CROP MONITORING WITH DUAL POL SENTINEL-1 DATA: TIME SERIES ANALYSIS AND CROP CLASSIFICATION

Using Sentinel-1 (C-band) data obtained in 2015 and 2016 over the Czech Republic, in the area of Chrudim, we will analyse how the radar backscatter changes over time and we will produce crop classification maps.

There are a total of 24 Sentinel-1 acquisitions, which have the following characteristics: Mode Interferometric Wide, Product Type Ground Range Detected High resolution, Processing level 1 Standard, Polarisation VV+VH, Path 73, Frame 158. The full list of IDs can be found in **Annex A**.

Using such a large number of inputs has the advantage of increasing the detail in the time series and producing more accurate classification results. But of course it also increases considerably the computing time. Therefore in this exercise you will pre-process only 3 of the inputs, in order to learn how to do it. The remaining 21 inputs have been pre-processed for you prior to the course, so you can save time and use them directly in the time series and classification parts.

Besides, a set of backup outputs has been produced for you in advance, for each of the steps. You are welcome to refer to them to check your own results, or to use them as inputs if you experience any issues at a certain stage.

User Handbook: https://sentinel.esa.int/web/sentinel/user-guides/sentinel-1-sar

Coordinates of the subset area (decimal degrees)

Below are the coordinates of the area of interest in decimal degrees, used to subset the Sentinel-1 images and covering an area of 520.7 km^2. The same coordinates but in WKT format can be found in your auxiliary data folder.

North latitude bound	50.067208
West latitude bound	15.729975
South latitude bound	49.859164
East latitude bound	16.033744

Crop classification on arable land for Czech Republic:

The polygons come from the CzechAgri demonstrator of the Sentinel-2 for Agriculture (Sen2Agri) project. The data are courtesy of GIZ and more information on the project can be found here http://www.esa-sen2agri.org/302/. These data contain the following classes:

1 - winter rapeseed
2 - winter cereals
3 - spring cereals
4 – sugar beet
10 - fodder crops

We will visualize the time series of certain pixels which belong to different classes. The coordinates of those pixels, also called pins, can be found in **Annex B**. For an explanation of how to create the pins using polygons as an input, see **Annex E**.

1. Open the S-1 scenes
    1.1. Open your Inputs folder. It contains the 3 images that you will pre-process yourself. Can you see the acquisition dates of each of them, contained in the image name?
    1.2. Drag and drop the image from 22 November 2015 from your Inputs folder into the Product Explorer of SNAP
    1.3. Observe its metadata and bands folder

    The S1 GRD images need to be pre-processed. This includes a radiometric correction, speckle filtering, geometric correction and, finally, a conversion into logarithmic scale for better visualization.
    First, we will get familiar with SNAP and with the processing steps by applying each step manually to a single image. This is useful to become acquainted with the software, but it is not practical when it comes to processing a large amount of images. Therefore, after that we will make use of the Graph Builder to create a graphical workflow, and then we will use the Batch Processing tool to apply the workflow to all scenes at once.

    1.4. Demonstration on pre-processing a single image manually:
        1.4.1. Apply Orbit File:
        - First, click on Help / Help Contents and search for “Apply Orbit File”. Read about this operator
        - Click on Radar / Apply Orbit File
        - Observe the output name that is generated by default. It consists of the original name, with the “_Orb” suffix. Leave it as it is
        - Under Directory, select the Outputs/ Step1 folder
        - In the Processing Parameters tab, check the “Do not fail if new orbit file is not found” box
        - Click Run. The output will appear in your Product Explorer window
        - Note that, inside the product, the Metadata folder contains now a Processing Graph section. Click on it. What is the first node? What is the second node?

        1.4.2. Thermal Noise Removal:
        - As before, click on Help / Help Contents and search for this tool. Read about it
        - Click on Radar / Radiometric / S-1 Thermal Noise Removal
        - Your source product should be the output of the previous step
        - Add a meaningful sufix ("_NoiseRem") to avoid overwriting the source product
        - Under Directory, select the Outputs/ Step1 folder
        - In Processing Parameters, make sure the Remove Thermal Noise box is checked
        - Click Run. It may take several minutes
        - As before, observe the Metadata folder of your output

        For the following steps, check the Help if you want to know more about the operator. If you have doubts on how a certain product was processed, remember to check the contents of the Metadata folder.

        To visualize several images, use the Window / Tile Horizontally option, and then, under the Navigation tab, make sure you select the two buttons that synchronise view and cursor across multiple windows.

        1.4.3. Subset the images:
        - Raster / Subset
        - In the Spatial Subset tab, click on Geo Coordinates
        - Enter the coordinates listed in the introduction of this exercise. You will see the blue rectangle in the preview of the tool adjusts its size
        - In the Band Subset tab, ensure both VV and VH Intensities are checked
        - Click OK
        - In the subset that appears inside the Product Explorer window, right click / Save As. A pop-up will ask you about converting the product to BEAM-DIMAP format: select YES
        - Navigate to the Outputs/ Step1 folder, and Save
        - Observe the output has, by default, the prefix “subset_0_of_” added

- Observe the Metadata folder contains the subset info under a newly created section, called "history"

1.4.4. Radar / Radiometric / Calibrate
- Observe the output has the suffix "_Cal" added automatically
- Under Directory, select the Outputs/ Step1 folder
- In the Processing Parameters tab, ensure "Output sigma0 band" is selected
- Click Run

1.4.5. Radar / Speckle Filtering / Single Product Speckle-Filter
- Under Directory, select the Outputs/ Step1 folder
- In Processing Parameters, select the Lee filter with a 3x3 window size
- Click Run

1.4.6. Radar / Geometric / Terrain Correction / Range-Doppler Terrain-Correction
- Under Directory, select the Outputs/ Step1 folder
- In Processing Parameters, we will leave the defaults but observe the different options and read about them in the Help section if needed
- Click Run

1.4.7. Raster / Data Conversion / Bands to/From dB
- Under Directory, select the Outputs/ Step1 folder
- Click Run

After you are comfortable with SNAP, you can remove from your Product Explorer window all the images that remain opened from this stage. Step 1 is meant as an introductory demonstration of the software, but we will not use those outputs for the rest of the exercise.

Even though now you are able to process single images manually, you will often need to pre-process many more images than that, so let's build a graph that will enable us to process a batch of images at once.

2. Create a graphical workflow for pre-processing
   2.1. Go to Tools / Graph Builder
   2.2. By right-clicking in the white space of the graph builder, you can add operators and create a graphical workflow. Respecting the order below, add the following tools:
      - Add / Radar / Apply Orbit File. Check the "Do not fail if new orbit file is not found" box
      - Add / Radar / Radiometric / Thermal Noise Removal
      - Add / Raster / Geometric / Subset. Select Geographic Coordinates. Paste the WKT coordinates that you will find in aux_data / Step2_subset_coordinates.txt, click Update. **Annex C** explains how to get coordinates in WKT format
      - Add / Radar / Radiometric / Calibration. In the Calibration operator select "Output sigma0 band"
      - Add / Radar / Speckle Filtering / Speckle-Filter. Select "Lee" filter. Set the window size to 3x3
      - Add / Radar / Geometric / Terrain Correction / Terrain-Correction. Leave the defaults
      - Add / Raster / Data Conversion / LinearToFromdB
      - Add / Input-Output / Write
   2.3. Connect the different operators by moving the mouse over the different operators and dragging the red arrow to connect them
   2.4. As output folder select Outputs, and save your graph as "Step2_my_graph"

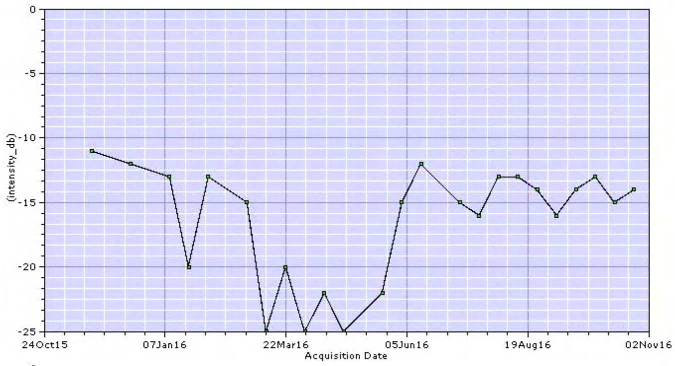
3. Batch Processing
   As explained in the introduction, you will pre-process and subset 3 of the 24 input files. In Step 1, you have already pre-processed the first of those 3 images manually. This was a demo to introduce SNAP to you. An option would be to pre-process the other 2 using the Batch Processing tool. However, the names assigned

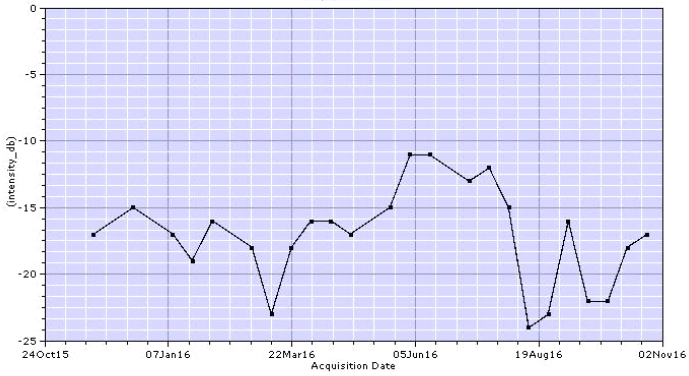
by the Batch Processing tool do not add suffixes to the output names. Just for consistency in the names of your outputs, we will pre-process again the first image but this time using the graph.
The remaining 21 images of the period have been pre-processed and cropped for you prior to the course and can be found in Outputs / Step3.

3.1. First, open the Outputs / Step3 folder and observe that the 21 pre-processed outputs are there. This will also be the folder where you save the results of your 3 images. In that way, the 24 outputs will be together.
3.2. Tools / Batch Processing
3.3. To pre-process the 3 images, click "Add Opened" in the I/O Parameters tab
3.4. Load your graph from step 2 and click through the different operators to see parameters
3.5. Under Directory, select the Outputs / Step3 folder
3.6. Run the batch process.
3.7. In your Product Explorer window, keep only the 3 outputs you just produced, closing the other images
3.8. Now open as well the other images that were pre-processed for you before the course (in folder Outputs / Step3)

4. Display time series of known crops
The location of each pin indicates a point in a field where we know the type of crop that was growing that year.

4.1. Make sure one of the bands (e.g. Sigma0_VH_db) is displayed, so that functions in the Pin Manager will be activated. It does not matter which image you choose
4.2. View / Tool Windows / Pin Manager
4.3. Import the pin.placemark file, which contains the coordinates of all pins (it is located in the "Aux" folder). Adjust colours if you wish.
4.4. Select all pins and click on "Transfer the selected pins to other products". Then select all products and click OK. This will make sure you see all pins overlaid in any image you choose to display
4.5. View / Tool Windows / Radar / Time Series
4.6. In the Time Series window click on the settings symbol. Using the Add Opened button, add the 24 pre-processed subsets. Click "Apply". Then you can close the pop up window.
4.7. Using the "Filter Bands" symbol in the time series window, select the band (in this example, we select Sigma_VH_db).
4.8. Then, select "Show for all pins", or "Show for selected pins". This will update the display of the tool, showing the time series of those pins.
4.9. Another way of visualizing the time series is by moving the mouse over the image. For that, ensure that the button "Show at cursor position" is activated
4.10. Note that it may take a few seconds for the time series to display. It sometimes helps to zoom into your image, or hover or click in the image view with your mouse
4.11. Observe the time series plot for all pins in the same graph. You can now see the backscatter for the different crops over the course of a year
4.12. If possible, complement or compare your results with NDVI time series for the same pins (e.g. using the ESA EO Browser), and with rainfall measurements from meteorological stations of the area (e.g. from www.weatheronline.com)
4.13. To learn how to visualize the average backscatter of a polygon over time, have a look at **Annex F** below





Time series obtained from S1 for the following pins, in VH polarisation:
Top: Sugar Beet, Bottom: Winter Rapeseed

5. Multitemporal, polarimetric analysis
For this section, the data need to be gathered in a stack:

5.1. Create stack
- Radar / Coregistration / Stack Tools / Create Stack and add the 24 pre-processed subsets
- Resampling type: Nearest neighbour
- Adapt the output name and folder, then run. This step will take several minutes
- In case of issues with the tool, remember that you have a backup available at Outputs_backup/Step5. You can use that backup to carry on with the next steps.

5.2. View various temporal and polarimetric RGB composites of the speckled filtered stack, by varying the date or the polarisation:
- Window / Open RGB Image Window
- Varying the date, for example Red = VH 09Jan2016, Green = VH 20May 2016, Blue = VH 17 Sept2016
- Varying the polarisation, for example: Red = VV, Green = VH, Blue = VV/VH from the same date
  Note: to enter a formula, such as the division VV/VH, click the "…"symbol next to your channel and use the pop up that will appear

5.3. Calculate the average backscatter over time:
- Use the stack from Step 5.1. as input for this step
- Create a subset that only keeps the bands of one of the polarisation channels: Raster / Subset and select first only the VV bands
- Radar / Coregistration / Stack tools / Stack averaging
- Use the Mean Averaging function
- Re-do these steps for the VH bands

6. Classify crop types
6.1. You have the Stack from step 5.1 opened. Close any other products that have remained opened.
6.2. Import the vector containing training areas for each crop type

- In the Product Explorer window, first select the Vector Data folder of the product by just clicking once on it. This will allow the next step to be active
- Vector / Import / ESRI shapefile
- Navigate to Aux_data /Training_data. Select all the shapefiles (one per crop type) using SHIFT on your keyboard, then Click Open, and click NO in all the "Import Geometry" dialogues that will pop up
- You should now see the Vector Data folder in the stack product
- Save the Stack by right clicking on it and selecting "Save Product", and, to avoid overwriting it, save it in the Outputs/Step6 folder with the prefix "Step6_2_".

6.3. Multi temporal Random Forest Classification with SNAP
Tip: Go to Help, type Random Forest Classification, and Random Forest Classifier Operator, to read about the tool

6.4. Raster / Classification / Supervised Classification / Random Forest Classifier
- In the ProductSet Reader tab, add the stack created in step 6.2 above
- In the Random Forest Classifier tab, use the parameters below:
    - Evaluate Classifier: uncheck if you want
    - Number of trees: 20
    - This is a low number of trees, which will produce a result quickly. In general, the more trees, the more accurate are the results. However, the improvement decreases as the number of trees rises. The number of trees is typically lower than 300
    - In step 7.6. you will open results produced before the course with higher number of trees
    - Select all shapefiles as training vectors
    - Select all bands as feature bands
- In the Write tab, select your output folder and give a meaningful output name
- Click Run. With 20 trees, the process will take only a couple of minutes
- In the Outputs_backup /Step6 folder, you will find the results produced with higher number of trees. These can take considerably longer to be produced: with 50 trees, 10 min. With 200 trees, 25 min. With 500 trees, 50min
- Drag each of them into SNAP, ready for the next step

7. Classification results

Results should appear in your Bands folder inside each of your Stack products

7.1. Give all of the results the same colour display: for each of them, open the Colour Manipulation tab. Click on "Import Colour Palette from text file" and import the one saved in aux_data / Step6_colour_palette.cpd. Then select "Apply to other bands"

7.2. In the Navigation tab, make sure the "Synchronises views across multiple image windows" option is clicked

7.3. Explore and compare different results. Choose one (e.g. the one with 500 trees) and display it

7.4. Import the vectors from the Czech Agri demonstrator classification:
- Vector / Import / ESRI Shapefile
- Navigate to aux_data / Validation data and import all the shapefiles
- Click No for each pop up window that will appear
- The validation polygons will now appear inside the Vector Data folder of the stack you selected in the step above

7.5. Go to Layer / Layer Manager and compare the validation polygons with the classification results

7.6. Classification results using a single polarisation channel (VH only and VV only) have been produced for you and are stored at outputs_backup / Step6 / SinglePolarisation. Open them and compare them with the dual pol ones

Annex A: List of Sentinel-1 original IDs

- S1A_IW_GRDH_1SDV_20151122T164248_20151122T164313_008720_00C6A3_E33A
- S1A_IW_GRDH_1SDV_20151216T164247_20151216T164312_009070_00D065_C84E
- S1A_IW_GRDH_1SDV_20160109T164247_20160109T164312_009420_00DA5E_038B
- S1A_IW_GRDH_1SDV_20160121T164246_20160121T164311_009595_00DF6E_3466
- S1A_IW_GRDH_1SDV_20160202T164246_20160202T164311_009770_00E487_A9DB
- S1A_IW_GRDH_1SDV_20160226T164246_20160226T164311_010120_00EEB8_2133
- S1A_IW_GRDH_1SDV_20160309T164246_20160309T164311_010295_00F3AD_0289
- S1A_IW_GRDH_1SDV_20160321T164246_20160321T164311_010470_00F8A3_96A2
- S1A_IW_GRDH_1SDV_20160402T164247_20160402T164312_010645_00FDA7_6D4C
- S1A_IW_GRDH_1SDV_20160414T164247_20160414T164312_010820_0102EC_753F
- S1A_IW_GRDH_1SDV_20160426T164247_20160426T164312_010995_01084E_C34F
- S1A_IW_GRDH_1SDV_20160520T164249_20160520T164314_011345_01137E_521F
- S1A_IW_GRDH_1SDV_20160601T164249_20160601T164314_011520_011934_0817
- S1A_IW_GRDH_1SDV_20160613T164250_20160613T164315_011695_011EAD_0C0B
- S1A_IW_GRDH_1SDV_20160707T164252_20160707T164317_012045_0129DA_6BD8
- S1A_IW_GRDH_1SDV_20160719T164252_20160719T164317_012220_012F8B_4B6C
- S1A_IW_GRDH_1SDV_20160731T164253_20160731T164318_012395_01354B_8922
- S1A_IW_GRDH_1SDV_20160812T164253_20160812T164318_012570_013B19_6789
- S1A_IW_GRDH_1SDV_20160824T164254_20160824T164319_012745_0140FA_0A75
- S1A_IW_GRDH_1SDV_20160905T164254_20160905T164319_012920_0146CB_9289
- S1A_IW_GRDH_1SDV_20160917T164255_20160917T164320_013095_014C73_2CCD
- S1A_IW_GRDH_1SDV_20160929T164255_20160929T164320_013270_015226_F1FA
- S1A_IW_GRDH_1SDV_20161011T164255_20161011T164320_013445_0157AD_C664
- S1A_IW_GRDH_1SDV_20161023T164255_20161023T164320_013620_015D28_8B7D

Annex B- Coordinates of the Pins

In this exercise we visualize the time series of certain pixels which belong to different classes. The coordinates of those pixels, also called pins, can be found below:

Crop type	Latitude	Longitude
Winter Rapeseed	49.905	15.999
Fodder	49.918	15.974
Winter Cereals	49.911	15.932
Spring Cereals	49.932	15.943
Sugar Beet	49.923	15.932

Annex C- Getting coordinates in WKT format from SNAP:

In SNAP, to use the Subset tool as part of a workflow and then run it for several files with batch processing, you need to provide the coordinates of your subset in WKT format.
An easy way to obtain them in this format is to draw a polygon along the perimeter of the area that will be your subset, then double clicking on it so it becomes highlighted in yellow. Finally right click and select “WKT from Geometry” from the drop-down menu that appears.
The coordinates in WKT format will then appear in a pop-up window. You can easily copy them, and paste them in the Subset tool of your graph.

Annex D - Comment on the pre-processing steps:

Since you have a time series, another possibility for the pre-processing is to create a graph with the following steps, which exclude the Speckle Filter:

- Add / Radar / Apply Orbit File
- Add / Radar / Radiometric / Thermal Noise Removal
- Add / Radar / Radiometric / Calibration
- Add / Radar / Geometric / Terrain Correction / Range Doppler Terrain-Correction

Then create a stack:

- Radar / Coregistration / Stack Tools / Create Stack
- Use as Resampling Type: None, Initial Offset Method: Product Geolocation, and Output Extents: Master

After this, run a Multi-temporal Speckle Filtering:

- Radar / Speckle Filtering / Multi-temporal Speckle Filter
- Use the stack as the input.
- Convert the bands to decibels.

Annex E: Creating pins with SNAP

In the following example, the input is a series of shapefiles, each of which contains a set of polygons from the same crop type. We will create one pin for each of the crop type classes.

1. Open SNAP and load one of your pre-processed subsets.
2. Display one of its bands
3. Import the polygons via Vector / Import / ESRI Shapefile. In the pop up window that will appear, click “No”
4. Decide for which crop type you will set the first pin. Then go to Layer / Layer Manager and under Vector Data uncheck the boxes of all the other crop types
5. Access the Pin Manager via View / Tool Windows / Pin Manager
6. Make sure the Tools toolbar is activated, via View / Toolbars / Tools, which contains the Pin Placing button
7. Zoom into your image, and use the Pin Placing button to set your pin in the desired location, inside one of the polygons of your chosen crop type. As an alternative, with the option “Create and Add New Pin” you can enter the precise coordinates of a certain location.
8. Adjust name and colour of the pin
9. Repeat for the other crop types
10. Once you have your collection of pins, select all and use one of the Export Selected Pins button to save them. You can choose to save them in XML format or in flat text format.
11. This file, which contains the pins, can later on be imported into SNAP, just as we did in step 4.3 above

Annex F: Visualizing the average backscatter of Regions of Interest over time

1. Load all the pre-processed subsets of S1 in SNAP
2. Display one of their bands
3. Vector / Import / ESRI Shapefile and Import the polygons for a certain class (e.g. Sugar Beet) The crop type shapefile we use in this example contains multiple polygons, so depending on your goal you can proceed in two ways:
    a. If you want to visualize the time series of individual polygons of that shapefile:
        - Import the shapefile and in the pop up window click **Yes**
        - This will display each polygon separately, as you will see in the Vector Data folder of your product
        - However, the Time Series tool will display the info of all the polygons contained in the shapefile, resulting in an unclear visualization. To solve that, in the Vector Data folder you can delete the polygons you don't want to visualize yet (right click on their name)
    b. If you want to visualize the average time series for all the polygons contained in your shapefile:
        - Import the shapefile and in the pop up window click **No**. This will import all polygons under the same name, so your Vector Data folder will only show one vector for all the polygons
4. In the Time Series tool, load the pre-processed subsets as explained in steps 4.6 above
5. Choose the band (VV or VH) that you want to display, as explained in step 4.7 above
6. You can uncheck the "Show at cursor position" button
7. Click the Show Averaged AOI button, and in the pop-up, select Mean
8. After a few seconds the average time series will display. Note that if you choose option 1.b. above, the time series is the temporal behaviour of the average of all polygons in the specific shapefile (vector) you imported