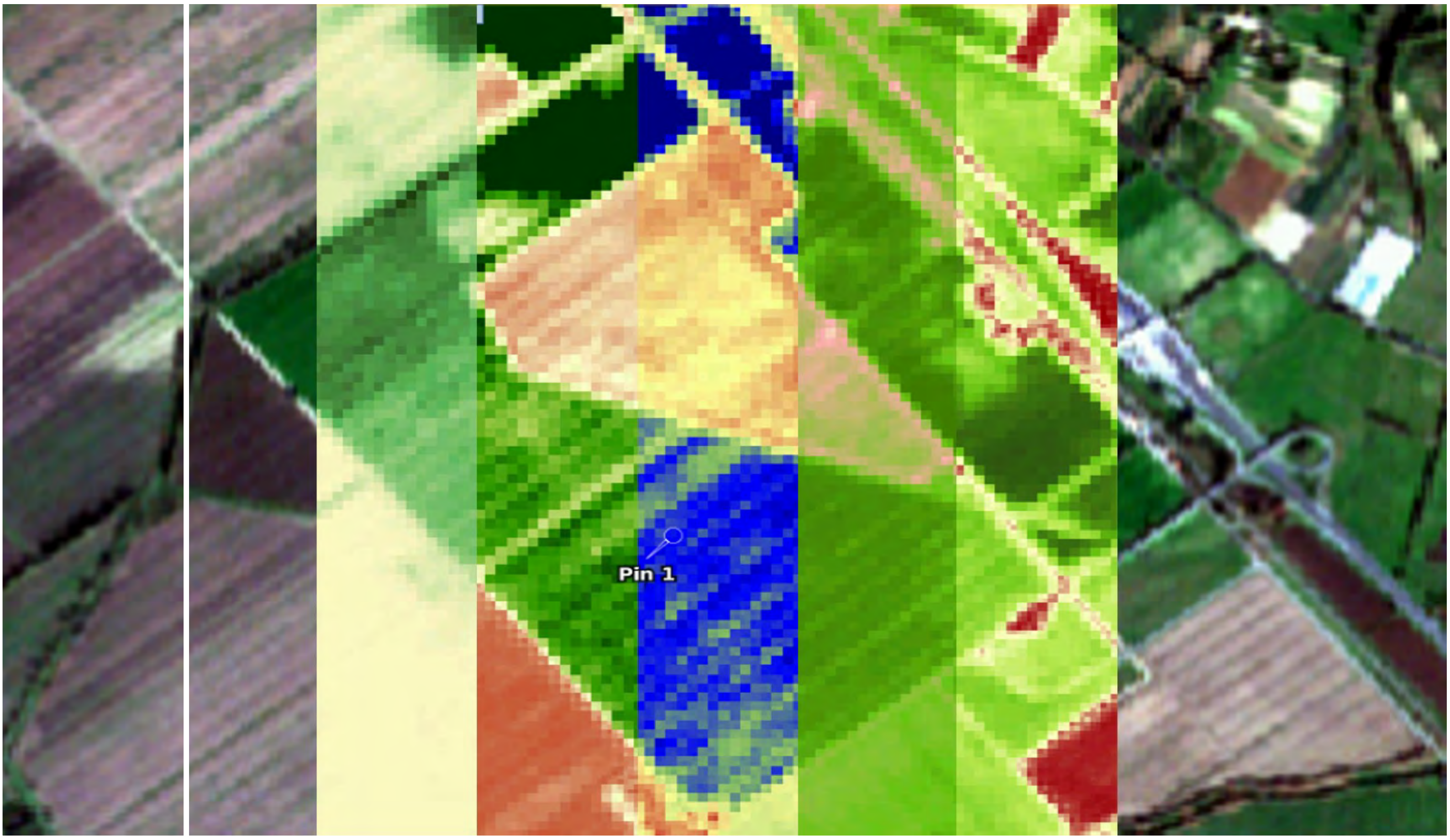

TRAINING KIT – LAND11

VEGETATION MONITORING FOR AGRICULTURE
MACCARESE, ITALY 2018 - 2020

Research and User Support for Sentinel Core Products

The RUS Service is funded by the European Commission, managed by the European Space Agency and operated by CSSI and its partners.

Authors would be glad to receive your feedback or suggestions and to know how this material was used. Please, contact us on training@rus-copernicus.eu

Cover images produced by RUS Copernicus

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Date of publication: May 2020

Version: 1.1

Suggested citation:

Serco Italia SPA (2020). *Vegetation monitoring for agriculture - Maccarese, Italy (version 1.1).* Retrieved from RUS Lectures at https://rus-copernicus.eu/portal/the-rus-library/learn-by-yourself/

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1 Introduction

The Research and User Support for Sentinel core products (RUS) service provides a free and open scalable platform in a powerful computing environment, hosting a suite of open source toolboxes pre-installed on virtual machines, to handle and process data derived from the Copernicus Sentinel satellites constellation.

As the world population grows so does the demand for food, fuel, and raw materials provided by agriculture. However, the Earth stubbornly stays the same size and so the growing needs must be satisfied on increasingly smaller area of arable land per capita while taking into account environmental sustainability and climate change effects and their mitigation. We need to make our agricultural production increasingly more effective – using less resources to grow more. Remote sensing is an ideal tool to assist the evolution of agricultural practices in order to face this major challenge, by providing repetitive information on crop status throughout the season at different scales and for different actors.

There is a large number of remote sensing sensors used today for monitoring of crops, from precision farming to large scale food security assessments. In this webinar we will introduce the use of Sentinel-2 multi spectral data to derive high resolution information on crop biophysical parameters such as Leaf Area Index (LAI), fraction of Absorbed Photosynthetically Active Radiation (fAPAR), Fraction of Vegetation Cover (FVC), and the Canopy chlorophyll and Water content (CCC, CWC). These parameters provide information on vegetation/crop status such as health, water/nutrient stress, etc. and serve as input for estimation of more complex variables such as yield.

For theoretical introduction please watch: https://youtu.be/xEwy8UMGu7M on RUS Copernicus Training channel.

2 Training

Approximate duration of this training session is two hours.

2.1 Data used

- 10 low-cloud Sentinel-2A Level 2A tile (Tile ID: T32TQN) acquired from 29 January to 15 November 2018 [downloadable @ https://scihub.copernicus.eu/]

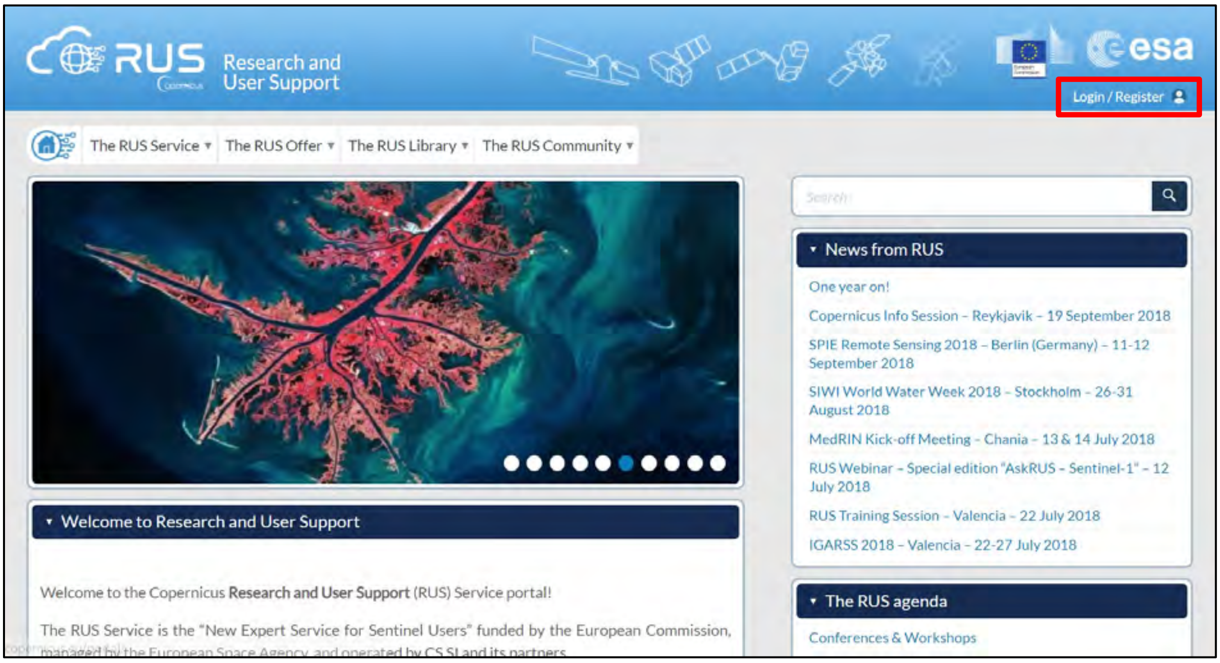
    1. *S2A_MSIL2A_20180129T101251_N0206_R022_T32TQM_20180129T135502.zip*
    2. *S2B_MSIL2A_20180213T101119_N0206_R022_T32TQM_20180213T135340.zip*
    3. *S2A_MSIL2A_20180406T100031_N0207_R122_T32TQM_20180406T110023.zip*
    4. *S2A_MSIL2A_20180416T100031_N0207_R122_T32TQM_20180416T120852.zip*
    5. *S2B_MSIL2A_20180421T100029_N0207_R122_T32TQM_20180421T120642.zip*
    6. *S2A_MSIL2A_20180426T100031_N0207_R122_T32TQM_20180426T120750.zip*
    7. *S2A_MSIL2A_20180526T100031_N0208_R122_T32TQM_20180526T161700.zip*
    8. *S2B_MSIL2A_20180531T100029_N0208_R122_T32TQM_20180531T125926.zip*
    9. *S2B_MSIL2A_20180620T100029_N0208_R122_T32TQM_20180620T182958.zip*
    10. *S2B_MSIL2A_20180630T100029_N0208_R122_T32TQM_20180630T144100.zip*

2.2 *Software in RUS environment*

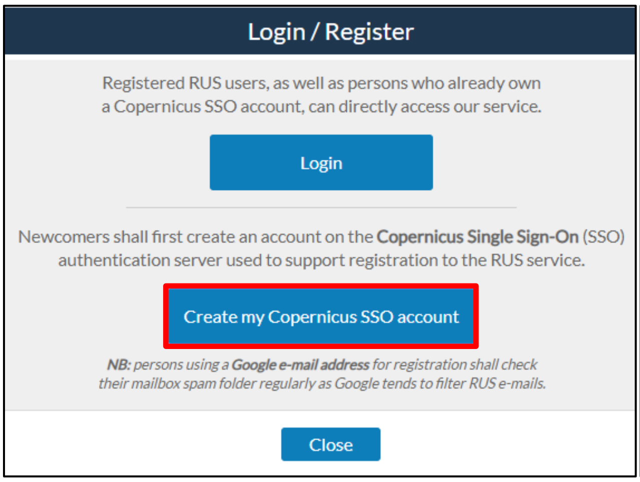
Internet browser, SNAP + Sentinel-2 Toolbox, QGIS, (Extra steps: Sen2Cor, Google Earth)

3 Register to RUS Copernicus

To repeat the exercise using a RUS Copernicus Virtual Machine (VM), you will first have to register as a RUS user. For that, go to the RUS Copernicus website (www.rus-copernicus.eu) and click on ***Login/Register*** in the upper right corner.

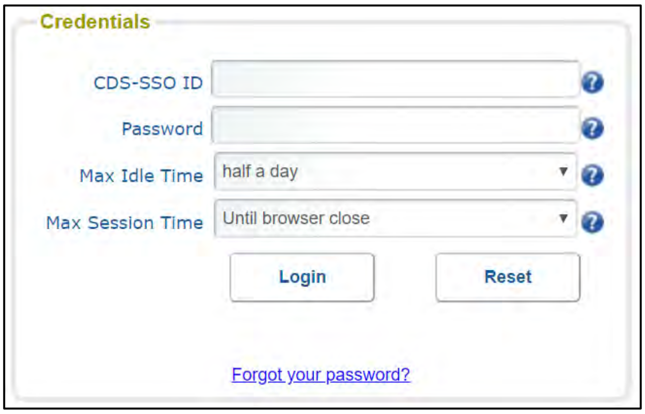


Select the option ***Create my Copernicus SSO account*** and then fill in ALL the fields on the **Copernicus Users' Single Sign-On Registration**. Click ***Register***.

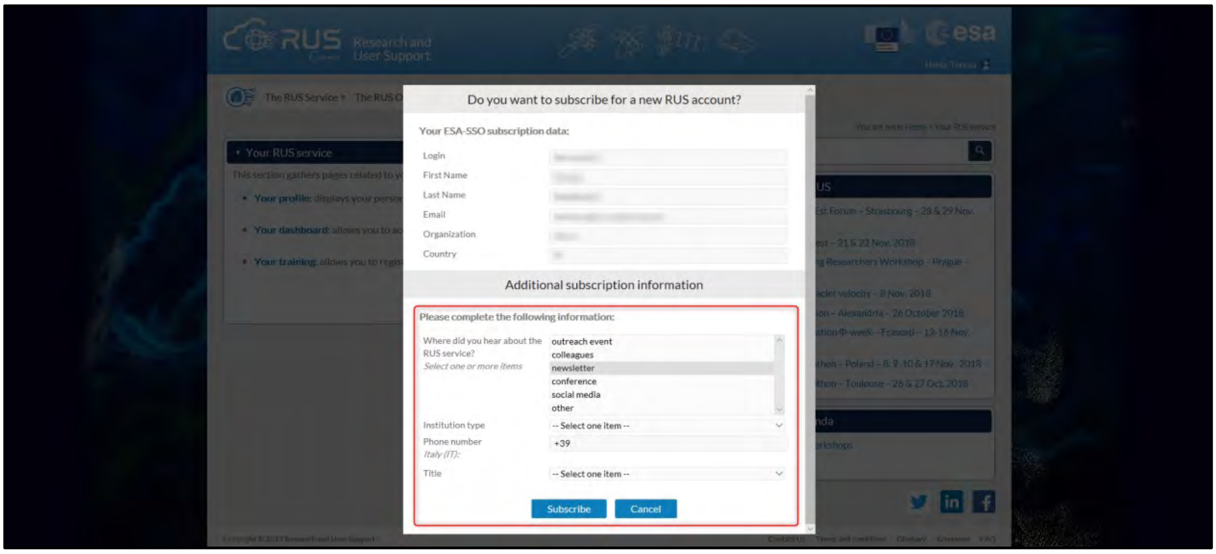


Within a few minutes you will receive an e-mail with activation link. Follow the instructions in the e-mail to activate your account.

You can now return to https://rus-copernicus.eu/, click on ***Login/Register***, choose ***Login*** and enter your chosen credentials.

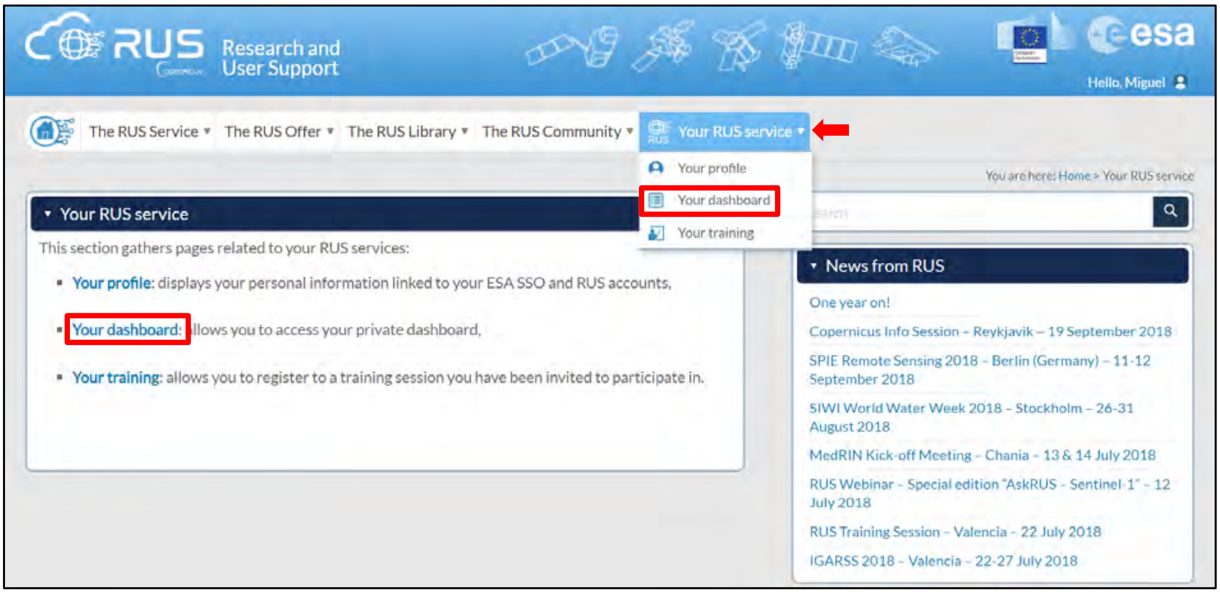


Upon your first login you will need to enter some details. You must fill all the fields.

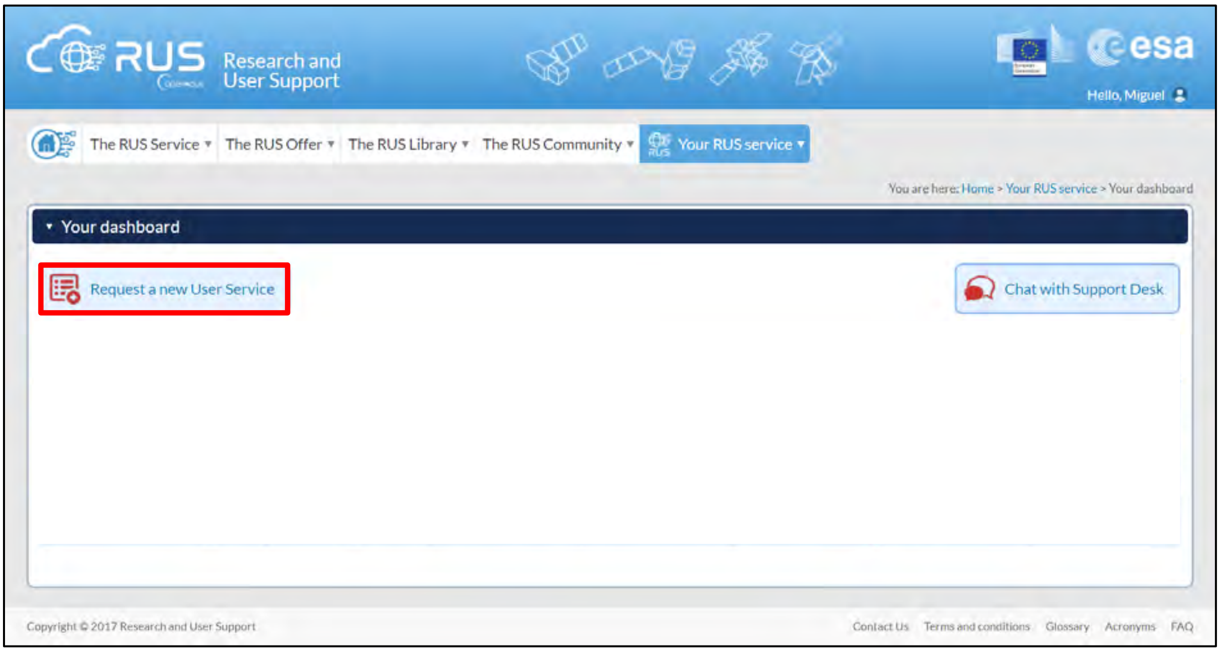


4 Request a RUS Copernicus Virtual Machine

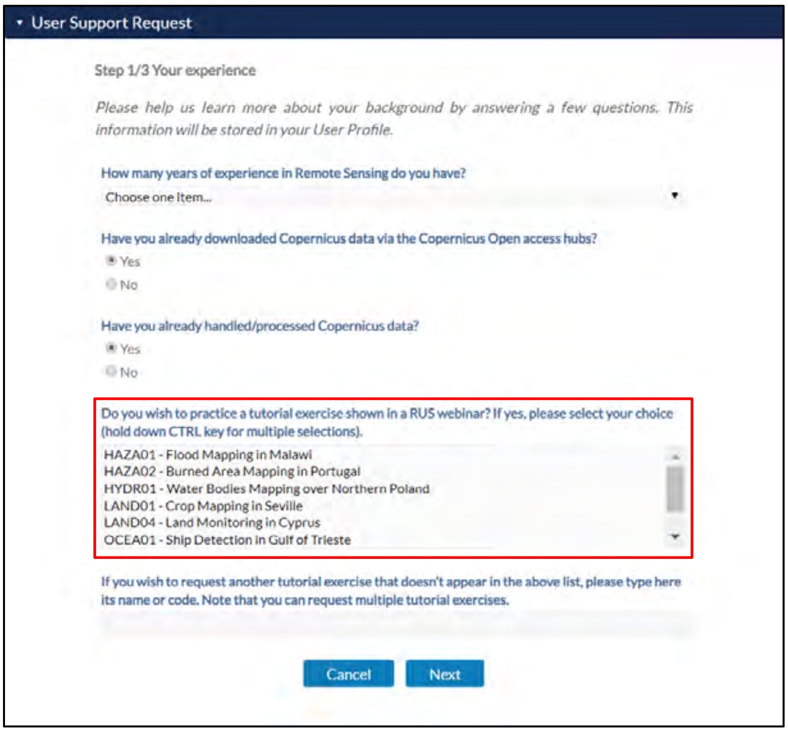
Once you are registered as a RUS user, you can request a RUS Virtual Machine to repeat this exercise or work on your own projects using Copernicus data. For that, log in and click on ***Your RUS Service → Your Dashboard***.



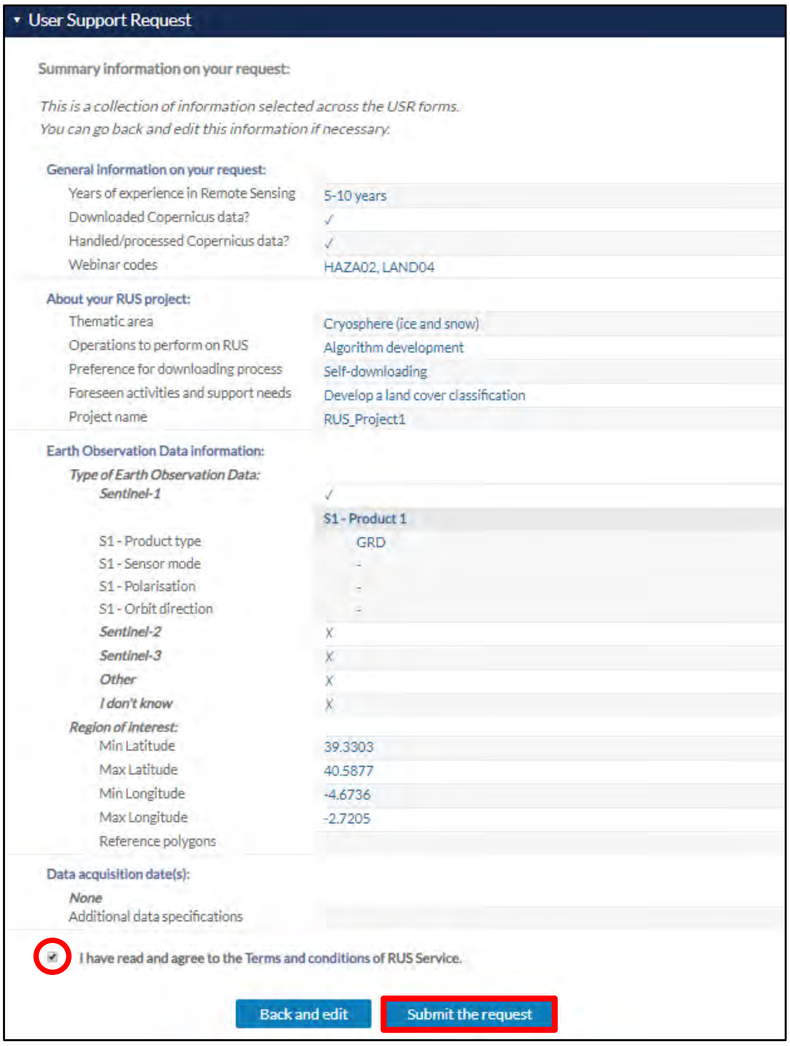
Click on ***Request a new User Service*** to request your RUS Virtual Machine. Complete the form so that the appropriate cloud environment can be assigned according to your needs.



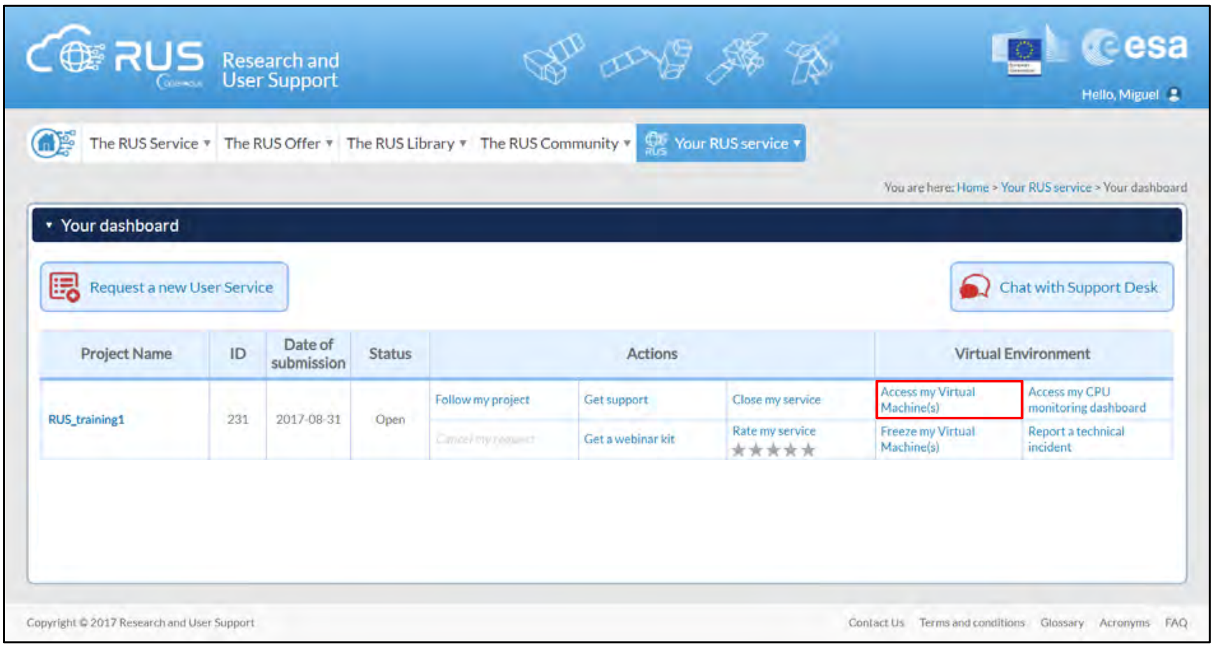
If you want to repeat this tutorial (or any previous one) select the one(s) of your interest in the appropriate field.



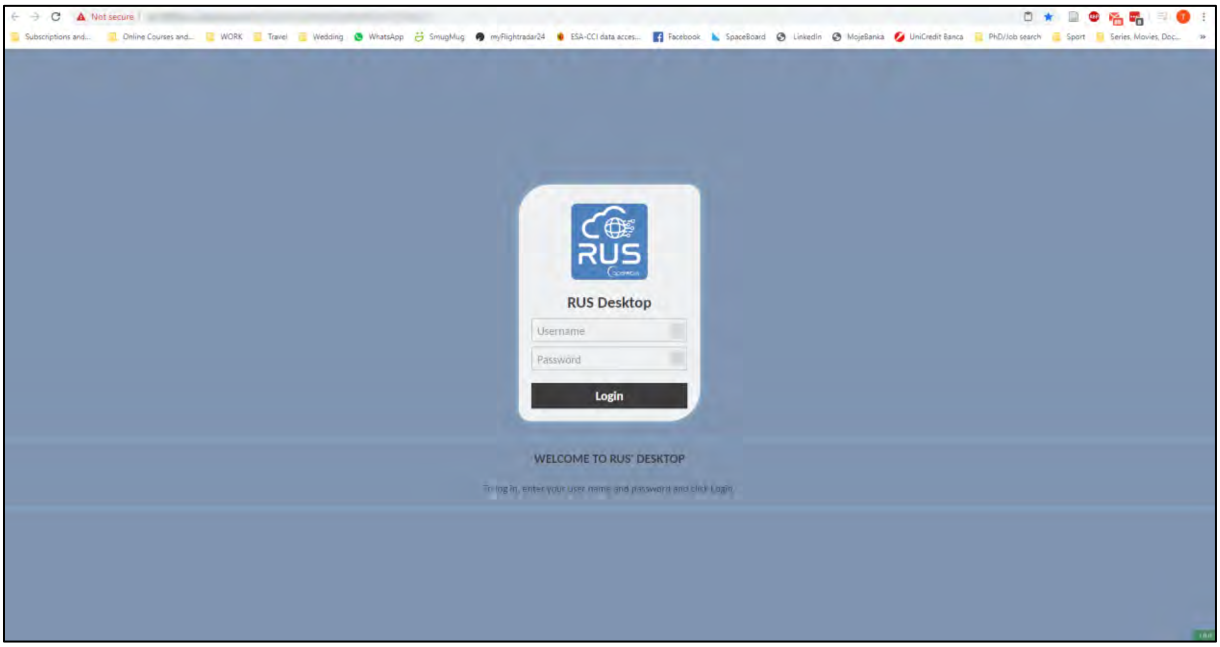
Complete the remaining steps, check the terms and conditions of the RUS Service and submit your request once you are finished.



Further to the acceptance of your request by the RUS Helpdesk, you will receive a notification email with all the details about your Virtual Machine. To access it, go to ***Your RUS Service → Your Dashboard*** and click on ***Access my Virtual Machine***.



Fill in the login credentials that have been provided to you by the RUS Helpdesk via email to access your RUS Copernicus Virtual Machine.



This is the remote desktop of your Virtual Machine.

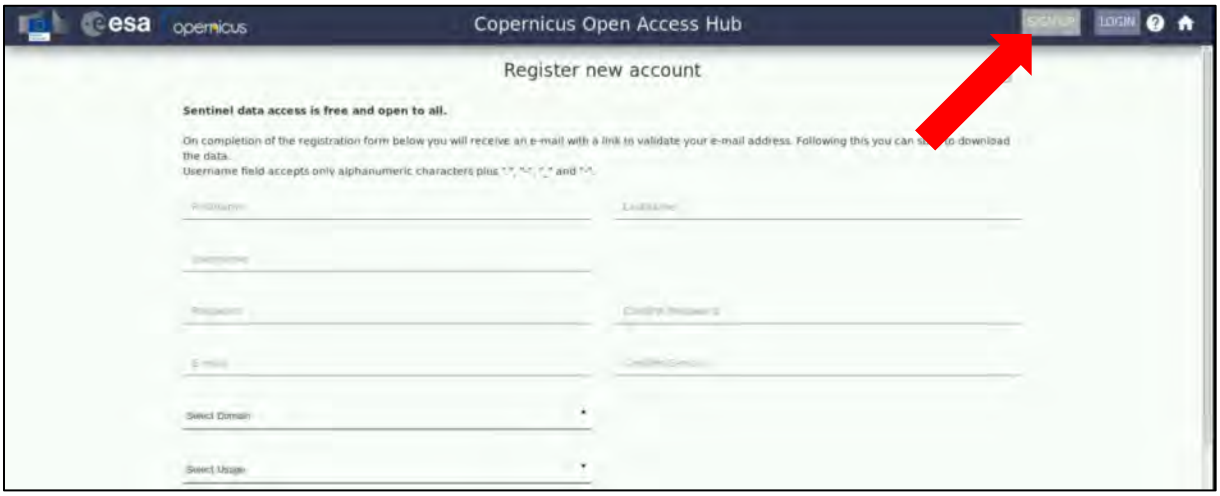
5 Step by step

5.1 *Data download – ESA SciHUB*

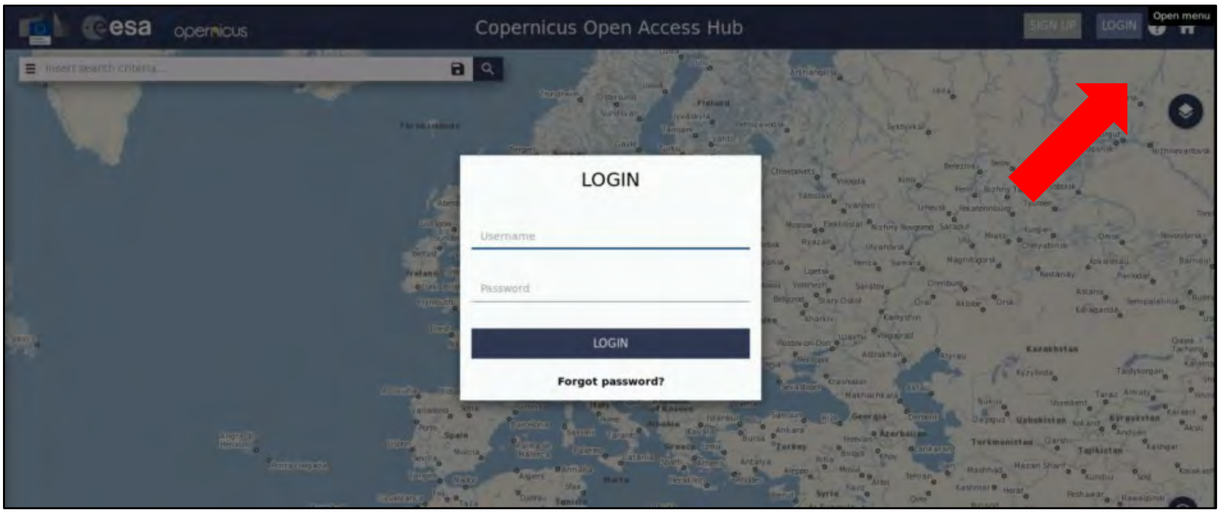
In this step we will download the Sentinel-2 scenes from the Copernicus Open Access Hub using the online interface (**Applications → Network → Web Browser** or click the link below).

Go to https://scihub.copernicus.eu/

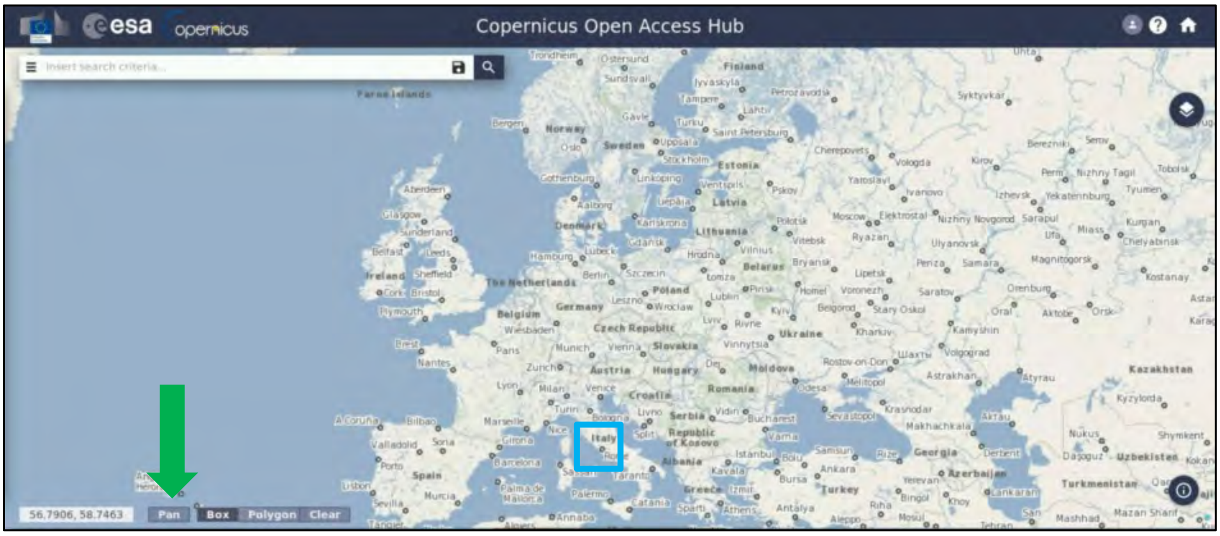
Go to “**Open HUB**”, if you do not have an account please register by going to “**Sign-up**” in the LOGIN menu in the upper right corner.



After you have filled in the registration form, you will receive an activation link by e-mail. Once your account is activated or if you already have an account, “**LOGIN**”.



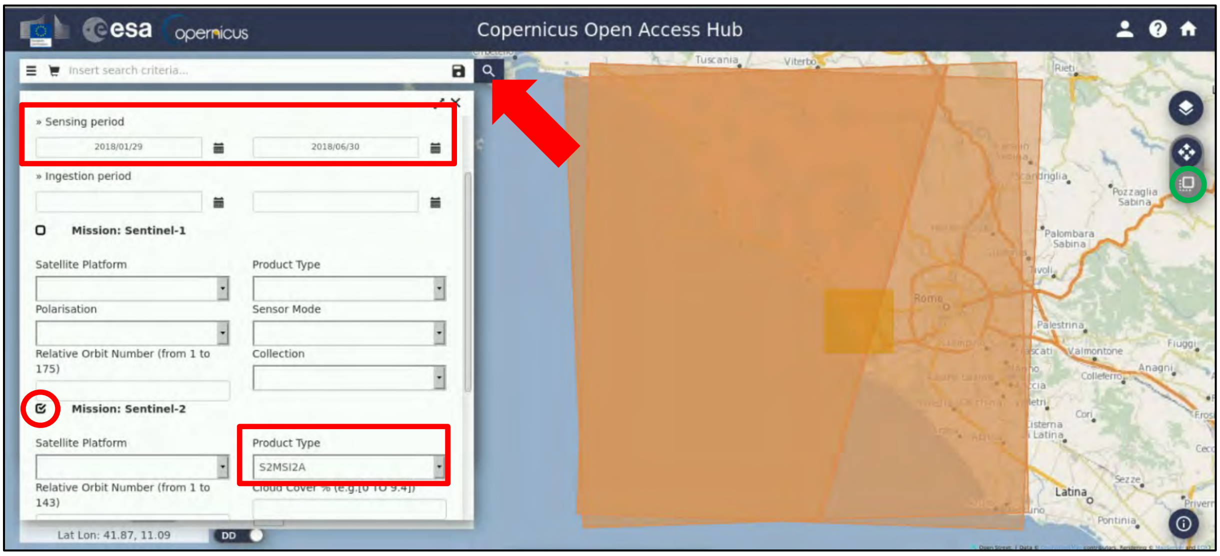
Switch the rectangle-drawing mode to pan mode by clicking on the “**Pan**” icon in the lower left corner of the map (**Green arrow**) and navigate over Italy (**approximate area – blue rectangle**).



Switch to drawing mode and draw a search rectangle over the lake approximately as indicated below (yellow). Open the search menu (red arrow) and specify the following parameters:

Sensing period: From 2018/01/29 to 2018/06/30
Check Mission: Sentinel-2
Product Type: S2MSIL2A

Press "**Search**" (red arrow below).

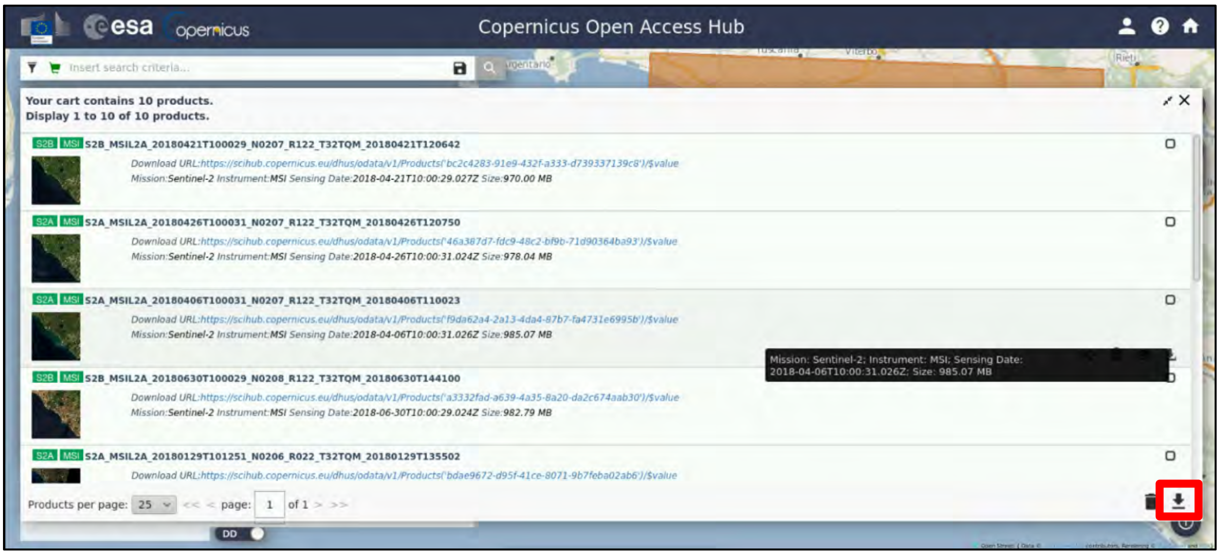


In our case, the search returns four results depending on the exact search area defined. Using the icon, import only the following products to **Cart**:

*S2A_MSIL2A_**20180129T101251**_N0206_R022_**T32TQM**_20180129T135502.zip*
*S2B_MSIL2A_**20180213T101119**_N0206_R022_T32TQM_20180213T135340.zip*
*S2A_MSIL2A_**20180406T100031**_N0207_R122_T32TQM_20180406T110023.zip*
*S2A_MSIL2A_**20180416T100031**_N0207_R122_T32TQM_20180416T120852.zip*
*S2B_MSIL2A_**20180421T100029**_N0207_R122_T32TQM_20180421T120642.zip*
*S2A_MSIL2A_**20180426T100031**_N0207_R122_T32TQM_20180426T120750.zip*
*S2A_MSIL2A_**20180526T100031**_N0208_R122_T32TQM_20180526T161700.zip*
*S2B_MSIL2A_**20180531T100029**_N0208_R122_T32TQM_20180531T125926.zip*
*S2B_MSIL2A_**20180620T100029**_N0208_R122_T32TQM_20180620T182958.zip*
*S2B_MSIL2A_**20180630T100029**_N0208_R122_T32TQM_20180630T144100.zip*

Then click on the Profile icon in the upper left corner (marked with green circle above) and go to

Cart. You should now have six products in your cart. Click on the arrow to **Download the Cart**.



The grey products are currently placed in an Offline archive: to learn how to request them please follow the steps outlined here: https://scihub.copernicus.eu/userguide/LongTermArchive

TIP: Alternatively, you can try to retrieve the products from other repositories such as: PEPS (https://peps.cnes.fr/rocket/#/home) or ONDA DIAS Catalogue (https://catalogue.onda-dias.eu/catalogue/) or others. Registering for a free account is usually necessary, but archived data retrieval will be faster than with Open Access Hub.

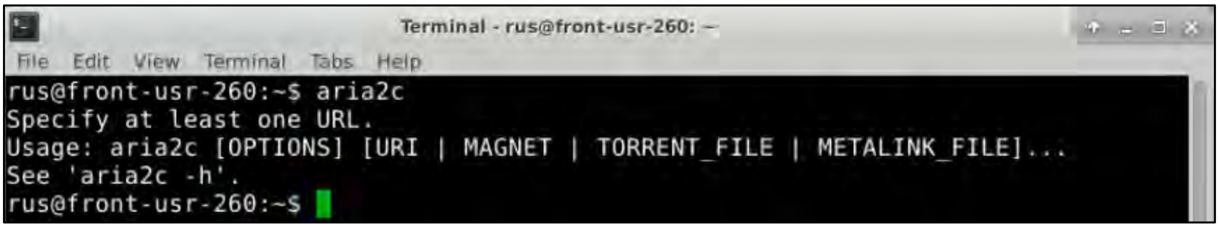
A ***products.meta4*** file will be downloaded to your ***/home/rus*** folder. To download our data, we will use **aria2** tool. To use the tool, we first need to place the **products.meta4** file to the folder where we wish our data to be downloaded to:

/shared/Training/LAND11_VegetationMonitoring4Agri_Italy/Original

First, let's test our aria2 installation. To do this we open the Command Line (in the bottom of your desktop window) and type:

```
aria2c
```

The correct response should be as follows:



NOTE 1: If (**and only if**) the response is "-bash aria2c: command not found". Then we have to install the tool, to do this in command line type: `sudo apt-get install aria2`

When requested type: Y

Then you can test your installation again.

If the response is "**-bash aria2c: command not found**" see NOTE 1. If you have received the correct response, then we can run the tool by typing the following commands in the command line (replace **<username>** and **<password>** with your login credentials for Copernicus Open Access Hub):

```
cd /shared/Training/LAND11_VegetationMonitoring4Agri_Italy/Original
aria2c --http-user='<username>' --http-passwd='<password>' --check-certificate=false --max-concurrent-downloads=2 -M products.meta4
```

The first line changes our directory to the target directory. The second line runs the download tool (Type the red text all in a single line). All twelve products will be downloaded to the ***Original*** folder, two products in parallel automatically.

(**Note** that the constraint of maximum 2 parallel downloads at a time is imposed by the Copernicus Access Hub, if you increase the number, your download will fail). This might take some time.

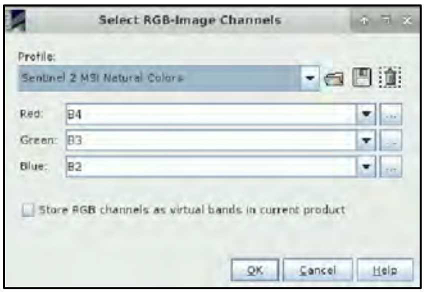
5.2 Data exploration

Launch SNAP (icon on desktop). When the SNAP window opens click **Open product** and navigate to: ***/shared/Training/LAND11_VegetationMonitoring4Agri_Italy/Original/***

Open the first S2 product (from 29 January 2018). We can first investigate the structure of the Sentinel-2 Level 2A products (see NOTE 2). Click on the dot next to the product name to expand the structure. The L1C products contain (among others):

- 13 TOA (top-of-atmosphere) reflectance bands
- Quality flags

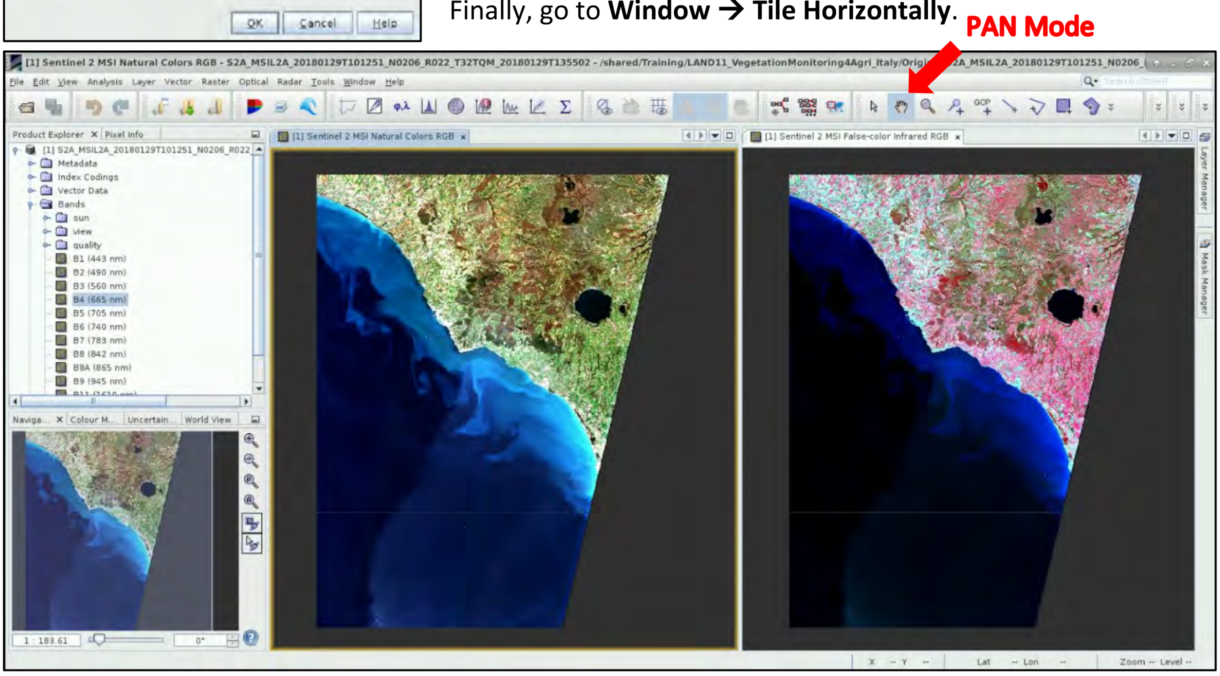
Now, let's visualize the product. We will visualize it in true (natural) colours and as a false color composite which is better for distinguishing water surfaces. **Right-click** the product and click **Open RGB image window,** a new window will open. From the drop-down menu select:



Profile : Sentinel 2 MSI Natural Colors
Click **OK**.

When the image opens, repeat the same but choose the false colour Profile.

Profile : Sentinel 2 MSI False-color Infrared
Finally, go to **Window → Tile Horizontally**.



NOTE 2: The Sentinel-2 data are distributed as 100x100 km tiles resampled to a common grid in WGS84 UTM projection at two levels of processing:

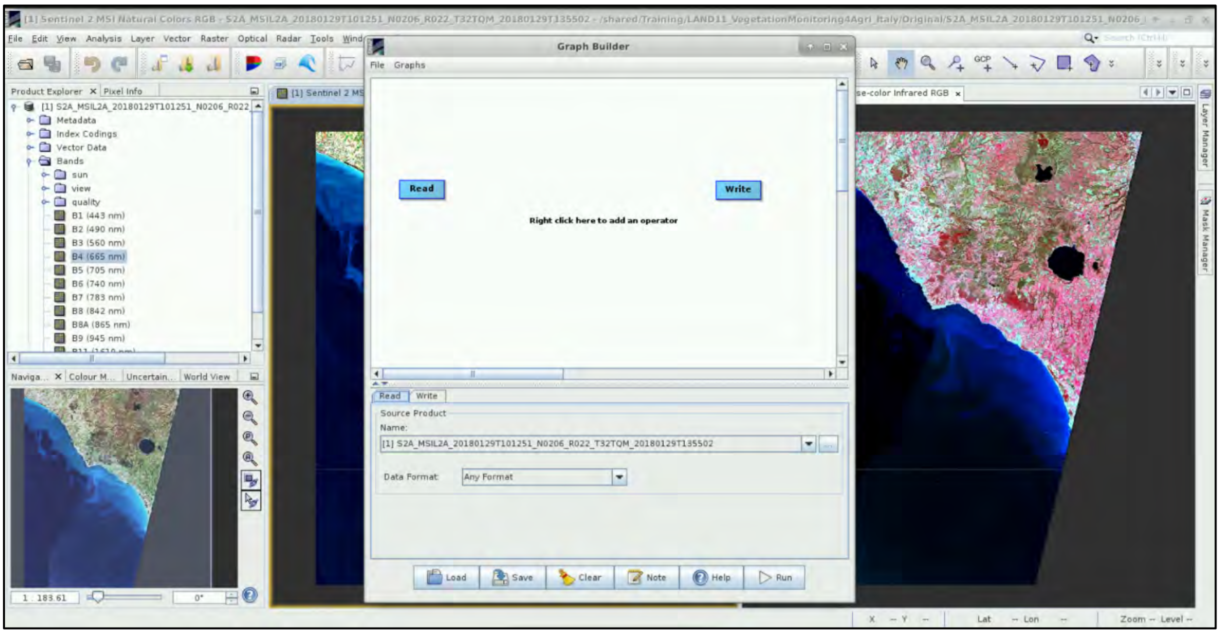
- Level-1C – Top-Of-Atmosphere reflectances, systematically generated since the start of the mission.
- Level-2A – Bottom-Of-Atmosphere reflectances (atmospherically and radiometrically corrected), systematically produced for products acquired over Europe since the spring of 2017, the coverage has increased through 2018 to reach global coverage in the beginning of 2019. It can be produced on user side by applying the Sen2Cor algorithm.

5.3 STEP 1 – Pre-Processing

Processing the data one by one would not be very time effective. However, we can use either the **Batch Processing** tool available in SNAP or the GPT tool (command line) to process all images automatically.

To use either method, we first need to define the process we want to apply and all its steps. We can do this using the **GraphBuilder** tool. Another advantage of the **GraphBuilder** is that only the final product will be physically saved, and we save valuable disk space.

So, let's build our graph. First, in the **Product Explorer** select the first loaded product (so it is highlighted), then go to **Tools → GraphBuilder**.



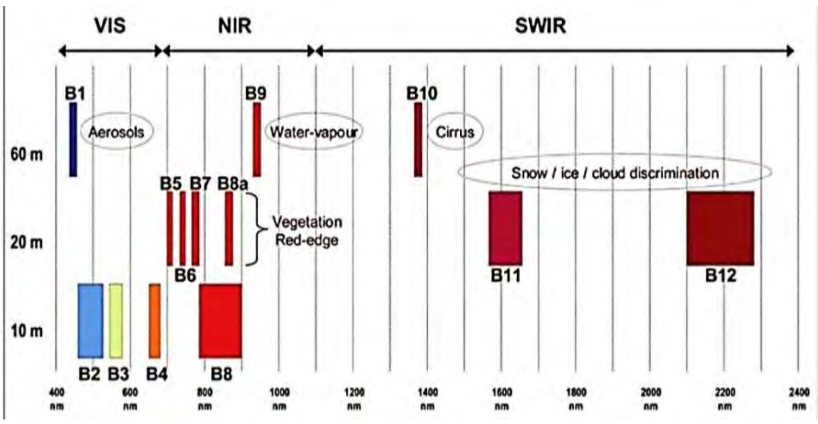
At the moment, the graph only has two operators: **Read** (to read the input) and **Write** (to write the output).

The 13 bands in Sentinel-2 products do not all have the same resolution (therefore size) as mentioned in NOTE 3. Many operators do not support products with bands of different sizes so first we need to resample the bands to equal resolution.

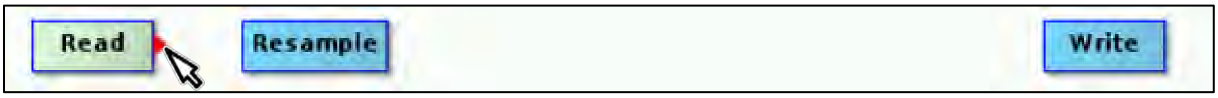
To add the appropriate operator, right-click the white space between existing operators and go to **Add → Raster → Geometric → Resample.**

A new operator rectangle appears in our graph and a new tab appears below. Now connect the new **Resample** operator with the **Read** operator by clicking to the right side of the **Read** operator and dragging the red arrow towards the **Resample** operator.

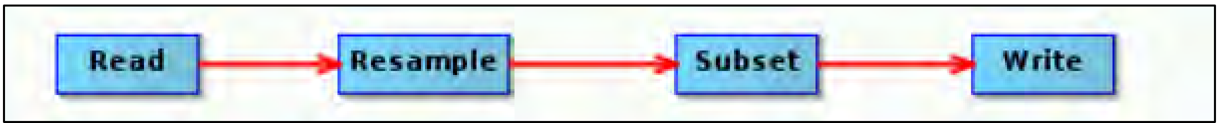
NOTE 3: The input product contains 13 spectral bands in three different spatial resolutions (The surface area measured on the ground and represented by an individual pixel). When we open the RGB view all our input bands have 20 m resolution, however, the view is displayed in the full 10 m resolution.



Credits: ESA 2015



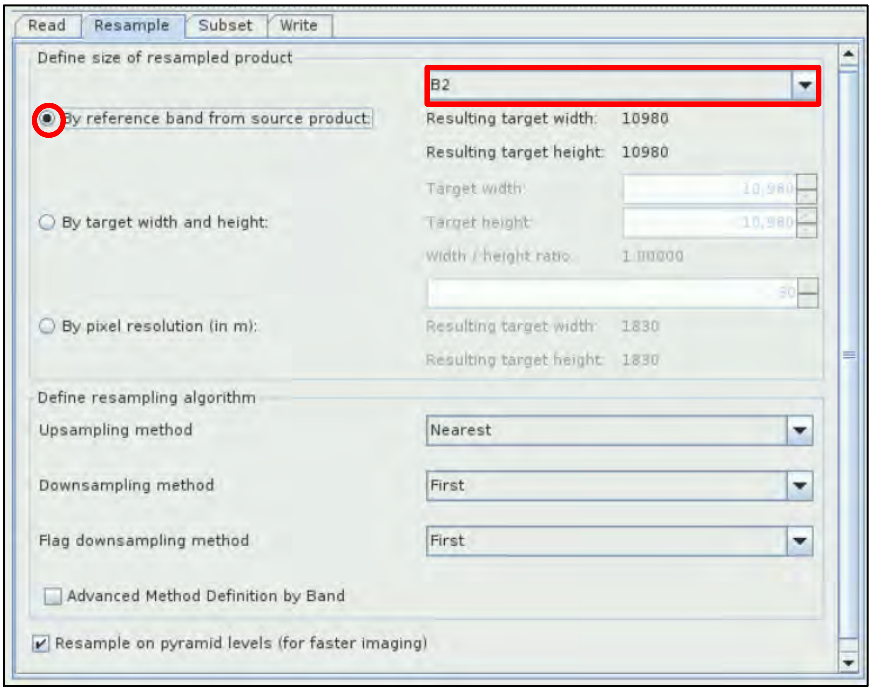
Next step will be to subset the images to the area of interest, we do this by right-clicking the white space somewhere right of the resample operator and going to **Add → Raster → Geometric → Subset.** Connect the **Subset** operator with the **Resample** operator.



Finally, connect the **Subset** operator to the **Write** operator.

Now, let's set the parameters. In the **Resample** tab, we set:

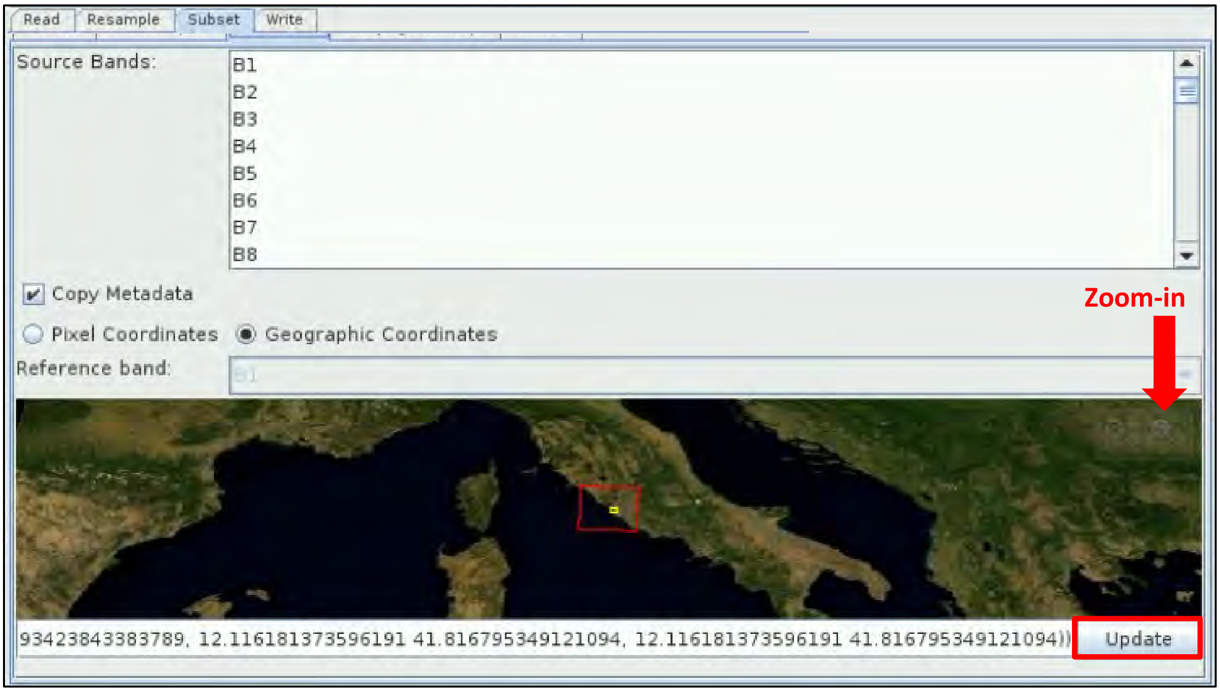
Under **Define size of resampled product**: Select the "**By reference band from source product**" and choose the **B2** band (we will resample all the bands to 10m resolution).



In the **Subset** tab, select **Geographic Coordinates**, in the text-window paste the subset polygon coordinates in Well-Known-Text format (WKT) from ***Expressions_WQ.txt*** file in:

/shared/Training/LAND11_VegetationMonitoring4Agri_Italy/

```
POLYGON ((12.188833156432 41.90177193536, 12.248943376218 41.90008525013,
12.246701805438 41.85586135019, 12.186632885123 41.857545435452, 12.188833156432
41.90177193536)
```



We can leave the **Read** and **Write** tabs unchanged. Now, save the graph as ***STEP1_Graph_Prep.xml*** to: ***/shared/Training/LAND11_VegetationMonitoring4Agri_Italy/Processing/*** by clicking **Save** at the bottom of the window and then close the **GraphBuilder** window.

In this tutorial, we will use the GPT and shell script to automatize the processing of our 10 products. To do this, we must first edit the saved graph file.

To edit the file, leave SNAP and in the file explorer, navigate to the …/***Processing*** folder and right-click on the saved graph file. Select **Open with** -> **Open with "Mousepad".** When the file is open, go to **View -> Line Numbers** for easier navigation.

Now, we need to replace the input and output file path with a pattern that will allow the **shell script** (See NOTE 4) to recognize and replace it with appropriate value for each file automatically.

> NOTE 4: A shell script is a computer program designed to be run by the Unix shell, a command-line interpreter. The various dialects of shell scripts are considered to be scripting languages. The one used in this exercise is called Bash script (https://en.wikipedia.org/wiki/Bash_(Unix_shell)). Typical operations performed by shell scripts include file manipulation, program execution, and printing text.
> If you wish to run this exercise on Windows, you can replicate the steps in any programming language you are familiar with, such as Python or R.

In line **7** (in the node with id='Read') replace the path to input file with (between <file> and </file>): *$Input* **("$" signifies that what follows is a parameter)**.

STEP1_Graph_Prep.xml - Mousepad

File Edit Search View Document Help

```
1 <graph id="Graph">
2   <version>1.0</version>
3   <node id="Read">
4     <operator>Read</operator>
5     <sources/>
6     <parameters class="com.bc.ceres.binding.dom.XppDomElement">
7       <file>/home/rus/shared/Training/LAND11_VegetationMonitoring4Agri_Italy/Original/S2A_MSIL2A_20180129T101251_N0206_R022_T32TQM_20180129T135502.zip</file>
8     </parameters>
9   </node>
```

*STEP1_Graph_Prep.xml - Mousepad

File Edit Search View Document Help

```
1 <graph id="Graph">
2   <version>1.0</version>
3   <node id="Read">
4     <operator>Read</operator>
5     <sources/>
6     <parameters class="com.bc.ceres.binding.dom.XppDomElement">
7       <file>$Input</file>
8     </parameters>
9   </node>
```

In line **51** (in the node with id='Write') replace the path to output file with (between <file> and </file>): *$Output*

```
45   <node id="Write">
46     <operator>Write</operator>
47     <sources>
48       <sourceProduct refid="Subset"/>
49     </sources>
50     <parameters class="com.bc.ceres.binding.dom.XppDomElement">
51       <file>/home/rus/shared/Tutorial_DEV/LAND11_VegetationBiophysicalParameters/Empty_S2A_MSIL2A_20180129T101251_N0206_R022_T32TQM_20180129T135502_resampled.dim</file>
52       <formatName>BEAM-DIMAP</formatName>
53     </parameters>
54   </node>
```

```
45   <node id="Write">
46     <operator>Write</operator>
47     <sources>
48       <sourceProduct refid="Subset"/>
49     </sources>
50     <parameters class="com.bc.ceres.binding.dom.XppDomElement">
51       <file>$Output</file>
52       <formatName>BEAM-DIMAP</formatName>
53     </parameters>
54   </node>
```

Now, go to the to the ***…/Processing/Code/*** folder and open the STEP1_script_gpt.sh

STEP1_script_gpt.sh - Mousepad

File Edit Search View Document Help

```
1 #!/bin/bash
2
3 output_folder=/shared/Training/LAND11_VegetationMonitoring4Agri_Italy/Processing/Pre-processed/
4 nameStart=Subset_S2_MSIL2A_
5 nameEnd=.dim
6
7 for i in $(ls -d -1 /shared/Training/LAND11_VegetationMonitoring4Agri_Italy/Original/*.zip)
8 do
9          product_basename=$(basename $i)
10         ac_date=$(echo $product_basename | cut -d '_' -f 3)
11         Output_pathname=$output_folder$nameStart$ac_date$nameEnd
12         gpt /shared/Training/LAND11_VegetationMonitoring4Agri_Italy/Processing/STEP1_Graph_Prep.xml -PInput=$i -POutput=$Output_pathname
13 done
14
```

On line **1**, we specify that the script should be run with Bash scripting language. (See NOTE 4)

```
1 #!/bin/bash
```

On line **3**, **4** and **5**, we specify our desired output folder path, and the pattern beginning and ending of the output name respectively.

```
3 output_folder=/shared/Training/LAND11_VegetationMonitoring4Agri_Italy/Processing/Pre-processed/
4 nameStart=Subset_S2_MSIL2A_
5 nameEnd=.dim
```

Line **7** signifies the start of the loop. The script will loop over all files in the specified folder ending with *".zip"*. In each iteration, the path to one input file is denoted by *"i"*.

"do" on line **8** and *"done"* on line **13** enclose the steps that should be performed on each input product.

```
 7 for i in $(ls -d -1 /shared/Training/LAND11_VegetationMonitoring4Agri_Italy/Original/*.zip)
 8 do
```

On line **9**, we extract the name of the input product; on line **10**, we extract the date of the acquisition from the name.

```
 9          product_basename=$(basename $i)
10          ac_date=$(echo $product_basename | cut -d '_' -f 3)
```

On line **11**, we create the final path and name of our output, combining our specified output folder path, the beginning of the output name, the acquisition date and specified name end including the format suffix.

```
11          Output_pathname=$output_folder$nameStart$ac_date$nameEnd
```

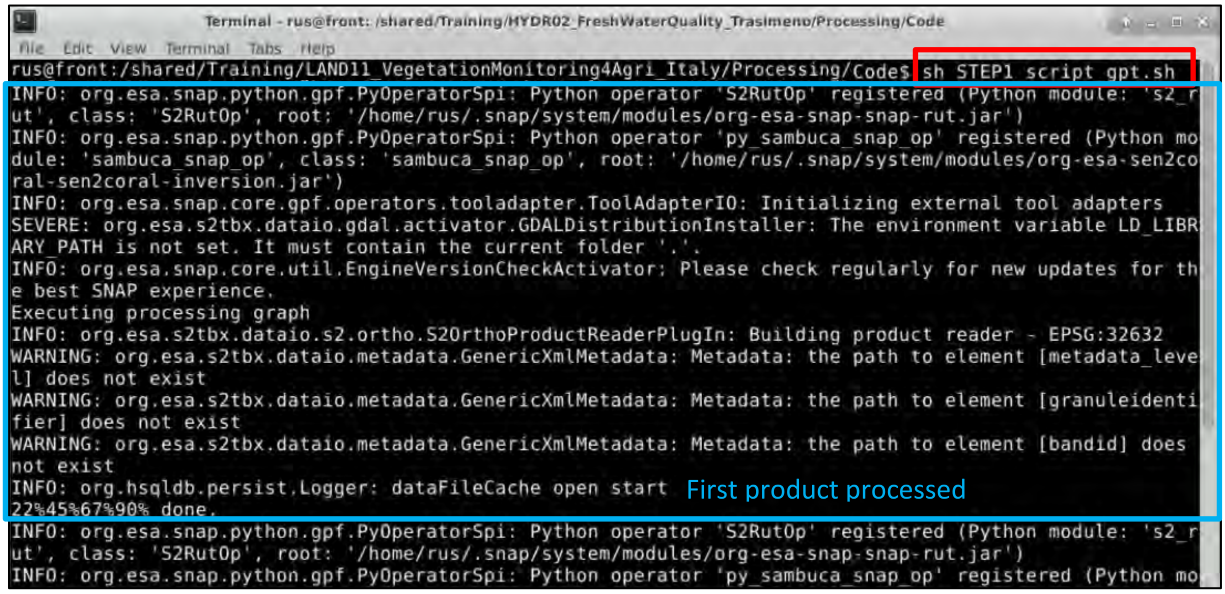
On line **12**, we call GPT and specify the path to our saved and edited graph file. Then with -P{variable name} we specify the parameters to be replaced in the graph file (marked with $ in the graph file). We have set the variables when we edited the .xml graph file – **Input, Output**. On line **13**, the loop is closed.

```
12          gpt /shared/Training/LAND11_VegetationMonitoring4Agri_Italy/Processing/STEP1_Graph_Prep.xml -PInput=$i -POutput=
    $Output_pathname
13 done
```

If your input and output folders are different you need to edit the file accordingly and save it. To run the script, we navigate to the folder where it is saved ***(/shared/Training/LAND11_VegetationMonitoring4Agri_Italy/Processing/Code/)*** and right-click on the white space and go to **Open Terminal Here**. In the terminal type:

```
sh STEP1_script_gpt.sh
```

where *STEP1_script_gpt.sh* is the name of the Bash script file. Click **ENTER** to run the script.

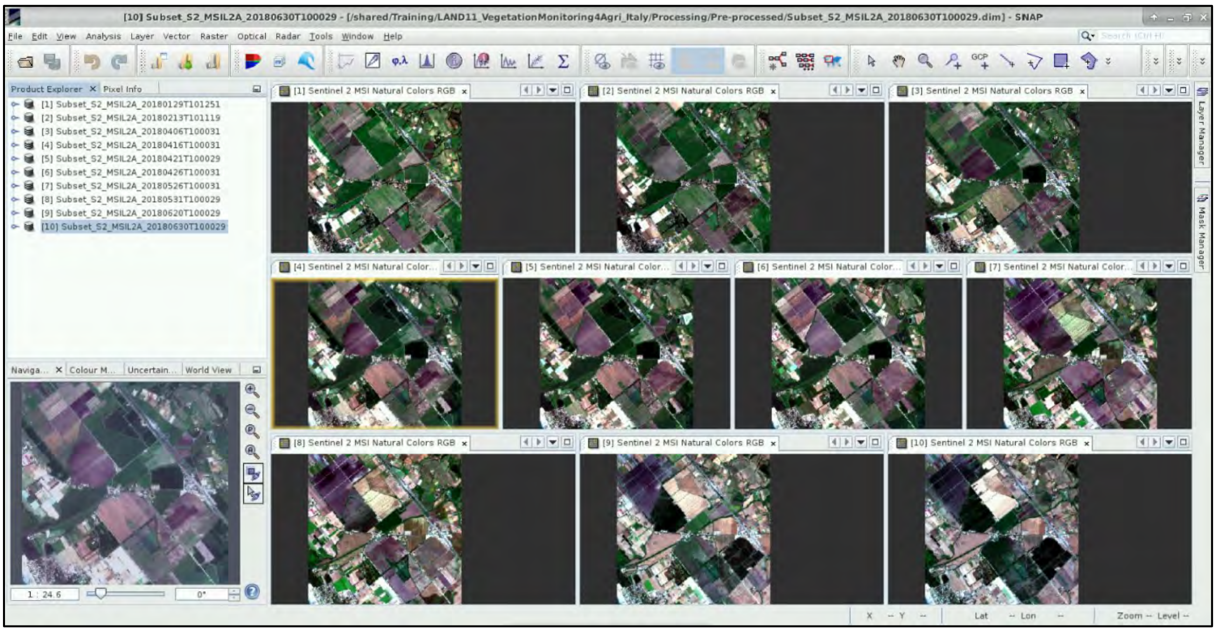


…

The processing time will depend on your VM setup. (approx. 3 mins with 30GB ram). You can check the ***/shared/Training/LAND11_VegetationMonitoring4Agri_Italy/Processing/Pre-processed*** for the output products. Close the terminal window.

Now, let's have a look at them. Go back to SNAP and go to **File → Session → Open session..** Navigate to ***/shared/Training/LAND11_VegetationMonitoring4Agri_Italy/*** and open ***Pre-processed.snap***

Once all products are loaded, right-click the first and go to **Open RGB image window.** Select the ***Sentinel 2 MSI Natural Colors*** profile and click OK. You can repeat this step for all products and the go to **Window → Tile Evenly.**



5.4 STEP 2 – Biophysical Parameter retrieval

Now, we will extract the vegetation biophysical parameters. A different number of methods exist for this purpose. From simple empirical regression to complex radiative transfer model inversions. The S2 SNAP Toolbox biophysical variable retrieval algorithm belongs to the latter category. It was developed by Weiss and Baret (INRA) and it is implemented as a collection of backpropagation artificial neural networks (ANN) trained using a globally representative set of simulations from a canopy radiative transfer (RT) model (PROSAIL: PROSPECT (Jacquemoud and Baret, 1990) + SAIL (Verhoef, 1984)). The use of the radiative transfer models is always associated with strong assumptions, in this case, particularly regarding canopy architecture (turbid medium model).

The algorithm is "generic", i.e. it should apply to any type of vegetation with reasonable performances. However, the assumption of canopy as turbid medium is more applicable to crops/grasses rather than for example forest canopies. This translates to better results for agricultural applications reported in literature.

We can run the processor both in the SNAP Graphical interface and in the GPT. We will choose the GPT in this exercise. Since we will be applying a single operator, we do not need to create a graph first, we will however still use the shell script to run the operator in batch on all our inputs.

Let's first have look at the operator in GPT. Open the Terminal window from the panel at the bottom of your screen and type:

```
gpt BiophysicalOp -h
```

By default, all the biophysical parameters will be output.

```
Terminal - rus@front: ~
File  Edit  View  Terminal  Tabs  Help
rus@front:~$ gpt BiophysicalOp -h
INFO: org.esa.snap.python.gpf.PyOperatorSpi: Python operator 'S2RutOp' registered (Python module: 's2_rut', class: 'S2RutOp', r
dules/org-esa-snap-snap-rut.jar')
INFO: org.esa.snap.python.gpf.PyOperatorSpi: Python operator 'py_sambuca_snap_op' registered (Python module: 'sambuca_snap_op',
: '/home/rus/.snap/system/modules/org-esa-sen2coral-sen2coral-inversion.jar')
INFO: org.esa.snap.core.gpf.operators.tooladapter.ToolAdapterIO: Initializing external tool adapters
SEVERE: org.esa.s2tbx.dataio.gdal.activator.GDALDistributionInstaller: The environment variable LD_LIBRARY_PATH is not set. It
 '.'.
INFO: org.esa.snap.core.util.EngineVersionCheckActivator: Please check regularly for new updates for the best SNAP experience.
Usage:
  gpt BiophysicalOp [options]

Description:
  The 'Biophysical Processor' operator retrieves LAI from atmospherically corrected Sentinel-2 products


Source Options:
  -Ssource=<file>    The source product.
                     This is a mandatory source.

Parameter Options:
  -PcomputeCab=<boolean>       Compute Cab (Chlorophyll content in the leaf)
                               Default value is 'true'.
  -PcomputeCw=<boolean>        Compute Cw (Canopy Water Content)
                               Default value is 'true'.
  -PcomputeFapar=<boolean>     Compute FAPAR (Fraction of Absorbed Photosynthetically Active Radiation)
                               Default value is 'true'.
  -PcomputeFcover=<boolean>    Compute FVC (Fraction of Vegetation Cover)
                               Default value is 'true'.
  -PcomputeLAI=<boolean>       Compute LAI (Leaf Area Index)
                               Default value is 'true'.
```

Now, we can go to the script we will use to run the processor on all the images automatically. It is similar to the one used previously for pre-processing. It is named ***STEP2_script_gpt_BioOp.sh*** and you can find it in: **/shared/Training/LAND11_VegetationMonitoring4Agri_Italy/Processing/Code/**

```
*STEP2_script_gpt_BioOp.sh - Mousepad
File  Edit  Search  View  Document  Help
1 #!/bin/bash
2
3 output_folder=/shared/Training/LAND11_VegetationMonitoring4Agri_Italy/Processing/BioOp/
4 oldEnd=.dim
5 newEnd=_BioOp.tif
6
7 for i in $(ls -d -1 /shared/Training/LAND11_VegetationMonitoring4Agri_Italy/Processing/Pre-processed/*.dim)
8 do
9          name=$(basename $i)
10         Output_pathname=$output_folder${name%$oldEnd}$newEnd
11         gpt BiophysicalOp -Ssource=$i -t $Output_pathname -f 'GeoTIFF'
12 done
```

On lines **3 to 5** we specify input parameters, such as the path to out output directory and the input file end and output file end, respectively. Our output format will be GeoTIFF, therefore the output file end must reflect this.

```
3 output_folder=/shared/Training/LAND11_VegetationMonitoring4Agri_Italy/Processing/BioOp/
4 oldEnd=.dim
5 newEnd=_BioOp.tif
```

Line **7** signifies the start of the loop. The script will iterate over all files in the specified folder ending with *".dim".* In each iteration the path to one input file is denoted by "*i*". *"do"* on line **8** and *"done"* on line **10** enclose the steps that should be performed on each input product.

```
7 for i in $(ls -d -1 /shared/Training/LAND11_VegetationMonitoring4Agri_Italy/Processing/Pre-processed/*.dim)
8 do
```

On line **9**, we extract the input file name, on line **10** we compose the new output path and name.

```
9          name=$(basename $i)
10         Output_pathname=$output_folder${name%$oldEnd}$newEnd
```

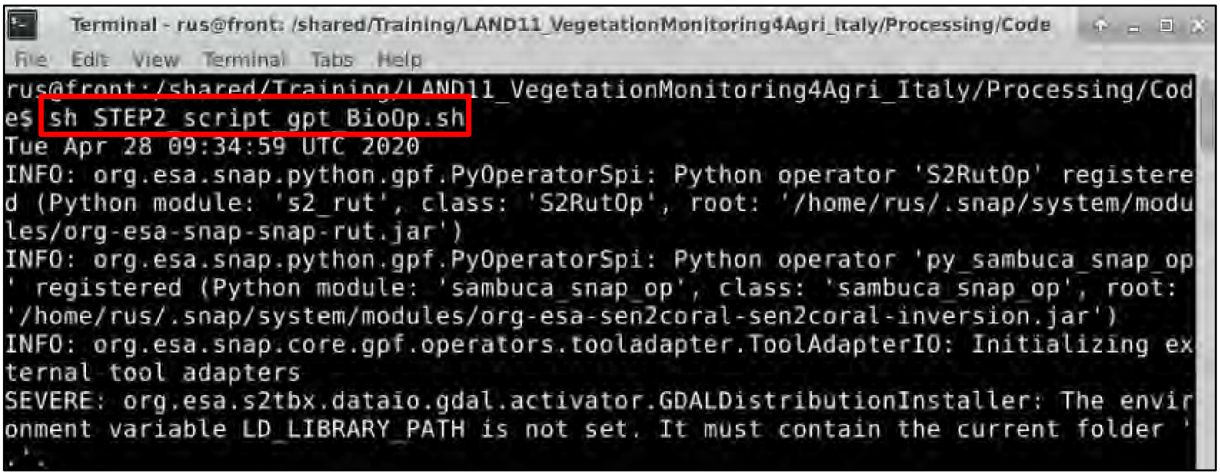
Finally, on line **11** we call GPT (SNAP command line utility) and the **BiophysicalOp** tool. Then we set the processing parameters, "done" at line **12** closes the loop.

```
11         gpt BiophysicalOp -Ssource=$i -t $Output_pathname -f 'GeoTIFF'
12 done
```

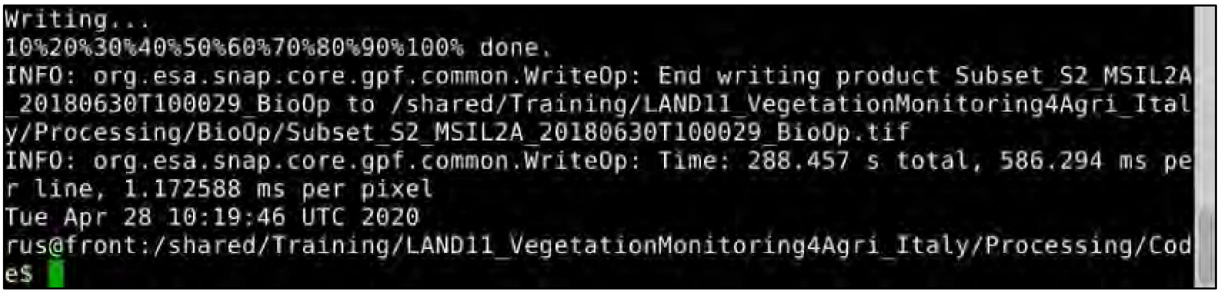
To run the script, we navigate to the folder where it is saved (*/shared/Training/LAND11_VegetationMonitoring4Agri_Italy/Processing/Code/*) and right-click on the white space and go to **Open Terminal Here**. In the terminal type:

```
sh STEP2_script_gpt_BioOp.sh
```

where *STEP2_script_gpt_BioOp.sh* is the name of the script file. Click **ENTER** to run the script.



…

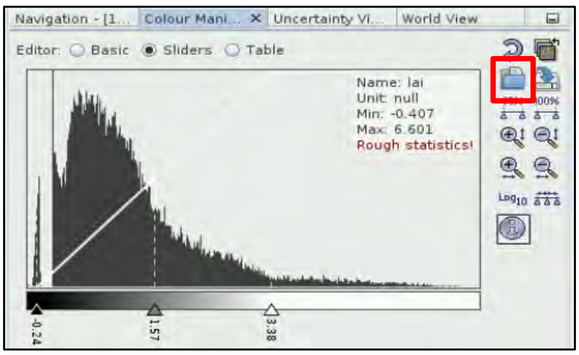


Note that the processing is quite time demanding and even for our small subset, the processing takes approximately 45 minutes (10 images, 30GB RAM VM).

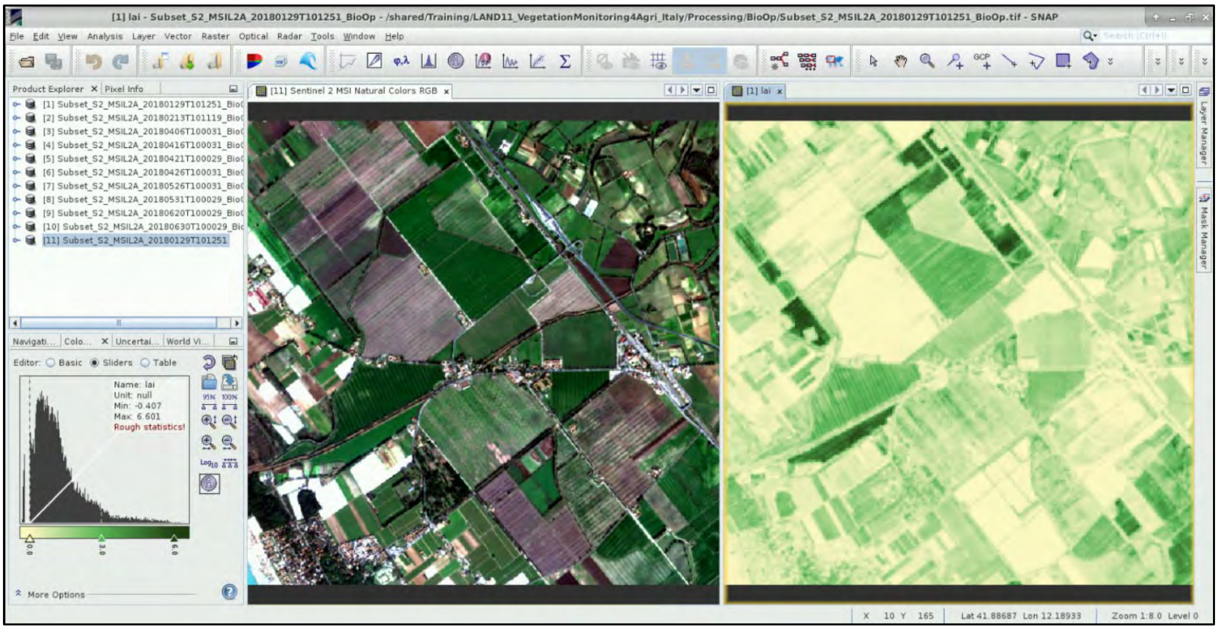
Go back to SNAP and go to **File → Session → Open Session**, then click **Yes** in the dialog that opens. Open: ***/shared/Training/LAND11_VegetationMonitoring4Agri_Italy/BioOp_processed.snap***

Now, let's investigate the results. In **Product Explorer,** open the structure of one product and go to Bands. Here we choose the product #1 from 29 January 2018 and opened the ***Bands → lai***.

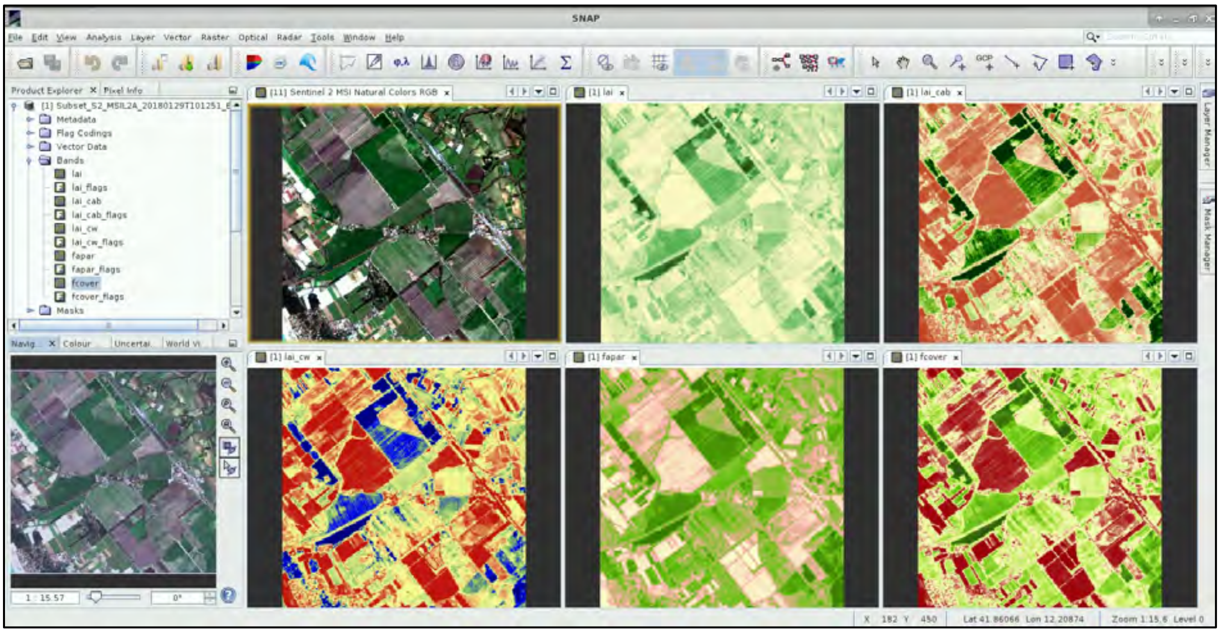
For each opened view you can go to the Colour Manipulation tab and click on Import colour palette from text file. In ***/shared/Training/LAND11_VegetationMonitoring4Agri_Italy/AuxData*** you can find the appropriate colour map for ***LAI.cpd***. To keep the pre-set values, click **No** in the **Import Colour Palette** dialog.



Then go to the last product **#11** and right-click on it. Select **Open RGB Image Window** and select the default **RGB profile: Sentinel-2 MSI Natural Colours**. Then, to visualize the images next to one another you can go to **Window → Tile Horizontally**.



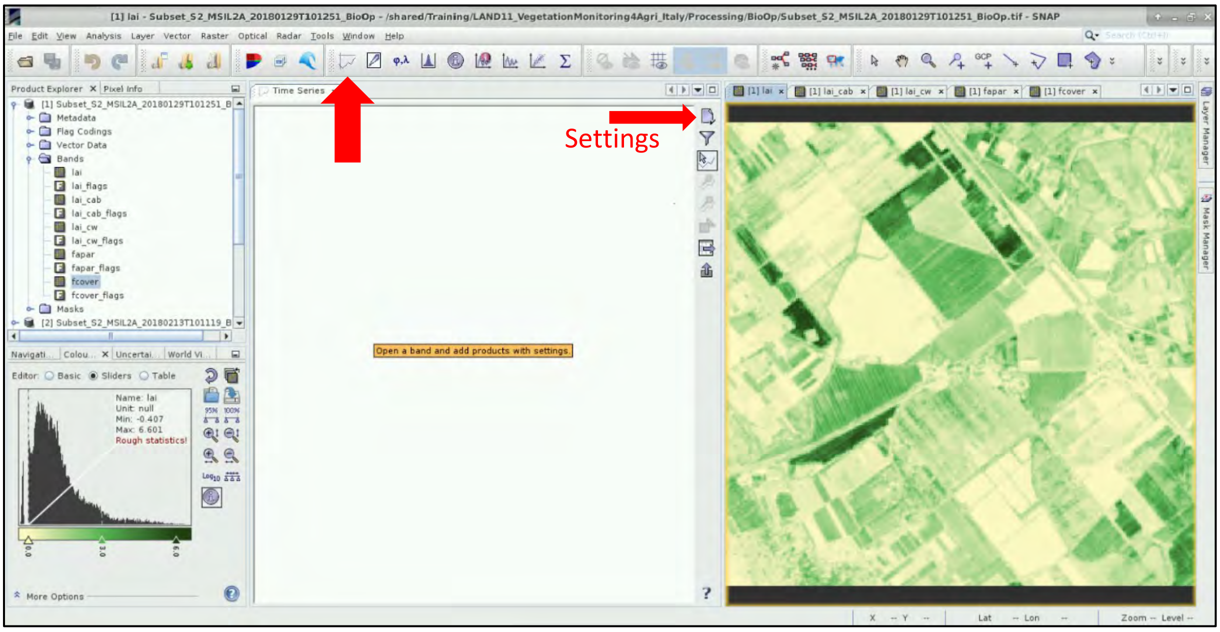
Compare the natural color composite and the LAI product side by side. Now go back also to product #1 and open also *lai_cab, lai_cw, fapar* and *fcover* band. For each band, apply the respective color palette from the AuxData folder.



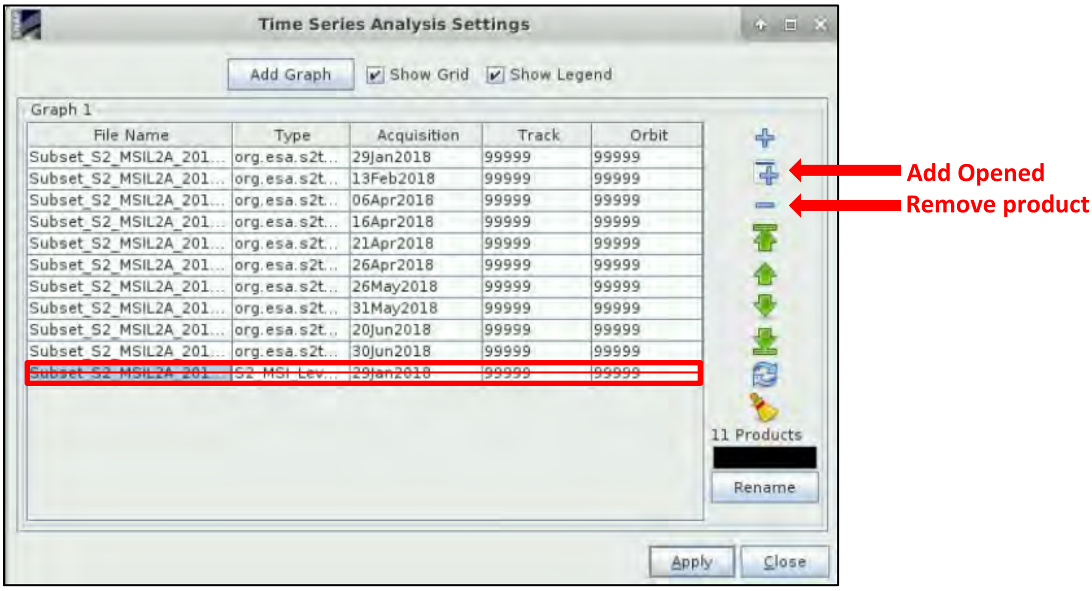
5.5 STEP 3 – Time series

Now let's see how the values develop throughout our observed period. To do this we will use the Time Series tool available in SNAP. You can find it in the top panel .

Open it and arrange windows as shown below. Then click on Settings.

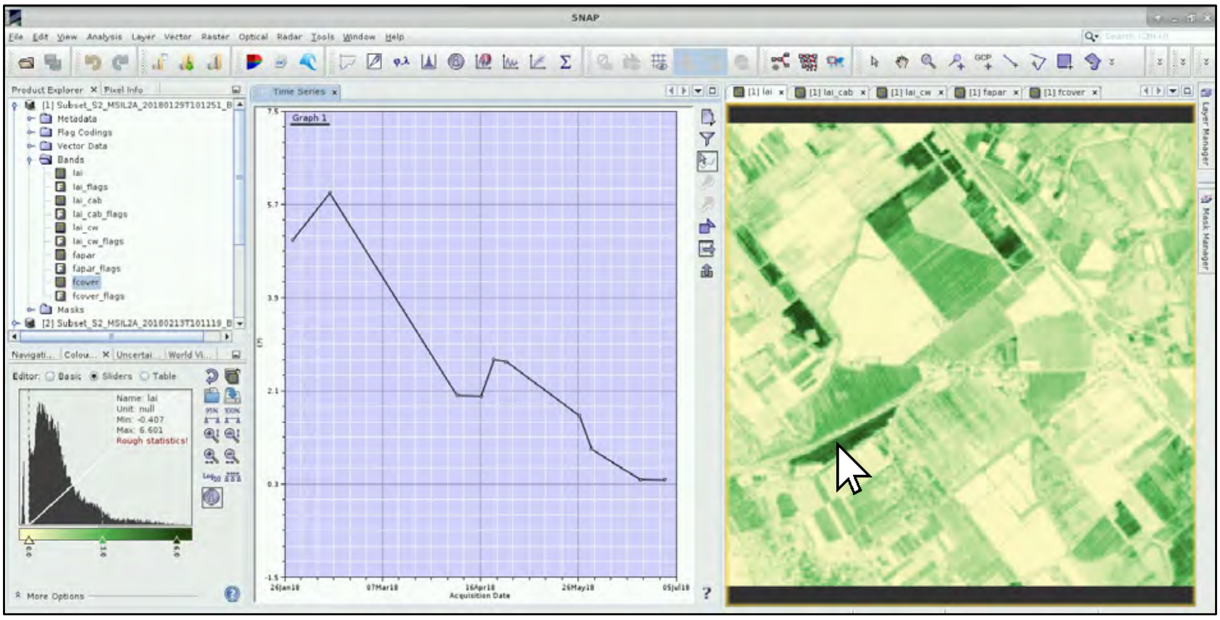


Once the settings menu opens, click on **Add Opened**. This will add all our loaded products, however, remember that we need to close the last product as it does not contain the biophysical parameters. To do this, select it in the list and click on the ***minus*** symbol. Then click **Apply** and **Close** the dialog.

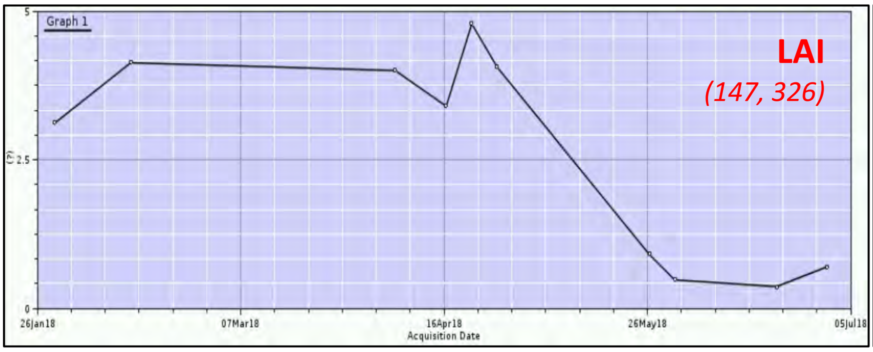


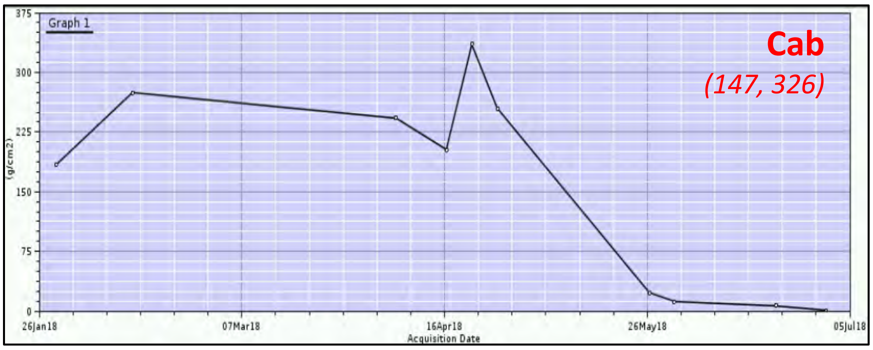
A line will appear on the graph, but we don't know which variable it corresponds to yet. So, the next step is to limit the bands. Click on the **Filter Bands** tool and select the *"lai"* band and click OK.

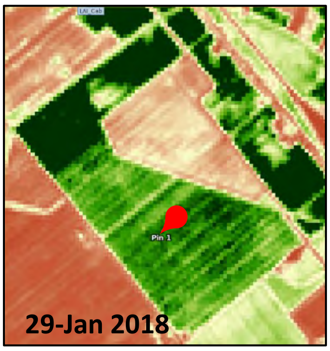
Now you can move the cursor over the "lai" image and for each position the graph will show the development over our timeseries.

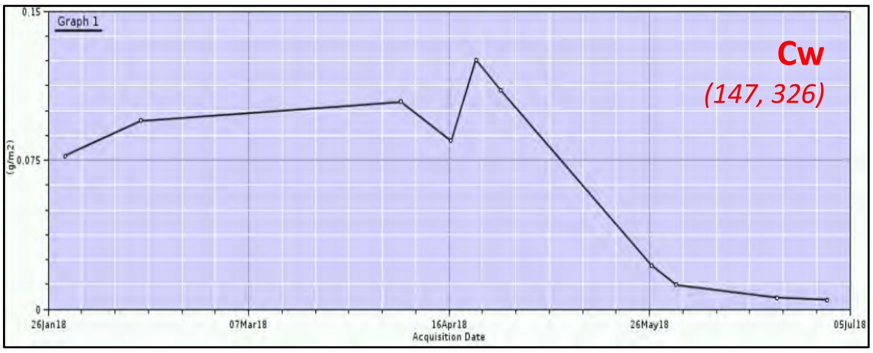


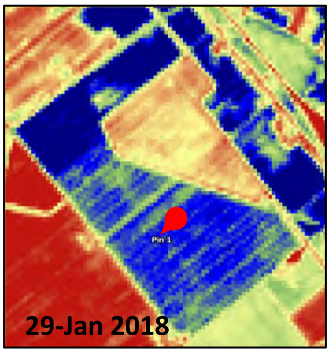
By selecting different bands, we can investigate various fields and the other variables.
(Unfortunately, at the time of writing of this tutorial the pin and polygon told in the Time Series Tool do not function reliably for Optical data)

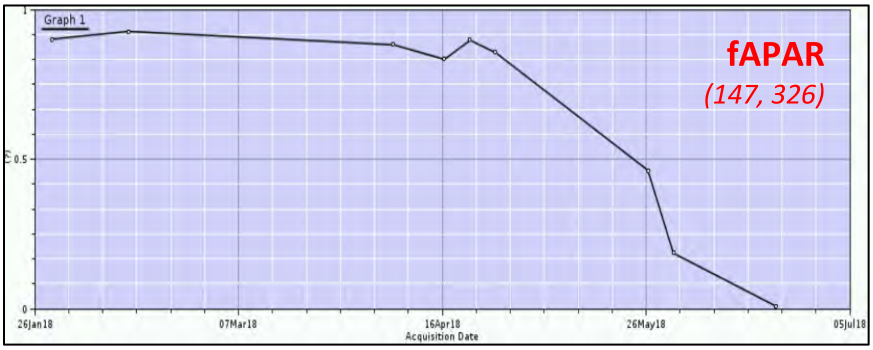


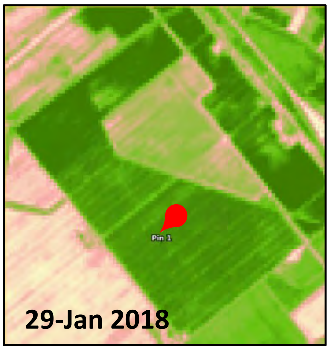


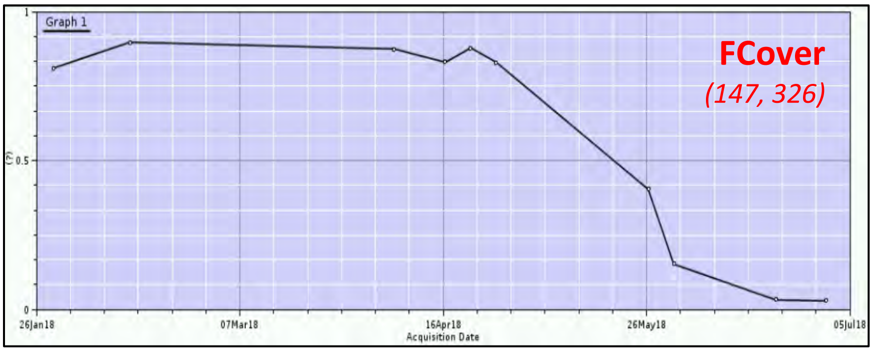












Once you are done exploring, go to **File → Session → Open Session..**, then click **Yes** in the dialog that opens. Then open: ***/shared/Training/LAND11_VegetationMonitoring4Agri_Italy/Validation.snap***

5.6 STEP 4 – Validation

We have field data for 4 dates, three of which match perfectly with our Image acquisition dates. For the fourth date an image also exists but it is contaminated by clouds and therefore not used here. Instead we use image acquired 2 days later, this can also help us to comprehend what effect this time difference has on the agreement with the field data.

Field data (date)	# Points	Image date
29-Jan. 2018	9	29-Jan. 2018
13-Feb. 2018	14	13-Feb. 2018
06-Apr. 2018	13	06-Apr. 2018
19-Apr. 2018	8	21-Apr. 2018

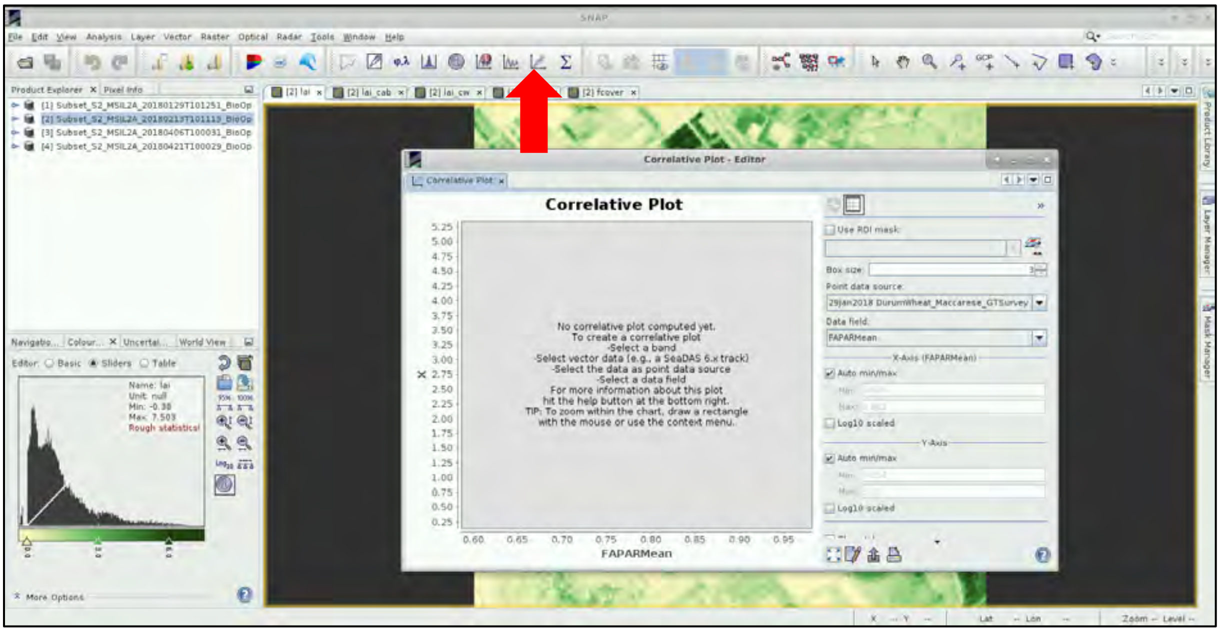
In the newly opened SNAP session, we now have 4 images opened. Let's have look at the image from 13 February 2018 (product #2) which has the most corresponding in situ data points.

First let's load the in-situ data by selecting (highlighting) the product in the **Product Explorer** and going to **Vector → Import → Vector from CSV.** Navigate to:

/shared/Training/LAND11_VegetationMonitoring4Agri_Italy/AuxData/
And open: ***13Feb2018 DurumWheat_Maccarese_GTSurvey.txt***

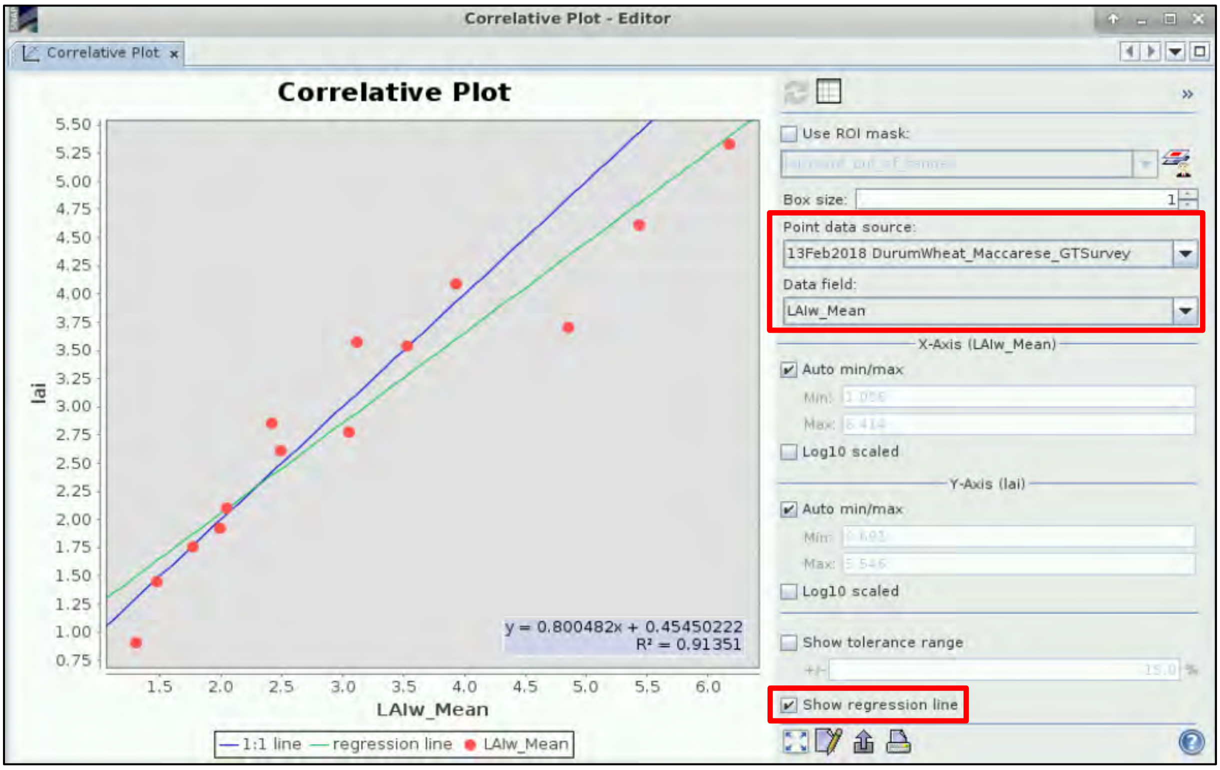
Then open the bands from product #2 (13 February 2018): *lai, lai_cab, lai_cw, fapar* and *fcover*

You can also apply the respective color palettes as we have done on page 21. On the image, white crosses appear indicating the in-situ measurements. SNAP offers the **Correlative Plot** tool , and you can open it from the top panel.



First, click into the ***(2) lai*** image view to link it to the graph (the graph will be minimised to the desktop taskbar – click on it to activate it again). Then set:

Point data source: 13Feb2018 DurumWheat_Maccarese_GTSurvey
Data field: *LAIw_Mean*
Select option to **Show regression line.**

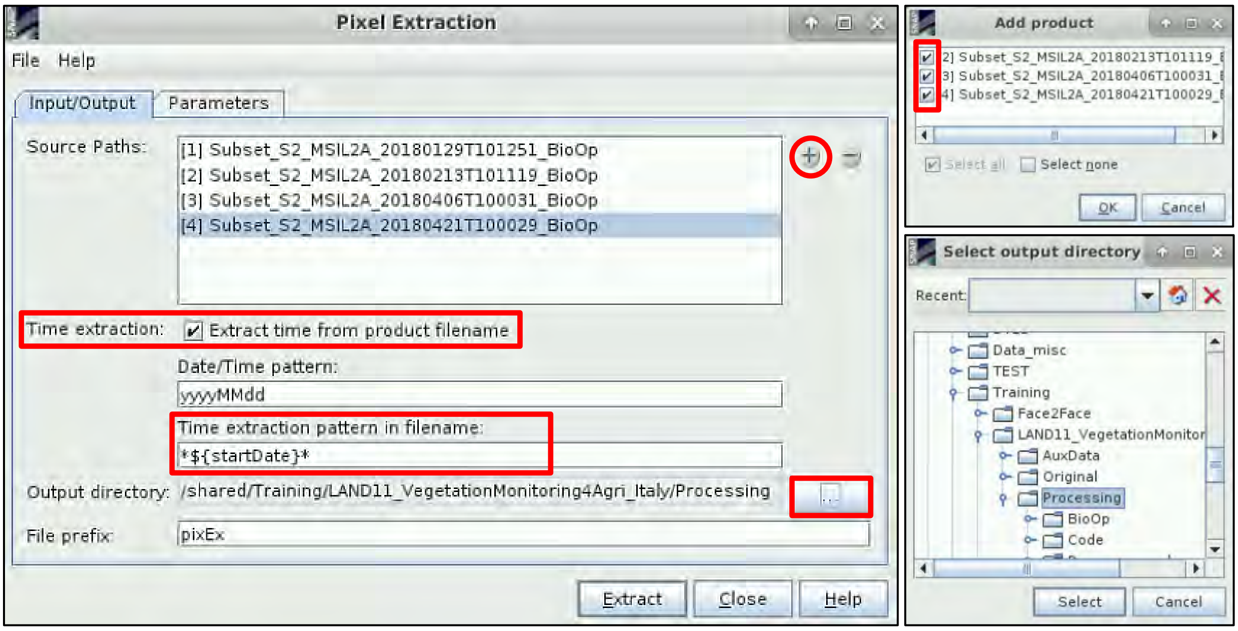


Here we can see a very good agreement between our in-situ and our calculated Leaf Area Index with the coefficient of determination of 0.91. You can also investigate other dates and variables.

We can also export the values. Write the values for all the images into a csv for better comparison in Libre Office Calc, Office Excel or import it to QGIS for example. For this we can use a very convenient Extract Pixel Values tool.

Go to **Raster → Export → Extract Pixel Values**. In the **Input/Output** tab, click on the **+** sign and select **Add product(s)…** in the dialog that opens select all. Then set:

Time extraction: ✓
Time extraction pattern in filename: **${startDate}**
Output directory: */shared/Training/LAND11_VegetationMonitoring4Agri_Italy/Processing/*

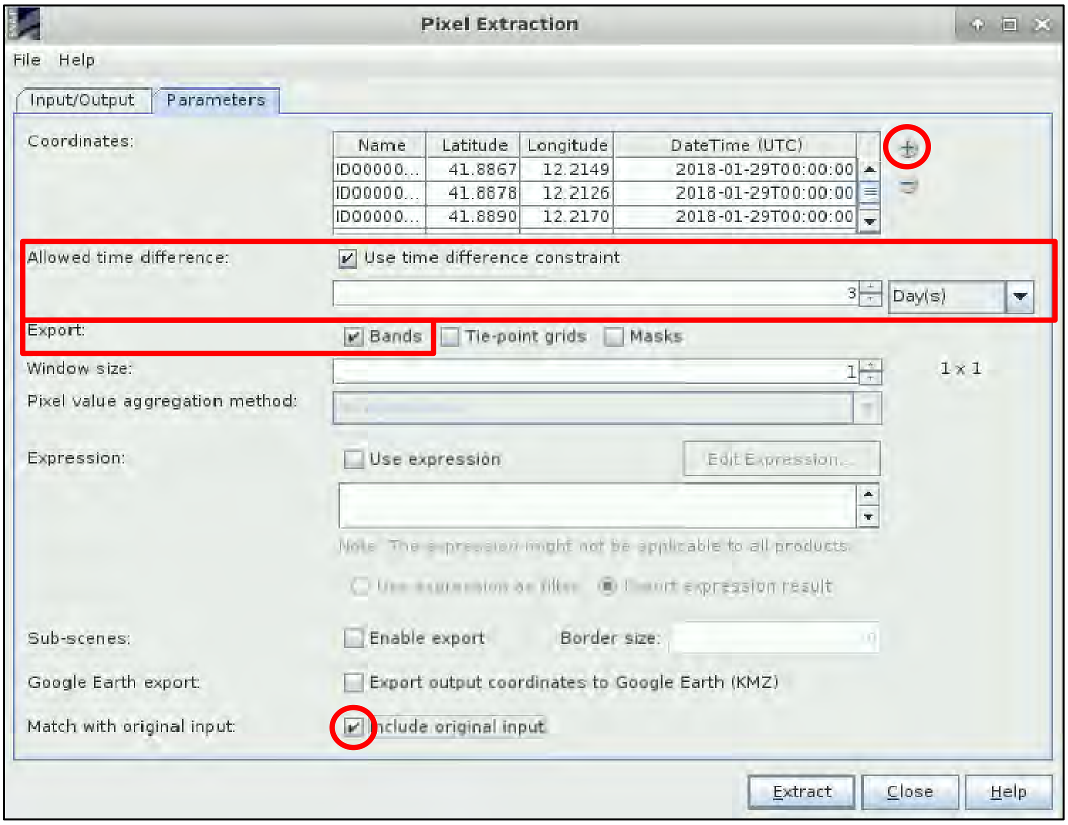


In the **Parameters** tab, in the **Coordinates** click on the **+** sign and select **Add measurements from CSV file…** the navigate to: ***/shared/Training/LAND11_VegetationMonitoring4Agri_Italy/AuxData/Field_data*** and open: ***Jan2018-April2018_DurumWheat_Maccarese_GTSurvey LATLONG.txt***

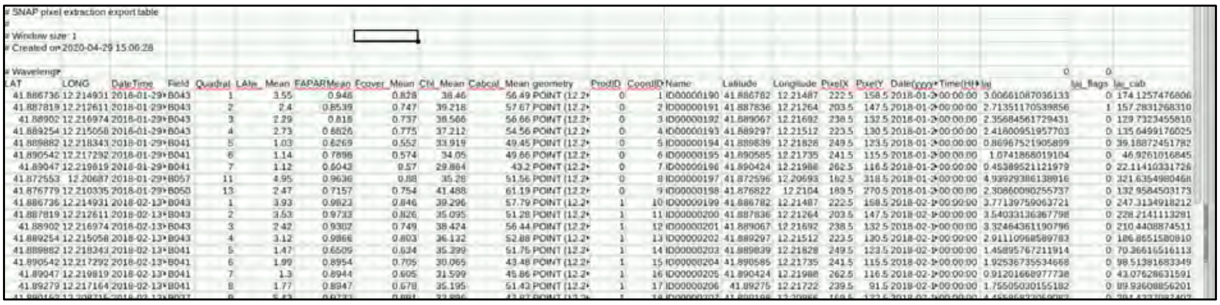
This text file contains all the in-situ observations for all dates and their appropriate coordinates, date of collection (in specific format: YYYY-MM-DDThh:mm:ss) and values for all the observed parameters.

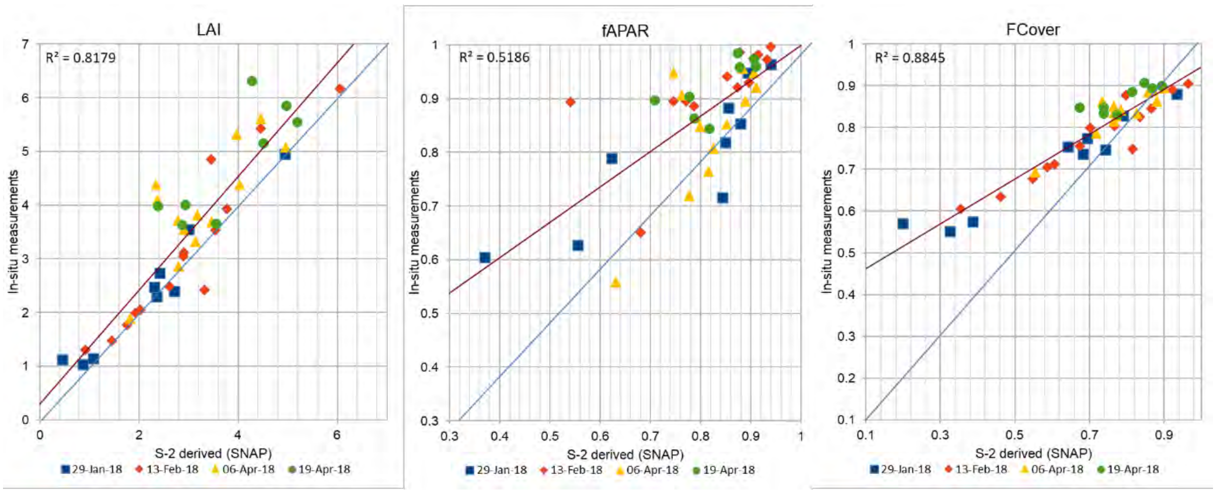
In the previous tab, we have extracted the date of acquisition from the name of each image product. Now we will use this date to match it with the in-situ data collection date. For each set of coordinates the pixel values will be extracted from the image that was acquired within 3 days of the in-situ data collection. To do this, set:

Use time difference constraint: ✓
Allowed time difference: 3 Days
Export: ✓ Bands
Match with original input: ✓ Include original input



Now we can click **Extract**. We can open the file in Libre Office… and process it further.





THANK YOU FOR FOLLOWING THE EXERCISE!

6 Extra steps

6.1 *Downloading the outputs from VM*

On your keyboard, press **Ctrl+Alt+Shift.** A pop-up window will appear on the left side of the screen. Click on the bar below **Devices**, the folder structure of your VM will appear. Navigate to your Processing folder and **double click any file you want to download.**

7 Sources & References

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Pasqualotto, N., Delegido, J., Van Wittenberghe, S., Rinaldi, M., Moreno, J., 2019. Multi-Crop Green LAI Estimation with a New Simple Sentinel-2 LAI Index (SeLI). Sensors 19, 904. https://doi.org/10.3390/s19040904

Upreti, D., Huang, W., Kong, W., Pascucci, S., Pignatti, S., Zhou, X., Ye, H., Casa, R., 2019. A Comparison of Hybrid Machine Learning Algorithms for the Retrieval of Wheat Biophysical Variables from Sentinel-2. Remote Sens. 11, 48 https://doi.org/10.3390/rs11050481

Lecture by Dr. Weiss - LAI/fCover/fAPAR/Chlorophyll retrieval concepts and methods - **9th Advanced Training Course on Land Remote Sensing**