

TRAINING KIT

SNOW COVER MAPPING WITH SENTINEL-2 FEBRUARY-MARCH 2019, ŠUMAVA











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 preinstalled on virtual machines, to handle and process data derived from the Copernicus Sentinel satellites constellation.

2 Snow mapping – background



Snow cover is an important driver of many climatic, hydrological and ecological processes and is a required input to many models aiming to study and predict them. Snow cover area (SCA) is also one of the essential climate variables (ECVs) specified by the Global Climate Observing System (GCOS) to be observed by remote sensing in support of the United Nations Framework Convention on Climate Change (UNFCCC) and the Intergovernmental Panel on Climate Change (IPCC).

There are multiple methodologies designed to observe snow cover using optical and SAR satellites. In this exercise you will learn how to process low-cloud optical Sentinel-2 data using the SNAP toolbox to create snow cover maps based on the Normalized Difference Snow Index (NDSI). The methodology has been adapted and simplified from Gascoin et al. (2019) - *Theia Snow collection: high-resolution operational snow cover maps from Sentinel-2 and Landsat-8 data. Earth System Science Data* 11 (2).

3 Training

Approximate duration of this training session is one hour.

3.1 Data used

- Four low/no-cloud Sentinel-2A Level 2A products (Tile ID: *T33UUQ*) acquired during February and March 2019 [downloadable @ <u>https://scihub.copernicus.eu/</u>]
 - S2B_MSIL2A_20190218T101059_N0211_R022_T33UUQ_20190218T161620.zip
 - S2A_MSIL2A_20190223T101021_N0211_R022_T33UUQ_20190223T123814.zip
 - S2B_MSIL2A_20190228T101029_N0211_R022_T33UUQ_20190228T143058.zip
 - S2B_MSIL2A_20190320T101029_N0211_R022_T33UUQ_20190320T195148.zip

3.2 Software in RUS environment

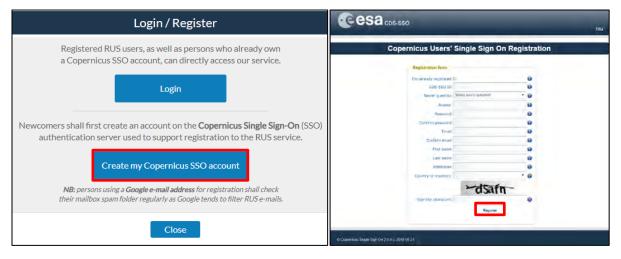
Internet browser, SNAP + Sentinel-2 Toolbox, Aria2

4 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 *	
	Senth
	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
	IGAR55 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 D	Do you want t	o subscribe for a new RUS account?	1	
	Your ESA-SSO subscription	data:		
+ Your RUS service	Login		_	A .
Iniguestion gathers pages related to w	FirstName			
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and the second s	Email		Est.For	
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· Your training silous you to mass	Country			
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	RUS service?	colleagues		
	Select one or more items	newsletter conference		
		social media	EDATA -	
		other		
	Institution type	Select one item	≺ nda	
	Phone number Italy (IT):	+39	arkana,	
	Title	Select one item	~	

5 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**.

CORRESPONDENCE Common Content	U C · LA	
The RUS Service The RUS Offer The RUS Library The RUS C Your RUS service	Community	You are here: Home > Your RUS serv
 This section gathers pages related to your RUS services: Your profile: displays your personal information linked to your ESA SSO Your dashboard: illows you to access your private dashboard, Your training: allows you to register to a training session you have been in the session you have been in the		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 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.

itep 1/3 Your experience	
Please help us learn more about your background by answ	vering a few questions. Th
information will be stored in your User Profile.	
How many years of experience in Remote Sensing do you have?	
Choose one Item	
Have you already downloaded Copernicus data via the Copernicus Op	en access hubs?
Yes	
0 No	
Have you already handled/processed Copernicus data?	
Yes.	
© No-	
Do you wish to practice a tutorial exercise shown in a RUS webinar? If (hold down CTRL key for multiple selections).	yes, please select your choice
HAZA01 - Flood Mapping in Malawi	
HAZA02 - Burned Area Mapping in Portugal HYDR01 - Water Bodies Mapping over Northern Poland	
LAND01 - Crop Mapping in Seville	
LAND04 - Land Monitoring in Cyprus OCEA01 - Ship Detection in Guif of Trieste	*
If you wish to request another tutorial exercise that doesn't appear in its name or code. Note that you can request multiple tutorial exercise:	

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:		
Thematicarea	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		
S1 - Polarisation	e	
S1 - Orbit direction	-	
Sentinel-2	x	
Sentinel-3	X	
Other	x	
I don't know	X	
Region of Interest: Min Latitude	20.0000	
Max Latitude	39.3303	
Min Longitude	40.5877 -4.6736	
Max Longitude	-2.7205	
Reference polygons	-2.7205	
and the second second		
Data acquisition date(s):		
None Additional data specifications		
Auditional 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
ur dashboard								
		-					_	
Request a new Us	er Servio	ce						Chat with Support Desk
Project Name	ID	Date of submission	Status		Actions		Virtual	Environment
10.4	1.55			Follow my project	Get support	Close my service	Access my Virtual Machine(s)	Access my CPU monitoring dashboard
aining1	231	2017-08-31	Open	Cancel averagest	Get a webinar kit	Rate my service	Freeze my Virtual Machine(s)	Report a technical
Project Name	1D 231		Status		Get support		Access my Virtual Machine(s) Freeze my Virtual	Access my Cf monitoring d Report a tech

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.

Applications				-		
alla System			BIRAT Schuseblar	() 385	R	SNAP
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		opernicus				

6 Step by step

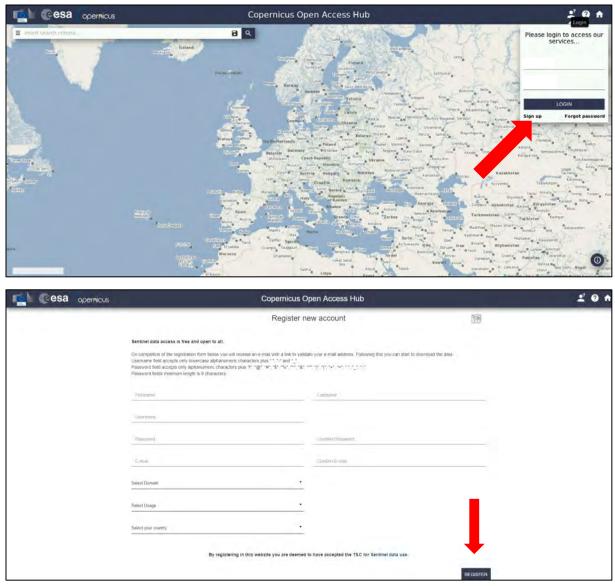
6.1 Data download – ESA SciHUB

In this step, we will download a Sentinel-2 scene from the Copernicus Open Access Hub using the online interface (Applications \rightarrow Network \rightarrow Firefox 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".

In the Full text search window type: *filename:*T33UUQ**

Open search menu by clicking to the left part of the search bar and specify following parameters:

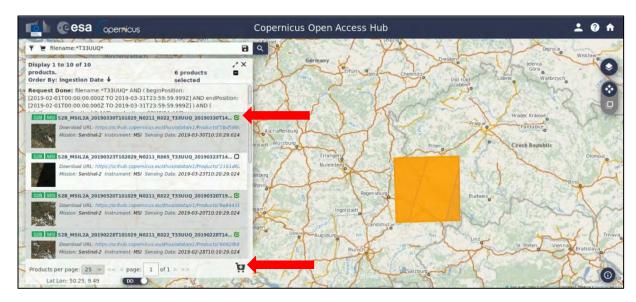
Sensing period: From 2019/02/01 to 2019/03/31 Check Mission: Sentinel-2 Product Type: S2MSIL2A Cloud Cover %: [0 TO 15]

	Copernicus Open Access Hub	± (
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Clock on the looking glass symbol to start the search. In our case the search returns 10 results, but not all are of interest to us.

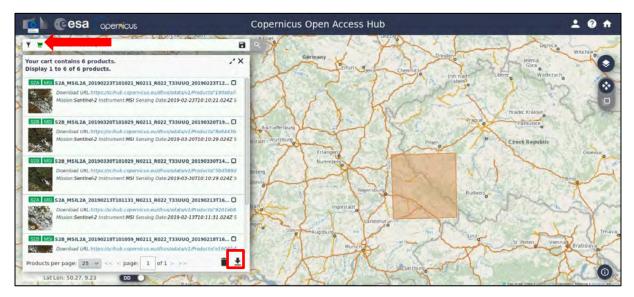
TIP: It may sometimes happen that the data used to create this exercise are temporarily unavailable. In such case, you can use other date period for the same location.



Go through the list and select these **4 full** scenes by checking the box as shown above:

- S2B_MSIL2A_20190218T101059_N0211_R022_T33UUQ_20190218T161620.zip
- S2A_MSIL2A_20190223T101021_N0211_R022_T33UUQ_20190223T123814.zip
- S2B_MSIL2A_20190228T101029_N0211_R022_T33UUQ_20190228T143058.zip
- S2B_MSIL2A_20190320T101029_N0211_R022_T33UUQ_20190320T195148.zip

Once they are all selected click on 🛱 to add the products to the cart. Then go to the cart by clicking on the green cart symbol left of the full text search. Finally, let's download the cart in the form of .meta file. The file contains links to each of the files, we will need the file and download client to download the actual data.



The *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 move the *products.meta4* file to the folder where we wish our data to be downloaded to - */shared/Training/CRYO03_SnowCover_Sumava/Original/*

Then, 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:

-					Terminal - rus@front-usr-260:	+ = = ×
File	Edit	View	Terminal	Tabs	Help	
Spec Usac See	cify ge: a 'ari	at le ria2c a2c		URL		

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 following commands in the command line (replace <username> and <password> with your login credentials for Copernicus Open Access Hub):

```
cd /shared/Training/CRY003_SnowCover_Sumava/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 single line). All four products will be downloaded to the *Original* folder two products in parallel automatically (Note that the constraint of maximum two parallel downloads at a time is imposed by the Copernicus Access Hub, if you increase the number the download will fail). This might take some time.

6.2 Data exploration

Open the SNAP Toolbox by clicking the SNAP Desktop icon on the desktop. When the SNAP window opens, go to File \rightarrow Sessions \rightarrow Open session and navigate to:

/shared/Training/CRYO03_SnowCover_Sumava/ORIGINAL_DATA.snap

All four downloaded products should be loaded when the session opens. We can first investigate the structure of the Sentinel-2 Level 2A products. Click on the dot next to the first product name to expand the structure. The L2A products have been atmospherically and radiometrically corrected and contain (among others):

- 13 surface (bottom-of-atmosphere) reflectance bands (see 1 NOTE 3)
- cloud and snow probability bands (we will use the snow probability band to compare with our results)
- scene classification (water, vegetation, cloud, snow/ice, shadow, unclassified)
- masks derived from cloud and snow probability bands and scene classification

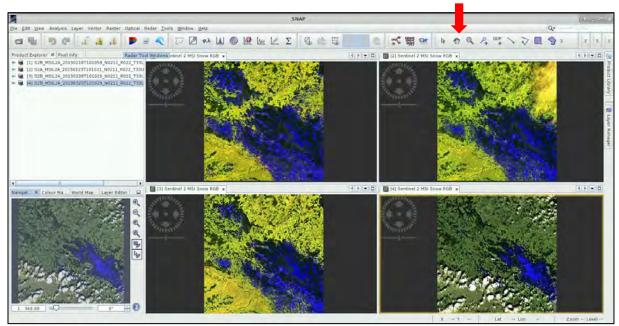


Now, we can visualize the products. We could use the true (natural) colours but for distinguishing snow it is better to use the Short-Wave Infrared (SWIR) and Red bands as these provide the best separability between cloud and snow (for more explanation, check the graph in \square NOTE 2). Right-click the first loaded product from 18 February and click **Open RGB image window**, a new window will open.

Set:	Red:	B12	Green:	B11	Blue:	B5
Red: Green: Blue:	Select RGB-Image el 2 MSI Atmospheric pe B12 B11 B5 e RGB channels as virt	enetratio	Save	valid	rendition wh smoke and green during white, grey, complete ab snow causes water is blac fires and volo	band combination provides a "natural-like" nile also penetrating atmospheric particles, haze. Vegetation appears dark and light g the growing season, urban features are cyan or purple, sands, soils. The almost psorption of Mid-IR bands in water, ice and s snow and ice to appear as dark blue and ck or dark blue. Hot surfaces such as forest cano calderas saturate the Mid-IR bands and ades of red or yellow.

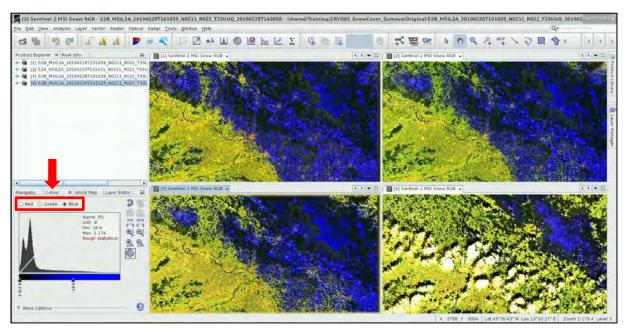
When you have selected the correct bands, click on the **Save** icon and save the new profile in the default folder as **Sentinel_2_MSI_Snow.rgb** in the default folder. Now open the RGB view for the other three products as well, using the saved profile (in drop down menu).

When you have all 4 Views opened, go to **Navigation pane** in the lower left and make sure the cursor and the views **are** linked. Then, go to **Window -> Tile Evenly**. Go back to **Navigation tab** and click **Zoom All** to centre the Views. All snow-covered areas appear in bright blue colour, in the four views ordered by date of acquisition you can see the decreasing extent of snow cover between 18 February (upper left) and 20 March 2019 (lower right).



The bright values of the cloud cover in the last image affect the visualization so it appears different than the other images (value distribution in the image affects the histogram stretch) but we can edit it to be visually comparable. Click on the "[4] Sentinel 2 MSI Snow RGB" window and go to **Colour Manipulation** tab, there you can edit the histogram stretch for each colour by moving the sliders. Move

the red slider to 0.22, then change to green and move the green slider to 0.29, finally change to the blue histogram and move the blue slider to 0.63. Click on the **Pan** mode and zoom in to explore closer.

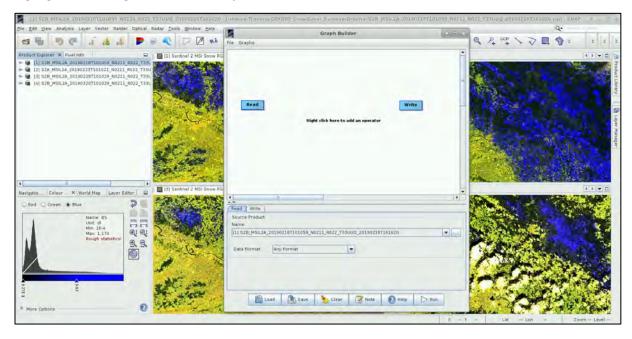


6.3 STEP 1 – Pre-processing

Processing the data one by one would be very time consuming and inconvenient. However, we can use the **Batch Processing** tool available in SNAP to process all images at the same time.

To use the tool, 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.

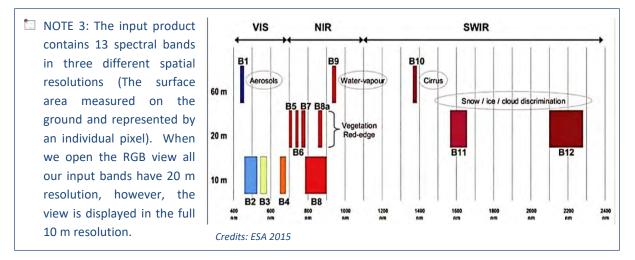
So, let's build our graph. First, in the **Product Explorer** select the first loaded product (so it is highlighted), then go to **Tools** \rightarrow **GraphBuilder**.



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 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.

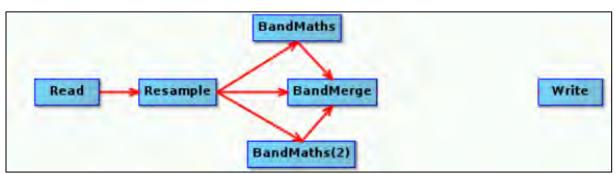
To add the appropriate operator, right-click the white space between existing operators and go to Add \rightarrow Raster \rightarrow Geometric \rightarrow Resample



A new operator rectangle appears in our graph and 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.

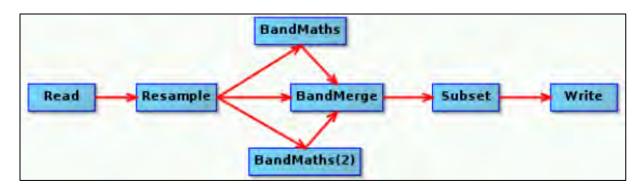


Now, we will add two BandMath operators from Add \rightarrow Raster \rightarrow BandMaths and then connect it to the **Resample** operator then repeat the operation to add BandMath(2).



Next, we add **BandMerge** operator from Add \rightarrow Raster \rightarrow BandMerge. Connect the Resample operator and both the **BandMaths** operators, to the **BandMerge** operator as shown below.

Next step will be to subset the images to the area of interest. Go to Add \rightarrow Raster \rightarrow Geometric \rightarrow Subset and connect the Subset operator with the BandMerge operator. Finally, connect the BandMerge operator to the Write operator.



At the moment, do not change anything in the parameter tabs, save the graph as *Graph_Preprocess.xml* under */shared/Training/CRYO03_SnowCover_Sumava/Processing* path by clicking Save at the bottom of the window and then close the **GraphBuilder** window.

In the **Product Explorer**, make sure the product [1] (18 February 2019) is selected (highlighted). Now we can open the Batch Processing tool at **Tools** \rightarrow **Batch Processing**.

We will add all four opened products to be processed. In the **I/O Parameters** tab, click **Add Opened** on the upper right (second from top) and click **Refresh**. Deselect the **Keep source product name**. Then click **Load Graph** at the bottom of the window, navigate to our saved graph and open it. We see that new tabs have appeared at the top of window corresponding to our operators.

	Write	ge Subset	s BandMe	aths BandMath	mple BandMa	Parameters Resar
	4	Orbit	Track	Acquisition	Туре	File Name
		99999	99999	18Feb2019	S2_MSI_Lev	MSIL2A_20190218
Add opene		99999	99999	23Feb2019		MSIL2A_20190223T.
	-	99999	99999	28Feb2019	S2_MSI_Lev	MSIL2A_20190228
	3	99999	99999	20Mar2019	S2_MSI_Lev	MSIL2A_20190320
Refresh						
Refresh						
Refresh	8					get Folder
Refresh	8					get Folder e as:
Refresh	8					
Refresh	8				4.51	e as:

Now, let's set the parameters. In **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).

V- V- V- V- V- V	Kerne Kerne Kerne	-
I/O Parameters Resample BandMaths	BandMaths BandMerge Subset Write	_
Define size of resampled product	(R2)	
By reference band from source product:	Resulting target width: 10980	-
	Resulting target height: 10980	
	Target midth 10.34	0
O By target width and height.	Target height 10.54	0
	width / height ratio. 1.00000	
G By pixel resolution (in m):	Resulting target midth 1098	
	Resulting target height: 1098	
Upsampling method	Nearest	T
Downsampling method	First	T
Flag downsampling method	First	1
4 I II		

Next in the first BandMath tab, we set the expression for the calculation of a first preliminary cloud mask. The cloud mask will be based on the cloud confidence band (see NOTE 4). In the **BandMaths** tab set:

Target band: "Cloud_Class" No-Data Value: "NaN" Then go to Edit Expression ... and type:

```
if quality_cloud_confidence > 90 then 2 else (if quality_cloud_confidence > 50 AND
B8 > 0.3 then 1 else 0)
```

NOTE 4: The cloud masks derived by the L2A processing are very conservative because It is computed at coarser resolution and was developed to remove surface reflectance variations due to could contamination. However, some clouds are semi-transparent in the SWIR band allowing snow detection. We will therefore use only very high confidence clouds > 90%, lower confidence clouds (50 - 90%) will be filtered by thresholding the NIR band. All other pixels will be considered cloud free.

Batch Processing : Graph_Pre-process.xml 👘 🙄 🕽		Arithm	etic Expression Edi	tor	+ = ×
File Graphs	Data sources:				Expression:
BandMaths BandMerge Subset Write	B1	*	0 + 0		if quality_cloud_confidence
I/O Parameters Resample BandMaths	82		0 - 0	-	> 90 then 2 else (if quality cloud confidence >
	B3			_	50 AND B8 > 0.3 then 1 else
Target Band: Cloud_Class	B4		6 + 6		0)
Target Band Type: float32	85		0/0		
Band Unit:	B6		(@)	_	
No-Data Value: NaN	87			-	
Expression:	B8	-	Constants	-	
	BBA	-	Operators	-	
	Show bands		Functions	-	
	Show masks		President sector	1001	1
	Show tie-point grids				
Edit Expression	Show single flags				errors.
Load Graph Run <u>C</u> lose <u>H</u> elp					OK <u>Cancel</u> <u>H</u> elp

Click **OK** to close the "Arithmetic Expression Editor" window.

Next in the second BandMath tab, we set the expression for the calculation of the Normalized Difference Snow Index (NDSI, see NOTE 5). In the **BandMaths** tab set:

Target band: "NDSI"			
No-Data Value: "NaN"			
Then go to Edit Expression and type:	(B3 - B11)/(B3 + B11)		
Batch Processing - Graph_Pre-process.xml + 🗉	Arithmetic	c Expression Editor	+ = ×
File Graphs	Data sources:		Expression:
BandMaths BandMerge Subset Write	81	@ + @	(B3 - B11)/(B3 + B11)
I/O Parameters Resample BandMaths	B2 B3	6 - 6	
Target Band: NDSI	B4	6 * 6	
Target Band Type: float32	BS	0/0	
Band Unit:	B6 B7	(@)	
No-Data Value: NaN	B8 *	Constants	-
Expression: (B3 - B11)/(B3 + B11)	Show bands	Operators	-
	Show masks	Functions	-
Edit Expression	Show te-point gride		
Load Graph Run <u>C</u> lose <u>H</u> el	•		QK <u>Cancel</u> <u>H</u> elp

NOTE 5: When identifying the snow presence, green (~ 0.5 − 0.6 nm) and SWIR (~ 1.6mm) wavelengths are commonly used. Snow generally appears very bright at optical wavelengths as do clouds, however unlike clouds (not all) it strongly absorbs radiation SWIR wavelengths. To identify snow cover and differentiate it from most clouds we can therefore use the Normalized Difference Snow Ratio (NDSI):

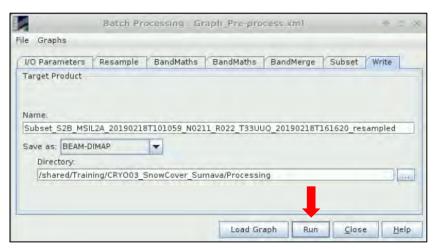
$NDSI = \frac{Green - SWIR}{Green + SWIR}$

In the **BandMerge** tab, keep the default parameters. In the **Subset** tab we select bands: **B3**, **B4**, **B11**, **B12**, **Cloud_Class** and **NDSI** (to select multiple, hold Ctrl). Then click to select the **Geographic Coordinates** option and paste the area of interest definition in WKT (well know text) format to the text window below the map. Click **Update** and then click the **Zoom-in** icon see your subset on the map.

POLYGON	((12.750	5 49.305	7, 13.7601	49.3057,	13.76011	48.7043,	12.7505	48.7043,
12.7505	49.3057,	12.7505	49.3057))					

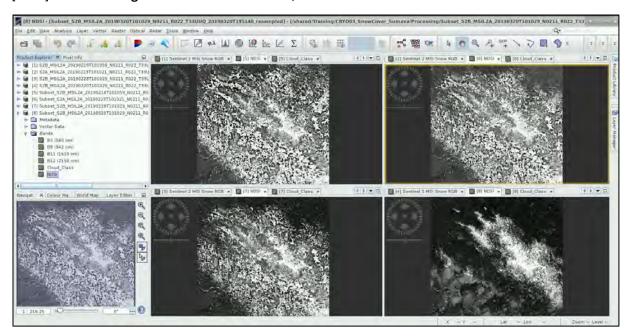
I/O Parameters	Resample	BandMaths	BandMaths	BandMerge	Subset	Write
ource Bands:	view_zenit view_azim					
	view_azini					
	view_azim					
	view_zenit					
	view_azim					
	Cloud_Cla	SS				
Copy Metadata	NDSI					
	No. of	aphic Coordina	ates			
☑ Copy Metadata 〕 Pixel Coordinat	No. of	aphic Coordina	ates	R.		6.0
	No. of	aphic Coordina	ates	1		6. 0
	No. of	aphic Coordina	ates			e. c
	No. of	aphic Coordina	ates			8.0
	No. of		ates			6.0
	No. of	aphic Coordina	ates			6

In the **Write** tab, check that the name contains **20190218** but do not change anything. Set the output directory: */shared/Training/CRYO03_SnowCover_Sumava/Processing*



And let's click **Run.** This might take approximately 4-5 minutes depending on your machine.

Now, you should have four new products in the **Product Explorer** window. Let's have a look at them. For that expand product [5] and in **Bands** folder, double click the NDSI band. When it opens move it by dragging the top of the tab to the corresponding RGB image window. Now do the same for products [6-8]. Then in **Navigation** tab at the lower left, click Zoom All



You can also open the cloud mask in the same manner for each processed product.

6.4 STEP 2 – snow detection

The approach used in this exercise has been adapted and simplified from the method used for the Theia Snow collection (Gascoin et al. 2019). It is based on two pass detection using the NDSI:

1) First pass – We use conservative threshold applied to NDSI. Some turbid waters can have similar high NDSI value, therefore we will use an additional criterion on the red reflectance to avoid false snow detection in these areas. Cloud-free pixel is then classified as snow when:

$$(NDSI < n_1) AND (\rho_{red} < r_1)$$

Where n_1 and r_2 are the selected thresholds, during the first pass they are set conservatively high to avoid false detections. If the above expression is not fulfilled, then the pixel is marked as "no snow"

Minimum value of NDSI for the pass 1 snow test - n_1	0.4
Minimum value of the red band (B4) for the pass 1 snow test - r_1	0.2

2) Second pass – Now we can use the results from the first pass detection and a digital elevation model to estimate the elevation of the snow line (minimum snow elevation *z*_s). Above the snow line we can then apply less conservative thresholds for the above criterion. The approach assumes there are no large altitudinal variations in the snow line position within the study area. We will also use: Forest Type (FTY) 2015 (High Resolution Layer) provided by European Environment Agency (available from Copernicus Land Service) to remove dense forest areas that may be misclassified as no-snow. (See ¹ NOTE 5 p. 24)

Minimum value of NDSI for the pass 2 snow test – n_2	0.15
Minimum value of the red band (B4) for the pass 2 snow test – r_2	0.04
Minimum detected snow cover percentage in elevation band to identify Z _s	35 %
Size of the elevation band in the DEM used to define Z _s	50

6.4.1 Snow detection – first pass

In this step we will apply the conservative thresholds as well as load supporting data (DEM and Forest Type map) for the second pass detection. As in pre-processing we will use the graph builder to enable batch processing of our four products.

So, let's build our graph. First, in the **Product Explorer**, right-click on product [1] and go to Close Product, then click No (we do not want to save changes). Do the same for the other original data [2 - 4]. So only the pre-processed products remain open.

Then we select (highlight) the first product [5] (Subset 18 February 2019) and go to **Tools** \rightarrow **GraphBuilder**. Add following operators and connect them as shown on the image:

- Add \rightarrow Raster \rightarrow BandMaths
- Add \rightarrow Raster \rightarrow BandMerge
- Add \rightarrow Input-Output \rightarrow Read
- Add → Raster → DEM Tools → AddElevation

BandMaths			
Read	> BandMerge	> AddElevation	> Write
Read(2)			

Important!!! Now go to the Read(2) tab below the graph and click on the _____, then navigate to the /shared/Training/CRY003_SnowCover_Sumava/AuxData/ and select Forest_Type_CLS.tif

TIP: We have to do this due a bug in the SNAP Batch processing which at the time of writing this tutorial it has not been fixed. The bug makes it impossible to see the second Read tab in the Batch processing window. We can however bypass this problem by setting this parameter in the graph and then saving it with it (only possible if the input of the second Read operator does not change).

When done, click **Save** at the bottom of the window and save the graph as **Graph_pass1.xml** in: /shared/Training/CRYO03_SnowCover_Sumava/Processing/

Now, we can close the **GraphBuilder** window and open the **Batch Processing** tool (**Tools -> Batch Processing**).

We will add all opened products. In the **I/O Parameters** tab, click **Add Opened** on the upper right (second from top) and click **Refresh**. Deselect the **Keep source product name**. Then click **Load Graph** at the bottom of the window, navigate to our saved graph and open it.

1	1 1	-		1erge AddElev	Maths BandM	as relatives a Leens
	4	Orbit	Track	Acquisition	Туре	File Name
		99999	99999	18Feb2019		ubset_S2B_MSIL2A_20
Add oper		99999	99999	23Feb2019		ubset_S2A_MSIL2A_20
	-	99999	99999	28Feb2019	and the second s	ubset_S2B_MSIL2A_20
	否	99999	99999	20Mar2019	S2_MSI_Lev	ubset_S2B_MSIL2A_20
Refresh						
	**					Farget Folder
						Farget Folder
					-	
			112			Save as:

Now, let's set the parameters. In the BandMaths tab, set:

Target band: "Snow_pass1"

No-Data Value: "NaN"

```
Expression: if (Cloud_Class < 2 AND NDSI > 0.4 AND B4 > 0.2) then 1 else 0
```

Batch Pr	ocessing : Graph_passl.xml + C ×		Arithmetic Expressio	on Ed	itor	- E X
File Graphs		Data sources:			Expression:	
BandMerge A	ddElevation Write	B3	@ + @		if (Cloud_Class < 2	
terror and the state of the state	ameters BandMaths	B4 B11	@ - @		> 0.4 AND B4 > 0.2) else 0	then I
Target Band:	Snow_pass1	812	6 + 6			
Target Band Type:	float32	Cloud_Class	0/0			
Band Unit		NDSI	(@)			
No-Data Value:	NaN		Constants	-		
Expression;	if (Cloud_Class < 2 AND NDSI > 0.4 AND B4	Show bands	Operators	-		
		Show masks	Functions	-		
	Edit Expression.	Show the point grids				
	Load Graph Run <u>C</u> lose <u>H</u> elp				OK Cancel	Help

Keep the default settings in the **BandMerge** tab and in the **AddElevation** tab select:

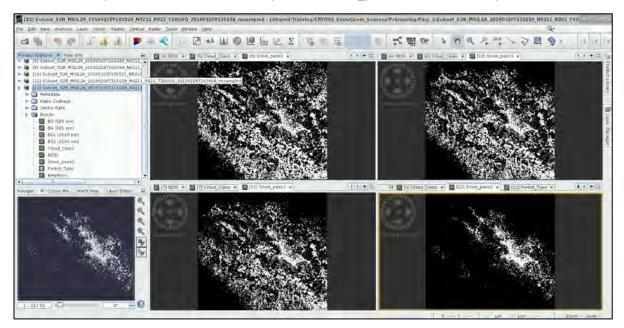
Digital Elevation Model: *SRTM 1Sec HGT (Auto Download)* **Elevation Band Name**: *"elevation"*

Bat	tch Processing : Graph_pass1.xml	1 E X
ile Graphs		
I/O Parameters Band	dMaths BandMerge AddElevation Write	
Digital Elevation Model:	SRTM 1Sec HGT (Auto Download)	-
DEM Resampling Method:	BICUBIC_INTERPOLATION	-
Elevation Band Name:	elevation	1
	D	

In the **Write** tab, you can notice that the **Name** of the output is identical to the name of input, unfortunately this is a problem of the software and in batch processing we can not change it. For this reason, we will use a different directory to save our outputs. Click on the ..., then navigate to: /shared/Training/CRYO03_SnowCover_Sumava/Processing/Pass_1/

Batch Pro	cessing : Graph_pass1.xmi	×
e Graphs		
I/O Parameters BandMaths	BandMerge AddElevation Write	
arget Product ame:	.01059 N0211 R022 T33UUQ 20190218T16	1520 seconded
ubset_325_M3122A_2019021013	-	1020 resampled
ave as: BEAM-DIMAP		
Directory: /shared/Training/CRY003_Sno	owCover_Sumava/Processing/Pass_1	

When the new products are created, let's open the "Snow_pass1" band for each product.



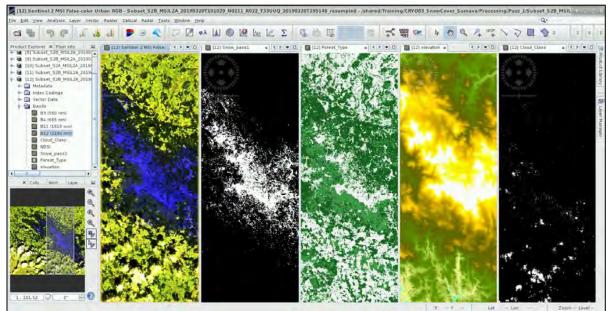
6.4.2 Snow detection – second pass

For the second pass it is not possible to use batch processing as the snow line must be estimated for each image separately. The graphical interface of SNAP is not ideal for this and script approach would be more convenient, but for the purposes of presenting the methodology we will use the graphical interface.

First let's close all opened views. Go to **Window** \rightarrow **Tile Single**, then right-click on the tab of any view and select **Close All**. Then in **Product Explorer**, right-click on product [12] and go to Open RGB Image Window, choose the default profile (Red: B12, Green: B11, Blue: B4)

In the **Colour Manipulation** tab, move the red slider to 0.22, then change to green and move the green slider to 0.29, finally change to the blue histogram and move the blue slider to 0.63.

Then open views for bands: *Snow_pass1, Forest_Type, Elevation, Cloud_Class* (in Colour Manipulation tab move the black slider to 0). Then go to Window \rightarrow Tile Horizontally.



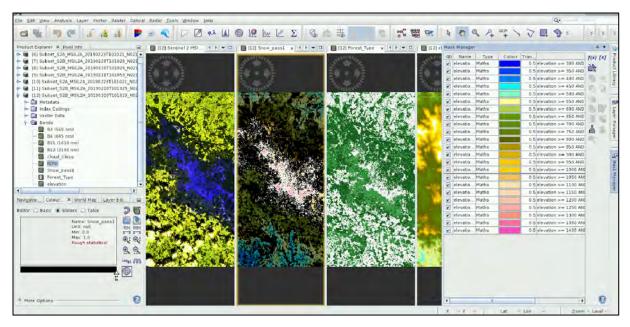
Next, we will estimate the snow line elevation. We will do this by "dividing" the image into elevation bands of 50 m from 350 m to 1450 m. For each elevation band we calculate the percentage of snow coverage for non-forest surfaces (See 🗀 NOTE 5).

NOTE 5: In dense forest (mainly coniferous), new snow covers the branches and can be usually detected. However, as the snow gets older/heavier, it slides off the branches to the forest floor and is effectively hidden from view. Such areas are then incorrectly classified as no-snow. This can skew the snow line elevation estimate as well as cause errors in estimation of total snow cover.

First, we will load our elevation classes. Go to **View** \rightarrow **Tool Windows** \rightarrow **Mask Manager**. A tab will open on the right side of the SNAP window. At the moment it should be empty, here you can either create masks from geometry or using pixel value thresholds and expressions or you can load mask prepared previously. We will use the last option.

Click inside the [12] Snow_pass1 view and then in the **Mask Manager** click on and open /shared/Training/CRYO03_SnowCover_Sumava/AuxData/masks_elevation_noforest.xml

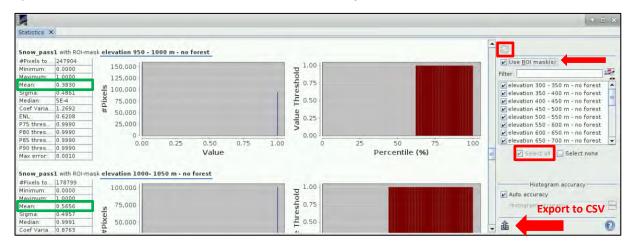
The new masks will appear, select all to be visible over the [12] Snow_pass1 view.



These masks are created as an expression: *elevation* >= *i* AND *elevation* < *j* AND *Forest_Type* == 0 where **i** and **j** are the bounds of the elevation band.

	0	All non-forest areas
	1	Broadleaved forest
	2	Coniferous forest
	254	Unclassifiable (no satellite image available, or clouds, shadows, or snow)
	255	Outside area

Now, click inside the [12] Snow_pass1 view again and then click on Statistics Σ . A new window will open. Select Use ROI mask(s), then click Select All and Refresh Ξ .



The calculation will take about a minute. Once it is finished you can see statistics of Snow_pass1 for each elevation band. Since our Snow_pass1 band is binary – snow (1)/no-snow (0) - we can use the Mean*100 as equivalent for percentage cover.

By scrolling down, you can find which elevation band has Mean > 0.35. In the case of our selected image the elevation band with snow coverage > 35% is 950 m - 1000 m (statistics can also be exported to CSV format). We can now close the Statistics window.

Now, let's run the second pass, here are the parameters for each product:

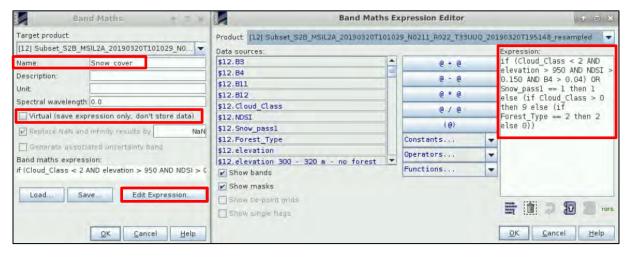
	Image date	n ₂	r 2	Zs
	18 Feb. 2019			400 m
	23 Feb. 2019	0.15	0.04	400 m
	28 Feb. 2019		0.04	600 m
-	20 Mar. 2019			950 m

In Product Explorer, right-click on the product [12] and go to Band Maths...

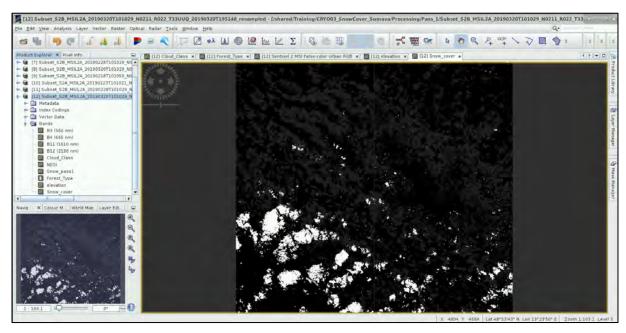
```
Target band: "Snow_cover"
Expression:
```

```
if (Cloud_Class < 2 AND elevation > 950 AND NDSI > 0.150 AND B4 > 0.04)
OR Snow_pass1 == 1 then 1 else (if Cloud_Class > 0 then 9 else (if
Forest_Type == 2 then 2 else 0))
```

Deselect Virtual (save expression only, don't store data) - we want the band to be stored!



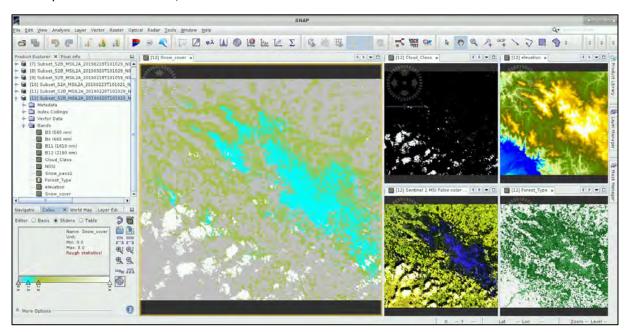
Click OK. A new band will be created and opened automatically.



Let's enhance the visualization a bit by loading prepared colour palette. In Colour Manipulation tab, click on and open:

/shared/Training/CRYO03_SnowCover_Sumava/AuxData/Snow_cover_map_palette.cpd

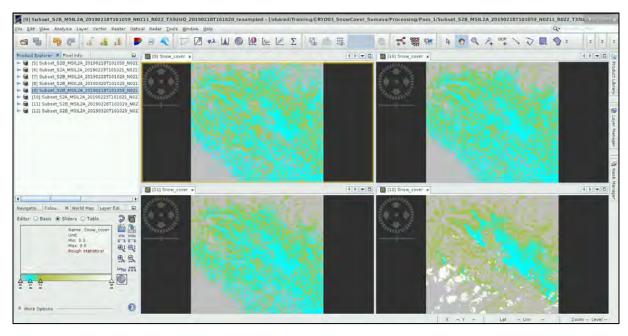
Then click **No** in the dialog that appears – We do NOT want to automatically distribute the points of colour palette between min/max.



The colours can then be interpreted as follows:

0	No-snow
1	Snow
2	Coniferous forest (protentional snow cover)
9	Cloud

Now repeat the process for the products [9-11].



6.5 Snow cover area

Now we can export our results to GeoTIFF for further processing or we can for example estimate the area of open snow cover (not dense forest).

To do this let's click inside the view of one of our results ([12] for example) and go to **Mask Manager** tab. Click on f(x), an expression window will open (same as for Band Math), type $Snow_cover = 1$

A new mask will appear at the bottom of the list. We can change the name to "Snow".

2	Snow	Maths	0.5 Snow_cover == 1
	elevatio	Maths	0.5 elevation >= 1400 AN
	elevatio	Maths	0.5 elevation >= 1350 AN
	elevatio	Maths	0.5 elevation >= 1300 AN
	crevatio	Hours	0.5 0000000 22 2200 814

Then in the main SNAP, window go to **Raster** \rightarrow **Masks** \rightarrow **Mask Area** ... and select the "Snow" mask.

C	ompute Mask	Area	* 🗆 🗙
Select Mask:	Snow		-
	asters of differentiate of differentiate of differentiate of the second		Help

Click OK.

Number of Mask pixels:	5842700
Mask area:	583.493 km^2
Mean pixel area:	0.000 km^2
Minimum pixel area:	0.000 km^2
Maximum pixel area:	0.000 km^2
Mean earth radius:	6378.137 km

THANK YOU FOR FOLLOWING THE EXERCISE!

7 Extra steps

7.1 Export as GeoTIFF

To convert the results into GeoTIFF format, select (highlight) the product in **Product Explorer** and go to **File** \rightarrow **Export** \rightarrow **GeoTIFF**. Navigate to your desired folder and click **Save**.

If you do not wish to save the whole product with all bands, you can use the **Subset** button to perform spatial and/or band subset.

	SNAP - Export Product	(• = ×
Save In:	Processing 💌 🖪 🖻	
Did 🗖		<u>S</u> ubset
Pass_1		
Subset_S2	2A_MSIL2A_20190223T101021_N0211_R022_T33UUQ_20190223T123814_resampled	
Subset_S2	2B_MSIL2A_20190218T101059_N0211_R022_T33UUQ_20190218T161620_resampled	
Subset_S2	2B_MSIL2A_20190228T101029_N0211_R022_T33UUQ_20190228T143058_resampled	
Subset_S2	2B_MSIL2A_20190320T101029_N0211_R022_T33UUQ_20190320T195148_resampled	
100 C		
4	<u> </u>	
File <u>N</u> ame:	Subset_S2_MSIL2A_20190228_Calculated.tif	
Files of Type:	GeoTIFF product (*.tif,*.tiff)	-
	Export Product	Cancel

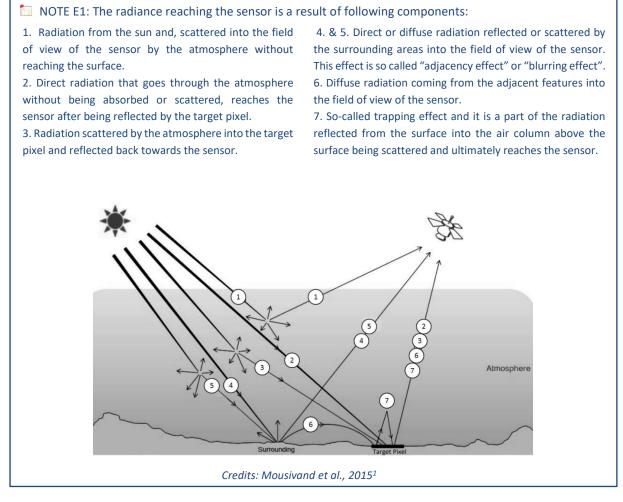
Specif	y Product Subset	+ = ×		Specify P	roduct Subset	t	+ = ×
Spatial Subset Band Subs	et Metadata Subset		Spatial Subset	Band Subset	Metadata Subs	set	
	Pixel Coordinates G Scene start X: Scene start Y: Scene start Y: Scene end X: Scene end Y: Scene stap X: Scene step X: Scene step Y: Subset scene width: Subset scene height Source scene height Source scene height Use Preview Use Preview	eo Coordinates	B3 B4 B11 B12 Cloud_Class NDS1 Snow_pass1 Forest_Type elevation V Snow_cover	SRTM 15ec HGT	/ 84 / 811		
	Estimated.	raw storage size: 356.9M Cancel Help			Est	imated, raw stor	

7.2 Atmospheric correction

Solar radiation reflected by the Earth's surface to satellite sensors is affected by its interaction with the atmosphere. The objective of applying an atmospheric correction is to determine true surface (Bottom-Of-Atmosphere, BOA) reflectance values from the Top-Of-Atmosphere (TOA) reflectance values, by removing atmospheric effects. (See INOTE E1) Atmospheric correction is especially important in cases where multi-temporal images are compared and analysed as it is in our case. (Mousivand et al. 2015)

Sen2Cor is a processor for Sentinel-2 Level 2A product generation and formatting; it performs the atmospheric, terrain and cirrus correction of Top-Of-Atmosphere Level 1C input data. Sen2Cor creates Bottom-Of-Atmosphere, optionally terrain and cirrus corrected reflectance images; additional, Aerosol

Optical Thickness, Water Vapour, Scene Classification Maps and Quality Indicators for cloud and snow probabilities.



In the **I/O Parameters**, make sure product [1] is selected. In the Processing Parameters tab, change the resolution to 10 m. Click **Run** ...

SEN2COR	↑ □ ×	SEN2COR + • ×
File Help		File Help
I/O Parameters Processing Parameters		//O Parameters Processing Parameters
Source Product		Display execution output
Source product: [1] S2A_MSIL1C_20170604T112121_N0205_R037_T29TNE_20170604T112		Scene only
		Resolution: 10
Run Clos	e <u>H</u> elp	<u>R</u> un <u>C</u> lose <u>H</u> elp

This is rather a time demanding process and requires approximately 30 minutes per image (with 8GB RAM).

The process creates two new Level 2-A products in the ".SAFE" format in the input data folder.

7.3 Downloading the outputs from VM

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.**



8 References

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