





TRAINING KIT – HYDR03

DROUGHT MONITORING WITH SENTINEL-2 Case study: Western Cape Province, 2015-2020









Research and User Support for Sentinel Core Products

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The following training material has been prepared by Serco Italia S.p.A. within the RUS Copernicus project.

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1 Introduction to RUS

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.



Theewaterskloof Dam outside Cape Town drying out. Source:https://memeburn.com/2018/02/theewaterskl oof-dam-cofferdam/

Surface water is crucial resource sustaining human lives. It provides water for domestic and commercial use, it is used in agriculture (irrigation) and electricity production. Even small water bodies play a key role as the offer habitats to wildlife, often being a refuge for species but also provide livestock with fresh water. Therefore, in regions prone to drought such as Western Cape Province in South Africa, identification and monitoring of surface water, is necessary to assure the continuity of water supply for citizens, local economy but also to maintain natural habitats. More frequent and

long-lasting droughts caused by global environmental changes are affecting many regions around the world. Warmer temperatures increase evaporation, lessening at the same time the water availability and causing soil and vegetation to dry out.

A three-year's drought threatened South Africa's Western Cape Province. From 2016 until 2018 this region suffered a drought crisis, causing water dams to shrink significantly. The Cape Town claimed this period to be the worst drought in 100 years. In February 2018, the Theewaterskloof dam, which is the biggest dam in the province and provides about 50% of Cape Town's water needs dropped to its 11% of capacity. The city water consumption has fallen from 317 million gallons per day in 2015 to about 137 million gallons per day. Fast detection of any changes in surface water extent and its availability is crucial and enables decision-makers to take proper actions, in this case responsible water management.

Satellite remote sensed data are widely used in detecting and monitoring waterbodies and with Sentinel-2 data, we will have a chance to detect waterbodies using different water indices and see changes in the water extent during the drought period.

2 Training

Approximate duration of this training session is **one and a half** hour.

The Training Code for this tutorial is HYDR03. If you wish to practice the exercise described below within the RUS Virtual Environment, register on the <u>RUS portal</u> and open a User Service request from Your RUS service \rightarrow Your dashboard.

2.1 Data used

- 16 low-cloud Sentinel-2A Level 1C images (Tile ID: T34HCH) acquired in wet and dry season from years 2016-2020 and one image from 2015 [downloadable at @<u>https://scihub.copernicus.eu/</u>using the .meta4 file provided in the Original folder of this exercise]
- Data and instructions how to perform the exercise stored locally

@/shared/Training/HYDR03_DroughtMonitoring_WesternCape/AuxData/

2.2 Software in RUS environment

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

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.



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	CDS-SSO ID Password Max Idle Time Max Session Time	half a day Until browser close	v	000000000000000000000000000000000000000
Users who already have a COPERNICUS SSO account can login here:		Login Re	set]

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

The RUS Service * The RUS C	Do you want t	to subscribe for a new RUS account?	-	
	Your ESA-SSO subscription	data:		
+ Your RUS service	Login			9
This section gathers pages relates [to m	FirstName			
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	Select one or more items	newsletter	arana - Palia	
		conference social media	ithmn - Fould	
		other		
	Institution type	Select one item	× da	
	Phone number Italy (IT);	+39	arkateuro-	
	Title	Select one item	~	

4 Request a RUS Copernicus Virtual Machine

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



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

CORRUS Research and User Support	an and the th	Hello, Miguel 🔹
The RUS Service The RUS Offer The RUS Library The I	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	Con	act Us Terms and conditions Glossary Actomyms 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 answering 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 Open access	hubs?
® Yes	
No	
Have you already handled/processed Copernicus data?	
Have you already handled/processed Copernicus data?	
Have you already handled/processed Copernicus data? Yes No	
Have you already handled/processed Copernicus data? Yes No Do you wish to practice a tutorial exercise shown in a RUS webinar? If yes, pleas (hold down CTRL key for multiple selections).	e select your choice
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Have you already handled/processed Copernicus data? Yes No No Do you wish to practice a tutorial exercise shown in a RUS webinar? If yes, pleas (hold down CTRL key for multiple selections). HAZA01 - Flood Mapping in Malawi HAZA02 - Burned Area Mapping in Portugal	e select your choice
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Have you already handled/processed Copernicus data? Yes No Do you wish to practice a tutorial exercise shown in a RUS webinar? If yes, pleas (hold down CTRL key for multiple selections). 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	e select your choice

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

This is a collection of information selected	d across the USR forms.	
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	-	
S1 - Polarisation	-	
S1 - Orbit direction	-	
Sentinel 2	~	
Other	Ĉ.	
I dan't know	× ·	
Region of Interest:	0	
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		
The state of the s	and distance of PALIC Constant	

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	Jser Servi	ce					5	Chat with Support Desk
Project Name	ID	Date of submission	Status		Actions		Virtual	Environment
				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

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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Staree Teas				
C 💮 RUS				
opernicus				

5 Step by step

5.1 Data download – ESA SciHUB

In this step, we will download Sentinel-1 scenes 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.

	Copernicus	s Open Access Hub	<u>*</u> @ A
Interest source estimations	Rand Rand Rand Rand Rand Rand Rand Rand	Image: Description Description Image:	Please login to access our services Please login to ac
	Copernic	us Open Access Hub	201
	Regist Sentinel data access is free and open to all. On completion of the registration form below you will receive an e-mail with a limit Usemane field accepts only avortance alphaniumenc, characters pais ***** and Password field accepts only apontanumenc, characters pais ************************************	ter new account to validate your e-mail address. Pollowing this you can start to download the data المعالي معالي معالي معالي معالي المعالي	1999 1997
	Fustname	1 autranne	
	Userman	(Durities) Drawellet	
	E-main	(Izralari) Esmin	
	Select Donalin		
	Select Usage	<u>.</u>	•
	Selict your country	<u>.</u>	
	By registering in this website you are d	eemed to have accepted the T&C for Sentinei data use.	REGISTER

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 - log-in.

5.2 Download data

In this exercise, we will analyze 16 Sentinel-2A images from years 2015-2020 from different seasons. (See \frown NOTE 1). Table below shows the date and reference of the images that will be used:



Please note that every user account is only allowed to request 1 offline product every 30 minutes, if there is free space in the queue. The number of concurrent requests for offline products from all users is limited. You may receive an error when trying to download. If so, try again later.

DATE	SEASON	IMAGE ID
2015-08-10	wet	S2A_MSIL1C_20150810T084916_N0204_R121_T34HCH_20150810T084917
2016-04-06	dry	S2A_MSIL1C_20160406T081652_N0201_R121_T34HCH_20160406T083818
2016-08-24	wet	S2A_MSIL1C_20160824T081602_N0204_R121_T34HCH_20160824T084517
2016-12-02	dry	S2A_MSIL1C_20161202T082312_N0204_R121_T34HCH_20161202T084729
2017-03-02	dry	S2A_MSIL1C_20170302T081841_N0204_R121_T34HCH_20170302T084108
2017-08-09	wet	S2A_MSIL1C_20170809T081601_N0205_R121_T34HCH_20170809T084800
2017-12-27	dry	S2A_MSIL1C_20171227T082341_N0206_R121_T34HCH_20171227T120556
2018-03-27	dry	S2A_MSIL1C_20180327T081601_N0206_R121_T34HCH_20180327T141730
2018-08-24	wet	S2A_MSIL1C_20180824T081601_N0206_R121_T34HCH_20180824T122203
2018-12-22	dry	S2A_MSIL1C_20181222T082341_N0207_R121_T34HCH_20181222T100215

2019-02-20	dry	S2A_MSIL1C_20190220T081951_N0207_R121_T34HCH_20190220T103552
2019-08-09	wet	S2A_MSIL1C_20190809T081611_N0208_R121_T34HCH_20190809T103427
2019-12-17	dry	S2A_MSIL1C_20191217T082341_N0208_R121_T34HCH_20191217T102431
2020-02-25	dry	S2A_MSIL1C_20200225T081921_N0209_R121_T34HCH_20200225T104030
2020-08-23	wet	S2A_MSIL1C_20200823T081611_N0209_R121_T34HCH_20200823T110549
2020-11-11	dry	S2A_MSIL1C_20201111T082201_N0209_R121_T34HCH_20201111T102216

To improve the data acquisition process, we will use a download manager (See \square NOTE 2) that will take care of downloading all products that will be used in this exercise. The metadata of the Sentinel products are contained in a *products.meta4* file created using the 'Cart' option of the Copernicus Open Access Hub.

NOTE 2: A download manager is a computer program dedicated to the task of downloading possibly unrelated stand-alone files from (and sometimes to) the Internet for storage. For this exercise, we will use aria2. Aria2 is a lightweight multi-protocol & multi-source command-line download utility. More info at: https://aria2.github.io/

The *products.meta4* file containing the links to the Sentinel-2 products to be downloaded have been already created following the methodology explained (See NOTE 3). You can find the *products.meta4* files saved in the following path:

Path: /shared/Training/HYDR03_DroughtMonitoring_WesternCape/Original/

Before using the downloading manager and the .meta4 file, let us test if *aria2* is properly installed in the Virtual Machine. To do this, open the Command Line (in the bottom of your desktop window) and type:

aria2c



If *aria2* is properly installed, the response should be as follows. If the response is '-bash aria2c: command not found' it means aria2 is not installed (See \square NOTE 4).



Once finished, test the installation as explanied before.

Once *aria2* is ready to use, we can start the download process. For that, we need to navigate to the folder where the *products.meta4* is stored. Type the following command in the terminal and run it.

```
cd shared/Training/HYDR03_DroughtMonitoring_WesternCape/Original/
```

Next, type the following command (in a single line) to run the download tool. Replace *username* and *password* (leave the quotation marks) with your login credentials for Copernicus Open Access Hub (COAH). Do not clear your cart in the COAH until the download process is finished. This expression is stored also in /AuxData/ folder of this training kit in text file named: *Expressions.txt*

aria2c --http-user='username' --http-passwd='password' --check-certificate=
false --max-concurrent-downloads=2 -M products.meta4



The Sentinel products will be saved in the same path where the *products.meta4* is stored. All 16 products will be downloaded to the */Original* folder.

(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.

Lastly, navigate to the folder where our data are saved: *shared/Training/HYDR03_DroughtMonitoring_WesternCape/Original/* and unzip all 16 products by right-clicking each and going to "Extract Here".

	Griginal - File Manager	s
File Edit View Go	Hetp	
🧔 🍲 👘	/shared/Training/HYDR03_DroughtMonitoring_WesternCape/Original/	Ć
DEVICES File System	Name S2A_MSILIC_20190220T081951_N0207_R121_T34HCH_20190220T103552.SAFE S2A_MSILIC_20190809T081611_N0208_R121_T34HCH_20190809T103427_SAFE	Size Type 4.1 kB folder 4.1 kB folder
	S2A_MSILIC_20191217T082341_N0208_R121_T34HCH_20191217T102431.SAFE	4.1 kB folder 4.1 kB folder
Desktop	SZA_MSILIC_20200823T081611_N0209_R121_T34HCH_20200823T110549.SAFE	4.1 kB folder 4.1 kB folder
shared	S2A_MSIL1C_20150810T084916_N0204_R121_T34HCH_20150810T084917.zip	815.5 MB Zip archive 803.9 MB Zip archive
Browse Network	S2A_MSIL1C_20160824T081602_N0204_R121_T34HCH_20160824T084517.zip S2A_MSIL1C_20161202T082312_N0204_R121_T34HCH_20161202T084729.zip	818.5 MB Zip archive 827.3 MB Zip archive
	S2A_MSIL1C_20170302T081841_N0204_R121_T34HCH_20170302T084108.zip S2A_MSIL1C_20170809T081601_N0205_R121_T34HCH_20170809T084800.zip	825.7 MB Zip archive 824.3 MB Zip archive
	SZA_MSILIC_20171227T082341_N0206_R121_T34HCH_20171227T120556.zip	828.1 MB Zip archive
	33 items (13.2 GB), Free space: 644.5 GB	-

Your folder should have the same structure as shown below.

5.3 SNAP – open and explore data

Launch SNAP (icon on desktop). When the SNAP window opens click **Open product** and navigate to: /shared/Training/HYDR03_DroughtMonitoring_CapeTown/Original/

Open the first S2 product (from 10 August 2015). We can first investigate the structure of the Sentinel 2 Level 1C products. 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) colors 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:

N

Profile

Red B4

Green: B3

Blue: B2

Sentinel 2 MSI Natural Colors

Select RGB-Image Channels

- - - -

-

-

-

Profile: Sentinel 2 MSI Natural Colors

Click OK. The RGB image will be opened at the View window. When the image opens, repeat the same but choose the false color profile. Select:

Profile: Sentinel 2 MSI False-color Infrared. Click OK.

Finally, go to Window \rightarrow Tile Horizontally.



For the purpose of this training atmospherically corrected (See 📒 NOTE 5). Images are stored in the folder: /shared/Training/ HYDR03_DroughtMonitoring_WesternCape/Original/Level-2A/

- 📁 NOTE 5: 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 produces for products acquired over the Europe since the spring of 2017, the coverage has increased through 2018 to reach global coverage in the beginning of 2019. Can be produced on user side by applying the Sen2Cor algorithm. (See: Extra steps 6.1)

Note: Atmospheric correction of one image take some time. Processing of one image in Virtual Machine environment takes about 25 minutes. For your convenience we will proceed with images already atmospherically corrected.

Now, let's investigate the **cloud cover** and **water mask bands** that are the result of atmospheric correction applied to the level 2 products. Close for now the views created. Now navigate in SNAP navigate to File -> Session -> Open session.. and go to the path where the SNAP session is stored: to /shared/Training/ HYDR03_DroughtMonitoring_WesternCape/AuxData/. Open file called preprocessing.snap. In Product Explorer window 16 atmospherically corrected products (Level-2) should appear. Select the first product from August 2015 [1] and go to Masks → scl. Open masks scl_cloud_high_proba (Cloud high probability), scl_water (Water) and scl_thin_cirrus (Thin cirrus). Pixels with detected clouds/cirus/water will appear white in the respective masks.

Now you should have four bands open in your **View** window. Go to **Window** \rightarrow **Tile Evenly** and then



go to the Navigation tab, click Zoom All

We can see that as expected our image is almost cloudless. The default water mask distributed with the Level-2 product, however, does not look very accurate.

5.4 STEP 1 – Pre-processing

Processing the data one by one while having 16 images 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**.

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The For Ten winder other recen water object water Ten	Graph Builder	+ : × -		an C		ICP N	<u> </u>				
	File Graphs		14	<7 C	- 14	+ +	₹ L	4 2	-	2	5
Product Explorer × Pixel Info		^								4 > -	
- G [1] S2A_MSIL2A_20150810T084916_N9999_R121_T34HCH		1	NO.	190	10- 10-	- IN SHAP	Contrast	a bet a	446.00	5 A 30	
[2] 52A_MSILZA_20160406T081652_N9999_R121_T34HCH					SET S	FELL		Rei	1	19.	
- @ [4] S2A MSIL2A 20161202T082312 N9999 R121 T34HCH		-					100				
← 🗑 [5] S2A_MSIL2A_20170302T081841_N9999_R121_T34HCH		1	- 4	12.30			5.21	B	1		5 Q
← 🐱 [6] 52A_MSIL2A_20170809T081601_N9999_R121_T34HCH			20	64 6	S John	X	28.44	122	12		
III S2A MSILZA 201712271082341 N9999 R121 T34HCH	Read				12	2.75	1		ALL A		
- 🗑 [9] SZA_MSILZA_20180824T081601_N9999_R121_T34HCH	Bight click here to add an operator				in the	1200	1	61.2	ile i	- 34	
► 🗟 [10] S2A_MSIL2A_20181222T082341_N9999_R121_T34HCF			1	1 Open	-	123	1 3		200	T. S.	
[11] S2A_MSILZA_20190220T081951_N9999_R121_T34HCF						1		10 0	1	100	9
←				-	<* _()	Were.			123	204	ager
- 🗟 (14) S2A_MSIL2A_20200225T081921_N9999_R121_T34HCF			х.	1	10 per	- +·	-		ALC: N	12	
←					REE	a start			- AL	Sec. 1	
- [10] 52A_MSIC2A_202011111082201_N9999_R121_154HCF				EX.	a base	C. Land		ι,	and in the second		
				in R.	A P	- then			t a la		
Navigati X Colour Ma Uncertaint World View 🖬		- 5		20		1000	100			C. Service	
			3.4	12.3	- Charles	15.14	(Spart	- Egy	6.0.6	A.	ger
	Read Write		ų t	25		1		1		- 3	
e set a set of the set	Source Product			1995		Contraction of	100		3.54	and a	
	Name:		8 P.	and the second		Auch			1	- 68	
	[1] S2A_MSIL2A_20150810T084916_N9999_R121_T34HCH_20211117T091205	T		ste			100	8.31	11-2		1
			1	150	20.1	100	第17-	1.51	1.0	10	
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				- 27		4.8.7	6. L.	1000	-1-1		10.1
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			14		a start	the ca	20		S. 1.		
				100				1.2			9
	Brand Brann & class Brand Brand		-	2.12	100	1.8		100	M	198	\$
	Luau Save Sciear Mote Meip D Kun				1.10	5.2	-	1	1812	1.14	5
1: 84.75			ATK.		1 2 X 2	RC ASE.	CHOIL P	10.00	0.0.6	of the second	

At the moment, the graph only has two operators: *Read* (to read the input) and *Write* (to write the output). First of all, we can remove *Write operator* to not create confusion. To delete the operator, **right click** on it and select **Delete**.

Read		Write Add Delete Connect Graph
Read Resamp Source Product Name: [1] S2A_MSIL2A	ile Subset Write 20150810T084916 N9999 R121 T34HCH 20211117T1	091205
Data Format:	Any Format	
	.oad 🔠 Save 🏷 Clear 📝 Note	🕐 Help 🕞 Run

5.4.1 Resample

The 13 bands in Sentinel-2 products do not all have the same resolution (therefore size) as mentioned in $\stackrel{\frown}{=}$ NOTE 6. Many operators do not support products with bands of different sizes, so we need to resample the bands to equal resolution first.

To add the operator right-click the white space between the 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.



Below the white box with the graphical representation of the tools used in a processing chain, you will find a panel which allows to change the parameters of all tools placed into processing chain. We will update the parameters one by one here.

Do not change anything in the **Read** tab.

In the Resampling Parameters tab under **"Define size of resampled product"**, choose: By reference band from source product: **B2**

	B2	
By reference band from source product:	Resulting target width:	10980
	Resulting target height	10980
	Target width	10 580-
By target width and height:	Target beight	10.980
	Width / height ratio:	1.00010
		00.
By pixel resolution (in m):	Resulting target width	1098
	Resulting target height:	1096
Define resampling algorithm		
Upsampling method	Nearest	
Downsampling method	First	
Flag downsampling method	First	
Advanced Method Definition by Band		
Resample on pyramid levels (for faster imagi	ng)	

5.4.2 Subset

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.

|--|

In the Subset tab we are going to keep only the bands which will be necessary in next steps of the analysis. In the parameter *Source band* select following bands to keep in the final product: **B2**, **B3**, **B4**, **B8**, **B11**, **B12**. Then we are going to clip our image only to the area of interest, which in our case is Theewaterskloof dam. Below the option *Copy metadata* select the option of subset *Geographic coordinates*. Below the world view window in the white text box copy and paste the subset polygon coordinates in Well-Known-Text format (WKT) from *Expressions.txt* file stored in: */shared/Training/HYDR03_DroughtMonitoring_WesternCape/AuxData/*

```
POLYGON ((19.061834340155283 -33.955691701708375, 19.379564169402002 -33.96
028594353146, 19.376352000158878 -34.12895277789442, 19.057993224051753 -34
.124329459334305, 19.061834340155283 -33.955691701708375))
```

Source Bands: B B B B B B B B B B B B B B B B B B B	B1 A B2 A B3 B3 B4 B5 B6 B7 B8 V Geographic Coordinates
€ B B B B B B B Copy Metadata O Pixel Coordinates teference band:	B2 B3 B4 B5 B6 B7 B8 B8 Ceographic Coordinates
B B B B B B B B Copy Metadata Pixel Coordinates Leference band:	B3 B4 B5 B6 B7 B8 Geographic Coordinates
B B B B B B B Copy Metadata O Pixel Coordinates teference band:	B4 B5 B6 B7 B8 • •
B: Bi Bi D: Dixel Coordinates teference band:	85 86 88 • © Geographic Coordinates
B B D O Copy Metadata Pixel Coordinates	B6 B7 B8 • • •
B Bi Copy Metadata Pixel Coordinates Reference band:	B7 B8 ↓ ↓
Copy Metadata Pixel Coordinates Reference band:	© Geographic Coordinates
Copy Metadata Pixel Coordinates	Geographic Coordinates
Pixel Coordinates Reference band:	Geographic Coordinates
Reference band:	
	Lange and the second
719, 19.061834335327	715 -33.955692291259766, 19.06183433532715 -33.955692291259766) Update
(Internet	Brann & days Right Out
Load	Save Save Note Help Run

5.4.3 Write

Now, finally we can add Write operator and connect it to the Subset.

Change the directory of the output products to the path: /shared/Training/HYDR03_DroughtMonitoring_CapeTown/Processing/preprocessing/.

Subset Write

Read	Resample S	ubset Write				
Target P	roduct					
Name: Subset_	S2A_MSIL2A_20	150810708491	5_N9999_R121_T	34HCH_2021111	7T091205_resa	mpled.
Save as:	BEAM-DIMAP	-				
Direc	ctory:				_	-
/horr	ne/rus/shared/	Fraining/HYDR03	DroughtMonitori	ing_WesternCap	e/Processing/pr	eprocessing
ī	÷0.			_]		
	Load	Save	Clear	Note	Help	Run

Now, save the graph as *Graph_preprocessing.xml* to: /shared/Training/HYDR03_DroughtMonitoring_WesternCape/AuxData/ by clicking Save at the bottom of the window.

5.4.4 Batch processing

Batch Processing is used when we want to apply identical pre-processing steps at once to multiple images. Once we have our graph with pre-processing steps created we are ready to apply the same steps to all 16 images.

There are several approaches to do batch processing in SNAP, but in this step we will make use of builtin tool in SNAP – **Batch Processing tool.** To do this first close the **Graph Builder** window.

Then open **Batch Processing** tool (**Tools** \rightarrow **Batch Processing**). In the **I/O Parameters** tab we will add all opened products from the **Product Explorer** window [1]-[16] by **Add Opened** \rightarrow on the upper right (second icon from the top) and then click **Refresh** (second icon from the bottom). Like this we have loaded all 16 images from 2015-2020 of the same area.

In the I/O Parameters tab, under the Target Folder:

- a) keep the format (Save as) is set to BEAM-DIMAP,
- b) change the directory to:

/shared/Training/HYDR03_DroughtMonitoring_WesternCape/ Processing/preprocessing/

- c) and the option "*Keep source product name*" **unchecked.** Do it **before** uploading the graph into Batch Processing Tool (See NOTE 7).
- NOTE 7: The product file names will be identical to the input file names. If you set your output directory to the folder that contains your input data, the input data will be overwritten!

Then click on **Load Graph** at the bottom of the window, and you should now navigate to saved **Graph_preprocessing.xml** file and open it. We see that new tabs have appeared at the top window corresponding to our operators from pre-processing graph.

File Name Type Acquisition Track Orbit S2A_MSIL2A_20150810 S2_MSI_Lev 10Aug2015 99999 99999 99999 99999 S2A_MSIL2A_20160406 S2_MSI_Lev 06Apr2016 99999 99999 S9999 S2A_MSIL2A_20180327 S2_MsiLev 27Dec2017 S9999 S9999 S9999 S9999 S9999 S2A_MSIL2A_20180824 S2_MsiLev 27Dec2018 S9999 S9999 S9999 S2A_MSIL2A_20190809 S2_MSI_Lev 20Feb2019 S9999 S9999	I/O Parameters Resa	ample Subse	et Write						
S2A_MSIL2A_20150810 S2_MSI_Lev 10Aug2015 99999 99999 99999 S2A_MSIL2A_20160406 S2_MSI_Lev 06Apr2016 99999 99999 99999 S2A_MSIL2A_20160824 S2_MSI_Lev 02Aug2016 99999 99999 99999 S2A_MSIL2A_20161202 S2_MSI_Lev 02Aug2016 99999 99999 99999 S2A_MSIL2A_201710302 S2_MSI_Lev 02Mar2017 99999 99999 99999 S2A_MSIL2A_20170302 S2_MSI_Lev 02Mar2017 99999 99999 99999 99999 S2A_MSIL2A_20180327 S2_MSI_Lev 27Dec2017 99999 99999 99999 99999 99999 S2A_MSIL2A_20180824 S2_MSI_Lev 27Dec2018 999999	File Name	Туре	Acquisition	Track	Orbit		4		
S2A_MSIL2A_20160406 S2_MSI_Lev 06Apr2016 99999 99999 99999 S2A_MSIL2A_20160824 S2_MSI_Lev 24Aug2016 99999 99999 99999 S2A_MSIL2A_20161202 S2_MSI_Lev 02Dec2016 99999 99999 99999 S2A_MSIL2A_20170802 S2_MSI_Lev 02Dec2017 99999 99999 99999 S2A_MSIL2A_20170802 S2_MSI_Lev 02Mar2017 99999 99999 99999 S2A_MSIL2A_20180327 S2_MSI_Lev 27Dec2017 99999 99999 99999 S2A_MSIL2A_20180824 S2_MSI_Lev 27Mar2018 99999 99999 99999 S2A_MSIL2A_20180824 S2_MSI_Lev 27Dec2017 99999 99999 99999 S2A_MSIL2A_20180824 S2_MSI_Lev 27Dec2018 99999 99999 99999 S2A_MSIL2A_20180220 S2_MSI_Lev 20Feb2019 99999 99999 99999 99999 99999 99999 99999 99999 99999 99999 99999 99999 99999 99999 99999 99999 99999	S2A_MSIL2A_20150810	S2_MSI_Lev	10Aug2015	99999	99999	-	-		
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S2A_MSIL2A_20161202 S2_MSI_Lev 02Dec2016 99999 99999 S2A_MSIL2A_20170302 S2_MSI_Lev 02Mar2017 99999 99999 S2A_MSIL2A_20170302 S2_MSI_Lev 09Aug2017 99999 99999 S2A_MSIL2A_2017127 S2_MSI_Lev 27Dec2017 99999 99999 S2A_MSIL2A_20180327 S2_MSI_Lev 27Dec2017 99999 99999 S2A_MSIL2A_20180327 S2_MSI_Lev 27Mar2018 99999 99999 S2A_MSIL2A_20180824 S2_MSI_Lev 22Dec2018 99999 99999 S2A_MSIL2A_20190220 S2_MSI_Lev 22Dec2018 99999 99999 S2A_MSIL2A_20190805 S2_MSI_Lev 20Feb2019 99999 99999 99999 S2A_MSIL2A_20190805 S2_MSI_Lev 17Dec2019 99999 99999 16 Products S2A_MSIL2A_20191217 S2_MSI_Lev 17Dec2019 99999 99999 16 Products Save as:	S2A_MSIL2A_20160824	S2_MSI_Lev	24Aug2016	99999	99999		-		
S2A_MSIL2A_20170302 S2_MSI_Lev 02Mar2017 99999 99999 S2A_MSIL2A_20170809 S2_MSI_Lev 09Aug2017 99999 99999 S2A_MSIL2A_20171227 S2_MSI_Lev 27Dec2017 99999 99999 S2A_MSIL2A_20180327 S2_MSI_Lev 27Dec2017 99999 99999 S2A_MSIL2A_20180327 S2_MSI_Lev 27Mar2018 99999 99999 S2A_MSIL2A_20181222 S2_MSI_Lev 24Aug2018 99999 99999 99999 S2A_MSIL2A_20190220 S2_MSI_Lev 20Feb2019 99999 99999 99999 S2A_MSIL2A_20190220 S2_MSI_Lev 20Feb2019 99999 99999 99999 S2A_MSIL2A_20190220 S2_MSI_Lev 0Peb2019 99999 99999 99999 S2A_MSIL2A_20190220 S2_MSI_Lev 0Peb2019 99999 99999 99999 99999 99999 S2A_MSIL2A_20190200 S2_MSI_Lev 17Dec2019 99999 99999 99999 16 Products Target Folder S2 S2 MSIL2A_201200225 S2 MSIL2A_201200225	52A_MSIL2A_20161202	S2_MSI_Lev	02Dec2016	99999	99999		-		
S2A_MSIL2A_20170809 S2_MSI_Lev 09Aug2017 99999 99999 S2A_MSIL2A_20171227 S2_MSI_Lev 27Dec2017 99999 99999 S2A_MSIL2A_20180327 S2_MSI_Lev 27Mer2018 99999 99999 S2A_MSIL2A_20180824 S2_MSI_Lev 27Mar2018 99999 99999 S2A_MSIL2A_20180824 S2_MSI_Lev 22Dec2018 99999 99999 S2A_MSIL2A_20190220 S2_MSI_Lev 22Dec2018 99999 99999 99999 S2A_MSIL2A_20190220 S2_MSI_Lev 20Feb2019 99999 99999 99999 S2A_MSIL2A_20190220 S2_MSI_Lev 20Feb2019 99999 99999 99999 S2A_MSIL2A_20190220 S2_MSI_Lev 20Feb2019 99999 99999 99999 S2A_MSIL2A_20190220 S2_MSI_Lev 17Dec2019 99999 99999 99999 16 Products Target Folder Save as:	S2A_MSIL2A_20170302	S2_MSI_Lev	02Mar2017	99999	99999		1		
S2A_MSIL2A_20171227 S2_MSI_Lev 27Dec2017 99999 99999 S2A_MSIL2A_20180327 S2_MSI_Lev 27Mar2018 99999 99999 S2A_MSIL2A_20180824 S2_MSI_Lev 24Aug2018 99999 99999 S2A_MSIL2A_20180824 S2_MSI_Lev 24Aug2018 99999 99999 S2A_MSIL2A_20180824 S2_MSI_Lev 22Dec2018 99999 99999 S2A_MSIL2A_20190220 S2_MSI_Lev 20Feb2019 99999 99999 99999 S2A_MSIL2A_20190809 S2_MSI_Lev 20Feb2019 99999 99999 99999 S2A_MSIL2A_20190809 S2_MSI_Lev 17Dec2019 99999 99999 99999 S2A_MSIL2A_20191217 S2_MSI_Lev 17Dec2019 99999 99999 16 Products Target Folder Save as:	S2A_MSIL2A_20170809	S2_MSI_Lev	09Aug2017	99999	99999				
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S2A_MSIL2A_20181222 S2_MSI_Lev 22Dec2018 99999 99999 S2A_MSIL2A_20190220 S2_MSI_Lev 20Feb2019 99999 99999 99999 S2A_MSIL2A_20190220 S2_MSI_Lev 20Feb2019 99999 99999 99999 S2A_MSIL2A_2019020 S2_MSI_Lev 09Aug2019 99999 99999 99999 S2A_MSIL2A_20191217 S2_MSI_Lev 17Dec2019 99999 99999 16 Products Target Folder Save as:	S2A_MSIL2A_20180824	S2_MSI_Lev	24Aug2018	999999	99999		JEL		
S2A_MSIL2A_20190220 S2_MSI_Lev 20Feb2019 99999 99999 99999 S2A_MSIL2A_20190809 S2_MSI_Lev 09Aug2019 999999 99999 99999 S2A_MSIL2A_20191217 S2_MSI_Lev 17Dec2019 99999 99999 16 Products S2A_MSIL2A_20200225 S2_MSI_Lev 17Dec2019 99999 99999 16 Products Target Folder Save as:	S2A MSIL2A 20181222	S2_MSI_Lev	22Dec2018	99999	99999			4	
S2A_MSIL2A_20190809 S2_MSI_Lev 09Aug2019 99999 99999 S2A_MSIL2A_20191217 S2_MSI_Lev 17Dec2019 99999 99999 S2A_MSIL2A_20200225 S2_MSI_Lev 17Dec2019 99999 99999 Save as:	S2A_MSIL2A_20190220	S2_MSI_Lev	20Feb2019	99999	99999		3		Refresh
S2A_MSIL2A_20191217 S2_MSI_Lev 17Dec2019 99999 99999 S2A_MSIL2A_20200225 S2_MSI_Lev 25Eeb2020 99999 99999 16 Products Target Folder Save as:	S2A_MSIL2A_20190809	S2_MSI_Lev	09Aug2019	99999	99999				
S2A MSII 2A 20200225 S2 MSI Lev 25Eeb2020 99999 99999 16 Products Target Folder Save as:	S2A_MSIL2A_20191217.	S2_MSI_Lev	17Dec2019	999999	99999				
Target Folder Save as: Directory:	S2A MSIL2A 20200225	S7 MSLLev	25Eeb2020	999999	999999		16 Products		
Save as: Directory:	Target Folder								
Directory.	Save as:	-							
	Directory:								
An an el rue Uniar est HTT PUE IV cou introlonis. Constantis		NEL CICLEMINEN							
		-					(Less)		

In the **Resample tab** make sure that under **Define size of resampled product**, option "*By reference band from source product*" is selected and then that the **B2** is highlighted as a reference band. This way we will ensure that all the bands will be resampled to 10 m resolution.

Batch Processing : C	araph_processing.xml		• •	×	_	Batch	Processing : Gra	ph_processing.xn	nl	1	*
le Graphs				File (iraphs						
I/O Parameters Resample Subset Write	2			NO I	arameters	Resample	Subset Write				
Define size of resampled product			-	Source	e Bands:	B1					1
	82					B3					-
By reference band from source product:	Resulting target width:	10980				B4					
	Resulting target height:	10980				B5 B6					
	Target width		23 280			B7					
 By target width and height. 	Targat height		22 2 20	RO	mu Matadata	Do					
	Whith a height ratio.	1.00000		OP	el Coordinat	es 🖲 Georg	ranhic Coordinates				
				Refer	ence band:		opine coordinates				1
O By pixel resolution (in m)	Resulting target width	1830						The state of the		-	
	Resulting target height.	1090					and The		12	1000	
Define resampling algorithm							1.1	The Assessment			
Upsampling method	Nearest		-								
and the second	Locate						R			1000	
Downsampling method	First		-								
Contraction and Balling	in the second se			19, 1	9.061834335	32/15 -33.9	5692291259766, 15	.06183433532715 -33	9556922912	25976677	Update
Flag downsampling method	First		-								
Advanced Method Definition by Band											
			1				Bup come	to Load Crank	Run	Class	Halp
Run rer	note Load Graph	Run <u>C</u> lo	ese Help				Run remo	Load Graph	Run	Figse	Teib

At the Subset, check if all parameters are exactly the same as set in Graph Builder previously.

In the **Write** tab, under the **Name** keep the default name (*Subset_* and *_resampled* will be added). At the directory make sure that the path to:/shared/Training/HYDR03_DroughtMonitoring_WesternCape/Processing/preprocessing.

Click Run.

	Butch Proc	assing = 0	iraph_	preproces	ing.	unit		* D X
File Graphs								
Processing comple	eted in 2,33 m	inutes						
VO Parameters	Resample	Subset	Write	1				
Target Product								
Name								
2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2								
Subset S2A MS	IL2A_20201113	T082201_N	19999_R	121_T34HCH	202	1111771	75909_res	ampled
Subset S2A MS	IL2A_20201113 DIMAP	T082201_N	19999 <u></u> 8	121_T34HCH	202	1111771	75909_res	ampled
Subset S2A_MS Save as: BEAMI	IL2A_20201113 DIMAP	1T082201_N	19999_R	121_T34HCH	202	1111771	75909_res	ampled
Subset_S2A_MS Save as: BEAM-I Directory us/shared/Tr	IL2A_20201113 DIMAP aining/HYDR03	DroughtMd	19999_R	121_T34HCH	_202	ocessin	75909_res	ampled
Subset_S2A_MS Save as: BEAM-I Directory Is/shared/Tr	IL2A_20201113 DIMAP aining/HYDR03	DroughtMe	19999_R	121_T34HCH	_202	ocessin	75909_res	ampled
Subset_S2A_MS Save as: BEAM- Directory Is/shared/Tr	IL2A_20201113 DIMAP aining/HYDR03	DroughtMe	19999_R	121_T34HCH	1_202	oceșsini	75909_res	ampled
Subset S2A_MS Save as: BEAM- Directory Is/shared/Tr	IL2A_20201113 DIMAP raining/HYDR03	DroughtMe	19999_R	121_T34HCH	1_202	ocessin	75909_res	ampled
Subset S2A MS Save as: BEAM-1 Directory Is/shared/Tr	IL2A_20201113 DIMAP aining/HYDR03	DroughtMe	19999_R	121_T34HCH g_WesternCa	1_202	ocessing	75909_res	ampled
Subset S2A MS Save as: BEAM-1 Directory Is/shared/Tr	IL2A_20201113 DIMAP	DroughtMe	onitorin	121_T34HCH g_WesternCa	pe/Pr	ocessing	75909_res	ssing)
Subset_S2A_MS Save as: BEAM-1 Director: Is/shared/Tr	IL2A_20201113 DIMAP	DroughtMe	anitorin	121_T34HCH	1_202		75909_res	ampled ssing)

The processing time will depend on your VM setup. (Approx. 3 mins with 30GB ram).

You can check the */shared/Training/HYDR03_DroughtMonitoring_WesternCape/Processing/ preprocessing/* for the output products. Once the processing is done close the **Batch Processing**

window. All pre-processed products will appear automatically at the **Product Explorer** window.

Once all products are loaded [17]-[32], right-click the first and go to **Open RGB image window**. Select the profile: **Sentinel 2 MSI Land/Water** and click **OK**. You can repeat this step for all products and the go to **Window** \rightarrow **Tile Evenly.** On the left in the Navigation

Sentine	1 2 MSI Land/Water	
Red:	88	
Green:	B11	
Blue:	B4	*
Stor	e RGB channels as virtual bands in cu	irrent product

panel select: Zoom all 🔍



STEP 2 | Water radiometric indices calculation 5.5

To detect water bodies, we will use several water radiometric indices from S2 data. A variety of different water indices exist and can be applied for different purposes. We will first introduce here 4 indices selected for the purpose of this training. Later we are going to calculate them for all 16 images. We will use different water radiometric indices to create later a water mask based on the results of the water response to specific band combinations. Generally, water only reflects in the visible light range. As water has almost no reflection in the near infrared range it is very distinct from other surfaces. Because of this absorption property water bodies as well as features containing water can easily be detected, located and delineated with remote sensing.

5.5.1 NDWI

To detect the water bodies, we will use several water radiometric indices proposed in the literature. First index that we will use is the Normalized Difference Water Index. It was proposed by McFeeters2 to detect surface waters in wetland environments and to allow for the measurement of surface water extent. It allows also to:

B3 - B8

- i) maximize the reflectance of the water body in the green band;
- ii) minimize the reflectance of water body in the NIR band. McFeeters's NDWI is calculated as:



5.5.2 **MNDWI**

The main limitation of previously described NDWI index is that it is not efficient in sites where built-up areas signal noise can affect the water surface signal. It was noticed that the water bodies have stronger absorbability in the SWIR band than in the NIR band, while the built-up areas have greater radiation in the SWIR band than in the NIR band (Xu, 2006). Based on this finding the Modified Normalized Water Index was proposed which allows to suppress and even removing built-up land noise as well as vegetation and soil noise and therefore enhance water bodies extraction.

The MNDWI is calculated using following equation:

$$MNDWI = \frac{Green - SWIR1}{Green + SWIR1} = \frac{B3 - B11}{B3 + B11}$$

5.5.3 MNDWI + 5

In 2015 the modification of existing *Modified Normalized Vegetation Index was introduced (MNDVI* + V). This index use NIR and Red band (*Zhou et al., 2017*) and it combines the Enhanced Vegetation Index and Normalized Difference Vegetation Index. This combination makes it more sensitive to surface water features, enhancing the ability to map their distribution. This index shows great performance also in flood detection and mapping as well as monitoring surface water resources (*Bhaga et al. 2020*). Using this index surface water will have negative values (<0) so opposite to all other water indices tested in this exercise.

 $MNDWI + 5 = \frac{NIR - Red}{NIR + Red} = \frac{B8 - B4}{B8 + B4}$

5.5.4 AWEI

This is the last index which has been tested in this training. The **Automated Water Extraction Index** has been introduced by *Feyisa et.at (2014)*. And it was designed to improve water extraction accuracy with a stable threshold value. This index introduced two equations which are AWEI_{sh} (used in this exercise) and AWEI_{nsh}. In this training we concentrated only on one AWEI index and it is AWEI_{sh} which enhance water bodies detection by removing shadow pixels. Both indices however use combination of blue, green, NIR, SWIR1 and SWIR2 bands.

The equation used for calculating this index is following:

AWEI = Blue + 2.5 * Green - 1.5 * (NIR + SWIR1) - (0.25 * SWIR2) = B2 + 2.5 * B3 - 1.5 * (B8-B11) - (0.25 * B12)

5.5.5 Water radiometric indices calculation

To calculate the water radiometric indices described we will create another short graph. We will produce four water radiometric indices for all 16 images. First we will create short graph that calculates indices for all images at once. Then newly created bands will be stacked to one product which corresponds to each sensing date of images used. Band merge will be crucial to perform later Time Series analysis in SNAP as it is one the requirements of this tool.

Go to **Tools** \rightarrow **Graph Builder**. First of all, we can remove **Write operator** to not create confusion. To delete the operator, **right click** on it and select **Delete**.

Then to calculate water indices add four **Band Maths(1-4)** operators (one for each water index): Add \rightarrow Raster \rightarrow BandMaths.

We will calculate the indices based on the mathematical equations applied on different bands of the product. The expressions used to calculate these water indices are stored in file: *Expression.txt* (lines: 10 – 13) which is stored in: */shared/Training/HYDR03_DroughtMonitoring_WesternCape/AuxData/*

After you placed all four **BandMaths** operators to your graph you can edit the parameters (expressions used for calculation of each index).

After all four **BandMaths** operators are added you can click again on the white space in the graph builder go to Add \rightarrow Raster \rightarrow BandMerge and connect all four BandMaths operators to Band Merge. As a last step go to Add \rightarrow Input-Output \rightarrow Write. Connect Band Merge to Write operator. Your final graph should look like this below:

Read BandMaths BandMa Source Product Name	dMaths Maths(2) BandMerge Maths(3) taths(4)	• Write
Read BandMaths BandMa Source Product		Nillerne Write
	(ths(2) BandMaths(3) BandMaths(4) Ban	and the latter
Data Format	0810T084916_N9999_R121_T34HCH_20211117T	1091205_resamp 💌 📖

Now move to the tabs below the graphical representation of operators and edit parameters.

Do not change anything in the **Read** operator tab.

In the **BandMaths tab** which indicates the first water radiometric index to calculate:

- change Target band name: NDWI
- go to *Edit Expression* button and copy and paste following equation to calculate the new band.

Expressions are also stored in the *Expression.txt* file in the Training folder: /shared/Training/HYDR03_DroughtMonitoring_WesternCape/AuxData/)

Go to **Band Math** tab and copy and paste following condition statement (expression):

Read BandMaths BandMaths(2) BandMaths(3) BandMaths(4) BandMerge Write		Arithmetic Exp	ression Editor	+ = >
arget Band. NDWI	Data sources:		Expression:	
and line	B2	6+6	(83-88)7(83+88)	
-Data Value: 0.0	B4	6 - 6		
pression: (B3-B8)/(B3+B8)	B8	6 * 6		
	B11	6/6		
	812	(@)		
		Constants	T	
	🕑 Show bands	Operators		_
	Show masks	Functions		

In Band Math(2) tab:

- change Target band name: MNDWI
- go to *Edit Expression* button and copy and paste following equation to calculate the new band:

Read BandMaths BandMaths(2) BandMaths(3) BandMaths(4) BandMerge Write		Arithmetic E	xpres	sion Editor	0 0
Target Band MNDW	Data sources:			Expression:	
arget Band Type: float32	B2	0 + 0	-	(B3 - B11)/ (B3 + B11)	
and Unit	83	6 - 6			
lo-Data Value: 0.0	84	0 * 0	-		
(B3-B11)(B3+B11)	811	0/0			
	812				
		(@)	_		
		Constants	-		
	Show bands	Operators	-		
	Show masks	Functions	-	1.00	
	Show be-point grids		_		

In Band Math(3) tab:

- change Target band name: MNDWI5
- go to *Edit Expression* button and copy and paste following equation to calculate the new band:

		Antenne trap	ression Euror	- EL 3
Band: MNDWI5	Data sources:		Expression:	
Band Type: float32	B2	0+0	(B8 - B4)/(B8 + B4)	
Sand Unit	B3	0 - 0		
ta Value: 0.0	88	6 * 6		
xpression: 88-84/168+84/	B11	0/0		
	612	(@)		
		Constants	-	_
	Show bands	Operators	+	
	Show masks	Functions		

In Band Math(4) tab:

- change Target band name: AWEI
- go to *Edit Expression* button and copy and paste following equation to calculate the new band:

```
B2 + 2.5 * B3 - 1.5 *(B8-B11) - 0.25 * B12
```

arget Band:	AWEI	Data sources:		Expression:	
arget Band Type	: float32	82	0+0	B2 + 2.5 * B3 - 1.5 * (BB	3+ B11) - 0.25
and Unit:		B3	6 - 6	B12	
o-Data Value:	0.0	B4	0.1.0		
apression. B2 + 2.5 * B3 - 1.5 * (B8 + B11) - 0.25* B12	B2 + 2.5 * B3 - 1.5 * (B8+ B11) - 0.25* B12	811	6.6		
		812	6/6		
			(@)		
			Constants	-	
		Show bands	Operators	-	
		Show masks	Functions		
	Edit Expression	Show the point grids			Ok an arrow

In the next tab **BandMerge** we will merge all water radiometric indices. To do that select all bands (with CTRL key pressed) in the *Source Bands* parameter.

Read BandMaths BandMaths(2) BandMaths(3) BandMaths(4) BandMerge Write	Read BandMaths BandMaths(2) BandMaths(3) BandMaths(4) BandMerge Write
Source Bonds NOW: Subset 524 MSL24 20150010764915 (M9999 R121_T34HCH_202111177091205 r MNDWI: Subset 524 MSL24 20150010764916 N9999_R121_T34HCH_20211117T091205 r MNDWIS: Subset 524 MSL24 201500107064916 (M9999_R121_T34HCH_20211117T091205 re	Target Product
	Name:
	Subset_S2A_MSIL2A_20150810T084916_N9999_R121_T34HCH_20211117T091205_resampled_BandMath
	Save as. BEAM-DIMAP
	Directory
	/home/rus/shared/Training/HYDR03_DroughtMonitoring_WesternCape/Processing/preprocessing
🖹 Load 🖄 Save 🏷 Clear 📝 Note 🔞 Help 🕞 Run	🖆 Load 🖳 Save 🍾 Clear 🏹 Note 🔞 Help 🕞 Run

Do not change anything in Write tab.

Now, save the graph as **Graph_WIs.xml** to: /shared/Training/HYDR03_DroughtMonitoring_WesternCape/AuxData/ by clicking Save at the bottom of the window.

5.5.6 Graph Processing Tool | GPT

In this exercise, we will use the **SNAP GPT** command line interface (which can be found in the bin folder of the Sentinel Toolbox installation) to process our Sentinel- products. This tool is used to execute SNAP raster data operators in batch-mode. The operators can be used stand-alone or combined as a directed acyclic graph (DAG). Processing graphs are represented using XML files. Using the GPT provides a convenient way to use operators in a headless environment or in batch mode (See NOTE 8).

NOTE 8: To run an operator using GPT, it is necessary to indicate the path to the source product(s), to the target product and to other operator-specific parameters which might be mandatory or specific. As for complex operators the call from the command line can easily become confusing, it is also possible to pass the required settings in form of a xml-encoded graph file. It will then suffice to just pass the graph as parameter to the GPT.

To access **GPT**, open a **Terminal** window by clicking on its icon - **b** - write the following text and press enter (See **b** NOTE 9).



gpt

NOTE 9: Note that in the RUS Copernicus Virtual Machines, the gpt command is an environment variable and can be called directly from the terminal. If this is not your case, you will have to set it or specify the path to gpt to call the program.

To process our images in batch mode using GPT we need to change the input and output reference to specific input/output files by variables (See NOTE 10).Navigate to the following path, right click on the graph file (*Graph_Wls.xml*) and select **Open With -> Open with Mousepad**.

Once the xml file is opened, click on View -> Line Numbers.

Path: /shared/Training/HYDR03_DroughtMonitoring_WesternCape/AuxData/

NOTE 10: The graph created in the **Graph Builder** tool in **SNAP** is an xml document that contains the different operators that have been added. The xml document is structured in a way that all the information of a specific operator is specified between the and tags.

In **line 7**, delete only the path to the input image highlighted in orange (do not remove *<file>* and *</file>*) and write *\$input* (as highlighted in green). Line **7** should look like this:

<file>\$input</file>





In line **105**, delete only the path to the output image highlighted in orange (do not remove *<file>* and *</file>*) and write *\$output2* (as highlighted in green). Line **105** should look like this:

```
<file>$output</file>
```

```
<node id="Write"
 99
             <operator>Write</operator>
100
101
           <sources>
102
               <sourceProduct refid="BandMerge"/>
103
            </sources>
     class="com.bc.ceres.binding.dom.XppDomElement">
    <file>/home/rus/shared/Training/HYDR03_DroughtMonitoring_WesternCape/Processing/preprocessing/
Subset_S2A_MSIL2A_201508107084916_N9999_R121_T34HCH_20211117T091205_resampled_BandMath.dim</file>
104
105
106
                <formatName>BEAM-DIMAP</formatName
            </parameters>
107
```

99	<node id="Write"></node>
100	<pre><operator>Write</operator></pre>
101	<sources></sources>
102	<sourceproduct refid="BandMerge"></sourceproduct>
103	
104	<pre><pre>cparameters class="com.bc.ceres.binding.dom.XppDomElement"></pre></pre>
105	<file>\$output</file>
106	<formatname>BEAM-DIMAP</formatname>
107	
108	
1	

5.5.7 Batch processing

Once the graph is modified with the *\$input* and *\$output* variables, we are ready to process them in batch mode with GPT. For that, when an image is processed, the *\$input* and *\$output* variables have to change with the appropriate name. There are several approaches to do so but, in this exercise, we will use a bash script (See $\stackrel{\frown}{=}$ NOTE 11).

NOTE 11: 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.wikipeia.org/wiki/Bash</u> (Unix shell)). Typical operations performed by shell scripts include file manipulation, program execution, and printing text. If you want to run this exercise on Windows, you can replicate the steps in any programming language you are familiar with, such as Python or R.

Now, go to the path: /shared/Training/HYDR03_DroughtMonitoring_WestrenCape/AuxData/and open the file named: Script_WIs.sh.



On line **1**, we specify that the script should be run with Bash scripting language (See 🛄 NOTE 11).

1#!/bin/bash

On line **3**, **4** we specify folder where input data are stored and output folder (respectively) where our results will be saved.

3 Path_S2=/shared/Training/HYDR03 DroughtMonitoring WesternCape/Processing/preprocessing/ 4 output folder=/shared/Training/HYDR03 DroughtMonitoring WesternCape/Processing/WIs/

On lines **7** and **8** we specify the pattern of the beginning of the input product (line **7**) and ending of the output (line **8**).

7 oldEnd=.dim 8 newEnd=_WIS Line **11** signifies the start of the loop. The script will loop 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 **12** and "done" on line **19** enclose the steps that should be performed on each input product.

11 for i in \$(ls -d -1 \$Path_52\$Subset_52A*.dim) 12 do

On line **13**, we extract the name of the input product; on line **14**, we extract the <u>date of the acquisition</u> from the Sentinel-2 product.

 13
 ac_datetime=\$(echo \$i | cut -d * -f 6)

 14
 n=\$(echo \$ac_datetime | cut -d * T' -f 1)

On line **15** and **17** we specify that once the script will run, information about current date will be provided (printed) in the Terminal.

On line **16** 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) – input and output variables. We also create the output product name combining the sensing date of the product and the suffix for each output product. On line **19**, the loop is closed.

date gpt /shared/Training/HYDR03_DroughtMonitoring_WesternCape/AuxData/Graph_WIs_GPT.xml -Pinput=S1 -Poutput= 16 Soutput folderSnSnewEnd 17 date 18 19 done

Once the script is saved, we can run it. Navigate to *.../AuxData/* folder where shell script file is sotred. Right-click on the white space and go to **Open Terminal Here.** In the terminal type:

sh Script_WIs.sh

where Script_Wis.sh is the name of the Bash script file. Click Enter to run the script.



The processing time will depend on your VM setup (approx. 2-3 min with 30 GB RAM). You can check the: */shared/Training/HYDR03_DroughtMonitoring_WesternCape/Processing/WIs/* for the output products. Close the terminal window. Once the images are processed you should see the list of products like this:

	Wis - File Manager		. * . =
File Edit View Go	Help		
👙 🔮 🚰 🔤	shared/Training/HYDR03_DroughtMonitoring_Westerr	Cape/Processing/WIs/	C
DEVICES	Name	Size Type	Date Modified +
The Surfam	20170302 Wis data	4.1 kB folder	Sunday
File System	20161202 Wis data	4.1 kB folder	Sunday
PLACES	20160824 Wis.data	4.1 kB folder	Sunday
-	20160406 Wis.data	4.1 kB folder	Sunday
and the	20150810_Wis.data	4.1 kB folder	Sunday
Desktop	20201111 Wis.dim	19.3 MB XML docum	ent Sunday
G Task	20200823_WIs.dim	17.6 MB XML docum	ent Sunday
I hozu	20200225_Wis.dim	23.8 MB XML docum	ent Sunday
shared	20191217_Wis.dim	12.7 MB XML docum	ent Sunday
	20190809_Wis.dim	13.6 MB XML docum	ent Sunday
NETWORK	20190220_Wis.dim	38.9 MB XML docum	ent Sunday
Stowse Network	20181222_Wis.dim	10.9 MB XML docum	ent Sunday
	20180824_Wis.dim	36.8 MB XML docum	ent Sunday
	20180327_WIs.dim	17.4 MB XML docum	ent Sunday
	- 20171227_Wis.dim	24.7 MB XML docum	ent Sunday
	20170809_Wis.dim	14.1 MB XML docum	ent Sunday
	20170302_Wis.dim	34.6 MB XML docum	ent Sunday
	- 20161202_WIS.dim	15.6 MB XML docum	ent Sunday
	37 (tems (353 8 MR)) Free share: 500 8 GR	TT & EAD, VAN, downed	ant Countra

5.6 STEP 3 / Time Series

Now, let's have a look at different water radiometric indices, output from Bash processing. Go back to SNAP and go to **File -> Session -> Open session..**

Navigate to */shared/Training/HYDR03_DroughtMonitoring_WesternCape/AuxData/* and open water_indices.snap

You can now investigate different indices over the period from 2015 until 2020. Expand **Bands** of each product in **Product Explorer**. You will notice that all products have bands with the same name. This is the requirement of **Time Series Tool** in SNAP. In order to plot temporal changes in a graph compared bands need to have the same name.

We can compare different water indices now in different period (for example in this case MNDWI5 index). We can observe how the water level changed between the 2016 (April) and in the image from 2018 (March) when the drought had its peak and finally we will compare with the image from 2020 (February).



SNAP offers a time series analysis tools suitable to represent temporal evolution and improve monitoring activities. In order to be able to compare the images they were produced in batch processing in a way that they all have common naming convention (sensing date_WIs).

Expand each product and open the *Bands* folder. Double click for example on the *NDWI* band of all 16 products [1]-[16] to visualize the NDWI values in each date (wet and dry seasons). Then go to **Window -> Tile Evenly** to synchronize all views.

Produ	ct Explorer × Pixel Info	
-	[1] 20150810_WIs	
	[2] 20160406_WIs	
-	[3] 20160824_Wis	
	[4] 20161202_WIs	
	(5) 20170302_WIs	



Click on the Time Series Analysis button on the main toolbar to open the toolview. In the panel below the **Product Explorer** next to **World View** new tab will appear (as indicated above). In the **Time**

Series Analysis window, press the button to configure your graph and press the icon to add all the open products in SNAP to the time series analysis. Press the refresh icon (), rename the graph to NDWI. Then, click Apply and Close.

	Time Seri	es Analysis Set	tings		0.0
	Add Graph	Show Grid	Show Lege	nd	
iraph 1					
File Name	Туре	Acquisition	Track	Orbit	1 4
0150810 Wis	BandMath	10Aug2015	99999	99999	
0160406 Wis	BandMath	06Apr2016	99999	99999	
0160824 Wis	BandMath	24Aug2016	99999	99999	
0161202_WIs	BandMath	02Dec2016	99999	99999	
0170302 Wis	BandMath	02Mar2017	99999	99999	
0170809 Wis	BandMath	09Aug2017	99999	99999	
0171227_WIs	BandMath	27Dec2017	99999	99999	<u></u>
0180327_Wis	BandMath	27Mar2018	99999	99999	
0180824_Wis	BandMath	24Aug2018	99999	99999	
0181222 Wis	BandMath	22Dec2018	99999	99999	
0190220_Wis	BandMath	20Feb2019	99999	99999	
0190809_Wis	BandMath	09Aug2019	99999	99999	
0191217_WIs	BandMath	17Dec2019	99999	99999	1
0200225 Wis	BandMath	25Feb2020	99999	99999	16 Produ
0200823_Wis	BandMath	23Aug2020	99999	99999	
0201111_Wis	BandMath	11Nov2020	99999	99999	Renar
					1 1
0201111_WIs	BandMath	11Nov2020	99999	9	Appl

Now click on the **Filter Bands** (\square) of the **Time Series Analysis** tool. In the

pop-up window select *NDWI* and click **Ok.** Make sure you select also icon to see the select band values in the position of your cursor. You can see the evolution of the NDWI values of each pixel in the graph, labeled with the year and month. Move to the area in the southern part of the dam and inspect that we can clearly see the differences in water radiometric indices values.

Available Bands	
AWEI MNDWI MNDWIS	
NDWI	
Select all 🔲 Select none	1
<u>o</u> k <u>c</u>	ancel



You can clearly see the seasonality of the NDWI values over different period (wet and dry season). You can also conclude that in the period between late 2016 and until the beginning of 2018 there has been very low NDWI value over the selected area. It suits to the period of the worst drought in this area. Moreover this image gives you also an idea of the pixel values over the water areas (generally the water area is indicated by the NDWI values > 0. We can see that in the period of drought this value In this exact position of cursor dropped to value below 0 which indicates that this pixel was not recognized anymore as water but as non-water area in indicated period. If you want to export the graph, you can do it as a text file (.csv) or as an image. Use the dedicated buttons in the lower right

corner of the **Time Series Analysis Tool** (and and). You can investigate in the same way all other indices. You can find below Time Series graph of MNDWI +5 band which assigns values >0 to non-water areas, water is represented in this case in values 0<. What is important is that again we can see very clearly here the drought period which corresponds to known period of drought in this region.



5.7 STEP 4 | Water area and water mask

The second objective of this training is to explore the differences in the extent of water during the drought period.

The surface water pixels generally appear much brighter than other surfaces (apart from the pixel values derived from MNDWI+5 water index). We will merge now information coming from all 4 Sentinel-2 derived water radiometric indices (NDWI, MNDWI, MNDWI+5 and AWEI) to create a new band for each acquisition date that will contain only water surfaces.

For this purpose we will use a **threshold value** for pixel to be classified as water. For the NDWI, MNDWI and AWEI bands the threshold will be equal to **>=0** but in case of pixel values derived from the MNDWI+5 index pixels with values **below 0** so **(<=0)** represent water surface. First of all simple method to extract the information on water area in different period of time will be presented here. For this purpose we will compare the water area changes in wet season. First open the **MNDWI+5 band** from 3 products: [1]20150810_WIs, [3]20160824_Wis and [6]20170809_WIs by double click on that band.

Then go to **Window -> Tile Horizontaly.** In *Navigation* click on the icon to see the whole area of all products. Then in the panel with tools on the right go to **Mask Manager** Tool.



Here we will create a virtual mask, which will separate water surface in all three images. We will create the mask based on the logical band math expression. To create the first mask click on the icon f(x)

<u>*</u>	New Logical B	and M	aths Expression	• = ×
Data sources:			Expression:	
NDWI	@ and @		MNDWI5<0	
MNDWI MNDWIS	@ or @			
AWEI	not @			
	(@)			
	Constants			
	Operators	-		
Show bands	Functions	-	-	
Show masks				
Show tie-point grids				
🔲 Shaw wig)- Haga				Ok, no errors.
			<u>o</u> k	ancel <u>H</u> elp

New window will open. Then you should see a list of four water indices bands stored in collocated product. In the *Expression* window type: *MNDWI5<0*. Like this we can select only water pixels. Save the equation by clicking **OK**.



You will see that new mask has been created in **Mask Manager.** It is also overlaid over the image from 2015-08-10. Repeat the same steps for other 2 displayed products.

SNAP offers also a possibility to calculate the area of the mask. Because in this case the mask indicates the dam area only, we can use this option to see changes in the extent of this water body during the drought period. We will compare the area of the dam from before the drought (2015) in wet season with water extent from 2016 and 2017 also during the wet season (August).

Select the first view of the image from 2015. To display the mask area navigate to main toolbar on the top of SNAP window. Go to **Raster -> Mask -> Mask area**



In the new window you will see the area of the mask (water) displayed in km². The area of the mask is calculated based on the number of pixels which fall within created mask. Repeat the same steps for other 2 products. Then you can compare the how the water area dropped significantly over two years. What is important is that these changes are visible during the wet season. Later we will assess the changes during all time period including images from dry season as well.

Compute Mask Are	ea - [65] 🔶	© ×	Compute Mask Ar	ea - [67] 🙃	⊡ ×	Compute Mask Ar	ea - [70] 🔶	0 X
Number of Mask pixels:	449904		Number of Mask pixels:	360373		Number of Mask pixels:	195899	
Mask area:	45.082	km^2	Mask area:	36.111	km^2	Mask area:	19.631	km^2
Mean pixel area:	0.000	km^2	Mean pixel area:	0,000	km^2	Mean pixel area:	0.000	km^2
Minimum pixel area:	0.000	km^2	Minimum pixel area:	0.000	km^2	Minimum pixel area:	0.000	km^2
Maximum pixel area:	0.000	km*2	Maximum pixel area:	0.000	km^2	Maximum pixel area:	0.000	km^2
Mean earth radius:	6378,137	km	Mean earth radius:	6378.137	km	Mean earth radius:	6378.137	km
	ОК	Help		<u>o</u> k	Help		<u>o</u> k	Help

To close this window press Ok.

One important drawback of this mask area method in SNAP is that you cannot store the water mask area and you cannot calculate it for several images at once to compare such mask area. That is why in **Extra steps** part of this tutorial you will see how to perform such area analysis in **QGIS**.

Because we want to see the dynamics in water extent during the drought period and compare it with the water extent after the drought we will use **Batch Processing** again. For this we need to first create a new simple graph in **Graph Builder** to be able to process all 16 images simultaneously. We will extract water pixels based on pixel values coming from all four water indices. With this method we will create again a new band that will only contain the water surface.

Now close the current views. Go to **Tools -> Graph Builder.** Add a **Band Math** operator, right click on it and select *Connect graph*.

2	Graph Builder : Graph_water_mask.xml	+ 0 ×
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		=
	Read BandMaths Write	-
•		•
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Nan	ne:	
[1]	20150810_Wis	T
Dat	ta Format Any Format 💌	
	🖺 Load 💁 Save 🍾 Clear 📝 Note 🔞 Help 🕻	> Run

In **Read** operator leave everything as default.

Go to **Band Math** tab and copy and paste following condition statement (expression):

Target Band: vat	er mask						
Farget Band Type: floa	t32	12					
Band Unit:							
No-Data Value: 0.0							
apression. If (M	NDWI >=0 01 NDWI >=0 0	AL MINDY	M2 <=0 0FAWEL>= 0 0FEN 1 EISE 0				
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8	Arithmetic E	xpres	sion Editor				
ata sources:	Arithmetic E	xpres:	Sion Editor Expression:				
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Nata sources: NEWI NIDWI NIDWIS	Arithmetic E:	xpres	sion Editor Expression: if (MNDWI >=0 or NDWI >=0 or MNDWI5 <=0 or AWEI >= 0) then 1 else 0				
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Nata sources: NDWI NDWI5 NWEI Show bands	Arithmetic E @ + @ @ - @ @ * @ @ / @ (@) Constants Operators Functions	xpres	sion Editor Expression: if (MNDWI >=0 or NDWI >=0 or MNDWIS <=0 or AWEI >= 0) then 1 else 0				
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if (MNDWI>=0 or NDWI>=0 or MNDWI5<=0 or AWEI>=0) then 1 else 0

Under **Write** operator do not change anything in the name of the output product. Make sure that you select **GeoTIFF** as output file type. For your output set following *Directory*:

Path: /shared/Training/HYDR03_DroughtMonitoring_WesternCape/Processing/water_mask/

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01500	oro_ma_band	man				
ave a	s: GeoTIFF					
Dire	ectory:					
/ho	ime/rus/share	d/Training/HYL	DR03_DroughtMon	itoring_westerno	.ape/Processing	/water_mask

Once your graph is ready click **Save** and store the graph under the name: **Graph_water_mask.xml.** Store graph under following path:

/shared/Training/HYDR03_DroughtMonitoring_WesternCape/AuxData/

Now we can start process of extracting only water pixels from the collocated product using just created graph. Close **Graph Builder** tool. Go to **Tools -> Batch Processing.** In **I/O parameters** tab we will add all opened products from the **Product Explorer** window [1]-[16] by **Add Opened** The upper right

(second icon from the top) and then click **Refresh** ²² (second icon from the bottom). Like this we have loaded all 16 images from 2015-2020 of the same area. Then:

- a) Deselect option *Keep source product name*
- b) Click on Load Graph at the bottom of the window, and you should now navigate to saved Graph_water_mask.xml file and open it. We see that new tabs have appeared at the top window corresponding to our operators from pre-processing graph.

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20180327 Wis	BandMath	27Mar2018	99999	99999		
20180824 Wis	BandMath	24Aug2018	99999	99999		
20181222 Wis	BandMath	22Dec2018	99999	99999		
20190220 Wis	BandMath	20Feb2019	99999	99999		
20190809 Wis	BandMath	09Aug2019	99999	99999		
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20201111_Wis	BandMath	11Nov2020	99999	99999		
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Target Folder						
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In **Band Math** tab do not change anything. In **Write** tab do not change the output product name. The suffix "_BandMath" will be added to all products. Make sure to save product as GeoTIFF file. Keep the previously set directory: /shared/Training/HYDR03_DroughtMonitoring_WesternCape/Procesing/water_mask. Once Batch Processing parameters are ready click **Run**.

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		L
	Run remote Load Graph Run Close Help	Run remote Load Graph Run Close Help

Processing will last about 1 minute.

After that we can visually compare the water mask generated with the combined threshold from different water radiometric indices with all water indices bands. Below you can see generated water mask (lower right corner) compared to bands of different water indices from 2015-08-10. You can see that this method gave satisfactory results.



5.8 Visualization (QGIS) and comparison

Let's compare now the extent of the Theewaterskloof dam over the years 2015-2020 to see the

evolution of its area. Launch **QGIS Desktop** application. Double click on the icon in your Desktop. In the main window click on Open Project. Navigate to the path /shared/Training/HYDR03_DroughtMonitoring_WesternCape/AuxData/ where QGIS project is stored. Click on the file named: Drought_Monitoring.qgs and open it.

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- 10 - 1		File name: Drought_Monitoring.qgz	Open
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To create a visualization of the dynamics in the Theewaterskloof dam extent the water mask GeoTIFF files created in SNAP (chapter 5.6) were converted to polygons. Then the selection of water areas only was made based on the pixel values (=1) assigned to water surface in the mask. Then the area of all water surface polygons were calculated. All steps of this processing in QGIS is described in details in Extra Steps chapter (6.2).

The final layers which are included in *Drought_Monitoring.qgs* QGIS project are stored in: /shared/Training/HYDR03_DroughtMonitoring_WesternCape/Processing/vectors/water_area_cha nges/folder.

To visualize the layers of the water extent right-click on the first polygon layer and select **Zoom to layer**.

You should be able to see following visualization. Visualization below shows the dynamics in dam extent in dry period from 2016 till 2020.



You can also explore how the dam changed its shape during the wet season when you compare the images from August for all dates. We can see that the dam came back to the original shape in 2020.



Moreover the area of the dam in each 3-4 months period from 2015-2020 was calculated in QGIS. Chart below represents changes in the water surface area, indicating seasonal variations but also the drought period from 2016-2018. Water area from about 42 km2 in 2015 shrunk into about 11 km2 in 2018. We can see also that in 2020 the water area came back to its previous shape. Monitoring seasonal changes in the water level and consecutively also in water area is important in case of the crisis such as the one in 2018 when the Cape Town area almost run out of water for their citizens.



6 Extra steps

6.1 Atmospheric correction

The "Level 1C" data we have downloaded are radiometrically and geometrically corrected (including orthorectification and spatial registration). However, atmospheric correction is applied only to the Level 2A data which are not available for our study site at this time.

TIP 1: Level 2A have been systematically produced for newly acquired products over Europe since the spring of 2017, the coverage has been increasing through 2018 to reach global coverage in the beginning of 2019.

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 NOTE 12) Atmospheric correction is especially important in cases where multi-temporal images are compared and analysed as it is in our case.¹

In this tutorial, we will use the Sen2Cor processor. Sen2Cor is a processor for Sentinel-2 Level 2A product generation and formatting; it performs the atmospheric, terrain and cirrus correction of TopOf-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.

NOTE 12: : The radiance reaching the sensor is a result of following components:

1. Radiation from the sun and, scattered into the field of view of the sensor by the atmosphere without reaching the surface.

2. Direct radiation that goes through the atmosphere without being absorbed or scattered, reaches the sensor after being reflected by the target pixel.

3. Radiation scattered by the atmosphere into the target pixel and reflected back towards the sensor.

4. & 5. Direct or diffuse radiation reflected or scattered by the surrounding areas into the field of view of the sensor. This effect is so called "adjacency effect" or "blurring effect".6. Diffuse radiation coming from the adjacent features into the field of view of the sensor.

7. So-called trapping effect and it is a part of the radiation reflected from the surface into the air column above the surface being scattered and ultimately reaches the sensor.



Go to Optical → Thematic Land Processing → Sen2Cor and select Sen2Cor280.

In the **I/O Parameters** tab, click on "…" next to the product name and navigate to the **Original** folder. Open the **".SAFE"** folder of the 2015 product first. Then open the **MTD_MSIL1C.xml** file. In the **Processing Parameters** tab change the resolution to **"ALL"** and select **"Display execution output".** Click **Run.**

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File Help		File Help
I/O Parameters Processing Parameters		1/O Parameters Processing Parameters
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GRANULE HTML rep_info NSPIRE xml fi INSPIRE xml fi IMTD_MSILIC.xml	S2A_MSIL1C_2015081	0/2+/20-477500 Progress[%]: 55.76 : PID-11676, L2A_Tables: band WVP exported, elapsed time[s]: 28.850, total: 0.24.95, 327265 Progress[%]: 58.28 : PID-11676, L2A_Tables: band TCI exported, elapsed time[s]: 67.429, total: 0.26.02,756082 Progress[%]: 58.30 : PID-11676, L2A_Tables: stop export, elapsed time[s]: 0.515, total: 0.26032,73141 Progress[%]: 10.00 : Application terminated successfully.
Files of Type: All Files	Select Cancel	Run Close Help

This is rather a time demanding process and requires approximately 30 minutes per image (with 30GB RAM). Unfortunately, you need to repeat the same steps for other products as well. So the same procedure should be applied to products [2]-[16]. Close **Sen2Cor** window when all processing is completed.

You will see three new products created at the **Product Explorer** window, named **"Output Product"**. Select them all, right click on them and select **"Close All Products"**. Click **"No"** to the following windows that will appear.

This process creates three new Level 2-A products in the **.SAFE** format in the **Original** folder. Move them to: **/shared/Training/HYDR03_DroughtMonitoring_WesternCape/Original/Level-2A**.

6.2 Calculate the drought area in QGIS

Due to the fact that SNAP software does not offer possibility to extract water area based on the water mask pixels in an automatic way for all 16 bands. This process was added to Extra steps in this tutorial and will be performed in QGIS.

In order to process the data Open **QGIS Desktop** application. Double click on the icon **Desktop**. In the main window select icon **New Project**. In the panel **Browser** navigate to .tiff water masks exported from SNAP in a final step of this exercise. Navigate to the path: /shared/Training/HYDR03_DroughtMonitoring_WesternCape/Processing/water_masks/ select all 16 rasters and drag and drop to the Layers panel below.



Now in order to extract the area of the dam we will need to convert raster files to vector format. To do that we will use batch processing tool in QGIS. First open **Processing Toolbox**. It should be a panel on the right. If you do not see it, in main menu bar go to **View -> Panels -> Processing Toolbox**. Now the panel on the right side of QGIS application should appear. In *Search* window write *"Polygonize"* and select tool **Polygonize (raster to vector).** Double click on this tool and new window will open.

2		Polygonize (Raster to Vector)	
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		0%	II see
lun as Batch Pr	ocess	Run	Close Help

You can perform this step in Batch Processing too in QGIS (note that for this you need to make sure that your QGIS application is up to date, sometimes when new updates are not installed this processing in batch mode will not function).

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If you want to run vectorization only on one image in the tool window select just the image you want to vectorize, go to *Vectorized* box and select directory where your product should be saved. Click **Run** to launch the process. Your vectorized layer should looks like below:



As a result you will receive a polygon layer which will be automatically opened in **Layers panel**. Open attribute table of the polygon (*Vectorized*). Right-click on it in and select **Open Attribute table.** You will see that the attribute table contains only one column "DN" and has two classes. In geotiff raster values = 1 corresponded to water pixels.

So next step will be to select water area from the whole vector file. Go to **Processing Toolbox** again and open tool **"Select by attribute".** In *Input Layer* select your polygon you want to process. Then in the *Selection attribute* leave "DN" column. In *Operator* select "=" and in the window *Value* type **1.** In this way you will select only water polygons. Click **Run.**

2	Select by Attribute	+ -
Parameters Log		Select by attribute
Input layer		This algorithm creates a selection in a
Poly_20150810 [EPSG:32734]	*	features is defined based on the values
Selection attribute		of an attribute from the input layer.
123 DN	•	
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-	*	
Value [optional]		
Modify current selection by		
creating new selection	•	
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kun as Batch Process		Run Close Help

Once the water are selected you will see them highlighted in yellow in QGIS when you go to your polygon layer. Then we should extract selected features to have only the water area.

Go again to Processing Toolbox and select tool Extract selected features.

In a new window which appear you can also process the images in **Batch mode**. Click on the button **Run as Batch Process.** In **Input layer** click on the button next "…" and choose option "Select Open Layers" there click on the option "Select all" and click Ok. Next to the column **Selected features** change assign the output path. Navigate to the folder you want to store your data and select shapefile as a file type. In the small window **Autofill settings** select option "*Fill with parameter values*". In the *Parameter to use option* leave *Input layer*. Click **Run**.

2	Batch Processing - Extr	act selected features	10	E 2
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Input la	yer	Selected features		
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Poly_20161202		g/vectors/water_areas/water_Poly_20161202.sl	200	
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Poly 20201111		g/vectors/water areas/water Poly 20201111.sl	***	
Load layers on completion	<u>I</u>			-121
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		Run Close	He	In.

If you would like to calculate the area of the dam more precisely without having other polygons outside of the dam which have been classified as water (due to noise or other parameters) then you can use the layer named: *ThewaterskloofDam.shp* stored in */AuxData/* folder to clip your all selected polygons. This can also be run in a Batch Process in QGIS. To do this go to **Vector -- > Geoprocessing Tools -- > Clip.** As Input layer select the polygon layer you want to clip. In the option *Overlay* layer select the layer with the extent to which you want to clip your polygon file (*ThewaterskloofDam.shp*). You can also create a buffer of the original dam layer (of for example 30m and then use it to clip your polygons).

		Clip	+ =
Parameters	Log		Clip
Input layer Theswatekof_Dam [EPSG:32734]		1 • [m]	 This algorithm clips a vector layer using the features of an additional polygon layer. Only the parts of the features in the input layer that fall within the polygons of the Overlay layer will be
Overlay laye	er atekof_Dam [EPSG:32734 Telecones criv	1 · · · ·	added to the resulting layer. The attributes of the features are not modified, although properties such as area or length of the features will be modified by the clipping operation. If
Clipped [Create ten Ø Open out	nporary layer] tput file after running algo	vrithm	such properties are stored as attributes those attributes will have to be manually updated.
		0%	1 Canoni

As a next step we will calculate the area of each water layer in 16 polygon shapefiles. For this go to Processing Toolbox and select tool **Add geometry attributes.** You can also run it as batch process which will speed up calculations. As input layers select clipped layers of the water areas from all dates.

	Add Geometry Attributes	• 5
Parameters Log Input layer Clip_water_Poly_20150811 Calculate using Layer CRS Added geom info [Create temporary layer]	0 [EPSG:32734] + 2	Add geometry attributes This algorithm computes geometric properties of the features in a vector layer. It generates a new vector layer with the same content as the input on but with additional attributes in its attributes table, containing geometric measurements. Depending on the generatry type of the table will be different
Open output file after runn	ing algorithm	
☑ Open output file after runn	uing algorithm	II. Canval

Because we would like to see the changes in the water area in all polygon layers we need to merge all the layers now into one shapefile. Go to Processing Toolbox and select tool **Merge vector layers**. In the box *Input layers* select all the layers with the geometry (area and perimeter of the polygon information). Save the file to your directory and click **Run**.

Parameters Log			Merge	vector layers
Input layers			This algorit layers of th	hm combines multiple vecto e same geometry type into a
			single one.	
Destination CRS [optional]	Q Multiple	selection	· · · · · ·	tables are different, the ble of the resulting layer will
Merged	✓ area_clip_water_Poly ✓ area_clip_water_Poly	20150810 (EPS Sele	ect All BW	attributes from all input attributes will be added for laver name and source.
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	4			

Now finally we can assess complete information on the evolution of the extent of the dam.

Go to the last tool you will use in QGIS for this training. Navigate to Processing Toolbox and choose tool **Statistics by categories.** In Input vector layer place Merged polygon. In the field *Field to calculate statistics* select **"area"** field. In the field *Field(s) with categories* select "layer" (as shown below) click Ok. Save the file in .csv format. Click **Run.** At the end you will receive a table with the area of the dam summarized by the name of the layer which indicates the exact sensing date.

		Annan anna anna anna anna anna anna ann	
Parameters Log		Statistics by	categorie:
Input vector layer		This algorithm calcu	lates statistics of
Merged [EPSG:32734]		inelds depending on	a parent class.
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The output of this calculation should looks as below:

		Statis	tics by catego	ry :: Features T	otal: 16, Filtere	d: 16, Selected	1: 0		1.01	e x
3				9						
layer *	count	unique	min	max	range	sum	mean	median	stddev	
area_clip_wa	2	2	1380000	41330300	39950300	42710300	21355150	21355150	19975150	13
area_clip_wa	2	2	594200	24712200	24118000	25306400	12653200	12653200	12059000	59
area_clip_wa	2	2	653100	33660600	33007500	34313700	17156850	17156850	16503750	65
area_clip_wa	2	2	447900	30703100	30255200	31151000	15575500	15575500	15127600	44
area_clip_wa	1	1	20835100	20835100	0	20835100	20835100	20835100	0	20
area_clip_wa	2	2	376000	17409200	17033200	17785200	8892600	8892600	8516600	37
area_clip_wa	3	3	418800	14079800	13661000	14944700	4981566.666	446100	6433432.140	41
area_clip_wa	96	25	100	10428600	10428500	10890300	113440.625	100	1058889.329	. 50
area_clip_wa	2	2	433100	29777200	29344100	30210300	15105150	15105150	14672050	43
area_clip_wa	2	2	516600	33338400	32821800	33855000	16927500	16927500	16410900	51
area_clip_wa	2	2	185900	30301500	30115600	30487400	15243700	15243700	15057800	18
area_clip_wa	2	2	896500	40457200	39560700	41353700	20676850	20676850	19780350	89
area_clip_wa	2	2	1051900	40572000	39520100	41623900	20811950	20811950	19760050	10
area_clip_wa	2	2	743100	36865900	36122800	37609000	18804500	18804500	18061400	74
area_clip_wa	2	2	1403900	43747900	42344000	45151800	22575900	22575900	21172000	14
area_clip_wa	1	1	48901700	48901700	0	48901700	48901700	48901700	0	48
						1				
	layer area_clip_wa	layer count area_clip_wa 2 area_clip_wa 2 area_clip_wa 2 area_clip_wa 2 area_clip_wa 2 area_clip_wa 1 area_clip_wa 2 area_clip_wa 2 area_clip_wa 3 area_clip_wa 2 area_clip_wa 2	Iayer count unique area_clip_wa. 2 2 area_clip_wa. 2 2 <t< td=""><td>Statistic colspan="2">Statistic colspan="2" layer count unique min area_clip_wa. 2 1380000 1380000 area_clip_wa. 2 594200 1 area_clip_wa. 2 653100 1 area_clip_wa. 2 2 653100 area_clip_wa. 2 2 447900 area_clip_wa. 1 1 2000 area_clip_wa. 2 3 36000 area_clip_wa. 2 3 448900 area_clip_wa. 2 3 4000 area_clip_wa. 3 3 41800 area_clip_wa. 2 3 43100 area_clip_wa. 2 3 5000 area_clip_wa. 2 2 10500 area_clip_wa. 2 2 10500 area_clip_wa. 2 2 10500 area_clip_wa. 2 2 10500 area_clip_wa. 2</td></t<> <td>Statistic transmission layer count unique min max area_clip_wa. 2 1380000 41303000 area_clip_wa. 2 594200 247122001 area_clip_wa. 2 594200 3666600 area_clip_wa. 2 63100 3666000 area_clip_wa. 2 2 447900 3666000 area_clip_wa. 1 1 2035100 3685100 area_clip_wa. 2 2 376000 17409200 area_clip_wa. 3 3 100 1428600 area_clip_wa. 2 2 100 1428600 area_clip_wa. 2 2 100 1428600 area_clip_wa. 2 2 100 333400 area_clip_wa. 2 2 18500 301500 area_clip_wa. 2 2 18500 4057200 area_clip_wa. 2 2 10100 4057200</td> <td>Statistic vice vice vice vice vice vice vice vi</td> <td>Statistic by category : Features totic f. Filteret: 16, Filter: 16, Filteret: 16, Filteret: 16, Filteret: 1</td> <td>Statistic bic statistic bic statistic</td> <td>Statistic Unique max range sum media layer count unique min max range sum mean media areaclipuma 2 0 94000 24130300 950300 4210300 2135150 2135150 areaclipuma 2 0 94000 2412000 2418000 203000 205000 20</td> <td>Statistic bic bic bic bic bic bic bic bic bic b</td>	Statistic colspan="2">Statistic colspan="2" layer count unique min area_clip_wa. 2 1380000 1380000 area_clip_wa. 2 594200 1 area_clip_wa. 2 653100 1 area_clip_wa. 2 2 653100 area_clip_wa. 2 2 447900 area_clip_wa. 1 1 2000 area_clip_wa. 2 3 36000 area_clip_wa. 2 3 448900 area_clip_wa. 2 3 4000 area_clip_wa. 3 3 41800 area_clip_wa. 2 3 43100 area_clip_wa. 2 3 5000 area_clip_wa. 2 2 10500 area_clip_wa. 2 2 10500 area_clip_wa. 2 2 10500 area_clip_wa. 2 2 10500 area_clip_wa. 2	Statistic transmission layer count unique min max area_clip_wa. 2 1380000 41303000 area_clip_wa. 2 594200 247122001 area_clip_wa. 2 594200 3666600 area_clip_wa. 2 63100 3666000 area_clip_wa. 2 2 447900 3666000 area_clip_wa. 1 1 2035100 3685100 area_clip_wa. 2 2 376000 17409200 area_clip_wa. 3 3 100 1428600 area_clip_wa. 2 2 100 1428600 area_clip_wa. 2 2 100 1428600 area_clip_wa. 2 2 100 333400 area_clip_wa. 2 2 18500 301500 area_clip_wa. 2 2 18500 4057200 area_clip_wa. 2 2 10100 4057200	Statistic vice vice vice vice vice vice vice vi	Statistic by category : Features totic f. Filteret: 16, Filter: 16, Filteret: 16, Filteret: 16, Filteret: 1	Statistic bic statistic	Statistic Unique max range sum media layer count unique min max range sum mean media areaclipuma 2 0 94000 24130300 950300 4210300 2135150 2135150 areaclipuma 2 0 94000 2412000 2418000 203000 205000 20	Statistic bic bic bic bic bic bic bic bic bic b

Here you can assess other statistical parameters. You can delete the columns which are not of your interest. Enable editing in the table and select option **Delete fields.** The area was calculated in m². You can convert it to km² using **Field calculator** in this attribute table. To do that add a new field and divide the "sum" column by 1000000.

	Q	Field Calculator	1 E .
	12 Day same & many more		
	Create a new field	✓ Update e	xisting field
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OK Cancel			OK Cancel Help

At the end your table will look like this:

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1	260	1 0 ···	13 6 5 6 % 1			
ab	alayer 🔹 =	8			+ Update All	
	layer 🔹	sum	area_km2			
1	area_clip_wa	42710300	42.71			
2	area_clip_wa	25306400	25.31			
3	area_clip_wa	34313700	34.31			
4	area_clip_wa	31151000	31.15			
5	area_clip_wa	20835100	20.84			
6	area_clip_wa	17785200	17.79			
7	area_clip_wa	14944700	14.94			
8	area_clip_wa	10890300	10.89			
9	area_clip_wa	30210300	30.21			
10	area_clip_wa	33855000	33.85			
11	area_clip_wa	30487400	30.49			
12	area_clip_wa	41353700	41.35			
13	area_clip_wa	41623900	41.62			
14	area_clip_wa	37609000	37.61			
15	area_clip_wa	45151800	45.15			
16	Show All Featu	48901700 res _	00 RN			5(7)

You can also visualize now your results as the data are stored in .csv file. You can plot a graph to see the differences in the water extent.

Thank you for following the exercise!

7 Further reading and resources

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