





TRAINING KIT – COAS01

NEARSHORE BATHYMETRY DERIVATION with SENTINEL-2 Case Study: Gulf of Chania, Crete - Greece, August 2018











Research and User Support for Sentinel Core Products

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1 Introduction

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



Gulf of Chania, NW Crete, Greece. Mean Depth by EMODnet.

We will employ RUS to derive the nearshore bathymetry in the Gulf of Chania (Crete, Greece) using Sentinel-2 data.

Recent advances in satellite technology in terms of higher spatial resolution, multi-spectral bands, open data access, etc. have enhanced the ability for the monitoring and management of

coastal areas. Satellite images are to be one of the most potential alternatives to water depth estimation due to the wide area coverage, repeatability, and low cost. Depth retrieval using the Empirical Bathymetry method can follow the approach of: a) Lyzenga et al. (1978, 2006) proposing log-linear correlation between multiband and water depth values, and focusing mainly on removing all other reflected parameters attenuating water bottom signals, and b) Stumpf et al. (2003) using a ratio of bands and the difference in attenuation of different bands in water.

Sentinel-2 is a wide-swath, high-resolution, multi-spectral imaging mission, also supporting water cover monitoring. The acquired data, mission coverage and high revisit frequency are particularly effective for Satellite Derived Bathymetry (SDB) application.

This exercise is focused on SDB using the ratio transform algorithm developed by Stumpf et al. (2003) and Sentinel-2 imagery for depth derivation.

2 Training

Approximate duration of this training session is three hours.

2.1 Data used

 One Sentinel-2 image Level 2A acquired on August 24, 2018. [downloadable @ <u>https://scihub.copernicus.eu/</u>]

```
S2B_MSIL2A_20180824T090549_N0208_R050_T34SGE_20180824T151929
```

 Auxiliary data stored locally at: /shared/Training/COAS01_BathymetryDerivation_Greece/AuxData

2.2 Software in RUS environment

Internet browser, SNAP + Sentinel-2 Toolbox

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 e-mail 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.	CDS-SSO ID			0
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.	Max Idle Time	half a day	Ŧ	0
REGISTER COPERNICUS SSO account	Max Session Time	Until browser close	۲	0
Users who already have a COPERNICUS SSO account can login here:		Login	Reset]
Close		Forgot your password?		

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

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	Your ESA-SSO subscription	data:		
+ Your RUS service	Login			9
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	Institution type	Select one item	v nda	
	Phone number Italy (IT):	+39	price impro-	
	Title	Select one item	~	

4 Request a RUS Copernicus Virtual Machine to repeat a Webinar

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



Select one or more webinars check the field *"I have read and agree to the Terms and conditions of RUS Service"* and then click on **Request Webinar Training** to request your RUS Virtual Machine.

CORRUS General Research and User Support	Se an and	# #	Helo, Georgia
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		You are here: Home > Your	RUS service ~ Your training activities
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You wish to practice a tu » Please select your choi	itorial exercise shown in a RUS webinar? Ice		
Select one or more items	5'		
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I have read and agr	ree to the Terms and conditions of RUS Service.		
	Request Webin	ar Training	

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**.

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Your dashboard								
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Request a new U	lser Servi	ce					9	Chat with Support Desl
Project Name	ID	Date of submission	Status		Actions		Virtual	Environment
State				Follow my project	Get support	Close my service	Access my Virtual Machine(s)	Access my CPU monitoring dashboard
RUS_training1			Open	Cancel my request	Get a webinar kit	Rate my service	Freeze my Virtual Machine(s)	Report a technical incident
					Octa webmar kit	*****	Machine(s)	incident

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

	RUS Desktop
	Username
	Password
	Login
	WELCOME TO RUS' DESKTOP
To log in, e	nter your user name and password and tilck Login.

This is the remote desktop of your Virtual Machine.

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5 Step by step

5.1 Data download – ESA SciHUB

In this step we will download one Sentinel-2 scene from the Copernicus Open Access Hub using the online interface (**Applications** \rightarrow **Network** \rightarrow **Web Browser** or click the link below). Go to <u>https://scihub.copernicus.eu/</u>



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.



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Navigate to Greece (approximate area – green rectangle).

Zoom in over Crete island, switch to "**drawing mode**" and draw a search rectangle approximately as indicated below. Open the search menu by clicking to the left part of the search bar and specify the following parameters:

Sensing period:	From 2018/08/24 to 2018/08/24
Select:	Mission: Sentinel-2
Product Type:	S2MSI2A



Then click on the **"Search"** icon **Q**.

In our case, the search returns 2 results for the time period we set over our area of study. Select the westward one, the: S2B_MSIL2A_20180824T090549_N0208_R050_T34SGE_20180824T151929 and then click on the download icon below.

The product will be downloaded to */home/rus* as zip archive. Move it to the following folder: */shared/Training/COAS01_BathymetryDerivation_Greece/Original*



For the case that you want to use a Level-1C product as mentioned in the Chapter 6.1, download the S2B_MSIL1C_20180824T090549_N0206_R050_T34SGE_20180824T132333 product.

5.2 SNAP – open and explore data

Launch SNAP (icon on desktop). When SNAP opens, click **Open Product**, navigate to the folder in */shared/Training/COAS01_BathymetryDerivation_Greece/Original* and open the Sentinel-2 zipped image. To visualize the product, right click and select **Open RGB Image Window**.

In the new window set the following parameters: **Profile**: Sentinel-2 MSI Natural Colors **Red**: B4 **Green**: B3 **Blue**: B2



The Sentinel-2 MSI scene has 0% cloud cover and was acquired in Level-1C i.e. orthorectified (in cartographic projection), TOA (top-of-atmosphere) reflectance with spatial registration on a global reference system with sub-pixel accuracy.

In the context of this exercise, only bands with 10 meter spatial resolution will be used (See 1), the visible (VIS) Blue (band 2), Green (band 3), Red (band 4) and Near Infrared (NIR) band (band 8).

The selection of bands was based on literature review (Stumpf et al., 2003; Drakopoulou et al., 2018), as the use of blue and green bands seems to be most common in SDB application with a strong linear correlation with depth. The NIR band is used for masking land.

To display the different bands in the View Window, expand the **Bands** folder of the image and double click in on them (B2, B3, B4, B8).

To synchronize the views, go to **Navigation** tab in the lower left (red arrow) and make sure the cursor and the views will are linked.







5.3 Resample

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

Go to **Raster** → **Geometric Operations** → **Resampling**.

In the **I/O Parameters** tab keep as "Source Product" the loaded on SNAP product, and under the "Target Product", set as **Name: S2_MSIL2A_20180824_resampled**.

Select **"Save as**" and under **Directory**: click on the **....**, navigate to the folders and select the appropriate path as: **/shared/Training/COAS01_BathymetryDerivation_Greece/Processing**

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

	Resampling	* • ×		Resam	pling		+ = ×
File Help			File Help				
I/O Parameters Resa	mpling Parameters		1/O Parameters	Resampling Parameters			
Source Product			Define size of re	sampled product			
Name:			By reference	e band from source product:	82		-
[1] S2B_MSIL2A_201808	824T090549_N0208_R050_T34SGE_20180824T151929				Resulting target width	: 10980	
Target Product					Resulting target heigh	t 10980	
Name			O By target wi	dth and height	Target width		10,550
S2_MSIL2A_20180824_r	esampled	D	Cr of inger in	ant and the gran	Target height		10.540-
Save as BEAM-DIM	AP 👻				Width / height ratio	1.00000	
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/shared/Training/ML	T0321_NearshoreBathymetry_Crete/Processing				Resulting target width	1419	
Open in SNAP					wearing argerneig	ir töna	
			Define resampli	ng algorithm			
			Upsampling me	thod:	Nearest		
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			Advanced M	ethod Dennibon by Band			
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		Run Class					class.
		Run Close				B	

Click Run. After the process is completed, if a window appears, click OK. Close the Resampling Window.



A new product [2], named **S2_MSIL2A_20180824_resampled** appeared in the **Product Explorer** Window.

5.4 Subset

Sentinel-2 Level-2A images cover an area of about 100x100 km². To simplify our analysis and focus on the region of interest (ROI) that is of primary interest we can create a subset of the larger scene.

Specify Product Subset Spatial Subset Band Subset Metadata Subset

Keep the resampled product selected and go to **Raster** \rightarrow **Subset**.

In the **Spatial Subset** tab select the **Pixel Coordinates** tab and set the following parameters:



Right click on the subset product that will appear at the Product Explorer Window and click on Save as. Navigate to /shared/Training/COAS01_BathymetryDerivation_Greece/Processing folder and save the product as Subset_S2_MSIL2A_20180824_resampled. When a dialogue window appears click YES.

Right-click the product [3] and click **Open RGB image window** and from the dropdown menu select:

Profile: Sentinel 2 MSI Natural Colors

Click **OK**. We can see that it contains only the area we selected to subset.



Right click on it, close it, and load from the *Processing* folder the saved **Subset_S2_MSIL2A_20180824_resampled** product to continue with our processing steps.

5.5 Land Mask

To proceed with the next steps we have first to mask the land cover in all four bands (B2, B3, B4, B8). Therefore, we have to create a land mask with values consisting of 0 and 1 for land and sea, respectively. NIR band will be used to mask land from the image, since the water appears dark and facilitates to discriminate water from land, which looks much brighter. The mask can be created either with the use of a threshold value of the NIR band that separates land from sea, or a polygon which describes the land. Finally, by applying the land mask in each band we will create a masked image that contains only the aquatic elements.

Right- click on Subset_S2_MSIL2A_20180824_resampled go to Band Maths and set Name: Land_mask

Then click on **Edit Expression** and set at the **Band maths expression**: if B8 > 0.05 then NaN else 1



Click **OK**. In the **Product Explorer Window**, the new band has been added, double click on it to visualize the land mask.



Keep in mind that from now on we will use Band Maths a lot.

To apply the land mask in each of the rest 3 bands we need to work with, right-click on this product **Subset_S2_MSIL2A_20180824_resampled** go to **Band Maths** and set the parameters for band B2:

Name: B2_Land_mask

Band maths expression: B2 * Land_mask

	Band Maths	16 E K		В	and Maths Expres	sion E	ditor	+ = ×
Target product			Data sources:				Expression:	
[3] Subset_S2_M	SiL24_20180824_resampled		view azimuth B12	-	0 + 0		B2 * Land_mask	1
Name:	B2_Land_mask		Land_mask					
Description			scl nodata		6 - 6	_		
Unit:			scl saturated defective		6 * 6			
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Virtual Isave a	expression only, don't store data!		scl_cloud_shadow	_	1.0	_	-	
Replace NaN	and infinity results by	NeN	scl_vegetation	-	(@)	_		
Generate ass	ociated uncertainty band		scl_not_vegetated	-	Constants	-		
Band maths expri	ession		Show bands		Operators	-		
			Show masks		Functions	-		
Load	Save Edit Ex	pressión	Show be-point grids					Ok, no errors.
	QK	Cancel Help					QK	<u>Cancel</u> <u>H</u> elp

Click **OK**. The new band has been added in Product Explorer Window.

Repeat the process for bands B3, B4, B8, giving them the relative name each time:

Name: B3_Land_mask Band maths expression: B3 * Land_mask

Name: B4_Land_mask Band maths expression: B4 * Land_mask

Name: B8_Land_mask Band maths expression: B8 * Land_mask

They will all appear at the product on the left, and they will also open in the **View Window**. Once you check that all of them have been created successfully, you can close the Views. Right click on the product and click **Save**, to store the new bands created.

5.6 Sun Glint Correction

Sun glint is a common phenomenon in satellite images and it essentially refers to the specular reflection of the sun on water surfaces. The water-leaving reflectance can be difficult to observe due to the reflection of direct sunlight on the air-water interface (sunglint) in the direction of the satellite. The viewing geometry of Sentinel-2 satellite makes it vulnerable to sunglint contamination. Sun glint removal is a pre-processing step of multispectral images which is necessary when the amount of sun glint prevents the visibility of the sea bottom, usually in cases of marine habitat mapping.

There are several available sun glint removal methods for high resolution images and coastal applications. In this exercise we will apply the deglint methodology proposed by Hedley et al. (2005) that describes the linear relationships between NIR and visible bands using linear regression based on a sample of the image pixels.

To apply the correction we have to use one or more image samples of sun glinted regions to scale the relationship between the NIR signal and sun glint. These regions are chosen to include a range of pixel glint levels, but an assumed consistent underlying brightness and very low water-leaving reflectance in the NIR, typically deep water areas (Kay et al., 2009). To establish the relationship a linear regression between the two bands is performed over a deep water area, where the contribution from below the water surface is assumed homogenous, and so the derived relationship is only based on the surface reflectance.

Double click on band **B8_Land_mask** and then go to **Vector** \rightarrow **Import** \rightarrow **ESRI Shapefile** to open the image samples **geometry_Polygon** shown below. You can find this file, if you navigate to the following path: */shared/Training/COAS01_BathymetryDerivation_Greece/AuxData*. Once you select it, at the dialogue window that will appear, click **No**.

Then go to the SNAP toolbar and select the **Scatter Plot** to plot the NIR band against the VIS bands.



NOTE 3: The equation (1) described by Hedley et al. (2005) for the deglinting of a multispectral image is: $R'_i = R_i - b_i (R_{NIR} - Min_{NIR})$

where R_i is the deglinted pixel in band i, R_i is the reflectance from visible band i, b_i is the regression slope, R_{NIR} is the NIR band value and the Min_{NIR} the minimum NIR value of the sample.



To deglint a visible wavelength band, a regression is performed between the NIR brightness and the brightness in the visible band using a sample set of pixels, which would be homogeneous if not for the presence of sun glint (e.g. deep water). For other pixels, the slope of the regression is then used to predict the brightness in the visible band that would be expected if those pixels had a NIR value of Min_{NIR} (equation (1)). Min_{NIR} is the NIR value expected from a pixel with no sun glint, which can be estimated by the minimum NIR value found in the sample.

In the Scatter Plot set the following parameters, (Subset_S2_MSIL2A_20180824_resampled selected):

Use ROI mask: geometry_Polygon

X-Axis: B8_Land_mask

Y-Axis: B2_Land_mask

Then click the **Refresh View** 🔯 .

The plot will be created. Right-click on the plot and select **Copy Data to Clipboard**.

		Scatter Plot		23	
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E 0.0375		and the second	- N.	B8 Land mask	-
2 0.0350		Pronerties		Y-Axis	
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0.0225		Zoom Out		B2_Land_mask	-
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0.0	0100 0.0125 0.0150 0.	0. Select Mask 'scatter_plot_area'	0.0250 0.0275	0.030	6

Go on the top left corner of the screen, go to **Applications** \rightarrow **Office** \rightarrow **LibreOffice Calc** open a new sheet and paste the data. Click **OK** to the window that will appear.

Select all cells and go to Edit \rightarrow Cell Protection (make sure the lock is removed, otherwise it will not allow you to perform any analysis on the data). Stretch a bit the columns of the cells if you want, for better visualization.

Select **Columns A and B**. Those are the ones that contain the values we will work with. Go to **Insert** \rightarrow **Chart** and select as **Chart Type** the XY (Scatter) of **Points Only**.

	Cha	rt Wizard			+ ×
Steps 1. Chart Type 2. Data Range 3. Data Series 4. Chart Elements	Choose a Chart Type Bar Pie Area Line XY (Scatter) Bubble Met Stock Column and Line	Points On Line type St Sort by X	Point Point raight : values	s Only	
Help	< Bac	k Next	> F	Inish	Cancel

Click **Next** until you reach the **Data Series.** Choose the **Data Series** having the NIR band (B8) values on X-axis and the VIS band (B2, then B3 and then B4) values on Y-axis.

Set for X-axis: \$Sheet1.\$A\$16:\$A\$718 and for Y-axis: \$Sheet1.\$B\$16:\$B\$718. Then, click Finish.

Remember that what we need to set for **X-axis**, are the values on column A, when you will apply this in your case, you might have a different range than the A16-A718. The same logic applies for **Y-axis**. <u>KEEP THIS IN MIND FOR ALL THE REST SHEETS YOU WILL WORK WITH, FOR EACH OCCASION</u>.

	Ch	art Wiza	rd		• ×
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1. Chart Type 2. Data Range	Subset_S2_MSIL2A_20180824		Name X-Values Y-Values	ame \$Sheet1.\$B Values \$Sheet1.\$A Values \$Sheet1.\$B	
3. Data Series 4. Chart Elements			Range for X-Valu \$Sheet1.\$A\$16	ues :\$A\$718	-
		_	Data labels		
	Add	1			7
	Remove	+			
	Customize Data Ra	nges for	Individual Data	Series	*
Help	< Ba	ack	Next >	Finish	Cancel

This is the initial chart. You can double click on the blue points and modify their colour or width for better visualization.



We now need to perform the **Regression Analysis** to retrieve the slope of the regression and use the values from the R^2 equation. Go to Data \rightarrow Statistics \rightarrow Regression... Under Data, set as before:

For Independent variable(s) (X) range: \$Sheet1.\$A\$16:\$A\$718

For Independent variable(s) (Y) range: \$Sheet1.\$B\$16:\$B\$718

For Results to: \$Sheet1.\$E\$1

Make sure that as Output Regression Type, the Linear Regression is selected. Click OK.

Re	gression	+ = ×
Data		
Independent variable(s) (X) range:	\$Sheet1.\$A\$16:\$A\$718	4
Dependent variable (Y) range:	\$Sheet1.\$B\$16:\$B\$718	7
Both X and Y ranges have labels	5	
Results to:	\$Sheet1.\$E\$1	7
Grouped by		
Columns	O Rows	
Output Regression Types		
Linear Regression		
 Logarithmic Regression 		
O Power Regression		
Options		
Confidence level 0.95		
Calculate residuals 🔲 Force i	intercept to be zero	
нер	OK	Cancel

The Regression results will appear on the Sheet.

Click on the Data Points within the chart, once. Then right-click on them and select **Insert Trend Line**. You can also modify its colour and width if you double click on it. Then right click again and select **Insert R² and Trend Line Equation.** The number in the red rectangle below, is the number we need for B2.



When you have reached that step, you can **Save** the Sheet with the name **B2_Land_mask** under the */shared/Training/COAS01_BathymetryDerivation_Greece/Processing* folder.

Repeat the process from 5.6 chapter so far, for bands B3 and B4 as well.

Now let's continue with the deglint steps in SNAP. Right-click again at the product we are working on, go to **Band Maths** and set the following parameters for deglinting band B2:

Name: B2_deglint

Band maths expression: B2_Land_mask - 0.91574 * (B8_Land_mask - 0.001)

Band Maths		Bi	and Maths Express	on E	ditor		* = ×
Target product	Data sources:				Expression:		
(3) Subset_S7_MSIL7A_20180824_resampled	view_azimuth_Bl1	-	0 + 0		B2_Land_mask - 0	.91574 *	(B8_Land_mask -
Name: I B2_deglint	view_zenith_B12		8.8	-	0.001)		
Description	view_azimuth_B12		6.6	_			
Unit	Land_mask		6 * 6				
Spectral wavelength: 0.0	B2_Land_mask		0/0				
Virtual (save expression only, don't store data)	B3_Land_mask		101	-			
Replace NaN and infinity results by NaN	B4_Land_mask		(@)	-			
Generate associated uncertainty band	B8_Land_mask		Constants	-			
Band maths expression.	Show bands		Operators	-			
	Show masks		Functions	-			
Load Save Edit Expression	Show be-point grids						Ok, no errors.
QK Cancel Help						ok s	ancel <u>H</u> elp

Accordingly, set the following parameters for deglinting band B3 and band B4:

Name: B3_deglint

Band maths expression: B3_Land_mask - 1.00116 * (B8_Land_mask - 0.001)

Name: B4_deglint

Band maths expression: B4_Land_mask - 1.0223 * (B8_Land_mask - 0.001)

Right click and **Save** the product.

To visualize the correction for sun glint, right-click on the **Subset_S2_MSIL2A_20180824_resampled** product and select **Open RGB Image Window**.

Select the following parameters:

	Select RGB-Image Channels			Red : B4_deglint
Profile: Sentine	el 2 MSI Natural Colors (modified)	88		Blue: B2_deglint
Red:	\$3.B4_deglint	-		
Green:	\$3.B3_deglint	-		
Blue:	\$3.B2_deglint	-		
Stor	Expre re RGB channels as virtual bands in current p	roduct	Help	



You can open an RGB image if you want before applying the sunglint correction and compare them.

5.7 Dark-Object Atmospheric Correction

Dark Object Subtraction (DOS) is an empirical atmospheric correction method which assumes that reflectance from dark objects includes a substantial component of atmospheric scattering. This atmospheric offset generated from the image itself can be removed by subtracting this value from every pixel in the band. However, this value is different for each band and can be also estimated as the value of the histogram's cut-off point at the lower end (Chavez, 1998). The most effective dark target would be optically-deep water with expected zero reflectance.

Right-click again on the **Subset_S2_MSIL2A_20180824_resampled** product, go to **Band Maths** and set the parameters for band **B2_deglint**:

Name: B2_DOS

Band Maths	× 📕	В	and Maths Express	ion E	ditor	+ = ×
Target product	Data sources:				Expression:	
(3) Subset_52_M5IL2A_20180824_resampled	B3_Land_mask	•	0+0		B2_deglint - 0.005	
Name: IB2_DOS Description	B4_Land_mask B8 Land_mask	-	0 - 0			
Unit	B2_deglint		6 * 6			
Spectral wavelength: 0 0	B3_deglint	-11	@/@			I
Replace NaN and infinity results by	sk scl_nodata		(@)			
Generate associated uncertainty band	scl_saturated_defective		Constants	-		
Band maths expression	Show bands		Operators	-		
	Show masks		Functions	-		
Load Save Edit Expression	Show be-point grids					Ok, no errors.
QK. Cancel Help					<u>OK</u> C	ancel <u>H</u> elp

Band maths expression: B2_deglint - 0.005

Also, set the following parameters for <u>only</u> the band **B3_deglint**:

Name: B3_DOS

Band maths expression: B3_deglint - 0.001

You can derive the 0.005 and 0.001 values if you create a histogram for each band, and just keep the minimum value it has. E.g.: 0.001 is the value for band B3_deglint. Right click the product and **Save** it.



5.8 Satellite Derived Bathymetry

For the derivation of the bathymetry data from the Sentinel-2 image we will adopt the model developed by Stumpf et al. (2003), based on the principle that each band has a different absorption level over water and this diversity level theoretically will produce the ratio between bands. This ratio then will generate a simultaneous change when the depth changes. (See INOTE 4).

For this exercise, the ratio will be applied for the pair of Blue-Green (B2-B3) bands and for n = 1000. In order to define the constants of Equation 2 (See \square NOTE 3), calibration dataset of points with known depths are also required. The available multi and single beam echo sounding data have been derived from the Hellenic Centre for Marine Research, Hellenic National Oceanographic Data Centre (HCMR/HNODC) (<u>https://www.hcmr.gr/en/</u>), published in Drakopoulou et al. (2018).

NOTE 4: The ratio model of Stumpf et al. (2003) is given in the following equation (2):

$$Z = m_1 \frac{\ln(nR_w(\lambda_i))}{\ln(nR_w(\lambda_j))} - m_0$$
where Z is the estimated depth, m₁ is a tunable constant to scale the ratio to depth, n is a fixed constant for all areas, R_w is the reflectance of water for bands i or j, and m₀ is the offset for a depth of 0 m (Z=0). The fixed value of n is chosen to assure both that the logarithm will be positive under any condition and that the ratio will produce a linear response with depth.

Right click again on the product and go to **Band Maths** to calculate the band ratio of equation (2) by setting the following parameters:

Name: B3B2

Band Maths R Band Maths Expression Editor arget product Data sources xpression: log(1000 * B3_DOS) / log (1000 * B2_DOS) [3] Subset 52 MSIL2A 20180824 resampled 81 6+6 8382 82 6 . 6 Description B3 6.6 **B**4 ength 0.0 85 @ / @ rtual (save expression only, don't store data BG (0) Feplace NaN and infinity results by 87 Constants., BB -Generate associated uncertainty band id maths expression Show bands Operators., -Show masks Functions... -E E 2 2 3 Load. Save... <u>о</u>к QK. Cancel Hels Cancel Help

Band maths expression: log (1000 * B3_DOS) / log (1000 * B2_DOS)

Click OK.

We now proceed with the automatic extraction of pixel values in both bands from geographical coordinates of all the bathymetric data points by using **text/*.csv** file. Go to **Raster** \rightarrow **Export** \rightarrow **Extract Pixel Values**.

Check that the product at Source path is Subset_S2_MSIL2A_20180824_resampled and in the Input/Output tab define the Output directory as: /shared/Training/COAS01_BathymetryDerivation _GreeceProcessing

In **Parameters** tab select **Add measurements from CSV file** in the upper right corner. Add the file **bathy_coord** from */shared/Training/COAS01_BathymetryDerivation_Greece/AuxData* folder. In addition, unselect **Tie-point grids** and **Masks** boxes and check **Include original input** box.

	Pixel Extraction + 7		Pixel Extraction	10 S. N
File Help		File Help		
Input/Output	Parameters	Input/Output Parameters		
Source Paths:	(3) Subset_S2_MSIL2A_20180824_resampled	Coordinates Allowed time difference: Export: Window size Pixel value aggregation methor Expression:	Name Latitude Longtude DateTime (UTC) 000000041 55 5566 23 8480 0 000000043 55 5506 23 8480 0 000000045 55 5278 23 8480 0 000000045 55 5278 23 8480 0 000000045 55 5278 23 8480 0 000000045 55 55278 23 8420 0 000000045 55 55278 23 8420 0 000000045 55 55278 23 8420 0 000000045 55 55278 23 8420 0 0 0 Use time difference constraint 0 0 0 0 Bands Tre-point grids Masks 0 0 0 Use expression Edit Ejorest sont 0 0 0	2 3
Time extraction:	Bitract time from product filename Date/Time pattern Investmin Time extraction pattern & filename Informediate Statement	Sub-scenes	Sets: The anomanism religit rat be applied to all products Uses extremented as filler Copier expression exact: Enable expert E	
Output directory:	. /home/rus/shared/Training/MLT0321_NearshoreBathymetry_Crete/Processing	Google carbi export.	Export output coordinates to woogle Earth (KMZ)	
File prefix:	pixEx	Match with original input:	include original input	
	Extract Close He		t Estract Cit	ise <u>H</u> elp

Click Extract.

SNAP creates the following two files in the **Processing** folder:

- pixEx_productIdMap.txt
- pixEx_S2_MSI_Level-2A_measurements.txt

Go to **Applications** \rightarrow **Office** \rightarrow **LibreOffice Calc** and go to **File** \rightarrow **Open:** pixEx_S2_MSI_Level-2A_measurements.txt, from */shared/Training/COAS01_BathymetryDerivation_Greece/Processing*

We will perform again a Regression Analysis, like we did before. This time select Columns BT and B.

Go to **Insert** \rightarrow **Chart** and select as **Chart Type** the XY (Scatter) of **Points Only**. Click **Next** until you reach the **Data Series**.

Choose the **Data Series**, set the **B3B2** band values on X-axis and the **Depth** (in meters) values on Y-axis.

Set for **X-axis**: \$'pixEx_S2_MSI_Level-2A_measurements'\$BT\$8:\$BT\$54 and for **Y-axis**: \$'pixEx_S2_MSI_Level-2A_measurements'\$B\$8:\$B\$54

Then, click Finish.

By performing the regression analysis of the data we derive the constants m_1 and m_0 as per Stumpf et al. (2003), while the R^2 indicates the correlation value.

Go to **Data** \rightarrow **Statistics** \rightarrow **Regression**... Under **Data**, set as before:

For Independent variable(s) (X) range: \$'pixEx_S2_MSI_Level-2A_measurements'\$BT\$8:\$BT\$54

For Independent variable(s) (Y) range: \$'pixEx_S2_MSI_Level-2A_measurements'\$B\$8:\$B\$54

For **Results to**: \$'pixEx_S2_MSI_Level-2A_measurements'\$BV\$1

Make sure that as **Output Regression Type**, the **Linear Regression** is selected. Click **OK**.

Click on the Data Points within the chart, once. Then right-click on them and select **Insert Trend Line**. You can also modify its colour and width if you double click on it. Then right click again and select **Insert R² and Trend Line Equation**.



From this equation, we keep as $m_1 = -37.118$ and as $m_0 = +41.926$

To estimate the satellite bathymetry, right click on the **Subset_S2_MSIL2A_20180824_resampled** product and go to **Band Maths**.

Set the following parameters for equation (2):

Name: SDB

Band maths expression: -37.118 * B3B2 + 41.926

Band Maths C C X		Band Maths Expression B	Editor 🔹 📼 🛪
Target product:	Data sources:		Expression:
[3] Subset_S2_MSIL24_20180824_resampled	B1	0+0	-37.118 * B3B2 + 41.926
Name: SBD	B2		
Description	B3	6 - 6	
Unit	B4	6 * 6	
Spectral wavelength 0.0	85	8/8	1
Virtual (save expression only, don't store data)	B6	ere	
Replace NaN and infinity results by NaN	B7	(@)	
Generate associated uncertainty band	88	Constants 🔻	
Band maths expression:	Show bands	Operators 🔻	
	Show masks	Functions 👻	
Load, Save Edit Expression	Show be-point grids		Sk, no errors.
QK Cancel Help			QK Cancel Help

Click **OK**. Double click on the SDB band that had been created at the product on the left, to visualize it.

Go to the **Colour Manipulation** tab and load a colour palette. Click on the *Import colour palette from text file icon*, navigate to */shared/Training/COAS01_BathymetryDerivation_Greece/AuxData* folder and select set the Bathymetry palette. Click **Open**. Then set the following data display range:

Min: 0.0

Max: 24.0



Go in the **Pixel Info** tab on the left, and the pixel information will be displayed while you move the mouse over the band image view.

Save the product.

We will now continue to the Sen2Coral Processor.

5.9 Sen2Coral

Sen2Coral plugin for SNAP toolbox is based on the exploitation of the Sentinel-2 mission for mapping (habitat, bathymetry, and water quality) and detection change for coral reef health assessment and monitoring. Sen2Coral includes the automatic processing for sun glint correction and Empirical Bathymetry Estimation:

5.9.1 Deglint Processor

Go to Optical \rightarrow Thematic Water Processing \rightarrow Sen2Coral \rightarrow Processing modules \rightarrow Deglint Processor.

In the **I/O Parameters** tab, select the opened image **Subset_S2_MSIL2A_20180824_resampled** in the Source Product field and leave the default output name for the target product name.

Define the directory as /shared/Training/COAS01_BathymetryDerivation_Greece/Processing

In the **Processing Parameters** tab set the following parameters:

Sun Glint Areas: geometry_Polygon (make sure you write it exactly like that, orelse, it will not be read)

Source Bands: B2, B3, B4

Reference Band: B8

Deglint 🔹 🗉 😣		Deglint	+ = ×
e Help	File Help		
I/O Parameters Processing Parameters	1/O Parameters	Processing Parameters	
Source Product	Sun Glint Areas:	geometry_Polygon	
[3] Subset_S2_MSIL2A_20180824_resampled		81 82 83	
Target Product	Source Bands:	84 85 86	
Subset_S2_MSIL2A_20180824_resampled_deglint		B7 B8	*
Directory: _T0321_NearshoreBathymetry_Crete/Processing		B1 B2 B3	
Open in SNAP	Reference Band:	B4 B5 B6	
		B7 B8	
	Include refer	ence bands in output product	
	MinNIR string:	-1.0	
	🖌 Mask all neg	ative reflectance values	
<u>R</u> un <u>C</u> lose		Bun	Close

5.9.2 Empirical Bathymetry Processor

The Empirical Bathymetry processor maps bathymetry based on regression of log band ratio (Lyzenga method). Ancillary data are required of known bathymetry.

Go to **Optical** \rightarrow Thematic Water Processing \rightarrow Sen2Coral \rightarrow Processing modules \rightarrow EmpiricalBathymetry Processor.

In the **I/O Parameters** tab, select the same image again in the Source Product field and <u>leave the</u> <u>default output name for the target product name</u>.

Define the directory: /shared/Training/COAS01_BathymetryDerivation_Greece/Processing

In the **Processing Parameters** tab, the bands used to estimate the bathymetry have to be selected, as well as the full path to a file containing the set of bathymetry point data (latitude, longitude, depth). Set the following parameters:

Bands to be used: B2_DOS, B3_DOS

Bathymetry point data: /shared/Training/COAS01_BathymetryDerivation_Greece/AuxData/ bathy_points.csv

N value: 10000.0 (default)

e neip	rite rielp	
I/O Parameters Processing Parameters	1/O Parameters Pro	cessing Parameters
Source Product Source product: [3] Subset_S2_MSIL2A_20180824_resampled Target Product Name: ubset_S2_MSIL2A_20180824_resampled_empBathymetry Save as: BEAM-DIMAP	Bands to use:	B3_Land_mask B4_Land_mask B8_Land_mask B2_deglint B3_deglint B4_deglint B2_DOS B3_DOS B3B2 SBD
TO321_NearshoreBathymetry_Crete/Processing Open in SNAP	Bathymetry point data. N value:	rete/AuxData/bathy_points.csv

Click Run.

In the **Product Explorer Window**, the new product is created. Double click on its band to visualize it.

Go to the **Colour Manipulation** tab and load a colour palette. Click on the *Import colour palette from text file icon*, navigate to */shared/Training/COAS01_BathymetryDerivation_Greece/AuxData* folder and select set the Bathymetry palette. Click **Open**. Then set the following data display range:

Min: 0.0

Max: 24.0



THANK YOU FOR FOLLOWING THE EXERCISE!

6 Extra steps

6.1 Atmospheric Image Correction

This step refers to the case that you use a Level-1C image instead of a Level-2A.

To atmospherically correct Sentinel-2 observation data over water bodies we will use iCOR Sentinel-2 plugin for SNAP toolbox. iCOR allows the corrections for atmospheric effects for coastal and transitional waters, while it corrects adjacency effects and improves the image quality at the water-land boundary. The iCOR algorithm (version 2.0) is an image-based correction which attempts to determine the aerosol optical thickness using the spectral variability of land pixels in the scene. You can find additional information in the existing literature (De Keukelaere et al., 2018). The generated output contains Bottom-Of-Atmospheric (BOA) reflectance, which are above water-leaving-reflectance. (For more info about the installation of the plugin, click here)

When the plugin is loaded in SNAP, the tool can be accessed through **Optical** \rightarrow **iCOR** \rightarrow **iCOR**-S-2.

In the **I/O Parameters** tab, select the opened image in the source product field and leave the default output name for the target product name.

	ICOR-SENTINEL-2	• E ×
le Help		
I/O Parameters	Processing Parameters	
Source Product		
Source product:		
[1] S2B_MSIL1C	20180824T090549_N0206_R050_T34SGE_20180	624T132333 🔻
S2B_MSIL1C_20	180824T090549_N0206_R050_T345GE_20180824	T132333_processed
Directory		
Open in SNAM		
	Run	Close Help

In the **Processing Parameters** tab adapt the default parameters but also select the **Simecoption** to apply adjacency correction over water bodies.

	ICOR-SENTINEL-2	↑ □ ×
File Help		
I/O Parameters Proces	ing Parameters	
Display execution output		
Target product file:	[/tmp/S2B_MSIL1C_20180824T090549_N0206_R050_T34SGE_20180824T132333_processed.tif	
Keep intermediate:	false	-
Waterband:	B08	-
Watermask:		0.05
Cloudaveragethreshold:		0.19
Cloudlowbandid:	801	-
Cloudlowthreshold:		0.25
🖌 Cloudmaskoption		
Cloudmaskcirrusthreshold		0.01
 Aotoption 		
Aotoverride:		0.1
Wvoption		
Watervaporoverride:		2.0
Simecoption		
Adjwindow:		1
	<u>R</u> un <u>C</u> lose	<u>H</u> elp

For Sentinel-2, three output files are created for each tile in the /tmp/ file:

- *_60M.tif containing all spectral information at 60 m spatial resolution
- *_20M.tif only bands with original spatial resolution of 20 m
- *_10M.tif only bands with original spatial resolution of 10 m

For the purpose of this exercise we will use the output product of 10-meter spatial resolution. Open the product in SNAP and then expand the **Bands** folder. The product contains four bands which correspond accordingly to VIS bands B2, B3, B4, and NIR band B8.

1	(0)1	1.1	B02	Ĺ	490	1	65	1	10	L
1	(1)2	1	B03	T.	560	1	35	1	10	1
1	(2)3	1	B04	1	665	1	30	1	10	I.
1	(3)4	1	B08	1	842	1	115	1	10	1

Save the product as **S2B_MSIL1C_20180824_10M** at the: /shared/Training/COAS01_BathymetryDerivation_Greece/Processing folder and load it on SNAP.

During this process some negatives reflectance values were created in the open sea due to water conditions. In this case we have to exclude them from the bands. Right click on the product and select **Band Maths**. Set the parameters:

Name: B2

Band maths expression: if band_1 < 0 then NaN else band_1



Repeat the step for the rest of the bands, accordingly:

Name: B3

Band maths expression: if band_2 < 0 then NaN else band_2

Name: B4

Band maths expression: if band_3 < 0 then NaN else band_3

Name: B8

Band maths expression: if band_4 < 0 then NaN else band_4

Finally, right click and **Save** the product. These will be the bands that you will use for the next steps.

Then you can continue with the exercise applying all steps from Chapter 5.4 and on.

6.2 Downloading the outputs from the VM

In your VM, press Ctrl+Alt+Shift.

A pop-up window will appear on the left side of the screen. Click on the bar below **Devices**, navigate to the folders you have saved the files you want to download and **double click** on them. The downloading process to your local computer will start automatically.



7 Further reading and resources

SENTINEL-2 MSI Introduction – https://sentinel.esa.int/web/sentinel/user-guides/sentinel-2-msi/

ESA Sentinel Online – <u>https://sentinel.esa.int/web/sentinel/missions/sentinel-2</u>

Science Toolbox Exploitation Platform (STEP) – <u>http://step.esa.int/main/toolboxes/sentinel-2-toolbox/</u>

iCOR plugin for SNAP for OLCI data -

https://cdn2.hubspot.net/hubfs/2834550/marketing/MAILS/iCOR/iCORpluginUserManual_OLCI_v1. 0.pdf

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