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**Practical Exercise:**

## Snowmelt Area Maps from Sentinel-1 SAR Data

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### Overview

The algorithm for snowmelt area mapping applies change detection and is applicable to C-band and X-Band SAR data, co- and/or cross-polarization. The reduced backscattering coefficient (σ°) of wet snow compared to surfaces that are snow-free or covered by dry snow (the reference image) provides the basis for segmentation of the snowmelt areas. Due to the high dielectric losses of water, σ° of snow decreases with increasing liquid water content, whereas dry seasonal snow is transparent at C-band; the backscatter signal comes from the snow/ground interface (Nagler and Rott, 2000). In order to reduce the impact of terrain-induced effects on backscatter in the segmentation procedure, backscatter ratios of snow and reference images are computed which are acquired from repeat-pass orbits (same look angle).

Dense forests obscure the signal from the ground (or snow pack) below and have to be flagged out in SAR snow retrievals. In this exercise we use the SAR image of a mountain area from late spring when the lower limit of the snow covered area was approximately at the elevation of the upper tree-line.

In this exercise we use Sentinel-1 Ground-Range-Detected (GRD) swath data (Level-1) in Interferometric Wide Swath (IW) mode. The backscatter values in GRD images refer to horizontal surface areas (Fig. 1). In the operational ENVEO processing line for snowmelt area retrieval we use Single Look Complex (SLC) data which allow for better geometric correction of terrain-induced distortions, but require more processing power and/or processing time (Nagler et al., 2016). Areas with layover (ambiguous return signals) and radar shadow need to be flagged out.

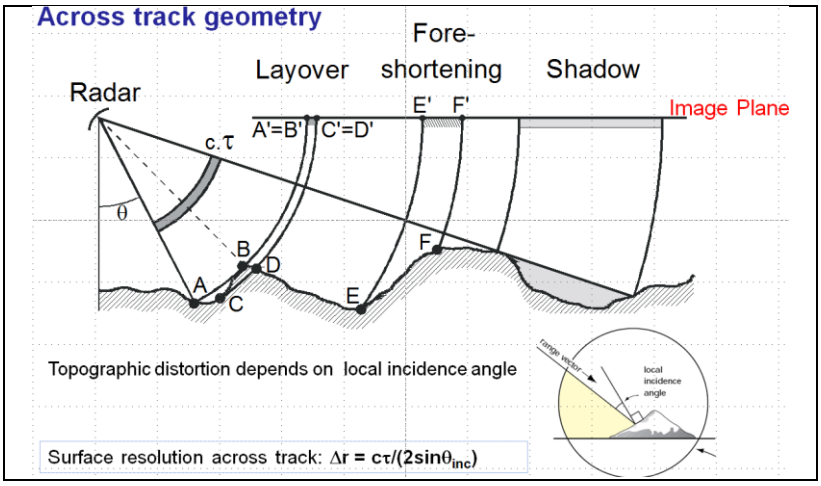
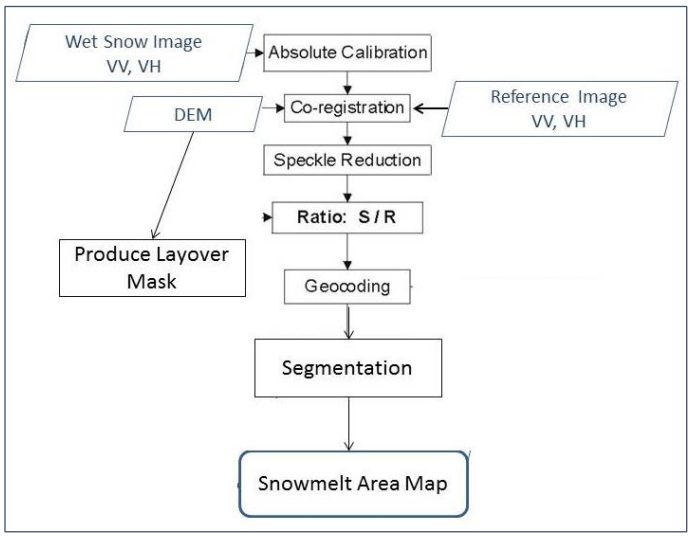



Fig 1. Across-track SAR-geometry. Projection of return signals from complex terrain onto a horizontal image plane (as provided in GRD images).

A flowline of the man processing steps for generating the snowmelt area map in this exercise is shown in Fig.2. This is a simplified version of the operational processing lines (Nagler at al., 2016) but contains the essential steps.




**References:**

Nagler T. and H. Rott, 2000: Retrieval of Wet Snow by Means of Multitemporal SAR Data. IEEE Trans. Geosc. Remote Sensing, Vol 38(2), 754-765.

Nagler, T., Rott, H., Ripper, E., Bippus, G., Hetzenecker, M. 2016. Advancements for snowmelt monitoring by means of Sentinel-1 SAR. *Remote Sens*., 8(4), 348; doi:10.3390/rs8040348.

## Input Data

Data for snowmelt area retrieval are Sentinel-1 (S1) C-Band SAR data in Interferometric Wide Swath (IW) mode at VV and VH polarizations, swath width 250 km, 5 m x 20 m nominal ground resolution. In the exercise a S1 image from 29 April 2016 is used for mapping snowmelt area. A winter image (30 January 2017) with dry snow and snow-free surfaces is used as reference image for change detection and segmentation.

- S1A_IW_GRDH_1SDV_20160429T170653_20160429T170718_011039_0109A8_4159 (zip)

Sentinel-1 GRD swath data (Level-1), resampled to 10 m x 10 m, acquired in IW mode, VV and VH polarizations, 2016-04-29. The zip file contains also auxiliary0data (orbit state vectors, calibration coefficients, etc.). The image covers a section of the SAR track, extending from Munich to the main ridge of the European Alps. These GRD data are not corrected for geometric distortion.

- subset_0_of_S1A_IW_GRDH_1SDV_20170130T170640_[…]_Orb_Cal.dim
- Associated directory:
  subset_0_of_S1A_IW_GRDH_1SDV_20170130T170640_20170130T170705_015064_0189E2_96FF_Orb_Cal.data

Subsection of GRD image of 2017-01-30 covering a section of the Austrian Alps. The surfaces were covered by dry snow (transparent for C-band SAR). This is the reference image for segmentation of wet snow. For these data orbit correction and radiometric calibration have already been performed. The relevant files are in the associated directory.

- EUDEM_ATWest_utm32wgs84_100m

DEM in UTM projection, 100 m grid.

## Work Flow

***Processing Tool:*** SNAP

### *1. Import, Visualize and Browse Sentinel-1 Data*

1.1. Start SNAP and import the zip file of 29th April 2016: File → Import → SAR Sensor → SENTINEL-1

1.2. In the "Product Explorer" you see the file name. Left clip opens the directory, go to "bands, and double click the respective band for view (e.g. Amplitude VV, Amplitude VH).

1.3. Browse the SAR image. Use zoom for checking different areas and try to identify different land cover classes and topographic features. Check the direction of radar illumination (line-of-sight, LOS) and how this affects the representation of mountain areas in the image.

Hint for scrolling and zooming multiple layers: *Click on Main Menu → View → Synchronise Image Views to get for all open images the same subset in the display window*

### *2. Radiometric Calibration of the Backscatter Data*

2.1 Apply the orbit file operator (for improved geo-referencing). Orbit state vectors are provided in the metadata. Main Menu → Radar → Run ... Apply Orbit File: use the predefined processing parameters.

2.2 Perform radiometric calibration of the orbit corrected data: Main Menu → Radar → Radiometric → Calibrate → in the tab "Processing Parameters" select "*Output $\sigma^0$ band*" and select both, VV and VH channels.

*Comment:* $\sigma^0$ is the normalized backscatter coefficient per unit surface area. The $\sigma^0$ values in GRD images are valid for horizontal surface areas.

### *3. Coregister the SAR data and apply speckle filter*

3.1 Load the orbit corrected and calibrated subset of 30 January 2017 from the input directory: Main Menu → File → Open Product → navigate to directory with the extracted input data and select the file *subset_0_of_S1A_IW_GRDH_1SDV_20170130T170640_[…]_Orb_Cal.dim* → Open

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

a) Load the orbit *corrected calibrated* data file of 29 April 2016 and the 30 January 2017 file
b) Select the data of 30 January 2017 as master (move this file to the top of the list using the ↑ arrow on the right side)
c) In Tab "DEM-Assisted-Coregistration" open the drop-down menu "Digital Elevation Model" and select "External DEM"
d) Click on the dots right of the "External DEM" field, navigate to the auxiliary data directory and select the " 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.

3.3 Reduce speckle by filtering the coregistered data: Main Menu → Radar → Speckle Filtering → "Single Product Speckle Filter." In the Processing Parameters, select the 4 bands (VV and VH, 2 dates) in the coregistered stack and apply the *Frost filter*:
Proposed filter size x/y: 7 x 7, damping factor: 2.
You may optionally test also other filter sizes.

3.4 Compare the filtered co- and cross-pol images with the unfiltered images.

### *4. Generate ratio images*

From the filtered bands (7x7 filter window), generate $\sigma^0$ ratio images (separately for VV and VH) for the wet snow cover image (29 April 2016) versus the reference image (30 January 2017), store the data:

4.1 Calculate ratios, separately for co- and cross-pol: Raster → Band Maths → define name of output layer and unlock "Virtual". Open "Edit Expression" → specify data source $\sigma^0_{29April}$ / $\sigma^0_{30Jan}$, and the math expression

4.2 Compare the resulting VV and VH ratio maps.

4.3 Convert σ0 ratios into dB: Right click on band (ratio VV, VH) → Linear to/from dB → Confirm

4.4 Convert the resulting virtual band to real layer: right click on band (ratio in dB) → Convert band

Save the product file!

## *5 Generate the layover/shadow mask and perform terrain corrected geocoding for the mask and ratio images*

5.1 Generate layover/shadow 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 4.1)
   - specify name of target product

b) Tab Processing Parameters:
   - Select the Sigma0_VH layer of 30 January 2017
   - 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 Perform geocoding of the 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 Source Band "layover_shadow_mask"
   - 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 the 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 "File" .1→ Export → GeoTIFF and save file on local disk.

5.4 Perform geocoding of 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 snowmelt area map*

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

6.2 Generate wet snow maps from geolocated co- and cross-pol band ratios in dB (output from Step 5.4) selecting a ratio threshold THR: Main Menu → Raster → Band Maths…*Operators*:

*if "RATIO_POL_IN_dB" < THR then* number for WETSNOW else number for SNOWFREE

Recommended THR: -3 dB. You may test other thresholds.

In the output layer, set for *WETSNOW* the number 200, for *SNOWFREE* 100.

6.3 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 seperately in single files, follow the procedure described in Ex1 – Step 5.4).

### Visualization and comparison with snow map from optical sensor

### Tool: QGIS

**<u>Input Data</u>**

- FSC_Salomonson_subset_of_S2A_OPER_MTD_SAFL1C_PDMC_20160429T214911_R022_V20160429T101028_20160429T101028_s2resampled

Snow map derived from Sentinel-2 data of 29 April 2016. Fractional snow cover, derived from VIS and SWIR bands with the algorithm of Salomonson and Appel.

- ESACCI_LC_L4_LCCS_Map_300m_PIY_2015_v207_EPSG32632_Alps_10m.tif

Map of surface land cover types from ESA Land Cover CCI.

- Colour look up tables (QGIS "Style") for the snowmelt area maps, the Radar layover/shadow mask, the optical snow map, and the land cover map.

## *7 Load the snowmelt area map and snow map from optical data in QGIS and compare results*

7.1 Start QGIS and load the following raster files:

- Snowmelt area 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)
- Salomoson-based snow map
- 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 colour 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):

- Snowmelt area  maps: WET_SNOW_color_LUT.qml
- Radar shadow/layover mask: RADAR_SHADOW_color_LUT.qml
- Sentinel-2 based snow product:  FSC_Salomonson_color_LUTqml
- Surface classification map: ESA_LC_color_LUT.qml

**7.3** Sort the layers into the following order:

Top: Snowmelt area map from Sentinel-1
Radar shadow/layover mask
Sentinel-2 based snow maps
Surface classification map

You can switch between the layers for visualization and comparison. The LUT of the snow map is se as transparent so that the layers below are also visible.

**7.4** Compare the snowmelt area maps of from Sentinel-1 with the fractional snow cover map from Sentinel-2 and check the impact of topography, radar-line-of-sight direction and land cover on differences between the products.