Surface Soil Moisture Estimation by using Sentinel-1 and Sentinel-2 Data

Objective

The objective of this course is to show how to map the surface soil moisture over agricultural plots (summer and winter crops) and grasslands using the free and open source software QGIS, by coupling radar (Synthetic Aperture Radar "SAR") and optical images acquired at high spatial resolution ($\sim 10 \text{ m x } 10 \text{ m}$).

Study site and satellite data

The study site located near Montpellier city, South of France (figure 1) is an agricultural area (15 km x 15 km). Figure 1 shows layout, made using QGIS, of a satellite image acquired over the study site by Sentinel-2A (S2A).



Figure 1: Study site located at 5 km east of Montpellier city, in the south of France. The background of the map is an optical image acquired by the satellite S2A. The geographical coordinates are in UTM (Universal Transverse Mercator), zone 31 N.

Satellite data used:

- One Sentinel-1 GRD image acquired on 10 October 2016
- One Sentinel-2 image acquired on 15 October 20161. Radar images

1.1 Download images

To download the radar images, create first an account on the ESA website¹. The steps to create accounts are available on the web pages.



¹ https://scihub.copernicus.eu/dhus/#/home

1.2 Calibration of Radar Image in SNAP

In order to calibrate the radar image, you should first install SNAP software². Once the SNAP is downloaded, you can calibrate the radar image as follows:

1- Open Im- age in SNAP	> Open the SNAP software
	➢ Import the radar image into SNAP : « Main Menu » → « Open Product » then select the S1 im- age
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	Product Explorer × Pixel Info —
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² http://step.esa.int/main/download/snap-download/

2- Create a	➤ To create the graph builder: « Main Menu » → « Graph Builder » then select the S1 image
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	Sentinel-1 TOPS > Terrain-Flattening ThermalMoireRemoval
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	In the calibration menu select the bands (in the figure below it is VH and VV) to be calibrated
	Activate the option "output sigma 0 band" to have an output image in linear unit. The image in
	linear unit should be used to calculate mean values of SAR backscattering signal (pixel values
	in linear image)
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> Finally Click on the RUN button

2. Optical image

2.1 Overview

In this tutorial, one optical image is downloaded from Theia website with a processing level 2A for the date 15/10/2016. However, optical images of Sentinel-2 mission could be also downloaded, as the radar image, from ESA website as explained in paragraph 1. Please make sure that the optical image is of level 2A. Otherwise, if the image is of level 1C, a calibration is required to obtain the 2A level image. This calibration is also performed by the SNAP software using the "sen2cor" module.

2.2 Calculation of NDVI

The optical image is downloadable as 13 separate spectral bands. To facilitate the use of the optical image, only the red (band 4), and near infrared (band 8) bands are used. The NDVI is first calculated from the red and infra-red band. The NDVI image is then clipped and re-projected to obtain the same projection of the radar image (WGS-84).

1- Calculation of the NDVI	> To calculate the NDVI :
image	• Import in QGIS the images found in folder "SENTINEL2A_20161015-104513- 300_L2A_T31TEJ_D_V1-1"
	✓ SENTINEL2A_20161015-104513-300_L2A_T31TEJ_D_V1-1_FRE_B4.tif (Red Band)
	✓ SENTINEL2A_20161015-104513-300_L2A_T31TEJ_D_V1-1_FRE_B8.tif (Infrared Band)
	• In the menu bar, click on « Raster » → « Raster Calculator »
	• In the window that appears, type the formula below. With this formula, the NDVI-values are mul- tiplied by 100. This allows converting the encoding of the NDVI image into 16 bits without lose precision, and consequently accelerate the segmentation of the NDVI image.
	 100*(("SENTINEL2A_20161015-104513-300_L2A_T31TEJ_D_V1-1_FRE_B8@1"-"SENTI-NEL2A_20161015-104513-300_L2A_T31TEJ_D_V1-1_FRE_B4@1")/("SENTI-NEL2A_20161015-104513-300_L2A_T31TEJ_D_V1-1_FRE_B8@1"+"SENTI-NEL2A_20161015-104513-300_L2A_T31TEJ_D_V1-1_FRE_B4@1")) In « Output Layer », name the image as: « NDVI_20161015.tif ».
	• Finally, click on « OK » . Once processing is complete, the output image appears in the « Laver »
	and « Display » part of the QGIS interface.
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	the NDVI image (NDVI_20161015.tif) and convert into a 16-bit integer	
• In the r	menu har click on "Rester" > "Projection > "Warn (Renroject) >	
• In the h	nenu bar, enek on « Kaster » – 4 « Hojecuon » – 4 « Warp (Keproject) »	
• In the w	vindow that appears, select in « Input Layer » the NDVI image (NDVI_201610	15.tif)
• In the «	a Target CRS » choose EPSG:4326 –WGS84	
• In the or	uption « No data » enter -32768	
• In the «	Advanced Parameters » choose Output data type "Int16"	
• In « Re]	projected » enter NDVI_20161015_wgs84_int16.tif	
• Finally.	click on « Run ». Once processing is complete, the output image appears in the	« Laver »
and « D	Display » part of the QGIS interface.	,
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	• In « Clipped » enter NDVI_20161015_wgs84_int16_clip.tif				
	• Finally, click on « Run ». Once processing is complete, the out and « Display » part of the QGIS interface.	tput imag	ge ap	pears	s in the « Layer »
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3. Segmentation of NDVI

3.1 Land Cover Map

To facilitate the manipulation of the land cover map, this map is first clipped, and then reprojected to WGS 84. Procedures for clip and re-project an image are explained earlier in section 2.2. The clipped and reprojected land cover map will be called ocsol_clip_wgs84.tif

3.2 Segmentation of crop's areas and grasslands

To delimit the spatial units, a mask is first generated from the land cover map to determine the crop and grasslands areas. Then, the NDVI image is used to segment crop and grasslands areas into homogeneous segments (spatial units).

1-Determination	> To create the mask image, we will use the Raster Calculator
and grasslands.	• Select the NDVI image clipped as the layer extent.
and segmenta-	• In the «Expression » type the formula below:
tion	• In the « Expression » type the formula below.
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	"OCS_2021_WGS84_Clip" = 13
	Using this formula, the pixels of the land cover map (OCS_2021_WGS84_Clip.tif) with values
	equal to 5 to 13 are set to 1 in the mask image (mask.tif), while the other pixels are set to 0.
	• Name the output image: mask tif
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	Expression valid
	OK Cancel Help
	> To set the same geographical origin and pixel size we will use the OTB tool "Superimpose" :
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	- Select the Mask image as the image to reproject
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• Name the vector layer of the output segmentation as follows: « output vector file
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« seg_crops_grass.shp » and the « output labeled image » as « seg_crops_grass.tif »
• Click on « run » to execute the segmentation function. Once processing is complete, the vec layer of the segmentation appears in the « Layers » and « Display » part of the QGIS interfa
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3.3 Elimination of small spatial units

To eliminate the small spatial units present in the segmented image, a smoothing of polygon is first applied. A buffer zone of $10 \text{ m} (0.0001^{\circ})$ inside each polygon is produced. Then, the number of pixels in each polygon is calculated. Finally, polygons with number of pixels less than 20 are deleted.

1- Elimina-	> To smooth polygons:
tion of small spatial units	• In the main menu, click on « Processing » → « Toolbox »
-F	• In the window that appears, click on « Vector geometry » \rightarrow « Smooth »
	• In "Input I even a calcot the vector layer of the comparisation (see arous arous sho)
	• In « Input Layer » select the vector layer of the segmentation (seg_crops_grass.snp),
	• In « Offset » enter the number 0.5 (unit = pixel)
	• In « Smoothed » enter the output file name (seg_crops_grass_smooth.shp)
	• Click on « run ». Once the processing is complete, the output file appears in the « Layer » and « Display » part of the QGIS interface.
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	Maximum node angle to smooth with geometries containing a higher containing a higher
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	✓ Open output file after running algorithm out. The iterations
	parameter dictates how many smoothing
	rterations will be applied to each geometry. A higher
	number of iterations results in smoother
	geometries with the cost of greater
	0% Cancel
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	> To perform a buffer zone of 10 m :
	• In the menu bar, click on « Processing » → « Toolbox »
	• In the window that appears, click on « Vector geometry » -> « Buffer »
	• In the window that appears, select the input layer (seg_crops_grass_smooth.shp)
	• In « Distance » enter the number -0.0001° (-10 m)
	• In « Buffer » enter the output file name (seg_crops_grass_smooth_buff.shp)
	• Click on « run ». Once the processing is complete, the output file appears in the « Layers » and « Display » part of the QGIS interface.

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> To remove entities with a number of pixels less than 20:						
• Open the attribute table of the vector layer seg_crops_grass_smooth_buff.shp :« right click » on the vector layer → « Open attribute table »						
• Activate the edit mode						
 Click on « Select features using an expression » and type «"nb_count" is Null or "nb_count" <20 » 						
• Click on the icon « delete selected features » $\overline{\overline{\mathbb{D}}}$						
• Disable the edit mode						
Q Buffered :: Features Total: 11342, Filtered: 11342, Selected: 10108 Image: Selected: 11342, Filtered: 11342, Selected: 10108 Image: Selected: 10108						
	DN nb_count					
1	1	Q Select by Expression - Buffered		×		
2	2	Expression Function Editor				
3	3	= + - / * ^ () '\n'	Q. Search Show Values	group field		
4	4	"nb_count" is Null or "nb_count" <20	Aggregates - Arrays Dou Color exp	uble-click to add field name to ression string.		
5	5		Conditionals Conversions Conversions Conversions	ht-Click on field name to open ntext menu sample value loading tions.		
6	6		Date and Time Fields and Values	Notes		
/	/		123 DN Value	es 🔍 Search		
ð Q	ð Q		Files and Paths Fuzzy Matching	All Unique 10 Samples		
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10	10 5		Map Layers Maps Math			
12	12		Operators Rasters			
13	13	Output preview: 1	Decord and Attributes	Select Eastures		
14	14	··~\$				
15	15 0.1960					

4. Mapping soil moisture

4.1. Calculation of mean backscattered signal, mean incidence angle, and mean NDVI

For each spatial unit (polygon), the mean of the backscattered radar signal (linear scale) in VVpolarization, of the local incidence angle, and of the NDVI were calculated. Then, the mean-values are exported to csv.

1- Calcula- tion of mean backscattered radar signal, mean inci- dence angle, and mean NDVI for each spatial unit.	 Calculate the mean backscattered radar signal (linear scale) using all pixels containing in each polygon (spatial unit) : Import the radar image (Sigma0_VV) and the incidence angle image (incidenceangle), and the segmentation vector layer segmentation seg_crops_grass_smooth_buff-10.shp. In the menu bar, click on « Processing » → « Toolbox » In the window that appears, click on « Raster Analysis » → « Zonal Statistics » In « Raster layer » select the Sigma0.img In « Vector layer containing zones » select the vector layer seg_crops_grass_smooth_buff.shp In « Output column prefix » type « M_VV » to denote that it is the mean (M) of the radar backscattering coefficient in VV Click on « Statistics to calculate » button and check only the option « Mean » Click on « ok ». Once the processing is complete, the values of the mean are saved in the attribute 					
		×				
	Parameters Log	Zonal				
	Raster layer	statistics				
	Sigma0_VV [EPSG:4326]	This algorithm				
	Raster band	calculates statistics of				
	Band 1: Sigma0_W a raster layer for each					
	Vector layer containing zones					
	ector layer.					
	Output column prefix					
	Statistics to calculate					
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	0%	Cancel				
	Run as Batch Process	Run Close Help				
	Repeat the above step for the incidence angle image and the NDVI in "M_NDVI" as column prefix respectively	nage using "M_Inc" and				

Open the attr	ibute tabl	le to check the results			
\succ To export the	from the vector layer to .csv file				
• Import the segmentation vector layer seg_crops_grass_smooth_buff.shp					
• Right click o	• Right click on the vector layer seg_crops_grass_smooth_buff.shp, and select « Save As »				
• In « Format	» select t	the option « Comma Separated Values csv »			
• In « File nar	ne », ente	er the following name 20161010.csv			
• Check the fo	llowing fi	fields only: DN M VVmean M Incmean and M NDVImean			
• Check the 10	nowing n				
• Click off « Of	x »				
Please note, 1 identifier of e signal in HV	n each fil ach segm (linear sc	le .csv, the first, second, third and fourth columns should be in the order : the nent (DN), backscattered radar signal in VV (linear scale), backscattered rada cale), local incidence angle, and NDVI.			
Q Save Vector	.ayer as	×			
Format	Comm	ma Separated Value [CSV]			
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	Add saved file to map OK Cancel Help				

4.2 Application of the soil moisture estimation algorithm

To apply the soil moisture estimation algorithm, you should use the script consisting of programming codes written in Python language (apply_algo.py) to run the algorithm algo.sav (soil moisture estimation by neural network). The script use as input a file .csv that contains the statistics (mean of radar signal in VV and HV polarizations, incidence angle, and NDVI) and produces a text file that contains the identifier of each spatial unit and the associated estimated moisture.

1- Execution of the algorithm to estimate the moisture on each polygon	 To apply the soil moisture estimation algorithm: Move the csv files to the same directory as the script (apply_algo.py) Open the script (apply_algo.py) : « Right Click on the script » → « Edit with IDLE »
	• In the « zonal_stat » variable, put the name of the file .csv containing the statistics: zonal_stat = « 20161010.csv »
	• Click on « F5 » on the keyboard to launch the algorithm
	• A text file is automatically generated (results_stat_20161010.txt). In this text file, the first col- umn is the identifier (DN), and the second column is the estimated soil moisture.

4.3 Production of soil moisture maps

To produce soil moisture maps, joins are made according to the identifier (DN) between the text files that contain the estimated moisture values and the vector layer seg_cultures_prairie_liss_buf-10.shp. This allows adding in the attribute table of the vector layer seg_cultures_prairie_liss_buf.shp the estimated moisture values for the dates of the radar images (19/01/2017 and 26/01/2017). Then, visualization in the form of a map of the estimated moisture values is carried out.

1- Join according to the identifier and viewing maps	 > Add the estimated moisture values in the attribute table of the vector layer seg_crops_grass_smooth_buff.shp • Import the vector layer seg_crops_grass_smooth_buf.shp and the text file results_20161010.txt. To import the last file, click on « Add Layer » → « Add Delimited Text Layer » in the menu bar. While importing the text file, make sure that you well specify the delimiter (space) and check the
	"No Geometry" button as shown in the figure below.
	2 25 12.76 3 26 4.57 4 28 2.57 5 32 22.28 Close Add Help

 Right click on the vector « Joins » → « + » 	or layer seg_crops_grass_smooth_buf-10.shp \rightarrow « Properties » \rightarrow	
• In the window that appears, select in « Join Layer » the text file results_stat_20160119.txt, choose « DN » in « Join field » and « Target field »		
• Click on « ok »		
• Open the attribute table of attribute table.	f the vector layer to verify that the estimated moisture values are in the	
Add vecto		
	Fresidts stat 20170119	
Join field	123 DN	
Farget field	123 DN 🔹	
Cache joir	n layer in virtual memory	
Create at	tribute index on join field use which fields are joined	
Custo	om field name prefix	
	OK Cancel	
To visualize as a map the	soil moisture values estimated for the date 19/01/2017	
• Right click on the vector l	ayer seg_crops_grass_smooth_buf.shp -> « Properties »	
• In the window that appear	rs, go to the tab « style » and choose the option « graduated »	
• In « Column », choose t 10/10/2016	he column that contains the estimated moisture values for the date	
• In « Color Ramp » choos	se a Color degradation	
• In « Classes » define 7 cl	asses	
In Walnass 1. Cast 1		
• In « values » define the l are [5-10], [10-15],, [3	ower and upper bounds of each class. In the figure below, the classes 5-40] (vol.%)	
• Click on « Ok »		
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4.4 Soil moisture maps

This section presents a spatial visualization of the estimated soil moisture values at each spatial unit (polygon). Figure below shows the soil moisture map of the date 10/10/2016. The map of shows that the soil of the study site is dry with moisture values between 5 and 20 vol.%.

