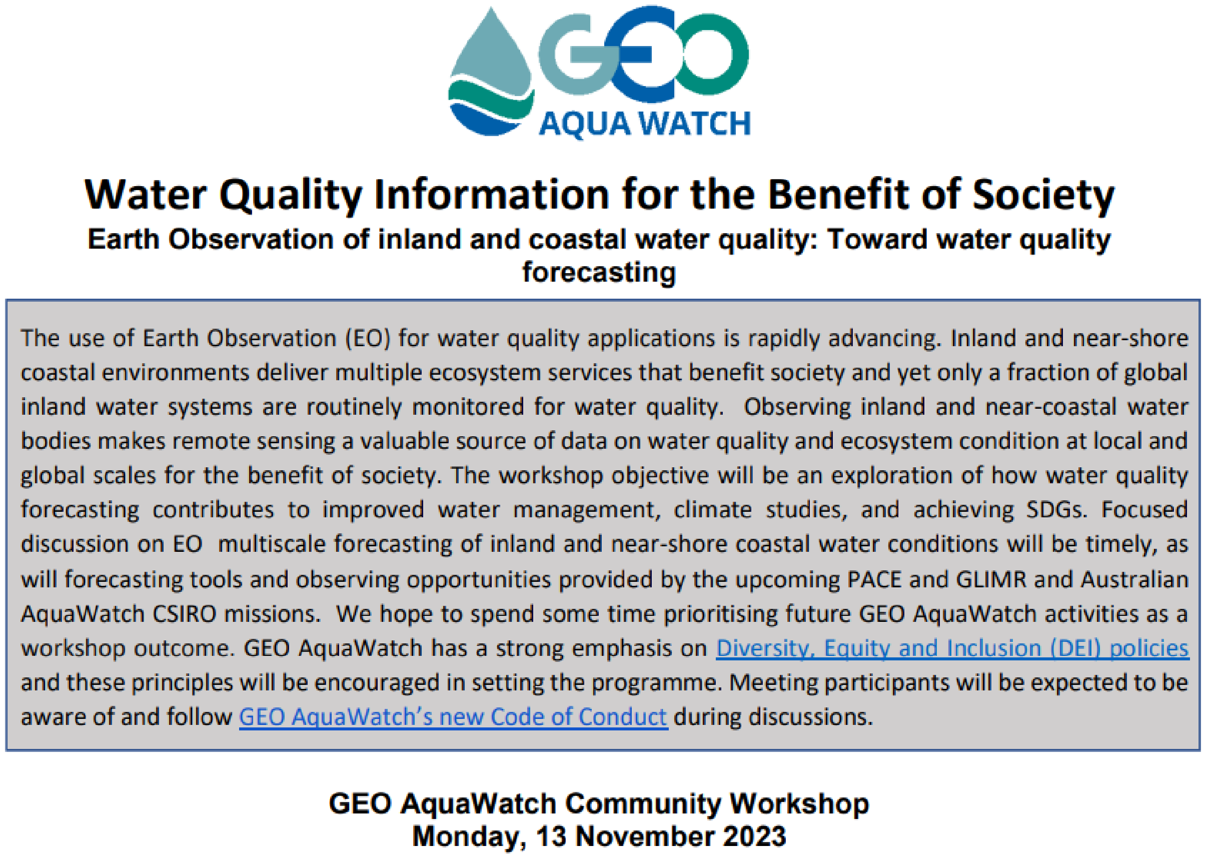
Tutorial
MAPEO WATER

Mon, 13 Nov – 14:00-17:00

Liesbeth De Keukelaere
R&D Professional Water & Coast

vito remote sensing

remotesensing.vito.be



AQUA WATCH

Water Quality Information for the Benefit of Society

Earth Observation of inland and coastal water quality: Toward water quality forecasting

The use of Earth Observation (EO) for water quality applications is rapidly advancing. Inland and near-shore coastal environments deliver multiple ecosystem services that benefit society and yet only a fraction of global inland water systems are routinely monitored for water quality. Observing inland and near-coastal water bodies makes remote sensing a valuable source of data on water quality and ecosystem condition at local and global scales for the benefit of society. The workshop objective will be an exploration of how water quality forecasting contributes to improved water management, climate studies, and achieving SDGs. Focused discussion on EO multiscale forecasting of inland and near-shore coastal water conditions will be timely, as will forecasting tools and observing opportunities provided by the upcoming PACE and GLIMR and Australian AquaWatch CSIRO missions. We hope to spend some time prioritising future GEO AquaWatch activities as a workshop outcome. GEO AquaWatch has a strong emphasis on Diversity, Equity and Inclusion (DEI) policies and these principles will be encouraged in setting the programme. Meeting participants will be expected to be aware of and follow GEO AquaWatch's new Code of Conduct during discussions.

GEO AquaWatch Community Workshop
Monday, 13 November 2023

10:00-10:15 Towards Fiducial Reference Measurements for water-leaving radiance reflectance with drone observations - Liesbeth De Keukelaere*, VITO; Sindy, Sterckx, VITO; Robrecht Moelans, VITO; Els Knaeps, VITO; Agnieszka Bialek, NPL; and Niall Origo, NPL

This research was funded by European Union's Horizon 2020 research and innovation programme under grant agreement No 776480 (MONOCLE), grant agreement No 101004186 (Water-ForCE), and was supported by the Belgian Science Policy (Belspo) under Grant SR/00/381 (TIMBERS) and Grant SR/67/311 (DRONESED)

MONOCLE
Multiscale Observation Networks for Optical monitoring of Coastal waters, Lakes and Estuaries

Water - ForCE

Contact: liesbeth.dekeukelaere@vito.be