AlignSAR Tutorial

Version 1.1 (2024-01-22)

University of Twente, University of Leeds, RHEA System S.p.A.,
AGH University of Krakow

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Chapter 1

Introduction

This document provides a tutorial of using AlignsAR package to create SAR benchmark datasets, and describes the concepts of some relevant methods. This document is complied by Ling Chang.

1.1 Main contributors

This package is accomplished by all AlignSAR members, including e.g. Xu Zhang, Anurag Kulshrestha, Serkan Girgin, Alfred Stein, Ling Chang, José Manuel Delgado Blasco, Angie Catalina Carrillo Chappe, Andrea Cavallini, Marco Uccelli, Andy Hooper, Milan Lazecky, Wojciech Witkowski, Magdalena Łucka, Artur Guzy. The main contributors for script development and related description are Anurag Kulshrestha, Xu Zhang, José Manuel Delgado Blasco, Angie Catalina Carrillo Chappe, Milan Lazecky, Serkan Girgin, and Ling Chang.

1.2 Installation

All scripts for the AlignSAR package can be found on the GitHub web page:

https://github.com/AlignSAR/alignSAR.

The user can directly download them to a local computer, using e.g. `git clone` `https://github.com/AlignSAR/alignSAR` in the terminal.

SAR data preprocessing requires using either ESA SNAP or Doris-5. The user can either use Docker with our provided Docker file, or download SNAP via ESA SNAP, and Doris-5 via GitHub AlignSAR and manually install them on the computer. Note that the version of Doris 5 on GitHub AlignSAR, namely itc-doris_5_patch2023, is an updated version upon GitHub TUD-Doris, and if the user uses Doris-5 via GitHub TUD-Doris, the trouble shooting when installing it is included in Appendix A.

By creating a Docker that contains the pre-installed necessary software tools, i.e. SNAP 9.0, Doris and a Python 3 environment and other customised scripts, the end users can directly follow the procedure to create SAR benchmark datasets without installing the required software tools by the end users.

The instruction of Docker software installation on e.g. Ubuntu refers to dokcer-docs, and DigitalOcean.

To build the AlignSAR docker image, a user should install docker and download Dockerfile provided in the github repository (`https://github.com/AlignSAR/alignSAR`) to a dedicated directory. Inside the directory, the user can build the image using:

```
docker build -t alignsar .
```

and test the image by running an interactive terminal session using:

```
docker run -it alignsar
```

Note that one needs to run these commands in terminal, and in the same folder as the 'docker' file stored. Here 'alignsar' is to be mounted, and can be customized by the enduser. To unmount 'alignsar' one can directly close the terminal.

As we have stated, interferometric functionality is provided by both SNAP and Doris software. While SNAP is installed in the Docker image, several manual steps must be performed in order to install Doris 5 (which is called by Python 2). For this, please follow the instructions in Appendix A.

Afterwards, please set correct paths to the Doris-5 installation directory by editing files /root/DorisITCupdate/doris/doris_stack/main_code/doris_main.py (Line 5) and

/root/DorisITCupdate/doris/install/doris_config.xml (Line 2).

The directory should be set as /root/Doris5ITCupdate

Chapter 2

Definition of SAR benchmark datasets and data sources

2.1 SAR signatures

Here we recap the identified representative SAR signatures which are classified into three categories [1].

1. Category 1:

   Single polarimetric signatures, like amplitude, intensity, backscatter coefficient, (interferometric) phase and coherence.

2. Category 2:

   Multi polarimetric signatures, such as co-, dual polarization cross product, and summation, difference and ratio of the co-, dual, quad polarization intensities, and entropy, scattering mechanisms, SAR vegetation index (RVI), and SAR soil moisture.

3. Category 3:

   Inherited attributes from additional geospatial observations, e.g. land use land cover type, cadastral features, temperature, atmospheric phase, and geological information.

Based on the quality level, we extract the pixel with high quality, namely SAR benchmark dataset (SARbd) [4]. We provide SARbd in radar coordinates (as intermediate products), and SARbd in geo coordinates. We categorize SARbd into three different levels in terms of the quality level of SARbd. Level 1, namely **SARbd-L1**, is merely based on SAR statistics; Level 2, namely **SARbd-L2**, is based on external geospatial reference data; and Level 3, namely **SARbd-L3**, is based on both SAR statistics and external geospatial reference data.

2.2 Useful data sources

Many SAR data and other geospatial (reference) data can be collected freely, for instance,

- Sentinel-1a&b SAR data can be downloaded from ASFvertex and scihub
- ERS and Envisat can be downloaed via eogateway
- GPS dataset is stored in surfdrive. More GPS observations can be found on NGLStation
- AHN (actual height of Netherlands) can be collected via pdok
- Topographic map (TOPNL) can be found on brt
- SRTM can be downloaded via earthexplorer
- Copernicus DEM can be downloaded via panda
- DTM (Digital Terrain Model of Poland) can be downloaded via DTMPoland
- Land Cover Map - HRL - High Resolution Layers can be found via POLSA
- Geological data – Boreholes and Mining areas are stored on dmpgi and more detailed information for boreholes can be found via pgi

Chapter 3

Procedure description

3.1 Use case: Case in the Netherlands

We have three use cases, one in the Netherlands, one in Poland and one in India. Here we take the first use case in the Netherlands as a demo. The site is in the northern part of the country in the vicinity of the Groningen gas field and the Wadden Sea, see Fig. 3.1. This region is active due to both human activities like oil/gas extraction and geo-processes like wetland dynamics. The Groningen region is affected by land subsidence and earthquakes, due to human activity.

Seven C-band Sentinel-1A acquisitions (Path 15, Frame 169) in ascending orbit were collected. They have VV and VH polarization channels, and were acquired separately on 09 Jan, 21 Jan, 02 Feb, 14 Feb, 26 Feb, 10 Mar and 22 Mar 2022. The python script to automatically download these acquisitions is attached in DownloadCode, see data list in Fig. 3.2. The area of interest is outlined by purple in Fig. 3.1, and its shape file can be obtained via aoi. The orbital data can be collected from POEORB.

For instance, using a denoising method, multi-temporal filtering (Eq. (B.1)) on these 7 Sentinel-1 amplitude images in VV, the speckle noise can be reduced, see Fig. 3.3. The zoomed-in images (line $200-400$, pixel $2000-2200$) for the original and filtered SAR images are indicated in red and green separately. The spatial window size was set to 3×3 for this example.

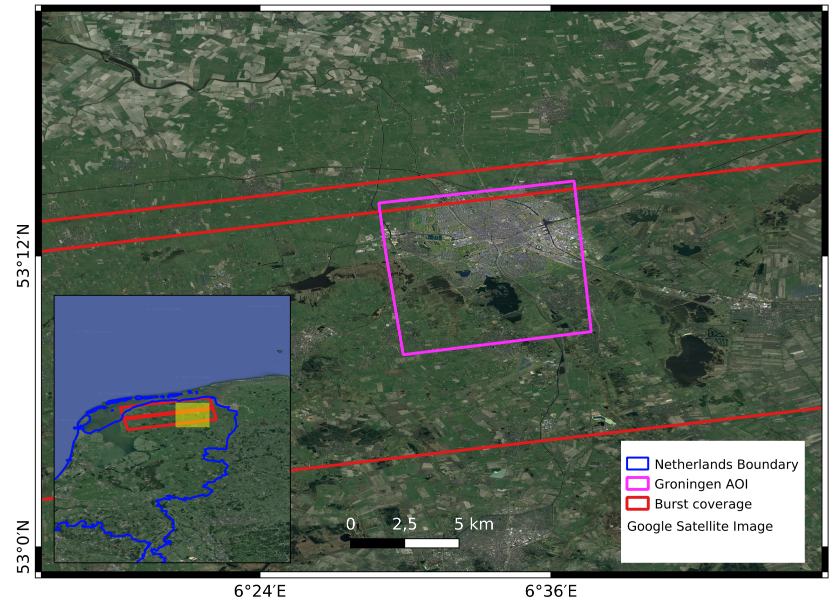


Figure 3.1: Study area for Use case 1: Groningen, The Netherlands. The city is shown within the pink polygon and corresponds to the amplitude image in Fig. 3.3. The yellow area in the inset map shows the overview of the outer map.

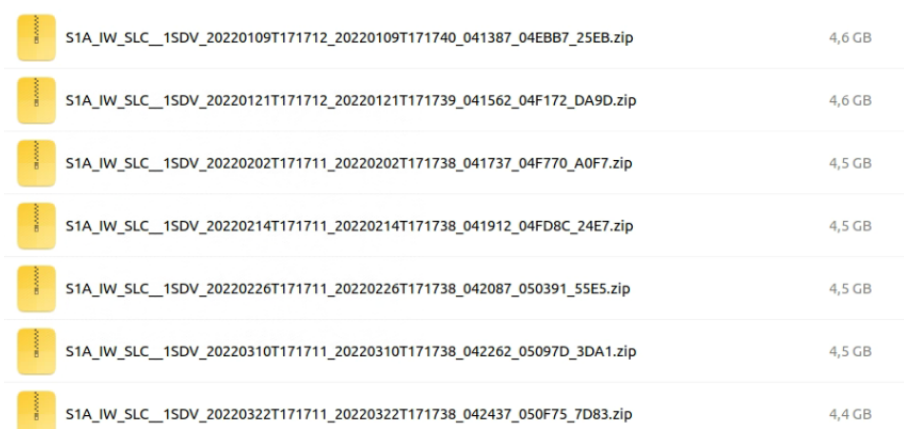


Figure 3.2: List of Sentinel-1 SLC data used

3.1.1 Creation of SAR signatures: Category-1 and -2

To generate Category-1 and -2 SAR signatures, Doris-5 is used. Here we show some basic procedures and parameter configuration. After Doris-5 installation (e.g. in the folder of /software/doris/), downloading the seven Sentinel-1 SAR images via DownloadCode, and the corresponding orbital data via Sentinel-1OrbitatASF, save Sentinel-1 SAR data and

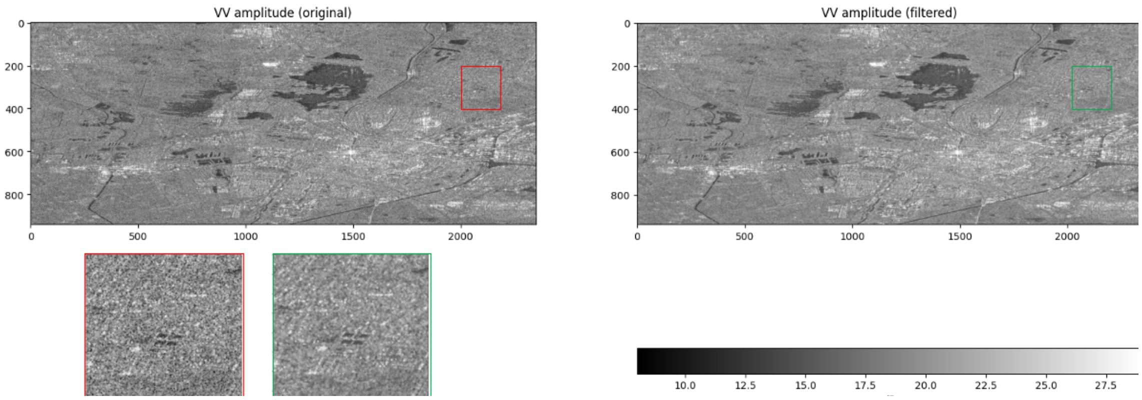


Figure 3.3: Multi-temporal filter example

its orbital data in separate folders. Next go to /software/doris/prepare_stack, and run the python scripts: `python2 prepare_datastack_main.py`. This script will ask to define the different folders that were created before. Here is an example:

Enter the path to the archive data folder: /home/ling/d2/groningendata
Which polarisation do you want to use (vv,hh,vh,hv): vv
Which SAR data track/path do you want to work with? (explore on https://scihub.copernicus.eu/dhus/) : 15
Is this track ascending or descending? (asc/dsc) : asc
Enter the path to the folder of new datastack: /home/ling/d2/groningen/process
Enter full path to the shapefile: /home/ling/d2/groningen/aoi/gro_aoi.shp
Enter the path to the folder of the orbit files: /home/ling/d2/groningen_orbit
Do you want to generate the DEM file automatically (Yes/No): Yes
Enter path to the dem folder: /home/ling/d2/groningen/DEM
Do you want to use parallel computing (Yes/No): Yes
How many cores do you want to use: 2
What is the start date of your stack in yyyy-mm-dd (can be changed later): 2022-01-09
What is the end date of your stack in yyyy-mm-dd (can be changed later): 2022-03-22
What is the master date of your stack in yyyy-mm-dd (can be changed later): 2022-02-14

Note that `https://scihub.copernicus.eu/dhus/` has been replaced by `https://dataspace.copernicus.eu`. After providing answers to these questions, the

DEM will be automatically downloaded, and the terminal will show the processing status, like

```
https://e4ftl01.cr.usgs.gov/MEASURES/SRTMGL1.003/2000.02.11/SRTMGL1_page_1.html status200
received ok
https://e4ftl01.cr.usgs.gov/MEASURES/SRTMGL1.003/2000.02.11/SRTMGL1_page_2.html status200
received ok
https://e4ftl01.cr.usgs.gov/MEASURES/SRTMGL1.003/2000.02.11/SRTMGL1_page_3.html status200
received ok
https://e4ftl01.cr.usgs.gov/MEASURES/SRTMGL1.003/2000.02.11/SRTMGL1_page_4.html status200
received ok
https://e4ftl01.cr.usgs.gov/MEASURES/SRTMGL1.003/2000.02.11/SRTMGL1_page_5.html status200
received ok
https://e4ftl01.cr.usgs.gov/MEASURES/SRTMGL1.003/2000.02.11/SRTMGL1_page_6.html status200
received ok
https://e4ftl01.cr.usgs.gov/MEASURES/SRTMGL3.003/2000.02.11/ status200 received ok
https://e4ftl01.cr.usgs.gov/MEASURES/SRTMGL30.002/2000.02.11/ status200 received ok
([], [], [])
Bounding box is:
from 51.6 latitude to 54.800000000000004
from 4.9 longitude to 8.200000000000001
total file size is 3841 in latitude and 3961 in longitude
total file size is 3841 in latitude and 3961 in longitude
Save data to geotiff
Calculate geoid correction for SRTM data
Correct DEM for geoid
–2023-10-01 15:06:06– https://github.com/anurag-kulshrestha/geoinformatics/raw/master/
WW15MGH.DAC
Resolving github.com (github.com)... 140.82.121.3
Connecting to github.com (github.com)—140.82.121.3—:443... connected.
```

```
HTTP request sent, awaiting response... 302 Found Location:
https://raw.githubusercontent.com/anurag-kulshrestha/geoinformatics/master/ WW15MGH.DAC
[following]
–2023-10-01 15:06:07– https://raw.githubusercontent.com/anurag-kulshrestha/geoinformatics/master/
WW15MGH.DAC
Resolving raw.githubusercontent.com (raw.githubusercontent.com)... 2606:50c0:8001::154,
2606:50c0:8003::154, 2606:50c0:8002::154, ... Connecting to raw.githubusercontent.com
(raw.githubusercontent.com)—2606:50c0:8001::154—:443... connected. HTTP request sent,
awaiting response... 200 OK Length: 2076480 (2,0M) [application/octet-stream] Saving to:
'/home/ling/d2/groningen/DEM/EGM96_15min.dat'
/home/ling/d2/groning 100
2023-10-01 15:06:07 (58,9 MB/s) - '/home/ling/d2/groningen/DEM/EGM96_15min.dat' saved
[2076480/2076480]
0 .. 10 .. 20 .. 30 .. 40 .. 50 .. 60 .. 70 .. 80 .. 90 .. 100 - Done Input file size is 3961, 3841
0...10...20...30...40...50...60...70...80...90...100 - done.
```

The stack folder will be created in /home/ling/d2/groningen/process, containing create_dem.sh, dem doris_input.xml, doris_stack.sh, download_sentinel.sh, input_files, and stack. The 'dem' folder includes dem.raw, dem.raw.doris_inputfile, dem.raw.q, dem.raw.var, and dem.tiff (SRTM1 for this case). The 'stack' folder is empty for the time being. One can still modify 'doris_input.xml' to decide to run/cancel any processing steps by defining 'Yes' or 'No'. For instance, if one doesn't want to run coherence processing, in the 'doris_input.xml' file, one can define <do_coherence>No</do_coherence>. After the 'doris_input.xml' modification, run the command `bash doris_stack.sh`.

To showcase the extracted SAR signatures, a demo '`signature_extraction_demo.ipynb`' on Juypter notebook is created, as well as an illustration shown in Fig. 3.4. The python script, namely '`Jupyter_input_preapre.py`' can be used to convert e.g. .raw data to .npy file that can be directly and interactively processed on jupyter notebook.

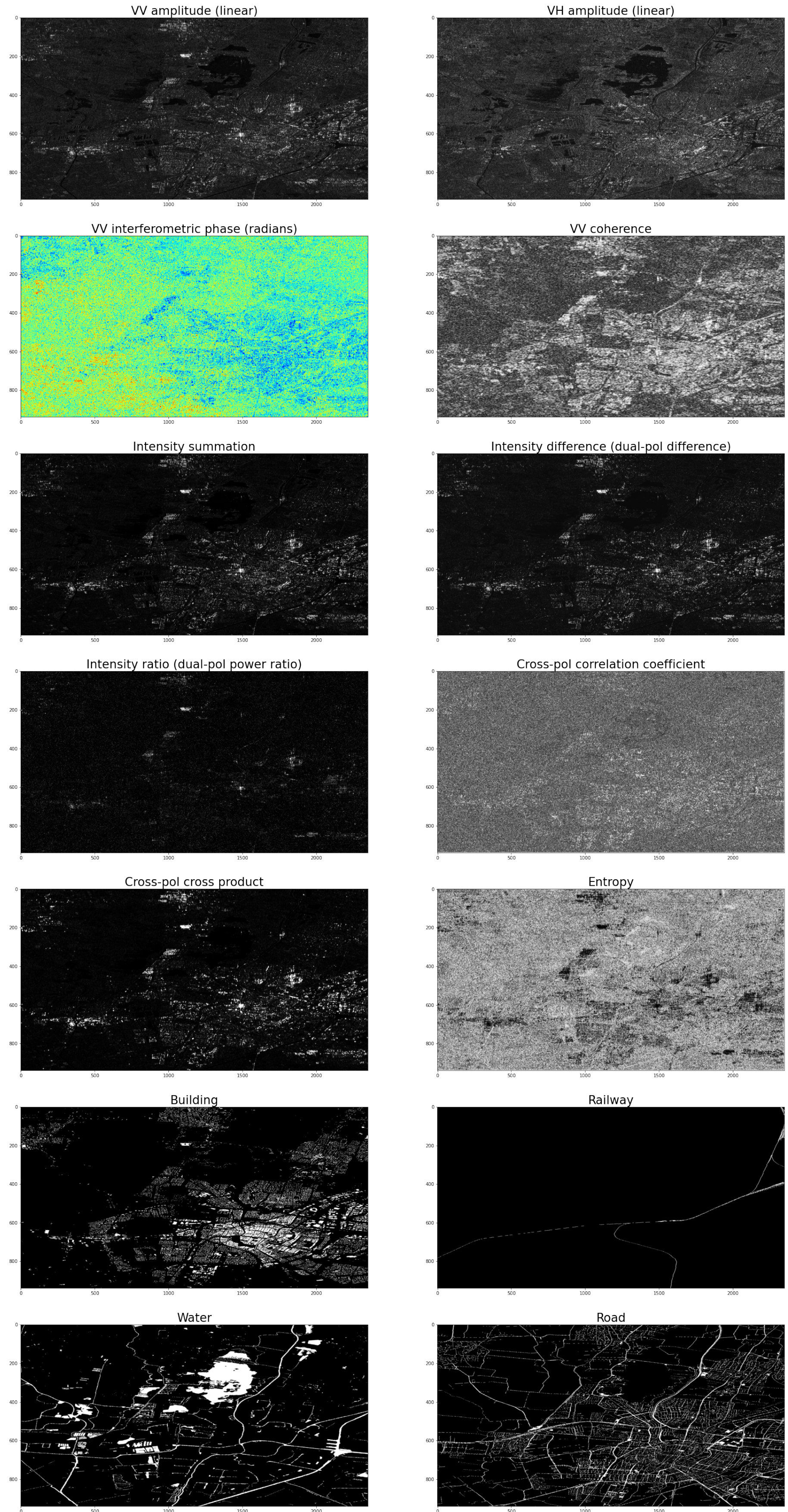


Figure 3.4: 14 SAR signatures for the acquistion on 09 Jan 2022

3.1.2 Creation of SAR signatures: Category-3

To create Category-3 SAR signature, Radarcoding shall be implemented for the additional geospatial data.

3.1.3 Radarcoding concept

Radarcoding is a step to convert all available data to radar coordinates, and link radar scatterers in SAR images with the counterparts in the reference datasets registered in geographic coordinate systems. Radarcoding is used to associate Category-3 signatures to radar scatterers. The Radarcoding script, namely `rdrCode_main.py` is python based [2].

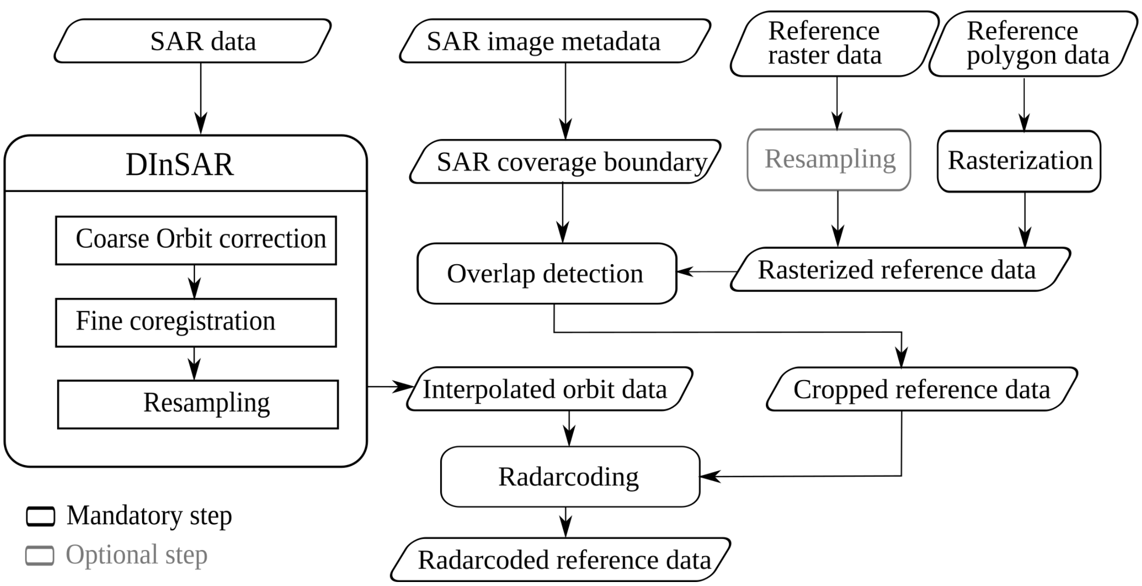


Figure 3.5: Radarcoding procedure [2]

The Radarcoding procedure is illustrated in Fig. 3.5. A stack of SAR images (≥ 2) is used and coregistered, resampled and aligned to the common master grids using differential SAR Interferometry (DInSAR). The mid-line number, PRF (pulse repetition frequency), RSR (range sampling frequency), first-line timing and first-pixel timing information are taken from the SAR image metadata. The SAR coverage boundary is extracted using the extreme extent coordinates from the satellite image metadata.

The additional reference observations may contain point-line-polygons, like topographic maps including land use land cover clarification product. For such observations, we rasterize them class-wise using the GDAL rasterize function. Here, the choice of the raster image resolution is dependent upon the size of reference polygons, the spatial resolution of the SAR data and the processing limitations of the computer. If the reference datasets are available as rasters, e.g. optical images, Generic Atmospheric Correction Online Service for InSAR (GACOS) atmospheric phase delay maps [7], the datasets can be used directly for radarcoding. They can be optionally resampled to a required spatial resolution, especially for datasets with ultra-fine resolutions.

Rasterized reference data are then cropped, based on SAR coverage boundary information, and later radar coordinates are assigned (with range and azimuth indices), namely radarcoded reference data.

To run Rdr-Code, the user needs to define the name of the file that needs to be radarcoded. If it is a multilayered file, i.e. with multiple bands in raster data, or multiple layers in vector, then the name of layers needs to be mentioned.

The alternative option for radarcoding is a function called `snap_rdrcode.py`, allowing radarcoding from data prepared by SNAP and developed based on GMTSAR radarcoding routines.

In the end, all SAR signatures can be directly converted to a geographic (e.g. WGS-84) coordinate system using Doris-5 (when setting '<do_calc_coordinates>Yes</do_calc_coordinates>' in 'doris_input.xml') or geocoding tables generated by SNAP, see Fig. 3.6. For the later option, we generate geocoding look-up tables based on the reference acquisition that will be later used to transform signatures generated in radar coordinates from this and other precisely coregistered acquisitions in the data stack.

The geocoding script `geocode_ifg_snap.sh` calls a SNAP processing graph file

`graph_geocoding_s1_geotiff.xml` that contains two operations: Multilooking and Terrain Correction (using Copernicus DEM automatically downloaded by SNAP) leading to geocoding the data to a 0.00027 deg (30 m) resolution GeoTIFF grid in the WGS-84 system that can be further converted to another coordinate system (e.g. UTM).

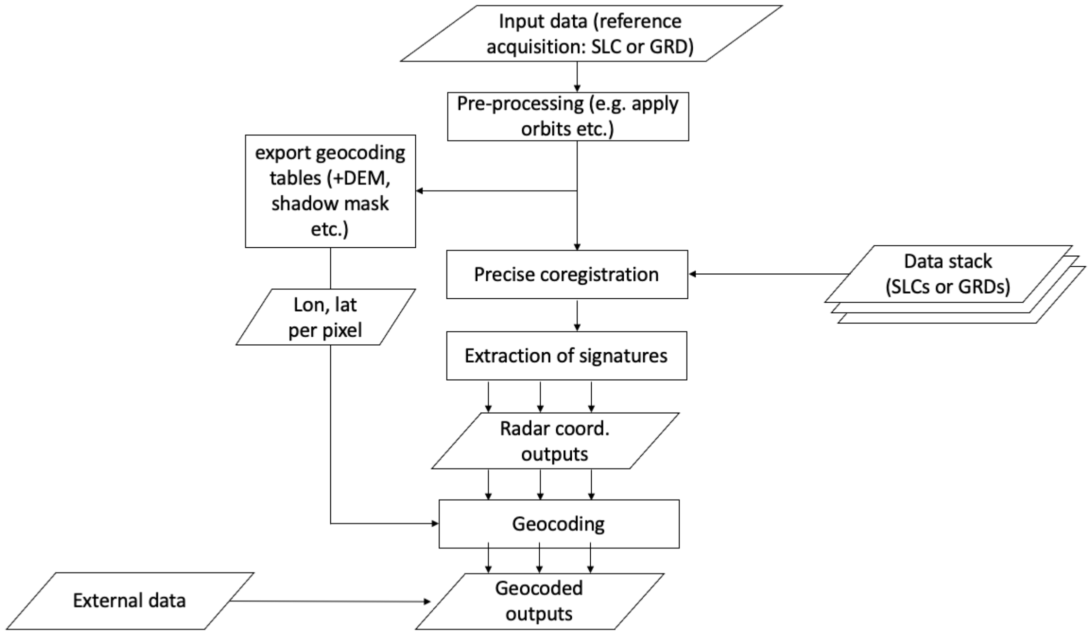


Figure 3.6: Procedure of extracting geocoded SAR signature

Usage:

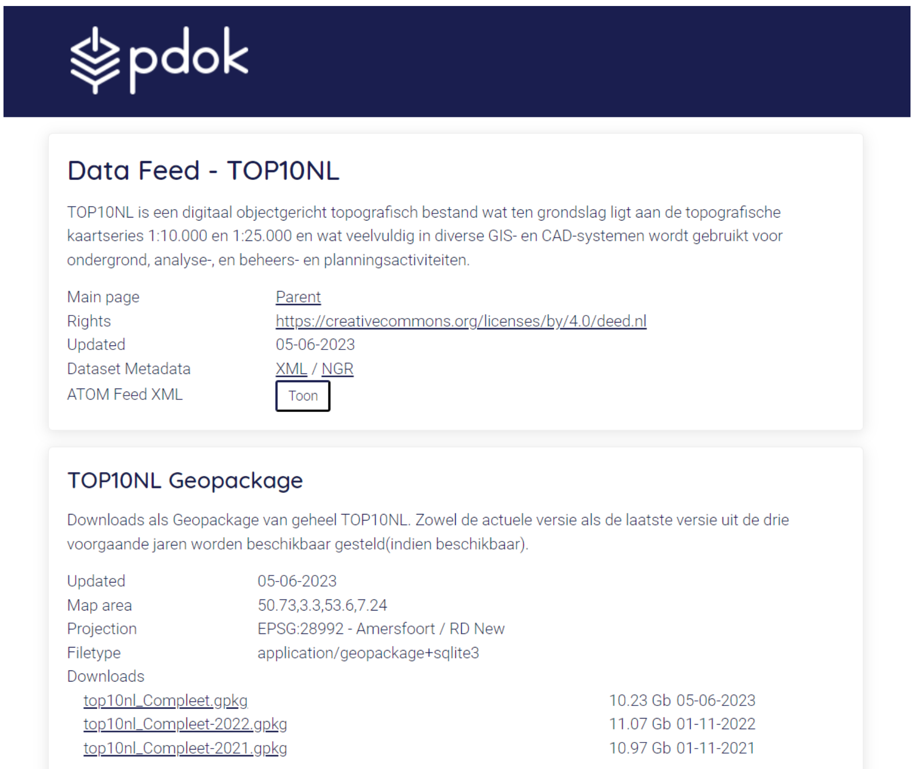
`geocode_ifg_snap.sh XX.dim /output/path [bandname]`

Note if bandname is not provided, the script would geocode all bands found inside the SNAP dim file structure.

3.2 Geospatial data TOP10NL collection and coversion

We take the geographic base map TOP10NL data as an example, obtained through `https://service.pdok.nl/brt/topnl/atom/top10nl.xml`, see Fig. 3.7. For TOP10NL Geopackage block, three versions of TOP10NL data are included which were updated in different years. Here, we select the 2022 version '*top10nl_Compleet − 2022.gpkg*', which aligns with the SAR dataset.

The TOP10NL data in 'gpkg' format can be viewed by using QGIS. When importing the TOP10NL data into the QGIS, a pop-up window shows all the attribute layers as shown in Fig. 3.8. Here, 'top10nl_gebouw_vlak' (buildings), 'top10nl_spoorbaandeel_lijn' (railways), 'top10nl_waterdeel_vlak' (water bodies), 'top10nl_wegdeel_vlak' (roads) are se-



pdok

Data Feed - TOP10NL

TOP10NL is een digitaal objectgericht topografisch bestand wat ten grondslag ligt aan de topografische kaartseries 1:10.000 en 1:25.000 en wat veelvuldig in diverse GIS- en CAD-systemen wordt gebruikt voor ondergrond, analyse-, en beheers- en planningsactiviteiten.

Main page	Parent
Rights	https://creativecommons.org/licenses/by/4.0/deed.nl
Updated	05-06-2023
Dataset Metadata	XML / NGR
ATOM Feed XML	Toon

TOP10NL Geopackage

Downloads als Geopackage van geheel TOP10NL. Zowel de actuele versie als de laatste versie uit de drie voorgaande jaren worden beschikbaar gesteld(indien beschikbaar).

Updated	05-06-2023
Map area	50.73,3.3,53.6,7.24
Projection	EPSG:28992 - Amersfoort / RD New
Filetype	application/geopackage+sqlite3
Downloads	

top10nl_Compleet.gpkg	10.23 Gb 05-06-2023
top10nl_Compleet-2022.gpkg	11.07 Gb 01-11-2022
top10nl_Compleet-2021.gpkg	10.97 Gb 01-11-2021

Figure 3.7: pdok website showing where to download TOP10NL

lected to obtain additional SAR signatures by radarcoding, which are highlighted in blue (Fig. 3.8), and later visualized by QGIS as the screenshot illustrated in Fig. 3.9.

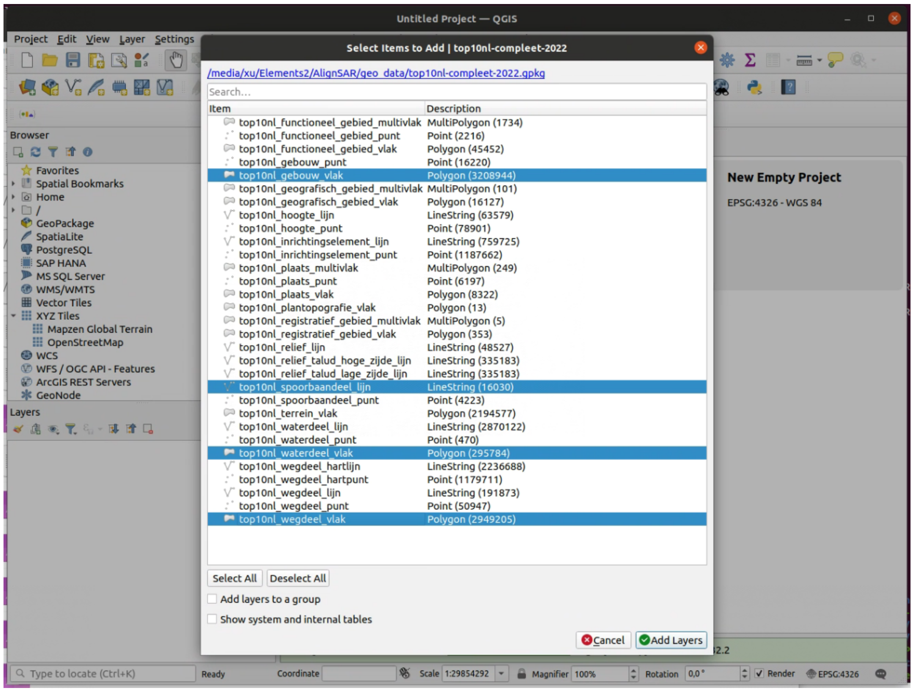


Figure 3.8: TOP10NL imported onto QGIS

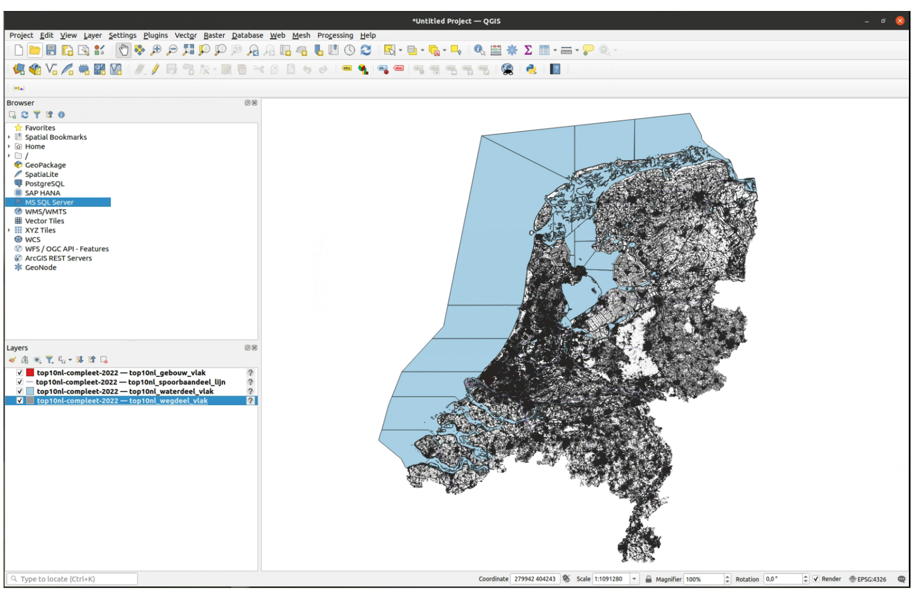


Figure 3.9: Overview of the four selected TOP10NL layers on QGIS

The radarcoding scripts can be found via ‘AlignSAR/alignSAR/rdrcode‘ on Github, as shown in Fig. 3.10. The user only needs to set the parameters in ‘Input_card.txt‘ file as shown in Fig. 3.11. In Line 8, the project ID can be defined. From Line 14 to Line 21, these parameters are part of the parameters in Doris preprocessing. Note that in Line 17, for 'SensorName', the user can keep it as e.g. 's1', if older SAR data are used like from Envisat. Such setting will not affect the radarcoding result. From Line 27 to Line 32, these parameters are prepared for the TOP10NL data for radarcoding. Line 27 is the TOP10NL data downloaded from PDOK. Line 28 can set the value to ‘True‘ or ‘False‘ to either crop the datasets or not. Line 29 is the data type of the reference data. The data can be in polygon or raster format. Line 30 shows the layer name that we want to extract from the reference data. The ‘resolution‘ in Line 31 is suggested to be larger than 0.0001 decimal degrees. The ‘burn_val‘ in Line 32 is the space distance used to separate the adjacent layers. Line 38 can set the intermediate folder path to store the intermediate radarcoding products as shown in Fig. 3.12. Line 39 is prepared for the interferogram generation. To select their option or not, the user can set ‘True‘ or ‘False.‘

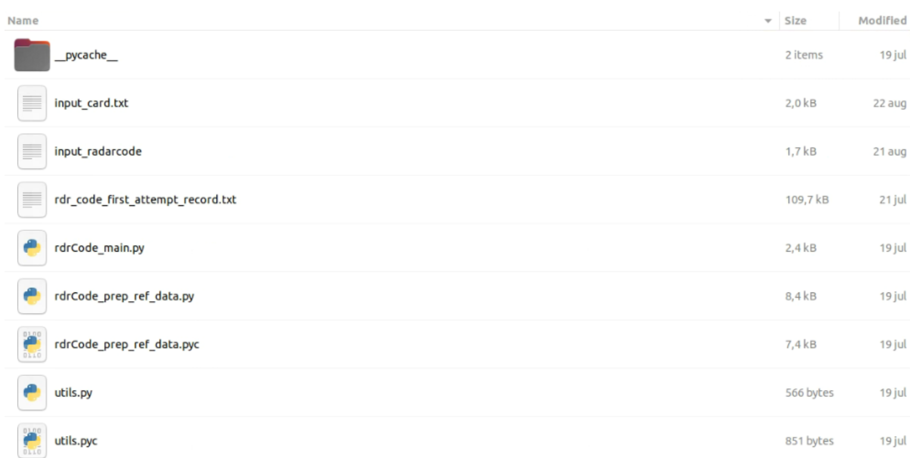


Figure 3.10: Overview of the radarcoding script files

After this parameter setup, the user can open the terminal and go to the folder where the ‘`python rdrCode_main.py`‘ file exists. Then, run ‘`python rdrCode_main.py --inputFile input_card.txt`‘, the radarcoding process will run automatically. Finally, the radarcoding products, e.g., ‘top10nl_gebouw_vlak_radarcoded.raw‘ can be found in the master image folder (../new_datastack/stack_vv/20220214). Note that in the in-

```
% --------------------------------------------------------------------
% Radarcoding project parameters
% --------------------------------------------------------------------

%**********************************
% Project parameters
%**********************************
project_id = 'rdr_test'


%**********************************
% SAR data parameters
%**********************************
SARDataDir  =  '/media/xu/Elements2/AlignSAR/Doris_Processing/Doris_Processing_36_Groningen/sar_data_2022' %Path to the SAR data directory
dorisProcessDir  = '/media/xu/Elements2/AlignSAR/Doris_Processing/Doris_Processing_36_Groningen/new_datastack/stack_vv % 'Full path to the processing directory')
cropAoi     = '/media/xu/Elements2/AlignSAR/Doris_Processing/Doris_Processing_36_Groningen/AOI' % 'Full path to shapefile used to crop the data'
sensorName  = 's1'%  's1 | paz | tsx'
orbit_dir   = '/media/xu/Elements2/AlignSAR/Doris_Processing/Doris_Processing_36_Groningen/orbit_files'
startDate   = '20220109'
stopDate    = '20220322'
masterDate  = '20220214'

%**********************************
% Ref data params
%**********************************

refDataFile = '/media/xu/Elements2/AlignSAR/geo_data/top10nl-compleet-2022.gpkg'% 'Full path to shapefile/or geotiff raster for the reference data to be radarcoded'
cropSwitch  = 'True'% True | False % Whether the datasets need to be cropped to the cropAoi file boundary
refDataType = 'polygon' %polygon/raster
layerNames  = ['top10nl_wegdeel_vlak', 'top10nl_waterdeel_vlak', 'top10nl_gebouw_vlak', 'top10nl_spoorbaandeel_lijn'] %List of layer names in the shapefile to be
radarcoded
resolution  = 0.00015%decimal degrees
burn_val    = 1 %m

%**********************************
% processing options
%**********************************

int_process_dir = '/media/xu/Elements/AlignSAR/radarcoding/groningen_processing_test %intermediate processing dir
doInSAR     = 'False'% Whether to do InSAR interferogram generation or not
```

Figure 3.11: Overview of radarcoding inputcard

top10nl_gebouw_vlak.tif	593,6 MB	20 aug
top10nl_gebouw_vlak_reproj_0.00015.hdr.aux.xml	550 bytes	20 aug
top10nl_gebouw_vlak_reproj_0.00015.hdr	652 bytes	20 aug
top10nl_gebouw_vlak_reproj_0.00015.raw	372,0 MB	20 aug
top10nl_gebouw_vlak_reproj_0.00015.tif	372,0 MB	20 aug
top10nl_spoorbaandeel_lijn.tif	593,6 MB	20 aug
top10nl_spoorbaandeel_lijn_reproj_0.00015.hdr.aux.xml	550 bytes	20 aug
top10nl_spoorbaandeel_lijn_reproj_0.00015.hdr	652 bytes	20 aug
top10nl_spoorbaandeel_lijn_reproj_0.00015.raw	372,0 MB	20 aug
top10nl_spoorbaandeel_lijn_reproj_0.00015.tif	372,0 MB	20 aug
top10nl_waterdeel_vlak.tif	593,6 MB	20 aug
top10nl_waterdeel_vlak_reproj_0.00015.hdr.aux.xml	550 bytes	20 aug
top10nl_waterdeel_vlak_reproj_0.00015.hdr	652 bytes	20 aug
top10nl_waterdeel_vlak_reproj_0.00015.raw	372,0 MB	20 aug
top10nl_waterdeel_vlak_reproj_0.00015.tif	372,0 MB	20 aug
top10nl_wegdeel_vlak.tif	593,6 MB	20 aug

Figure 3.12: Overview of radarcoding intermediate output

put_radarcode, on line 10 the default setting 'Height = 0.0 // average WGS84 height' is not used for radarcoding. This parameter HEIGHT (if specified) is only used for the image cropping calculation of the crop, using geo-coordinates information.

Alternatively, radarcoding of a GeoTIFF file in WGS-84 can be performed using functions from `snap_rdrcode.py` based on the outputs from SNAP containing orthorectified coordinates per pixel (e.g. outputs of SNAP2STAMPS) (function `snap_geo2rdc`), or corresponding outputs e.g. by the GEOCODE step of doris (function `geo2rdc`).

A demonstration is shown below to illustrate how radarcoding works using SNAP. First of all, the SNAP radarcoding script can be downloaded in alignSAR Github (`https://github.com/AlignSAR/alignSAR/blob/main/rdrcode/snap_rdrcode.py`). Besides, `'bin'` and `'snap_graphs'` folders should be downloaded to the local computer. They are prepared for script installation. There are two required inputs: one is the preprocessed `.dim` file generated by using SNAP, as shown in Fig. 3.13. The 'orthorectifiedLat' and 'orthorectifiedLon' must be provided for the input; the other one is the image that needs to be radarcoded. Finally, following the scripts in `'snap_radarcode.py'`, from Line 7 to 25, radarcoding can be done using jupyter notebook.

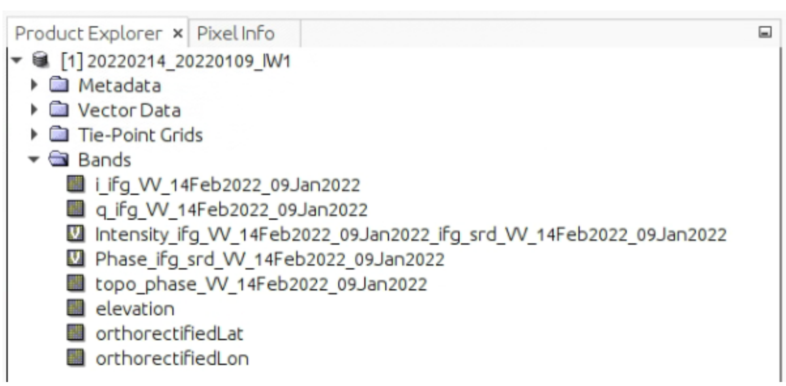


Figure 3.13: Overview of SNAP's output '.dim' file demonstration

3.3 SAR signature extraction demonstration

As we have done in Sec. 3.1.1, to obtain SAR benchmark datesets first in radar coordinates (ultimately in geo-coordinates) using Doris, we apply a standard interferogram generation procedure using Doris for these seven Sentinel-1 SAR images in VV and VH. All coregistered images can be found on `https://alignsar.stargazer-cod.ts.net/ITC_data/demo_data.zip`. The standard output of these coregistered images covers the folders listed in Fig. 3.14, and in each 'date' folder, it has raw images (.raw) and their preview images in .ras and log/dumpy files, see Fig. 3.15. For instance, 'cint_srd.raw' is the resultant interferogram after removing reference and topographic phase, 'coherence.raw' is the coherence maps, and 'slave_rsmp.raw' is the coregistered and resampled slave image. Note that there are no 'cint_srd.raw' and 'coherence.raw' for the master 'date folder' – '20220214'.

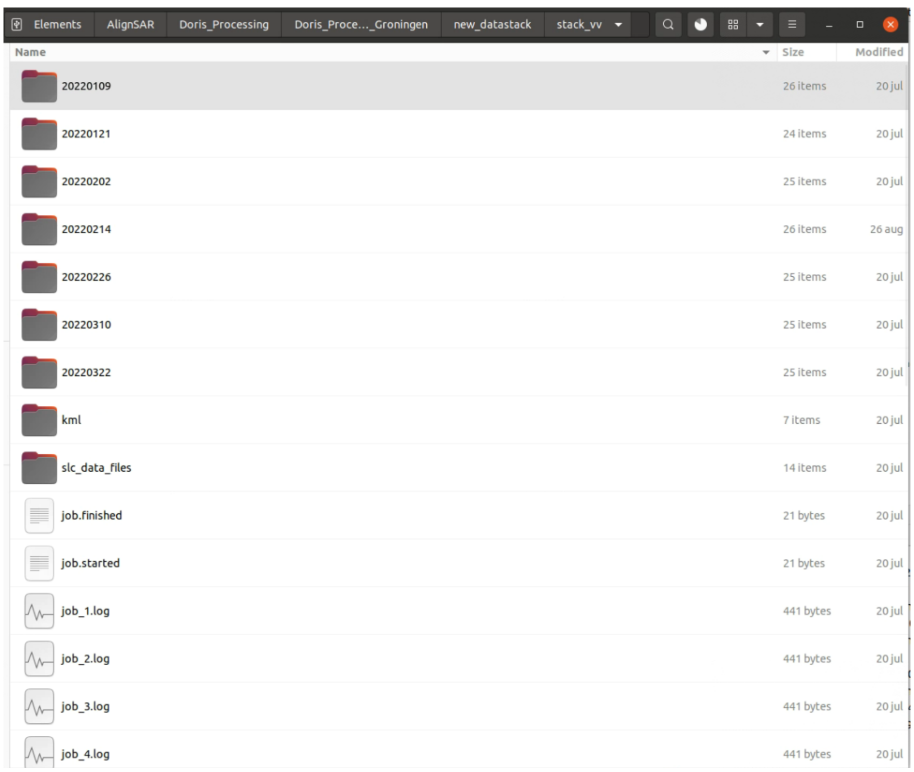


Figure 3.14: Overview of Doris preprocessed output

The SAR signatures contain:

1. VV amplitude (linear),

2. VH amplitude (linear),

3. VV interferometric phase [in radians],

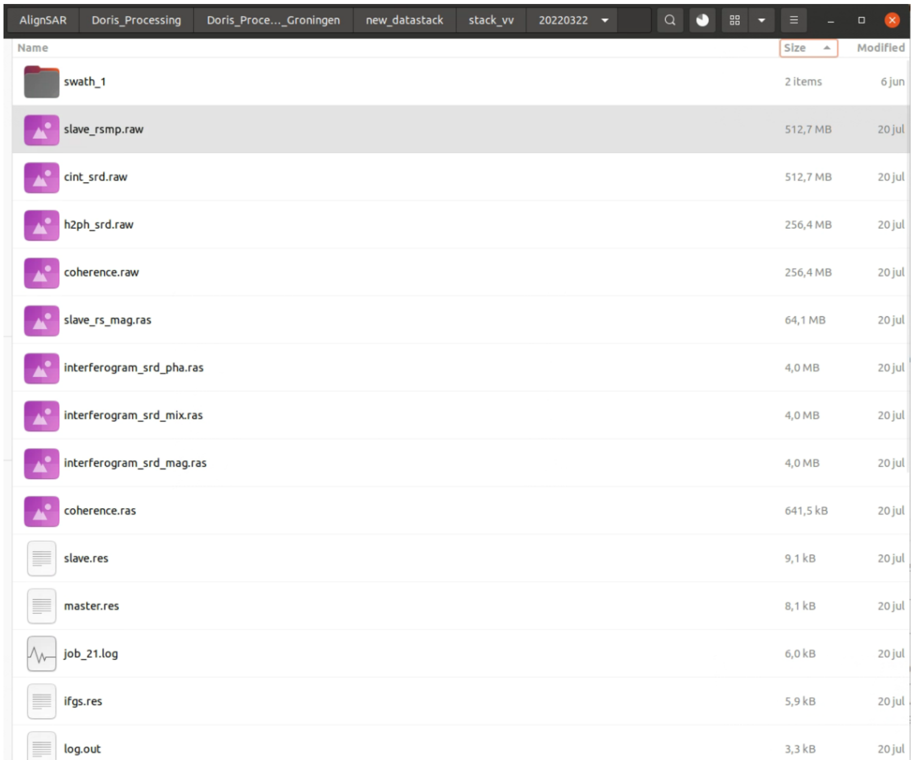


Figure 3.15: Output from Doris-based interferogram generation in a slave 'date' folder

4. VV coherence,
5. Intensity summation $|S_{VV}|^2 + |S_{VH}|^2$, (S_{VV} and S_{VH} represent complex number in VV and VH)
6. Intensity difference (dual-pol difference) $|S_{VV}|^2 - |S_{VH}|^2$,
7. Intensity ratio (dual-pol power ratio) $|S_{VV}|^2/|S_{VH}|^2$,
8. cross-pol correlation coefficient,
9. cross-pol cross product,
10. entropy,
11. buildings (TOP10NL),
12. roads (TOP10NL),

13. water (TOP10NL),

14. railways (TOP10NL).

These SAR signatures are extracted and calculated based on 'cint_srd.raw', 'coherence.raw', and 'slave_rsmp.raw'. A NetCDF data format is prepared to contain the signatures along with their global and local attributes. Particularly, global and local attributes are defined separately as shown in Table 3.1 and Table 3.2. The global attributes describe the basic information for all the signatures. For instance, 'sar_date_time' describes the acquisition time of the current SLC image where all signatures are extracted, as shown in Fig. 3.16. The local attributes belong to the signatures that are stored in 'variables' as shown in Fig. 3.17. As an example, 'VV interferometric phase', its local attributes: unit is radians, the format is float32, the range is between $(-\pi,\ \pi]$, and description is the phase difference between master and slave acquisition.

To build up the NetCDF data format with global and local attributes, the user should first give the path of the unzipped raw SLC folder to parameter 'sar_folder_path' in 'signature_extraction.py' Line 311, e.g., 'sar_folder_path = /(your doris processing path)/Doris_Processing_36_Groningen/sar_data_2022/'. The next folder level should contain 7 raw SLC folders. Then, in the '`Meta_info_extraction_global_local.py`' file, the user can define the global attributes themselves from Line 61 to 69. The attributes before 'sar_date_time' can be added or deleted manually, while the later attributes will be extracted from 'xml' files of unzipped raw SLC folder automatically, as shown in Fig. 3.18. Lines 80 to 198 have prepared local attributes for 14 signatures. The local attributes for each signature, e.g., 'VV_amplitude_attr', are defined in a dictionary format with keywords and their values, e.g., keywords 'Format' and its value 'float32", as shown in Fig. 3.19. The user is free to add or delete the keywords and values.

Having the global and local attributes prepared, we will continue with the signatures. In 'signature_extraction.py' (Fig. 3.20), Lines 249 and 250 should be given the paths to the VV and VH preprocessed folder, e.g., '(your data folder)/new_data
stack/stack_vv/.' It is similar to the VH mode in Line 250. In Line 252, the user should

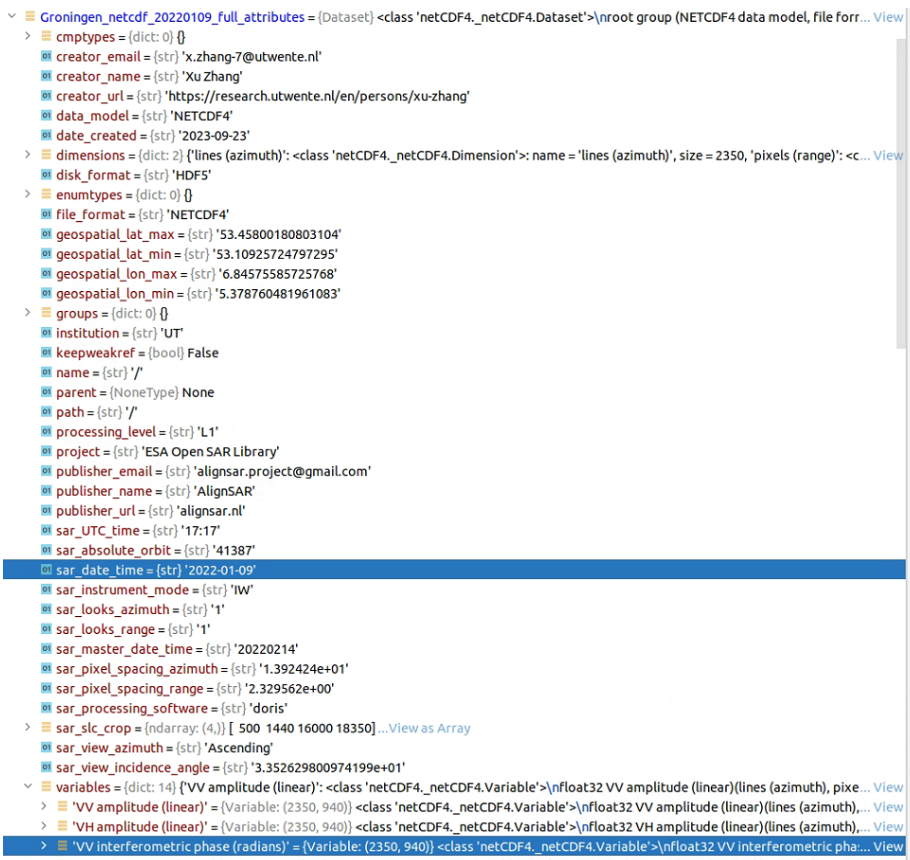


Figure 3.16: Global attributes example of NetCDF data format

```
sar_pixel_spacing_azimuth = {str} '1.392424e+01'
sar_pixel_spacing_range = {str} '2.329562e+00'
sar_processing_software = {str} 'doris'
> sar_slc_crop = {ndarray: (4,)} [ 500  1440 16000 18350] ...View as Array
sar_view_azimuth = {str} 'Ascending'
sar_view_incidence_angle = {str} '3.352629800974199e+01'
v variables = {dict: 14} {'VV amplitude (linear)': <class 'netCDF4._netCDF4.Variable'>\nfloat32 VV amplitude (linear)(lines (azimuth), pixe... View
  > 'VV amplitude (linear)' = {Variable: (2350, 940)} <class 'netCDF4._netCDF4.Variable'>\nfloat32 VV amplitude (linear)(lines (azimuth),... View
  > 'VH amplitude (linear)' = {Variable: (2350, 940)} <class 'netCDF4._netCDF4.Variable'>\nfloat32 VH amplitude (linear)(lines (azimuth),... View
  v 'VV interferometric phase (radians)' = {Variable: (2350, 940)} <class 'netCDF4._netCDF4.Variable'>\nfloat32 VV interferometric pha:... View
      Description = {str} 'phase difference between master and slave acquisition'
      Format = {str} 'float32'
      Range = {str} 'between -pi and +pi'
      Units = {str} 'radians'
      always_mask = {bool} True
      chartostring = {bool} True
    > datatype = {dtype[float32]: ()} float32
    > dimensions = {tuple: 2} ('lines (azimuth)', 'pixels (range)')
    > dtype = {dtype[float32]: ()} float32
      mask = {bool} True
      name = {str} 'VV interferometric phase (radians)'
      ndim = {int} 2
      scale = {bool} True
    > shape = {tuple: 2} (2350, 940)
      size = {int} 2209000
    > Protected Attributes
  > 'VV coherence' = {Variable: (2350, 940)} <class 'netCDF4._netCDF4.Variable'>\nfloat32 VV coherence(lines (azimuth), pixels (range))'... View
  > 'Intensity summation' = {Variable: (2350, 940)} <class 'netCDF4._netCDF4.Variable'>\nfloat32 Intensity summation(lines (azimuth), p... View
  > 'Intensity difference (dual-pol difference)' = {Variable: (2350, 940)} <class 'netCDF4._netCDF4.Variable'>\nfloat32 Intensity differenc... View
  > 'Intensity ratio (dual-pol power ratio)' = {Variable: (2350, 940)} <class 'netCDF4._netCDF4.Variable'>\nfloat32 Intensity ratio (dual-pc... View
  > 'Cross-pol correlation coefficient' = {Variable: (2350, 940)} <class 'netCDF4._netCDF4.Variable'>\nfloat32 Cross-pol correlation coef... View
  > 'Cross-pol cross product' = {Variable: (2350, 940)} <class 'netCDF4._netCDF4.Variable'>\nfloat32 Cross-pol cross product(lines (azim... View
  > 'Entropy' = {Variable: (2350, 940)} <class 'netCDF4._netCDF4.Variable'>\nfloat32 Entropy(lines (azimuth), pixels (range))\n  Units: \r... View
  > 'Buildings' = {Variable: (2350, 940)} <class 'netCDF4._netCDF4.Variable'>\nfloat64 Buildings(lines (azimuth), pixels (range))\n  Units:... View
  > 'Railways' = {Variable: (2350, 940)} <class 'netCDF4._netCDF4.Variable'>\nfloat64 Railways(lines (azimuth), pixels (range))\n  Units: '... View
  > 'Water' = {Variable: (2350, 940)} <class 'netCDF4._netCDF4.Variable'>\nfloat64 Water(lines (azimuth), pixels (range))\n  Units: \n  F... View
  > 'Roads' = {Variable: (2350, 940)} <class 'netCDF4._netCDF4.Variable'>\nfloat64 Roads(lines (azimuth), pixels (range))\n  Units: \n  F... View
    __len__ = {int} 14
> vltypes = {dict: 0} {}
> Protected Attributes
```

Figure 3.17: Local attributes example of NetCDF data format

```
    Global_attr = {'processing_level':'L1', 'date_created': '2023-09-23', 'creator_name': 'Xu Zhang', 'creator_email': 'x.zhang-7@utwente.nl', \
                'creator_url': 'https://research.utwente.nl/en/persons/xu-zhang', 'institution': 'UT', 'project': 'ESA Open SAR Library', 'publisher_name': 'Alig
                'publisher_email': 'alignsar.project@gmail.com', 'publisher_url': 'alignsar.nl', 'geospatial_lat_min': '53.10925724797295', \
                'geospatial_lat_max': '53.45800180803104', 'geospatial_lon_min': '5.378760481961083', 'geospatial_lon_max': '6.84575585725768', \
               'sar_date_time':sar_date_time, 'sar_master_date_time':sar_master_date_time, 'sar_UTC_time':sar_UTC_time, 'sar_instrument_mode':sar_instrument_mode
                'sar_looks_range':sar_looks_range, 'sar_looks_azimuth':sar_looks_azimuth, 'sar_pixel_spacing_range':sar_pixel_spacing_range, \
                'sar_pixel_spacing_azimuth':sar_pixel_spacing_azimuth, 'sar_processing_software':sar_processing_software, \
                'sar_absolute_orbit':sar_absolute_orbit, 'sar_view_azimuth':sar_view_azimuth, 'sar_view_incidence_angle':sar_view_incidence_angle, \
                'sar_slc_crop':sar_slc_crop}
    return Global_attr
```

Figure 3.18: Global attributes in Python file

```
VV_amplitude_attr={
    'Units': 'voltage [linear]',\
    'Format': 'float32',\
    'Description': 'the absolute value of every complex number in VV channel'
  }
```

Figure 3.19: Local attributes in Python file

set the master date to avoid reading master coherence or interferogram maps. In Line 253, the user can choose whether to crop the images. If setting ‘True‘ in the following Line 254, the user can define the crop region. The parameters of ‘CRP_LIST‘ are the first line, last line, first pixel, and last pixel, assuming the coordinate starts from the top left. Line 255 shows the maximum number of SAR images. Line 257 indicates the type of reading maps. Three map types are defined here: ‘cpx‘ represents complex SAR images, ‘ifg‘ means interferogram, and ‘coh‘ is the coherence map. They are prepared to generate SAR signatures 1-10. As we have seven SAR SLC acquisitions, each acquisition has signatures 1-10. Then, Line 266 is the folder path to the TOP10NL radarcoding signatures. From Line 268 to Line 271, the user can give the file name of the radarcoding files. These four variables are prepared for signatures 11-14. Finally, using the scripts from Line 273 to 301, we have extracted and calculated 14 signatures stored in 2-dimensional numpy arrays, which will be stored in the ‘variables‘ along with their local attributes, as shown in Fig. 3.17.

At this stage, the global and local attributes, and the 14 signatures are prepared. A loop operation is described from Line 312 to 343 to assemble them into NetCDF data format. Line 312 defines the number of acquisitions, which also means the number of NetCDF data files. In each NetCDF data file, we name it using its acquisition date in Line 321. The signature size and global attributes are defined from Line 325 to Line 329. Line 331 gives the number of signatures. Later, another loop builds up each signature along with its local attributes into the NetCDF data file. Note that from Lines 334 to 337, conditional lines are used to define the signature format, since the four TOP10NL layers are ’float64’ and the others are ’float32’.

3.4 Machine learning scripts for LULC classification

After obtaining 14 SAR signatures, an ANN (artificial neural network) is implemented for land use land cover (LULC) classification, see the scripts in the folder ’MLscripts/Netherlands-LULC’. One can directly run `main.ipynb` under ’data_preparation’ folder, after define the

```python
if __name__=='__main__':
    doris_stack_dir_VV = '/media/xu/Elements2/AlignSAR/Doris_Processing/Doris_Processing_36_Groningen/new_datastack/stack_vv/'
    doris_stack_dir_VH = '/media/xu/Elements2/AlignSAR/Doris_Processing/Doris_Processing_36_Groningen/new_datastack/stack_vh/'
    #paz_doris_stack = '/media/anurag/AK_WD/PAZ_Processing/stack'
    master_date = 20220214 #'20220214'#'20170117'
    CROPPING = True
    CRP_LIST = [500, 1440, 16000, 18350]#[2000, 3500, 8500, 10000]# [first line, last line, first pixel, last pixel]
    MAX_IMAGES = 30
    # SP_AVG_WIN_SIYE = 3
    map_type = 'cpx' # 'cpx', 'ifg', 'coh'

    #Get the dates
    dates = get_dates(doris_stack_dir_VV, master_date)[:MAX_IMAGES]
    print(dates)
    #Extract the stack array
    vv_arr_stack = get_stack(dates, master_date, doris_stack_dir_VV, map_type, crop_switch=CRP_LIST, crop_list=CRP_LIST, sensor='s1')
    vh_arr_stack = get_stack(dates, master_date, doris_stack_dir_VH, map_type, crop_switch=CRP_LIST, crop_list=CRP_LIST, sensor='s1')

    top10_path = '/media/xu/Elements2/AlignSAR/Doris_Processing/Doris_Processing_36_Groningen/new_datastack/stack_vv/20220214/'
    # top10NL layers' file name
    top10_building_file_name = top10_path + 'top10nl_gebouw_vlak_radarcoded.raw'
    top10_railway_file_name = top10_path + 'top10nl_spoorbaandeel_lijn_radarcoded.raw'
    top10_water_file_name = top10_path + 'top10nl_waterdeel_vlak_radarcoded.raw'
    top10_road_file_name = top10_path + 'top10nl_wegdeel_vlak_radarcoded.raw'
```

Figure 3.20: Parameters that are to be changed in ‘`singnature_extraction.py`‘

proper file directory where the NetCDF data is stored. For our case, as an example, we define: path = '../data/Groningen_netcdf_20220109_full_attributes.nc' in `main.ipynb`. After all csv files generated, one moves to 'training' folder, and run `main.ipynb` (which is in 'training' folder). The LULC classification result is illustrated in [4].

As this document is mainly focused on introducing how to create SAR benchmark datasets using AlignSAR package, Section 3.4 is short, and we welcome peers to try out our scripts in 'MLscripts' and contribute to the script improvement.

Field name	SAR usage: Global attributes
processing_level	SAR data processing level.
date_created	The creation date of SAR data.
creator_name	Creator's name.
creator_email	Creator's contact information.
creator_url	Creator's webpage.
institution	Creator's affiliation.
project	Project's name.
publisher_name	Publisher's name.
publisher_email	Publisher's contact information.
publisher_url	Publisher's official website.
geospatial_lat_min	data spatial coverage, minimum latitude value [decimal degrees].
geospatial_lat_max	data spatial coverage, maximum latitude value [decimal degrees].
geospatial_lon_min	data spatial coverage, minimum longitude value [decimal degrees].
geospatial_lon_max	data spatial coverage, maximum longitude value [decimal degrees].
sar_date_time	Center date time of the product, in UTC.
sar_reference_date_time	Reference image acquisition time, in UTC.
sar_instrument_mode	The name of the sensor acquisition mode that is used.
sar_looks_range	Number of range looks, which is the number of groups of signal samples (looks) perpendicular to the flight path.
sar_looks_azimuth	Number of azimuth looks, which is the number of groups of signal samples (looks) along the flight path.
sar_pixel_spacing_range	The range pixel spacing is the distance between adjacent pixels perpendicular to the flight path in meters (m).
sar_pixel_spacing_azimuth	The azimuth pixel spacing is the distance between adjacent pixels parallel to the flight path in meters (m).
sar_processing_software	Software used for InSAR processing. For instance "ESA SNAP Toolbox": "8.0", "SNAPHU": "1.4.2".
sar_absolute_orbit	Absolute orbit (track) of the input datasets.
sar_relative_orbit	Relative orbit (track) of the input datasets.
sar_view_azimuth	The azimuth angle (heading) of the center of the product.
sar_view_incidence_angle	The incidence angle of the center of the product.
sar_slc_crop	The crop region based on AOI. From left to right are the first line, last line, first pixel, and last pixel.

Table 3.1: Metadata/attributes information

Field name	**SAR usage: Local attributes**
unit	The unit of the SAR signature.
format	The format of the SAR signature.
range	The value range of the SAR signature.
description	The detailed description of the SAR signature.

Table 3.2: Cont. Metadata/attributes information

Appendix A

Doris installation, implementation and trouble shooting

In this appendix, we introduce the installation of Doris-5, and offer solutions to some installation and implementation errors.

We made updates upon the Doris-5 published by the radar group at the Delft University of Technology on TUDelftGeodesy github. The updated Doris-5 scripts can be found via AlignSAR on github, or Doris-Surfdrive. Note that if you download Doris-5 package via TUDelftGeodesy, be sure that you rename 'Doris-master' to 'doris'. Because having the hyphen '-' in a software directory will introduce errors when invoking Doris-5 python scripts that are under the folder 'Doris-master'. Doris-Surfdrive also provides some Doris-5-required software packages under the folder 'doris5_required_software'. As Doris-5 is built upon python2 and only compatible with the old version of the required software packages, we recommend using the packages in 'doris5_required_software'.

Here we give an installation demonstration, based on the installation descriptions in INSTALL.txt on TUDelftGeodesy. The operating system we recommend is Ubuntu:18.04.

- Installation of FFTW library (fftw-3.2.1 is offline)

  In the terminal, create a folder where to install software, e.g. /home/username/software, then run wget -c http://www.fftw.org/pub/fftw/fftw-3.2.2.tar.gz

gunzip fftw-3.2.2.tar.gz

tar xvf fftw-3.2.2.tar

cd fftw-3.2.2/

./configure –prefix=‘pwd‘ –enable-float

make

make install

- Compilation of the doris core run

  cd ../doris_core

  ./configure

  Edit 'Makefile', here is an example:

  ——————

  compiler: g++

  fftw: y

  FFTW LIB DIR: /home/username/software/fftw-3.2.2/lib

  FFTW INCLUDE DIR: /home/username/software/fftw-3.2.2/include

  veclib: n

  lapack: n

  Little endian: y

  DEBUG version: n

  Install in dir: /usr/local/bin

  ——————

  (Note that g++ has the version of 7.5.0.)

  when running 'make' in the terminal, you may encounter an error like

---

bk_messages.hh:214:26: error: invalid conversion from ‘char’ to ‘const char*’ [-fpermissive]

strcat(name_,'\0'); ;// terminate id

The solution is to edit 'bk_messages.hh', change its Line 214 strcat(name_,'\0'); to name_[9] = '\0';

Then run 'sudo make install'. If 'construct_dem.sh' does not exist in doris/bin, then copy one to 'bin' folder.

- Compilation of Doris utilities

  cd ../sartools

  In 'Makefile', edit 'INSTALL_DIR', like INSTALL_DIR = /usr/local/bin and edit cpxfiddle.cc, change if (argv[optind]=='\0') to if (*argv[optind]=='\0')

  then run 'make' and 'sudo make install'

  cd ../envisat_tools

  In 'Makefile', change INSTALL_DIR = /usr/local/bin, and CC = g++ //[it was gcc]

  then run 'make' and 'sudo make install'

- Installation of useful external software

  gfortran: version is 7.5.0

  gunzip getorb_doris.tar.gz

  tar xvf getorb_doris.tar

  In 'Makefile': change

  FC = gfortran

- Installation of Doris - Python part

  Python has the version of 2.7. use pip2 to install Python packages, for instance: sudo pip2 install requests

  pip2 install GDAL==2.2.2

  pip2 install shapely==1.7.1

  sudo pip2 install pygeoif

  sudo pip2 install lxml

  sudo pip install -U pyopenssl

  sudo pip install numpy scipy matplotlib requests fiona pyproj fastkml osr

  In case you encounter error during GDAL installation, try to install libgdal first and then set up appropriate paths:

  sudo apt-get install libgdal-dev

  export CPLUS_INCLUDE_PATH=/usr/include/gdal

  export C_INCLUDE_PATH=/usr/include/gdal

Here we showcase the Doris-5 implementation.

- Create an account

  for the downloading of SRTM DEMs at https://urs.earthdata.nasa.gov/users/new, and create an account for downloading Sentinel data at https://urs.earthdata.nasa.gov/users/new/

- Move to the install directory

  cd ../install

  python init_cfg.py and fill in the different paths and user accounts. Here is an example:

  Enter the path to doris: /usr/local/bin/doris

  Enter the path to cpxfiddle: /usr/local/bin/cpxfiddle

Enter the path to snaphu: /usr/local/bin/snaphu

Enter your username for scihub (https://scihub.copernicus.eu/dhus/#/self-registration)lchang?

Enter your password for scihub ?

Enter your username for srtm download (https://urs.earthdata.nasa.gov/users/new/)Chang?

Enter your password for srtm download ?

Doris is initialized. If you want to make changes later, you can change the doris_config.xml file in 'install' folder or run this script again.

- Run the stack preparation script (Move to the prepare_stack directory)

  cd prepare_stack

  Run the python script:

  python prepare_datastack_main.py

  Here is an example:

  Enter the path to the archive data folder: /home/ling/d2/groningendata

  Which polarisation do you want to use (vv,hh,vh,hv): vv

  Which track do you want to work with? (explore on https://scihub.copernicus.eu/dhus/) : 15

  Is this track ascending or descending? (asc/dsc) : asc

  Enter the path to the folder of new datastack: /home/ling/d2/groningen/processing
  Enter full path to the shapefile: /home/ling/d2/groningen/aoi/G1.shp

  Enter the path to the folder of the orbit files: /home/ling/d2/groningen_orbit

  Do you want to generate the DEM file automatically (Yes/No): Yes

  Enter path to the dem folder: /home/ling/d2/groningen/DEM

  Do you want to use parallel computing (Yes/No): Yes

  How many cores do you want to use: 2

What is the start date of your stack in yyyy-mm-dd (can be changed later): 2022-01-09

What is the end date of your stack in yyyy-mm-dd (can be changed later): 2022-03-22

What is the master date of your stack in yyyy-mm-dd (can be changed later): 2022-02-14

Note that track number is the path number of Sentinel-1, and edit 'create_dem.py' and change 'server = http://e4ftl01.cr.usgs.gov' to 'server = https://e4ftl01.cr.usgs.gov'. The doris directory can be edited in 'doris_config.xml' under the folder 'software/doris/install', like <source_path>/home/username/software/doris</source_path>

In case you encounter error like ImportError: No module named html.parser, simply change 'from html.parser import HTMLParser' to 'from HTMLParser import HTMLParser' in create_dem.py

- run bash doris_stack.sh

  be sure that you edit 'doris_main.py' in 'software/doris/doris_stack/main_code' folder, add edit sys.path.append('/home/username/software/') and provide the absolute directory of Doris-5 software.

Appendix B

Denoising example

To reduce noise in SAR images, Denoising step is provided. For this step, a number of spatial filtering methods, e.g. filtering methods embedded in SNAP, AI based filtering methods and multi-temporal speckle filtering methods, is included. For instance, the multi-temporal speckle filtering is proposed by [5]. As reviewed by [1], in case of applying this filter on SAR amplitude, for a pixel at position (rg, az), with the amplitude value $A^k(rg, az)$, at the kth acquisition, its resultant amplitude value after the filter, denoted by $\tilde{A}^k(rg, az)$, can be expressed as,

$$\tilde{A}^k(rg, az) = [[A^k(rg, az)]_{filter\_space}]_{filter\_time} = S^k(rg, az)T(rg, az), \tag{B.1}$$

where the spatial filter output is $S^k(rg, az) = [A^k(rg, az)]_{filter\_space}$. The Boxcar filter, Lee-sigma filter [3] and IDAN (Intensity Driven Adaptive Neighborhood) filter [6] are examples of the spatial filter methods. The subscript $filter\_space$ and $filter\_time$ indicate the spatial and temporal filter process respectively. The temporal filter output $T(rg, az)$ is defined as

$$T(rg, az) = \frac{1}{m+1} \sum_{i=1}^{m+1} \frac{A^i(rg, az)}{[A^i(rg, az)]_{filter\_space}}, \tag{B.2}$$

where $m + 1$ is the total number of SAR image acquisitions, $A^i(rg, az)$ represents SAR amplitude at position (rg, az) of ith acquisition, $i \in [1, m + 1]$. Having the spatial filter output as a divisor in Eq. (B.2), we can normalize the amplitude values. The multi-temporal speckle filtering method is scripted with python, namely 'speckle_filt.py'.

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