Project funded by EUROPEAN UNION

PONTOS

Black Sea CROSS BORDER COOPERATION

**Common borders. Common solutions.**

# PONTOS VIRTUAL TRAINING MODULES

December 2022

PONTOS-EU.AUA.AM

AUA ACOPIAN CENTER for the ENVIRONMENT

CERTH CENTRE FOR RESEARCH & TECHNOLOGY HELLAS

ΔΗΜΟΚΡΙΤΕΙΟ ΠΑΝΕΠΙΣΤΗΜΙΟ ΘΡΑΚΗΣ DEMOCRITUS UNIVERSITY OF THRACE

GREEN ALTERNATIVE

Project funded by EUROPEAN UNION

PONTOS

Black Sea CROSS BORDER COOPERATION

Common borders. Common solutions.

# Module 5

## The Application of Earth Observation: Chlorophyll-A Concentration & Eutrophication Dynamics with the Example of Assessments via PONTOS platform

**Common borders. Common solutions.**

*Responsible Partner – American University of Armenia*

*Supporting Partner - Environmental Protection and Mining Inspection Body of the Republic of Armenia*

*Slides and scripts prepared by – Garabet Kazanjian, Maria Zoidou, Nikolaos Kokkos*

*Contact Information – pontos@aua.am*

*This module is developed in the frames of the BSB 889 PONTOS Project*

Project funded by EUROPEAN UNION

PONTOS

Black Sea CROSS BORDER COOPERATION

Common borders. Common solutions.

## LEARNING OBJECTIVES OF MODULE 1

Learn about the causes and impacts of eutrophication in water ecosystems

Familiarize yourself with the history of remote sensing and chlorophyll-a (challenges and solutions)

Identify the satellites used for water quality monitoring

Download freely available satellite images

Learn how to calculate chl-*a* concentrations from satellite images using ESA’s SNAP toolkit

Use the PONTOS Data Cube to calculate Total Suspended Matter (TSM) concentrations

Project funded by EUROPEAN UNION

PONTOS

Common borders. Common solutions.

## MODULE STRUCTURE

01 Eutrophication in water ecosystems (causes and impacts)

02 Using remote sensing to monitor eutrophication dynamics

03 Calculating chl-*a* using the SNAP toolkit and C2RCC processor

04 Using the PONTOS Data Cube to calculate Total Suspended Matter

Project funded by EUROPEAN UNION

PONTOS

Black Sea CROSS BORDER COOPERATION

## Common borders. Common solutions.

# 01 Eutrophication in water ecosystems (causes and impacts)

**This section will introduce you to the classification of water ecosystems and their trophic states, issues related to water quality monitoring, eutrophication and its drivers, as well as, the importance of ensuring the good status of water bodies.**

Image source: ConserveEnergyFuture

PONTOS

Project funded by EUROPEAN UNION

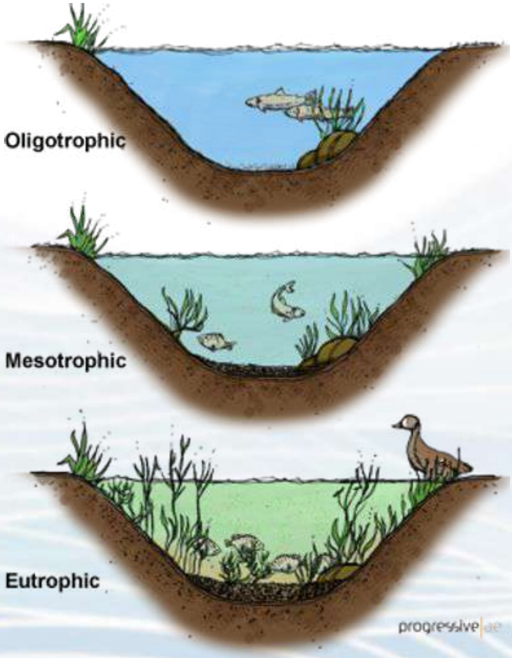
Black Sea CROSS BORDER COOPERATION

**Common borders. Common solutions.**

# Eutrophication in water ecosystems

**Aquatic ecosystems are classified into 3 main trophic states** (*i.e.* nutrient content):

1. **Oligotrophic systems:**
   Characterized by very low nutrient content (likely nitrogen (N) and/or phosphorus (P) being a limiting factor, thus very low productivity. Very high water transparency.
2. **Mesotrophic systems:**
   Higher nutrient content leads to higher primary productivity (more plants and algae), likely higher secondary productivity, lower water transparency due to higher dissolved organic matter and algal grow
3. **Eutrophic systems:**
   Very high nutrient content, excessive algal blooms, turbid waters.



Common borders. Common solutions.

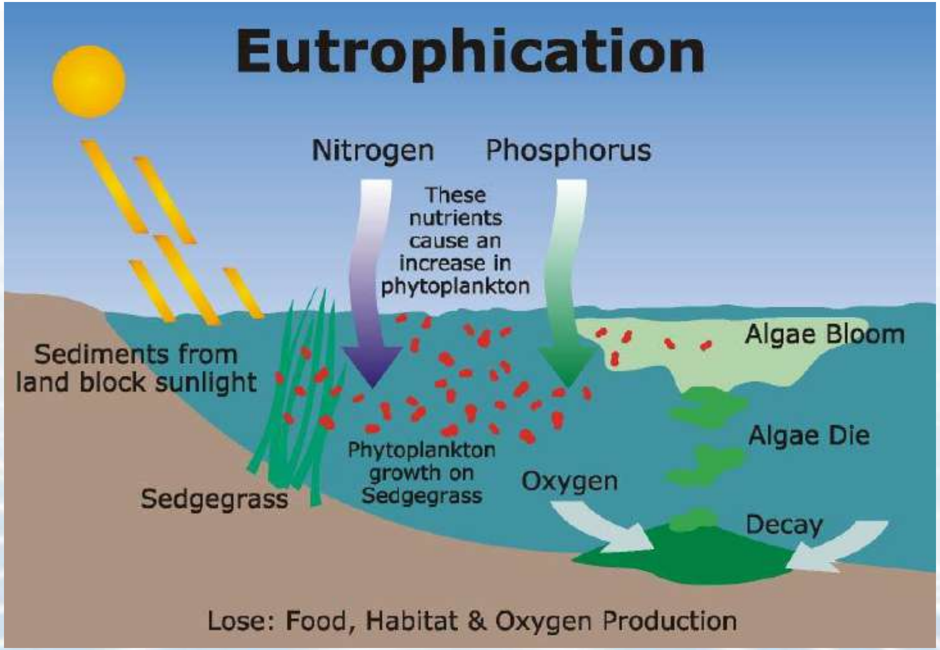
# Eutrophication in water ecosystems

Image source: tnluser

Eutrophication is the process of excessive algal growth due to increased nutrient (particularly N & P loading).

Eutrophication can lead to:

- Increased BOD (Biological $O_2$ Demand)
- Potential anoxia
- Reduced biodiversity
- Toxic cyanobacterial blooms
- Increased undesirable emissions ($CH_4$, $H_2S$)
- Release of bad odours
- Loss of ecosystem services



# Eutrophication in water ecosystems

Causes of eutrophication may include:

- Agriculture & husbandry
- Urbanization
    - Habitat destruction/land change
    - Untreated sewage
    - Land erosion
- Floods

=> Indicator / outcome of anthropogenic impacts and water quality deterioration.

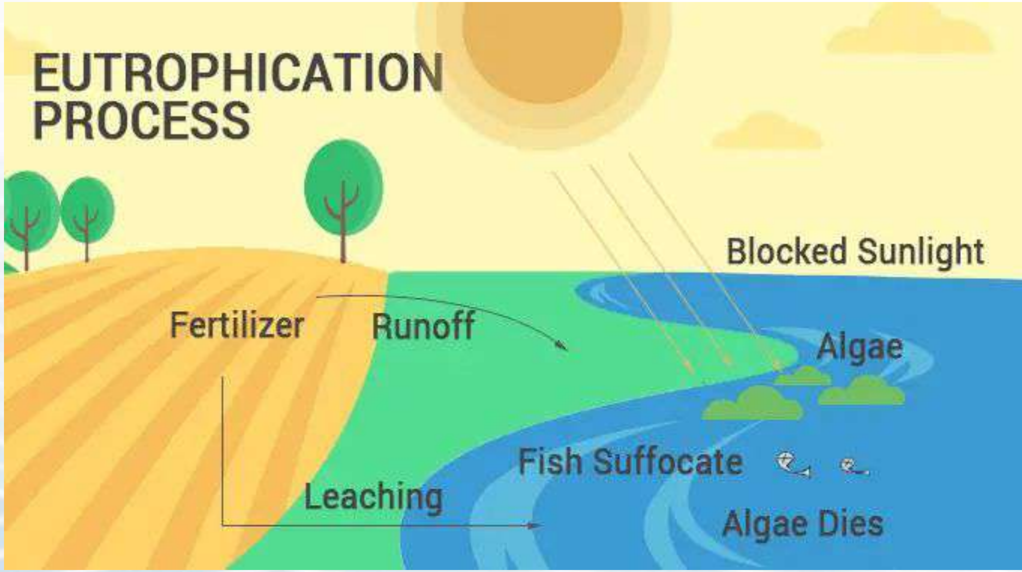



Image source: earthhow

# Eutrophication in water ecosystems

To assess eutrophication and algal biomass in water ecosystems, researchers often use the concentrations of chlorophyll-*a* (chl-*a*) as a proxy measurement. Chl-*a* is:

- A pigment found in plants & algae. It is vital for photosynthesis and is what gives plants their green color.
- Positively correlated with algal biomass.
- Often used as an indicator to monitor water quality. For instance, reporting of chl-*a* concentrations is required as part of the EU Water Framework Directive (WFD).

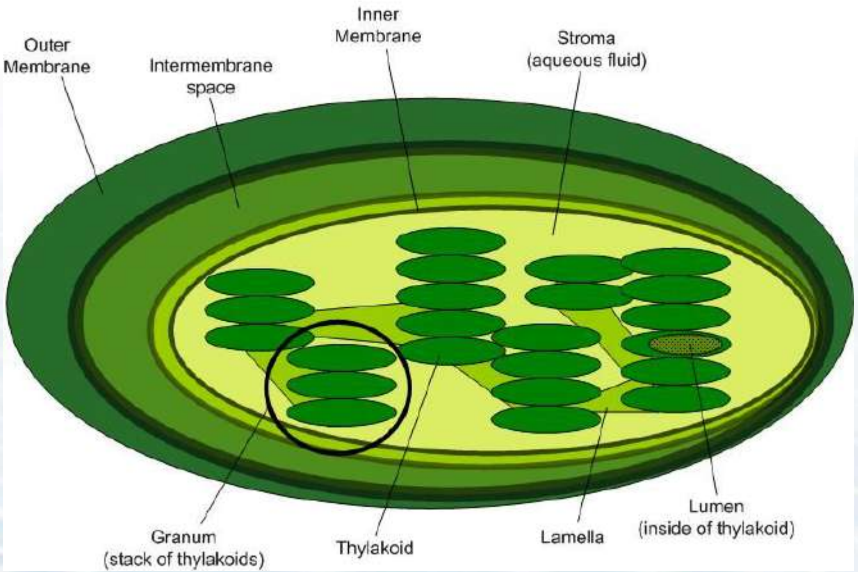



Image source: Wikimedia Commons

Project funded by EUROPEAN UNION

PONTOS

Black Sea CROSS BORDER COOPERATION

**Common borders. Common solutions.**

## 02 Using remote sensing to monitor eutrophication dynamics

To compliment the *in-situ* measurements of chl-*a* and algal biomass / productivity

To measure other water quality parameters: Turbidity, Total suspended matter (TSM), Dissolved Organic Matter (DOM), etc.

But there are challenges:

- Isolating the chl-*a* signal from other optically active compounds
- The diel (vertical) movements of plankton in the water column
- Atmospheric correction

Image source: NASA/Science Photo Library

Project funded by EUROPEAN UNION

PONTOS

Black Sea CROSS BORDER COOPERATION

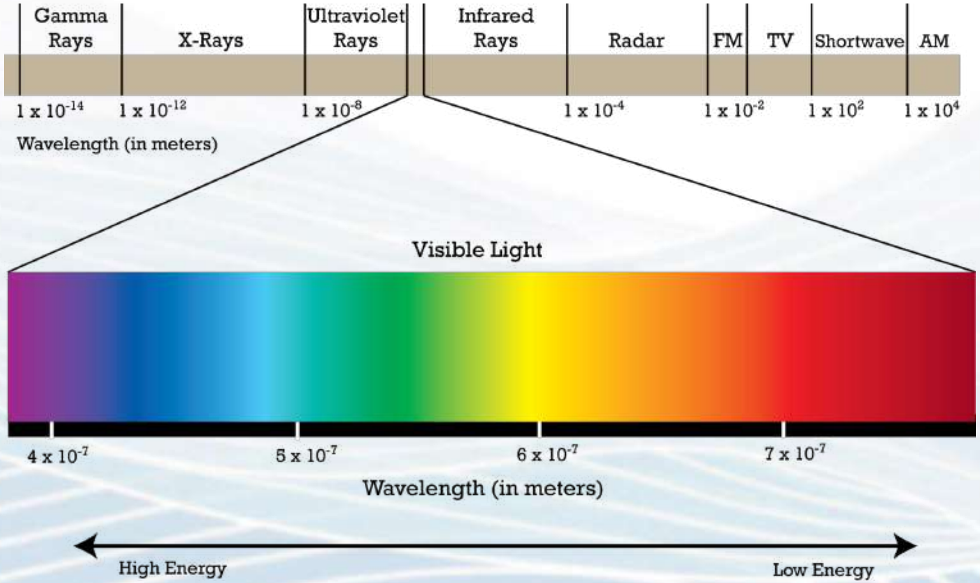
**Common borders. Common solutions.**

## Using remote sensing to monitor eutrophication dynamics

To assess eutrophication dynamics via remote sensing, it is convenient to measure chl-*a* concentrations due to its optical properties.

Chl-*a* has higher reflectance in lower wavelengths (blue + green regions) at lower concentrations.

=> It works very well in marine ecosystems but has historically posed challenges in inland waters with higher [chl-*a*]+ humic substances



Project funded by EUROPEAN UNION

PONTOS

Black Sea CROSS BORDER COOPERATION

**Common borders. Common solutions.**

# Using remote sensing to monitor eutrophication dynamics

## Historical overview:

Earliest chl-*a* estimation via remote sensing started in the late 1970s in marine waters [Nimbus 7, Coastal Zone Color Scanner (CZCS), based on 2 bands]

SeaWIFS, MODIS, MERIS, Landsat 7,8,9, Sentinel 2, 3 (OLCI) have all since been launched that can estimate chl-*a*.

Satellites with multispectral images ⇒ possibility of more complex algorithms to estimate chl-*a* in inland waters

Making use of neural networks to better isolate and identify specific optical characteristics

Image source: ESA

Project funded by EUROPEAN UNION

PONTOS

Black Sea CROSS BORDER COOPERATION

Common borders. Common solutions.

# Satellites used in water quality remote sensing

Landsat 4-5

2009-2011

Landsat 7 ETM+

2012

Landsat 8

2013-2015

Sentinel 2

2015-2019

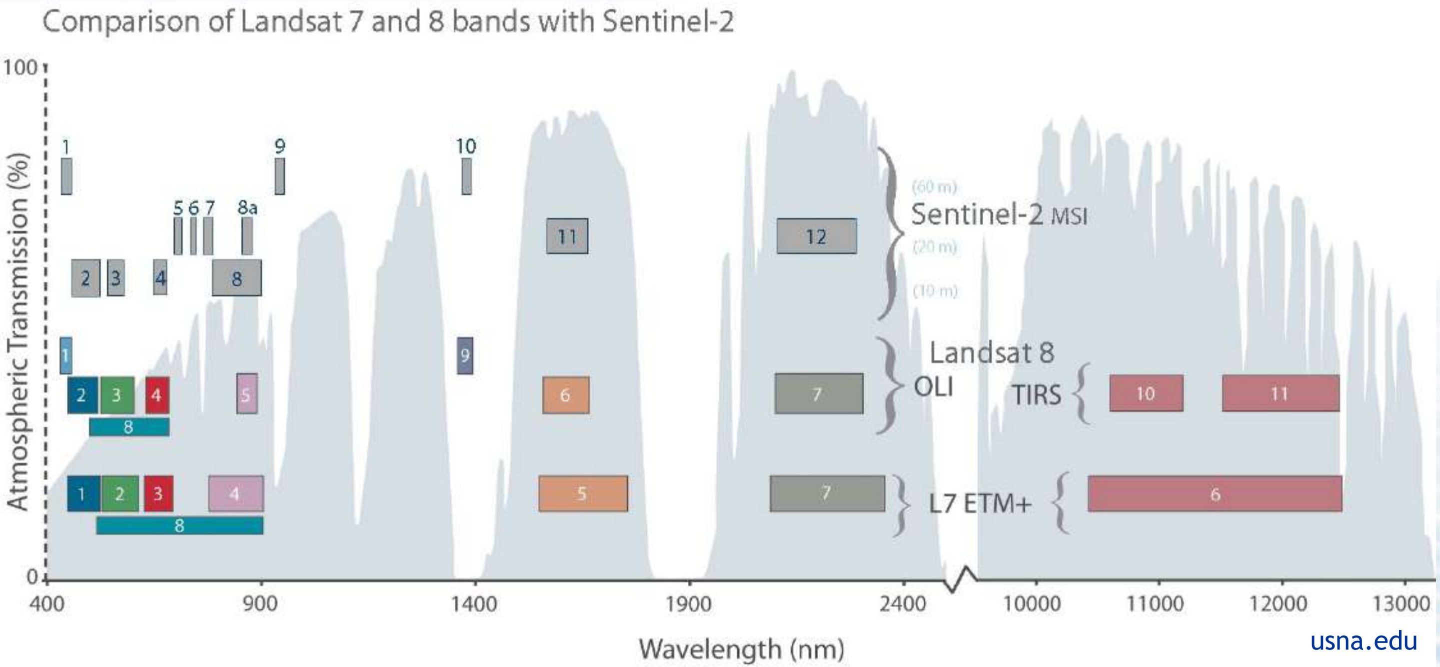
Project funded by EUROPEAN UNION

PONTOS

Black Sea CROSS BORDER COOPERATION

**Common borders. Common solutions.**

# Wavelengths & bands of satellites used in water quality remote sensing




usna.edu

Project funded by EUROPEAN UNION

PONTOS

Black Sea CROSS BORDER COOPERATION

**Common borders. Common solutions.**

# Wavelengths & bands of satellites used in water quality remote sensing

Sentinel-2 properties:

- Time period: 2015 – 2021
- Sentinel 2A and 2B: polar orbit, phased at 180° to each other
- Equipped with multispectral instrument (MSI) with 13 spectral bands
- Wide swath width (290 km)
- Revisit: 5 days at equator (2 satellites)
- Level 1C and 2A (atmospherically corrected)

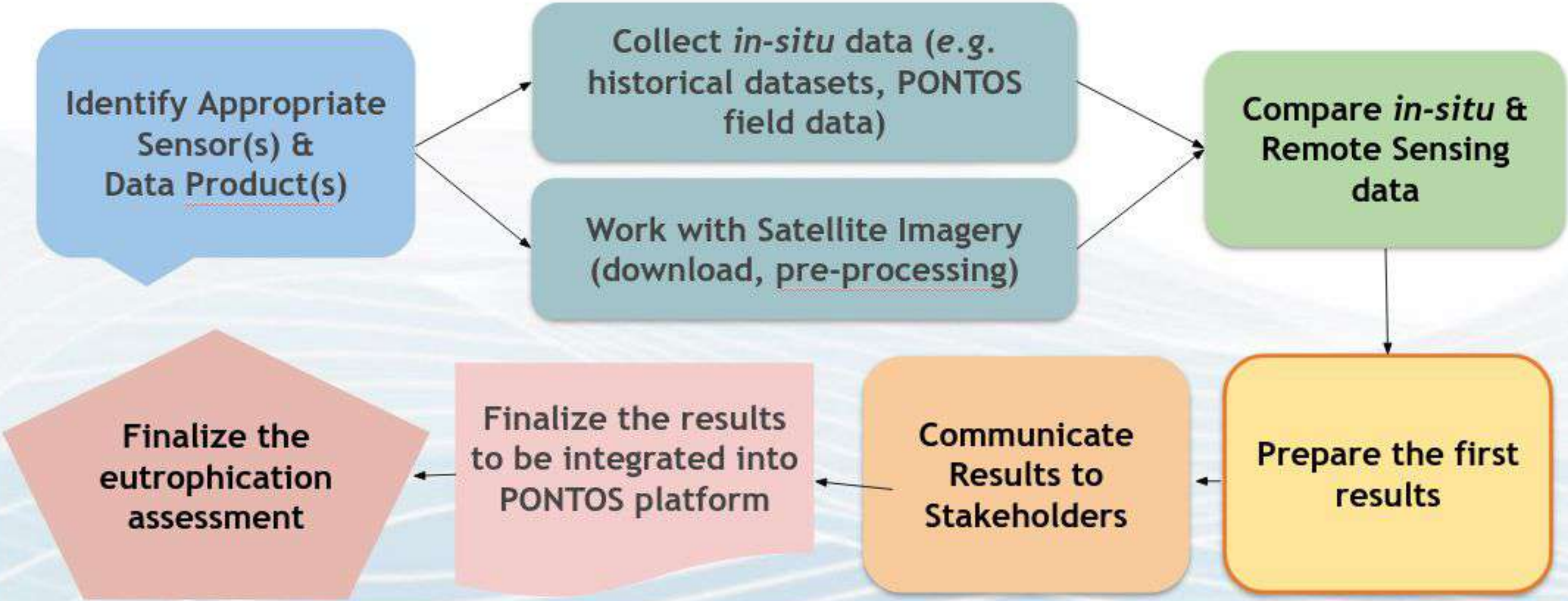
| | Waveband | Central λ (nm) | Bandwidth (nm) | Spatial resolution (m) |
|---|---|---|---|---|
| 1 | Coastal aerosol | 442.7 | 21 | 60 |
| 2 | Blue | 492.4 | 66 | 10 |
| 3 | Green | 559.8 | 36 | 10 |
| 4 | Red | 664.6 | 31 | 10 |
| 5 | Vegetation red edge | 704.1 | 15 | 20 |
| 6 | Vegetation red edge | 740.5 | 15 | 20 |
| 7 | Vegetation red edge | 782.8 | 20 | 20 |
| 8 | Near infrared | 832.8 | 106 | 10 |
| 8A | Narrow near infrared | 864.7 | 21 | 20 |
| 9 | Water vapour | 945.1 | 20 | 60 |
| 10 | Shortwave infrared – Cirrus | 1373.5 | 31 | 60 |
| 11 | Shortwave infrared | 1613.7 | 91 | 20 |
| 12 | Shortwave infrared | 2202.4 | 175 | 20 |

Sentinel 2 bands and their characteristics (sentinel.esa.int)

Project funded by EUROPEAN UNION

**Common borders. Common solutions.**

## Using remote sensing to monitor eutrophication dynamics



Project funded by EUROPEAN UNION

PONTOS

Black Sea CROSS BORDER COOPERATION

**Common borders. Common solutions.**

# 03 Calculating chl-*a* using the SNAP toolkit and C2RCC processor

## Estimating chl-*a* concentrations using the C2RCC processor:

- It started as 'The CoastColour' Project
- It was amended by additional neural networks and eventually renamed as Case 2 Regional CoastColour (C2RCC)
- It is applicable to all past and current ocean colour sensors as well as Sentinel-2
- It is available as a package in ESA's SNAP Toolbox

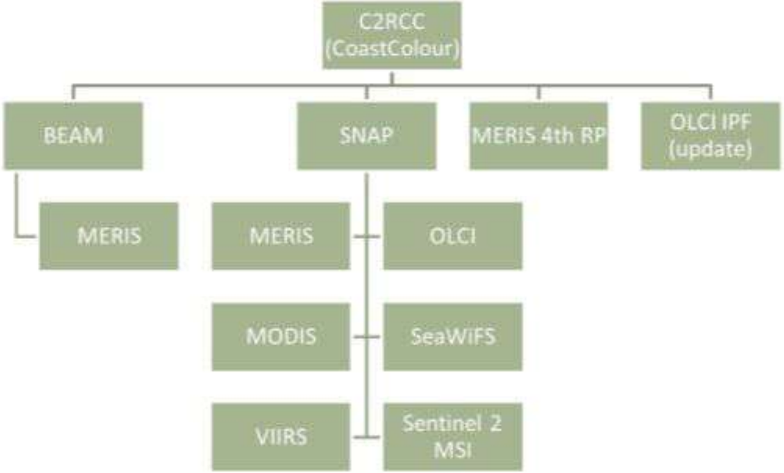



*Figure 4: C2RCC processor family tree*

Image source: Brockmann *et al.*, 2016

Project funded by EUROPEAN UNION

PONTOS

Black Sea CROSS BORDER COOPERATION

Common borders. Common solutions.

# Calculating chl-*a* using the SNAP toolkit and C2RCC processor

## Estimating chl-*a* concentrations using the C2RCC processor

The model uses 5 components for scattering and absorption:

1. pigment absorption (apig)
2. detritus (adet)
3. gelbstoff (agelb)
4. white scatterer (bwhit) - calcareous material
5. typical sediment scatterer (btsm)

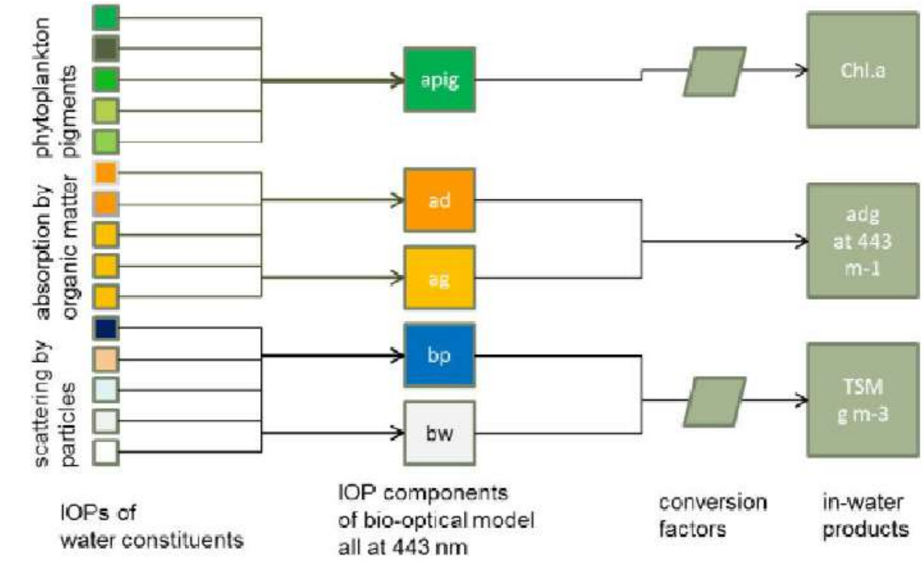



Image source: Brockmann *et al.*, 2016

Project funded by EUROPEAN UNION

PONTOS

Black Sea CROSS BORDER COOPERATION

**Common borders. Common solutions.**

# Calculating chl-*a* using the SNAP toolkit and C2RCC processor

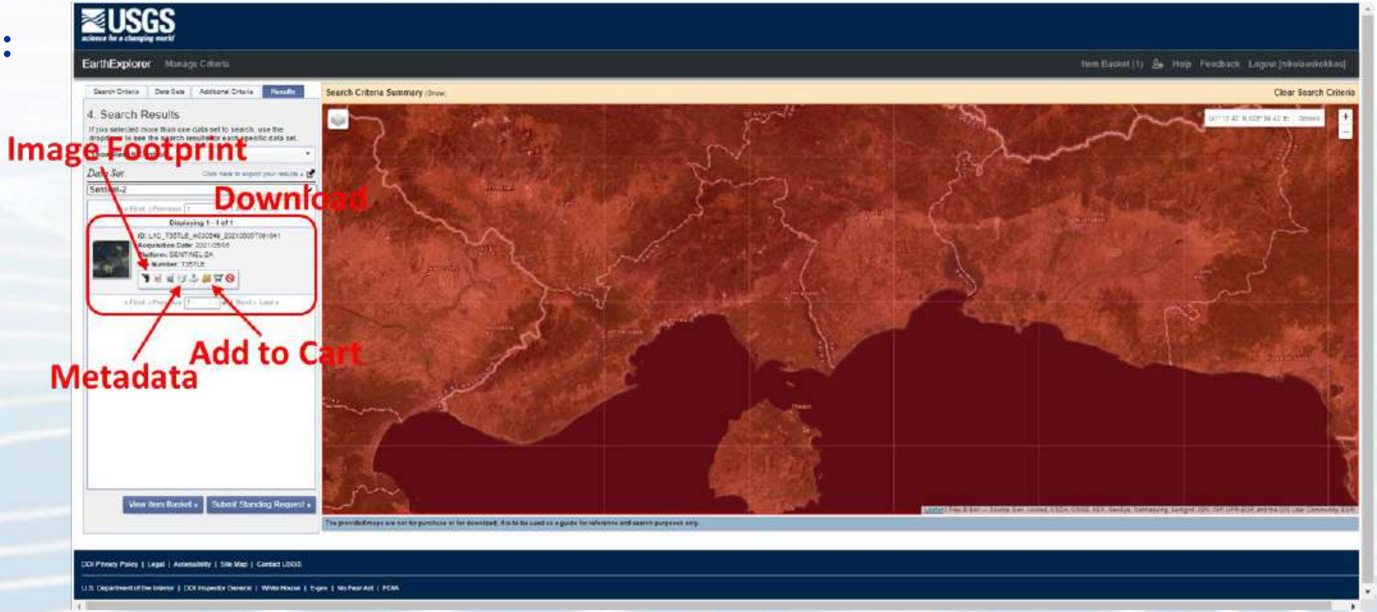
Downloading freely available satellite images:

1. For Landsat images, use the USGS Earth Explorer website [earthexplorer.usgs.gov]

# Calculating chl-*a* using the SNAP toolkit and C2RCC processor

Downloading freely available satellite images:

You can then add the selected product to cart, view its metadata, or download it directly.



Project funded by EUROPEAN UNION

PONTOS

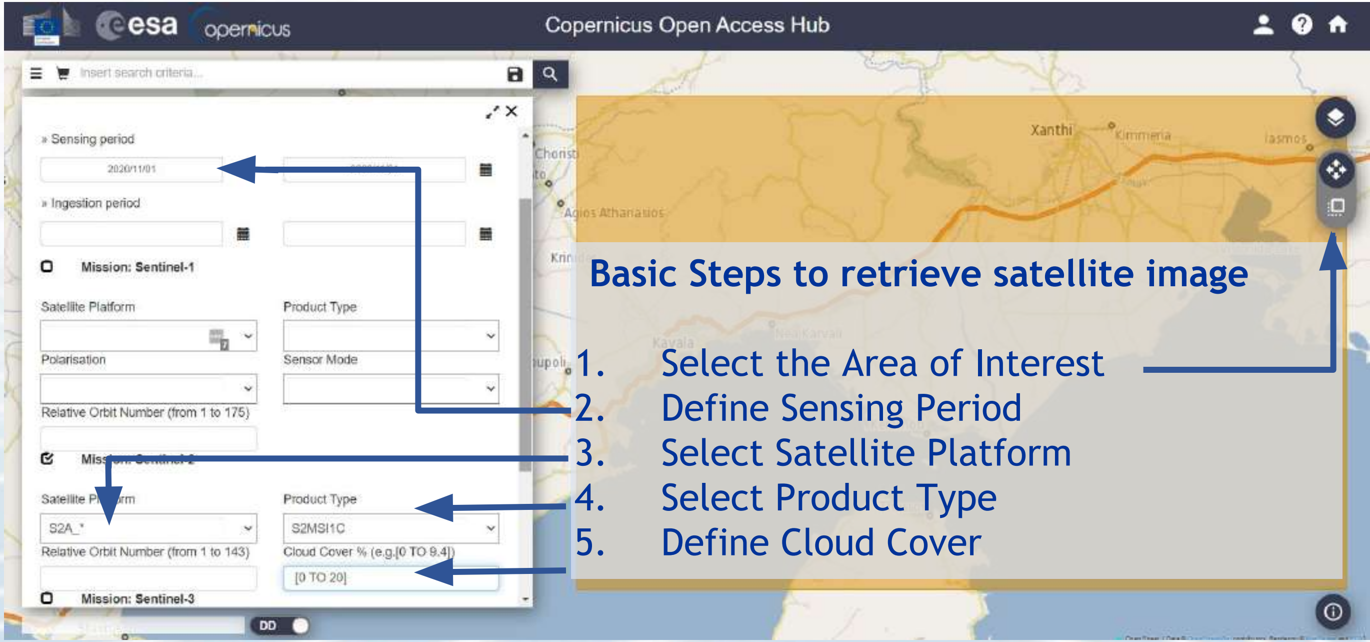
Black Sea CROSS BORDER COOPERATION

**Common borders. Common solutions.**

# Calculating chl-*a* using the SNAP toolkit and C2RCC processor

## Downloading freely available satellite images:

2. For Sentinel images, use the Copernicus Open Access Hub [scihub.copernicus.eu/dhus/]




**Basic Steps to retrieve satellite image**

1. Select the Area of Interest
2. Define Sensing Period
3. Select Satellite Platform
4. Select Product Type
5. Define Cloud Cover

Project funded by EUROPEAN UNION

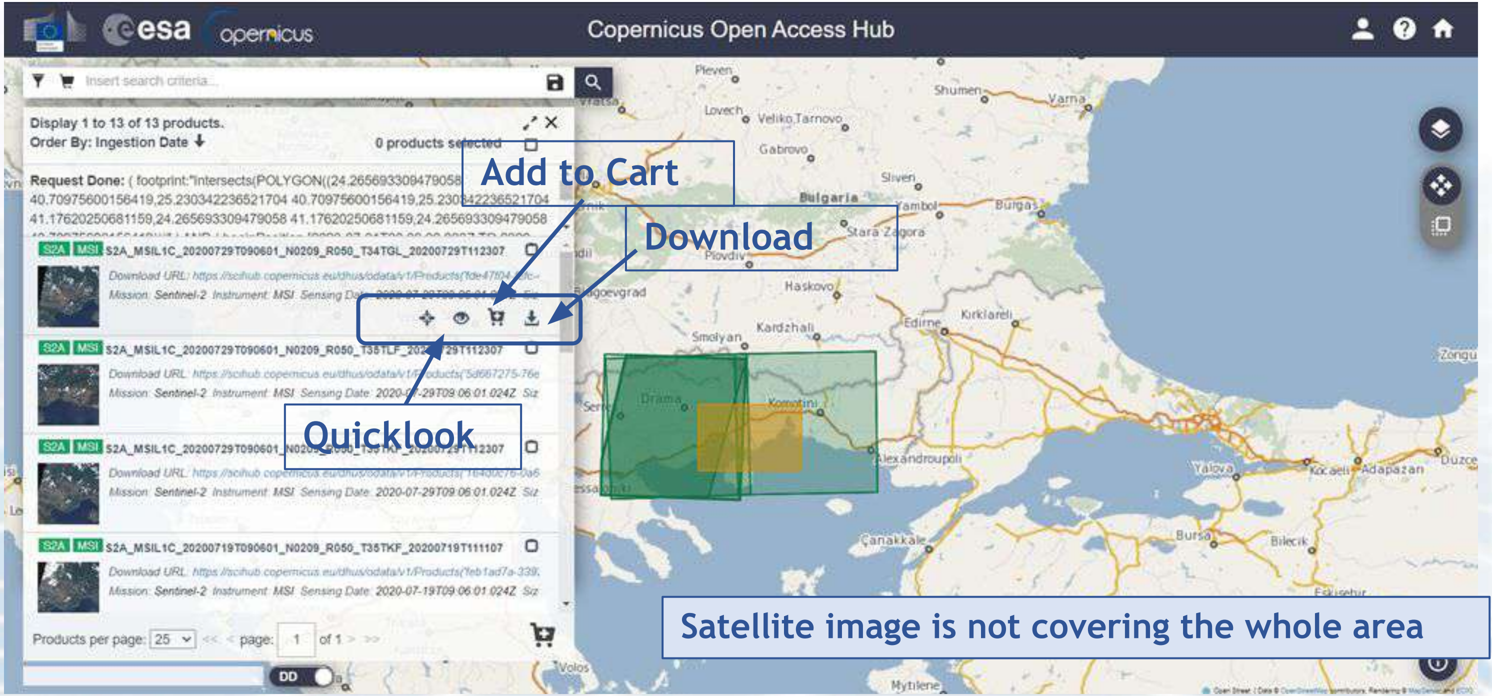
PONTOS

Black Sea CROSS BORDER COOPERATION

**Common borders. Common solutions.**

# Calculating chl-*a* using the SNAP toolkit and C2RCC processor

Choose image(s) and add to cart or download directly.




Satellite image is not covering the whole area

Project funded by EUROPEAN UNION

PONTOS

Black Sea CROSS BORDER COOPERATION

**Common borders. Common solutions.**

# Calculating chl-*a* using the SNAP toolkit and C2RCC processor

## Sentinelsat:

makes searching, downloading and retrieving the metadata of Sentinel satellite images from the Copernicus Open Access Hub easy.

[sentinelsat.readthedocs.io/en/stable/]

```
from sentinelsat import SentinelAPI, read_geojson, geojson_to_wkt
from datetime import date
api = SentinelAPI('user', 'password', 'https://scihub.copernicus.eu/dhus')

# search by polygon (WKT format), time, and SciHub query keywords
footprint = geojson_to_wkt(read_geojson('/path/to/map.geojson'))

products = api.query(footprint,
             date = ('20151219', date(2015, 12, 29)),
             order_by = 'ingestiondate',
             orbitdirection: 'DESCENDING',
                          platformname = 'Sentinel-2',
             producttype = 'S2MSI1C',
                          cloudcoverpercentage = (0, 20))
# download all results from the search
api.download_all(products)
# GeoJSON FeatureCollection containing footprints and metadata of the scenes
api.to_geojson(products)
```

Project funded by EUROPEAN UNION

PONTOS

Black Sea CROSS BORDER COOPERATION

**Common borders. Common solutions.**

## Calculating chl-*a* using the SNAP toolkit and C2RCC processor

### Sentinel nomenclature:

Identifies a Level-1C product acquired by Sentinel-2A on the 29th of July, 2020 at 9:06:01 AM. It was acquired over Tile 35TKF during Relative Orbit 050, and processed with PDGS Processing Baseline 02.09.

S2A_MSIL1C_20200729T090601_N0209_R050_T35TKF_20200729T112307

mission ID

Product Level

sensing start time

PDGS Processing Baseline number

Relative Orbit number

Tile Number field

Product Discriminator

All the bands included in the file are in JPEG2000 format.

In addition, a “True Colour Image” in JPEG2000 format is included within the Tile folder of Level-1C products in this format and a manifest xml file that tells the computer what is inside the file.

Project funded by EUROPEAN UNION

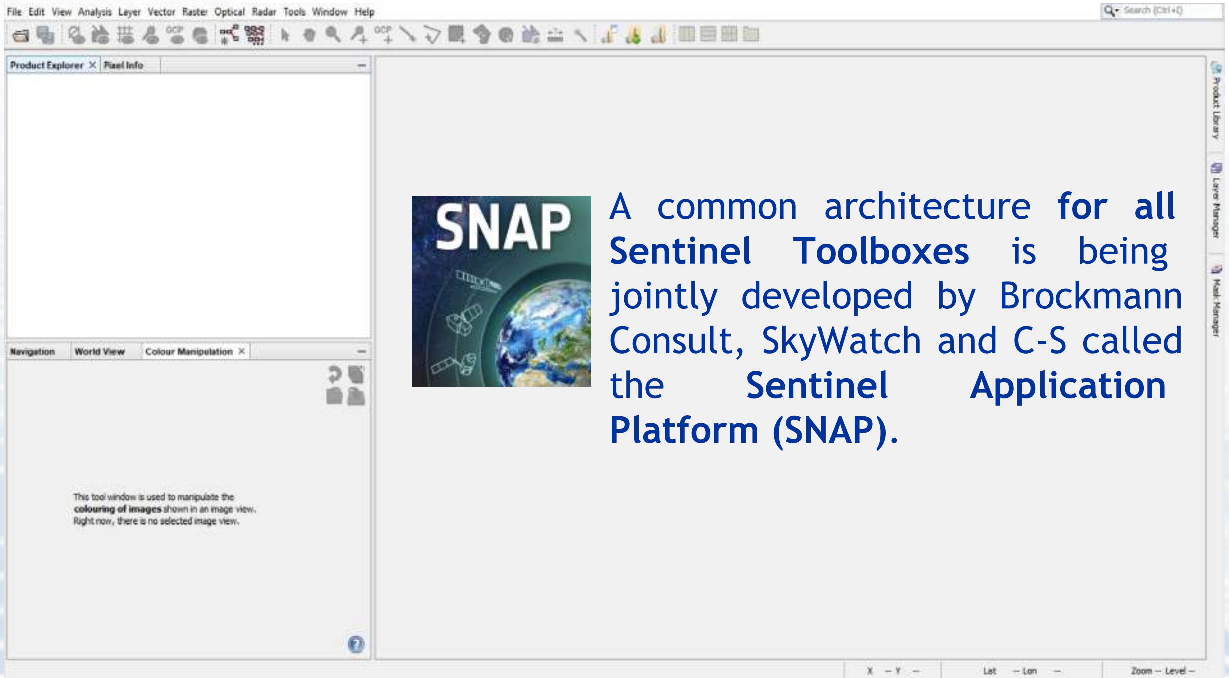
PONTOS

Black Sea CROSS BORDER COOPERATION

**Common borders. Common solutions.**

# Calculating chl-*a* using the SNAP toolkit and C2RCC processor

To process the downloaded images, we will use the European Space Agency’s (ESA) Sentinel Application Platform (SNAP) [https://step.esa.int/main/download/snap-download/]

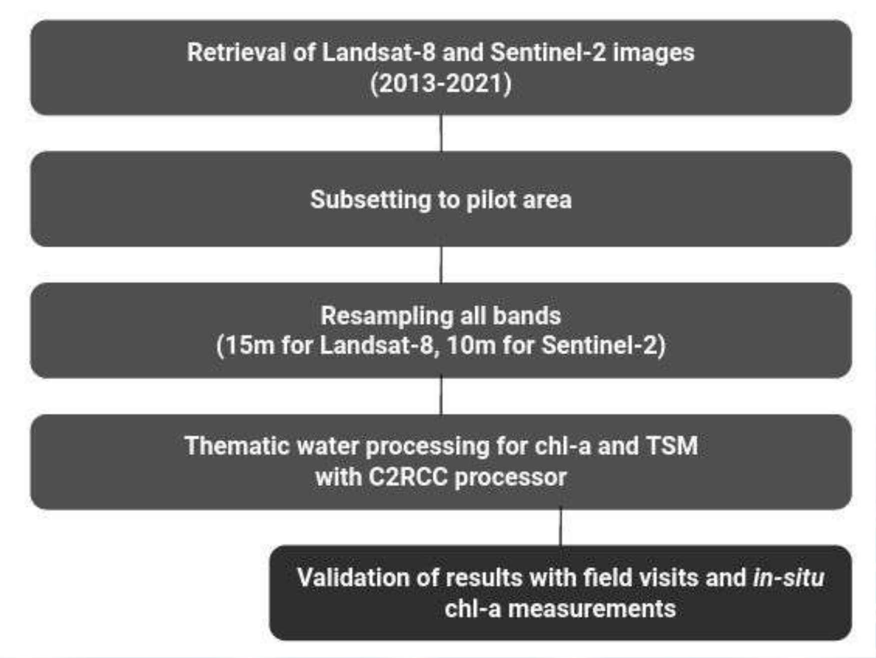



A common architecture **for all Sentinel Toolboxes** is being jointly developed by Brockmann Consult, SkyWatch and C-S called the **Sentinel Application Platform (SNAP).**

Common borders. Common solutions.

# Calculating chl-*a* using the SNAP toolkit and C2RCC processor

## Overview of method:



Project funded by EUROPEAN UNION

PONTOS

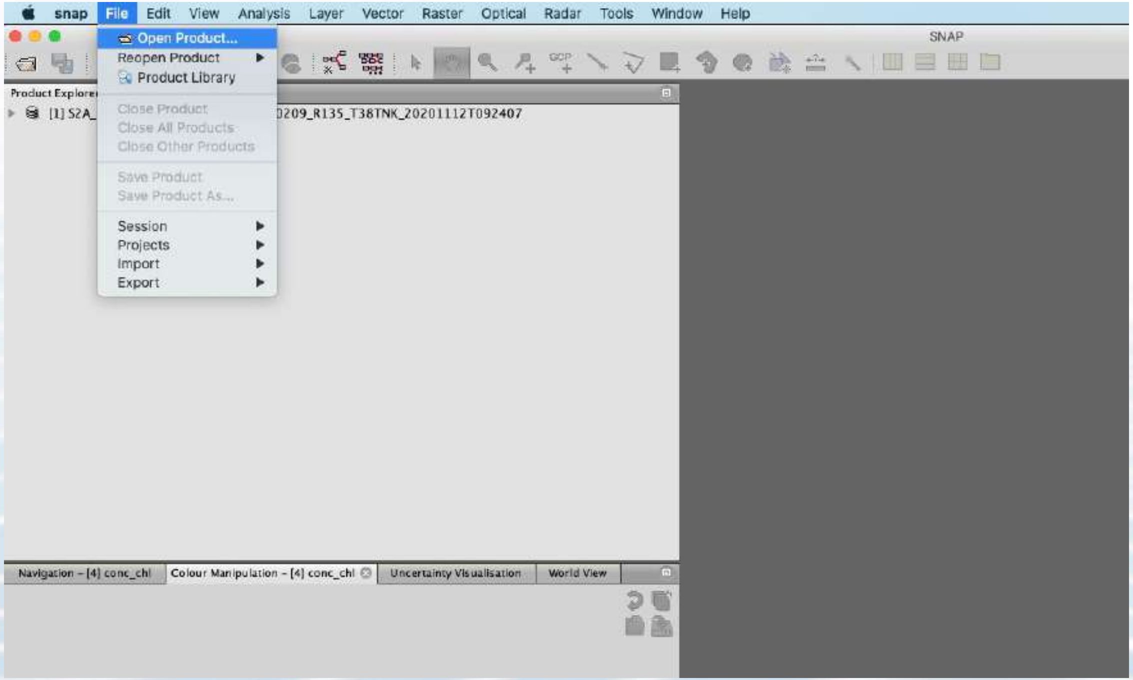
Common borders. Common solutions.

Black Sea CROSS BORDER COOPERATION

# Calculating chl-*a* using the SNAP toolkit and C2RCC processor

To import satellite image, go to File → Open Product.

Alternatively, you can also 'Drag & Drop' the file into the Product Explorer window.



Project funded by EUROPEAN UNION

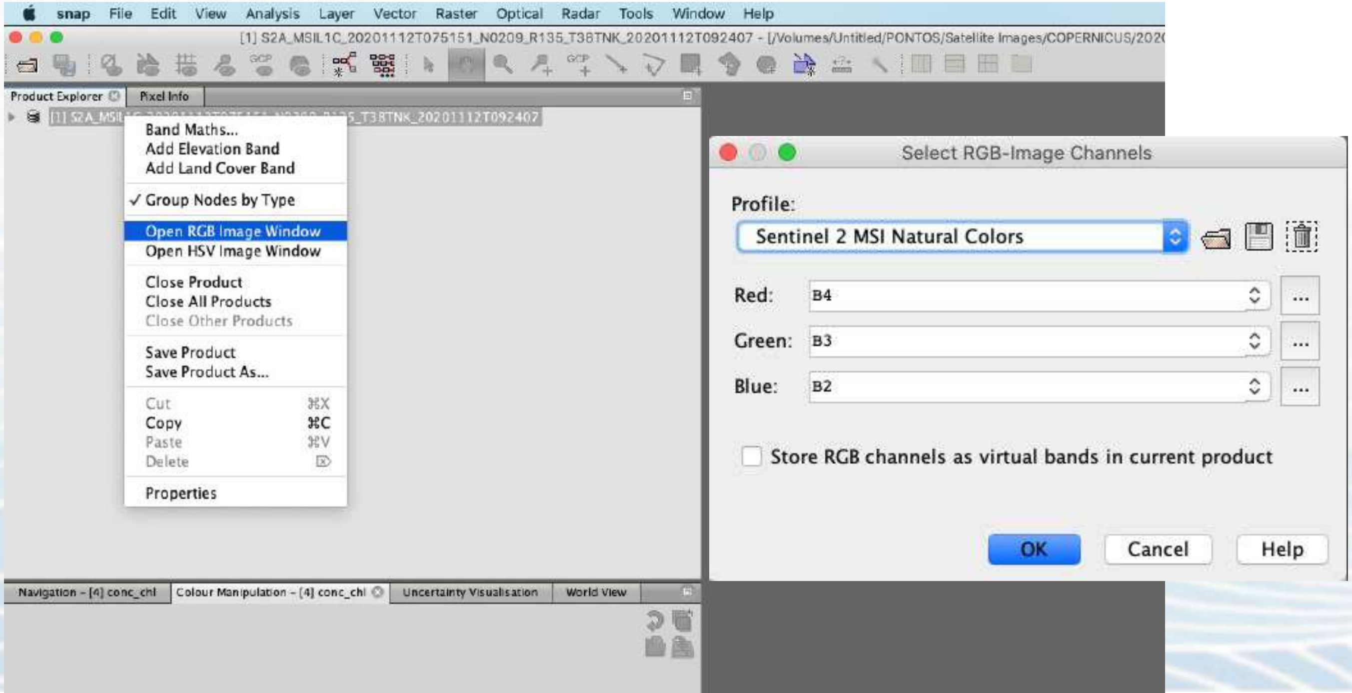
PONTOS

Black Sea CROSS BORDER COOPERATION

**Common borders. Common solutions.**

# Calculating chl-*a* using the SNAP toolkit and C2RCC processor

To visualize the imported image, right click on the product and press on ‘Open RGB Image Window’.



Project funded by EUROPEAN UNION

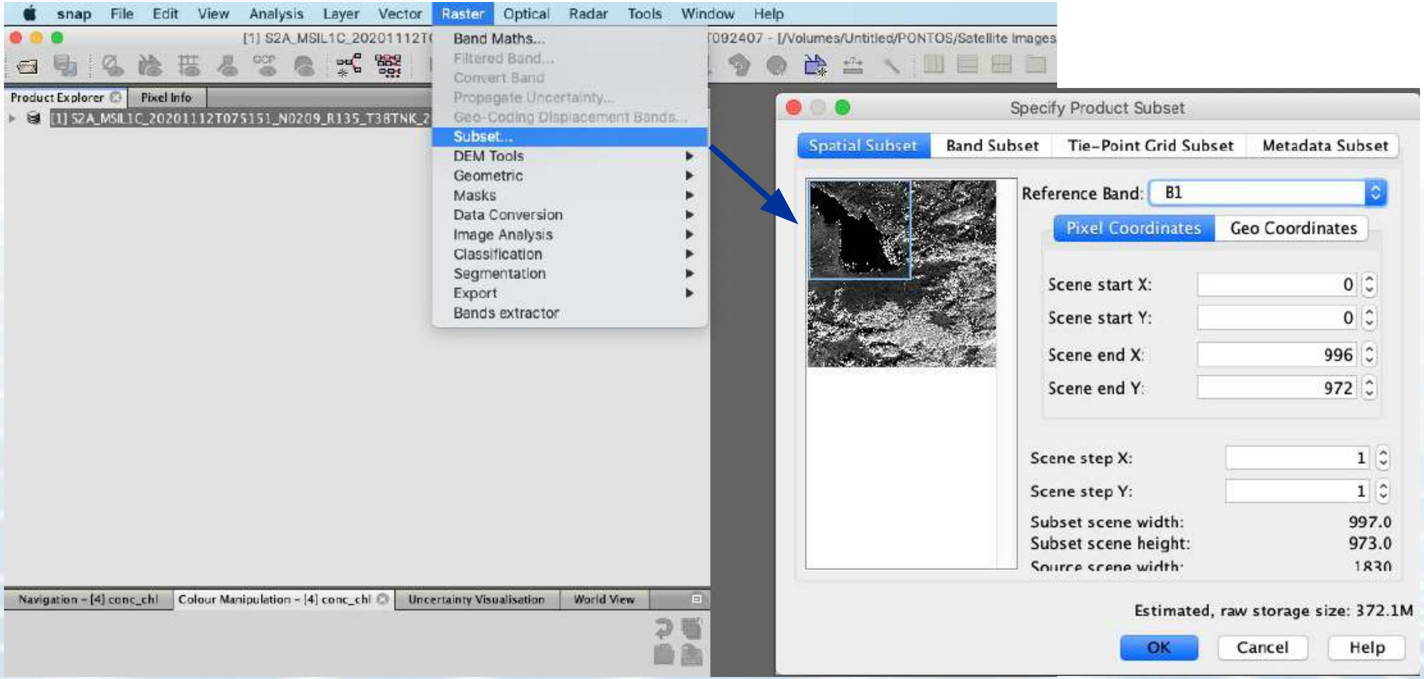
PONTOS

Black Sea CROSS BORDER COOPERATION

**Common borders. Common solutions.**

# Calculating chl-*a* using the SNAP toolkit and C2RCC processor

To select an area of interest, go to the ‘Raster’ tab and select subset. There you can use the visual tool, to choose your focus area.



Project funded by EUROPEAN UNION

PONTOS

Black Sea CROSS BORDER COOPERATION

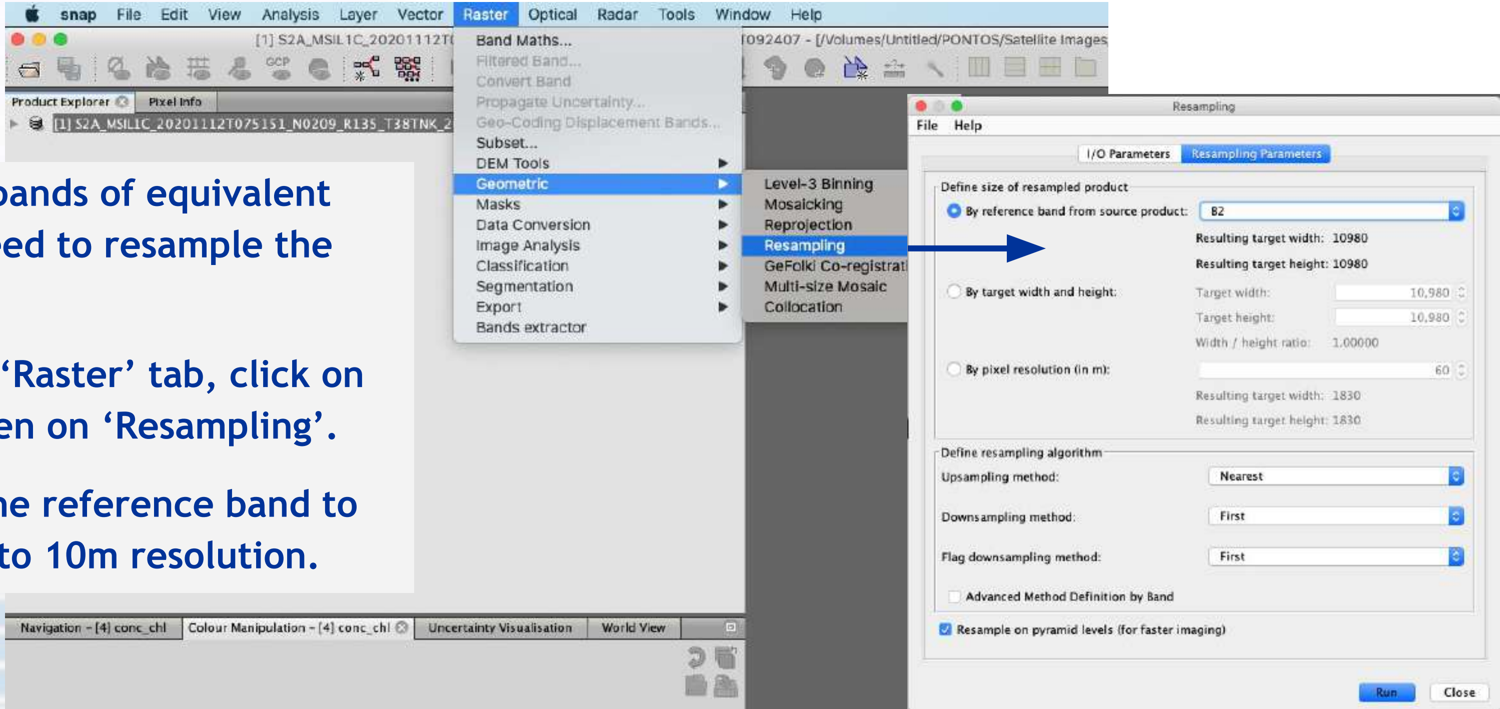
**Common borders. Common solutions.**

# Calculating chl-*a* using the SNAP toolkit and C2RCC processor

To make all image bands of equivalent resolution, we'll need to resample the product file.

To do so, go to the 'Raster' tab, click on 'Geometric' and then on 'Resampling'.

We will use B2 as the reference band to resample all bands to 10m resolution.



**Common borders. Common solutions.**

# Calculating chl-*a* using the SNAP toolkit and C2RCC processor

Alternatively, you can perform bulk processing using the Graph Processor Tool (GPT).

## Bulk Processing with Graph Processor Tool (GPT)


```xml
<graph id="Graph">
  <version>1.0</version>
  <node id="Read">
    <operator>Read</operator>
    <sources/>
    <parameters class="com.bc.ceres.binding.dom.XppDomElement">
      <file>D:\Desktop\Παρουσίαση SPM\Images from SPM MArre\Satellite\S2A_MSIL1C_20200729T090601_N0209_R050_T35TKF_20200729T112307.zip</file>
    </parameters>
  </node>
  <node id="Resample">
    <operator>Resample</operator>
    <sources>
      <sourceProduct refid="Read"/>
    </sources>
    <parameters class="com.bc.ceres.binding.dom.XppDomElement">
      <referenceBand>B2</referenceBand>
      <targetWidth/>
      <targetHeight/>
      <targetResolution/>
      <upsampling>Nearest</upsampling>
      <downsampling>First</downsampling>
      <flagDownsampling>First</flagDownsampling>
      <resamplingPreset/>
      <bandResamplings/>
      <resampleOnPyramidLevels>true</resampleOnPyramidLevels>
    </parameters>
  </node>
  <node id="Subset">
    <operator>Subset</operator>
    <sources>
      <sourceProduct refid="Resample"/>
    </sources>
    <parameters class="com.bc.ceres.binding.dom.XppDomElement">
      <sourceBands/>
      <region>0,0,0,0</region>
      <referenceBand/>
      <geoRegion>POLYGON ((23.58807945251465 41.0165901184082, 24.727497100830078 41.0165901184082, 24.727497100830078 40.66456985473633, 23.58807945251465 40.66456985473633, 23.58807945251465 41.0165901
      <subSamplingX>1</subSamplingX>
      <subSamplingY>1</subSamplingY>
      <fullSwath>false</fullSwath>
      <tiePointGridNames/>
      <copyMetadata>true</copyMetadata>
    </parameters>
  </node>
  <node id="Write">
    <operator>Write</operator>
    <sources>
      <sourceProduct refid="Subset"/>
```


$variable

Resample

Subset

eXtensible Markup Language file length : 2,479 lines : 70 Ln : 18 Col : 22 Sel : 0 | 0 Unix (LF) ISO 8859-7 INS

Project funded by EUROPEAN UNION

PONTOS

Black Sea CROSS BORDER COOPERATION

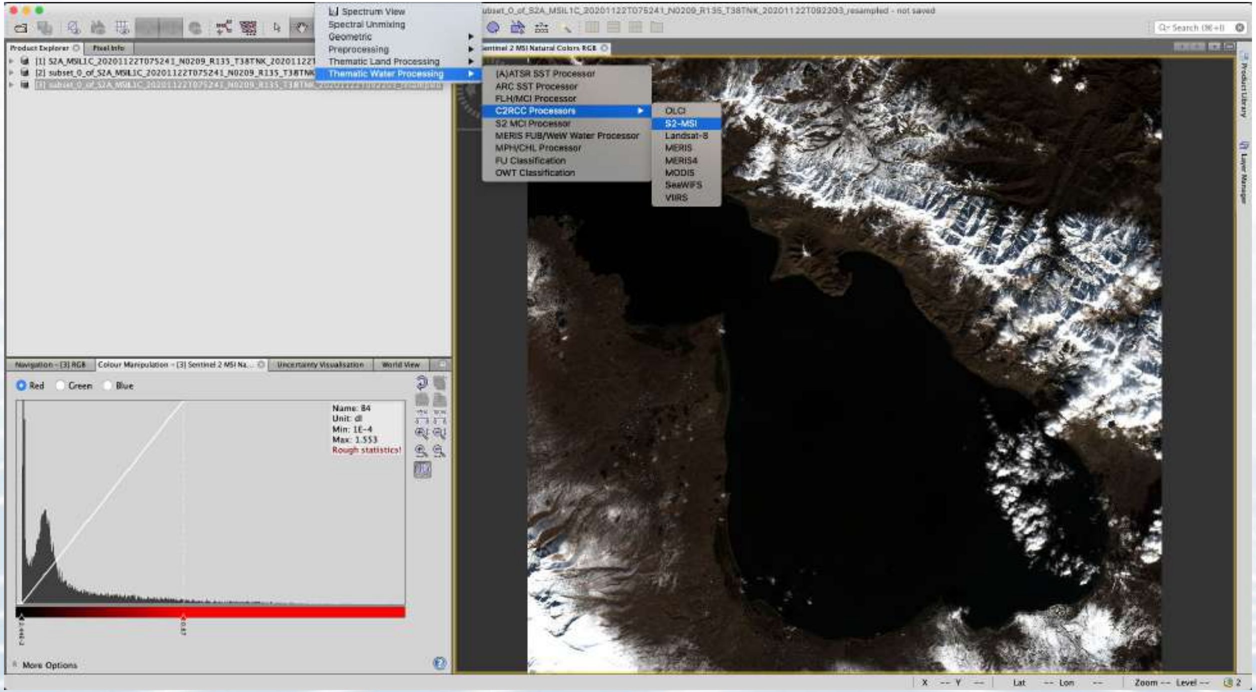
Common borders. Common solutions.

# Calculating chl-*a* using the SNAP toolkit and C2RCC processor

Now to calculate chl-a and TSM concentrations, we will use the C2RCC processor.

To do so, go to the 'Optical' tab, then select 'Thematic Water Processing' and choose 'C2RCC Processors'.

Select the processor equivalent to your product (*e.g.* S2-MSI for Sentinel-2 images).



Project funded by EUROPEAN UNION

PONTOS

Black Sea CROSS BORDER COOPERATION

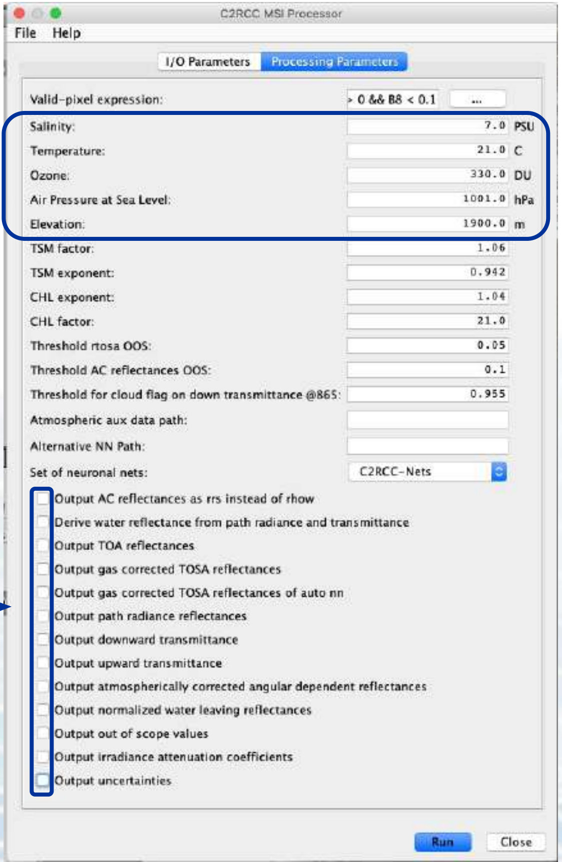
Common borders. Common solutions.

# Calculating chl-*a* using the SNAP toolkit and C2RCC processor

There, change the values of the following parameters to match the *in-situ* conditions at the time the image was taken:

- Salinity
- Temperature
- Ozone
- Pressure
- Elevation

\+ untick all below boxes



Project funded by EUROPEAN UNION

PONTOS

Black Sea CROSS BORDER COOPERATION

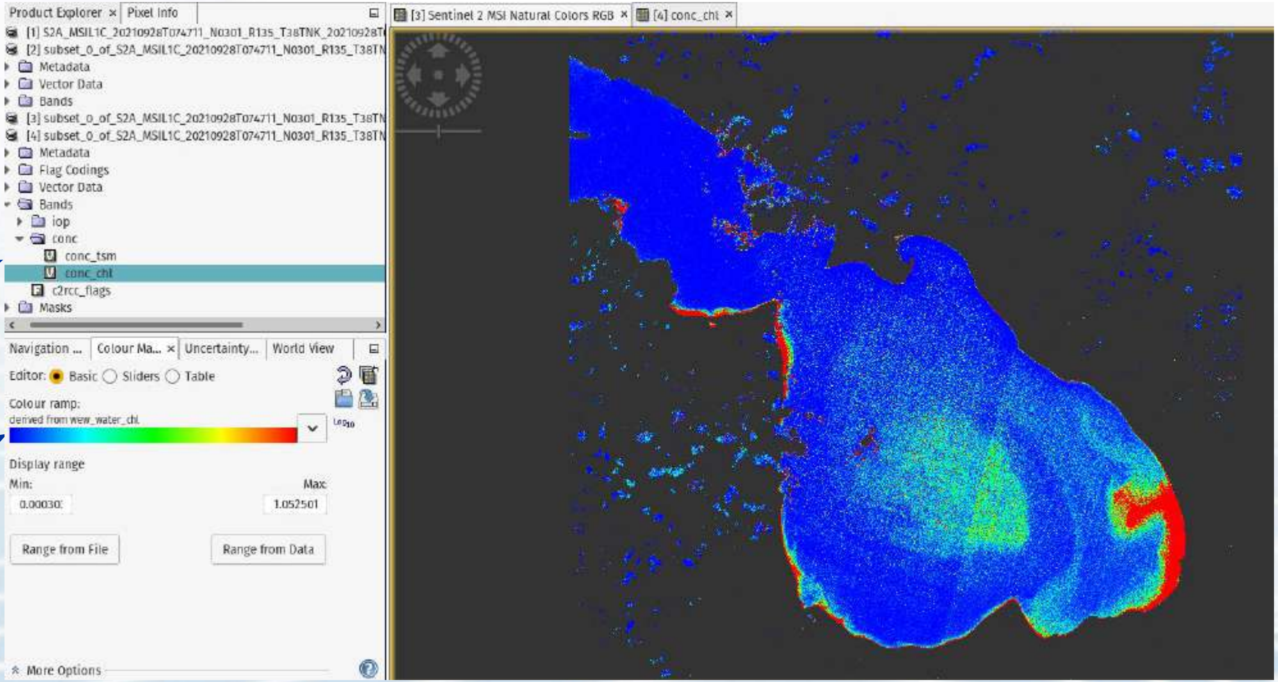
Common borders. Common solutions.

# Calculating chl-*a* using the SNAP toolkit and C2RCC processor

Double click on the latest created product to expand, then click on ‘Bands’ → ‘conc’. There you will have 2 newly created images:

- chl-*a* concentration
- TSM

You can select the colour of each image from a number of available templates and specify the data range.



Project funded by EUROPEAN UNION

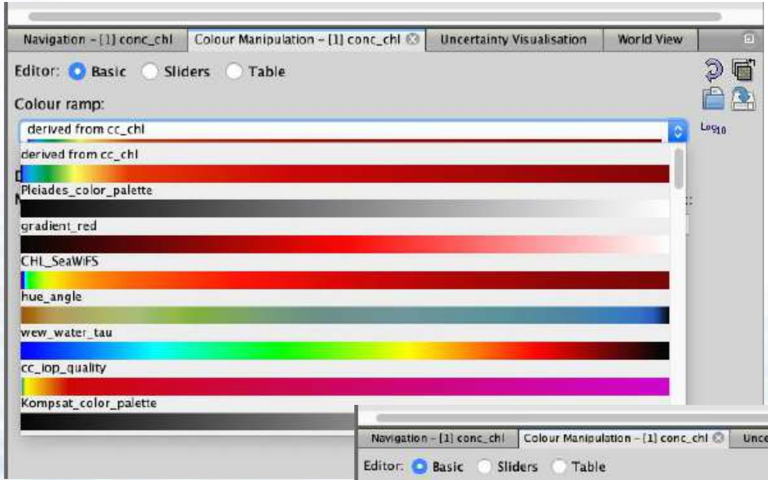
PONTOS

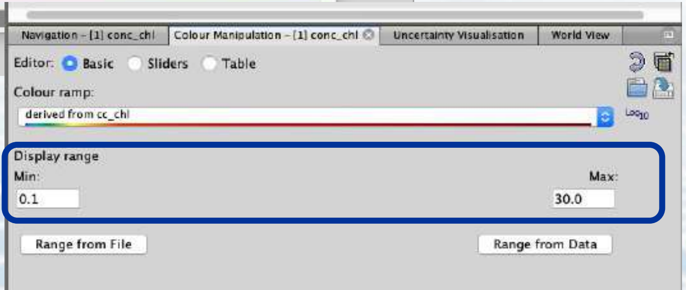
Black Sea CROSS BORDER COOPERATION

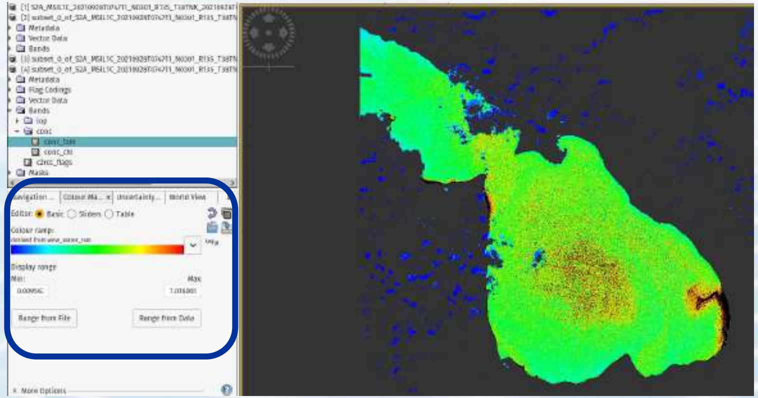
**Common borders. Common solutions.**

# Calculating chl-*a* using the SNAP toolkit and C2RCC processor

Select the colour of each image from a number of available templates and specify the data range.



Project funded by EUROPEAN UNION

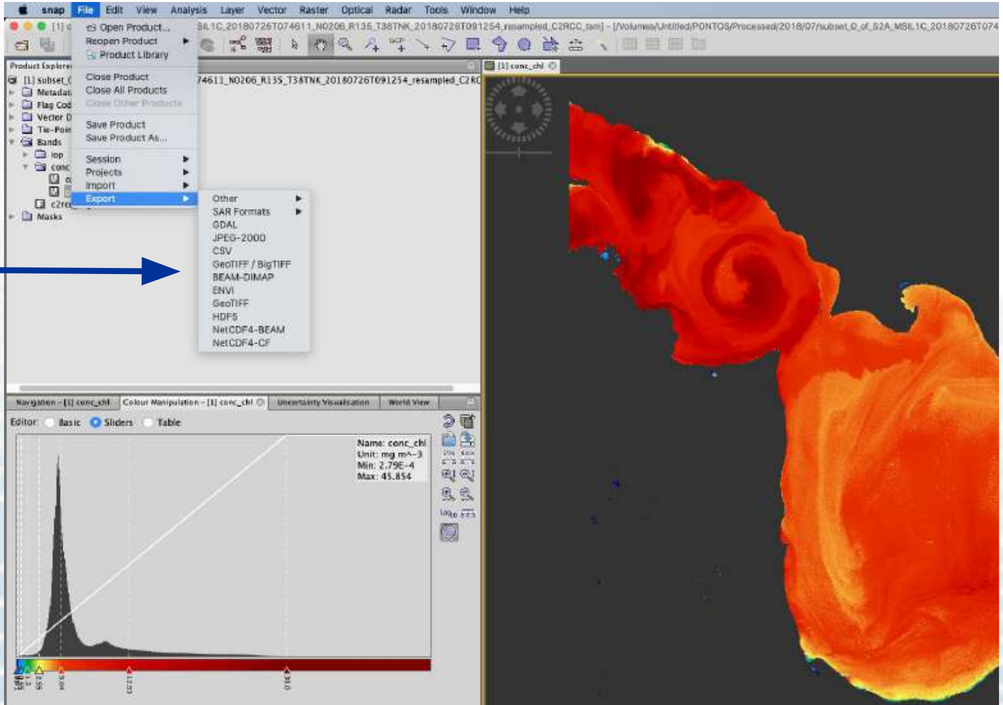
PONTOS

Black Sea CROSS BORDER COOPERATION

**Common borders. Common solutions.**

## Calculating chl-*a* using the SNAP toolkit and C2RCC processor

You can export the created images by clicking on ‘File’ → ‘Export’ and selecting on any of the desired file formats, including GeoTIFF, JPEG-2000, NetCFD4, ENVI, HDF5, etc.



Project funded by EUROPEAN UNION

PONTOS

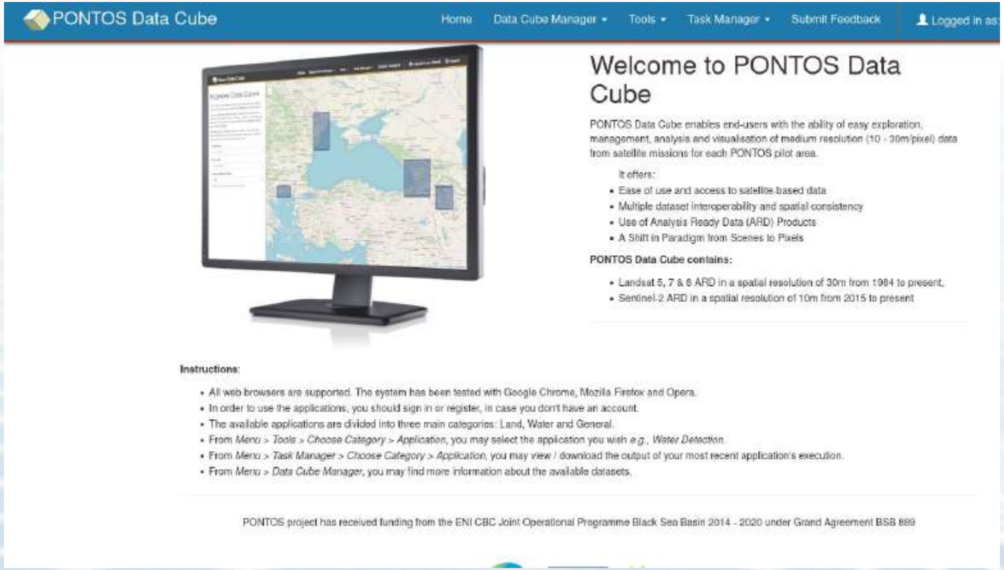
Black Sea CROSS BORDER COOPERATION

## Common borders. Common solutions.

# 04 Using the PONTOS Data Cube to calculate Total Suspended Matter

The last part of this module will describe how to use the PONTOS Data Cube to calculate the Total Suspended Matter (TSM) in water bodies.

TSM is an indication of water turbidity (*i.e.* low water clarity), thus high TSM concentrations could often indicate low water quality, water pollution, and anthropogenic pressure.



Project funded by EUROPEAN UNION

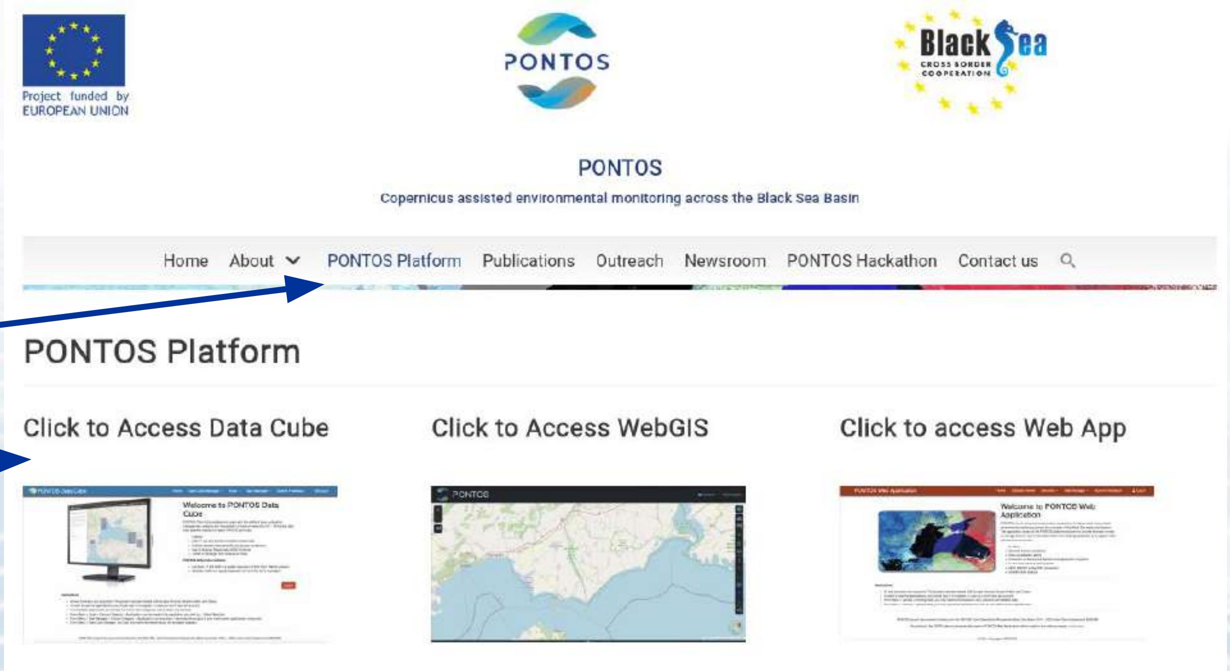
PONTOS

Common borders. Common solutions.

# Using the PONTOS Data Cube

To access the PONTOS Data Cube:

1. Go to the PONTOS project website (pontos-eu.aua.am)
2. Click on the tab entitled "PONTOS Platform"
3. Now, click to Access Data Cube



Project funded by EUROPEAN UNION

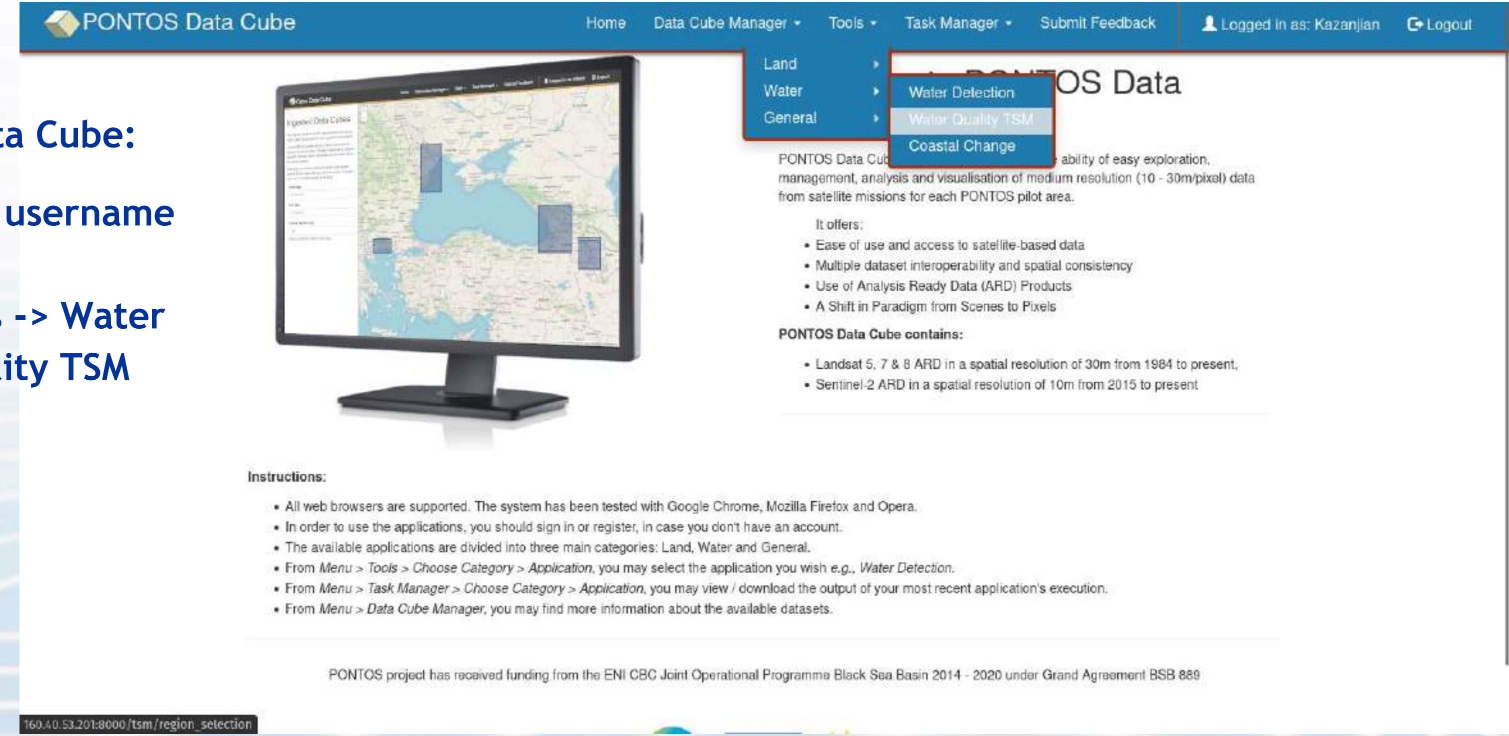
PONTOS

Common borders. Common solutions.

Black Sea CROSS BORDER COOPERATION

## On the PONTOS Data Cube:

1. Register your username
2. Sign in
3. Click on Tools -> Water -> Water Quality TSM

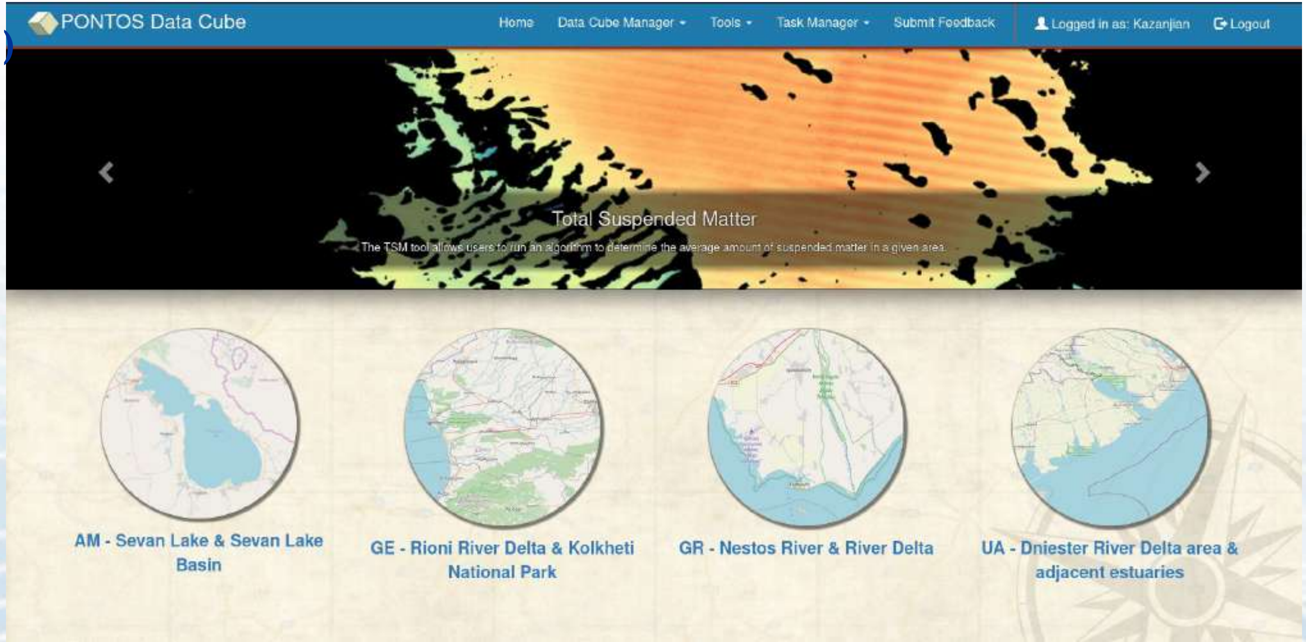


Project funded by EUROPEAN UNION

Common borders. Common solutions.

# Using the PONTOS Data Cube

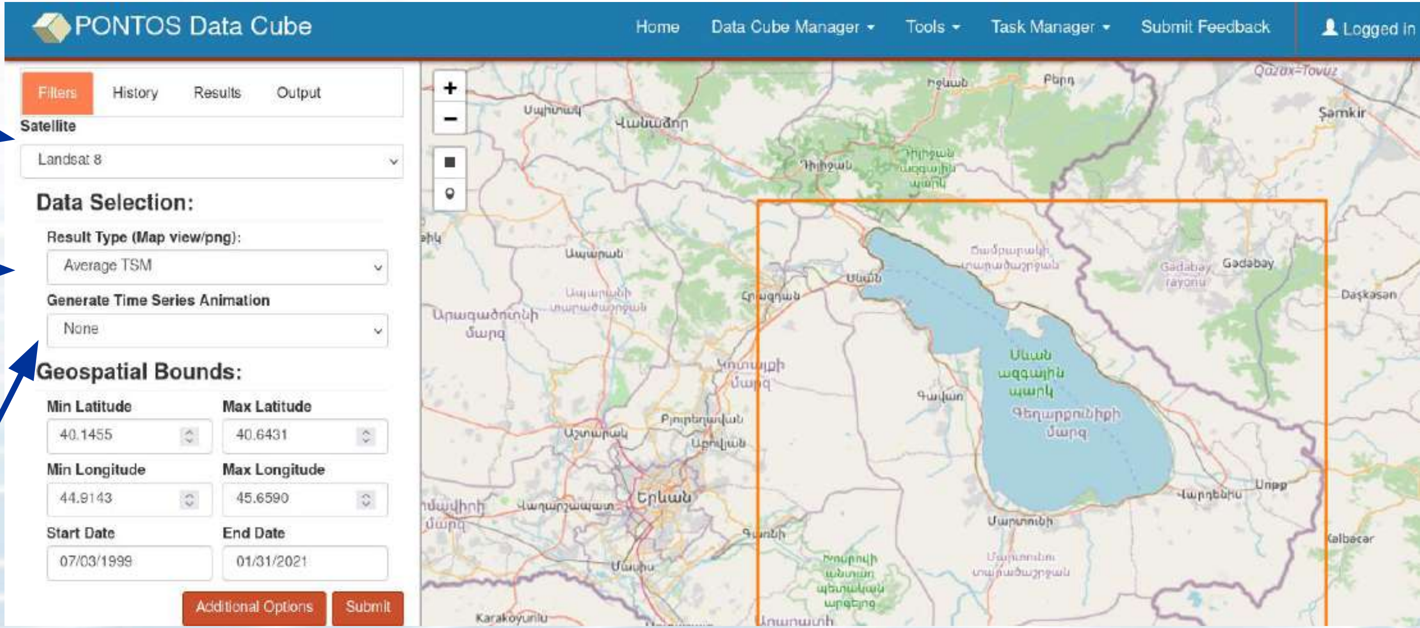
Choose the pilot site (location) you are interested in to perform your query.



# Using the PONTOS Data Cube

Here you can select:

1. Images from specific satellites
2. TSM results shown as
   a. Average
   b. Minimum
   c. Maximum
   d. Variability
3. Option to generate a time series animation



Project funded by EUROPEAN UNION

PONTOS

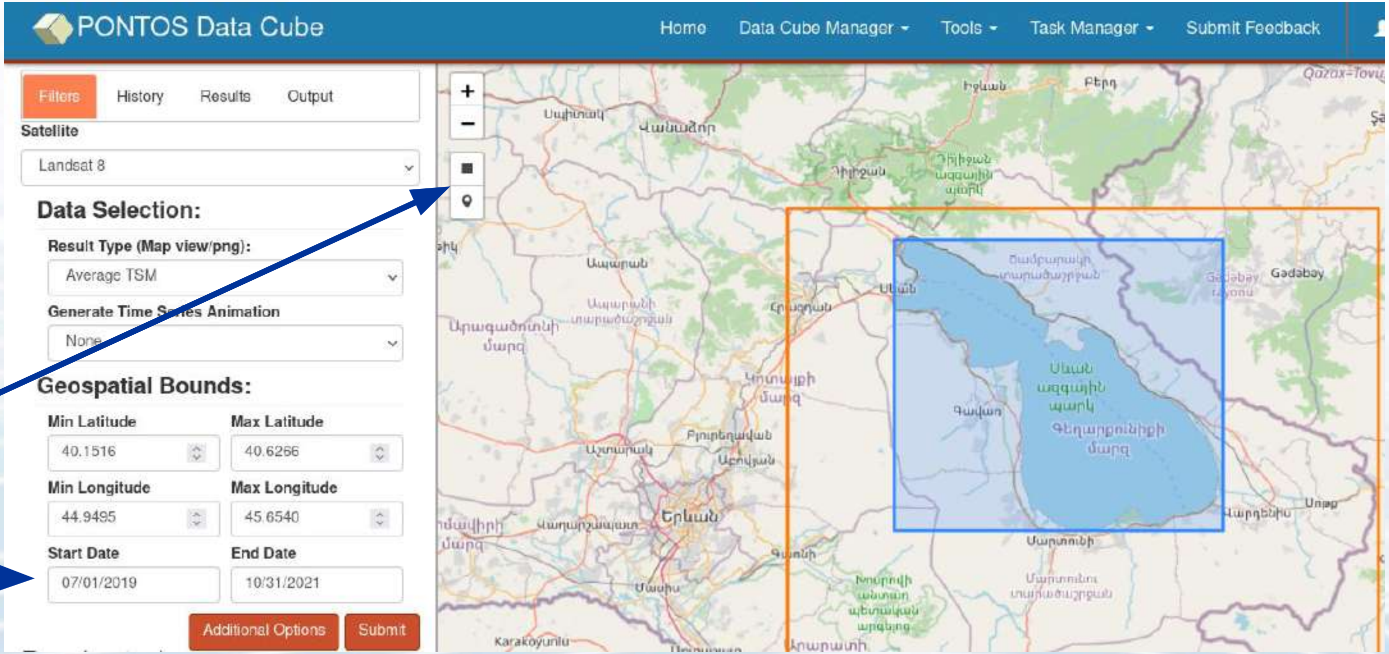
Black Sea CROSS BORDER COOPERATION

**Common borders. Common solutions.**

# Using the PONTOS Data Cube

## Here you can select (cont'd):

1. The spatial boundaries either
   a. via entering the exact coordinates
   b. By drawing a polygon
2. The period of interest for your analysis



Project funded by EUROPEAN UNION

PONTOS

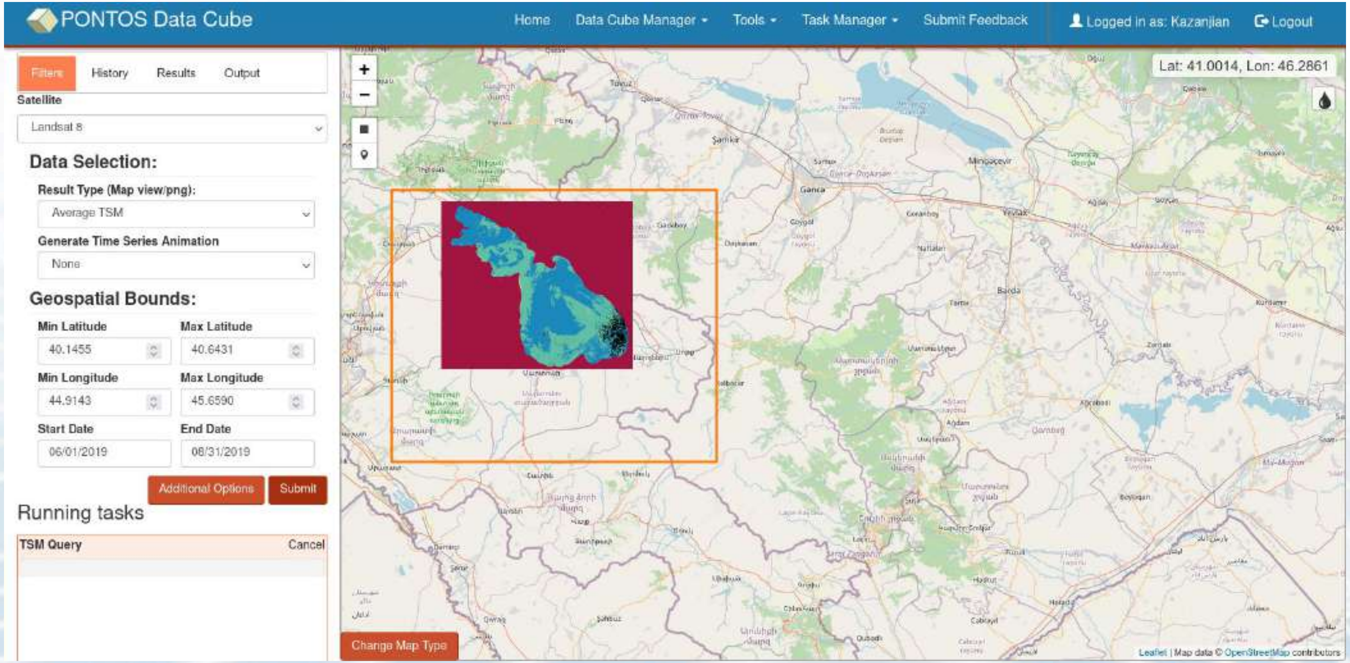
Black Sea CROSS BORDER COOPERATION

**Common borders. Common solutions.**

# Using the PONTOS Data Cube

When you click submit, you will notice a TSM Query appear under running tasks.

Wait till the query is completed and a colored picture will appear within the selected boundaries, showing the TSM concentrations as specified in your query.



Project funded by EUROPEAN UNION

PONTOS

Common borders. Common solutions.

# Using the PONTOS Data Cube

To review any of your previous queries, you can click on 'Task Manager' → Water → Water Quality TSM.

There you will see a list of all your requested queries.

Click on Details for more information.

Project funded by EUROPEAN UNION

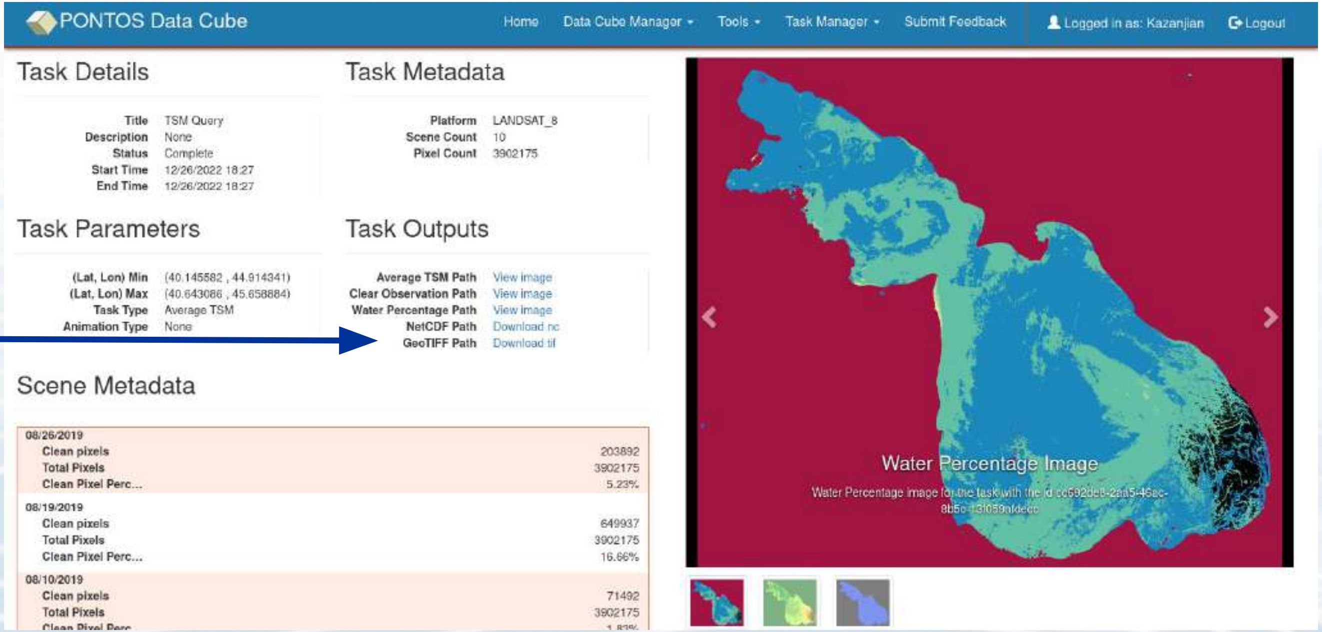
PONTOS

Black Sea CROSS BORDER COOPERATION

**Common borders. Common solutions.**

# Using the PONTOS Data Cube

Here you will see the details of your query and be able to download the produced images in GeoTIFF or NetCDF format.



**Common borders. Common solutions.**

Joint Operational Programme Black Sea Basin 2014-2020
Copernicus Assisted Environmental Monitoring across the Black Sea Basin – PONTOS
December 2022

Joint Operational Programme Black Sea Basin 2014-2020 is co-financed by the European Union through the European Neighbourhood Instrument and by the participating countries: Armenia, Bulgaria, Georgia, Greece, Republic of Moldova, Romania, Turkey, and Ukraine.

This publication has been produced with the financial assistance of the European Union.