

TRAINING KIT – LAND11

VEGETATION MONITORING FOR AGRICULTURE MACCARESE, ITALY 2018 - 2020









Research and User Support for Sentinel Core Products

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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: <u>https://youtu.be/xEwy8UMGu7M</u> 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 @ <u>https://scihub.copernicus.eu/</u>]
 - 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
 - S2A_MSIL2A_20180526T100031_N0208_R122_T32TQM_20180526T161700.zip
 S2B_MSIL2A_20180531T100029_N0208_R122_T32TQM_20180531T125926.zip
 - S2B_MSIL2A_201805311100029_N0208_R122_T32TQM_201805311123926.zlp
 S2B_MSIL2A_20180620T100029_N0208_R122_T32TQM_20180620T182958.zlp
 - 10. S2B_MSIL2A_20180630T100029_N0208_R122_T32TQM_20180630T144100.zip

2.2 Software in RUS environment

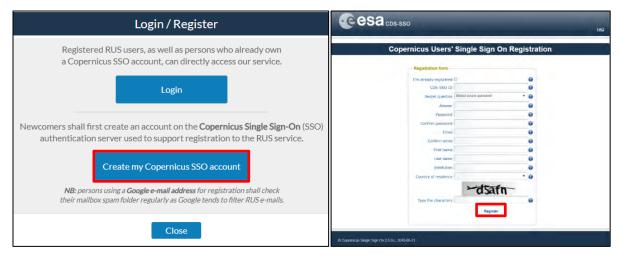
Internet browser, SNAP + Sentinel-2 Toolbox, QGIS, (Extra steps: Sen2Cor, Google Earth)

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 (<u>www.rus-copernicus.eu</u>) and click on *Login/Register* in the upper right corner.

CORRUS Research and User Support	
The RUS Service * The RUS Offer * The RUS Library * The RUS Community *	
	Scerch
	News from RUS
	One year on!
	Copernicus Info Session - Reykjavik - 19 September 2018
	SPIE Remote Sensing 2018 – Berlin (Germany) – 11-12 September 2018
	SIWI World Water Week 2018 – Stockholm – 26-31 August 2018
	MedRIN Kick-off Meeting - Chania - 13 & 14 July 2018
	RUS Webinar – Special edition "AskRUS – Sentinel-1" – 12 July 2018
Welcome to Research and User Support	RUS Training Session - Valencia - 22 July 2018
	IGARSS 2018 - Valencia - 22-27 July 2018
Welcome to the Copernicus Research and User Support (RUS) Service portal!	The RUS agenda
The RUS Service is the "New Expert Service for Sentinel Users" funded by the European Commission,	Conferences & Workshops

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 email to activate your account.

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

Login / Register	Credentials			-
The registration system to access the RUS service platform has moved toward the COPERNICUS Single Sign On authentication server. New Users who have not yet registered to the RUS portal shall first create a COPERNICUS SSO account. Note that your Copernicus SSO account will be activated only after the reception of the third email sent by the Copernicus service. We advise you to consult this document and this page to facilitate your registration procedure. REGISTER COPERNICUS SSO account Users who already have a COPERNICUS SSO account can login here: Login	CDS-SSO ID Password Max Idle Time Max Session Time	half a day Until browser close Login Reset	Ÿ Ÿ	000
Close		Forgot your password?		

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

The RUS Service * The RUS O	Do you want to	o subscribe for a new RUS account?	^		
Your ES	5A-SSO subscription of	data:			
Your RUS service Login		And and a second se	- 1	4	
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Email		the second se			
Your dashboard: allows you to a Organize	zation	and the second s			
Your training allows you to regis	у	*			
	Additio	nal subscription information			
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Please of	complete the following	ng Information:			
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		conference social media			And a
		other	~		0.4820
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Phone n Italy (IT)		+39			Sine.
Title		Select one item	~		Mill States

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** \rightarrow **Your Dashboard**.

The RUS Service • The RUS Offer • The RUS Library •	Helto, Miguel
Your RUS service	Your profile You are here: Home > Your RUS ser Your dashboard
This section gathers pages related to your RUS services: • Your profile: displays your personal information linked to you	Your training Your training News from RUS
Your dashboard: Illows you to access your private dashboard	One year on! Copernicus Info Session – Reykjavik – 19 September 2018
Your training: allows you to register to a training session you	SIWI World Water Week 2018 - Stockholm - 26-31
	August 2018 MedRIN Kick-off Meeting - Chania - 13 & 14 July 2018 RUS Webinar - Special edition "AskRUS - Sentinel-1" - 12
	RUS Webmar - special edition AskRUS - sentine: 1 - 12 July 2018 RUS Training Session - Valencia - 22 July 2018 IGARSS 2018 - Valencia - 22-27 July 2018

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.

CORRUS Research and User Support	Helto, Miguel 🛔
The RUS Service • The RUS Offer • The RUS Library • The RUS Community • 👷 Your RUS service •	You are here: Home > Your RUS service > Your dashboard
Your dashboard	
Request a new User Service	Chat with Support Desk
Copyright © 2017 Research and User Support	onLact Us Terms and conditions Glossary Acronyms FAQ

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

ease help us learn more about your background by answering a few questio formation will be stored in your User Profile. ow many years of experience in Remote Sensing do you have? Choose one Item ave you already downloaded Copernicus data via the Copernicus Open access hubs? Yes No ave you already handled/processed Copernicus data? Ves No o you wish to practice a tutorial exercise shown in a RUS webinar? If yes, please select your of	nns. Th
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IAZA01 - Flood Mapping in Malawi	
IAZA02 - Burned Area Mapping in Portugal IYDR01 - Water Bodies Mapping over Northern Poland	- 11
AND01 - Crop Mapping in Seville	- 11
AND04 - Land Monitoring in Cyprus ICEA01 - Ship Detection in Gulf of Trieste	*
you wish to request another tutorial exercise that doesn't appear in the above list, please typ s name or code. Note that you can request multiple tutorial exercises.	pe here
	- Harde

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

Summary information on your request:		
This is a collection of information selected		
You can go back and edit this information	if necessary.	
General information on your request:		
Years of experience in Remote Sensing	5-10 years	
Downloaded Copernicus data?	1	
Handled/processed Copernicus data?	1	
Webinar codes	HAZA02, LAND04	
About your RUS project:		
Thematic area	Cryosphere (ice and snow)	
Operations to perform on RUS	Algorithm development	
Preference for downloading process	Self-downloading	
Foreseen activities and support needs	Develop a land cover classification	
Project name	RUS_Project1	
Earth Observation Data information:		
Type of Earth Observation Data:		
Sentinel-1	1	
	S1-Product 1	
S1 - Product type	GRD	
S1 - Sensor mode	4	
S1 - Polarisation	a	
S1 - Orbit direction	-	
Sentinel-2	x	
Sentinel-3	×	
Other	x	
I don't know	×	
Region of Interest: Min Latitude	39.3303	
Max Latitude	40.5877	
Min Longitude	-4.6736	
Max Longitude	-2.7205	
Reference polygons		
Data acquisition date(s):		
None		
Additional data specifications		
I have read and agree to the Terms and	conditions of RUS Service.	

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**.

							You are here: Home >	Your RUS service > Your dash
Your dashboard								
Request a new L	lser Servio	ce						Chat with Support Desk
Project Name	ID	Date of submission	Status		Actions		Virtual	Environment
	200			Follow my project	Get support	Close my service	Access my Virtual Machine(s)	Access my CPU monitoring dashboard
RUS_training1	231	2017-08-31	Open		Get a webinar kit	Rate my service	Freeze my Virtual Machine(s)	Report a technical incident

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.

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opernicus				

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 \rightarrow Network \rightarrow Web Browser or click the link below).

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



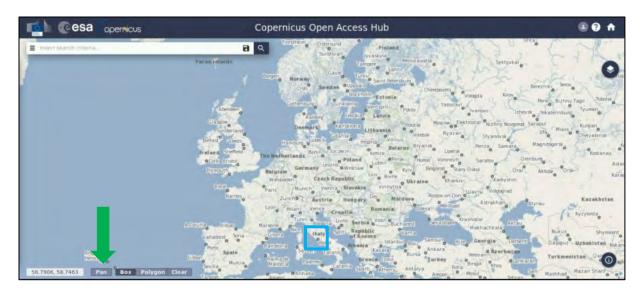
Go to "**Open HUB**", if you do not have an account please register by going to "**Sign-up**" in the LOGIN menu in the upper right corner.

💼 @esa	opernicus	Copernicus Open Access Hub	
		Register new account	
	Sentinel data access is free	and open to ail.	
	the data.	n form below you will receive an e-mail with a link is validate your e-mail address. Following this you o hanumeric characters plus "", """, "," and ".".	can ax vo download
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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".

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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 2018/06/30Check Mission:Sentinel-2Product Type:S2MSIL2A

Press "Search" (red arrow below).

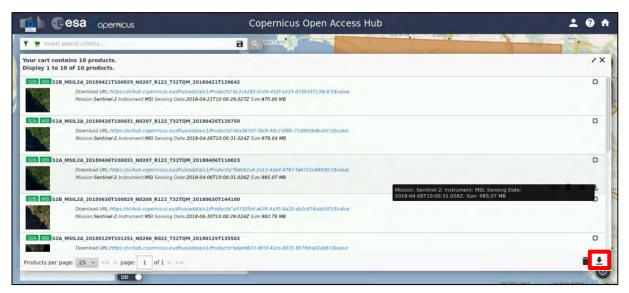
esa opernicu	JS	Copernicus Open Access Hub
🗑 Insert search criteria		a q Tuscarila Viterto
» Sensing period	2018/06/30	
» Ingestion period	-	entinglia Pezzaglio Satina
O Mission: Sentinel-1		Palenbara
Satellite Platform	Product Type	
Polarisation	Sensor Mode	Rame
Relative Orbit Number (from 1 to 175)	Collection	Stand Standard Flug Standard Standard Anagen Standard Standard Sta
Mission: Sentinel-2		terra Contesta
Satellite Platform	Product Type	Latina Latina
Relative Orbit Number (from 1 to 143)	S2MSI2A	Latina
Lat Lon: 41.87, 11.09	•	Pontinie

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_201804216T120852.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_20180526T100031_N0208_R122_T32TQM_20180526T161700.zip
S2B_MSIL2A_20180520T100029_N0208_R122_T32TQM_20180531T125926.zip
S2B_MSIL2A_20180620T100029_N0208_R122_T32TQM_20180630T142058.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: <u>https://scihub.copernicus.eu/userguide/LongTermArchive</u>

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

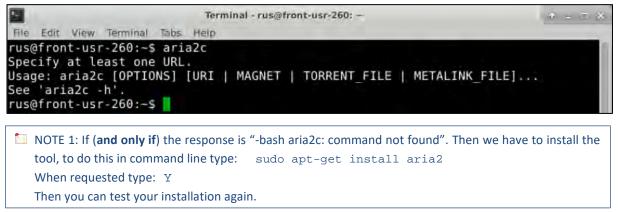
A *products.meta4* file will be downloaded to your */home/rus* folder. To download our data, we will use **aria2** tool. To use the tool, we first need to place the **products.meta4** file to the folder where we wish our data to be downloaded to:

/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:



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.

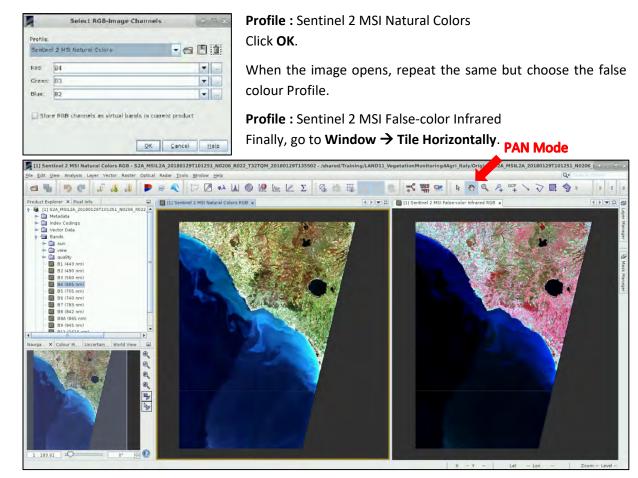
5.2 Data exploration

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:



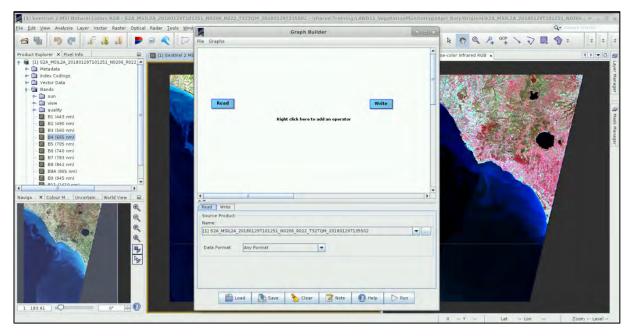
- NOTE 2: The Sentinel-2 data are distributed as 100x100 km tiles resampled to a common grid in WGS84 UTM projection at two levels of processing:
 - Level-1C Top-Of-Atmosphere reflectances, systematically generated since the start of the mission.
 - Level-2A Bottom-Of-Atmosphere reflectances (atmospherically 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** \rightarrow **GraphBuilder**.



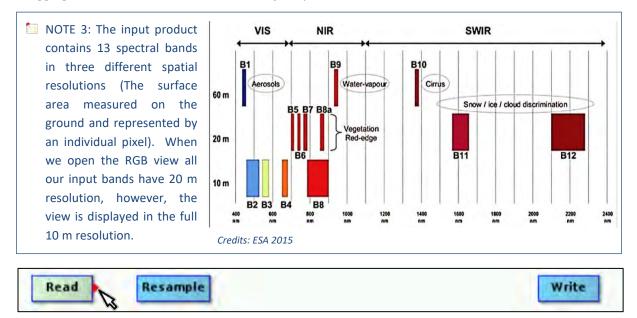
At the moment, the graph only has two operators: **Read** (to read the input) and **Write** (to write the output).

The 13 bands in Sentinel-2 products do not all have the same resolution (therefore size) as mentioned in 1 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 \rightarrow Raster \rightarrow Geometric \rightarrow 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.



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 \rightarrow Raster \rightarrow Geometric \rightarrow 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).

Define size of resampled product		
	B2	*
By reference band from source product:	Resulting target width:	10980
	Resulting target height:	10980
	Target width:	10,980
O By target width and height:	Target height	10,980
	width / height ratio.	1.00000
		50-
By pixel resolution (in m):	Resulting target width	1830
	Resulting target height:	1830
Define resampling algorithm		
Upsampling method	Nearest	-
Downsampling method	First	
Flag downsampling method	First	
Advanced Method Definition by Band		

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/

Read Resample Sub	Set Write	
Source Bands:	B1 B2 B3 B4	
	85 86 87 88	
🖌 Copy Metadata		Zoom-in
O Pixel Coordinates Reference band:	s Geographic Coordinates	
A STATE THE		

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 rightclick 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 (<u>https://en.wikipedia.org/wiki/Bash (Unix shell)</u>). 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.

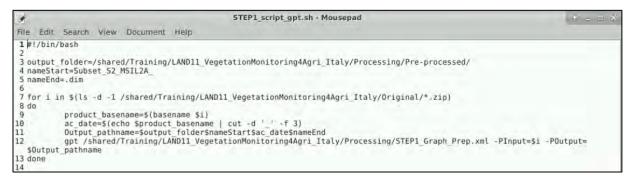
In line **7** (in the node with id='Read') replace the path to input file with (between <file> and </file>): *\$Input* ("\$" signifies that what follows is a parameter).

1	STEP1_Graph_Prep.xml - Mousepad	E ×
Fi)e	Edit Search View Document Help	
234567	<pre>graph id="Graph"> <version>l.0</version> <uode id="Read"></uode></pre>	
۶ File	*STEP1_Graph_Prep.xml - Mousepad Edit Search View Document Help	* <u>-</u> 0 *
1<23456789	<pre>yraph id="Graph"> <version>1.0</version> <node id="Read"> <voperator>Read</voperator></node></pre> <sources></sources> <sources></sources> <file>\$Input</file>	Ļ

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



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



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 <u>date of the acquisition</u> 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

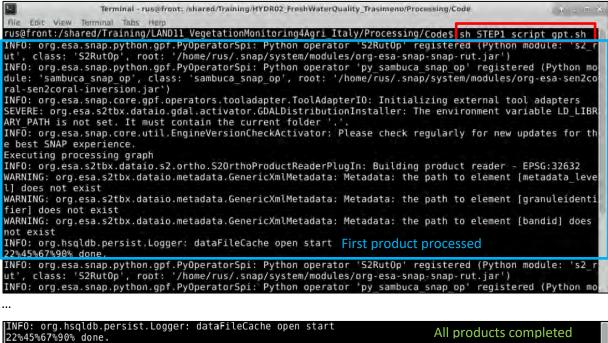
On line **12**, we call GPT and specify the path to our saved and edited graph file. Then with -P{variable name} we specify the parameters to be replaced in the graph file (marked with \$ in the graph file). We have set the variables when we edited the .xml graph file – **Input, Output**. On line **13**,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

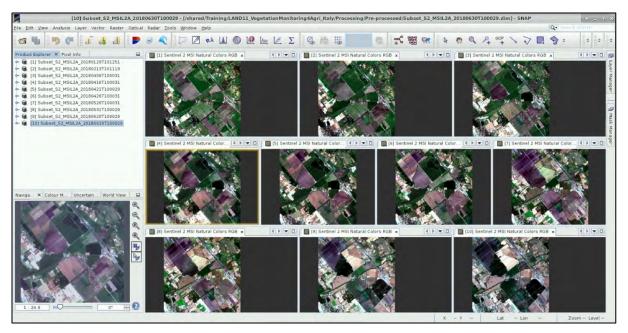


rus@front:/shared/Training/LAND11 VegetationMonitoring4Agri Italy/Processing/Codes

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** \rightarrow **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 Biophysical(
	.PyOperatorSpi: Python operator 'S2RutOp' registered (Python module: 's2 rut'	, class: 'S2RutOp', r
dules/org-esa-snap-snap-rut.		
	.PyOperatorSpi: Python operator 'py_sambuca_snap_op' registered (Python modul ules/org-esa-sen2coral-sen2coral-inversion.jar')	le: 'sambuca_snap_op',
INFO: org.esa.snap.core.gpf.c	operators.tooladapter.ToolAdapterIO: Initializing external tool adapters	
SEVERE: org.esa.s2tbx.dataio	gdal.activator.GDALDistributionInstaller: The environment variable LD_LIBRARY	Y_PATH is not set. It
INFO: org.esa.snap.core.util	EngineVersionCheckActivator: Please check regularly for new updates for the t	best SNAP experience.
Usage:		
gpt BiophysicalOp [options]		
Description:		
The 'Biophysical Processor	operator retrieves LAI from atmospherically corrected Sentinel-2 products	
Source Options:		
	rce product.	
	a mandatory source.	
11125 25		
Parameter Options:		
-PcomputeCab= <boolean></boolean>	Compute Cab (Chlorophyll content in the leaf)	
	Default value is 'true'.	
-PcomputeCw= <boolean></boolean>	Compute Cw (Canopy Water Content)	
	Default value is 'true'.	
-PcomputeFapar= <boolean></boolean>	Compute FAPAR (Fraction of Absorbed Photosynthetically Active Radiation)	
	Default value is 'true'.	
-PcomputeFcover= <boolean></boolean>	Compute FVC (Fraction of Vegetation Cover)	
	Default value is 'true'.	
-PcomputeLAI= <boolean></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/



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/Bio0p/
4 oldEnd=.dim
5 newEnd= BioOn.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 \$1)	
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.

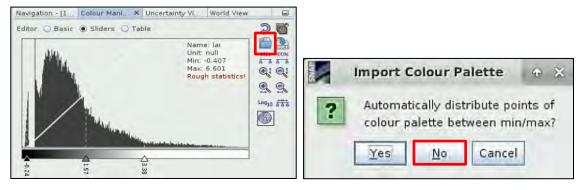
Terminal - rus@front: /shared/Training/LAND11_VegetationMonitoring4Agri_Italy/Processing/Code 📀 🚊	1
e Edit View Terminal Tabs Help	
<pre>S@front:/shared/Training/LAND11_VegetationMonitoring4Agri_Italy/Processing/ sh STEP2 script gpt BioOp.sh</pre>	Cod
Apr 28 09:34:59 UTC 2020	
F0: org.esa.snap.python.gpf.PyOperatorSpi: Python operator 'S2RutOp' regist (Python module: 's2_rut', class: 'S2RutOp', root: '/home/rus/.snap/system/m s/org-esa-snap-snap-rut.jar')	
O: org.esa.snap.python.gpf.PyOperatorSpi: Python operator 'py_sambuca_snap registered (Python module: 'sambuca_snap_op', class: 'sambuca_snap_op', roo nome/rus/.snap/system/modules/org-esa-sen2coral-sen2coral-inversion.jar') O: org.esa.snap.core.gpf.operators.tooladapter.ToolAdapterIO: Initializing rnal_tool_adapters	t:
/ERE: org.esa.s2tbx.dataio.gdal.activator.GDALDistributionInstaller: The en ment variable LD LIBRARY PATH is not set. It must contain the current folde	
lting 20%30%40%50%60%70%80%90%100% done.	
FO: org.esa.snap.core.gpf.common.WriteOp: End writing product Subset S2 MSI 0180630T100029_BioOp to /shared/Training/LAND11_VegetationMonitoring4Agri_I	
Processing/BioOp/Subset_S2_MSIL2A_20180630T100029_BioOp.tif F0: org.esa.snap.core.gpf.common.WriteOp: Time: 288.457 s total, 586.294 ms Line, 1.172588 ms per pixel	pe
e Apr 28 10:19:46 UTC 2020	
@front:/shared/Training/LAND11_VegetationMonitoring4Agri_Italy/Processing/	Cod

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).

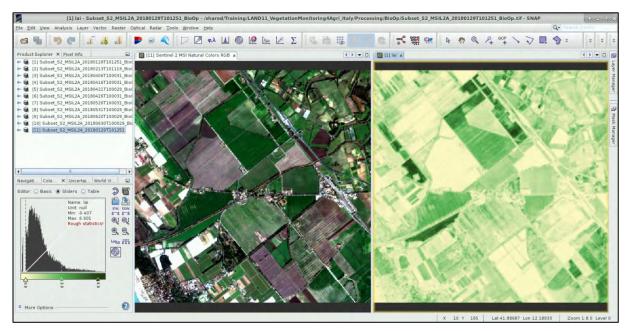
Go back to SNAP and go to File \rightarrow Session \rightarrow Open Session, then click Yes in the dialog that opens. Open: /shared/Training/LAND11_VegetationMonitoring4Agri_Italy/BioOp_processed.snap

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** \rightarrow **lai**.

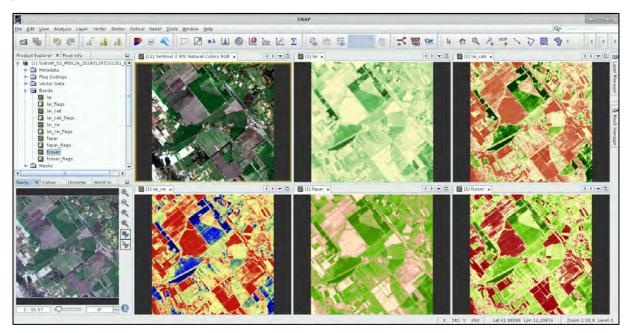
For each opened view you can go to the Colour Manipulation tab and click on Import colour palette from text file . In */shared/Training/LAND11_VegetationMonitoring4Agri_Italy/AuxData* you can find the appropriate colour map for *LAI.cpd*. To keep the pre-set values, click **No** in the **Import Colour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



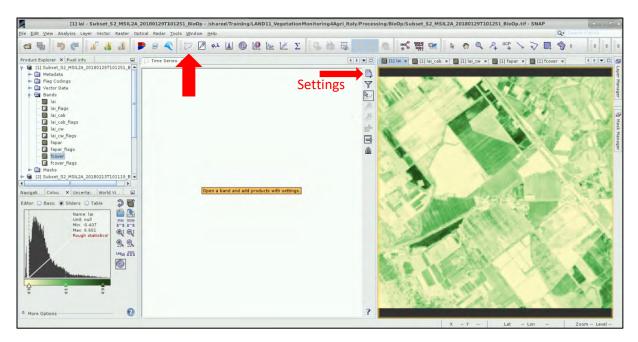
Compare the natural color composite and the LAI product side by side. Now go back also to product #1 and open also *lai_cab*, *lai_cw*, *fapar* and *fcover* band. For each band, apply the respective color palette from the AuxData folder.



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 \Box .

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



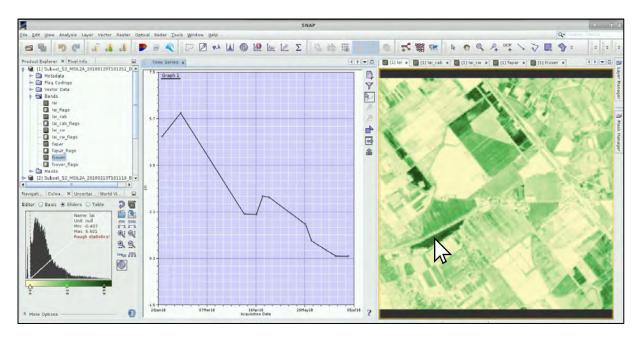
Once the settings menu opens, click on **Add Opened**. This will add all our loaded products, however, remember that we need to close the last product as it does not contain the biophysical parameters. To do this, select it in the list and click on the *minus* symbol. Then click **Apply** and **Close**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

1	Time Seri	ies Analysis Se	ttings		* = ×	
	Add Graph	Show Grid	Show Le	gend		
Graph 1						
File Name	Type	Acquisition	Track	Orbit	4	
Subset S2 MSIL2A 201	org.esa.s2t	29Jan2018	99999	99999		
Subset S2 MSIL2A 201	org.esa.s2t	13Feb2018	99999	99999		Add Opened
Subset S2 MSIL2A 201	org.esa.s2t	06Apr2018	99999	99999		Remove produc
Subset S2 MSIL2A 201	org.esa.s2t	16Apr2018	99999	99999		
Subset S2 MSIL2A 201	org.esa.s2t	21Apr2018	99999	99999	著	
Subset S2 MSIL2A 201	org.esa.s2t	26Apr2018	99999	99999		
Subset S2 MSIL2A 201	org.esa.s2t	26May2018	99999	99999		
Subset S2 MSIL2A 201	org.esa.s2t	31May2018	99999	99999		
Subset S2 MSIL2A 201	org.esa.s2t	20Jun2018	99999	99999	2	
Subset S2 MSIL2A 201	org.esa.s2t	30Jun2018	99999	99999		
Subset S2 MSIL2A 201	S2 MSI Lev	29jan2018	99999	99999	2	
					5	
					11 Products	
					Rename	
					-	

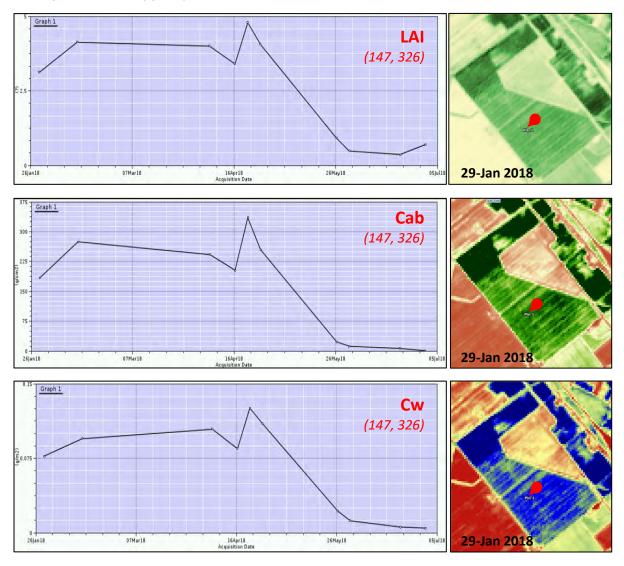


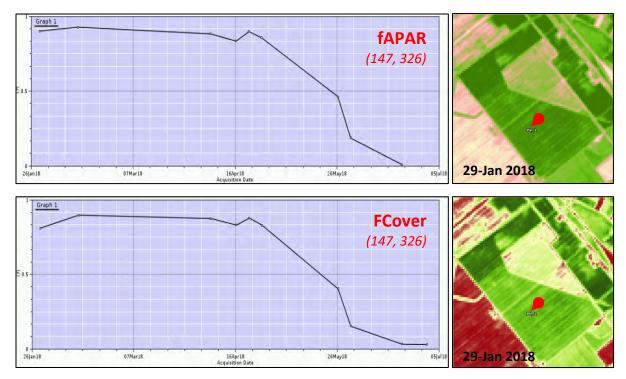
A line will appear on the graph, but we don't know which variable it corresponds to yet. So, the next step is to limit the bands. Click on the **Filter Bands** \Im tool and select the *"lai"* band and click OK.

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 \rightarrow Session \rightarrow 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

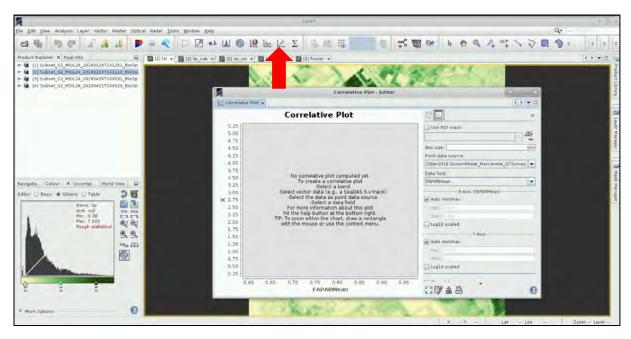
In the newly opened SNAP session, we now have 4 images opened. Let's have look at the image from 13 February 2018 (product #2) which has the most corresponding in situ data points.

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

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

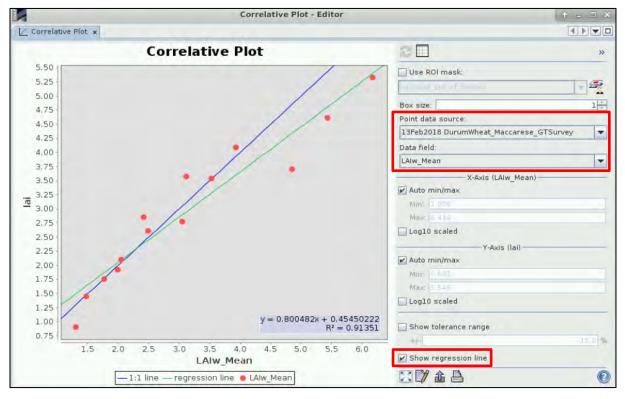
Then open the bands from product #2 (13 February 2018): *lai, lai_cab, lai_cw, fapar* and *fcover*

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 $\downarrow _$, 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** \rightarrow **Export** \rightarrow **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: \checkmark

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

	Pixel Extraction		* 🗉 ×	Add product 🔹 📼 😣
File Help				 2] Subset_S2_MSIL2A_20180213T101119_ 3] Subset_S2_MSIL2A_20180406T100031_
Input/Output	Parameters			4] Subset_52_MSIL2A_20180421T100029_
Source Paths:	 Subset_S2_MSIL2A_20180129T101251 Subset_S2_MSIL2A_20180213T101115 Subset_S2_MSIL2A_20180406T100031 Subset_S2_MSIL2A_20180406T100025 Subset_S2_MSIL2A_20180421T100025 	BioOp BioOp	⊕ ≈	Select gill Select none QK Cancel
Time extraction:	Extract time from product filename			Recent.
	Date/Time pattern:			Cata_misc Cata_misc
	ууууMMdd		1	e 📑 Training
	Time extraction pattern in filename: *\${startDate}*		1	
Output directory:	/shared/Training/LAND11_VegetationMonit	toring4Agri_Italy/Processing		↔
File prefix:	pixEx			Code
		<u>Extract</u> <u>C</u> lose	Help	Select Cancel

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

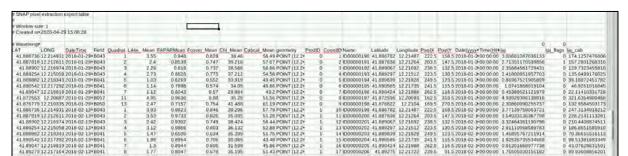
This text file contains all the in-situ observations for all dates and their appropriate coordinates, date of collection (in specific format: YYYY-MM-DDThh:mm:ss) and values for all the observed parameters.

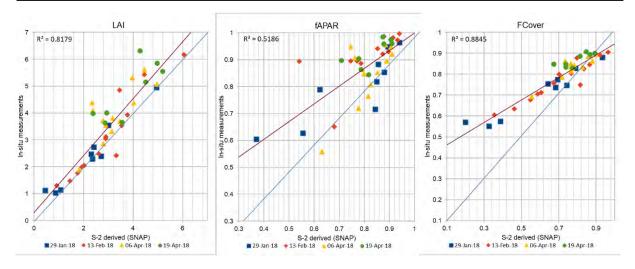
In the previous tab, we have extracted the date of acquisition from the name of each image product. Now we will use this date to match it with the in-situ data collection date. For each set of coordinates the pixel values will be extracted from the image that was acquired within 3 days of the in-situ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

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

2	Pixel Extraction	
le Help		
Input/Output Parameters		
Coordinates:	Name Latitude Longitude DateTime (UTC) ID00000 41.8867 12.2149 2018-01-29T00:00:00 ID00000 41.8878 12.2126 2018-01-29T00:00:00 ID00000 41.8890 12.2170 2018-01-29T00:00:00	
Allowed time difference:	🖌 Use time difference constraint	
	3 + Day(s)	-
Export:	🕑 Bands 🔄 Tie-point grids 🔛 Masks	
Window size:	1 × 1 × 1	
Pixel value aggregation method:	7	
Expression:	Use expression Edit Expression.	
	Note: The expression might not be applicable to all products.	
	\bigcirc the economic of the \bigcirc \bigcirc the expression result	
Sub-scenes:	Enable export Border size:	
Google Earth export:	Export output coordinates to Google Earth (KMZ)	
Match with original input:	iclude 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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Lecture by Dr. Weiss - LAI/fCover/fAPAR/Chlorophyll retrieval concepts and methods - <u>9th Advanced Training</u> <u>Course on Land Remote Sensing</u>