Common borders. Common solutions.

Training of Trainers in Thessaloniki (GR)

10.03.2022

Training material on PONTOS Data Cube

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TABLE OF CONTENTS

1. INTRODUCTION

This training material aims to facilitate the training of trainers on PONTOS Data Cube taking place in Thessaloniki on 10.03.2022. PONTOS Data Cube, as an essential part of the PONTOS platform, targets on easing the production of maps from Earth Observation (EO) satellite data and supporting the means by which environmental monitoring in the Black Sea Basin area is accomplished. Following the launch of the PONTOS platform, end-users, i.e., stakeholders, researchers, students, will be enabled to use the various tools offered by PONTOS Data Cube in relation with the different PONTOS pilot sites. In this training material, the theoretical background and the functionalities of PONTOS Data Cube are presented.

2. THEORETICAL BACKGROUND

Remotely acquired Earth Observation (EO) data are essential in enhancing our knowledge and understanding of Earth processes as well as in supporting long-term global coverage of them through time.

For the assistance and support of environmental monitoring and decision making based on EO data, the Earth has been constantly observed by satellites since 1972, providing regular and multispectral observations of the planet (Giuliani et al., 2020). Nowadays, researchers are able to reach a variety of remote sensing information in the form of images acquired by various and diverse satellites and sensors in plentiful temporal, spatial and spectral resolutions.

However, conventional approaches in terms of acquisition, distribution, store, management and analysis of EO data are liable to limitations regarding volume (e.g., tera to petabytes), variety and heterogeneity (e.g., radar or optical) and velocity (e.g., new data are becoming available on a daily basis). Stepping further from conventional local infrastructures (e.g., desktop computers) and data distribution methods (e.g., scene-based file download) (CEOS, 2017) to open source software and analysis platforms (Dhu et al., 2019) is regarded as a fundamental advancement in tackling the challenges with reference to accessing, processing and storing EO data.

Multi-dimensional Data Cubes (DC) are regarded as an innovative approach and an effective solution in storing, organizing, managing and analyzing EO data by addressing volume, variety and velocity challenges. **The term "Data Cube" indicates a set of image time series affiliated with spatially aligned**

pixels. Data Cubes of EO imagery, e.g., PONTOS Data Cube, are three-dimensional objects since each component possesses one temporal and two spatial dimensions (i.e., longitude and latitude) (Figure 1).

In this direction, the Earth Observation Satellite Commission (CEOS) System Engineering Office (SEO) has played a key role in the development of the Open Data Cube (ODC) software through a separate initiative called the "CEOS Data Cube" (CDC) (Rizvi et al., 2018). The ODC software targets on leveraging the various possibilities of EO satellite data as well as enlarging the provision of satellite Analysis Ready Data (ARD) products to end-users.

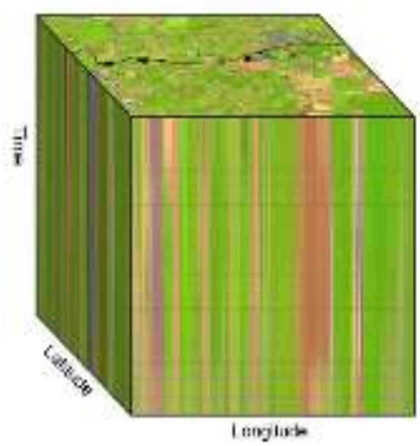

Figure 1. Dimensional axes of an EO Data Cube (Kopp et al., 2019).

Centre for Research and Technology Hellas (CERTH) has adopted the previously mentioned approach in terms of PONTOS project and the implementation of PONTOS platform. PONTOS Data Cube was implemented in the direction of enabling end-users with the ability of easy exploration, analysis, management and visualization of satellite EO ARD for each pilot of this project. It aims to strengthen the value and impact of EO satellite data in the Black Sea Basin and each pilot area of PONTOS project by addressing some essential needs of EO satellite data users, as it:

- decreases time and specialized knowledge that is required in order to access, explore and process satellite data,
- contains a big volume of EO ARD satellite data in order to minimize the time and complexity that their pre-processing demands,
- does not require the availability of computational infrastructure on the side of the end-user,
- includes tools which can be used to perform various analyses by exploiting EO ARD satellite data.

3. TECHNICAL OVERVIEW

PONTOS Data Cube constitutes a Python web-application. It is built on CEOS SEO Open Data Cube (ODC) software suite, release 2.21, which encloses a collection of Python frameworks and libraries and a PostgreSQL database for the purpose of accessing, exploring, managing, performing analyses and visualizing satellite EO ARD. The fully customizable open-source code of CEOS SEO ODC is publicly available under Apache License, Version 2.0., at CEO SEO's public repository (https://github.com/ceos-seo). PONTOS Data Cube couples a user-friendly web-design with a modular architecture generating a web-based user-friendly User Interface (UI), which seizes the possibilities of the Open Data Cube software.

In the back-end, the PostgreSQL database is used to index and ingest EO satellite data and their metadata. EO data are managed as GeoTIFF data format during the indexing, while as Network Common Data Format (NetCDF) files during the ingestion process. The above mentioned data are handled with the use of Geospatial Data Abstraction Library (GDAL) (Appel & Pebesma, 2019) and specific Python libraries (e.g., numpy, matplotlib, scikit-learn, scipy, rasterio etc.).

ARD datasets from multiple EO satellite missions contained in PONTOS Data Cube can be accessed through various offered tools (please refer to Chapter 4.) in order for the end-user to perform custom analysis cases over specific user-defined areas and time ranges (please refer to Chapter 5.2). PONTOS Data Cube incorporates ARD satellite datasets over PONTOS project's defined regions of interest. These datasets correspond to:

- **Landsat 5 TM** USGS Collection 1 Higher Level SR scenes (Level 2) in a spatial resolution of 30m for the time range 1984 to 2011,
- **Landsat 7 ETM+** USGS Collection 1 Higher Level SR scenes (Level 2) in a spatial resolution of 30m for the time range 1999 to 2021,
- **Landsat 8 OLI/TIRS** USGS Collection 1 Higher Level SR scenes (Level 2) in a spatial resolution of 30m for the time range 2013 to 2021,
- **Sentinel-2 MSI** Level-2A scenes in a spatial resolution of 10m for the time range 2015 to 2021.

This archive contains approximately 99,000 images (Figure 2.), occupying a total volume of 20.82 TB.

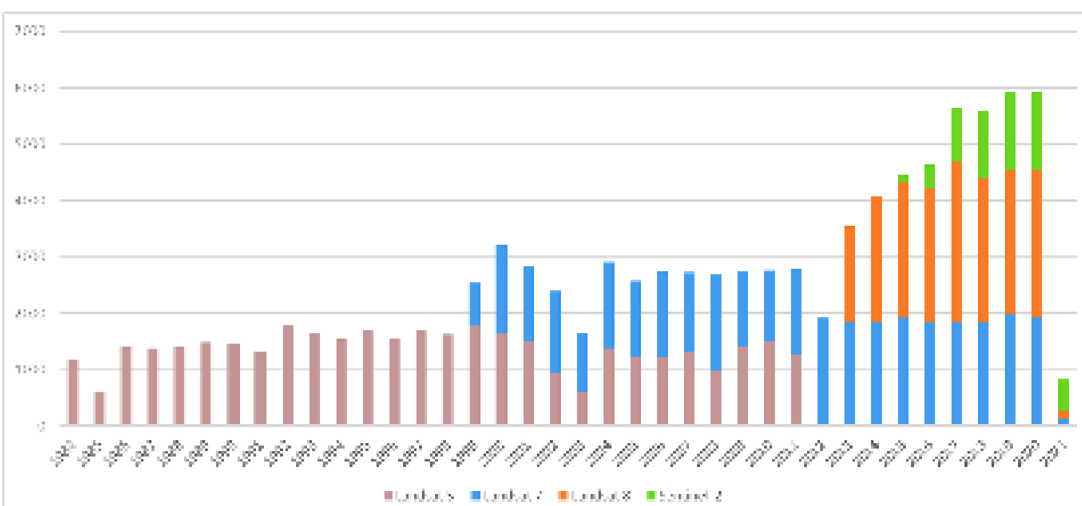

Figure 2. Overview of images number contained within PONTOS Data Cube broken down by year and satellite mission.

Regarding the defined areas that are incorporated and custom analyses to be performed in PONTOS Data Cube, those correspond to PONTOS' pilot sites:

- PONTOS - AM (Armenia): Sevan Lake and Sevan Lake Basin
- PONTOS - GE (Georgia): Rioni River Delta and Kolkheti National Park
- PONTOS - GR (Greece): Nestos River and Nestos River Delta
- PONTOS - UA (Ukraine): Coastline from Odessa city to the Danube river delta as well as Dniester river delta area and adjacent estuary.

As PONTOS Data Cube operates with the ingested products, i.e., in NetCDF format, of EO datasets, the names of the ingested EO datasets for each corresponding pilot area and EO dataset source are presented in detail in Table 1.

Table 1. Names of ingested EO products per pilot area and dataset source.

Pilot Area	EO Dataset Source	Ingested product name
AM Sevan Lake & Sevan Lake Basin	Landsat 7	ls7_ledaps_AM_Sevan_Lake
	Landsat 8	ls8_lasrc_AM_Sevan_Lake
	Landsat 5	ls5_ledaps_AM_Sevan_Lake
	Sentinel-2	s2_l2a_AM_Sevan_Lake
GE Rioni River Delta & Kolkheti National Park	Landsat 7	ls7_ledaps_GE_KolkhetiNP
	Landsat 8	ls8_lasrc_GE_KolkhetiNP
	Landsat 5	ls5_ledaps_GE_KolkhetiNP
	Sentinel-2	s2_l2a_GE_KolkhetiNP
GR Nestos River & Nestos Delta	Landsat 7	ls7_ledaps_GR_Nestos
	Landsat 8	ls8_lasrc_GR_Nestos
	Landsat 5	ls5_ledaps_GR_Nestos
	Sentinel-2	s2_l2a_GR_Nestos
UA Dniester River Delta area & adjacent estuary	Landsat 7	ls7_ledaps_UA_Dniester
	Landsat 8	ls8_lasrc_UA_Dniester
	Landsat 5	ls5_ledaps_UA_Dniester
	Sentinel-2	s2_l2a_UA_Dniester

4. TOOL GUIDE

PONTOS Data Cube includes the deployment and support of several tools aiming to offer analyses of ARD in relation to water detection and quality, coastal change, spectral indices, fractional cover, custom mosaics and urbanization as well. These tools can be accessed through PONTOS Data Cube User Interface and they are divided into three main groups: water, land and general tools. The following sections comprise a complete listing of the supported tools as well as a glossary of processing options unique to each tool.

4.1 WATER-BASED TOOLS

The water group contains tools related to:

- Water Detection – Water Observations from Space (WOfS)
- Water Quality – Total Suspended Matter (TSM)
- Coastal Change – Change in a coastal region

4.1.1 WATER DETECTION

The water detection analysis tool allows users to run the WOfS (Water Observations from Space) algorithm on a selected area. WOfS constitutes a multi-spectral decision tree tool aiming to detect water (Figure 3.). It was developed in Australia (Mueller et al., 2016) focusing on improved water detection over standard water quality flags in Landsat products. The output is a time series of water classifications and observations (Figure 4.). This can indicate water cycle dynamics, historical water extent, and the risk of floods and droughts.

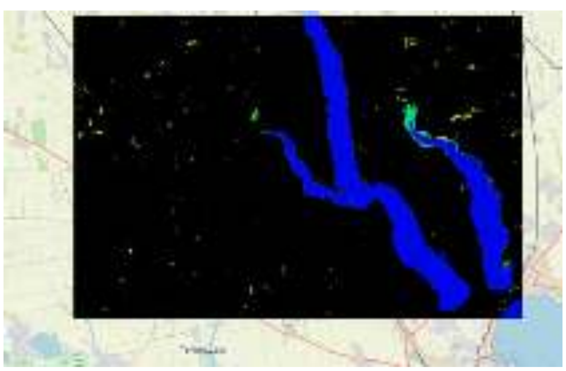

Figure 4. WOfS analysis over an area in Ukraine.

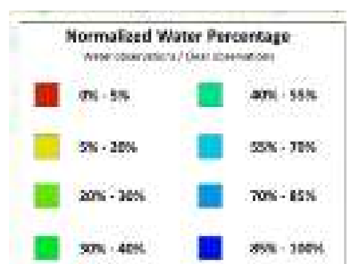

Figure 3. WOfS' tool legend.

Options:

Image Background Color

- Black: Sets the background to solid black
- White: Sets the background to solid white
- Transparent: Displays the selected area as the background

4.1.2 WATER QUALITY – TSM

This tool forms a water quality product based on an empirical algorithm developed in Australia. Particularly TSM is an index that uses Red and Green bands for the assessment of water quality and turbidity as an indicator of water condition (Lymburner et al., 2016). The output (Figure 5.) depicts the average TSM as grams per liter (g/L) (Figure 6.).

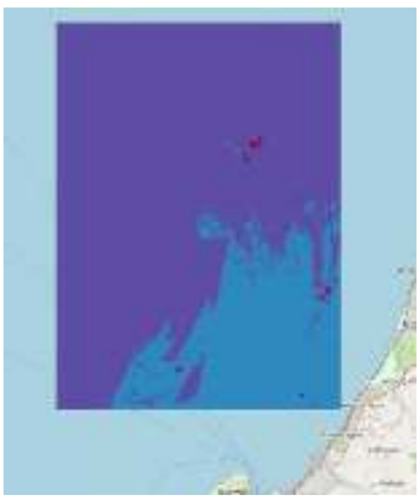

Figure 6. TSM analysis over an area in Georgia.

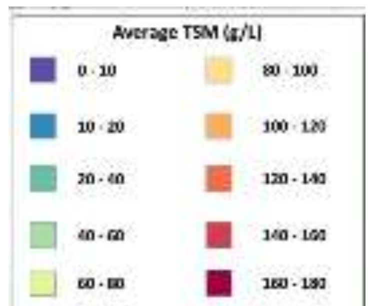

Figure 5. TSM tool's legend.

Options:

Result Type (Map view/PNG)

- Average TSM: Display the average TSM of every observation for the given pixel
- Minimum TSM: Display the lowest TSM from every observation for the given pixel
- Maximum TSM: Display the highest TSM from every observation for the given pixel
- TSM Variability: Variability of Total Suspended Matter

4.1.3 COASTAL CHANGE

Detection of changes in coastal boundaries comprises the main target of this algorithm, which is based on the WOfS algorithm . This tool results on the measurement of change in a coastal region based on two selected time periods (Figure 7.). It can display both the overall change in the coastal area as well as highlight gain or loss in coastlines (Figure 8.).

Figure 7. Coastal change analysis over Nestos River Delta in Greece.

Figure 8. Coastal change tool's legend.

4.2 LAND-BASED TOOLS

The land group contains tools related to:

- Urbanization – Normalized Difference Built-up Index (NDBI)
- Spectral Indices – Normalized Difference Vegetation Index (NDVI), Normalized Difference Water Index (NDWI), Normalized Difference Built Index (NDBI), Enhanced Vegetation Index (EVI), Soil Adjusted Vegetation Index (SAVI), Normalized Burn Ratio (NBR), Normalized Burn Ration 2 (NBR 2)
- Spectral Anomaly – Deviation in NDVI index from a specific baseline period
- Fractional Coverage – Vegetational fractional cover

4.2.1 URBANIZATION

This tool offers a measurement in the growth or loss of urbanized land in a selected area (Figure 9.). It uses NDBI (Normalized Difference Built-Up Index) as a proxy that correlates with urbanization (Figure 10.).

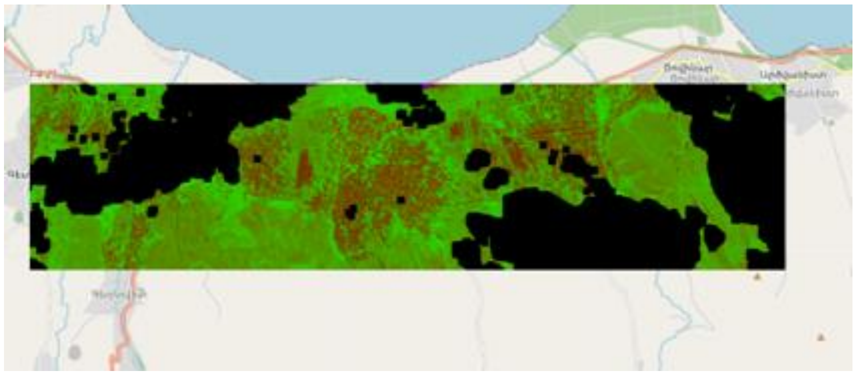

Figure 9. Urbanization over a selected region in Sevan's Lake Basin in Armenia.

Options:

<u>Compositing method</u>

- Least Recent Pixel: Creates a composite of the least recent pixels with no cloud coverage
- Max NDVI Pixel: Creates a composite using pixels with the max NDVI values
- Median Pixel: Creates a composite of the median recent pixels with no cloud coverage
- Min NDVI Pixel: Creates a composite using pixels with the min NDVI values
- Most Recent Pixel: Creates a composite of the most recent pixels with no cloud coverage

Figure 10. Urbanization tool's legend.

4.2.2 SPECTRAL INDICES

The selected spectral index can be used to monitor changes over a defined period of time for a particular feature of interest. This tool offers the calculation of the following spectral indices (Chatenoux et al., 2019):

- **Normalized Difference Vegetation Index (NDVI):** Constitutes the most common vegetation index where NDVI = (NIR-Red) / (NIR+Red).
- **Normalized Difference Water Index (NDWI):** A common index for water detection where NDWI = (Green-NIR) / (Green+NIR).
- **Normalized Difference Built-up Index (NDBI):** An index for detecting urbanization (Figure 3.9) where NDBI = (SWIR1-NIR) / (SWIR1+NIR).
- **Enhanced Vegetation Index (EVI):** Comprises an optimized vegetation index aiming to advance the vegetation signal with improved sensitivity over high biomass regions. EVI in the case of Lansat (Landsat EVI) is equivalent to 2.5 * (NIR-Red) / (NIR + 6*Red - 7.5*Blue + 1).
- **Soil Adjusted Vegetation Index (SAVI):** An index aiming to correct Normalized Difference Vegetation Index (NDVI) for the influence of soil brightness in areas where vegetative cover is low (https://www.usgs.gov/core-science-systems/nli/landsat/landsat-soil-adjusted-vegetation-index). In terms of Landsat, for Landsat 4-7 it is equivalent to ((Band 4 - Band 3) / (Band 4 + Band 3 + 0.5)) * (1.5), while for Landsat 8 SAVI = ((Band 5 - Band 4) / (Band 5 + Band 4 + 0.5)) * (1.5).
- **Normalized Burn Ratio (NBR):** An index similar to NDBI that is used to estimate burn severity. NBR= (NIR-SWIR1) / (NIR+SWIR1).

Options:

Compositing method

- Least Recent Pixel: Creates a composite of the least recent pixels with no cloud coverage
- Max NDVI Pixel: Creates a composite using pixels with the max NDVI values
- Median Pixel: Creates a composite of the median recent pixels with no cloud coverage
- Min NDVI Pixel: Creates a composite using pixels with the min NDVI values
- Most Recent Pixel: Creates a composite of the most recent pixels with no cloud coverage

4.2.3 SPECTRAL ANOMALY

This tool offers the identification of deviations in NDVI index starting from a specified baseline period. The output will indicate the areas with noteworthy increases and decreases in vegetation.

Options:

Baseline Period
Select the month(s) to focus the analysis on with the given time period.

4.2.4 FRACTIONAL COVER

It is used to estimate the average vegetation fractional cover utilizing a linear unmixing technique developed by (Guerschman, 2016). In terms of FC, each individual pixel is classified as a fraction of photosynthetic and non-photosynthetic vegetation (PV and NPV, respectively) and the remaining fraction of bare soil (BS) (Figure 11.).

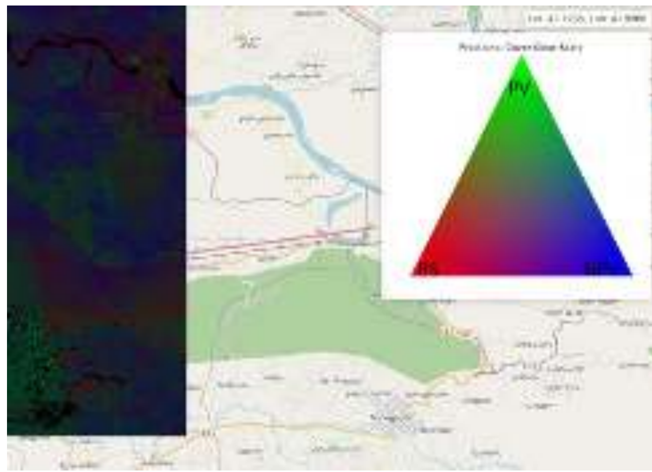

Figure 11. Fractional cover output over a region in Georgia's pilot.

4.3 GENERAL TOOLS

The general tools group contains tools related to:

- Custom Mosaic – Creation of cloud-free composites
- Cloud Coverage – Mosaic displaying cloud coverage

4.3.1 CUSTOM MOSAIC

This tool enables the end-users to produce cloud free composites of imagery (Figure 12.).

Options:

Result Type
The composite of any selected band among NIR, SWIR1, SWIR2, RED, GREEN and BLUE can be selected.

Compositing method

- Least Recent Pixel: Creates a composite of the least recent pixels with no cloud coverage
- Max NDVI Pixel: Creates a composite using pixels with the max NDVI values
- Median Pixel: Creates a composite of the median recent pixels with no cloud coverage

- Min NDVI Pixel: Creates a composite using pixels with the min NDVI values
- Most Recent Pixel: Creates a composite of the most recent pixels with no cloud coverage

Figure 12. True color composite of an area in Nestos River Delta in Greece.

4.3.2 CLOUD COVERAGE

This tool produces a mosaic depicting cloud coverage by calculating the percentage of pixels that are identified as clouds for the acquisitions that are selected.

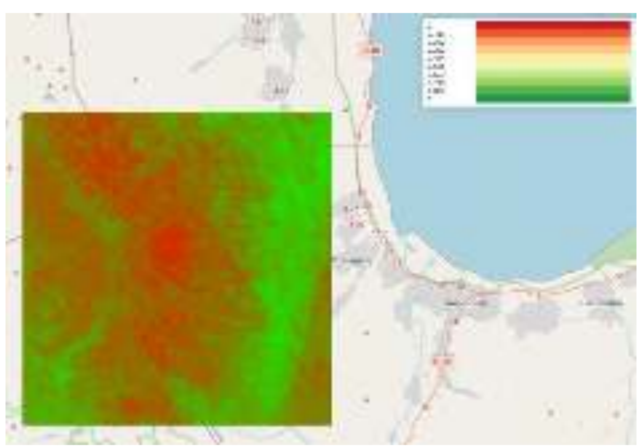

Figure 13. Cloud coverage output over a selected area in Sevan Lake Basin in Armenia.

5. USER INTERFACE GUIDE

PONTOS Data Cube's User Interface (UI) aims to provide end-users with the opportunity of accessing various integrated EO ARD datasets and perform analysis over defined regions of interest, i.e., PONTOS pilot sites, and time ranges. Moreover, the UI grants access to previously performed analyses. Users are also enabled to generate outputs either in a visual manner (images) or as data products in GeoTIFF or NetCDF format.

This guide section is designed to provide essential information on the use of PONTOS Data Cube UI as well as instructions for the performance of analyses and extraction of the outputs.

5.1 HOW TO LOGIN/ REGISTER

This section provides a quick guide on how to login or register on PONTOS Data Cube.

1) Visit PONTOS Data Cube on the address: http://160.40.53.201:8000/. At PONTOS Data Cube home page, please select "**Login**" (Figure 14.). In case there is an active user account, the login can take place with the user selected credentials (username and password).

Figure 14. PONTOS Data Cube home page.

Otherwise, click “**Register here**” to create a user account (Figure 15.). An account is required in order to use the UI features.

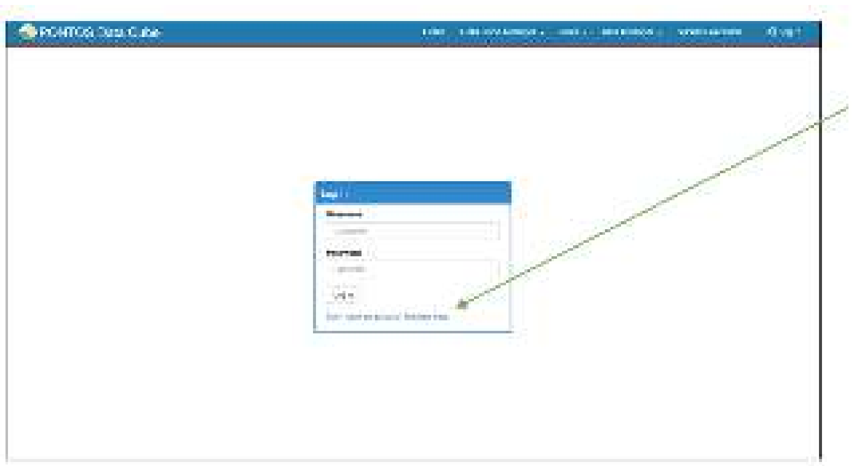

Figure 15. User registration form.

5.2 DATA CUBE MANAGER

The feature “Data Cube Manager” provides several options for exploring and viewing details of the datasets contained in PONTOS Data Cube (Figure 16.).

Figure 16. Data Cube Manager on PONTOS Data Cube UI.

1) **Data Cube Visualization:** Data Cube Visualization option provides visualization and browsing of the available satellite datasets contained in PONTOS Data Cube over PONTOS pilot sites. The available datasets are presented on an interactive map and they can be filtered by dataset type, i.e., Landsat 5, Landsat 7, Landsat 8 and Sentinel-2, or by date range (Figure 17.).

Figure 17. Filter available datasets by date range or dataset type on PONTOS Data Cube UI.

2) **Dataset Types:** This option lists all of the dataset type definitions that are adopted to describe the datasets contained in PONTOS Data Cube. Each dataset type consists of various data and metadata information about the corresponding platform, instrument, product type and measurements. Data and metadata information can be explored through the option "View definition" (Figure 18.). Please note that you should refer to each corresponding ingested product name according to Table 1. in Chapter 3.

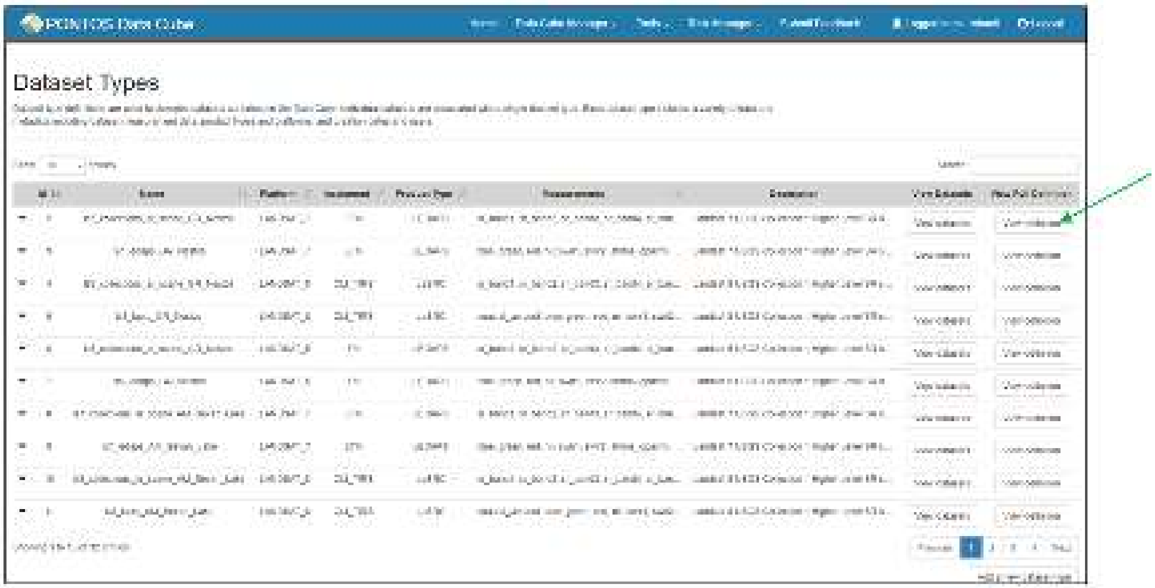

Figure 18. Exploration of data and metadata information of each dataset type.

3) **<u>Dataset Viewer:</u>** The dataset viewer presents in a table format all the data contained in the indexed and ingested products of PONTOS Data Cube. Through this option, the products can be filtered by product name, by time range (start and end date) as well as by spatial extents (Figure 19.).

Figure 19. Dataset Viewer options.

5.3 PERFORMING AN ANALYSIS

In this section, an example of how to perform an analysis through the PONTOS Data Cube UI is presented. For this example, we will use the tool "Fractional Cover".

1) Visit PONTOS Data Cube on the address: http://160.40.53.201:8000/ and login or register (please refer to section 5.1).

2) From the top menu bar, please select "**Tools**". Under the "Tools" menu, hover over "**Land**" group and select "**Fractional Cover**" (Figure 20.).

Figure 20. Tool selection.

3) You will be redirected to a page in which all the study areas that this tool can be applied, i.e., PONTOS pilot sites, will be listed (Figure 21.). Out of this page, please **select the pilot area** that you wish to perform the analysis simply by clicking the name of the area. For this example, we will perform the analysis for the pilot area "AM – Sevan Lake & Sevan Lake Basin".

Figure 21. Pilot area selection.

4) Upon the selection of the pilot area to perform the analysis, you will be redirected to the selected tool analysis page. You will mainly notice five panels: A) Details panel, B) Satellite selection panel, C) Data Selection panel, D) Geospatial bounds and Date selection panel and E) Status panel (Figure 22.).

   In order to run your analysis, select on “Satellite selection panel” the corresponding **satellite** mission dataset contained in PONTOS Data Cube that you wish to harness in your analysis. The available options are Landsat 5, Landsat 7, Landsat 8 and Sentinel-2. Right after, please select the **compositing method** in “Data Selection panel”. On this example, we will use Landsat 8 and “Max NDVI pixel” as compositing method.

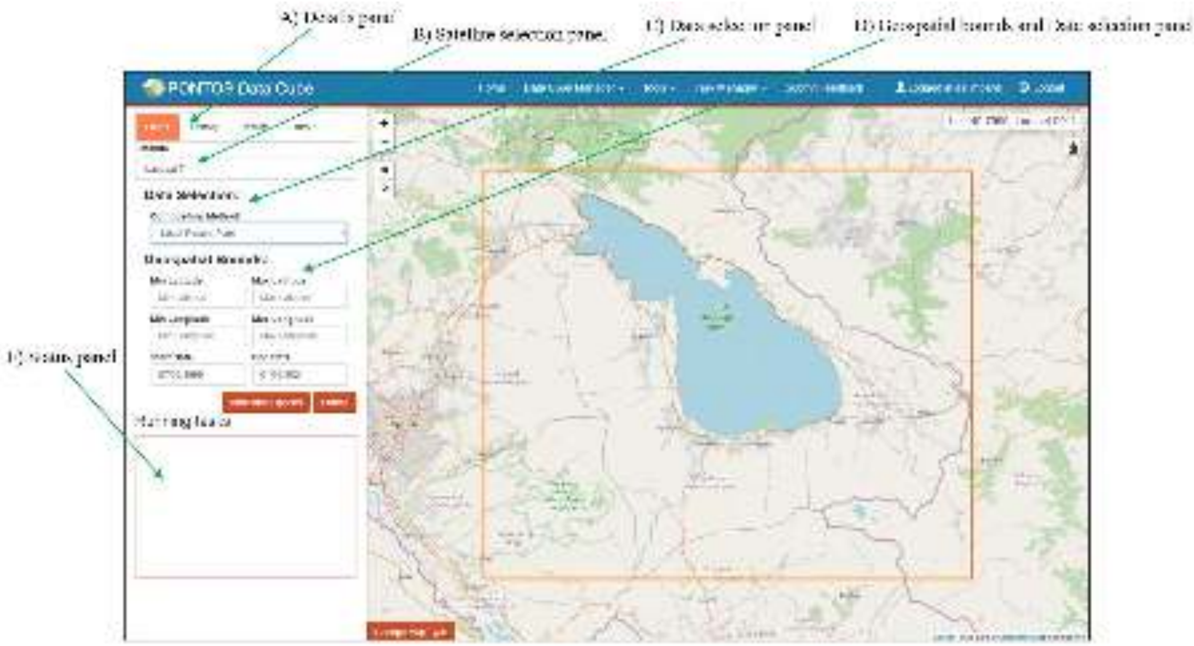

Figure 22. Feature panels on selected tool.

5) For the selection of a **sub-area** out of the map, please click and drag a rectangle anywhere within the orange box in order to define the region of interest for the analysis. In this way, you choose a spatial subset of the data. The orange box represents the maximum extents of the data contained in PONTOS Data Cube for each pilot (Figure 23.).

Figure 23. Maximum extents of the contained data and user defined analysis region.

6) The last step before performing your analysis is to select the temporal bounds (**start and end dates**) in the "Geospatial bounds and Date selection panel" in order to choose the temporal subset of the data.
7) Once all required fields for the analysis are filled, please click on the "**Submit**" button to start performing the Fractional Cover tool analysis (Figure 24.).

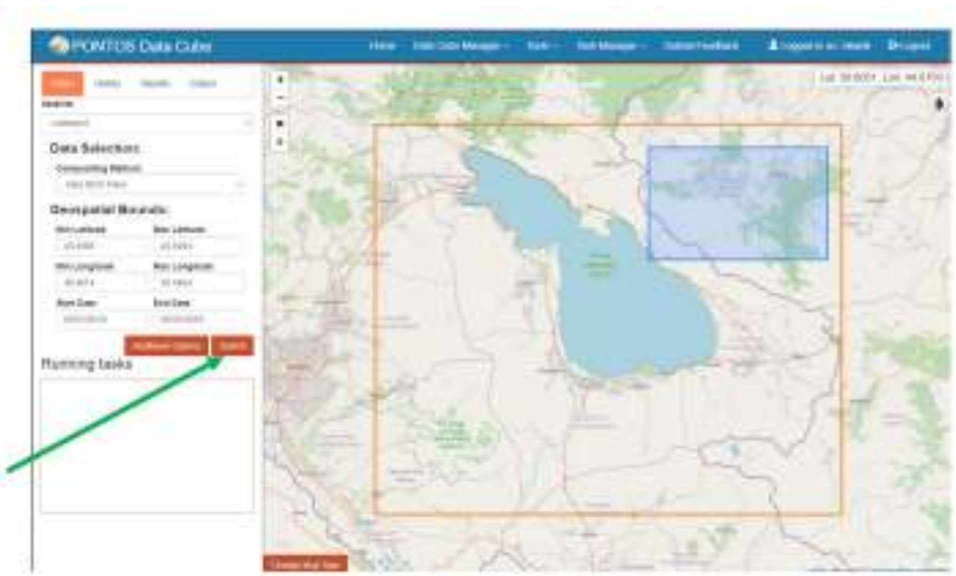

Figure 24. Perform the analysis by clicking on "Submit".

8) A new task labeled as "Fractional Cover Query" will appear on the status panel below "Running tasks". The red progress bar will show the progress of the analysis. The amount of time required for the analysis to be completed depends on the type of analysis as well as the chosen spatial and temporal extents (Figure 25.).

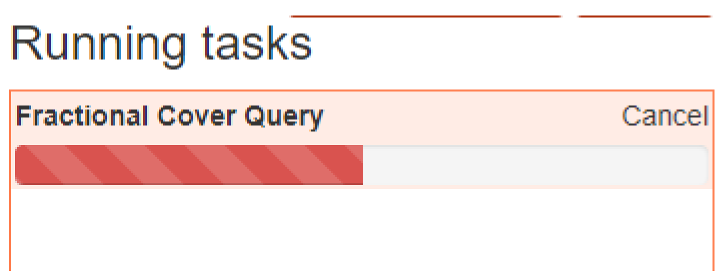

Figure 25. Progress of the analysis.

9) When the process is finished, the result will appear on the map. To view the information about the legend of this tool, please select the drop-shaped icon on the top right corner of the map (Figure 26.).

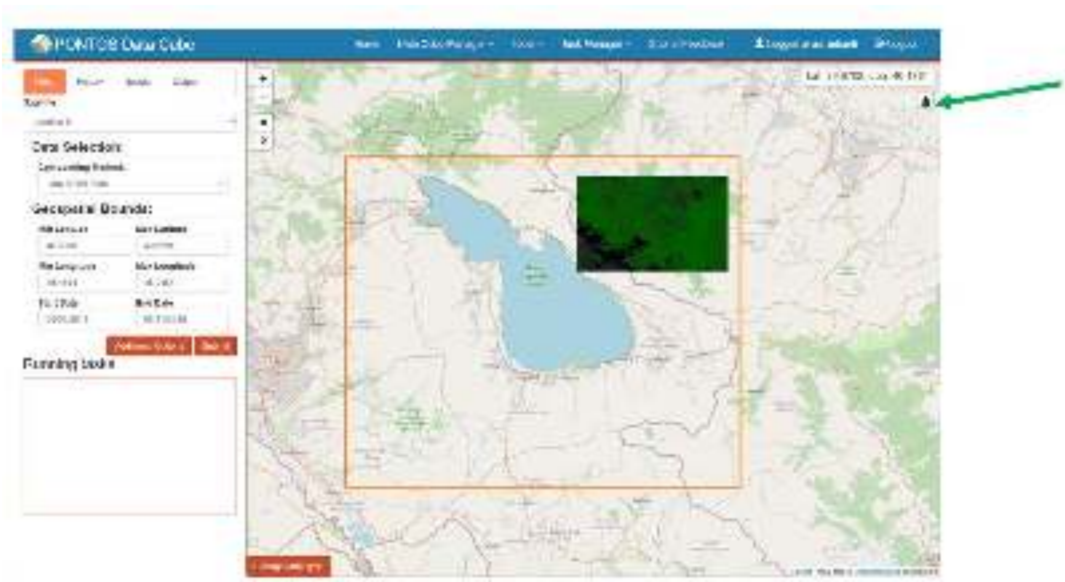

Figure 26. Output of the process.

5.4 TASK MANAGER

The "Task Manager" feature provides a display in a table format of a tool's completed analysis performances and it can be accessed from PONTOS Data Cube home page. It also provides the option of the output's downloading in order to be used for further analysis.

1) From the top menu bar, please select "**Task Manager**". Under the "Task Manager" menu, hover over the tool that the recent analysis was performed by. In this example, "**Land**" group and "**Fractional Cover**" should be selected (Figure 27.).

Figure 27. Tool’s task manager selection.

2) You will be redirected to a page with the history of the previously performed analyses for a specific tool. Information about the satellite, the area of the analysis as well as the temporal and spatial extents are provided. Please click on the “**Details**” button in order to access statistics and outputs for the selected performance (Figure 28.).

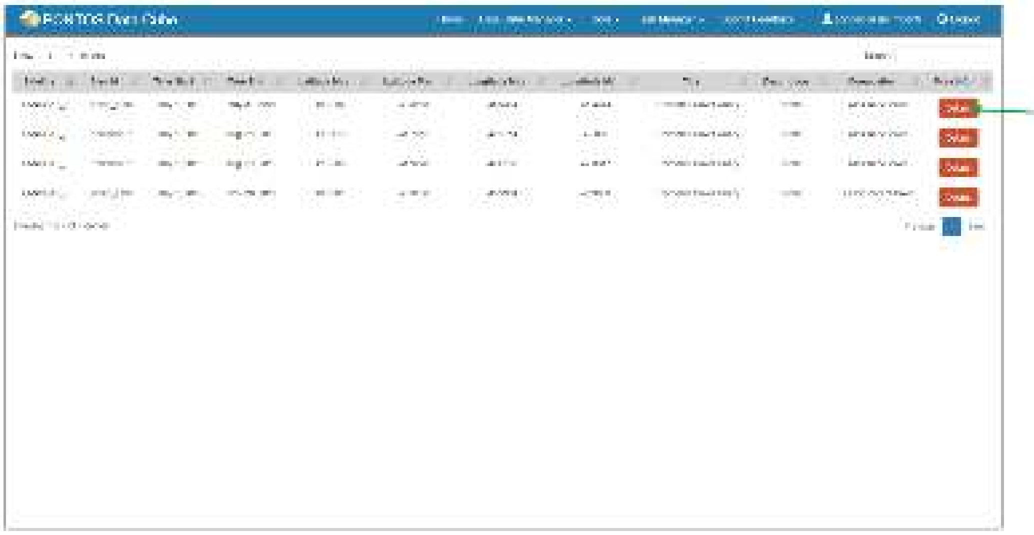

Figure 28. Access the details of a performed analysis.

3) Details of a performed analysis are presented. Information about the task details, task metadata, task parameters and scene metadata is available. On the panel "**Task Outputs**", the option to download the output of the analysis in NetCDF or GeoTIFF format is provided. Please click either on "**Download nc**" or on "**Download tif**" (Figure 29.).

Figure 29. Download the output of the analysis.

6. EXERCISE

Objective: The aim of this exercise is the user to become acquainted with the use of PONTOS Data Cube upon the comprehension of Chapter 5.

Hands-on practice: Please follow and complete the next steps. Feel free to improvise!

1) Visit PONTOS Data Cube.
2) Register or login.
3) From the top menu bar of PONTOS Data Cube home page, please select the group and tool of your choice.
4) Please select the pilot area that you wish to perform the analysis.
5) Navigate over the feature panels and select the satellite mission dataset that you wish to use for your analysis and the compositing method.
6) Following on, please define a specific sub-area out of the map.
7) Please select the start and end dates that you wish to perform the analysis.
8) Congratulations, now you are good to go! Please click on the "Submit" button to start the performance of your analysis.
9) Once the output of the process appears on the map, please click on the drop-shaped icon on the top right corner of the map and try to interpret the result.
10) If you wish to access the information of the analysis and download the output, please visit "Task Manager" from the top menu bar.
11) Select the group and the tool that you just performed the analysis.
12) Out of the table on the next page, please click on the "Details" button of the analysis you just performed.
13) Navigate over the details and metadata of the analysis.
14) Download the output as a NetCDF or GeoTIFF file.

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