SenSARP Documentation

Release 0.1

Thomas Weiß

Jan 31, 2022

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CHAPTER

ONE

CONTENT

1.1 Introduction

The Sentinel-1 mission consists of two polar-orbiting satellites acquiring Synthetic Aperture Radar data (SAR) at C-band (frequency of 5.405 GHz) with a revisit time of 6 days. The SAR data is distributed free of charge via the Copernicus Open Access Hub (https://scihub.copernicus.eu/) by European Space Agency (ESA) and the European Commission. Large archives are also provided by Data and Information Access Services (DIAS) which serve the purpose to facilitate the access and use of Sentinel Data. Due to the specific imaging geometry of the radar system, the acquired radar data contains different radiometric and geometric distortions. The radiometric quality is affected by spreading loss effect, the non-uniform antenna pattern, possible gain changes, saturation, and speckle noise. Geometric distortions such as foreshortening, layover or shadowing effects are based on the side looking radar acquisition system. To account for these radiometric and geometric distortions, the Sentinel-1 Level 1 data has to be corrected radiometrically and geometrically before the data can be used for further analysis or within third party applications. Therefore, either an automatic or manual pre-processing of Sentinel-1 images is needed.

1.1.1 Statement of need

Sentinel-1 satellites will provide continuous free available microwave remote sensing data of the entire globe at least until the end of 2030. Furthermore, ESA is not only providing Sentinel satellite images (e.g. Sentinel-1, Sentinel-2, Sentinel-3) but they also developed free open source toolboxes (Sentinel-1, 2, 3 toolboxes) for scientific exploitation. The toolboxes can be accessed and used via the Sentinel Application Platform (SNAP). SNAP offers a graphical interface were expert users can develop different processing schemes and apply them on the satellite images. Although, Sentinel-1 satellite data and a processing software are freely available, the usage of the data is mainly limited to expert users in the field of microwave remote sensing as different pre-processing steps need to be applied before using Sentinel-1 images.

SenSARP was developed to provide a push-button option to easily apply a rigid pre-processing pipeline with sensible defaults to a Sentinel-1 Level 1 SLC time series data as well as single Sentinel-1 Level 1 SLC images. Thus, non-expert users in the field of pre-processing microwave data are able to use radiometric and geometric corrected sigma nought backscatter data for their specific applications. Beside a rigid pre-processing pipeline, SenSARP provides filter options to retrieve only images of a specific year or images that contain a specific area of interest from a stack of downloaded Sentinel-1 data. Furthermore, the default processing scheme of SenSARP can handle if an area of interest is contained in two tiles of the same swath (due to storage reasons data of one Sentinel-1 satellite swath is provided by ESA within different tiles). Additionally, SenSARP checks if within a stack of Sentinel-1 images, one specific image was multiple processed by ESA and uses the newest.

For expert users, SenSARP provides the possibility to automate their pre-processing on a large scale by either modifying the default pre-processing scheme (modification of xml graph pre_processing_step1.xml) or create their own pre-processing scheme (create a new xml graph) with the graph builder of the SNAP software. They can benefit from the filter options, the default pre-processing step 2 (co-registration of images) and the SenSARP functions to stack all

processed and co-registered images within a netCDF file with additional image information e.g. satellite name, relative orbit and orbitdirection.

1.1.2 Getting Started

Please find instructions on how to download and install SenSARP in the *Installation for Linux (tested with Ubuntu 20.04)* section.

1.1.3 Support, contributing and testing

Please contribute using Github Flow. Create a branch, add commits, and open a pull request.

Reporting bugs

If you find a bug in SenSARP, please open an new issue and tag it "bug".

Suggesting enhancements

If you want to suggest a new feature or an improvement of a current feature, you can submit this on the issue tracker and tag it "enhancement".

Testing

The package is currently tested for Python >= 3.6 on Unix-like systems. To run unit tests, execute the following line from the root of the repository:

```
pytest
```

1.2 Installation for Linux (tested with Ubuntu 20.04)

Note: The SenSARP has been developed against Python 3.6. It cannot be guaranteed to work with previous Python versions.

The first step is to clone the latest code and step into the check out directory:

```
git clone https://github.com/multiply-org/sar-pre-processing.git
cd sar-pre-processing
```

1.2.1 Installation with Conda

Download and install Anaconda or Miniconda. Anaconda/Miniconda installation instructions can be found here

To install all required modules, use:

```
conda env create --prefix ./env --file environment.yml
conda activate ./env # activate the environment
```

To install SenSARP into an existing Python environment, use:

```
python setup.py install
```

To install for development, use:

```
python setup.py develop
```

1.2.2 Installation with virtualenv and python

Install system requirements:

```
sudo apt install python3-pip python3-tk python3-virtualenv python3-venv virtualenv
```

Create a virtual environment:

```
virtualenv -p /usr/bin/python3 env
source env/bin/activate # activate the environment
pip install --upgrade pip setuptools # update pip and setuptools
```

To install SenSARP into an existing Python environment, use:

```
python setup.py install
```

To install for development, use:

```
python setup.py develop
```

GDAL package needs to be installed too:

```
sudo apt install gdal-bin libgdal-dev

python -m pip install pygdal=="`gdal-config --version`.*"
```

1.2.3 Further information

Please see the environment file for a list of all installed dependencies during the installation process. Additionally, ESA's SNAP Sentinel-1 Toolbox (Version >8.0.3) has to be installed prerequisite. The Software can be downloaded here. To install the SNAP toolbox, open a terminal window and use:

```
bash esa-snap_sentinel_unix_8_0.sh
```

SenSARP uses only functionalities of the Sentinel-1 Toolbox.

Note: Currently, only SNAP version 8.0 can be downloaded from the website. To update SNAP to a version >8.0.3 please start the SNAP software. You will be asked if you want to search for update. Please search for updates and install all updates. After the updates are installed, you need to restart SNAP to initialize the updates correctly.

SNAP Toolbox need libgfortran for specific operations but currently libgfortran is not installed during the installation process of SNAP, therefore you might use:

```
sudo apt-get install gfortran
```

1.3 Usage

1.3.1 Example 1: Use default processing graph to pre-process single Sentinel-1 Level-1 SLC image

1. Requirements

- Installation of SenSARP
- Installation of ESA's SNAP Toolbox version >8.0.3
  - Currently only SNAP version 8.0 can be downloaded from the ESA website (https://step.esa.int/main/download/snap-download/). To update SNAP to a version >8.0.3 please start the SNAP software. You will be asked if you want to search for update. After the updates are installed you need to restart SNAP to initialize the installed updates.
  - SNAP Toolbox need libgfortran for specific operations but currently libgfortran is not installed during the installation process of SNAP therefore you might use `sudo apt-get install gfortran`
- Sentinel-1 SLC data
  - Instruction how to download Sentinel 1 data are given in Section 2

2. Download sample data from Sentinel Data Hub

Option 1: Download data from Sentinel Data Hub manually or via python package sentinelsat

Create Account (https://scihub.copernicus.eu/dhus/#/self-registration). (**Attention: Problem by using Copernicus Open Access Hub might be that older data is offline and need to be triggered first**). More information can be found at https://scihub.copernicus.eu/userguide/DataRestoration. Instruction to manually download data from Copernicus Open Access Hub can be found at https://blogs.fu-berlin.de/reseda/esa-scihub/. You can also try to download the data via python package sentinelsat

How to use sentinelsat

[1]:
```
# connect to the API
from sentinelsat import SentinelAPI, read_geojson, geojson_to_wkt
from datetime import date
user = 'user'
password = 'password'
# initialize settings
api = SentinelAPI(user, password)
```

Search for available data

[2]:
```
# search by polygon (MNI test site coordinates), time, and SciHub query keywords
footprint = geojson_to_wkt(read_geojson('coordinates_mni.geojson'))
products = api.query(footprint,
                     date=('20210701', '20210702'),
                     platformname='Sentinel-1',
                     producttype='SLC')
print('Following products will be downloaded')
print(api.to_dataframe(products).title.values)

print('These {} product need {} Gb of disk space'.format(len(products), api.get_products_
↪size(products)))
```

```
Following products will be downloaded
['S1B_IW_SLC__1SDV_20210701T051738_20210701T051805_027596_034B44_2DCF']
These 1 product need 7.72 Gb of disk space
```

Start download process (**Attention: might take a while and data will requries some free disk space**)

[3]:
```
# download all results from the search
# files will be downloaded to specified path
import os
path = os.path.expanduser('~/Desktop/data')
try:
    os.makedirs(path)
except: FileExistsError
api.download_all(products, path)
```

```
Downloading products:   0%|          | 0/1 [00:00<?, ?product/s]
```

```
Downloading S1B_IW_SLC__1SDV_20210701T051738_20210701T051805_027596_034B44_2DCF.zip:   0
↪%|          | 0.00/4.6...
```

```
MD5 checksumming:   0%|          | 0.00/4.62G [00:00<?, ?B/s]
```

[3]:
```
ResultTuple(downloaded={'87bc6000-e45b-4e06-9c8e-1db1908db1ca': {'id': '87bc6000-e45b-
↪4e06-9c8e-1db1908db1ca', 'title': 'S1B_IW_SLC__1SDV_20210701T051738_20210701T051805_
↪027596_034B44_2DCF', 'size': 4620218028, 'md5': 'b142da92c874236fbdd6572480b96128',
↪'date': datetime.datetime(2021, 7, 1, 5, 17, 38, 754000), 'footprint': 'POLYGON((14.
↪731479 47.650288,11.295774 48.053822,11.672503 49.676376,15.223297 49.271305,14.731479␣
↪47.650288))', 'url': "https://apihub.copernicus.eu/apihub/odata/v1/Products('87bc6000-
↪e45b-4e06-9c8e-1db1908db1ca')/$value", 'Online': True, 'Creation Date': datetime.
↪datetime(2021, 7, 1, 7, 24, 3, 755000), 'Ingestion Date': datetime.datetime(2021, 7, 1,
↪ 7, 21, 46, 931000), 'quicklook_url': "https://apihub.copernicus.eu/apihub/odata/v1/
↪Products('87bc6000-e45b-4e06-9c8e-1db1908db1ca')/Products('Quicklook')/$value", 'path':
↪ '/home/test/Desktop/data/S1B_IW_SLC__1SDV_20210701T051738_20210701T051805_027596_
↪034B44_2DCF.zip', 'downloaded_bytes': 4620218028}}, retrieval_triggered={}, failed={})
```

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Option 2: Manually search and download data from Alaska Satellite Facility (ASF)

You can search for Sentinel-1 data at https://search.asf.alaska.edu/. A NASA EOSDIS Earthdata Login account is required for downloading data and tools from ASF. Registering for an Earthdata Login account is free (https://urs.earthdata.nasa.gov/home). Instructions how to download data from ASF can be found at https://asf.alaska.edu/wp-content/uploads/2019/02/asf_datarecipe_bulk_download_from_vertex_python_script_v1.pdf.

3. Use default processing graph to pre-process a single Sentinel-1 Level-1 SLC image

Set paths for

- input_folder (path to stored Sentinel-1 SLC data (zip files) e.g. "~/Downloads")
- output_folder (path where processed data will be stored e.g. "~/output")
- gpt_loction (gpt is located in the bin folder of your SNAP installation)'

[4]:
```
input_folder = path
output_folder = path
gpt_location = os.path.expanduser('~/snap/bin/gpt')
```

Create config file with information about input folder, output folder and gpt path

[5]:
```
import yaml

with open('sample_config_file.yaml') as stream:
   data = yaml.safe_load(stream)

data['input_folder'] = input_folder
data['output_folder'] = output_folder
data['gpt'] = gpt_location

with open('test_config_file.yaml', 'wb') as stream:
   yaml.safe_dump(data, stream, default_flow_style=False,
                  explicit_start=True, allow_unicode=True, encoding='utf-8')
```

Optional config options for subsetting

[6]:
```
with open('test_config_file.yaml') as stream:
   data = yaml.safe_load(stream)

## Define region of interest
data['region']['lr']['lat'] = 48.2 # lower right latitude
data['region']['lr']['lon'] = 11.9 # lower right longitude
data['region']['ul']['lat'] = 48.4 # upper left latitude
data['region']['ul']['lon'] = 11.6 # upper left longitude
data['region']['subset'] = 'yes'

data['single_file'] = 'yes'
```

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```
with open('test_config_file.yaml', 'wb') as stream:
    yaml.safe_dump(data, stream, default_flow_style=False,
                   explicit_start=True, allow_unicode=True, encoding='utf-8')
```

Start pre-processing steps

[7]:
```
from sar_pre_processing.sar_pre_processor import *
import warnings
warnings.filterwarnings("ignore")

processing = SARPreProcessor(config='test_config_file.yaml')
processing.create_processing_file_list()
print('start step 1')
processing.pre_process_step1()
print('start step 2')
processing.pre_process_step2()
print('start step 3')
processing.pre_process_step3()
print('start add netcdf information')
processing.add_netcdf_information()
print('start create netcdf stack')
processing.create_netcdf_stack()
```

```
INFO:root:Found files within input folder: 1
INFO:root:year not specified
INFO:root:area of interest not specified
INFO:root:Number of found files that were double processed: 0.0
INFO:root:Number of found files with border issues: 0
INFO:root:area of interest specified
INFO:root:normalisation angle not specified, default value of 35 is used for processing
INFO:ComponentProgress:0
INFO:ComponentProgress:0
INFO:root:Process S1B_IW_SLC__1SDV_20210701T051738_20210701T051805_027596_034B44_2DCF.
↪zip with SNAP.
```

```
start step 1
```

```
INFO: org.esa.snap.core.gpf.operators.tooladapter.ToolAdapterIO: Initializing external␣
↪tool adapters
INFO: org.esa.s2tbx.dataio.gdal.GDALVersion: GDAL 3.0.4 found on system. JNI driver will␣
↪be used.
INFO: org.esa.s2tbx.dataio.gdal.GDALVersion: Installed GDAL 3.0.4 set to be used by SNAP.
INFO: org.esa.snap.core.util.EngineVersionCheckActivator: Please check regularly for new␣
↪updates for the best SNAP experience.
INFO: org.esa.s2tbx.dataio.gdal.GDALVersion: Installed GDAL 3.0.4 set to be used by SNAP.
```

```
Executing processing graph
```

```
INFO: org.hsqldb.persist.Logger: dataFileCache open start
WARNING: org.esa.s1tbx.sar.gpf.orbits.ApplyOrbitFileOp: No valid orbit file found for 01-
↪JUL-2021 05:16:30.000000
Orbit files may be downloaded from https://scihub.copernicus.eu/gnss/odata/v1/
and placed in /home/test/.snap/auxdata/Orbits/Sentinel-1/POEORB/S1B/2021/07
```

```
OpenSearch: https://scihub.copernicus.eu/gnss/search?q=platformname:Sentinel-1 AND␣
↪platformnumber:B AND producttype:AUX_RESORB AND beginposition:[2021-07-01T00:00:000Z␣
↪TO 2021-07-31T24:00:000Z]
```

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```
OpenSearch: 38 total results on 1 pages.
OpenSearch: https://scihub.copernicus.eu/gnss/search?q=platformname:Sentinel-1 AND␣
↪platformnumber:B AND producttype:AUX_RESORB AND beginposition:[2021-07-01T00:00:000Z␣
↪TO 2021-07-31T24:00:000Z]
OpenSearch: https://scihub.copernicus.eu/gnss/search?q=platformname:Sentinel-1 AND␣
↪platformnumber:B AND producttype:AUX_RESORB AND beginposition:[2021-06-01T00:00:000Z␣
↪TO 2021-06-31T24:00:000Z]
OpenSearch: 0 total results on 1 pages.
```

```
WARNING: org.esa.s1tbx.sar.gpf.orbits.ApplyOrbitFileOp: ApplyOrbit ignoring error and␣
↪continuing: java.io.IOException: No valid orbit file found for 01-JUL-2021 05:16:30.
↪000000
Orbit files may be downloaded from https://scihub.copernicus.eu/gnss/odata/v1/
and placed in /home/test/.snap/auxdata/Orbits/Sentinel-1/POEORB/S1B/2021/07
```

```
...12%...24%..34%...46%
```

```
INFO: org.esa.snap.core.dataop.dem.ElevationFile: http retrieving http://step.esa.int/
↪auxdata/dem/SRTMGL1/N48E011.SRTMGL1.hgt.zip
INFO: org.esa.snap.engine_utilities.download.DownloadableContentImpl: http retrieving␣
↪http://step.esa.int/auxdata/dem/egm96/ww15mgh_b.zip
```

```
...58%..68%...80%... done.
```

```
INFO:root:0
INFO:root:Single image, no co-register of images necessary
INFO:root:multi temporal filter cannot applied to a single image, just single speckle␣
↪filter is applied
INFO:ComponentProgress:0
INFO:ComponentProgress:0
```

```
start step 2
start step 3
```

```
INFO: org.esa.snap.core.gpf.operators.tooladapter.ToolAdapterIO: Initializing external␣
↪tool adapters
INFO: org.esa.s2tbx.dataio.gdal.GDALVersion: GDAL 3.0.4 found on system. JNI driver will␣
↪be used.
INFO: org.esa.s2tbx.dataio.gdal.GDALVersion: Installed GDAL 3.0.4 set to be used by SNAP.
INFO: org.esa.snap.core.util.EngineVersionCheckActivator: Please check regularly for new␣
↪updates for the best SNAP experience.
INFO: org.esa.s2tbx.dataio.gdal.GDALVersion: Installed GDAL 3.0.4 set to be used by SNAP.
```

```
Executing processing graph
```

```
INFO: org.hsqldb.persist.Logger: dataFileCache open start
```

```
...12%...24%.
```

```
27585 [main] INFO serverStartup - Nc4Iosp: NetCDF-4 C library loaded (jna_path='/home/
↪test/.snap/auxdata/netcdf_natives/8.0.5/amd64', libname='netcdf').
27602 [main] INFO serverStartup - NetcdfLoader: set log level: old=0 new=0
27658 [main] INFO serverStartup - Nc4Iosp: set log level: old=0 new=0
```

```
..36%...48%...60%...72%...84%.. done.
```

```
INFO:root:0
INFO:root:2021-08-29 17:54:26.666351
```

```
start add netcdf information
```

```
INFO:root:Number of scenes found for processing: 1
```

```
start create netcdf stack

Scene 1 of 1
/home/test/Desktop/data/step3/S1B_IW_SLC__1SDV_20210701T051738_20210701T051805_027596_
↪034B44_2DCF_GC_RC_No_Su_speckle.nc
```

4. View processed data

Load netcdf file with processed data

[8]:
```
import os
print(os.getcwd())
print(output_folder)
```

```
/home/test/Desktop/sar-pre-processing/docs/notebooks
/home/test/Desktop/data
```

[9]:
```
from netCDF4 import Dataset
import numpy as np

my_example_nc_file = os.path.join(output_folder, 'data.nc')
data = Dataset(my_example_nc_file, mode='r')
```

View information about dataset

[10]:
```
data
```

[10]:
```
<class 'netCDF4._netCDF4.Dataset'>
root group (NETCDF4 data model, file format HDF5):
    dimensions(sizes): lat(1603), lon(2403), time(1)
    variables(dimensions): float32 time(time), float32 orbitdirection(time), float32␣
↪relorbit(time), float32 satellite(time), float32 lat(lat), float32 lon(lon), float32␣
↪theta(time, lat, lon), float32 sigma0_vv_single(time, lat, lon), float32 sigma0_vh_
↪single(time, lat, lon), float32 sigma0_vv_norm_single(time, lat, lon), float32 sigma0_
↪vh_norm_single(time, lat, lon)
    groups:
```

Read data from netcdf file

[11]:
```
data.variables['orbitdirection'][:]
data.variables['time'][:]
lons = data.variables['lon'][:]
lats = data.variables['lat'][:]
vv = data.variables['sigma0_vv_single'][:]

vv_units = data.variables['sigma0_vv_single'].units
```

Close netcdf file

[12]:
```
data.close()
```

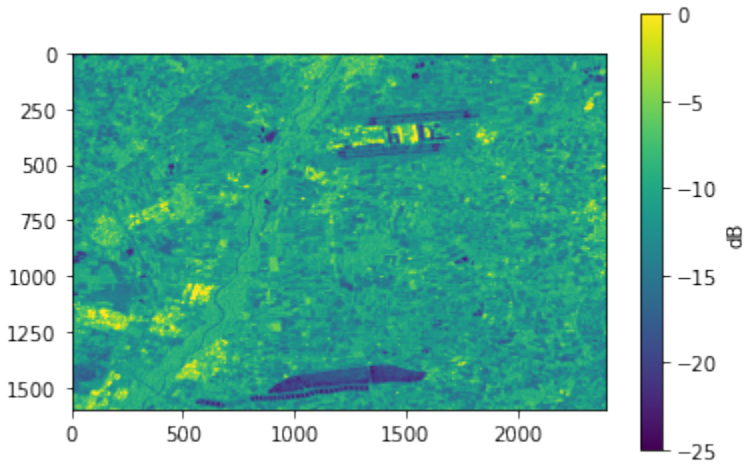
Plot vv polorized data

[13]:
```
%matplotlib inline
from ipywidgets import interactive
import matplotlib.pyplot as plt
import numpy as np

def f(x):
    # Problem: border pixel might be zero or negative
    # pixel eqal or smaller than zero are set to nan
    array = np.copy(vv[x])
    array[array <= 0] = np.nan
    # plot backscatter data in dB scale
    plt.imshow(10*np.log10(array))
    cbar = plt.colorbar()
    cbar.set_label('dB')
    plt.clim(-25, 0)

interactive_plot = interactive(f, x=(0,len(vv)-1))
interactive_plot
```

[13]:
```
interactive(children=(IntSlider(value=0, description='x', max=0), Output()), _dom_
↪classes=('widget-interact',)...
```



1.3.2 Example 2: Use default processing graphs to pre-process a time series of Sentinel-1 Level-1 SLC images

1. Requirements

- Installation of SenSARP
- Installation of ESA's SNAP Toolbox version >8.0.3
  - Currently only SNAP version 8.0 can be downloaded from the ESA website (https://step.esa.int/main/download/snap-download/). To update SNAP to a version >8.0.3 please start the SNAP software. You

will be asked if you want to search for update. After the updates are installed you need to restart SNAP to initialize the installed updates.

  - SNAP Toolbox need libgfortran for specific operations but currently libgfortran is not installed during the installation process of SNAP therefore you might use `sudo apt-get install gfortran`

- Sentinel-1 SLC data
  - Instruction how to download Sentinel 1 data are given in Section 2

2. Download sample data from Sentinel Data Hub

Option 1: Download data from Sentinel Data Hub manually or via python package sentinelsat

Create Account (https://scihub.copernicus.eu/dhus/#/self-registration). (**Attention: Problem by using Copernicus Open Access Hub might be that older data is offline and need to be triggered first**). More information can be found at https://scihub.copernicus.eu/userguide/DataRestoration. Instruction to manually download data from Copernicus Open Access Hub can be found at https://blogs.fu-berlin.de/reseda/esa-scihub/. You can also try to download the data via python package sentinelsat

How to use sentinelsat

[1]:
```
# connect to the API
from sentinelsat import SentinelAPI, read_geojson, geojson_to_wkt
from datetime import date
user = 'user'
password = 'password'
# initialize settings
api = SentinelAPI(user, password)
```

Search for available data

[2]:
```
# search by polygon (MNI test site coordinates), time, and SciHub query keywords
footprint = geojson_to_wkt(read_geojson('coordinates_mni.geojson'))
products = api.query(footprint,
                     date=('20210101', '20210110'),
                     platformname='Sentinel-1',
                     producttype='SLC')
print('Following products will be downloaded')
print(api.to_dataframe(products).title.values)

print('These {} product need {} Gb of disk space'.format(len(products), api.get_products_
↪size(products)))
```

```
Following products will be downloaded
['S1A_IW_SLC__1SDH_20210109T170737_20210109T170801_036064_043A0F_7B82'
 'S1A_IW_SLC__1SDV_20210108T051816_20210108T051844_036042_04393F_F99A'
 'S1B_IW_SLC__1SDV_20210107T052547_20210107T052614_025044_02FB1E_E0E4'
 'S1A_IW_SLC__1SDV_20210104T165938_20210104T170006_035991_043767_329F'
 'S1A_IW_SLC__1SDV_20210104T165913_20210104T165940_035991_043767_A0D0'
 'S1B_IW_SLC__1SDV_20210103T170648_20210103T170715_024993_02F97C_C72A'
 'S1B_IW_SLC__1SDV_20210102T051747_20210102T051814_024971_02F8D2_6318'
```

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```
 'S1A_IW_SLC__1SDV_20210101T052626_20210101T052654_035940_0435A9_E0CB']
These 8 product need 59.76 Gb of disk space
```

Start download process (**Attention: might take a while and data will requries some free disk space**)

[3]:
```
# download all results from the search
# files will be downloaded to specified path
import os
path = os.path.expanduser('~/Desktop/data2')
try:
    os.makedirs(path)
except: FileExistsError
api.download_all(products, path)
```

```
Downloading products: 0product [00:00, ?product/s]
```

[3]:
```
ResultTuple(downloaded={'4c653f3d-2df7-4a76-ac3a-01abedbc0232': {'id': '4c653f3d-2df7-
↪4a76-ac3a-01abedbc0232', 'title': 'S1B_IW_SLC__1SDV_20210107T052547_20210107T052614_
↪025044_02FB1E_E0E4', 'size': 4498240977, 'md5': '893B94C6E001FE655099F218950A5109',
↪'date': datetime.datetime(2021, 1, 7, 5, 25, 47, 737000), 'footprint': 'POLYGON((12.
↪658003 47.727371,9.287686 48.122635,9.664155 49.737373,13.147094 49.340591,12.658003␣
↪47.727371))', 'url': "https://apihub.copernicus.eu/apihub/odata/v1/Products('4c653f3d-
↪2df7-4a76-ac3a-01abedbc0232')/$value", 'Online': True, 'Creation Date': datetime.
↪datetime(2021, 1, 7, 10, 45, 2, 244000), 'Ingestion Date': datetime.datetime(2021, 1,␣
↪7, 10, 38, 7, 194000), 'quicklook_url': "https://apihub.copernicus.eu/apihub/odata/v1/
↪Products('4c653f3d-2df7-4a76-ac3a-01abedbc0232')/Products('Quicklook')/$value", 'path':
↪ '/home/test/Desktop/data2/S1B_IW_SLC__1SDV_20210107T052547_20210107T052614_025044_
↪02FB1E_E0E4.zip'}, '5ade5549-a789-45c3-8272-c1dd61295340': {'id': '5ade5549-a789-45c3-
↪8272-c1dd61295340', 'title': 'S1A_IW_SLC__1SDV_20210104T165913_20210104T165940_035991_
↪043767_A0D0', 'size': 4439128243, 'md5': 'DFB54E48755274374CE427CB0341C866', 'date':␣
↪datetime.datetime(2021, 1, 4, 16, 59, 13, 974000), 'footprint': 'POLYGON((11.140376 48.
↪259541,14.598722 48.660851,14.967645 47.044518,11.617335 46.644329,11.140376 48.
↪259541))', 'url': "https://apihub.copernicus.eu/apihub/odata/v1/Products('5ade5549-
↪a789-45c3-8272-c1dd61295340')/$value", 'Online': True, 'Creation Date': datetime.
↪datetime(2021, 1, 4, 22, 27, 41, 952000), 'Ingestion Date': datetime.datetime(2021, 1,␣
↪4, 22, 17, 8, 141000), 'quicklook_url': "https://apihub.copernicus.eu/apihub/odata/v1/
↪Products('5ade5549-a789-45c3-8272-c1dd61295340')/Products('Quicklook')/$value", 'path':
↪ '/home/test/Desktop/data2/S1A_IW_SLC__1SDV_20210104T165913_20210104T165940_035991_
↪043767_A0D0.zip'}, '7dae304e-a8ad-4e8e-900e-fa98a79b89eb': {'id': '7dae304e-a8ad-4e8e-
↪900e-fa98a79b89eb', 'title': 'S1B_IW_SLC__1SDV_20210102T051747_20210102T051814_024971_
↪02F8D2_6318', 'size': 4399102981, 'md5': '52FF677638B5831E8C0FC0DB9D750CD3', 'date':␣
↪datetime.datetime(2021, 1, 2, 5, 17, 47, 426000), 'footprint': 'POLYGON((14.519586 46.
↪940491,11.161615 47.340321,11.533187 48.955601,15.000459 48.554497,14.519586 46.
↪940491))', 'url': "https://apihub.copernicus.eu/apihub/odata/v1/Products('7dae304e-
↪a8ad-4e8e-900e-fa98a79b89eb')/$value", 'Online': True, 'Creation Date': datetime.
↪datetime(2021, 1, 2, 10, 47, 11, 479000), 'Ingestion Date': datetime.datetime(2021, 1,␣
↪2, 10, 37, 23, 997000), 'quicklook_url': "https://apihub.copernicus.eu/apihub/odata/v1/
↪Products('7dae304e-a8ad-4e8e-900e-fa98a79b89eb')/Products('Quicklook')/$value", 'path':
↪ '/home/test/Desktop/data2/S1B_IW_SLC__1SDV_20210102T051747_20210102T051814_024971_
↪02F8D2_6318.zip'}, 'e31a15e5-8afd-4b30-b2fd-49f597afa11e': {'id': 'e31a15e5-8afd-4b30-
↪b2fd-49f597afa11e', 'title': 'S1A_IW_SLC__1SDV_20210104T165938_20210104T170006_035991_
↪043767_329F', 'size': 4659709650, 'md5': '46E3C2CE59AC05DB6E215820ACD82C0A', 'date':␣
↪datetime.datetime(2021, 1, 4, 16, 59, 38, 805000), 'footprint': 'POLYGON((10.656260 49.
↪801006,14.231164 50.204681,14.622996 48.531536,11.169555 48.129627,10.656260 49.
↪801006))', 'url': "https://apihub.copernicus.eu/apihub/odata/v1/Products('e31a15e5-
↪8afd-4b30-b2fd-49f597afa11e')/$value", 'Online': True, 'Creation Date': datetime.
↪datetime(2021, 1, 4, 22, 28, 3, 971000), 'Ingestion Date': datetime.datetime(2021, 1,␣
↪4, 22, 19, 22, 84000), 'quicklook_url': "https://apihub.copernicus.eu/apihub/odata/v1/
↪Products('e31a15e5-8afd-4b30-b2fd-49f597afa11e')/Products('Quicklook')/$value", 'path':
↪ '/home/test/Desktop/data2/S1A_IW_SLC__1SDV_20210104T165938_20210104T170006_035991_
```

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Option 2: Manually search and download data from Alaska Satellite Facility (ASF)

You can search for Sentinel-1 data at https://search.asf.alaska.edu/. A NASA EOSDIS Earthdata Login account is required for downloading data and tools from ASF. Registering for an Earthdata Login account is free (https://urs.earthdata.nasa.gov/home). Instructions how to download data from ASF can be found at https://asf.alaska.edu/wp-content/uploads/2019/02/asf_datarecipe_bulk_download_from_vertex_python_script_v1.pdf.

3. Use default processing graph to pre-process a time series of Sentinel-1 Level-1 SLC images

Set paths for

- input_folder (path to stored Sentinel-1 SLC data (zip files) e.g. "~/Downloads")
- output_folder (path where processed data will be stored e.g. "~/output")
- gpt_loction (gpt is located in the bin folder of your SNAP installation)'

[4]:
```
input_folder = path
output_folder = path
gpt_location = os.path.expanduser('~/snap/bin/gpt')
```

Create config file with information about input, output and gpt location

[5]:
```
import yaml

with open('sample_config_file.yaml') as stream:
   data = yaml.safe_load(stream)

data['input_folder'] = input_folder
data['output_folder'] = output_folder
data['gpt'] = gpt_location

with open('test_config_file.yaml', 'wb') as stream:
   yaml.safe_dump(data, stream, default_flow_style=False,
                  explicit_start=True, allow_unicode=True, encoding='utf-8')
```

Set optional config options

[6]:
```
with open('test_config_file.yaml') as stream:
   data = yaml.safe_load(stream)

# Filter option
## Filter via year of interes
data['year'] = '2021'

## Define region of interest
data['region']['lr']['lat'] = 48.2 # lower right latitude
data['region']['lr']['lon'] = 11.9 # lower right longitude
data['region']['ul']['lat'] = 48.4 # upper left latitude
data['region']['ul']['lon'] = 11.6 # upper left longitude
```

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```
data['region']['subset'] = 'yes'

## Define multi-temporal filtering properties
data['speckle_filter']['multi_temporal']['apply'] = 'yes'
data['speckle_filter']['multi_temporal']['files'] = '5' # Number of files used for multi␣
↪temporal filtering

## Define incidence angle for normalization
data['normalization_angle'] = '35'

with open('test_config_file.yaml', 'wb') as stream:
   yaml.safe_dump(data, stream, default_flow_style=False,
                  explicit_start=True, allow_unicode=True, encoding='utf-8')
```

Start pre-processing steps

[7]:
```
from sar_pre_processing.sar_pre_processor import *
import warnings
warnings.filterwarnings("ignore")

processing = SARPreProcessor(config='test_config_file.yaml')
processing.create_processing_file_list()
print('start step 1')
processing.pre_process_step1()
print('start step 2')
processing.pre_process_step2()
print('start step 3')
processing.pre_process_step3()
print('start add netcdf information')
processing.add_netcdf_information()
print('start create netcdf stack')
processing.create_netcdf_stack()
```

```
INFO:root:Found files within input folder: 10
INFO:root:Number of found files for year 2021: 10
INFO:root:area of interest not specified
INFO:root:Number of found files that were double processed: 0.0
INFO:root:Number of found files with border issues: 4
INFO:root:area of interest specified
INFO:root:normalisation angle not specified, default value of 35 is used for processing
INFO:ComponentProgress:0
INFO:ComponentProgress:0
INFO:root:Process S1A_IW_SLC__1SDH_20210109T170737_20210109T170801_036064_043A0F_7B82.
↪zip with SNAP.
```

```
start step 1
```

```
INFO: org.esa.snap.core.gpf.operators.tooladapter.ToolAdapterIO: Initializing external␣
↪tool adapters
INFO: org.esa.s2tbx.dataio.gdal.GDALVersion: GDAL 3.0.4 found on system. JNI driver will␣
↪be used.
INFO: org.esa.s2tbx.dataio.gdal.GDALVersion: Installed GDAL 3.0.4 set to be used by SNAP.
INFO: org.esa.snap.core.util.EngineVersionCheckActivator: Please check regularly for new␣
↪updates for the best SNAP experience.
```

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```
INFO: org.esa.s2tbx.dataio.gdal.GDALVersion: Installed GDAL 3.0.4 set to be used by SNAP.
```

```
Executing processing graph
```

```
INFO: org.hsqldb.persist.Logger: dataFileCache open start
INFO: org.esa.snap.engine_utilities.download.DownloadableContentImpl: http retrieving␣
↪http://step.esa.int/auxdata/orbits/Sentinel-1/POEORB/S1A/2021/01/S1A_OPER_AUX_POEORB_
↪OPOD_20210129T120952_V20210108T225942_20210110T005942.EOF.zip

INFO:root:1
INFO:ComponentProgress:10
INFO:ComponentProgress:10
INFO:root:Process S1A_IW_SLC__1SDV_20210101T052626_20210101T052654_035940_0435A9_E0CB.
↪zip with SNAP.
```

```
 done.
```

```
INFO: org.esa.snap.core.gpf.operators.tooladapter.ToolAdapterIO: Initializing external␣
↪tool adapters
INFO: org.esa.s2tbx.dataio.gdal.GDALVersion: GDAL 3.0.4 found on system. JNI driver will␣
↪be used.
INFO: org.esa.s2tbx.dataio.gdal.GDALVersion: Installed GDAL 3.0.4 set to be used by SNAP.
INFO: org.esa.snap.core.util.EngineVersionCheckActivator: Please check regularly for new␣
↪updates for the best SNAP experience.
INFO: org.esa.s2tbx.dataio.gdal.GDALVersion: Installed GDAL 3.0.4 set to be used by SNAP.
```

```
Executing processing graph
```

```
INFO: org.hsqldb.persist.Logger: dataFileCache open start
INFO: org.esa.snap.engine_utilities.download.DownloadableContentImpl: http retrieving␣
↪http://step.esa.int/auxdata/orbits/Sentinel-1/POEORB/S1A/2020/12/S1A_OPER_AUX_POEORB_
↪OPOD_20210121T121629_V20201231T225942_20210102T005942.EOF.zip
```

```
...12%...24%...36%...48%...60%...72%...84%.. done.
```

```
INFO:root:0
INFO:ComponentProgress:20
INFO:ComponentProgress:20
INFO:root:Process S1A_IW_SLC__1SDV_20210108T051816_20210108T051844_036042_04393F_F99A.
↪zip with SNAP.
INFO: org.esa.snap.core.gpf.operators.tooladapter.ToolAdapterIO: Initializing external␣
↪tool adapters
INFO: org.esa.s2tbx.dataio.gdal.GDALVersion: GDAL 3.0.4 found on system. JNI driver will␣
↪be used.
INFO: org.esa.s2tbx.dataio.gdal.GDALVersion: Installed GDAL 3.0.4 set to be used by SNAP.
INFO: org.esa.snap.core.util.EngineVersionCheckActivator: Please check regularly for new␣
↪updates for the best SNAP experience.
INFO: org.esa.s2tbx.dataio.gdal.GDALVersion: Installed GDAL 3.0.4 set to be used by SNAP.
```

```
Executing processing graph
```

```
INFO: org.hsqldb.persist.Logger: dataFileCache open start
INFO: org.esa.snap.engine_utilities.download.DownloadableContentImpl: http retrieving␣
↪http://step.esa.int/auxdata/orbits/Sentinel-1/POEORB/S1A/2021/01/S1A_OPER_AUX_POEORB_
↪OPOD_20210128T121545_V20210107T225942_20210109T005942.EOF.zip
```

```
...11%...23%...34%...46%...57%...69%...80%... done.
```

```
INFO:root:0
INFO:ComponentProgress:30
INFO:ComponentProgress:30
INFO:root:Process S1B_IW_SLC__1SDV_20210102T051747_20210102T051814_024971_02F8D2_6318.
↪zip with SNAP.
INFO: org.esa.snap.core.gpf.operators.tooladapter.ToolAdapterIO: Initializing external␣
↪tool adapters
INFO: org.esa.s2tbx.dataio.gdal.GDALVersion: GDAL 3.0.4 found on system. JNI driver will␣
↪be used.
INFO: org.esa.s2tbx.dataio.gdal.GDALVersion: Installed GDAL 3.0.4 set to be used by SNAP.
INFO: org.esa.snap.core.util.EngineVersionCheckActivator: Please check regularly for new␣
↪updates for the best SNAP experience.
INFO: org.esa.s2tbx.dataio.gdal.GDALVersion: Installed GDAL 3.0.4 set to be used by SNAP.
```

```
Executing processing graph
```

```
INFO: org.hsqldb.persist.Logger: dataFileCache open start
INFO: org.esa.snap.engine_utilities.download.DownloadableContentImpl: http retrieving␣
↪http://step.esa.int/auxdata/orbits/Sentinel-1/POEORB/S1B/2021/01/S1B_OPER_AUX_POEORB_
↪OPOD_20210122T111559_V20210101T225942_20210103T005942.EOF.zip
```

```
...12%...24%..34%...46%...58%..68%...80%... done.
```

```
INFO:root:0
INFO:ComponentProgress:40
INFO:ComponentProgress:40
INFO:root:Process S1B_IW_SLC__1SDV_20210103T170648_20210103T170715_024993_02F97C_C72A.
↪zip with SNAP.
INFO: org.esa.snap.core.gpf.operators.tooladapter.ToolAdapterIO: Initializing external␣
↪tool adapters
INFO: org.esa.s2tbx.dataio.gdal.GDALVersion: GDAL 3.0.4 found on system. JNI driver will␣
↪be used.
INFO: org.esa.s2tbx.dataio.gdal.GDALVersion: Installed GDAL 3.0.4 set to be used by SNAP.
INFO: org.esa.snap.core.util.EngineVersionCheckActivator: Please check regularly for new␣
↪updates for the best SNAP experience.
INFO: org.esa.s2tbx.dataio.gdal.GDALVersion: Installed GDAL 3.0.4 set to be used by SNAP.
```

```
Executing processing graph
```

```
INFO: org.hsqldb.persist.Logger: dataFileCache open start
INFO: org.esa.snap.engine_utilities.download.DownloadableContentImpl: http retrieving␣
↪http://step.esa.int/auxdata/orbits/Sentinel-1/POEORB/S1B/2021/01/S1B_OPER_AUX_POEORB_
↪OPOD_20210123T111611_V20210102T225942_20210104T005942.EOF.zip
```

```
..10%..20%..31%..41%...51%..62%..72%..83%.. done.
```

```
INFO:root:0
INFO:ComponentProgress:50
INFO:ComponentProgress:50
INFO:root:Process S1B_IW_SLC__1SDV_20210107T052547_20210107T052614_025044_02FB1E_E0E4.
↪zip with SNAP.
INFO: org.esa.snap.core.gpf.operators.tooladapter.ToolAdapterIO: Initializing external␣
↪tool adapters
INFO: org.esa.s2tbx.dataio.gdal.GDALVersion: GDAL 3.0.4 found on system. JNI driver will␣
↪be used.
INFO: org.esa.s2tbx.dataio.gdal.GDALVersion: Installed GDAL 3.0.4 set to be used by SNAP.
```

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```
INFO: org.esa.snap.core.util.EngineVersionCheckActivator: Please check regularly for new␣
↪updates for the best SNAP experience.
INFO: org.esa.s2tbx.dataio.gdal.GDALVersion: Installed GDAL 3.0.4 set to be used by SNAP.
```

```
Executing processing graph
```

```
INFO: org.hsqldb.persist.Logger: dataFileCache open start
INFO: org.esa.snap.engine_utilities.download.DownloadableContentImpl: http retrieving␣
↪http://step.esa.int/auxdata/orbits/Sentinel-1/POEORB/S1B/2021/01/S1B_OPER_AUX_POEORB_
↪OPOD_20210127T111615_V20210106T225942_20210108T005942.EOF.zip
```

```
...12%...24%..34%...46%...58%..68%...80%... done.
```

```
INFO:root:0
INFO:ComponentProgress:60
INFO:ComponentProgress:60
INFO:root:Process S1A_IW_SLC__1SDV_20210104T165913_20210104T165940_035991_043767_A0D0.
↪zip with SNAP.
INFO: org.esa.snap.core.gpf.operators.tooladapter.ToolAdapterIO: Initializing external␣
↪tool adapters
INFO: org.esa.s2tbx.dataio.gdal.GDALVersion: GDAL 3.0.4 found on system. JNI driver will␣
↪be used.
INFO: org.esa.s2tbx.dataio.gdal.GDALVersion: Installed GDAL 3.0.4 set to be used by SNAP.
INFO: org.esa.snap.core.util.EngineVersionCheckActivator: Please check regularly for new␣
↪updates for the best SNAP experience.
INFO: org.esa.s2tbx.dataio.gdal.GDALVersion: Installed GDAL 3.0.4 set to be used by SNAP.
```

```
Executing processing graph
```

```
INFO: org.hsqldb.persist.Logger: dataFileCache open start
INFO: org.esa.snap.engine_utilities.download.DownloadableContentImpl: http retrieving␣
↪http://step.esa.int/auxdata/orbits/Sentinel-1/POEORB/S1A/2021/01/S1A_OPER_AUX_POEORB_
↪OPOD_20210124T121622_V20210103T225942_20210105T005942.EOF.zip
```

```
...12%...24%...34%...46%...58%...68%...80%...90% done.
```

```
INFO:root:0
INFO:ComponentProgress:70
INFO:ComponentProgress:70
INFO:root:Process S1B_IW_SLC__1SDV_20210110T165830_20210110T165857_025095_02FCB9_7015.
↪zip with SNAP.
INFO: org.esa.snap.core.gpf.operators.tooladapter.ToolAdapterIO: Initializing external␣
↪tool adapters
INFO: org.esa.s2tbx.dataio.gdal.GDALVersion: GDAL 3.0.4 found on system. JNI driver will␣
↪be used.
INFO: org.esa.s2tbx.dataio.gdal.GDALVersion: Installed GDAL 3.0.4 set to be used by SNAP.
INFO: org.esa.snap.core.util.EngineVersionCheckActivator: Please check regularly for new␣
↪updates for the best SNAP experience.
INFO: org.esa.s2tbx.dataio.gdal.GDALVersion: Installed GDAL 3.0.4 set to be used by SNAP.
```

```
Executing processing graph
```

```
INFO: org.hsqldb.persist.Logger: dataFileCache open start
INFO: org.esa.snap.engine_utilities.download.DownloadableContentImpl: http retrieving␣
↪http://step.esa.int/auxdata/orbits/Sentinel-1/POEORB/S1B/2021/01/S1B_OPER_AUX_POEORB_
↪OPOD_20210130T110934_V20210109T225942_20210111T005942.EOF.zip
```

```
...11%...23%...34%...45%..55%...66%...78%...90% done.
```

```
INFO:root:0
INFO:root:skip processing for /home/test/Desktop/data2/S1A_IW_SLC__1SDH_20210109T170737_
↪20210109T170801_036064_043A0F_7B82.zip. File does not exist
INFO:root:skip processing for /home/test/Desktop/data2/S1A_IW_SLC__1SDV_20210104T165938_
↪20210104T170006_035991_043767_329F.zip. File does not exist
INFO:root:skip processing for /home/test/Desktop/data2/S1B_IW_SLC__1SDV_20210110T165855_
↪20210110T165922_025095_02FCB9_4BB8.zip. File does not exist
INFO:ComponentProgress:0
INFO:ComponentProgress:0
INFO:root:Scene 1 of 7
INFO:root:Process S1A_IW_SLC__1SDV_20210101T052626_20210101T052654_035940_0435A9_E0CB_GC_
↪RC_No_Su.dim with SNAP.
```

```
start step 2
```

```
INFO: org.esa.snap.core.gpf.operators.tooladapter.ToolAdapterIO: Initializing external␣
↪tool adapters
INFO: org.esa.s2tbx.dataio.gdal.GDALVersion: GDAL 3.0.4 found on system. JNI driver will␣
↪be used.
INFO: org.esa.s2tbx.dataio.gdal.GDALVersion: Installed GDAL 3.0.4 set to be used by SNAP.
INFO: org.esa.snap.core.util.EngineVersionCheckActivator: Please check regularly for new␣
↪updates for the best SNAP experience.
INFO: org.esa.s2tbx.dataio.gdal.GDALVersion: Installed GDAL 3.0.4 set to be used by SNAP.
```

```
Executing processing graph
```

```
INFO: org.hsqldb.persist.Logger: dataFileCache open start
```

```
...12%...25%..35%..45%...57%..67%..77%...89% done.
```

```
-- org.jblas INFO Deleting /tmp/jblas7850174183669672141/libjblas.so
-- org.jblas INFO Deleting /tmp/jblas7850174183669672141/libgfortran-4.so
-- org.jblas INFO Deleting /tmp/jblas7850174183669672141/libjblas_arch_flavor.so
-- org.jblas INFO Deleting /tmp/jblas7850174183669672141/libquadmath-0.so
-- org.jblas INFO Deleting /tmp/jblas7850174183669672141
INFO:root:0
INFO:root:2021-08-29 18:57:58.801427
INFO:ComponentProgress:14
INFO:ComponentProgress:14
INFO:root:Scene 2 of 7
INFO:root:Process S1A_IW_SLC__1SDV_20210104T165913_20210104T165940_035991_043767_A0D0_GC_
↪RC_No_Su.dim with SNAP.
INFO: org.esa.snap.core.gpf.operators.tooladapter.ToolAdapterIO: Initializing external␣
↪tool adapters
INFO: org.esa.s2tbx.dataio.gdal.GDALVersion: GDAL 3.0.4 found on system. JNI driver will␣
↪be used.
INFO: org.esa.s2tbx.dataio.gdal.GDALVersion: Installed GDAL 3.0.4 set to be used by SNAP.
INFO: org.esa.snap.core.util.EngineVersionCheckActivator: Please check regularly for new␣
↪updates for the best SNAP experience.
INFO: org.esa.s2tbx.dataio.gdal.GDALVersion: Installed GDAL 3.0.4 set to be used by SNAP.
```

```
Executing processing graph
```

```
INFO: org.hsqldb.persist.Logger: dataFileCache open start
INFO: org.esa.snap.core.datamodel.Product: raster width 2403 not equal to 2404
```

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```
INFO: org.esa.snap.core.datamodel.Product: raster width 2403 not equal to 2404
INFO: org.esa.snap.core.datamodel.Product: raster width 2403 not equal to 2404
INFO: org.esa.snap.core.datamodel.Product: raster width 2403 not equal to 2404
INFO: org.esa.snap.core.datamodel.Product: raster width 2403 not equal to 2404
INFO: org.esa.snap.core.datamodel.Product: raster width 2403 not equal to 2404
INFO: org.esa.snap.core.datamodel.Product: raster width 2403 not equal to 2404
INFO: org.esa.snap.core.datamodel.Product: raster width 2403 not equal to 2404
INFO: org.esa.snap.core.datamodel.Product: raster width 2403 not equal to 2404
INFO: org.esa.snap.core.datamodel.Product: raster width 2403 not equal to 2404
INFO: org.esa.snap.core.datamodel.Product: raster width 2403 not equal to 2404
INFO: org.esa.snap.core.datamodel.Product: raster width 2403 not equal to 2404
WARNING: org.jlinda.core.Baseline: Max. error bperp modeling at 3D datapoints: 951621.
↪6928487846m
```

```
...12%...25%..35%..45%...57%..67%..77%...89% done.
```

```
-- org.jblas INFO Deleting /tmp/jblas8286044915352018441/libjblas.so
-- org.jblas INFO Deleting /tmp/jblas8286044915352018441/libgfortran-4.so
-- org.jblas INFO Deleting /tmp/jblas8286044915352018441/libjblas_arch_flavor.so
-- org.jblas INFO Deleting /tmp/jblas8286044915352018441/libquadmath-0.so
-- org.jblas INFO Deleting /tmp/jblas8286044915352018441
INFO:root:0
INFO:root:2021-08-29 18:59:12.674310
INFO:ComponentProgress:28
INFO:ComponentProgress:28
INFO:root:Scene 3 of 7
INFO:root:Process S1A_IW_SLC__1SDV_20210108T051816_20210108T051844_036042_04393F_F99A_GC_
↪RC_No_Su.dim with SNAP.
INFO: org.esa.snap.core.gpf.operators.tooladapter.ToolAdapterIO: Initializing external␣
↪tool adapters
INFO: org.esa.s2tbx.dataio.gdal.GDALVersion: GDAL 3.0.4 found on system. JNI driver will␣
↪be used.
INFO: org.esa.s2tbx.dataio.gdal.GDALVersion: Installed GDAL 3.0.4 set to be used by SNAP.
INFO: org.esa.snap.core.util.EngineVersionCheckActivator: Please check regularly for new␣
↪updates for the best SNAP experience.
INFO: org.esa.s2tbx.dataio.gdal.GDALVersion: Installed GDAL 3.0.4 set to be used by SNAP.
```

```
Executing processing graph
```

```
INFO: org.hsqldb.persist.Logger: dataFileCache open start
INFO: org.esa.snap.core.datamodel.Product: raster width 2403 not equal to 2404
INFO: org.esa.snap.core.datamodel.Product: raster width 2403 not equal to 2404
INFO: org.esa.snap.core.datamodel.Product: raster width 2403 not equal to 2404
INFO: org.esa.snap.core.datamodel.Product: raster width 2403 not equal to 2404
INFO: org.esa.snap.core.datamodel.Product: raster width 2403 not equal to 2404
INFO: org.esa.snap.core.datamodel.Product: raster width 2403 not equal to 2404
INFO: org.esa.snap.core.datamodel.Product: raster width 2403 not equal to 2404
INFO: org.esa.snap.core.datamodel.Product: raster width 2403 not equal to 2404
INFO: org.esa.snap.core.datamodel.Product: raster width 2403 not equal to 2404
INFO: org.esa.snap.core.datamodel.Product: raster width 2403 not equal to 2404
INFO: org.esa.snap.core.datamodel.Product: raster width 2403 not equal to 2404
INFO: org.esa.snap.core.datamodel.Product: raster width 2403 not equal to 2404
```

```
...12%...25%..35%..45%...57%..67%..77%...89% done.
```

```
-- org.jblas INFO Deleting /tmp/jblas1941578135814371655/libjblas.so
-- org.jblas INFO Deleting /tmp/jblas1941578135814371655/libgfortran-4.so
-- org.jblas INFO Deleting /tmp/jblas1941578135814371655/libjblas_arch_flavor.so
-- org.jblas INFO Deleting /tmp/jblas1941578135814371655/libquadmath-0.so
-- org.jblas INFO Deleting /tmp/jblas1941578135814371655
INFO:root:0
INFO:root:2021-08-29 19:00:26.270922
INFO:ComponentProgress:42
INFO:ComponentProgress:42
INFO:root:Scene 4 of 7
INFO:root:Process S1B_IW_SLC__1SDV_20210102T051747_20210102T051814_024971_02F8D2_6318_GC_
↪RC_No_Su.dim with SNAP.
INFO: org.esa.snap.core.gpf.operators.tooladapter.ToolAdapterIO: Initializing external␣
↪tool adapters
INFO: org.esa.s2tbx.dataio.gdal.GDALVersion: GDAL 3.0.4 found on system. JNI driver will␣
↪be used.
INFO: org.esa.s2tbx.dataio.gdal.GDALVersion: Installed GDAL 3.0.4 set to be used by SNAP.
INFO: org.esa.snap.core.util.EngineVersionCheckActivator: Please check regularly for new␣
↪updates for the best SNAP experience.
INFO: org.esa.s2tbx.dataio.gdal.GDALVersion: Installed GDAL 3.0.4 set to be used by SNAP.
```

```
Executing processing graph
```

```
INFO: org.hsqldb.persist.Logger: dataFileCache open start
INFO: org.esa.snap.core.datamodel.Product: raster width 2403 not equal to 2404
INFO: org.esa.snap.core.datamodel.Product: raster width 2403 not equal to 2404
INFO: org.esa.snap.core.datamodel.Product: raster width 2403 not equal to 2404
INFO: org.esa.snap.core.datamodel.Product: raster width 2403 not equal to 2404
INFO: org.esa.snap.core.datamodel.Product: raster width 2403 not equal to 2404
INFO: org.esa.snap.core.datamodel.Product: raster width 2403 not equal to 2404
INFO: org.esa.snap.core.datamodel.Product: raster width 2403 not equal to 2404
INFO: org.esa.snap.core.datamodel.Product: raster width 2403 not equal to 2404
INFO: org.esa.snap.core.datamodel.Product: raster width 2403 not equal to 2404
INFO: org.esa.snap.core.datamodel.Product: raster width 2403 not equal to 2404
INFO: org.esa.snap.core.datamodel.Product: raster width 2403 not equal to 2404
INFO: org.esa.snap.core.datamodel.Product: raster width 2403 not equal to 2404
```

```
...12%...25%..35%..45%...57%..67%..77%...89% done.
```

```
-- org.jblas INFO Deleting /tmp/jblas5133865250962490398/libjblas.so
-- org.jblas INFO Deleting /tmp/jblas5133865250962490398/libgfortran-4.so
-- org.jblas INFO Deleting /tmp/jblas5133865250962490398/libjblas_arch_flavor.so
-- org.jblas INFO Deleting /tmp/jblas5133865250962490398/libquadmath-0.so
-- org.jblas INFO Deleting /tmp/jblas5133865250962490398
INFO:root:0
INFO:root:2021-08-29 19:01:57.069051
INFO:ComponentProgress:57
INFO:ComponentProgress:57
INFO:root:Scene 5 of 7
INFO:root:Process S1B_IW_SLC__1SDV_20210103T170648_20210103T170715_024993_02F97C_C72A_GC_
↪RC_No_Su.dim with SNAP.
INFO: org.esa.snap.core.gpf.operators.tooladapter.ToolAdapterIO: Initializing external␣
↪tool adapters
INFO: org.esa.s2tbx.dataio.gdal.GDALVersion: GDAL 3.0.4 found on system. JNI driver will␣
↪be used.
```

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```
INFO: org.esa.s2tbx.dataio.gdal.GDALVersion: Installed GDAL 3.0.4 set to be used by SNAP.
INFO: org.esa.snap.core.util.EngineVersionCheckActivator: Please check regularly for new␣
↪updates for the best SNAP experience.
INFO: org.esa.s2tbx.dataio.gdal.GDALVersion: Installed GDAL 3.0.4 set to be used by SNAP.
```

```
Executing processing graph
```

```
INFO: org.hsqldb.persist.Logger: dataFileCache open start
INFO: org.esa.snap.core.datamodel.Product: raster width 2403 not equal to 2404
INFO: org.esa.snap.core.datamodel.Product: raster width 2403 not equal to 2404
INFO: org.esa.snap.core.datamodel.Product: raster width 2403 not equal to 2404
INFO: org.esa.snap.core.datamodel.Product: raster width 2403 not equal to 2404
INFO: org.esa.snap.core.datamodel.Product: raster width 2403 not equal to 2404
INFO: org.esa.snap.core.datamodel.Product: raster width 2403 not equal to 2404
INFO: org.esa.snap.core.datamodel.Product: raster width 2403 not equal to 2404
INFO: org.esa.snap.core.datamodel.Product: raster width 2403 not equal to 2404
INFO: org.esa.snap.core.datamodel.Product: raster width 2403 not equal to 2404
INFO: org.esa.snap.core.datamodel.Product: raster width 2403 not equal to 2404
INFO: org.esa.snap.core.datamodel.Product: raster width 2403 not equal to 2404
INFO: org.esa.snap.core.datamodel.Product: raster width 2403 not equal to 2404
```

```
...12%...25%..35%..45%...57%..67%..77%...89% done.
```

```
-- org.jblas INFO Deleting /tmp/jblas8785853447239672772/libjblas.so
-- org.jblas INFO Deleting /tmp/jblas8785853447239672772/libgfortran-4.so
-- org.jblas INFO Deleting /tmp/jblas8785853447239672772/libjblas_arch_flavor.so
-- org.jblas INFO Deleting /tmp/jblas8785853447239672772/libquadmath-0.so
-- org.jblas INFO Deleting /tmp/jblas8785853447239672772
INFO:root:0
INFO:root:2021-08-29 19:03:24.549310
INFO:ComponentProgress:71
INFO:ComponentProgress:71
INFO:root:Scene 6 of 7
INFO:root:Process S1B_IW_SLC__1SDV_20210107T052547_20210107T052614_025044_02FB1E_E0E4_GC_
↪RC_No_Su.dim with SNAP.
INFO: org.esa.snap.core.gpf.operators.tooladapter.ToolAdapterIO: Initializing external␣
↪tool adapters
INFO: org.esa.s2tbx.dataio.gdal.GDALVersion: GDAL 3.0.4 found on system. JNI driver will␣
↪be used.
INFO: org.esa.s2tbx.dataio.gdal.GDALVersion: Installed GDAL 3.0.4 set to be used by SNAP.
INFO: org.esa.snap.core.util.EngineVersionCheckActivator: Please check regularly for new␣
↪updates for the best SNAP experience.
INFO: org.esa.s2tbx.dataio.gdal.GDALVersion: Installed GDAL 3.0.4 set to be used by SNAP.
```

```
Executing processing graph
```

```
INFO: org.hsqldb.persist.Logger: dataFileCache open start
INFO: org.esa.snap.core.datamodel.Product: raster width 2403 not equal to 2404
INFO: org.esa.snap.core.datamodel.Product: raster width 2403 not equal to 2404
INFO: org.esa.snap.core.datamodel.Product: raster width 2403 not equal to 2404
INFO: org.esa.snap.core.datamodel.Product: raster width 2403 not equal to 2404
INFO: org.esa.snap.core.datamodel.Product: raster width 2403 not equal to 2404
INFO: org.esa.snap.core.datamodel.Product: raster width 2403 not equal to 2404
INFO: org.esa.snap.core.datamodel.Product: raster width 2403 not equal to 2404
INFO: org.esa.snap.core.datamodel.Product: raster width 2403 not equal to 2404
```

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```
INFO: org.esa.snap.core.datamodel.Product: raster width 2403 not equal to 2404
INFO: org.esa.snap.core.datamodel.Product: raster width 2403 not equal to 2404
INFO: org.esa.snap.core.datamodel.Product: raster width 2403 not equal to 2404
INFO: org.esa.snap.core.datamodel.Product: raster width 2403 not equal to 2404
```

```
...12%...25%..35%..45%...57%..67%..77%...89% done.
```

```
-- org.jblas INFO Deleting /tmp/jblas7411179791605111946/libjblas.so
-- org.jblas INFO Deleting /tmp/jblas7411179791605111946/libgfortran-4.so
-- org.jblas INFO Deleting /tmp/jblas7411179791605111946/libjblas_arch_flavor.so
-- org.jblas INFO Deleting /tmp/jblas7411179791605111946/libquadmath-0.so
-- org.jblas INFO Deleting /tmp/jblas7411179791605111946
INFO:root:0
INFO:root:2021-08-29 19:04:35.352154
INFO:ComponentProgress:85
INFO:ComponentProgress:85
INFO:root:Scene 7 of 7
INFO:root:Process S1B_IW_SLC__1SDV_20210110T165830_20210110T165857_025095_02FCB9_7015_GC_
↪RC_No_Su.dim with SNAP.
INFO: org.esa.snap.core.gpf.operators.tooladapter.ToolAdapterIO: Initializing external␣
↪tool adapters
INFO: org.esa.s2tbx.dataio.gdal.GDALVersion: GDAL 3.0.4 found on system. JNI driver will␣
↪be used.
INFO: org.esa.s2tbx.dataio.gdal.GDALVersion: Installed GDAL 3.0.4 set to be used by SNAP.
INFO: org.esa.snap.core.util.EngineVersionCheckActivator: Please check regularly for new␣
↪updates for the best SNAP experience.
INFO: org.esa.s2tbx.dataio.gdal.GDALVersion: Installed GDAL 3.0.4 set to be used by SNAP.
```

```
Executing processing graph
```

```
INFO: org.hsqldb.persist.Logger: dataFileCache open start
INFO: org.esa.snap.core.datamodel.Product: raster width 2403 not equal to 2404
INFO: org.esa.snap.core.datamodel.Product: raster width 2403 not equal to 2404
INFO: org.esa.snap.core.datamodel.Product: raster width 2403 not equal to 2404
INFO: org.esa.snap.core.datamodel.Product: raster width 2403 not equal to 2404
INFO: org.esa.snap.core.datamodel.Product: raster width 2403 not equal to 2404
INFO: org.esa.snap.core.datamodel.Product: raster width 2403 not equal to 2404
INFO: org.esa.snap.core.datamodel.Product: raster width 2403 not equal to 2404
INFO: org.esa.snap.core.datamodel.Product: raster width 2403 not equal to 2404
INFO: org.esa.snap.core.datamodel.Product: raster width 2403 not equal to 2404
INFO: org.esa.snap.core.datamodel.Product: raster width 2403 not equal to 2404
INFO: org.esa.snap.core.datamodel.Product: raster width 2403 not equal to 2404
INFO: org.esa.snap.core.datamodel.Product: raster width 2403 not equal to 2404
WARNING: org.jlinda.core.Baseline: Max. error bperp modeling at 3D datapoints: 1002303.
↪1955448636m
```

```
...12%...25%..35%..45%...57%..67%..77%...89% done.
```

```
-- org.jblas INFO Deleting /tmp/jblas2590257929860331368/libjblas.so
-- org.jblas INFO Deleting /tmp/jblas2590257929860331368/libgfortran-4.so
-- org.jblas INFO Deleting /tmp/jblas2590257929860331368/libjblas_arch_flavor.so
-- org.jblas INFO Deleting /tmp/jblas2590257929860331368/libquadmath-0.so
-- org.jblas INFO Deleting /tmp/jblas2590257929860331368
INFO:root:0
INFO:root:2021-08-29 19:05:54.247359
```

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```
INFO:root:skip processing for /home/test/Desktop/data2/S1A_IW_SLC__1SDH_20210109T170737_
↪20210109T170801_036064_043A0F_7B82.zip. File /home/test/Desktop/data2/step2/S1A_IW_SLC_
↪_1SDH_20210109T170737_20210109T170801_036064_043A0F_7B82_GC_RC_No_Su_Co.dim does not␣
↪exist.
INFO:root:skip processing for /home/test/Desktop/data2/S1A_IW_SLC__1SDV_20210104T165938_
↪20210104T170006_035991_043767_329F.zip. File /home/test/Desktop/data2/step2/S1A_IW_SLC_
↪_1SDV_20210104T165938_20210104T170006_035991_043767_329F_GC_RC_No_Su_Co.dim does not␣
↪exist.
INFO:root:skip processing for /home/test/Desktop/data2/S1B_IW_SLC__1SDV_20210110T165855_
↪20210110T165922_025095_02FCB9_4BB8.zip. File /home/test/Desktop/data2/step2/S1B_IW_SLC_
↪_1SDV_20210110T165855_20210110T165922_025095_02FCB9_4BB8_GC_RC_No_Su_Co.dim does not␣
↪exist.
INFO:ComponentProgress:0
INFO:ComponentProgress:0
```

```
start step 3
```

```
INFO: org.esa.snap.core.gpf.operators.tooladapter.ToolAdapterIO: Initializing external␣
↪tool adapters
INFO: org.esa.s2tbx.dataio.gdal.GDALVersion: GDAL 3.0.4 found on system. JNI driver will␣
↪be used.
INFO: org.esa.s2tbx.dataio.gdal.GDALVersion: Installed GDAL 3.0.4 set to be used by SNAP.
INFO: org.esa.snap.core.util.EngineVersionCheckActivator: Please check regularly for new␣
↪updates for the best SNAP experience.
INFO: org.esa.s2tbx.dataio.gdal.GDALVersion: Installed GDAL 3.0.4 set to be used by SNAP.
```

```
Executing processing graph
```

```
INFO: org.hsqldb.persist.Logger: dataFileCache open start
```

```
...10%...22%...34%...45%...
```

```
29455 [main] INFO serverStartup - Nc4Iosp: NetCDF-4 C library loaded (jna_path='/home/
↪test/.snap/auxdata/netcdf_natives/8.0.5/amd64', libname='netcdf').
29500 [main] INFO serverStartup - NetcdfLoader: set log level: old=0 new=0
29501 [main] INFO serverStartup - Nc4Iosp: set log level: old=0 new=0
```

```
55%...67%...79%...90% done.
```

```
INFO:root:0
INFO:root:2021-08-29 19:08:56.411130
INFO:ComponentProgress:14
INFO:ComponentProgress:14
INFO: org.esa.snap.core.gpf.operators.tooladapter.ToolAdapterIO: Initializing external␣
↪tool adapters
INFO: org.esa.s2tbx.dataio.gdal.GDALVersion: GDAL 3.0.4 found on system. JNI driver will␣
↪be used.
INFO: org.esa.s2tbx.dataio.gdal.GDALVersion: Installed GDAL 3.0.4 set to be used by SNAP.
INFO: org.esa.snap.core.util.EngineVersionCheckActivator: Please check regularly for new␣
↪updates for the best SNAP experience.
INFO: org.esa.s2tbx.dataio.gdal.GDALVersion: Installed GDAL 3.0.4 set to be used by SNAP.
```

```
Executing processing graph
```

```
INFO: org.hsqldb.persist.Logger: dataFileCache open start
```

```
...10%...22%...34%...45%...
```

```
21992 [main] INFO serverStartup - Nc4Iosp: NetCDF-4 C library loaded (jna_path='/home/
↪test/.snap/auxdata/netcdf_natives/8.0.5/amd64', libname='netcdf').
22011 [main] INFO serverStartup - NetcdfLoader: set log level: old=0 new=0
22012 [main] INFO serverStartup - Nc4Iosp: set log level: old=0 new=0
```

```
55%...67%...79%...90% done.
```

```
INFO:root:0
INFO:root:2021-08-29 19:11:42.027038
INFO:ComponentProgress:28
INFO:ComponentProgress:28
INFO: org.esa.snap.core.gpf.operators.tooladapter.ToolAdapterIO: Initializing external␣
↪tool adapters
INFO: org.esa.s2tbx.dataio.gdal.GDALVersion: GDAL 3.0.4 found on system. JNI driver will␣
↪be used.
INFO: org.esa.s2tbx.dataio.gdal.GDALVersion: Installed GDAL 3.0.4 set to be used by SNAP.
INFO: org.esa.snap.core.util.EngineVersionCheckActivator: Please check regularly for new␣
↪updates for the best SNAP experience.
INFO: org.esa.s2tbx.dataio.gdal.GDALVersion: Installed GDAL 3.0.4 set to be used by SNAP.
```

```
Executing processing graph
```

```
INFO: org.hsqldb.persist.Logger: dataFileCache open start
```

```
...10%...22%...34%...45%...
```

```
21802 [main] INFO serverStartup - Nc4Iosp: NetCDF-4 C library loaded (jna_path='/home/
↪test/.snap/auxdata/netcdf_natives/8.0.5/amd64', libname='netcdf').
21810 [main] INFO serverStartup - NetcdfLoader: set log level: old=0 new=0
21828 [main] INFO serverStartup - Nc4Iosp: set log level: old=0 new=0
```

```
55%...67%...79%...90%
```

```
INFO:root:0
INFO:root:2021-08-29 19:14:12.068346
INFO:ComponentProgress:42
INFO:ComponentProgress:42
```

```
 done.
```

```
INFO: org.esa.snap.core.gpf.operators.tooladapter.ToolAdapterIO: Initializing external␣
↪tool adapters
INFO: org.esa.s2tbx.dataio.gdal.GDALVersion: GDAL 3.0.4 found on system. JNI driver will␣
↪be used.
INFO: org.esa.s2tbx.dataio.gdal.GDALVersion: Installed GDAL 3.0.4 set to be used by SNAP.
INFO: org.esa.snap.core.util.EngineVersionCheckActivator: Please check regularly for new␣
↪updates for the best SNAP experience.
INFO: org.esa.s2tbx.dataio.gdal.GDALVersion: Installed GDAL 3.0.4 set to be used by SNAP.
```

```
Executing processing graph
```

```
INFO: org.hsqldb.persist.Logger: dataFileCache open start
```

```
...10%...22%...34%...45%...
```

```
13418 [main] INFO serverStartup - Nc4Iosp: NetCDF-4 C library loaded (jna_path='/home/
↪test/.snap/auxdata/netcdf_natives/8.0.5/amd64', libname='netcdf').
13434 [main] INFO serverStartup - NetcdfLoader: set log level: old=0 new=0
13435 [main] INFO serverStartup - Nc4Iosp: set log level: old=0 new=0
```

```
55%...67%...79%...90% done.

INFO:root:0
INFO:root:2021-08-29 19:16:33.320428
INFO:ComponentProgress:57
INFO:ComponentProgress:57
INFO: org.esa.snap.core.gpf.operators.tooladapter.ToolAdapterIO: Initializing external␣
↪tool adapters
INFO: org.esa.s2tbx.dataio.gdal.GDALVersion: GDAL 3.0.4 found on system. JNI driver will␣
↪be used.
INFO: org.esa.s2tbx.dataio.gdal.GDALVersion: Installed GDAL 3.0.4 set to be used by SNAP.
INFO: org.esa.snap.core.util.EngineVersionCheckActivator: Please check regularly for new␣
↪updates for the best SNAP experience.
INFO: org.esa.s2tbx.dataio.gdal.GDALVersion: Installed GDAL 3.0.4 set to be used by SNAP.

Executing processing graph

INFO: org.hsqldb.persist.Logger: dataFileCache open start

...10%...22%...34%...45%...

22425 [main] INFO serverStartup - Nc4Iosp: NetCDF-4 C library loaded (jna_path='/home/
↪test/.snap/auxdata/netcdf_natives/8.0.5/amd64', libname='netcdf').
22442 [main] INFO serverStartup - NetcdfLoader: set log level: old=0 new=0
22448 [main] INFO serverStartup - Nc4Iosp: set log level: old=0 new=0

55%...67%...79%...90% done.

INFO:root:0
INFO:root:2021-08-29 19:19:14.782446
INFO:ComponentProgress:71
INFO:ComponentProgress:71
INFO: org.esa.snap.core.gpf.operators.tooladapter.ToolAdapterIO: Initializing external␣
↪tool adapters
INFO: org.esa.s2tbx.dataio.gdal.GDALVersion: GDAL 3.0.4 found on system. JNI driver will␣
↪be used.
INFO: org.esa.s2tbx.dataio.gdal.GDALVersion: Installed GDAL 3.0.4 set to be used by SNAP.
INFO: org.esa.snap.core.util.EngineVersionCheckActivator: Please check regularly for new␣
↪updates for the best SNAP experience.
INFO: org.esa.s2tbx.dataio.gdal.GDALVersion: Installed GDAL 3.0.4 set to be used by SNAP.

Executing processing graph

INFO: org.hsqldb.persist.Logger: dataFileCache open start

...10%...22%...34%...45%...

22348 [main] INFO serverStartup - Nc4Iosp: NetCDF-4 C library loaded (jna_path='/home/
↪test/.snap/auxdata/netcdf_natives/8.0.5/amd64', libname='netcdf').
22375 [main] INFO serverStartup - NetcdfLoader: set log level: old=0 new=0
22387 [main] INFO serverStartup - Nc4Iosp: set log level: old=0 new=0

55%...67%...79%...90% done.

INFO:root:0
INFO:root:2021-08-29 19:21:56.809279
INFO:ComponentProgress:85
INFO:ComponentProgress:85
INFO: org.esa.snap.core.gpf.operators.tooladapter.ToolAdapterIO: Initializing external␣
↪tool adapters
```

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```
INFO: org.esa.s2tbx.dataio.gdal.GDALVersion: GDAL 3.0.4 found on system. JNI driver will␣
↪be used.
INFO: org.esa.s2tbx.dataio.gdal.GDALVersion: Installed GDAL 3.0.4 set to be used by SNAP.
INFO: org.esa.snap.core.util.EngineVersionCheckActivator: Please check regularly for new␣
↪updates for the best SNAP experience.
INFO: org.esa.s2tbx.dataio.gdal.GDALVersion: Installed GDAL 3.0.4 set to be used by SNAP.
```

```
Executing processing graph
```

```
INFO: org.hsqldb.persist.Logger: dataFileCache open start
```

```
...10%...22%...34%...45%...
```

```
21504 [main] INFO serverStartup - Nc4Iosp: NetCDF-4 C library loaded (jna_path='/home/
↪test/.snap/auxdata/netcdf_natives/8.0.5/amd64', libname='netcdf').
21543 [main] INFO serverStartup - NetcdfLoader: set log level: old=0 new=0
21543 [main] INFO serverStartup - Nc4Iosp: set log level: old=0 new=0
```

```
55%...67%...79%...90% done.
```

```
INFO:root:0
INFO:root:2021-08-29 19:24:31.369057
```

```
start add netcdf information
```

```
INFO:root:Number of scenes found for processing: 7
```

```
start create netcdf stack

Scene 1 of 7
/home/test/Desktop/data2/step3/S1A_IW_SLC__1SDV_20210101T052626_20210101T052654_035940_
↪0435A9_E0CB_GC_RC_No_Su_Co_speckle.nc

Scene 2 of 7
/home/test/Desktop/data2/step3/S1B_IW_SLC__1SDV_20210102T051747_20210102T051814_024971_
↪02F8D2_6318_GC_RC_No_Su_Co_speckle.nc

Scene 3 of 7
/home/test/Desktop/data2/step3/S1B_IW_SLC__1SDV_20210103T170648_20210103T170715_024993_
↪02F97C_C72A_GC_RC_No_Su_Co_speckle.nc

Scene 4 of 7
/home/test/Desktop/data2/step3/S1A_IW_SLC__1SDV_20210104T165913_20210104T165940_035991_
↪043767_A0D0_GC_RC_No_Su_Co_speckle.nc

Scene 5 of 7
/home/test/Desktop/data2/step3/S1B_IW_SLC__1SDV_20210107T052547_20210107T052614_025044_
↪02FB1E_E0E4_GC_RC_No_Su_Co_speckle.nc

Scene 6 of 7
/home/test/Desktop/data2/step3/S1A_IW_SLC__1SDV_20210108T051816_20210108T051844_036042_
↪04393F_F99A_GC_RC_No_Su_Co_speckle.nc

Scene 7 of 7
/home/test/Desktop/data2/step3/S1B_IW_SLC__1SDV_20210110T165830_20210110T165857_025095_
↪02FCB9_7015_GC_RC_No_Su_Co_speckle.nc
```

4. View processed data

Load netcdf file with processed data

[8]:
```
import os
print(os.getcwd())
print(output_folder)
```

```
/home/test/Desktop/sar-pre-processing/docs/notebooks
/home/test/Desktop/data2
```

[9]:
```
from netCDF4 import Dataset
import numpy as np

my_example_nc_file = os.path.join(output_folder, 'data2.nc')
data = Dataset(my_example_nc_file, mode='r')
```

View information about dataset

[10]:
```
data
```

[10]:
```
<class 'netCDF4._netCDF4.Dataset'>
root group (NETCDF4 data model, file format HDF5):
    dimensions(sizes): lat(1603), lon(2403), time(7)
    variables(dimensions): float32 time(time), float32 orbitdirection(time), float32␣
↪relorbit(time), float32 satellite(time), float32 lat(lat), float32 lon(lon), float32␣
↪theta(time, lat, lon), float32 sigma0_vv_norm_multi(time, lat, lon), float32 sigma0_vh_
↪norm_multi(time, lat, lon), float32 sigma0_vv_multi(time, lat, lon), float32 sigma0_vh_
↪multi(time, lat, lon), float32 sigma0_vv_single(time, lat, lon), float32 sigma0_vh_
↪single(time, lat, lon), float32 sigma0_vv_norm_single(time, lat, lon), float32 sigma0_
↪vh_norm_single(time, lat, lon)
    groups:
```

Read data from netcdf file

[11]:
```
data.variables['orbitdirection'][:]
data.variables['time'][:]
lons = data.variables['lon'][:]
lats = data.variables['lat'][:]
vv = data.variables['sigma0_vv_single'][:]

vv_units = data.variables['sigma0_vv_single'].units
```

Close netcdf file

[12]:
```
data.close()
```

Plot vv polorized data

[13]:
```
%matplotlib inline
from ipywidgets import interactive
import matplotlib.pyplot as plt
import numpy as np

def f(x):
```

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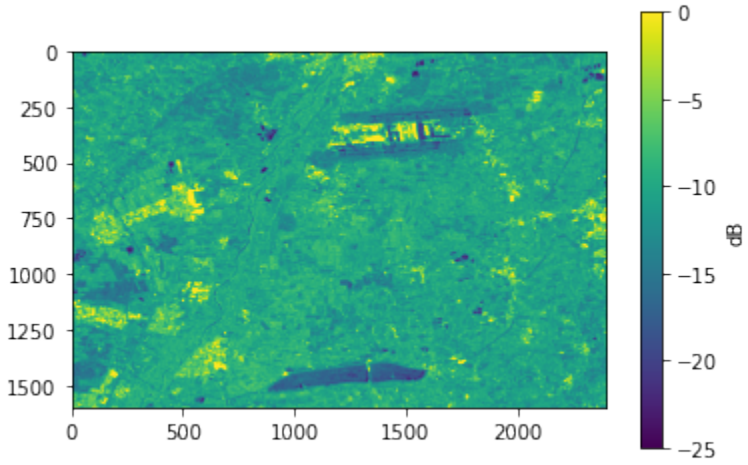
```
    # Problem: border pixel might be zero or negative
    # pixel eqal or smaller than zero are set to nan
    array = np.copy(vv[x])
    array[array <= 0] = np.nan
    # plot backscatter data in dB scale
    plt.imshow(10*np.log10(array))
    cbar = plt.colorbar()
    cbar.set_label('dB')
    plt.clim(-25, 0)

interactive_plot = interactive(f, x=(0,len(vv)-1))
interactive_plot
```

[13]:
```
interactive(children=(IntSlider(value=3, description='x', max=6), Output()), _dom_
↪classes=('widget-interact',)...
```



[ ]:

1.3.3 Example 3: Use user defined processing graphs to pre-process a time series of Sentinel-1 images

1. Requirements

- Installation of SenSARP
- Installation of ESA's SNAP Toolbox version >8.0.3
  - Currently only SNAP version 8.0 can be downloaded from the ESA website (https://step.esa.int/main/download/snap-download/). To update SNAP to a version >8.0.3 please start the SNAP software. You will be asked if you want to search for update. After the updates are installed you need to restart SNAP to initialize the installed updates.
  - SNAP Toolbox need libgfortran for specific operations but currently libgfortran is not installed during the installation process of SNAP therefore you might use `sudo apt-get install gfortran`
- Sentinel-1 SLC data
  - Instruction how to download Sentinel 1 data are given in Section 2

2. Download sample data from Sentinel Data Hub

Option 1: Download data from Sentinel Data Hub manually or via python package sentinelsat

Create Account (https://scihub.copernicus.eu/dhus/#/self-registration). (**Attention: Problem by using Copernicus Open Access Hub might be that older data is offline and need to be triggered first**). More information can be found at https://scihub.copernicus.eu/userguide/DataRestoration. Instruction to manually download data from Copernicus Open Access Hub can be found at https://blogs.fu-berlin.de/reseda/esa-scihub/. You can also try to download the data via python package sentinelsat

[1]:
```
# connect to the API
from sentinelsat import SentinelAPI, read_geojson, geojson_to_wkt
from datetime import date
user = 'user'
password = 'password'
# initialize settings
api = SentinelAPI(user, password)
```

Search for available data

[2]:
```
# search by polygon (MNI test site coordinates), time, and SciHub query keywords
footprint = geojson_to_wkt(read_geojson('coordinates_mni.geojson'))
products = api.query(footprint,
                     date=('20210704', '20210708'),
                     platformname='Sentinel-1',
                     producttype='GRD')
print('Following products will be downloaded')
print(api.to_dataframe(products).title.values)

print('These {} product need {} Gb of disk space'.format(len(products), api.get_products_
↪size(products)))
```

```
INFO:sentinelsat.SentinelAPI:Found 2 products
```

```
Following products will be downloaded
['S1A_IW_GRDH_1SDV_20210707T051822_20210707T051847_038667_04901E_1B6B'
 'S1B_IW_GRDH_1SDV_20210706T052551_20210706T052616_027669_034D60_888E']
These 2 product need 3.28 Gb of disk space
```

Start download process (**Attention: might take a while and data will requries some free disk space**)

[3]:
```
# download all results from the search
# files will be downloaded to specified path
import os
path = os.path.expanduser('~/Desktop/data4')
try:
    os.makedirs(path)
except: FileExistsError
api.download_all(products, path)
```

```
INFO:sentinelsat.SentinelAPI:Will download 2 products using 4 workers
```

```
Downloading products:   0%|          | 0/2 [00:00<?, ?product/s]
```

```
Downloading S1B_IW_GRDH_1SDV_20210706T052551_20210706T052616_027669_034D60_888E.zip:   0
↪%|          | 0.00/986...
```

```
Downloading S1A_IW_GRDH_1SDV_20210707T051822_20210707T051847_038667_04901E_1B6B.zip:   0
↪%|          | 0.00/983...
```

```
MD5 checksumming:   0%|          | 0.00/986M [00:00<?, ?B/s]
```

```
MD5 checksumming:   0%|          | 0.00/983M [00:00<?, ?B/s]
```

[3]:
```
ResultTuple(downloaded={'ce796d52-4f70-48f0-87bf-d698ec372e9f': {'id': 'ce796d52-4f70-
↪48f0-87bf-d698ec372e9f', 'title': 'S1B_IW_GRDH_1SDV_20210706T052551_20210706T052616_
↪027669_034D60_888E', 'size': 986204913, 'md5': '56c6d22b25610fb30b01212d0b35101b',
↪'date': datetime.datetime(2021, 7, 6, 5, 25, 51, 753000), 'footprint': 'POLYGON((12.
↪682894 47.832607,9.216668 48.236717,9.567789 49.733212,13.138339 49.327972,12.682894␣
↪47.832607))', 'url': "https://apihub.copernicus.eu/apihub/odata/v1/Products('ce796d52-
↪4f70-48f0-87bf-d698ec372e9f')/$value", 'Online': True, 'Creation Date': datetime.
↪datetime(2021, 7, 6, 7, 26, 2, 888000), 'Ingestion Date': datetime.datetime(2021, 7, 6,
↪ 7, 24, 14, 101000), 'quicklook_url': "https://apihub.copernicus.eu/apihub/odata/v1/
↪Products('ce796d52-4f70-48f0-87bf-d698ec372e9f')/Products('Quicklook')/$value", 'path':
↪ '/home/test/Desktop/data4/S1B_IW_GRDH_1SDV_20210706T052551_20210706T052616_027669_
↪034D60_888E.zip', 'downloaded_bytes': 986204913}, 'caf75225-cb85-4410-81cd-ff6ef52256ed
↪': {'id': 'caf75225-cb85-4410-81cd-ff6ef52256ed', 'title': 'S1A_IW_GRDH_1SDV_
↪20210707T051822_20210707T051847_038667_04901E_1B6B', 'size': 983271059, 'md5':
↪'4ba73f80273607ea8106cce310ba4d93', 'date': datetime.datetime(2021, 7, 7, 5, 18, 22,␣
↪410000), 'footprint': 'POLYGON((14.717325 47.687527,11.218726 48.096413,11.575086 49.
↪592331,15.178372 49.182144,14.717325 47.687527))', 'url': "https://apihub.copernicus.
↪eu/apihub/odata/v1/Products('caf75225-cb85-4410-81cd-ff6ef52256ed')/$value", 'Online':␣
↪True, 'Creation Date': datetime.datetime(2021, 7, 7, 10, 32, 2, 46000), 'Ingestion Date
↪': datetime.datetime(2021, 7, 7, 10, 30, 11, 282000), 'quicklook_url': "https://apihub.
↪copernicus.eu/apihub/odata/v1/Products('caf75225-cb85-4410-81cd-ff6ef52256ed')/
↪Products('Quicklook')/$value", 'path': '/home/test/Desktop/data4/S1A_IW_GRDH_1SDV_
↪20210707T051822_20210707T051847_038667_04901E_1B6B.zip', 'downloaded_bytes': 983271059}
↪}, retrieval_triggered={}, failed={})
```

Option 2: Download data from NASA Earth Data Search

You can search for Sentinel-1 data at https://search.asf.alaska.edu/. A NASA EOSDIS Earthdata Login account is required for downloading data and tools from ASF. Registering for an Earthdata Login account is free (https://urs.earthdata.nasa.gov/home). Instructions how to download data from ASF can be found at https://asf.alaska.edu/wp-content/uploads/2019/02/asf_datarecipe_bulk_download_from_vertex_python_script_v1.pdf.

3. Use user defined xml graph to process Sentinel-1 data (test case with Sentinel-1 GRD product)

Set paths for

- input_folder (path to stored Sentinel-1 SLC data (zip files) e.g. "~/Downloads")
- output_folder (path where processed data will be stored e.g. "~/output")
- gpt_loction (gpt is located in the bin folder of your SNAP installation)'

[5]:
```
input_folder = path
output_folder = path
gpt_location = os.path.expanduser('~/snap/bin/gpt')
```

Create config file with information about input, output and gpt location

[6]:
```
import yaml

with open('sample_config_file.yaml') as stream:
   data = yaml.safe_load(stream)

data['input_folder'] = input_folder
data['output_folder'] = output_folder
data['gpt'] = gpt_location

with open('test_config_file.yaml', 'wb') as stream:
   yaml.safe_dump(data, stream, default_flow_style=False,
                  explicit_start=True, allow_unicode=True, encoding='utf-8')
```

Expert user might create their own processing chain and use the functionally of SenSARP to automate the processing on scale

1. Create a user defined xml graph via SNAP's Graph Builder
   - information how to use SNAP's Graph Builder can be found at the step forum (https://forum.step.esa.int/t/graph-builder/5403)
2. Modify user defined xml graph to be used by SenSARP
   - Needed modification
     - Placeholder for input image within xml graph need to be specified
     - Placeholder for output image within xml graph need to be specified
     - If subset operator is used within user defined xml graph a placeholder for subset extent need to be specified

Additional functionality of SenSARP that can be used with user defined xml graph

- Filter option (year, area of interest)
- default pre_process_step2 (co-registration of time series images)
- creation of netCDF4 stack containing all processed images and information about orbit direction, relative orbit, satellite name

Find and show xml parts that need to be changed

[7]:
```
# Load xml graph
import xml.etree.ElementTree as ETree
user_xml_graph = '/home/test/Desktop/sar-pre-processing/sar_pre_processing/user_defined_
↪graphs/example_of_expert_user.xml'
tree = ETree.parse(user_xml_graph)
root = tree.getroot()

# find Operators Read, Write and Subset
read = root.find("./node/[operator='Read']")
read2 = read.find("./parameters[@class='com.bc.ceres.binding.dom.XppDomElement']")
write = root.find("./node/[operator='Write']")
subset = root.find("./node/[operator='Subset']")

# Old Version of user defined xml graph
print(ETree.tostring(read, encoding='utf8').decode('utf8'))
```

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```
print(ETree.tostring(write, encoding='utf8').decode('utf8'))
print(ETree.tostring(subset, encoding='utf8').decode('utf8'))
```

```
<?xml version='1.0' encoding='utf8'?>
<node id="Read">
    <operator>Read</operator>
    <sources />
    <parameters class="com.bc.ceres.binding.dom.XppDomElement" />
  </node>

<?xml version='1.0' encoding='utf8'?>
<node id="Write">
    <operator>Write</operator>
    <sources>
      <sourceProduct refid="Subset" />
    </sources>
    <parameters class="com.bc.ceres.binding.dom.XppDomElement">
      <file>/home/wodan/target.dim</file>
      <formatName>BEAM-DIMAP</formatName>
    </parameters>
  </node>

<?xml version='1.0' encoding='utf8'?>
<node id="Subset">
    <operator>Subset</operator>
    <sources>
      <sourceProduct refid="Terrain-Correction" />
    </sources>
    <parameters class="com.bc.ceres.binding.dom.XppDomElement">
      <sourceBands />
      <region>0,0,0,0</region>
      <referenceBand />
      <geoRegion />
      <subSamplingX>1</subSamplingX>
      <subSamplingY>1</subSamplingY>
      <fullSwath>false</fullSwath>
      <tiePointGridNames />
      <copyMetadata>true</copyMetadata>
    </parameters>
  </node>
```

Modify xml parts so the xml-graph can be used by SenSARP

[8]:
```
#Apply changes to user defined xml graph
ETree.SubElement(read2, "file").text = "$input"
for output in write.iter('file'):
    output_new = '$output'
    output.text = output_new
for area in subset.iter('geoRegion'):
    area_new = '$area'
    area.text = area_new
```

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```
tree.write('/home/test/Desktop/sar-pre-processing/sar_pre_processing/user_defined_graphs/
↪example_of_expert_user_modi.xml')

# print modified version of operators Read, Write and Subset
print(ETree.tostring(read, encoding='utf8').decode('utf8'))
print(ETree.tostring(write, encoding='utf8').decode('utf8'))
print(ETree.tostring(subset, encoding='utf8').decode('utf8'))
```

```
<?xml version='1.0' encoding='utf8'?>
<node id="Read">
    <operator>Read</operator>
    <sources />
    <parameters class="com.bc.ceres.binding.dom.XppDomElement"><file>$input</file></
↪parameters>
  </node>

<?xml version='1.0' encoding='utf8'?>
<node id="Write">
    <operator>Write</operator>
    <sources>
      <sourceProduct refid="Subset" />
    </sources>
    <parameters class="com.bc.ceres.binding.dom.XppDomElement">
      <file>$output</file>
      <formatName>BEAM-DIMAP</formatName>
    </parameters>
  </node>

<?xml version='1.0' encoding='utf8'?>
<node id="Subset">
    <operator>Subset</operator>
    <sources>
      <sourceProduct refid="Terrain-Correction" />
    </sources>
    <parameters class="com.bc.ceres.binding.dom.XppDomElement">
      <sourceBands />
      <region>0,0,0,0</region>
      <referenceBand />
      <geoRegion>$area</geoRegion>
      <subSamplingX>1</subSamplingX>
      <subSamplingY>1</subSamplingY>
      <fullSwath>false</fullSwath>
      <tiePointGridNames />
      <copyMetadata>true</copyMetadata>
    </parameters>
  </node>
```

Set additional config options

[9]:
```
with open('test_config_file.yaml') as stream:
   data = yaml.safe_load(stream)
```

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```
# Filter option
## Filter via year of interest
data['year'] = '2021'

## Define region of interest
data['region']['lr']['lat'] = 48.2 # lower right latitude
data['region']['lr']['lon'] = 11.9 # lower right longitude
data['region']['ul']['lat'] = 48.4 # upper left latitude
data['region']['ul']['lon'] = 11.6 # upper left longitude
data['region']['subset'] = 'yes'

## Set options to use user defined xml graph
data['use_user_defined_graphs'] = 'yes'
data['xml_graph_path'] = '/home/test/Desktop/sar-pre-processing/sar_pre_processing/user_
↪defined_graphs'
data['pre_process_step1'] = 'example_of_expert_user_modi.xml'

with open('test_config_file.yaml', 'wb') as stream:
   yaml.safe_dump(data, stream, default_flow_style=False,
                  explicit_start=True, allow_unicode=True, encoding='utf-8')
```

Start pre-processing steps

[10]:
```
from sar_pre_processing.sar_pre_processor import *
import warnings
warnings.filterwarnings("ignore")

processing = SARPreProcessor(config='test_config_file.yaml')
processing.create_processing_file_list()
print('start step 1')
processing.pre_process_step1()
print('start step 2')
processing.pre_process_step2()
print('start step 3')
processing.pre_process_step3()
print('start add netcdf information')
processing.add_netcdf_information()
print('start create netcdf stack')
processing.create_netcdf_stack()
```

```
INFO:root:Found files within input folder: 2
INFO:root:Number of found files for year 2021: 2
INFO:root:area of interest not specified
INFO:root:Number of found files that were double processed: 0.0
INFO:root:Number of found files with border issues: 0
INFO:root:area of interest specified
INFO:root:normalisation angle not specified, default value of 35 is used for processing
INFO:ComponentProgress:0
INFO:ComponentProgress:0
INFO:root:Process S1A_IW_GRDH_1SDV_20210707T051822_20210707T051847_038667_04901E_1B6B.
↪zip with SNAP.
```

```
start step 1
```

```
INFO: org.esa.snap.core.gpf.operators.tooladapter.ToolAdapterIO: Initializing external␣
↪tool adapters
INFO: org.esa.s2tbx.dataio.gdal.GDALVersion: Incompatible GDAL 3.3.1 found on system.␣
↪Internal GDAL 3.0.0 from distribution will be used.
INFO: org.esa.s2tbx.dataio.gdal.GDALVersion: Internal GDAL 3.0.0 set to be used by SNAP.
INFO: org.esa.snap.core.util.EngineVersionCheckActivator: Please check regularly for new␣
↪updates for the best SNAP experience.
INFO: org.esa.s2tbx.dataio.gdal.GDALVersion: Internal GDAL 3.0.0 set to be used by SNAP.
```

```
Executing processing graph
```

```
INFO: org.hsqldb.persist.Logger: dataFileCache open start
WARNING: org.esa.s1tbx.sar.gpf.orbits.ApplyOrbitFileOp: No valid orbit file found for 07-
↪JUL-2021 05:17:13.000000
Orbit files may be downloaded from https://scihub.copernicus.eu/gnss/odata/v1/
and placed in /home/test/.snap/auxdata/Orbits/Sentinel-1/POEORB/S1A/2021/07
```

```
OpenSearch: https://scihub.copernicus.eu/gnss/search?q=platformname:Sentinel-1 AND␣
↪platformnumber:A AND producttype:AUX_RESORB AND beginposition:[2021-07-01T00:00:000Z␣
↪TO 2021-07-31T24:00:000Z]
OpenSearch: 35 total results on 1 pages.
OpenSearch: https://scihub.copernicus.eu/gnss/search?q=platformname:Sentinel-1 AND␣
↪platformnumber:A AND producttype:AUX_RESORB AND beginposition:[2021-07-01T00:00:000Z␣
↪TO 2021-07-31T24:00:000Z]
OpenSearch: https://scihub.copernicus.eu/gnss/search?q=platformname:Sentinel-1 AND␣
↪platformnumber:A AND producttype:AUX_RESORB AND beginposition:[2021-06-01T00:00:000Z␣
↪TO 2021-06-31T24:00:000Z]
OpenSearch: 0 total results on 1 pages.
```

```
WARNING: org.esa.s1tbx.sar.gpf.orbits.ApplyOrbitFileOp: ApplyOrbit ignoring error and␣
↪continuing: java.io.IOException: No valid orbit file found for 07-JUL-2021 05:17:13.
↪000000
Orbit files may be downloaded from https://scihub.copernicus.eu/gnss/odata/v1/
and placed in /home/test/.snap/auxdata/Orbits/Sentinel-1/POEORB/S1A/2021/07
```

```
version = 3.31
...10%...21%...33%...44%...54%...65%...77%...88%. done.
```

```
INFO:root:0
INFO:ComponentProgress:50
INFO:ComponentProgress:50
INFO:root:Process S1B_IW_GRDH_1SDV_20210706T052551_20210706T052616_027669_034D60_888E.
↪zip with SNAP.
INFO: org.esa.snap.core.gpf.operators.tooladapter.ToolAdapterIO: Initializing external␣
↪tool adapters
INFO: org.esa.s2tbx.dataio.gdal.GDALVersion: Incompatible GDAL 3.3.1 found on system.␣
↪Internal GDAL 3.0.0 from distribution will be used.
INFO: org.esa.s2tbx.dataio.gdal.GDALVersion: Internal GDAL 3.0.0 set to be used by SNAP.
INFO: org.esa.snap.core.util.EngineVersionCheckActivator: Please check regularly for new␣
↪updates for the best SNAP experience.
INFO: org.esa.s2tbx.dataio.gdal.GDALVersion: Internal GDAL 3.0.0 set to be used by SNAP.
```

```
Executing processing graph
```

```
INFO: org.hsqldb.persist.Logger: dataFileCache open start
WARNING: org.esa.s1tbx.sar.gpf.orbits.ApplyOrbitFileOp: No valid orbit file found for 06-
↪JUL-2021 05:24:42.000000
```

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```
Orbit files may be downloaded from https://scihub.copernicus.eu/gnss/odata/v1/
and placed in /home/test/.snap/auxdata/Orbits/Sentinel-1/POEORB/S1B/2021/07
```

```
OpenSearch: https://scihub.copernicus.eu/gnss/search?q=platformname:Sentinel-1 AND␣
↪platformnumber:B AND producttype:AUX_RESORB AND beginposition:[2021-07-01T00:00:000Z␣
↪TO 2021-07-31T24:00:000Z]
OpenSearch: 36 total results on 1 pages.
OpenSearch: https://scihub.copernicus.eu/gnss/search?q=platformname:Sentinel-1 AND␣
↪platformnumber:B AND producttype:AUX_RESORB AND beginposition:[2021-07-01T00:00:000Z␣
↪TO 2021-07-31T24:00:000Z]
OpenSearch: https://scihub.copernicus.eu/gnss/search?q=platformname:Sentinel-1 AND␣
↪platformnumber:B AND producttype:AUX_RESORB AND beginposition:[2021-06-01T00:00:000Z␣
↪TO 2021-06-31T24:00:000Z]
OpenSearch: 0 total results on 1 pages.
```

```
WARNING: org.esa.s1tbx.sar.gpf.orbits.ApplyOrbitFileOp: ApplyOrbit ignoring error and␣
↪continuing: java.io.IOException: No valid orbit file found for 06-JUL-2021 05:24:42.
↪000000
Orbit files may be downloaded from https://scihub.copernicus.eu/gnss/odata/v1/
and placed in /home/test/.snap/auxdata/Orbits/Sentinel-1/POEORB/S1B/2021/07
```

```
version = 3.31
...11%...23%...34%...46%...57%...69%...80%... done.
```

```
INFO:root:0
INFO:ComponentProgress:0
INFO:ComponentProgress:0
INFO:root:Scene 1 of 2
INFO:root:Process S1A_IW_GRDH_1SDV_20210707T051822_20210707T051847_038667_04901E_1B6B_GC_
↪RC_No_Su.dim with SNAP.
```

```
start step 2
```

```
INFO: org.esa.snap.core.gpf.operators.tooladapter.ToolAdapterIO: Initializing external␣
↪tool adapters
INFO: org.esa.s2tbx.dataio.gdal.GDALVersion: Incompatible GDAL 3.3.1 found on system.␣
↪Internal GDAL 3.0.0 from distribution will be used.
INFO: org.esa.s2tbx.dataio.gdal.GDALVersion: Internal GDAL 3.0.0 set to be used by SNAP.
INFO: org.esa.snap.core.util.EngineVersionCheckActivator: Please check regularly for new␣
↪updates for the best SNAP experience.
INFO: org.esa.s2tbx.dataio.gdal.GDALVersion: Internal GDAL 3.0.0 set to be used by SNAP.
```

```
Executing processing graph
```

```
INFO: org.hsqldb.persist.Logger: dataFileCache open start
```

```
...
```

```
14638 [main] INFO serverStartup - Nc4Iosp: NetCDF-4 C library loaded (jna_path='/home/
↪test/.snap/auxdata/netcdf_natives/8.0.5/amd64', libname='netcdf').
14676 [main] INFO serverStartup - NetcdfLoader: set log level: old=0 new=0
14676 [main] INFO serverStartup - Nc4Iosp: set log level: old=0 new=0
```

```
11%...22%...32%...43%...53%...64%...75%...85%..
```

```
-- org.jblas INFO Deleting /tmp/jblas4819000381521070295/libjblas.so
-- org.jblas INFO Deleting /tmp/jblas4819000381521070295/libgfortran-4.so
-- org.jblas INFO Deleting /tmp/jblas4819000381521070295/libjblas_arch_flavor.so
```

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```
-- org.jblas INFO Deleting /tmp/jblas4819000381521070295/libquadmath-0.so
-- org.jblas INFO Deleting /tmp/jblas4819000381521070295
INFO:root:0
INFO:root:2021-08-29 20:28:51.715338
INFO:ComponentProgress:50
INFO:ComponentProgress:50
INFO:root:Scene 2 of 2
INFO:root:Process S1B_IW_GRDH_1SDV_20210706T052551_20210706T052616_027669_034D60_888E_GC_
↪RC_No_Su.dim with SNAP.
```

```
 done.
```

```
INFO: org.esa.snap.core.gpf.operators.tooladapter.ToolAdapterIO: Initializing external␣
↪tool adapters
INFO: org.esa.s2tbx.dataio.gdal.GDALVersion: Incompatible GDAL 3.3.1 found on system.␣
↪Internal GDAL 3.0.0 from distribution will be used.
INFO: org.esa.s2tbx.dataio.gdal.GDALVersion: Internal GDAL 3.0.0 set to be used by SNAP.
INFO: org.esa.snap.core.util.EngineVersionCheckActivator: Please check regularly for new␣
↪updates for the best SNAP experience.
INFO: org.esa.s2tbx.dataio.gdal.GDALVersion: Internal GDAL 3.0.0 set to be used by SNAP.
```

```
Executing processing graph
```

```
INFO: org.hsqldb.persist.Logger: dataFileCache open start
INFO: org.esa.snap.core.datamodel.Product: raster width 3341 not equal to 3340
INFO: org.esa.snap.core.datamodel.Product: raster width 3341 not equal to 3340
```

```
...
```

```
14858 [main] INFO serverStartup - Nc4Iosp: NetCDF-4 C library loaded (jna_path='/home/
↪test/.snap/auxdata/netcdf_natives/8.0.5/amd64', libname='netcdf').
14895 [main] INFO serverStartup - NetcdfLoader: set log level: old=0 new=0
14895 [main] INFO serverStartup - Nc4Iosp: set log level: old=0 new=0
```

```
11%...22%...32%...43%...53%...64%...75%...85%.. done.
```

```
-- org.jblas INFO Deleting /tmp/jblas4294428937644417987/libjblas.so
-- org.jblas INFO Deleting /tmp/jblas4294428937644417987/libgfortran-4.so
-- org.jblas INFO Deleting /tmp/jblas4294428937644417987/libjblas_arch_flavor.so
-- org.jblas INFO Deleting /tmp/jblas4294428937644417987/libquadmath-0.so
-- org.jblas INFO Deleting /tmp/jblas4294428937644417987
INFO:root:0
INFO:root:2021-08-29 20:29:42.545034
INFO:root:combination of default multi temporal speckle filter and user defined graphs␣
↪is not supported yet
```

```
start step 3
start add netcdf information
```

```
INFO:root:Number of scenes found for processing: 2
```

```
start create netcdf stack

Scene 1 of 2
/home/test/Desktop/data4/step2/S1B_IW_GRDH_1SDV_20210706T052551_20210706T052616_027669_
↪034D60_888E_GC_RC_No_Su_Co.nc
```

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```
Scene 2 of 2
/home/test/Desktop/data4/step2/S1A_IW_GRDH_1SDV_20210707T051822_20210707T051847_038667_
↪04901E_1B6B_GC_RC_No_Su_Co.nc
```

4. View processed data

Load netcdf file with processed data

[11]:
```
import os
print(os.getcwd())
print(output_folder)
```

```
/home/test/Desktop/sar-pre-processing/docs/notebooks
/home/test/Desktop/data4
```

[12]:
```
from netCDF4 import Dataset
import numpy as np

my_example_nc_file = os.path.join(output_folder, 'data4.nc')
data = Dataset(my_example_nc_file, mode='r')
```

View information about dataset

[13]:
```
data
```

[13]:
```
<class 'netCDF4._netCDF4.Dataset'>
root group (NETCDF4 data model, file format HDF5):
    dimensions(sizes): lat(2227), lon(3341), time(2)
    variables(dimensions): float32 time(time), float32 orbitdirection(time), float32␣
↪relorbit(time), float32 satellite(time), float32 lat(lat), float32 lon(lon), float32␣
↪Sigma0_VH(time, lat, lon), float32 Sigma0_VV(time, lat, lon)
    groups:
```

Read data from netcdf file

[14]:
```
data.variables['orbitdirection'][:]
data.variables['time'][:]
lons = data.variables['lon'][:]
lats = data.variables['lat'][:]
data.variables.keys()
```

[14]:
```
dict_keys(['time', 'orbitdirection', 'relorbit', 'satellite', 'lat', 'lon', 'Sigma0_VH',
↪'Sigma0_VV'])
```

[15]:
```
vv = data.variables['Sigma0_VV'][:]
```

Close netcdf file

[16]:
```
data.close()
```

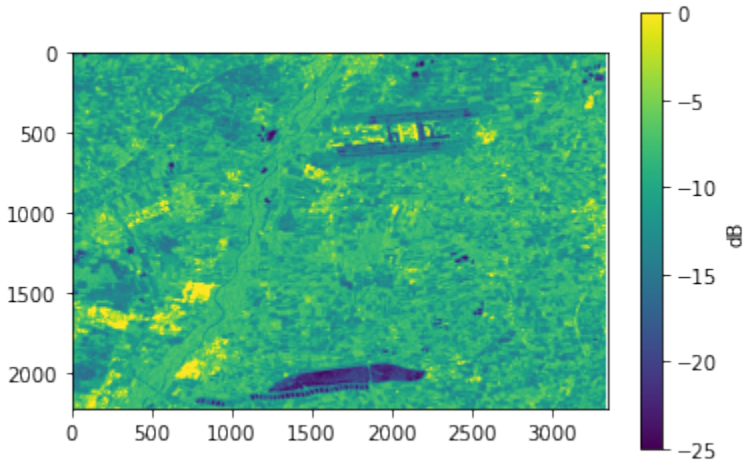
Plot vv polorized data

[17]:
```
%matplotlib inline
from ipywidgets import interactive
import matplotlib.pyplot as plt
import numpy as np

def f(x):
    # Problem: border pixel might be zero or negative
    # pixel eqal or smaller than zero are set to nan
    array = np.copy(vv[x])
    array[array <= 0] = np.nan
    # plot backscatter data in dB scale
    plt.imshow(10*np.log10(array))
    cbar = plt.colorbar()
    cbar.set_label('dB')
    plt.clim(-25, 0)

interactive_plot = interactive(f, x=(0,len(vv)-1))
interactive_plot
```

```
interactive(children=(IntSlider(value=0, description='x', max=1), Output()), _dom_
↪classes=('widget-interact',)...
```



1.3.4 Explanation of config file

```
# Sample config file
#====================
## Necessary parameters
#-----------------------
### Input folder with SAR data (zip format)
input_folder: '/media/test/Desktop/data' # values: string

### Output folder to store the pre-processed data
output_folder: '/media/test/Desktop/data' # values: string

### Location of SNAP's graph-processing-tool
gpt: /home/tweiss/snap/bin/gpt
```

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```
## Optional parameters
#-----------------------
### Year of interest (only images of the specified year will be processed)
#~~~~~~~~~~~~~~~~~~~
year: 2021 # values: integer

### Area of interest (only images containing the specified year will be processed)
#~~~~~~~~~~~~~~~~~~
region:
  subset: 'yes' # values: 'no' or 'yes'
  ul:
    lat: 48.40 # values: float
    lon: 11.60 # values: float
  lr:
    lat: 48.10 # values: float
    lon: 11.90 # values: float

### Used parameters of multi-temporal speckle filter
#~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
speckle_filter:
  multi_temporal:
    apply: 'yes' # values: 'no' or 'yes'
    files: '5' # values: integer

### Used parameter of incidence normalization (default angle is 35°)
#~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
normalisation_angle: 35 # values: float

### Single file processing (if filelist contains only one file single_file option is␣
↪automatically set to 'yes')
#~~~~~~~~~~~~~~~~~~~~~~~~
single_file: 'yes' # values: 'no' or 'yes'

### Usage of user defined xml graphs
#~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
#### Specification if user defined xml graph should be used
use_user_definde_graphs: 'no' # values: 'no' or 'yes'

#### Location of user defined xml files for processing
xml_graph_path: /media/test/Desktop/sar-pre-processing/sar_pre_processing/user_defined_
↪graphs

##### file names of user defined xml graphs
pre_process_step1: example_of_expert_user.xml
```

1.4 Default Pre-Processing Chain

The default pre-processing chain was developed to process Sentinel-1 SLC data to provide geometric and radiometric corrected Sigma nought backscatter values. Among other things the processed data can be used within different radiative transfer models (e.g. Integration Equation Model [1], Oh Model [2], [3], Dubois Model [4], Water Cloud Model [5], Single Scattering Radiative Transfer [6], [7]) to retrieve different land surface and/or vegetation parameters.

1.4.1 Overview

The different preprocessing steps are shown in Fig. 1.1 and Fig. 1.2. Additionally, every processing step is explained in more detail in the following subsections. As it can be seen in Fig. 1.1 and Fig. 1.2 the preprocessing work-flow is split in two main parts. The preprocessing methods in Fig. 1.1 can be applied separately for every image. Whereas the work-flow shown in Fig. 1.2 needs several images which were preprocessed by the different steps presented in Fig. 1.1.

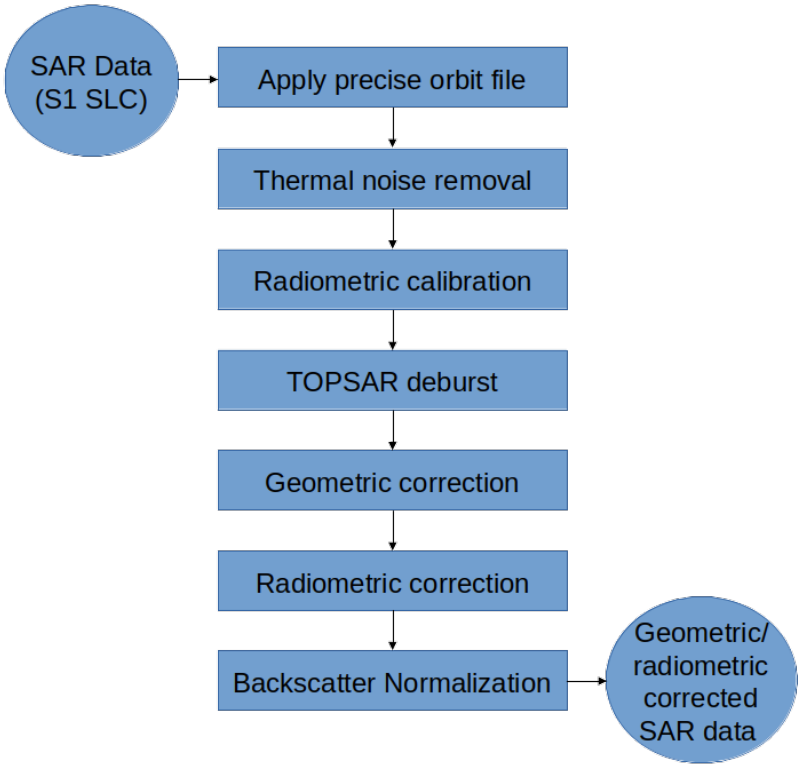

Fig. 1.1: Preprocessing chain showing processing steps to archive geometric and radiometric corrected Sentinel-1 data.

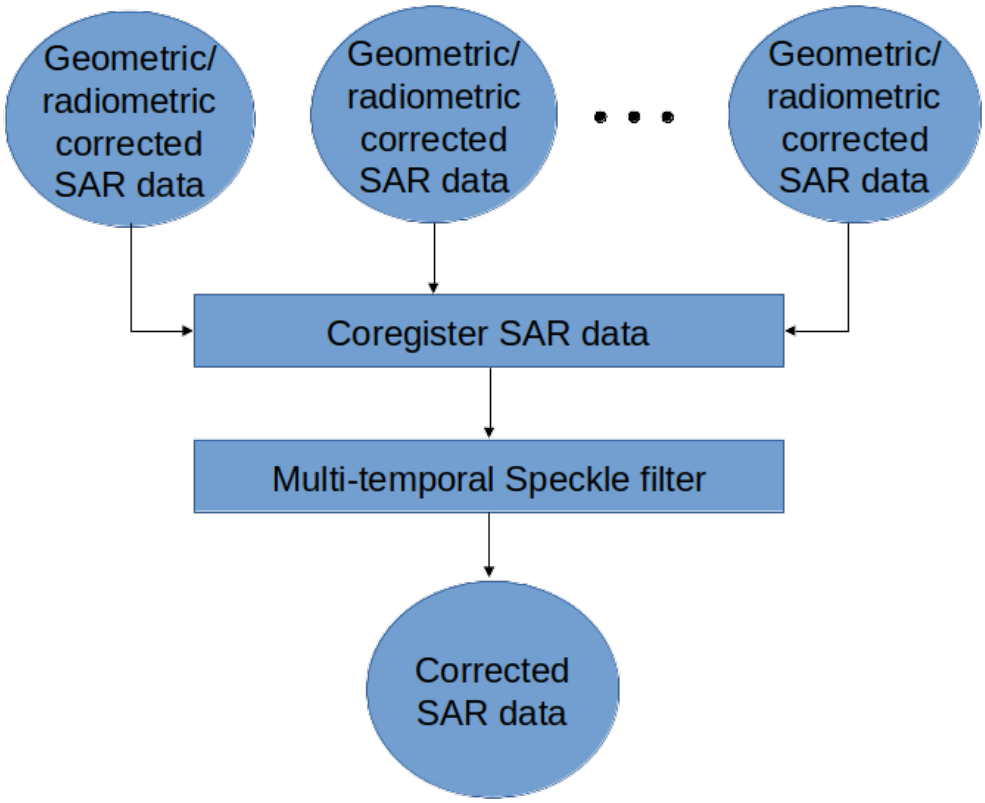

Fig. 1.2: Preprocessing chain showing processing steps to archive co-registered images which are multi-temporal speckle filtered

1.4.2 Sentinel-1 Level-1 SLC data

The preprocessing work-flow of Fig. 1.1 is based on Sentinel-1 Level-1 SLC data. Among some other sources Sentinel-1 data can be downloaded from ESA's Copernicus Open Access Hub (https://scihub.copernicus.eu/).

Sentinel-1 Level-1 SLC data are generated by the operational ESA Instrument Processing Facility (IPF). The SLC products are situated in slant range geometry. The slant range geometry is the natural radar one and is defined by the line-of-sight distance of the radar system to each reflecting object. The SLC product consists of focused SAR data in zero-Doppler orientation. Furthermore, for geo-referencing orbit and attitude information directly provided by the satellite are stored within the SLC product. Moreover the SAR data is corrected for errors caused by the well known azimuth bi-static delay, elevation antenna pattern and range spreading loss [8]. In contrary to Level-1 Ground Range Detected (GRD) products SLC data preserve the real and imaginary part of the backscatter signal and contain therefore also the phase information [8]. The IPF is generating SLC data for all available acquisition modes (StripMap (SM), Interferometric Wide (IW), Extra Wide (EW), and Wave (WV)) of the Sentinel-1 satellites. Further information about Sentinel-1 Level-1 products are gathered in ESA's Sentinel-1 User Handbook [8] available at https://earth.esa.int/documents/247904/685163/Sentinel-1_User_Handbook.

1.4.3 Precise orbit file

Theory / Purpose

During the acquisition of Sentinel-1 data the satellite position is recorded by a Global Navigation Satellite System (GNSS). To assure a fast delivery of Sentinel-1 products orbit information generated by an on-board navigation solution are stored within the Sentinel-1 Level-1 products. The orbit positions are later refined and made available as restituted or precise orbit files by the Copernicus Precise Orbit Determination (POD) Service. The POD products for Sentinel-1 data with given accuracy and availability after data acquisition are listed in Table 1.1.

Table 1.1: Accuracy specification for Sentinel-1 POD products [9]

Mission	POD Product	Accuracy	Latency
Sentinel-1	Restituted Orbit File	< 10 cm	3 hours
	Precise Orbit Ephemerides (POE) Orbit file	< 5 cm	20 days
	Attitude Restituted Data	< 0.005 deg	20 days

Precise orbit information can have a high influence on the quality of several preprocessing steps especially e.g. for the geo-referencing of the data. Therefore, it is always preferable to use the most accurate orbit information that is available.

Practical implementation

Since the preprocessing for the MULTIPLY project doesn't depend on near-real-time data the precise orbit file (available within 20 days) is used to update the orbit and velocity information within the Sentinel-1 SLC product. Therefore the operator "Apply Orbit Correction" of SNAP S1TBX toolbox is used.

Input:

- Sentinel-1 SLC IW image (downloaded from Copernicus Open Access Hub)
- Precise orbit file (automatic download by SNAP S1TBX)

Output:

- Sentinel-1 SLC IW image with updated orbit information

1.4.4 Thermal noise removal

Theory / Purpose

Thermal noise is caused by the background energy of a SAR receiver and independent from the received signal power. Like some other noise factors thermal noise appears randomly over the entire image. But in contrary to quantization noise like speckle, which is connected to the signal power, thermal noise is hardly noticeable. Therefore, high impact of thermal noise on the quality of the data is especially given in areas like calm lakes, rivers and other with a low mean signal response detected by the SAR system. For the purpose of correction the IPF is calculating a thermal noise Look up Table (LUT) which is stored within the Sentinel-1 Level-1 product. More information about the calculation of the thermal noise for Sentinel-1 is given in [10].

Practical implementation

The "Thermal Noise Removal" operator of SNAP S1TBX software is used to remove the thermal noise which is stored within a LUT within Sentinel-1 Level-1 products. Thermal noise removal can only applied on backscatter intensity therefore the phase information of the SLC data get lost.

Input:

- Sentinel-1 SLC IW image with updated orbit information

Output:

- Sentinel-1 SLC Intensity corrected by thermal noise

1.4.5 Radiometric calibration

Theory / Purpose

Sentinel-1 Level-1 products are not radiometric corrected by default. However, for the quantitative use of SAR images a radiometric calibration of radar reflectivity (stored as Digital Numbers (DN) within Sentinel-1 Level-1 products) to physical units (radar backscatter) is essential. Otherwise a comparison of SAR images from different sensors or even the same sensor for different acquisition dates or different acquisition modes is not possible. To apply a radiometric calibration a Calibration Annotation Data Set (CADS) with four Look Up Tables (LUTs) are provided within the Sentinel-1 Level-1 products by Sentinel-1 Instrument Processing Facility (IPF). The four LUTs are used to convert DN to sigma naught, beta naught and gamma or vice versa. More information about the radiometric calibration is given in [11].

Practical implementation

The "Radiometric Calibration" operator of SNAP S1TBX software is used to perform the conversion of DN to radar backscatter. In our case the output radar backscatter information is calibrated in Sigma naught.

Input:

- Sentinel-1 SLC Intensity corrected by thermal noise

Output:

- Sigma naught calibrated radar backscatter

1.4.6 TOPSAR Deburst

Theory / Purpose

Sentinel-1 Level-1 SLC images acquired in IW or EW swath mode consists of one image per swath and polarisation. IW products are made up of three swaths which means three images for single polarisation and six images for dual polarisation. EW products are made up of five swaths which means five images for single polarisation and ten images for dual polarisation. The sub-swath images consists of different bursts which are all processed as separate images. The different bursts are stored in one single image whereby each burst is separated by a black-filled demarcation [8]. For the usage of Sentinel-1 Level-1 SLC data only one sub-swath can be extracted or several/all sub-swath can be combined to one image with fluent transitions between the sub-swaths. More detailed information are provided in [8], [12] and [13].

Practical implementation

The "TOPSAR-Deburst" operator of SNAP S1TBX software is used to merge all sub-swath to retrieve one fluent image.

Input:

- Sigma naught calibrated radar backscatter (with different sub-swath)

Output:

- Sigma naught calibrated radar backscatter (with fluent transitions)

1.4.7 Geometric correction

Theory / Purpose

An important part of the preprocessing chain is the geometric terrain correction. The geometric correction is a conversion of the Sentinel-1 SLC data from slant range geometry into a map coordinate system. Due to the acquisition geometry of the SAR different topographical distortions like foreshortening, layover or shadowing effects occur. The appropriate way to correct these distortions is the Range-Doppler approach. The method needs information about the topography (normally provided by a Digital Elevation Model (DEM)) as well as orbit and velocity information from the satellite (stored within Sentinel-1 SLC product) to correct the mentioned distortions and derive a precise geolocation for each pixel of the image.

Practical implementation

A geometric correction of the input data is performed by using the "Range Doppler Terrain Correction" method implement in SNAP's S1TBX software. Data from the Shuttle Radar Topography Mission (SRTM) with a resolution of 1-arc second (30 meters) is used for the necessary DEM.

Input:

- Sigma naught calibrated radar backscatter (with fluent transitions)
- SRTM data with 1-arc second resolution (automatic download by SNAP S1TBX)

Output:

- Geometric corrected sigma naught calibrated radar backscatter (Map Projection WGS84)
- Incidence angle from ellipsoid
- Local incidence angle (based on SRTM)

1.4.8 Radiometric correction

Theory / Purpose

For the conversion of Sentinel-1 backscatter values to sigma or gamma naught, LUT's stored within the Sentinel-1 product are used (see *Radiometric calibration*). For the creation of the LUT's Sentinel-1 IPF is using an incidence angle of an ellipsoid inflated earth model [11]. Therefore, the local terrain variation within the image and their radiometric impact on the backscatter is considered insufficiently. A simple and widely used practice to consider the radiometric impact due to local terrain variations represents the approach to use the local incidence angle instead of the ellipsoid one [14]. The radiometric corrected backscatter σ^0_{NORLIM} used by kellndorfer_toward_1998 et al. [14] can be calculated as

$$\sigma^0_{NORLIM} = \sigma_{Ell} \frac{sin\theta_{LIA}}{sin\theta_{Ell}} \tag{1.1}$$

with θ_{LIA} as the local incidence angle, θ_{Ell} as the ellipsoid incidence angle used by IPF and the radar backscatter σ_{Ell} calculated by using LUT's provided by IPF.

Practical implementation

Within the "Range Doppler Terrain Correction" method of SNAP's S1TBX software the radiometric normalisation approach of kellndorfer_toward_1998 et al. [14] is implemented as a additional option. Unfortunately, the SNAP internal option can not be used with our kind of data. Therefore, normalisation after kellndorfer_toward_1998 et al [14] is done by coding the equations within the "BandMath" operator of SNAP's S1TBX. The used local incidence angle is provided by the previous applied "Range Doppler Terrain Correction" and therefore the local incidence angle is based on the SRTM data.

Input:

- Geometric corrected sigma naught calibrated radar backscatter (Map Projection WGS84)
- Incidence angle from ellipsoid
- Local incidence angle (based on SRTM)

Output:

- Radiometric and geometric corrected sigma naught calibrated radar backscatter (Map Projection WGS84)

1.4.9 Backscatter normalisation

Theory / Purpose

Beside the previously discussed geometric and radiometric distortions some other specific backscattering coefficient variations within the range direction of the image are caused by the image geometry of the SAR sensor. The backscattered energy of an illuminated area has not only a dependency on the area itself but also on the incidence angle. This means, backscatter values of a specific area with a small incidence angle return higher backscatter values then data of the same area acquired with a higher incidence angle. Incidence angle induced variations not only occur inside one image but also between images form different sensors as well as within one sensor through different acquisition geometries or different tracks or orbits. For a usage of Sentinel-1A and 1B time-series acquired with different orbits and/or different tracks and therefore most likly a high change between the incidence angles a backscatter normalisation is vital. A often and widely used technique to minimize backscatter variations caused by the incidence angle is the cosine correction [15]. The cosine correction is based on the Lambert's law for optics. Therefore, under the assumption that the backscattered energy in the upper hemisphere follows a cosine law and also the radiation variability has a cosine dependency, the received backscatter $\sigma^0_{\theta_i}$ and its dependency on the incidence angle can be written as

$$\sigma^0_{\theta_i} = \sigma^0_0 cos^n(\theta_i) \tag{1.2}$$

with a weighting factor n and the incidence angle independent backscatter σ_0^0. With the cosine correction the backscatter of the Sentinel-1 products can therefore normalised to a reference angle θ_{ref} with

$$\sigma_{ref}^0 = \frac{\sigma_{\theta_i}^0 cos^n(\theta_{ref})}{cos_{\theta_i}^n} \tag{1.3}$$

Studies show that the weighting factor n is dependent on the roughness [16] and therefore the backscatter variations can vary with different land cover types. A schematic illustration of the backscatter variations considering the incidence angle is given in Fig. 1.3.

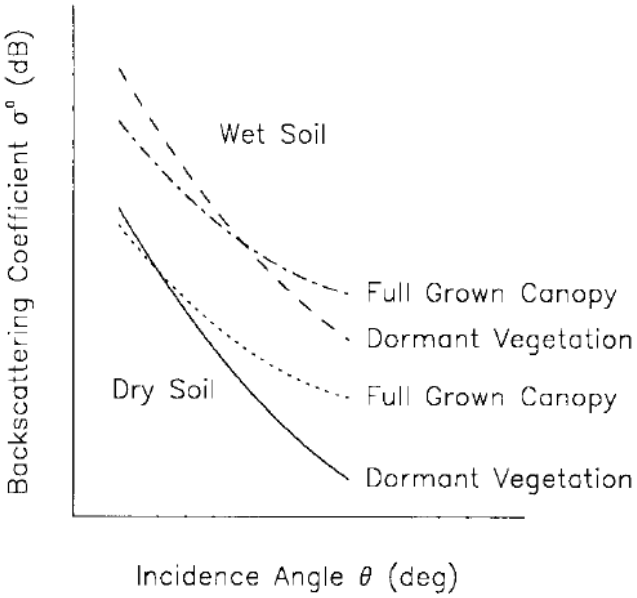

Fig. 1.3: Illustration of the backscatter variations considering the incidence angle dependency [17].

Practical implementation

The backscatter normlisation is applied by coding (1.3) in SNAP's S1TBX operator "BandMaths". As default a reference angle of 37,55° (average incidence angle for IW swath mode [10]) and a weighting factor of 2 (standard value) is specified. Through a configuration file the user can replace the default values for the reference angle and weighting factor to probably more suitable values of their specific applications.

Input:

- Radiometric and geometric corrected sigma naught calibrated radar backscatter (Map Projection WGS84)
- reference angle (default is 35°)
- weighting factor (default is 2)

Output:

- Radiometric and geometric corrected sigma naught calibrated radar backscatter values normalised to reference angle (Map Projection WGS84)

1.4.10 Co-registration

Theory / Purpose

For time-series analysis especially when applying a *Multi-temporal speckle filter* the SAR image has to be co-registered. The co-registration is a method to get every image of the time-series on the same grid and also the pixel resolution.

Practical implementation

The co-registration as a requirement for the *Multi-temporal speckle filter* is accomplished by the "Co-Registration" operator within SNAP's S1TBX. The "Co-Registration" operator in SNAP is defined as a completely automatic process. The operator consists of a stack creation (collocating master and slave image), a cross correlation (allignment between master ans slave image) and a warp (resamples pixels from the slave image to pixels of the master image).

Input:

- Master image
- Slave image(s)

Output:

- Co-registered images

1.4.11 Multi-temporal speckle filter

Theory / Purpose

A characteristic of images acquired by a SAR system is the visibility of random noise which look like "salt and pepper" within the image and is called speckle. The appearance of speckle is caused by the interferences of coherent echoes from individual scatterers within one pixel [18].The presence of speckle degrades the quality of the image and therefore it makes the interpretation of the SAR data more difficult. Over the years several approaches for speckle reduction were developed. They are mainly based on either multi-looking or filtering methods. Different filtering approaches like Frost, Lee etc. can be applied as a single or multi-temporal speckle filter. First findings with Sentinel-1 data show that a multi-temporal speckle filter provides better results in form of speckle reduction and resolution preservation then a single speckle filter. A major advantage for the usage of a multi-temporal speckle filter on Sentinel-1 data is the high temporal resolution availability. Nevertheless, more detailed studies on analysing the impact of different multi-temporal speckle filters on the retrieval of bio- and geophysical parameters from Sentinel-1 data are still lacking. Anyway, a usage of a multi-temporal filter significantly reduces the speckle and is therefore a essentinal part of our preprocessing chain.

Practical implementation

For the speckle reduction the "Multi-temporal Speckle Filter" operator within SNAP's S1TBX software is used. As default, 7 temporally consecutive images are used within the "Multi-temporal Speckle Filter" whereby the target image is temporally situated in the middle. The applied filter is a Lee filter with a spatial window size of 5x5 pixels, a sigma of 0.9, and a target window size of 3x3 pixels. The spatial averaging over pixel has a significant influence on spatial resolution information loss of the image. Therefore, the averaging pixel size might change during the project. If the image consists of two polarisations the filter is applied on each polarisation separately. The practical implementation in case of filter type, used polarisation, number of used images etc. may change with more experience of applying multi-temporal speckle filters and the occurring results.

Input:

- x co-registered images (can be specified within configuration file)

Output:

- speckle filtered images

1.4.12 Folder and data creation during pre-processing steps

Creation of

- **step1 (folder)**
  - temporary results after applying processing steps shown in Fig. 1.1
- **step2 (folder)**
  - co-registered images of step1
- **step3 (folder)**
  - final results
- foldername.nc (final netcdf stack file)

within specified output folder (config file)

1.4.13 Output layers of final netcdf stack file

Output layer of default pre-processing chain

- theta (local incidence angle)
- sigma0_vv_single (single speckle filtered radiometric and geometric corrected sigma nought backscatter)
- sigma0_vh_single (single speckle filtered radiometric and geometric corrected sigma nought backscatter)
- sigma0_vv_multi (multi speckle filtered radiometric and geometric corrected sigma nought backscatter)
- sigma0_vh_multi (multi speckle filtered radiometric and geometric corrected sigma nought backscatter)
- sigma0_vv_norm_single (single speckle filtered radiometric and geometric corrected sigma nought backscatter normalized to a specific incidence angle)
- sigma0_vh_norm_single (single speckle filtered radiometric and geometric corrected sigma nought backscatter normalized to a specific incidence angle)
- sigma0_vv_norm_single (multi speckle filtered radiometric and geometric corrected sigma nought backscatter normalized to a specific incidence angle)
- sigma0_vh_norm_single (multi speckle filtered radiometric and geometric corrected sigma nought backscatter normalized to a specific incidence angle)

1.4.14 Abbreviations and values within netcdf stack file

Abbreviation within variable names

- theta = local incidence angle
- sigma0 = radiometric and geometric corrected sigma nought backscatter
- vv = VV polarization
- vh = VH polarization

- single = single speckle filter was applied
- multi = multitemporal speckle filtered
- norm = backscatter was normalized to a specific incidence angle

Values of specific variables

- **orbitdirection**
  - 0 = Ascending
  - 1 = Descending
- **relorbit**
  - number of relative orbit
- **satellite**
  - 0 = Sentinel-1 A
  - 1 = Sentinel-1 B
- **name tags of processed data**
  - theta (local incidence angle)
  - sigma0 (radiometric and geometric corrected sigma nought backscatter)
  - vv (polarization vv)
  - vh (polarization vh)
  - single (single speckle filtered)
  - multi (multi temporal speckle filtered)
  - norm (backscatter normalized to a specific incidence angle)

References

1.5 Technical documentation

1.5.1 Sar-Pre-Processing

Wrapper module to launch preprocessor

class sar_pre_processing.sar_pre_processor.**PreProcessor**(***kwargs*)
Bases: object

static pre_process()

class sar_pre_processing.sar_pre_processor.**SARPreProcessor**(***kwargs*)
Bases: *sar_pre_processing.sar_pre_processor.PreProcessor*

add_netcdf_information()
Add information from original S1 image to processed NetCDF file. - update date information (wrong date information were stored due to coregistration process) - orbitdirection (ASCENDING, DESCENDING) - relative orbit - Satellite (S1A, S1B) - Frequency

create_netcdf_stack(*filename: Optional[str] = None*)
create one NetCDF stack file of pre-processed data Orbitdirection: '0 = Ascending, 1 = Descending' Satellite: '0 = Sentinel 1A, 1 = Sentinel 1B'

create_processing_file_list()
create a list with all to be processed file names

pre_process_step1()
Pre-process Sentinel-1 data - Default processing chain of SenSARP:

Pre-process S1 SLC data with SNAP's GPT

1) apply precise orbit file
2) thermal noise removal
3) calibration
4) TOPSAR-Deburst
5) Geometric Terrain Correction
6) Radiometric Correction (after kellndorfer et al.)
7) backscatter normalisation on specified angle in config file (based on Lambert's Law)

Output layers:

- longitude
- latitude
- localIncidenceAngle
- projectedLocalIncidenceAngle
- incidenceAngleFromEllipsoid
- elevation
- Sigma0_VV (VV-polarized Sigma nought backscatter no radiometric correction applied)
- Sigma0_VH (VH-polarized Sigma nought backscatter no radiometric correction applied)
- sigma0_vv_kelln (VV-polarized Sigma nought backscatter including radiometric correction after Kellndorfer)
- sigma0_vh (VH-polarized Sigma nought backscatter including radiometric correction after Kellndorfer)
- sigma0_vv_kelln_normalisation (VV-polarized Sigma nought backscatter including radiometric correction after Kellndorfer and normalization to one specific incidence angle)
- sigma0_vh_kelln_normalisation (VH-polarized Sigma nought backscatter including radiometric correction after Kellndorfer and normalization to one specific incidence angle)

- use processing chain of expert user

pre_process_step2()
pre_process_step1 has to be done first

pre_process_step2 only useful for processing time series data

1) co-register pre-processed data

!!! all files will get metadata of the master image !!! That is how SNAP does it! Metadata will be corrected within netcdf output files at the end of the preprocessing chain (def add_netcdf_information)

pre_process_step3()
pre_process_step1 and/or 2 has to be done first

processing time series data:

- apply multi-temporal speckle filter and single speckle filter

processing single image:

- apply single speckle filter

Output layers:

- theta (local incidence angle)
- sigma0_vv_single (single speckle filtered radiometric and geometric corrected sigma nought backscatter)
- sigma0_vh_single (single speckle filtered radiometric and geometric corrected sigma nought backscatter)
- sigma0_vv_multi (multi speckle filtered radiometric and geometric corrected sigma nought backscatter)
- sigma0_vh_multi (multi speckle filtered radiometric and geometric corrected sigma nought backscatter)
- sigma0_vv_norm_single (single speckle filtered radiometric and geometric corrected sigma nought backscatter normalized to a specific incidence angle)
- sigma0_vh_norm_single (single speckle filtered radiometric and geometric corrected sigma nought backscatter normalized to a specific incidence angle)
- sigma0_vv_norm_single (multi speckle filtered radiometric and geometric corrected sigma nought backscatter normalized to a specific incidence angle)
- sigma0_vh_norm_single (multi speckle filtered radiometric and geometric corrected sigma nought backscatter normalized to a specific incidence angle)

1.5.2 File list for Sar-Pre-Processing

Create List of SAR data which will be processed by sar_pre_processer module

class sar_pre_processing.file_list_sar_pre_processing.**SARList**(***kwargs*)
Bases: object

Object for creation of file list for preprocessing of Sentinel-1 data based on configuration file

create_list(***kwargs*)
Create file list for further processing

Filter option via config file - year - area of interest

Checking for

- double processed data by ESA
- area of interest contained in two tiles of same swath

1.5.3 netcdf-stack

class sar_pre_processing.netcdf_stack.**NetcdfStackCreator**(**kwargs)
Bases: object

Create NetCDF stack

create_netcdf_stack()

stacking()
stack all files into a new netcdf file created by function _create_empty_netcef_file

1.5.4 Attribute Dict

class sar_pre_processing.attribute_dict.**AttributeDict**(**entries)
Bases: object

A class to convert a nested Dictionary into an object with key-values accessibly using attribute notation (AttributeDict.attribute) instead of key notation (Dict["key"]). This class recursively sets Dicts to objects, allowing you to recurse down nested dicts (like: AttributeDict.attr.attr)

add_entries(**entries)

add_entry(*key*, *value*)

has_entry(*key*)

1.6 Authors

- Thomas weiß <"weiss.thomas@lmu.de">
- Tonio Fincke <"tonio.fincke@brockmann-consult.de">

1.7 Change Log SenSARP

1.7.1 [0.1] - 2021-04-20

initial version

1.7.2 [0.2] - 2022-01-18 (JOSS Paper)

JOSS Paper

- extensive revision

Documentation

- add installation guide using virtualenv and pip
- revise introduction
- add Statement of need
- add explanations of created files and used abbreviations
- name change from "MULTIPLY SAR pre-processing" to "SenSARP"
- **add notebooks (use cases)**
  - default_process_single_image.ipynb
  - default_process_time_series.ipynb
  - use_user_defined_graphs.ipynb
- remove notebook running_test_application.ipynb

Software

- add more explanation to config file
- add more documentation to functions of class SARPreProcessor
- add functionality that to user defined xml-graphs can be used
- add functionality that a single file can be processed
- class NetcdfStackCreator was partly rewritten
- functionality of shell file (solve_projection_problem.sh) was included within python code
- bug fixes

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Version 3, 29 June 2007

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CHAPTER

TWO

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The project leading to this application has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 687320.

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