





TRAINING KIT – OCEA05

SEN2CORAL TOOLBOX FOR CORAL REEF MONITORING GREAT BARRIER REEF, AUSTRALIA









Research and User Support for Sentinel Core Products

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

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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

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



BEFORE AND AFTER Healthy coral are full of colour, like the fire coral seen on the left. But stressors, including overly warm ocean water, cause symbiotic algae to abandon coral tissues, bleaching them (right). Credits: sciencenews.org (XL CATLIN SEAVIEW SURVEY)

The Great Barrier Reef (GBR) is the largest coral reef ecosystem on Earth. It stretches for thousands of kilometres along the coast of eastern Australia. The reef represents an immense natural and economic value and has been declared UNESCO World Heritage site in 1981.

In recent decades, there has been a growing concern regarding the deterioration of the GBR ecosystem health. It has been reported that between 1985 and 2010 51% of the

coral in the central and southern parts of the GBR has died as a result of combined effects of climate change-related causes such as severe heat waves, cyclones and invasive species outbreaks.

Sentinel-2 allows to monitor the majority of the world's coral reefs with increased temporal and spatial resolution. Sen2Coral toolbox available in SNAP has been specifically developed and validated for this purpose.

2 Training

Approximate duration of this training session is two hours.

The Training Code for this tutorial is OCEA05. If you wish to practice the exercise described below within the RUS Virtual Environment, register on the RUS portal and open a User Service request from Your RUS service \rightarrow Your dashboard.

2.1 Data used

A cloud-free Sentinel-2A Level 1C tile (Tile ID: T55LCD) acquired on July 21, 2016 [downloadable
 <u>https://scihub.copernicus.eu/</u>]

S2A_MSIL1C_20160721T004002_N0204_R059_T55LCD_20160721T003959

 Bathymetry training and validation datasets provided by John Hedley and derived from the 20m DEM/DDM for Lizard island:

Leon, Javier X; Phinn, Stuart R; Hamylton, Sarah; Saunders, Megan I (2012): A 20 m spatial resolution seamless multisource Digital Elevation/Depth Model for Lizard Island, northern Great Barrier Reef.

2.2 Software in RUS environment

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

3 Register to RUS Copernicus

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

CORRUS Research and User Support	
The RUS Service * The RUS Offer * The RUS Library * The RUS Community *	
	Senth
	News from RUS
	One year on!
	Copernicus Info Session - Reykjavik - 19 September 2018
	SPIE Remote Sensing 2018 – Berlin (Germany) – 11-12 September 2018
	SIWI World Water Week 2018 – Stockholm – 26-31 August 2018
	MedRIN Kick-off Meeting - Chania - 13 & 14 July 2018
	RUS Webinar – Special edition "AskRUS – Sentinel-1" – 12 July 2018
Welcome to Research and User Support	RUS Training Session – Valencia – 22 July 2018
	IGAR55 2018 - Valencia - 22-27 July 2018
Welcome to the Copernicus Research and User Support (RUS) Service portal!	The RUS agenda
The RUS Service is the "New Expert Service for Sentinel Users" funded by the European Commission,	Conferences & Workshops

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



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

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

Login / Register	Credentials			-
Login / Register Digin / Register The registration system to access the RUS service platform has moved toward the COPERNICUS Single Sign On authentication server. New Users who have not yet registered to the RUS portal shall first create a COPERNICUS SSO account. Note that your Copernicus SSO account will be activated only after the reception of the third email sent by the Copernicus service. We advise you to consult this document and this page to facilitate your registration procedure. REGISTER COPERNICUS SSO account Users who already have a COPERNICUS SSO account can login here: Login	CDS-SSO ID Password Max Idle Time Max Session Time	half a day Until browser close	Reset	0 0 0
Close		Forgot your password?		

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

The RUS Service * The RUS C	Do you want t	o subscribe for a new RUS account	? É		
	Your ESA-SSO subscription	data:			
+ Your RUS service	Login			9	
This section gathers pages estimated in m	FirstName				
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· Your dashboard: allows you to ac-	Organization				
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	Select one or more items	newsletter			10
		social media	and a second		1.20
		other		1	
	Institution type	Select one item	× Pda		
	Phone number Italy (IT):	+39	2/63		Series.
	Title	Select one item	~		1000

4 Request a RUS Copernicus Virtual Machine

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

The RUS Service * The RUS Offer * The RUS Library * The RUS	Community Vour RUS service •
Your RUS service	Your profile You are here: Home > Your RUS Your dashboard Your training
 Your profile: displays your personal information linked to your ESA SS Your dashboard: Illows you to access your private dashboard, Your training: allows you to register to a training session you have been selected as the session you have been your training session you have been your training session you have been your to register to a training session you have been your your training session you have been your your your your your your your your	And RUS accounts, One year on! Copernicus Info Session – Reykjavik – 19 September 20 SPIE Remote Sensing 2018 – Berlin (Germany) – 11-12 September 2018 SIWI World Water Week 2018 – Stockholm – 26-31 August 2018
	MedRIN Kick-off Meeting - Chania - 13.6.14 July 2018 RUS Webinar - Special edition "AskRUS - Sentinel-1" - July 2018 RUS Training Session - Valencia - 22 July 2018 IGARSS 2018 - Valencia - 22-27 July 2018

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

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

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

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	shubs?
Yes	
© No	
Have you already handled/processed Copernicus data?	
W 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
HAZA01 - Flood Mapping in Malawi	
HAZA02 - Burned Area Mapping in Portugal HYDR01 - Water Bodies Mapping over Northern Poland	
LAND01 - Crop Mapping in Seville	
LAND04 - Land Monitoring in Cyprus	-
OCEA01 - Ship Detection in Gulf of Trieste	
If you wish to request another tutorial exercise that doesn't appear in the above	list, please type here
its name or code. Note that you can request multiple tutorial exercises.	

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

Summary information on your request:					
This is a collection of information selected 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:					
Thematicarea	Cryosphere (ice and snow)				
Operations to perform on RUS	Algorithm development				
Preference for downloading process	Self-downloading				
Foreseen activities and support needs	Develop a land cover classification				
Project name	RUS_Project1				
Earth Observation Data information:					
Type of Earth Observation Data:					
Sentinel-1	1				
	S1-Product 1				
S1 - Product type	GRD				
S1 - Sensor mode					
S1 - Polarisation	a				
S1 - Orbit direction	1.1.8				
Sentinel-2	x				
Sentinel-3	X				
Other	x				
l don't know	×				
Region of Interest: Min Latitude	30 3303				
MaxLatitude	40.5877				
Min Longitude	-4.6736				
MaxLongitude	-2 7205				
Reference polygons	2,203				
Data acquisition date(s)-					
None					
Additional data specifications					
I have read and agree to the Terms and	conditions of RUS Service.				

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

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Your dashboard								
Request a new L	Jser Servi	ce					2	Chat with Support Desk
	1	Data of						
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	-		~	Follow my project	Get support	Close my service	Access my Virtual Machine(s)	Access my CPU monitoring dashboard
lUS_training1	231	2017-08-31	Open		Get a webinar kit	Rate my service	Freeze my Virtual Machine(s)	Report a technical incident

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



This is the remote desktop of your Virtual Machine.

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5 Sen2Coral

The Sen2Coral toolbox has been developed in the scope of the ESA SEON Programme Sen2Coral the objective of which is the is the scientific exploitation and validation of Sentinel-2 imagery for coral reef mapping (habitat, bathymetry and water quality) and change monitoring. (*Sen2coral User Guide*)

The toolbox contains six modules developed to support the four main processing chains designed by the Sen2Coral project.



We will explore each of the available modules and their purpose, with the exception of the Physics based model inversion (SWAM).

6 Step by step

6.1 Data download – ESA SciHUB

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

es:	a opermicus	Copernicus Open Access Hub	SCHIME LOGIN @ A
		Register new account	
	Sentinel data access is free	e and open to all.	
	On completion of the registrati the data. Username field accepts only a	ion form below you will receive an e-mail with a link to validate your e-mail address. Following this you can so to dow Iphanumeric characters plus **, **, *_* and **	micad
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After you have filled in the registration form, you will receive an activation link by e-mail. Once your account is activated or if you already have an account, "LOGIN".

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Switch the rectangle-drawing mode to pan mode by clicking on the "**Pan**" icon in the lower left corner of the map (**Green arrow**) and navigate over the Great Barrier reef (blue rectangle).



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

Sensing period:	From 2016/07/21 to 2016/07/21
Check Mission:	Sentinel-2

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🖉 linsert search criteria	Autorom	8 9	
		2×	6
Sort By.	» Order By		
Sensing Date •	Descending		
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Mission: Sentinel-3		Cape Tribulation	0
	1	and the second se	

Press "**Search**" (red arrow below). In our case, the search returns a single result depending on the exact search area defined. Download the scene:

S2A_MSIL1C_20160721T004002_N0204_R059_T55LCD_20160721T003959

Data will be downloaded to /home/rus/Downloads as ZIP archive. Move the archives to /shared/Training/OCEA05_Sen2Coral_GBR_TutorialKit/Original.



6.2 Atmospheric correction

Solar radiation reflected by the Earth's surface to satellite sensors is affected by its interaction with the atmosphere. The objective of applying an atmospheric correction is to determine true surface (Bottom-Of-Atmosphere, BOA) reflectance values from the Top-Of-Atmosphere (TOA) reflectance

values, by removing atmospheric effects. (See 🛄 NOTE 1) Atmospheric correction is especially important in cases where multi-temporal images are compared and analysed.



In this tutorial, we are using the Sentinel-2 Level-1C data as Level 2A data are not yet available for our study area and acquisition date (July 2016). 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.

Therefore, we need to use the Sen2Cor processor for Sentinel-2 Level 2A product generation and formatting; it performs the atmospheric, terrain and cirrus correction of Top-Of-Atmosphere Level 1C input data. Sen2Cor creates Bottom-Of-Atmosphere, optionally terrain and cirrus corrected reflectance images; additional, Aerosol Optical Thickness, Water Vapor, Scene Classification Maps and Quality Indicators for cloud and snow probabilities.

The Sen2Cor must be applied to data before any other processing steps. First, using a file manager go to /shared/Training/OCEA05_Sen2Coral_GBR_TutorialKit/Original

and unzip the zipped product archive. Right-click on the product and select Extract Here.

Sen2cor can be executed both via command line and via the graphical interface in SNAP. Here, we will use the command line. Inside the Original folder right click and select **Open Terminal Here**.



In the command line window, type:

```
L2A_Process ./S2A_MSIL1C_20160721T004002_N0204_R059_T55LCD_20160721T003959.SAFE --resolution=10
```

Then press ENTER.

5	Terminal - rus@front-usr-260: /shared/Training/OCEA05_Sen2Coral_GBR_TutorialKit/Original	(🔶 👝 🛋 🕺
File Edit	View Terminal Tabs Help	
rus@from ./S2A_MS	nt-usr-260:/shared/Training/OCEA05_Sen2Coral_GBR_TutorialKit/Original\$ SIL1C_20160721T004002_N0204_R059_T55LCD_20160721T003959.SAFEresoluti	L2A_Process on=10
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Sentinel	<pre>1-2 Level 2A Processor (Sen2Cor). Version: 2.5.5, created: 2018.03.19, product version <= 14.5 started</pre>	supporting L
Product Selecte	version: 14.2. Operation mode: TOOLBOX. Processing baseline: 02.04. ed resolution: 10 m.	
Progress 637, tot	s[%]: 0.02 : PID-9260, 20 m resolution must be processed first, elapsed tal: 0:00:01.484290	time[s]: 0,
Progress me[s]: (s[%]: 0.03 : PID-9260, L2A_ProcessTile: processing with resolution 20 m 0.130, total: 0:00:01.614280	, elapsed ti
Progress .000, to	s[%]: 0.03 : PID-9260, L2A_ProcessTile: start of pre processing, elapse otal: 0:00:01.614755	d time[s]: 0
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	Original - File Manager	* = = *
File Edit View	Go Help	
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DEVICES	S2A_MSIL1C_20160721T004002_N0204_R059_T55LCD_20160721T003959.SAFE	
The Custom	S2A MSIL2A 20160721T004002 N0204 R059 T55LCD 20160721T003959.SAFE	
PLACES	S2A_MSIL1C_20160721T004002_N0204_R059_T55LCD_20160721T003959.zip	

The process creates three new Level 2-A products in the ".SAFE" format in the original folder: /shared/Training/OCEA05_Sen2Coral_GBR_TutorialKit/Original

6.3 SNAP - open and explore data

Launch SNAP (icon on desktop). When the SNAP window opens click **Open product** and navigate to: /shared/Training/OCEA05_Sen2Coral_GBR_TutorialKit/Original

Then open the Level-2A product folder and open the MTD_MSIL2A.xml

In the **Product Explorer** window, right-click the Level-2A product from 2018 and click **Open RGB image window**, a new window will open. From the drop-down menu select:

Profile: Sentinel 2 MSI Natural Colors



Now, let's investigate the **cloud cover over our area of interest**. Zoom in to the area of interest as indicated above. We can see that our area of interest is cloudless.



6.4 Resample

The 13 bands in Sentinel-2 products do not all have same resolution (therefore size, see \square NOTE 2). While the *Sen2Coral* toolbox supports the products with bands of different sizes, many other operators such as *Subset*, do not. Therefore, we need to resample the bands to equal resolution first.

Go to **Raster** \rightarrow **Geometric Operations** \rightarrow **Resampling** (See \square NOTE 3).

Do not change anything in the **I/O Parameters** tab.

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

Resampling	* = ×	Resam	pling		* = X
File Help		File Help			-
1/O Parameters Resampling Parameters		1/O Parameters Resampling Parameters	1		
Source Product Name:		Define size of resampled product.			
[1] S2A_MSIL2A_20160721T004002_N0204_R059_T55LCD_2	20160721T003959	By reference band from source product	B2		
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Save as: EENTERNAS	07211003959_resampled	By target width and height:	Target width Target height: Width / height ratio	1 00000	10,960
🖉 Open in SNAP		By pixel resolution (in m):	Resulting target width: 1830 Resulting target height: 1830		66 <u>-</u>
		Upsampling method:	Nearest		-
		Downsampling method:	First		-
		Flag downsampling method:	First		
		Resample on pyramid levels (for faster in	naging)		
	<u>B</u> un <u>C</u> lose			Bun	Close

Click Run.

After the process is completed, if a window appears, click Yes.



A new product [2] appeared in the **Product Explorer** tab. Now we will have a look at the product. Close all the views we have open and expand the product structure by clicking the + sign on the left of the product name, then expand the **Band** folder and double click **B8** (842nm) - (NIR).

6.5 Subset

In the next step, we will subset the image to our area of interest. Click on the resampled product in the **Product Explorer** tab, to highlight it. Then go to **Raster** \rightarrow **Subset** and in the **Spatial Subset** tab, set **Pixel coordinates** to:

Spec	ify Product Subset		+ = ×	Scene start X:	2900
Spatial Subset Band Subset	Metadata Subset	1		Scene start Y:	1820
	Pixel Coordinates	Geo Coordinates		Scene end X:	4000
ALC: Y	Scene start X		2900	Scene end V·	2750
	Scene start Y: Scene end X:		4000	Seche end 1.	2750
3 Cart	Scene end Y:		2750		
	Scene step Y:		1		
	Subset scene width: Subset scene height:		1101.0 931.0		
	Source scene width: Source scene height:		10980		
	Use Pre <u>v</u> iew	Fix full width	n ht		
	E	Estimated, raw storage	size: 37.6M	Keep the othe	r Subs
		<u>OK</u> <u>C</u> ancel	Help	Click OK .	

Keep the other Subset tabs as by default. Click **OK**.

A new product will appear in the **Product Explorer** tab [3]. Note that the resampling and the subset products are virtual products only and are not physically saved.

Right-click the product [3] and click **Open RGB image window** and from the dropdown menu select **"Sentinel 2 MSI Natural Colors"**. Click **OK**.

Then go to the **Colour Manipulation** tab and click on **2** "Reset to defaults".



6.6 Deglint

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 (sun glint) in the direction of the satellite. The viewing geometry of Sentinel-2 satellite makes it vulnerable to sun glint contamination. In the presence of sun glint, we need to apply a glint removal algorithm in order to be able to observe the sea floor for the purpose of habitat mapping or bathymetry derivation.

There are several available sun glint removal methods for high resolution images and coastal applications. The algorithm implemented as part of the Sen2Coral toolbox was developed by Hedley et al., (2005). (See NOTE 4) While the algorithm gives reasonably good results, it is recommended to use images with minimal glint.



First, we need to use the polygon drawing tool to create ROI polygons over areas of the image containing sun glint. These should be over deep-water areas where no bottom reflectance is expected and all NIR reflectance is attributed to sun glint.

In the **Product Explorer** tab, double click on the **B8** (NIR band) to open it in view. Then in the **Colour Manipulation** tab, drag the white slider to value of *3E-2*. Now we see some brighter values over the deep-water areas.

	New Vector Data Container 🔹 👳 🗉 🗙
Name:	glint
	QK. Cancel Help

Then in the **Product Explorer** tab, select the subset product **[3]** and go to **Vector** → **New Vector Data Container**. In the dialog that opens, set the name to *"glint"* and click **OK**. Finally, click on the **Rectangle drawing tool** and draw polygons over the deep-water sun glint areas.



Then go to **Optical** \rightarrow **Thematic Water Processing** \rightarrow **Sen2Coral** \rightarrow **Processing Modules** \rightarrow **Deglint Processor**.

In the **I/O Parameters** tab, set the subset product [3] as **Source Product**. We can also change the **Target Product name** to something shorter and save the product to:

/shared/Training/OCEA05_Sen2Coral_GBR_TutorialKit/Processing

In the Processing Parameters tab, set:

Sun Glint areas: "glint" Source Bands: B2, B3, B4, B5 Reference Band: B8

Deglint	× 💹	Deglint	• = ×
File Help	File Help		
I/O Parameters Processing Parameters	//O Parame	ters Processing Parameters	1
Source Product Source product:	Sun Glint Ar	eas: glint B1	
[3] subset_1_of_S2A_MSH2A_20160721T004002	2_N020	82 83 84	1
Target Product Name: Subset S2A MSIL2A 20160721T resampled der	glint	ds: 85 86 87	
Save as: BEAM-DIMAP		86 81	
/home/rus/shared/Training/OCEA05_Sen2Co	oral_GBR_Tut	B2 B3 B4	bands to be used as pli
T description	Reference B	B5 B6 B7	
		88	*
	☑ Include r	reference bands in output product	t
	MinNIR strin	9: -1.0	
	Mask all	negative reflectance values	
	<u>Run</u>		<u>Run</u> <u>C</u> lose

Leave other settings as default and click **Run**. When the processing is finished, a new product [4] will appear in the **Product Explorer** tab. Right-click on the product and open RGB view.



The algorithm results in majority of the land areas to have negative value and therefore be automatically masked, however we still need to apply cloud, residual land and white cap mask.

6.7 Land, Cloud and White Cap Mask

Another essential pre-processing step is masking of the land, white caps (sea foam crest over the waves), clouds and cloud shadows. The first three refer to bright features that can identified due to the fact that the near infrared wavelengths do not penetrate into the water, so after deglint is applied, clear areas of water appear very dark. Clouds, white caps and land typically have high reflectance in the NIR, therefore we can set a threshold to mask them (see image below).



In Sen2Cor, a tool is available to create the mask. To apply it go to **Optical** \rightarrow **Thematic Water Processing** \rightarrow **Sen2Coral** \rightarrow **Processing Modules** \rightarrow **LandCloudWhiteCapMask Processor**.

In the I/O Parameters tab, set the subset deglint product [4] as Source Product. Save the product to: /shared/Training/OCEA05_Sen2Coral_GBR_TutorialKit/Processing

In the **Processing Parameters** tab, set:

Source Bands: B2, B3, B4, B5 Reference Band: B8 Maximum valid value: 0.05

LandCloudWhiteCapMaskOp 💿 🔬	Lan	dCloudWhiteCapMaskOp	* = *
ile Help	File Help		
I/O Parameters Processing Parameters	I/O Parameters	Processing Parameters	
Source Product Source product: [4] Subset_S2A_MSIL2A_20160721T004002_resampled10 Target Product	Source Bands:	82 83 84 85 88	
Name: Subset_S2A_MSIL2A_20160721T004002_resampled_deglint_mask		B2 B3	
Directory: ed/Training/OCEA05_Sen2Coral_GBR_TutorialKit/Processing		84 85	
Dpen in SNAP	Reference Band:	88	
	Maximum valid val	Je: 0.05	
	Mask all negati	ve reflectance values ce bands by default water=1 Land/Cloud=0	1.
<u>Run</u> <u>C</u> lose		B	un <u>C</u> lose

Click Run. A new masked product [5] containing also the mask band has been created.

However, the tool is unable to mask dark features such as cloud shadow or terrain shadow (can be seen on the above mask). The dark feature can be delineated manually, or we can use a threshold applied to band 2 to delineate them.

In the **Product Explorer**, right-click on the new masked product [5] and go to **BandMaths**. In the band math dialog set:

Name: Mask_All

Replace NaN and identify results by: NaN

Deselect Virtual (save expression only, don't store data)

Click on Edit Expression and set:

Expression: if B2 > 0.01 && LandCloudWhiteCapMask_B8 == 1 then 1 else 0

	Band Maths	A G X	Ban	d Maths Expressio	n Edi	tor n 🖬 🛪
Target product:			Product [5] Subset_S2A_MSIL2A_3	20160721T004002_res	ample	d_deglint_mask
[5] Subset_S2A_I	MSIL2A_20160721T004002_resamp	led_deglint_mask 💌	Data sources:			Expression:
Name:	Mask_All		\$5.88	6 + 6		if B2 > 0.01 &&
Description:			\$5.LandCloudWhiteCapMask_B8	0.0	-	LandCloudWhiteCapMask_B8 == 1
Unit		1	\$5.B2	6-6	_	then I etse o
Spectral wavelen	ath: 0.0		\$5.B3	6 • 6	-	
Spectral Wavelett	guilleto		\$5.B4	0/0		
Virtual (save	expression only, don't store data)		\$5,85	(@)		
Replace NaN	and infinity results by	NaN	\$5.glint	1.61	-	
Generate any	included uncertainty band			Constants	-	
Band maths expr	ression			Operators	-	
if B2 > 0.01 && 1	LandCloudWhiteCapMask_B8 == 1	then 1 else 0	V Show bands	Functions	-	
			Show masks			
Load	Save Edit	Expression	🔲 Shav, tie-point grids			
			Show single flags.			Ok, no errors.
	<u>o</u> k	<u>C</u> ancel <u>H</u> elp				QK. <u>C</u> ancel <u>H</u> elp

Then click **OK**. Now we can proceed to the applications.



We can turn off the visualization of the glint polygons by going to Layer Manager (right side of the screen or go to View \rightarrow Tool Windows \rightarrow Layer Manager) and deselecting *Vector data* \rightarrow *glint*.

6.8 Depth invariant indices

The calculation of depth invariant indices is a water column correction step that is frequently a useful pre-processing step for benthic classification. (See NOTE 5)

NOTE 5: The implementation it Sen2Coral follows Lyzenga (1978) and Green et al. (2000). The basic ideal is that attenuation of the reflectance is approximately inverse exponential with water depth, therefore the transform,

$$X_i = -\ln\left(R_i - R_i^{deep}\right)$$

approximately linearizes the effect of depth on reflectance. R_i is the pixel reflectance in band i, and R_i^{deep} , is the deep-water reflectance in that band. A plot of the pixel values of two such transformed bands over a benthic type with constant reflectance but at different depths will lie on a line (following figure).

In order to compute the depth invariant indices, we need to select two bands with sufficient water penetration to observe subsurface features of interest. For Sentinel-2 the bands 1-3 are the most useful, although 1-5 can fulfil the condition. We don't need to know the individual water attenuation coefficients in the two selected input bands, but we do need to know their ratio. This can be calculated from sample pixels over the same bottom type at different depths. *(SNAP Help)*

First, we need to define two groups of ROI polygons:

- Deep water ROI over deep-water regions. From this the deep-water reflectance value is estimated (see NOTE 5 above).
- Same bottom type at different depth it is best to select areas of bright sand bottom as they can be identified easily and due to their brightness provide good signal-to-noise ratio.

Right-click on the masked product [5] in the **Product Explorer** and go to **Vector** \rightarrow **New Vector Data Container**. In the dialog that opens, set the name to "deep". Click on the **Rectangle drawing tool**

and draw polygons over the deep-water, it is best to use the RGB View to identify suitable areas.

Then create another **New Vector Data Container** and name it *"same_type"* and draw polygons over the bright sand areas. On the image below, you can see the "deep" polygons indicated in green and the "same_type" polygons indicated in red.



Then to apply the processor, go to **Optical** \rightarrow **Thematic Water Processing** \rightarrow **Sen2Coral** \rightarrow **Processing Modules** \rightarrow **DepthInvariantIndices Processor.**

In the I/O Parameters tab, set the masked product [5] as **Source Product**. Save the product to: /shared/Training/OCEA05_Sen2Coral_GBR_TutorialKit/Processing

In the Processing Parameters tab, set:

Source Bands: B2, B3 Deep water area: "deep" Same bottom areas: "same_type"

	DepthInvariantIndicesOp	* = ×		DepthInvariantIndicesOp + 2 >
File Help			File Help	
I/O Parameters	Processing Parameters		I/O Parameters	Processing Parameters
Source Produc Source produc [5] Subset_S2	t t A_MSIL2A_20160721T004002_resample	d_de 💌		B8 LandCloudWhiteCapMask B8 B2 B3
Target Product Name: A_MSIL2A_2016	t 50721T004002_resampled_deglint_masi	k_depthInvariant	Source Bands:	B4 ∉The list of source bands. Mask_All
Save as: E Directory: ared/Traini	BEAM-DIMAP	Processing		
Open in SN	IAP			
			Deep water area:	deep
			Same bottom area	as: same_type
		Run Close		Run Close

Then click **Run** and when finished close the operator dialog. A new product [6] has appeared in the **Product Explorer**. It contains only one band, double click it to visualize it. Turn off the visualization of the polygons by going to **Layer Manager** and **deselecting** *Vector data*.

You can also play with the sliders in the **Colour Manipulation** tab, to increase the contrast a bit more (\blacktriangle -2.5, \blacktriangle -1.5, \triangle -0.5). We can also compare it with the original RGB image. To do this close all the except for the [5] Sentinel 2 MSI Natural RGB and the [6] DepthInvariantIndicesB2B3, then go to **Tools** \rightarrow **Tile Horizontally**.



We only see valid values over shallow areas where the solar radiation can penetrate to the sea floor and is reflected from the features of interest. Over deep areas we only see noise values.

We can now proceed to use the Depth Invariant Indices as an input to change detection or to habitat classification (see example of simple classification below – using depth invariant indices, bands 2-5 and bathymetry as input). This however, is not the purpose of this training.



6.9 Empirical Bathymetry

The next tool we will explore is the **Empirical Bathymetry** processor. Estimation of bathymetry by empirical regression is a commonly used method for mapping shallow water areas. However, this method is only applicable if in-situ data are available for the area of interest. These most commonly come from boat sonar system and in combination with cloudless and calm water image can be used as an input to simple regression method and calibration of the bathymetry retrieval algorithm.

The algorithm implemented in the Sen2Coral toolbox follows the method developend by Stumpf et al. (2003). It is based on the principle that the water attenuation coefficients differ between wavelengths (bands) and we can determine the ratio between the two bands which will change with depth (similarly as for the Depth Invariant Indices calculation) (See \square NOTE 6).

NOTE 6: The implementation in Sen2Coral follows by Stumpf et al. (2003). The basic ideal is that attenuation of the reflectance is approximately inverse exponential with water depth, i.e. we can estimate the depth *z* using following equation:

$$z = m_1 \frac{\ln \left(n R_w \left(\lambda_i \right) \right)}{\ln \left(n R_w \left(\lambda_i \right) \right)} + m_0$$

where m_1 is a tuneable 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 m_0 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. (SNAP Help)

Firstly, we need to go to Optical \rightarrow Thematic Water Processing \rightarrow Sen2Coral \rightarrow Processing modules \rightarrow EmpiricalBathymetry Processor.

In the **I/O Parameters** tab, select we select the pre-processed, deglinted and masked image [5] image as a source product field and save the product to:

/shared/Training/OCEA05_Sen2Coral_GBR_TutorialKit/Processing

In the **Processing Parameters** tab, we have to select two bands that will be used to estimate the bathymetry. Most commonly the bands 2 and 3 are used for Sentinel-2 as these offer the best combination of penetration depth and spatial resolution.

We also have to provide the path to the in-situ bathymetry point data. The training and validation datasets used here are in fact not in-situ data but were derived by John Hedley using random sampling of the 20m multisource Digital Elevation/Depth Model for Lizard Island (Leon et al., 2012). Only points with maximum depth of 20m have been used for the algorithm calibration, as this can be assumed as the maximum depth to which the retrieval from satellite data is possible.

🖋 lizard_leonetal_dem_bathy_training.csv - Mousepad 🔗 🚊 🖂 🗴 File Edit Search View Document Help -14.66406045,145.47290233,0.208896 -14.65933857,145.46959273,0.421879 14.68556171,145.4712675,0.56365 14.67055158,145.44314641,0.64998

The dataset must be in a CSV comadelimited format without headers and containing columns for latitude, longitude and depth.

Bands to be used: B2, B3

Bathymetry point data:

/shared/Training/OCEA05_Sen2Coral_GBR_TutorialKit/AuxData/lizard_leonetal_dem_bathy _training.csv

N value: 1000.0 (default)

EmpiricalBathymetryOp	* = X	Em	piricalBathymetryOp	* E ×
File Help	File	Help		
VO Parameters Processing Parameters	1/0	Parameters	Processing Parameters	
Source Product Source product: [5] Subset_SZA_MSIL2A_20160721_resampled_deglint_mask			B8 LandCloudWhiteCapMask B1 B2	<u>_</u> B8
Target Product Name: Subset_S2A_MSIL2A_20160721_resampled_deglint_mask_en IV Save as: BEAM-DIMAP	npBathymetry	ds to use	83 84 85	
Directory: /home/rus/shared/Training/OCEA05_Sen2Coral_GBR_Tuti @ Open in SNAP	orialKit/Proce	hymetry point alue:	data: al dem bathy validation	SNAP.csv
	<u>R</u> un <u>C</u> lose		B	un <u>C</u> lose

Then click **Run** and when finished close the operator dialog. A new product [7] has appeared in the **Product Explorer**. It contains only one band. Go to **Window** \rightarrow **Tile Single** and then double click the bathymetry band to visualize it. Turn off the visualization of the polygons by going to Layer Manager and deselecting *Vector data*.



We can now use the "*Mask_All*" band to mask out all the residual land, cloud and cloud shadow. In the **Product Explorer**, right-click on the new bathymetry product [7] and go to **BandMaths**. In the band math dialog set:

Name: EmpiricalBathymetry_B2_B3_masked

Replace NaN and identify results by: NaN

Deselect Virtual (save expression only, don't store data)Click on Edit Expression and set:

Expression: if \$5.Mask_All == 1 then \$7.EmpiricalBathymetry_B2_B3 else NaN

Note that we are using a band "Mask_All" from a different product, for this reason we can not use virtual band. We also have to pay attention to correct reference numbers in our expression.

Band Mai	hs a c x	Band	+ = ×				
Target product:		Product: [7] Subset_S2A_MSIL2A_20	0160721T004002_resam	npled	deglint_mask_empBathymetry		
[7] Subset_S2A_MSIL2A_20160721T004002_resampl 💌		Data sources:			Expression:		
Name: Empirica	Bathymetry_B2_B3_masked	\$7.EmpiricalBathymetry_B2_B3	0+0		if \$5.Mask_All == 1 then		
Description:		\$7.deep	0 - 0	\$7.EmpiricalBathymetry_B2_B3 else NaN			
Unit:		\$7.same_type	0 1 0				
Spectral wavelength: 0.0		\$7.gunt	6.6				
Virtual (save expression only, don't store data)			6/6				
Denlara Naki and Infinitu results hu Naki			(@)				
			Constants 👻				
Generate associated uncertainty band			Operators				
Band maths expression:		Show bands	Functions 👻				
Load Save	Edit Expression	Show masks Show tie-point grids Show single flags			Cancel Help		

Then click **OK**. Now we can visualize the band. In **Product Explorer**, go to the Vector data folder and delete the following: "glint", "deep", "same_type" (right-click \rightarrow Delete)

Then go to the **Colour Manipulation** tab and click on The **Description Colour Palette**, navigate to **/shared/Training/OCEA05_Sen2Coral_GBR_TutorialKit/AuxData/** and open **Bathymetry_Col.cpd** In the dialog that opens click **No**.





6.9.1 Validation

In SNAP we can also do a quick validation using a validation dataset also derived from the 20m multisource Digital Elevation/Depth Model for Lizard Island (Leon et al. 2012).

First, we need to load this dataset to as a vector from CSV file (or shapefile). In this case we use tabdelimited CSV with headers.



In **Product Explorer**, select the bathymetry product, then go to **Vector** \rightarrow **Import** \rightarrow **Vector from CSV**. Navigate to */shared/Training/OCEA05_Sen2Coral_GBR_TutorialKit/AuxData/* and open *lizard_leonetal_dem_bathy_validation_SNAP.csv*

In the Import CSV Data dialog, select Custom CRS \rightarrow Geographic Lat/Lon (WGS 84). Click OK. In the next dialog accept the default option.



Then click on the 🜌 Correlative plot tool on the top panel. In the dialog, deselect Use ROI mask, and

set: **Point data source:** *lizard_leonetal_dem_bathy_validation_SNAP* **Data field:** *Depth*

In **Y-Axis (EmpiricalBathymetry_B2_B3_masked)** deselect *Auto min/max* and set **Max:** 50 Select **Show tolerance range** and **Show regression line**.



We can export the graph and the bathymetry data for further use for example as one of the inputs for benthic habitat classification. When you are done examining the graph, close the graph window.

6.10 Radiometric Normalization via PIFs

The last tool we will have a look at is the **Radiometric Normalisation via PIFs**. This tool enables us to apply radiometric normalisation to imagery so values corresponding to the same surface are comparable throughout a timeseries. The method is based on the use of pseudo invariant features corresponding to optically bright (sand) or optically dark (seagrass) targets, deep waters, human made infrastructures (roofs, roads, airstrips) to intercalibrate two different images.

For this part of the exercise we will use a different study area – Adelaide reef - which shows some interesting results possibly related to the detection of bleaching event. The following pre-processing steps have already been applied to the images:

- Atmospheric correction Sen2Cor
- Resampling
- Subset
- Deglint
- Land Cloud and White Cap mask

Click on **Open product** and navigate to: /shared/Training/OCEA05_Sen2Coral_GBR_TutorialKit/Original/Adelaide_Reef/ and open the two images *.dim* files. Open the RGB view for both and then go to **Window** \rightarrow **Tile Horizontally**.

We will use the first image from 2016 as a master for the calibration of the second image from 2017. First, we need to draw polygons over features we expect not to change over time, such as bright sand, man made infrastructure or dark pelagic water.



Once you are done drawing the polygons, go to **Optical** \rightarrow **Thematic Water Processing** \rightarrow **Sen2Coral** \rightarrow **Processing modules** \rightarrow **RadiometricNormalizationPIFs Processor.**

In the I/O Parameters tab, set the masked product [8] as **Source Product**. Save the product to: /shared/Training/OCEA05_Sen2Coral_GBR_TutorialKit/Processing

In the **Processing Parameters** tab, set:

Source Bands: B1, B2, B3, B4, B5 Deep water area: geometry

RadiometricNormalisationPIFsOp 🔹 🗉 🗙	RadiometricNormalisationPIFsOp	* E *
File Help	File Help	
1/O Parameters Processing Parameters	1/O Parameters Processing Parameters	
Source Products Slave product [9] S2_MSIL2A_20170223T002701_Prep_deglint_mask	B8 LandCloudWhiteCapMask B1 B2	_B8
Reference product:	B3	
[8] S2_MSIL2A_20160708T003032_Prep_deglint_mask.	B4B5	
Target Product Name:	Source Bands:	
S2_MSIL2A_20170223T002701_Prep_deglint_mask_normal		
Save as: BEAM-DIMAP		
Directory:		
Øpen in SNAP	Pseudo-Invariant Features (PIFs) vector: geometry	
<u>Bun</u> <u>C</u> lose	Bun	Close

Click **Run.** A new product [10] had been created in the **Product Explorer**. If you try to visualize the image you will receive an error, this is due to a bug in the handling of the valid pixel expression. The visualization tool is searching for the *LandCloudWhiteCapMask_B8* band that does not exist in the new product. We have to add it from the original pre-processed product [9].

In **Product Explorer**, right-click on the new normalized product [10] and go to **BandMaths**. In the band math dialog set:

Name: LandCloudWhiteCapMask_B8

Replace NaN and identify results by: NaN

Deselect Virtual (save expression only, don't store data) Click on Edit Expression and type:

Expression: \$9. LandCloudWhiteCapMask_B8

	Band Maths 🛛 🕆 🗢 🗙	Band Maths Expression Editor				+ E ×	
Target product:		Product: [10] S2_MSIL2A_20170223T002701_Prep_deglint_mask_normal				-	
[10] S2_MSIL2A_20170223T002701_Prep_deglint 🔻		Data sources:		Expression:			
Name:	LandCloudWhiteCapMask_B8	\$10.81	0+0		\$9.LandCloudWhiteCapMask_B8		
Description:	Description:		\$10.82 \$10.83 \$10.84 @ * @				
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Spectral wavelength 0.0 Virtual (save expression only, don't store data) Replace Natz and mfinity results by NaN Generate associated uncertainty band		\$10.84					
		\$10.85	0/0	-			
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\$9.LandCloudWhiteCapMask_B8		Show bands	Functions 🔻				
		Show masks					
Load Save Edit Expression		Show the point grids					
		Show single flags				Ok, no errors.	
	QK <u>C</u> ancel <u>H</u> elp	1			<u>QK</u> <u>C</u> ancel	Help	

Click **OK**. Now we can visualize the result.

Open and arrange windows so the image from 2016 and the new normalized image from 2017 are displayed side by side (close all the other views and then go to **Window** \rightarrow **Tile Vertically**). Zoom-in to the area indicated below.



This image has been reported in Hedley et al. (2018) as it potentially captures a bleaching event. The coral in the second image appears much brighter, almost white. Bleaching is in general very difficult to capture in satellite images as the event generally occurs on the scale of weeks.

7 Extra steps

7.1 Downloading the outputs from VM

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



8 References

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