ESA Training Course on SAR / Optical

Applications to Snow and Ice – Practical Training

Vilnius, Lithuania, 07 July 2017

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Exercise 1: Generate high resolution binary and fractional snow maps from Sentinel-2 data over Lithuania

The daily generation of hemispheric or global snow cover extent products is usually based on medium resolution optical satellite data, such as Sentinel-3 SLSTR/OLCI, Terra/Aqua MODIS or NPP VIIRS. For assessing the quality of these products, snow maps generated from high resolution optical satellite data, as available from Sentinel-2 MSI or Landsat 8 OLI, can be used.

In this exercise, you will generate binary and fractional snow cover products from a Sentinel-2 scene over Lithuania acquired on 25th January 2017. You will use two approaches, both based on the Normalized Difference Snow Index (NDSI):

$$NDSI = \frac{\rho(VIS) - \rho(SWIR)}{\rho(VIS) + \rho(SWIR)}$$

ρ = Top of atmosphere reflectance

VIS = Visible band (0.56 μm)

SWIR = Short-Wave Infrared Band (1.6 μm)

A **binary snow classification** (snow / no snow) can be performed by the approach after Dozier and Painter (2004), applying thresholds on the NDSI and a Near Infrared band (NIR, e.g. 0.842 μm):

IF NDSI > 0.40 AND ρ(NIR) > 0.11 THEN snow in open land

IF 0.1 < NDSI < 0.4 THEN snow in forest

In forested areas, this approach aims on detecting the snow on ground. Use the mask, including forested areas, land and open water bodies, to discriminate forested areas and open land.

Fractional snow cover (FSC, 0 % - 100% snow) can be detected by the approach of Salomonson and Appel (2004, 2006), which was originally developed for MODIS data:

*FSC = –0.01 + 1.45 * NDSI*

In forested areas, this approach aims on detecting the viewable snow, i.e. the snow on top of the forest canopy.

1. Get an overview on the region and analyse spectral profiles of different surface classes using QGIS

1.1 Start QGIS, and load the following raster layers for the test site Lithuania (Main Menu → Layer → Add Layer → Add Raster Layer → navigate to the input data directory and select the data set → Open):

    a) Top of atmosphere reflectance of 12 May 2017 (Sentinel-2, Level 1C, quantized to value range 0 – 1): T35ULA_20170512T093041_B0010m_toaref_B2348.img & T35ULA_20170512T093041_B0020m_toaref_B5678A1112.img

    b) Bottom of atmosphere reflectance of 12 May 2017 (Sentinel-2, Level 2A, quantized to value range 0 – 1): L2A_T35ULA_20170512T093041_BOA2348scaled_10m.img

1.2 To display the images in the correct map projection, right click on one of the layers and select "Set Project CRS from Layer".

1.3 For the two images with 10 m pixel size (B2348), load the true colour composite using the band 3 for the red, band 2 for green and band 1 for blue band in QGIS. Stretch the minimum and maximum value ranges in both cases between 0.0 and 0.40 and use the Contrast enhancement "Stretch to MinMax" (double left click or right click on one layer → Properties).

> *TIP: When you have completed the correct display characteristics for one layer and want to apply exactly the same style on another layer, right click on the adjusted layer → Styles → Copy Style; then right click on the other layer → Styles → Paste Style. You can also paste the same style on multiple other layers if needed, by pressing the shift key during selection of multiple layers, then right click on one of the selected layers → Paste Style.*

1.4 Get familiar with the spectral signatures of different bands (VIS, NIR, SWIR) over different surface classes (forest, open water, cities, cultivated land, grassland). Make sure that you avoid regions affected by thin clouds. Use the Profile tool in Plugins to

    a) get the spectral top of atmosphere reflectance for the green (0.56 µm) and the shortwave infrared band (1.6 µm) along temporary polylines using the *Terrain Profile,* and save the resulting profiles as figures (.PNG).

    b) compare the spectral top of atmosphere reflectance of multiple bands over the different surface classes for single points using the *Temporal/Spectral Profile, and s*ave the resulting profiles as figures (.PNG).

2. Get an impression on the overall snow conditions on 25 January 2017 over Europe and import the Sentinel-2 and auxiliary datasets into SNAP:

Get a first overview of the snow and cloud conditions on 25 January 2017 over Europe using true- and false colour composite previews from MODIS data in the auxiliary data directory (open with any standard graphic program, e.g. Paint): RGB123_0.005deg_201701250745_201701251245_ MOD_panEU_ENVEOV2.1.00.jpeg and RGB651_0.005deg_201701250745_201701251245_MOD_ panEU_ENVEOV2.1.00.jpeg

2.1 In the input data directory, unzip the Sentinel-2 raw data set

2.2 Start SNAP, and import the Sentinel-2 data set and the land classification map:

    a) Sentinel-2 data set: File → Import → Optical Sensor → Sentinel-2 → S2 MSI L1C → Navigate to the S2 directory in the input data directory (S2A_MSIL1C_20170125T094251_ N0204_R036_T35ULA_20170125T094251.SAFE) and select the MTD_MSIL1C.xml file.

    b) Forest / water mask: File → Import → Generic Formats → GeoTIFF → Navigate to auxiliary data directory and select the file: ESACCI_LC_L4_LCCS_Map_300m_PIY_2015_v207_EPSG32635_Lithuania_10m.tif

2.3   Open the Metadata structure of the Sentinel-2 file (right click on Level-1C_User_Product and on Granules → Open Metadata Window) and get familiar with the basic information associated to the data set. Find the spectral information for the bands needed for the snow mapping approaches: physical band numbers, resolution (pixel size)

2.4   Load RGB composites of the Sentinel-2 image in the image viewer: Main Menu → Window → Open RGB Image Window → Load one after the other the three predefined profiles.

3.   *Resample the SWIR (1.6 µm) band to the pixel size of the VIS bands, and calculate the NDSI in SNAP*

3.1   In the main SNAP menu, select Raster → Geometric Operations → Resampling
Define the Resampling Parameters, using the 0.56 µm band as reference band, and the nearest neighbour resampling method. Save the output file.

3.2   In the main SNAP menu, select Raster → Band Maths (unlock the box "Virtual")
Calculate the NDSI based on the resampled data set using the 1.6 µm and the 0.56 µm bands

4.   *Generate and compare the binary and fractional snow maps from the Sentinel-2 scene*

4.1   Calculate the binary snow map using the approach of Dozier and Painter and use the land classification (LC) mask to differentiate the snow classification for open land, forested areas (code range 50 – 100), and excluding water bodies (code value 210):
Main Menu → Raster → Band Maths… (unlock the band "Virtual", define output layer name):
For the method after Dozier and Painter, use Operators to define conditional calculations. In the output, set the following values: water bodies = 20, snow free areas = 100, snow areas = 200:

if (LC == 210) then 20 else if(LC>=50 and LC<=100) and (0.1 < NDSI < 0.4) then 200.00 else if (LC<50 or LC>100 and LC<210 or LC>210) and (NDSI>0.40 and NIR > 0.11) then 200.00 else 100.00

4.2   Calculate the fractional snow cover map using the approach of Salomonson and Appel for all land areas, and set value range between 100 (snow free) and 200 (100 % snow covered):

*(-0.01 + 1.45 * NDSI) * 100 + 100*

4.3   Generated histograms of the binary and fractional snow cover maps: Select layer, then go to Main Menu → Analysis → Histogram:
For FSC map, set: min=100, max=200.0, #Bins: 100
For BS map, set: min=100, max=200, #Bins: 2
Save Charts as images.

4.4   Export snow layers into GeoTIFF Files.
If direct export does not work, save the snow layers in single files and export them afterwards into GeoTIFF files: Select the data set with the snow maps → Main Menu → Raster → Subset → In Tab Band Subset, select one layer → OK.

CONGRATULATIONS!!!

YOU SUCCESSFULLY COMPLETED ALL PROCESSING STEPS OF THE FIRST EXERCISE!!!

Now, take a deep breath, because it's time to start the real work:

let's interpret the results…

5. *Compare the results with a fractional snow cover map from MODIS data with about 500 m pixel size in QGIS*

5.1   Start QGIS and load the following raster files:
- Sentinel-2 top of atmosphere reflectance data set (within SNAP, create a raster subset from the resampled data set following the procedure described in Task 4.4, and select only the bands of interest. Then export the new product, e.g. into GeoTIFF format.)
- Snow maps from Sentinel-2 (exported from SNAP as GeoTIFF files)
- From the auxiliary data directory:
  - MODIS based snow map (FSC_0.005deg_201701250745_201701251245_MOD_panEU_ENVEOV2.1.00_EPSG32635_Lithuania_500m.tif)
  - Surface classification map from ESA Land Cover CCI (ESACCI_LC_L4_LCCS_Map_300m_PIY_2015_v207_EPSG32635_Lithuania_10m.tif)

5.2   Load specific color styles for the different layers (Right Click on layer → Properties → Style → Tab Style in the lower left part → Load Style → navigate to auxiliary data and load style):
- Sentinel-2 based snow products: FSCBIN_SNOW_color_LUT.qml
- MODIS based snow map: FSC_panEU_color_LUT.qml
- Surface classification map: ESA_LC_color_LUT.qml

5.3   Sort the layers into the following order:
Bottom: RGB composite of Sentinel-2 top of atmosphere reflectances, e.g. B11, B8 and B4
       Surface classification map
       MODIS based snow map
       Binary snow map from Sentinel-2
       Fractional snow map from Sentinel-2

5.4   Intercompare (visually) the resulting high-resolution snow maps from Sentinel-2 with the fractional snow cover map from MODIS data of the same date.

5.5   Where are major problems (e.g. yellow or green coloured areas in the Salomonson snow map)? Where are major differences between the different snow products (pixel size, fractional vs. binary information, what is the approximate sensitivity of the binary snow detection approach, i.e. which fraction of snow is classified)? What are the reasons for these problems and differences?

Exercise 2: Generated wet snow maps from Sentinel-1 data over the Alps

SAR data are independent on cloud cover or day light, but can only be used to detect wet snow cover extent in high alpine terrain. The method is based on the backscatter ratio of SAR images acquired at melting snow and at dry snow / snow free conditions (Nagler and Rott, 1999):

$$IF \ \frac{\sigma_{snow}^0}{\sigma_{ref}^0} < threshold \ THEN \ wet \ snow$$

The method has been widely used in mountain areas above the tree line to get maps of melting snow cover from C- or X-band SAR data.

In this exercise, you will use Sentinel-1 Interferometric Wide swath (IW) data over the Alps acquired on 29th April 2016 (melting conditions) and 30th January 2017 (dry snow conditions) with full resolution to detect the extent of melting snow end of April 2016. For simplicity, this exercise is based on ground range detection data (GRD) instead of usually used Single Look Complex (SLC) data from Sentinel-1.

1. Import Sentinel-1 data into SNAP

Unzip the Sentinel-1 raw file in the input data directory. Then start SNAP, import Sentinel-1 data sets, and get familiar with the radar data over the Alpine area

1.1   Import data set of 29 April 2016: File → Import → Radar Sensor → Sentinel-1 → Navigate to the raw S1 data in the input data directory and select the manifest.safe file).

1.2   Import data set of 30 January 2017 (subset, orbit corrected and calibrated): File → Open Product → Navigate to input data directory and select the file subset_0_of_S1A_IW_GRDH_1SDV_ 20170130T170640_20170130T170705_015064_0189E2_96FF_Orb_Cal.dim

1.3   From the scene of 29 April 2016, open the Abstracted metadata, and the amplitude and intensity bands (VV and VH) as image windows (right click on band → Open Image Window)

1.4   Acquaint yourself with the SAR data set: from which side is Sentinel-1 looking at the surface? Which features (e.g. water bodies, cities, mountains, anything else???) can you identify? What are the characteristics of these features? How do regions with layover/foreshortening look like?

> **TIP:** *Click on Main Menu → View → Synchronise Image Views to get for all open images the same subset in the display window.*

2. Prepare and calibrate the radar data

Before you do anything else with radar data in SNAP, apply the orbit file and calibrate the data.

2.1   Apply orbit file (for improved geometric accuracy) on the scene of 29 April 2016: Main Menu → Radar → Apply Orbit File: use the predefined processing parameters

2.2   Calibrate the orbit corrected data of 29 April 2016: Main Menu → Radar → Radiometric → Calibrate (select the radar backscatter coefficient σ[0] and VV (co-) and VH (cross-) polarizations in the processing parameters)

> σ[0] = *RADAR BACKSCATTER COEFFICIENT:*
> The normalised measure of the radar return from a distributed target, defined as per *unit area on the ground.*
> γ[0] = *RADAR BACKSCATTER COEFFICIENT:*
> The normalised measure of the radar return from a distributed target, defined as per *unit area perpendicular to the line of sight.*
> β[0] = *RADAR BRIGHTNESS COEFFICIENT:*
> The reflectivity per *unit area in slant range.*
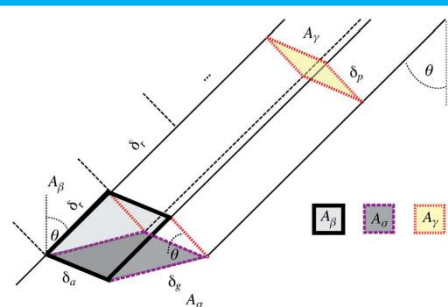
3. Coregister and filter the SAR data

3.1 Coregister the data using a DEM: Main Menu → Radar → Coregistration → DEM-Assisted Coregistration → DEM Assisted Coregistration:

    a) Load the orbit corrected calibrated data of 29 April 2016 and 30 January 2017

    b) Select the subset of 30 January 2017 as master (move on the top of the list using the arrows on the right side)

    c) In Tab DEM-Assisted-Coregistration, open the drop-down menu of Digital Elevation Model and select External DEM

    d) Click on the dots right of the External DEM field, navigate to the input data directory and select the EU DEM file EUDEM_ATWest_utm32wgs84_100m.tif

    e) In the tab Write, check/adapt as needed the output file name and the storage directory

    f) Click Run.

3.2 Reduce speckle by filtering the data: Main Menu → Radar → Speckle Filtering → Single Product Speckle Filter. Select the *Frost filter*, and test two different filter window sizes in the Processing Parameters:

    a) Filter size x/y: 3 x 3, dumping factor: 2.

    b) Filter size x/y: 7 x 7, dumping factor: 2.

3.3 Compare the filtered co- and cross-pol images with each other and with the unfiltered bands

4. Generate ratio images

From the filtered bands (7x7 filter window), generate co- and cross-polarized (VV and VH) σ^0 ratio images of the image acquired at melting conditions and the reference image acquired on a cold winter day:

4.1 Calculate ratios, separately for co- and cross-pol: Raster → Band Maths → define name of output layer and unlock "Virtual" → Edit Expression → σ^0_{SNOW} / $\sigma^0_{REFERENCE}$

4.2 Compare the resulting maps.

4.3 Convert σ^0 ratios into dB: Right click on layer → Linear to/from dB → Confirm

4.4 Convert virtual band to real layer: right click on layer → Convert band

Save the product file!

5. Generate layover/shadow mask and geolocate all necessary data sets

5.1 Generate layover/foreshortening masks: Main Menu → Radar → Geometric → Terrain Correction → SAR-Simulation:

    a) Tab I/O Parameters:

        • select Speckle filtered data set with band ratios (output from Step 4)

        • adapt name of target product

    b) Tab Processing Parameters:

        • Select the Sigma0_VH layer of 29 April 2016

        • Digital Elevation Model: select "External DEM" from Drop-Down Menu

        • External DEM: Navigate to the data directory and select the DEM file EUDEM_ATWest_utm32wgs84_100m.tif

        • DEM Resampling Method: BILINEAR_INTERPOLATION

        • Activate box "Save Layover-Shadow Mask"

    c) Click Run

5.2   Geolocate layover/shadow mask: Main Menu → Radar → Geometric → Terrain Correction → Range Doppler Terrain Correction:

    a) Tab I/O Parameters: select input data set and adapt target product name

    b) Tab Processing Parameters:

- Select the layover_shadow_mask layer
- Digital Elevation Model: select "External DEM" from Drop-Down Menu
- External DEM: Navigate to the data directory and select the DEM file EUDEM_ATWest_utm32wgs84_100m.tif
- DEM Resampling Method: BILINEAR_INTERPOLATION
- Map Projection: Custom CRS: Drop Down the Projection Menu, select UTM Zone (Geodetic Datum: WGS84); set Projection Parameters: Zone: 32, Hemisphere: North.

    c) Click Run.

5.3   Export shadow/layover layer into GeoTIFF: Select geolocated layover/shadow mask layer, then go to Main Menu → Export → GeoTIFF and save file on local disk.

5.4   Geolocate the ratio images in dB: Main Menu → Radar → Geometric → Terrain Correction → Range Doppler Terrain Correction:

    a) Tab I/O Parameters: select input data set and adapt target product name

    b) Tab Processing Parameters:

- Select the band ratios in dB
- Digital Elevation Model: select "External DEM" from Drop-Down Menu
- External DEM: Navigate to the data directory and select the DEM file EUDEM_ATWest_utm32wgs84_100m.tif
- DEM Resampling Method: BILINEAR_INTERPOLATION
- Map Projection: Custom CRS: Drop Down the Projection Menu, select UTM Zone (Geodetic Datum: WGS84); set Projection Parameters: Zone: 32, Hemisphere: North.

    c) Click Run.

6. Generate wet snow map

Create histograms from the geolocated co- and cross-pol band ratios in dB: Main Menu → Analysis → Histogram. Set the value range between –5 and +5, using 1000 bins.

Generate wet snow maps from geolocated co- and cross-pol band ratios in dB. Main Menu → Raster → Band Maths… (in the output layer, set wet snow areas = 200, dry snow or snow free areas = 100):

if RATIO_POL_IN_dB < −3 then WETSNOW else SNOWFREE

Export the wet snow maps into GeoTIFF file (if direct export does not work, or if you want to save the different wet snow maps in single files, follow the procedure described in Ex1 – Step 4.4).

CONGRATULATIONS!!!

YOU SUCCESSFULLY COMPLETED ALL PROCESSING STEPS!!!

Now, it's time to do the real work, so let's interpret the results…

7. Load generated wet snow product and FSC from optical data in QGIS and intercompare results

7.1   Start QGIS and load the following raster files:
- Wet snow maps (VH and VV) from Sentinel-1 (exported from SNAP as GeoTIFF files)
- Radar layover/shadow mask (VH) from Sentinel-1 (exported from SNAP as GeoTIFF file)
- From the auxiliary data directory:
  - MODIS based snow map (FSC_0.005deg_201604290650_201604291155_MOD_ panEU_ENVEOV2.1.00_EPSG32632_Alps_500m.tif)
    - Sentinel-2 based snow maps (S2A_OPER_MSI_L1C_TL_SGS__ 20160429T140042_A004452_T32TPTS_B0010m_toaref_fsc_salomonson.tif and S2A_OPER_MSI_L1C_TL_SGS__20160429T140042_A004452_T32TPTS_ B0010m_toaref_bin_dozier_ndsi40.tif)
  - Surface classification map from ESA Land Cover CCI (ESACCI_LC_L4_LCCS_Map_ 300m_PIY_2015_v207_EPSG32632_Alps_10m.tif)

7.2   Load specific color styles for the different layers (Right Click on layer → Properties → Style → Tab Style in the lower left part → Load Style → navigate to auxiliary data and load style):
- Wet snow maps: WET_SNOW_color_LUT.qml
- Radar shadow/layover mask: RADAR_SHADOW_color_LUT.qml
- Sentinel-2 based snow products: FSCBIN_SNOW_color_LUT.qml
- MODIS based snow map: FSC_panEU_color_LUT.qml
- Surface classification map: ESA_LC_color_LUT.qml
  For the surface classification map, set the following value ranges transparent: 0 – 49, 101 – 209, 221 – 255 (Double click on layer, Transparency, add value ranges using the plus sign). You should now see only the following classes: 50 – 100: forest, 210: water, 220: permanent snow and ice (=glaciers).

7.3   Sort the layers into the following order:
  Bottom: MODIS based snow map
  Sentinel-2 based snow map
  Wet Snow maps from Sentinel-1
  Radar shadow/layover mask
  Surface classification map

7.4   Intercompare (visually) the resulting wet snow cover products from Sentinel-1 with high-resolution snow maps from Sentinel-2 and the medium resolution fractional snow cover map from MODIS data of the same date.
  Which thematic information do you get from the SAR based and the optical based snow maps? What are advantages / disadvantages of the SAR based snow maps compared to optical snow maps? How could an end user benefit from combining the SAR based and optical based snow maps?