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Sentinels for Agricultural Statistics

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Document sheet

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Detailed record sheet

From version 1.0 to 1.x

Comment	Section	Problem description	Change

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Acronyms

Acronym	Definition
AD	Applicable Document
ATBD	Algorithm Theoretical Basis Document
BOA	Bottom-Of-Atmosphere
CADS	Calibration Annotation Data Set
DDF	Design Definition File
DEM	Digital Elevation Model
DN	Digital Number
EO	Earth Observation
ESA	European Space Agency
EW	Extra Wideswath
Fmask	Function of mask
GPF	Graph Processing Framework
IW	Interferometric Wide Swath
L1, L2, L2A, L3, L4	Level 1, Level 2, Level 2A, Level 3, Level 4
L8	Landsat-8
LaSRC	Land Surface Reflectance Code
LUT	Look-Up Table
MSI	Multi-Spectral Instrument
MTSF	Multi-Temporal Speckle Filtering
NIR	Near Infrared
OSV	Orbit State Vector
OTB	Orfeo Toolbox
S1 (S1A, S1B)	Sentinel-1 (A and B)
S2 (S2A, S2B)	Sentinel-2 (A and B)
SAR	Synthetic Aperture Radar

SC	Scene Classification
Sen4Stat	Sentinels for Agricultural Statistics
SLC	Single Look Complex
SM	StripMap
SNAP	Sentinel Application Platform
SWIR	ShortWave Infrared
TIR	Thermal Infrared
TOA	Top-Of-Atmosphere
UTM	Universal Transverse Mercator
WV	WaveMode

1 Logical model and processor overview

The "Earth Observation (EO) Data Pre-Processing" processor will carry out the pre-processing for all EO data supported by the Sen4Stat system: Sentinel-2 (S2), Landsat 8 (L8) and Sentinel-1 (S1). The possibility to also support Planet data will be further discussed in the project.

For optical sensors, the pre-processing will allow generating a cloud mask to be applied on the Sen2Cor Level 2A (L2A) images automatically produced by the European Space Agency (ESA) and available on the ESA SciHub and on most of the cloud providers. For the Synthetic Aperture Radar (SAR) sensors, the processor will transform the Level 1 (L1) products and into backscatter and coherence products (Figure 1-1). The following sections of this document detail the pre-processing chain for each sensor.

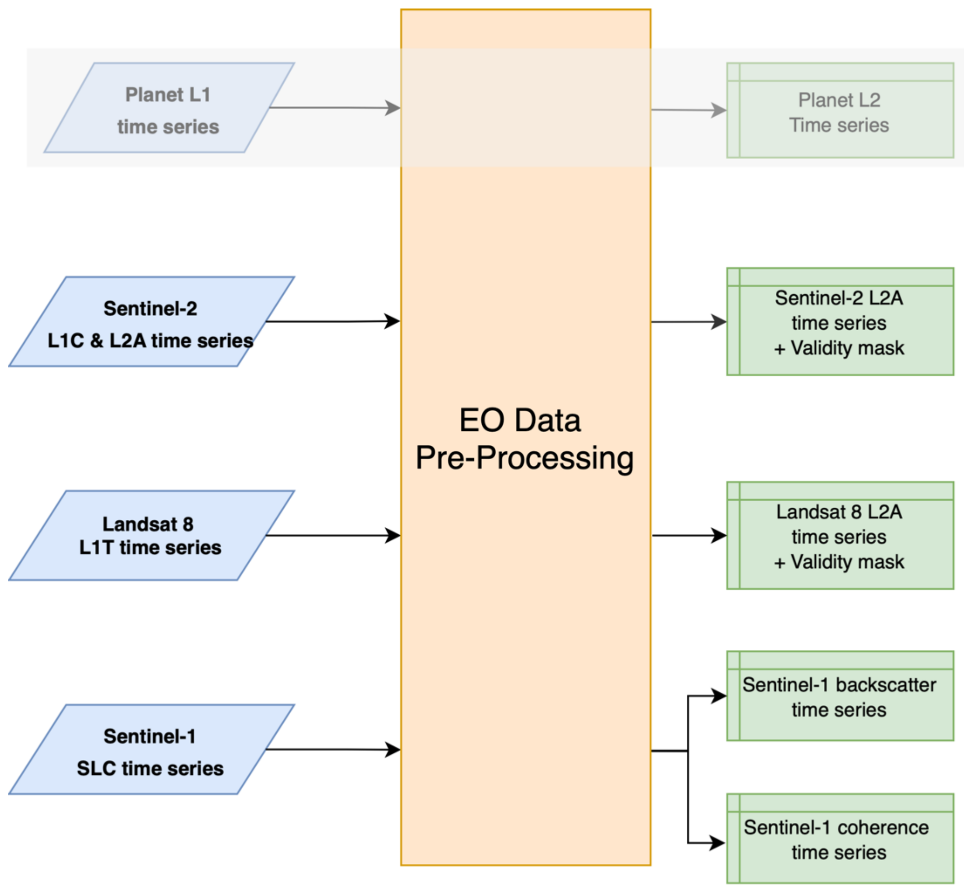

Figure 1-1. Workflow of the EO Data Pre-Processing

2 Input data

2.1 Optical data

The optical data supported by the Sen4Stat system are the following ones:

- S2 L1C and L2A;
- L8 L1T;
- Planet (to be confirmed).

S2 is the main optical sensor of the Sen4Stat system. Building on the Landsat and Spot missions' legacy, the S2 satellite constellation and its Multi-Spectral Instrument (MSI) were designed in the framework of the European Copernicus program for land surface and agriculture monitoring to measure the reflected solar spectral reflectance in 13 bands ranging from the visible to the ShortWave Infrared (SWIR) bands. The spectral bands include three narrow bands for cloud screening and atmospheric correction at 60 m, three red-edge bands providing key information about vegetation and two SWIR bands at 20 m, as well as the classical blue, green, red and near infrared (NIR) bands at 10 m[1, 2]. Since late 2015, the Sentinel-2A (S2A) satellite provides a revisit time of 10 days over Europe and Africa and of 20 days elsewhere while the successful launch of Sentinel-2B (S2B) in March 2017 insure a 5-day revisit time above all lands since December 2017.

L8 images can also be used to complement S2 data. L8 images have a spatial resolution of 30 meters and a repetitively of 16 bands. The spectral bands include deep blue, blue, green, red, NIR, SWIR1, SWIR2, cirrus, thermal infrared (TIR) 1, TIR 2 channels.

In a future version, the support of **Planet** imagery could be foreseen.

2.2 Synthetic Aperture Radar data

SAR data are provided by S1 satellite. First new space component of the European Copernicus missions, S1 is a polar-orbiting, all-weather, day-and-night SAR imaging mission performing C-band SAR imaging for land and ocean services. In order to achieve a short 6-day revisit time, it is composed of a constellation of two satellites, Sentinel-1A (S1A) and Sentinel-1B (S1B), successfully launched in 2014 and 2016 respectively. Both satellite units, S1A and S1B, fly in a quasi-polar, sun-synchronized (dawn–dusk) orbit at 693 km altitude, and in the same orbital plane 180° out of phase with each other[3, 4]. Four nominal operation modes are available: the StripMap (SM), the Interferometric Wideswath (IW), the Extra Wideswath (EW) and the Wave Mode (WV). All modes except WV are operated in dual polarization, realized by two separate receiving channels within the instrument[5]. In Sen4Stat, only the IW Single Look Complex (SLC) products are used because they preserve the real and imaginary part of the backscatter signal and contain therefore also the phase information which is essential for coherence computation.

[1] Drusch, M. et al. 2012. Sentinel-2: ESA's Optical High-Resolution Mission for GMES Operational Services. *Remote Sensing of Environment*, 120:25–36
[2] Gascon, F. et al. 2017. Copernicus Sentinel-2A Calibration and Products Validation Status. *Remote Sensing*, 9:584
[3] Torres, R. et al. 2012. GMES Sentinel-1 mission. *Remote Sensing of Environment*, 120:9–24
[4] Geudtner, D. et al. 2012. Sentinel-1 System Overview. In Proceedings of the 9th European Conference on Synthetic Aperture Radar, Nürnberg, Germany, 23–26 April 2012; pp. 159–161
[5] Schwerdt, M. et al. 2017. Independent System Calibration of Sentinel-1B. *Remote Sensing*, 9:511

3 Detailed workflow

3.1 Sentinel-2 pre-processing

S2 pre-processing consists in:

- generating a validity mask to identify invalid pixels for each image;
- applying the atmospheric correction to transform Top-Of-Atmosphere (TOA) (L1C) into Bottom-Of-Atmosphere (BOA) (L2A) reflectance.

The atmospheric correction does not need to be applied by the Sen4Stat system since the Sen2Cor L2A images are automatically produced by the ESA and available on the ESA SciHub and on most of the cloud providers. The Sen2Cor L2A images also include a Scene Classification (SC) mask, identifying the cloud, cloud shadows, snow, water, vegetation and invalid pixels. Since the quality of the cloud detection has been found not good enough, an external cloud detection algorithm is embedded in the Sen4Stat system, which relies on the Function of mask (Fmask) 4.2 algorithm[6]. Fmask is used for automated masking of clouds, cloud shadows, snow, and water for Landsat 4-8 and S2 images. The overall workflow is illustrated in Figure 3-1. Input and output data are presented in Table 3-1. The FMask parameters are shown in

Table 3-2.

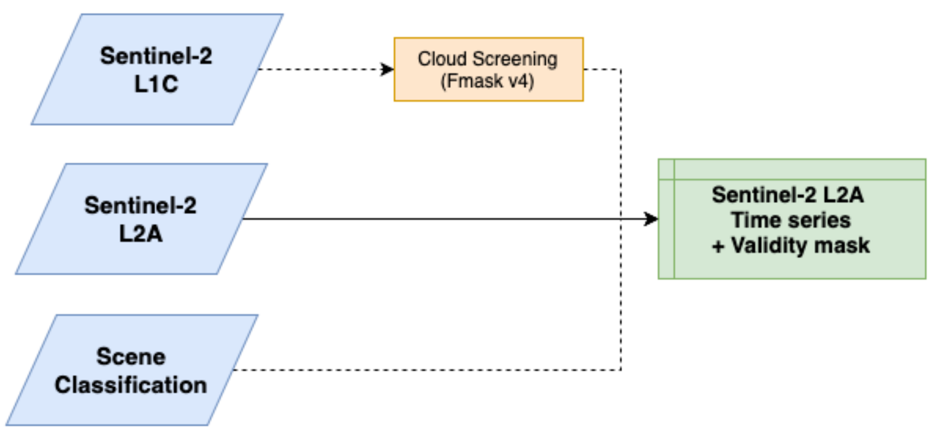

Figure 3-1. S2 pre-processing workflow

Table 3-1. Input and output data for the S2 pre-processing step

Input data	Description	Default value [format]
s2_b{xx}_ts_{tile}_L1C	S2 L1C surface reflectance TOA time series; {xx} = band number; {tile} = S2 tile name	[JPEG2000]
s2_b{xx}_ts_{tile}_L2A	S2 L2A surface reflectance BOA time series; {xx} = band number; {tile} = S2 tile name	[JPEG2000]

[6] Qiu S., et al. 2019. Fmask 4.0: Improved cloud and cloud shadow detection in Landsats 4-8 and Sentinel-2 imagery. *Remote Sensing of Environment*

s2_validityMask_{tile}_SC	Validity mask for each S2 acquisition date obtained with Scene Classification algorithm (part of Sen2Cor); {tile} = S2 tile name	[JPEG2000]
Output data	**Description**	**Default value [format]**
s2_b{xx}_ts_{tile}_L2A	S2 L2A surface reflectance time series; {xx} = band number; {tile} = S2 tile name	[JPEG2000]
s2_validityMask_{tile}_FM	Validity mask for each S2 acquisition date obtained with Fmask; {tile} = S2 tile name	[GeoTIFF]
s2_validityMask_{tile}_S4S	Sen4Stat validity mask for each S2 acquisition date combining Sen2Cor and Fmask; {tile} = S2 tile name	[GeoTIFF]

Table 3-2. Fmask parameters

Parameters	Role	Default value [format]
CloudBuffer	Dilated number of pixels for cloud	3 [pixels]
CloudShadowBuffer	Dilated number of pixels for cloud shadow	3 [pixels]
SnowBuffer	Dilated number of pixels for snow	0 [pixels]
PFPCLayerExtensioninRadius	Radius of dilation for Potential False Positive Cloud such as urban/built-up and (mountain) snow/ice.	0 [meters]
ShadowWater	Mask out the shadow of the cloud over water. We do not suggest mask out the cloud shadow over water since it is less meaningful and very time-consuming.	0, False [integer, binary]
CloudProbabilityThreshold	Cloud probability threshold. The default value depends on the country.	20.00 [float] ECU : 0.00 TZA : 5.00 SEN/ESP/MWI : 10.00
OutputResolution	Output resolution	20 [meters]
PFPCErosionRadius	Radius of erosion for Potential False Positive Cloud such as urban/built-up and (mountain) snow/ice.	90 [meters]

The Fmask 4.2 software is run using the Code 3-1.

```
sen4x/fmask
   -c CloudBuffer
   -s CloudShadowBuffer
   -n SnowBuffer
   -p CloudProbabilityThreshold
   -o s2_validityMask_{tile}_FM
   s2_b{xx}_ts_{tile}_L1C
```

Code 3-1. Fmask v4

The output of Fmask is an image with the following values (Table 3-3).

Table 3-3. Fmask classes

Fmask class	Description
0	Clear land
1	Clear water
2	Cloud shadow
3	Snow
4	Cloud
255	No data

Three options should be available in the Sen4Stat system:

1. **Fmask only (by default):** only the mask generated by Fmask is used. By default, pixels of cloud (=4), cloud shadow (=2) and no observation (=255) are set to invalid. The choice of classes to be masked must be configurable. For example, snow pixels (=3) will have to be set as invalid for the demonstration in Spain. Fmask classes are summarized in Table 3-3.
2. **Sen2Cor only:** only the SC map generated by Sen2Cor is used. By default, pixels of vegetation (=4), not vegetation (=5), water (=6) and unclassified (=7) pixels are set to valid. Other classes are set to invalid. SC classes are summarized in Table 3-4. ***This functionality will come in the next version***.

Table 3-4. Scene Classification (Sen2Cor) classes

SCL class	Description
0	No data
1	Saturated or defective
2	Dark area pixels
3	Cloud shadows
4	Vegetation
5	Not vegetated
6	Water
7	Unclassified

8	Cloud medium probability
9	Cloud high probability
10	Thin cirrus
11	Snow

3. **Fmask + Sen2Cor:** Fmask is used to mask clouds, and cloud shadows pixels while SC map is used to mask no data (=0) and saturated or defective (=1) pixels. This option takes advantage of the better cloud and cloud shadow detection of Fmask as well as the information on defective pixels related to the sensor that only Sen2Cor can detect. the original Sen2Cor validity mask is finally updated with the "cloud" and "cloud shadow" detections from Fmask (Code 3-2). ***This functionality will come in the next version***.

```
otbcli_bandMath
   -il s2_validityMask_{tile}_FM  s2_validityMask_{tile}_SC
   -out s2_validityMask_{tile}_S4S
   -exp "im1b1==2 || im1b1==4 || im2b1==0 || im2b1==1 ? 0 : 1"
```

Code 3-2. Fmask and SC map combination

3.2 Landsat-8 pre-processing

Coming in the next version

3.3 Planet pre-processing

Coming in the next version

3.4 Sentinel-1 backscattering sigma naught pre-processing

The sigma naught backscattering pre-processing chain starts from the raw S1 L1 SLC products and generates orthorectified and filtered backscattering image every 6 (or 12) days.

The pre-processing chain is done into 3 steps:

1. Pre-process raw S1 SLC image into radiometric calibrated and orthorectified sigma naught image;
2. Clip the obtained radiometric calibrated and orthorectified image to the S2 grid and reproject it into the same projection of the S2 data (which is WGS 84 / Universal Transverse Mercator (UTM) zone {x}).
3. Filter the clipped and reprojected image.

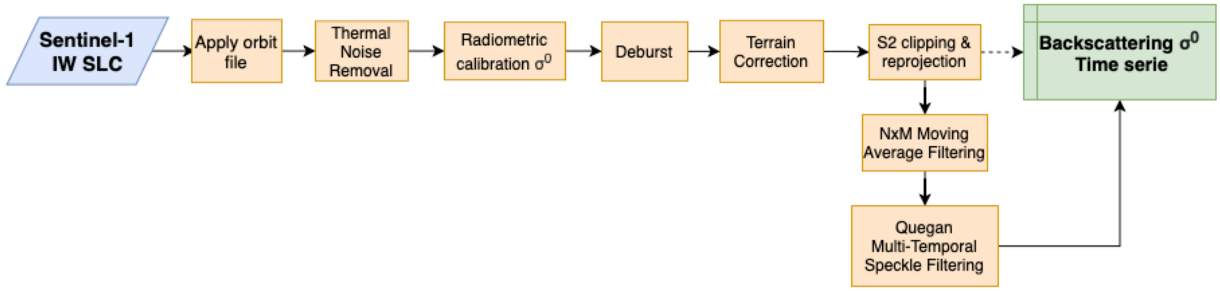

Figure 3-2. Sigma naught pre-processing workflow

3.4.1 Step 1: radiometric calibration & orthorectification

This first step is done using the Sentinel Application Platform (SNAP) and especially the *Sentinel-1 toolbox* developed for ESA by SkyWatch[7]. Input and output of this step are provided in Table 3-5.

Table 3-5. Input and output data for the radiometric calibration & orthorectification step

Input data	Description	Default value [format]
s1_raw_ts	S1 IW SLC raw time series	[SAFE/GeoTIFF]
Output data	**Description**	**Default value [format]**
bck_orb_tnr_{cal}_deb_tr_ts	Radiometric calibrated and orthorectified backscattering time series; {cal} = sigma or gamma naught	[GeoTIFF]

Thanks to the flexible Graph Processing Framework (GPF) provided in the SNAP architecture and the large collection of functionalities, it is possible to create processing graphs for batch processing and customized processing chains. The different tasks included in this radiometric calibration and orthorectification step are therefore documented as SNAP XML snippet.

3.4.1.1 Apply Orbit File

SAR products require additional Orbit State Vector (OSV) information to improve their spatial location accuracy. However, the OSV provided in the metadata of a SAR product are generally not accurate and can be refined with the *restituted orbit files* (high accuracy, < 10cm) or *precise orbit file* (very high accuracy, < 5cm) which are respectively available 3 hours and 20 days after data acquisition. Precise orbit information can have a high influence on the quality of several pre-processing steps. SNAP operator "*Apply Orbit File*" will try to download the *restituted orbit file* if the *precise orbit file* cannot be downloaded (i.e. doesn't exist).

Table 3-6. Parameters used in Apply Orbit File

Parameters	Role	Default value [format]
orbitType	Type of orbit file used (e.g. restituted, precise, …)	Sentinel Precise (Auto Download)

[7] https://sentinel.esa.int/web/sentinel/toolboxes/sentinel-1

polyDegree	Polynomial degree of the interpolation function for the orbit state vector (position and velocity of the satellite at the time of image acquisition)	3 [integer]
continueOnFail	Do not fail if new orbit file is not found	true

```
<node id="Apply-Orbit-File">
    <operator>Apply-Orbit-File</operator>
    <sources>
      <sourceProduct refid="TOPSAR-Split"/>
    </sources>
    <parameters>
      <orbitType>Sentinel Precise (Auto Download)</orbitType>
      <polyDegree>3</polyDegree>
      <continueOnFail>true</continueOnFail>
    </parameters>
</node>
```

Figure 3-3. XML snippet — Apply Orbit File

3.4.1.2 Thermal Noise Removal

Thermal noise is caused by the background energy of a SAR receiver and is independent from the received signal power. Thanks to a thermal noise Look-Up-Table (LUT) which is stored within the S1 L1 products, it is possible to remove it. This step of thermal noise removal can only be applied on backscatter intensity therefore the phase information of the SLC data gets lost. The SNAP XML snippet of this step is shown in Figure 3-4, while the associated parameters are listed in Table 3-7.

Table 3-7. Parameters used in Thermal Noise Removal

Parameters	Role	Default value [format]
selectedPolarisations	Polarisations selected	VV,VH
removeThermalNoise	Remove thermal noise	true
reIntroduceThermalNoise	Re-introduce thermal noise	false

```
<node id="ThermalNoiseRemoval">
    <operator>ThermalNoiseRemoval</operator>
    <sources>
      <sourceProduct>${sourceProduct}</sourceProduct>
    </sources>
    <parameters>
      <selectedPolarisations>VV,VH</selectedPolarisations>
      <removeThermalNoise>true</removeThermalNoise>
      <reIntroduceThermalNoise>false</reIntroduceThermalNoise>
    </parameters>
</node>
```

Figure 3-4. XML snippet — Thermal Noise Removal

3.4.1.3 Radiometric calibration

For the quantitative use of SAR images, a radiometric calibration of radar reflectivity (stored as Digital Numbers (DN)) to physical units (radar backscatter) is essential. Otherwise, a comparison of SAR images from different sensors or even from the same sensor but for different acquisition dates would not be possible. A Calibration Annotation Data Set (CADS) is provided with four LUTs used to convert DN to sigma naught, beta naught and gamma or vice versa. The SNAP XML snippet of this step is shown in Figure 3-5, while the associated parameters are listed in Table 3-8.

Table 3-8. Parameters used in Radiometric Calibration

Parameters	Role	Default value [format]
outputImageInComplex	Save as complex output	false
outputImageScaleInDb	Save in dB	false
createGammaBand	Create gamma0 virtual band	false
createBetaBand	Create beta0 virtual band	false
selectedPolarisations	Polarisations selected	VV,VH
outputSigmaBand	Save sigma0 band	false/true
outputGammaBand	Save gamma0 band	false
outputBetaBand	Save beta0 band	true/false

```xml
<node id="Calibration">
    <operator>Calibration</operator>
    <sources>
      <sourceProduct refid="ThermalNoiseRemoval"/>
    </sources>
    <parameters>
      <sourceBands/>
      <auxFile>Latest Auxiliary File</auxFile>
      <externalAuxFile/>
      <outputImageInComplex>false</outputImageInComplex>
      <outputImageScaleInDb>false</outputImageScaleInDb>
      <createGammaBand>false</createGammaBand>
      <createBetaBand>false</createBetaBand>
      <selectedPolarisations>VV,VH</selectedPolarisations>
      <outputSigmaBand>false</outputSigmaBand>
      <outputGammaBand>false</outputGammaBand>
      <outputBetaBand>true</outputBetaBand>
    </parameters>
 </node>
```

Figure 3-5. XML snippet — Radiometric Calibration

3.4.1.4 TOPSAR Deburst

Each sub-swath image consists of a series of bursts, where each burst was processed as a separate SLC image. The individually focused complex burst images are included, in azimuth-time order, into a single sub-swath image, with black-fill demarcation in between. The TOPSAR Deburst operator (Figure 3-6) is used to merge all sub-swaths and retrieve one fluent image. Associated parameters are shown in Table 3-9.

Table 3-9. Parameters used in TOPSAR Deburst

Parameters	Role	Default value [format]
selectedPolarisations	Polarisations selected	VV,VH

```
<node id="TOPSAR-Deburst">
    <operator>TOPSAR-Deburst</operator>
    <sources>
      <sourceProduct refid="Calibration"/>
    </sources>
    <parameters>
      <selectedPolarisations>VV,VH</selectedPolarisations>
    </parameters>
</node>
```

Figure 3-6. XML snippet — TOPSAR Deburst

3.4.1.5 Terrain Correction

The terrain correction is a conversion of the S1 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 which needs information about the topography (provided by a Digital Elevation Model (DEM)) as well as orbit and velocity information from the satellite (stored within S1 SLC product) to correct the mentioned distortions and derive a precise geolocation for each pixel of the image (Figure 3-7). Associated parameters are listed in Table 3-10. The pixel spacing for the orthorectified image will be set to 10 meters.

Table 3-10. Parameters used in Terrain Correction

Parameters	Role	Default value [format]
demName	DEM used in computing local illuminated area	SRTM 1Sec HGT
demResamplingMethod	Interpolation method for obtaining elevation values from the original DEM file	BILINEAR_INTERPOLATION
imgResamplingMethod	Interpolation methods for obtaining pixel values from the source image	BILINEAR_INTERPOLATION
pixelSpacingInMeter	User can specify pixel spacing in meters for orthorectified image	10.0 [m]
pixelSpacingInDegree	User can also specify the pixel spacing in degrees	8.983152841195215E-5 [deg]
mapProjection	The map projection types	WGS84
applyRadiometricNormalization	Radiometric normalization not needed because the product is previously calibrated	false

```xml
<node id="Terrain-Correction">
    <operator>Terrain-Correction</operator>
    <sources>
      <sourceProduct refid="TOPSAR-Merge"/>
    </sources>
    <parameters>
      <sourceBands/>
      <demName>SRTM 1Sec HGT</demName>
      <externalDEMFile/>
      <externalDEMNoDataValue>0.0</externalDEMNoDataValue>
      <externalDEMApplyEGM>true</externalDEMApplyEGM>
      <demResamplingMethod>BILINEAR_INTERPOLATION</demResamplingMethod>
      <imgResamplingMethod>BILINEAR_INTERPOLATION</imgResamplingMethod>
      <pixelSpacingInMeter>10.0</pixelSpacingInMeter>
      <pixelSpacingInDegree>8.983152841195215E-5</pixelSpacingInDegree>
      <mapProjection>
        GEOGCS["WGS 84",
        DATUM["WGS_1984",
        SPHEROID["WGS 84",6378137,298.257223563,
        AUTHORITY["EPSG","7030"]],
        AUTHORITY["EPSG","6326"]],
        PRIMEM["Greenwich",0,
        AUTHORITY["EPSG","8901"]],
        UNIT["degree",0.0174532925199433,
        AUTHORITY["EPSG","9122"]],
        AUTHORITY["EPSG","4326"]]
      </mapProjection>
      <alignToStandardGrid>false</alignToStandardGrid>
      <standardGridOriginX>0.0</standardGridOriginX>
      <standardGridOriginY>0.0</standardGridOriginY>
      <nodataValueAtSea>true</nodataValueAtSea>
      <saveDEM>false</saveDEM>
      <saveLatLon>false</saveLatLon>
      <saveIncidenceAngleFromEllipsoid>false</saveIncidenceAngleFromEllipsoid>
      <saveLocalIncidenceAngle>false</saveLocalIncidenceAngle>
      <saveProjectedLocalIncidenceAngle>false</saveProjectedLocalIncidenceAngle>
      <saveSelectedSourceBand>true</saveSelectedSourceBand>
      <outputComplex>false</outputComplex>
      <applyRadiometricNormalization>false</applyRadiometricNormalization>
      <saveSigmaNought>false</saveSigmaNought>
      <saveGammaNought>false</saveGammaNought>
      <saveBetaNought>false</saveBetaNought>
      <incidenceAngleForSigma0>
        Use projected local incidence angle from DEM
      </incidenceAngleForSigma0>
      <incidenceAngleForGamma0>
        Use projected local incidence angle from DEM
      </incidenceAngleForGamma0>
      <auxFile>Latest Auxiliary File</auxFile>
      <externalAuxFile/>
    </parameters>
</node>
```

Figure 3-7. XML snippet — Terrain Correction

3.4.2 Step 2: S2 clipping & reprojection

Once the image is calibrated and orthorectified, it is clipped to the extent of the S2 tile and reprojected into the same projection as the S2 images which is WGS 84 / UTM zone {x}. This step is done using GDAL (Code 3-3). Input and output data are shown in Table 3-11 and the parameters are defined in Table 3-12.

Table 3-11. Input and output data for the radiometric calibration & orthorectification step

Input data	Description	Default value [format]
bck_orb_tnr_{cal}_deb_tr_ts	Radiometric calibrated and orthorectified backscattering time series; {cal} = sigma or gamma naught	[GeoTIFF]
Output data	**Description**	**Default value [format]**
bck_orb_tnr_{cal}_deb_tr_ts _{tile}_{epsg}	Radiometric calibrated and orthorectified backscattering time series; {cal} = sigma or gamma naught; {tile} = S2 tile name; {epsg} = EPSG code	[GeoTIFF]

Table 3-12. Parameters for Clip to S2 grid step

Parameters	Description	Default value [format]
s_epsg	Source spatial reference	WGS84
t_epsg	Target spatial reference, same as S2 data	WGS84/UTM zone {x}
xmin ymin xmax ymax	Extent of S2 tile	- [float]

```
gdalwarp
   -wo USE_OPENCL=FALSE
   -s_srs {s_epsg}
   -t_srs {t_epsg}
   -te {xmin ymin xmax ymax}
   -te_srs {t_epsg}
   -tr 10 10
   -crop_to_cutline
   -overwrite
   -multi
   -r cubic
   bck_orb_tnr_{cal}_deb_tr_ts
   bck_orb_tnr_{cal}_deb_tr_ts_{tile}_{epsg}
```

Code 3-3. Image clipping & reprojection — *gdalwarp* command

3.4.3 Step 3: multi-temporal speckle filtering

The presence of speckle degrades the quality of the image and therefore makes the interpretation of the SAR data more difficult. For time series of SAR data, Multi-Temporal Speckle Filtering (MTSF) is the most widely used procedure for noise reduction. It provides better results in form of speckle reduction and resolution preservation than a single speckle filter.

The MTSF filtering step is divided into 3 sub-steps which are performed using the latest version of Orfeo ToolBox (OTB) (v7.2).

1. Moving average asymmetric filtering;
2. Outcore computation;
3. Multi-Temporal Speckle Filtering.

3.4.3.1 Moving average asymmetric filtering — Optional

This step is optional. It is applied to reduce the vertical aspect of the pixels due to the difference in range and azimuth resolution. The "asymmetric filtering" is a moving average filter of window size NxM, where N > M (Code 3-4). Input and output data are shown in Table 3-13 and the parameters are defined in Table 3-14.

Table 3-13. Input and output data for the Asymmetric Filtering step

Input data	Description	Default value [format]
bck_orb_tnr_{cal}_deb_tr_ts_{tile}_{epsg}	Radiometric calibrated and orthorectified backscattering time series; {cal} = sigma or gamma naught; {tile} = S2 tile name; {epsg} = EPSG code	[GeoTIFF]
Output data	**Description**	**Default value [format]**
bck_orb_tnr_{cal}_deb_tr_ts_{tile}_{epsg}**_AF**	Radiometric calibrated and orthorectified backscattering time series with asymmetric filtering; {cal} = sigma or gamma naught; {tile} = S2 tile name; {epsg} = EPSG code	[GeoTIFF]

Table 3-14. Parameters for the Asymmetric Filtering step

Parameters	Description	Default value [format]
asym_filter_N	Asymmetric Filtering window size (horizontal direction)	3 [integer]
asym_filter_M	Asymmetric Filtering window size (vertical direction)	1 [integer]

```
otbcli_BandMathX
   -il bck_orb_tnr_{cal}_deb_tr_ts_{tile}_{epsg}
   -out bck_orb_tnr_{cal}_deb_tr_ts_{tile}_{epsg}_AF
   -exp "mean(im1b1N{asym_filter_N}x{asym_filter_M})"
```

Code 3-4. Asymmetric filtering

3.4.3.2 Outcore computation

The purpose of this step is to identify areas that change a little over time, such as parcel boundaries. The first step of the Quegan speckle filter is the computation of the outcore function of the filter based on a list of orthorectified images (Code 3-5). This step is done with the OTB "*MultitempFilteringOutcore*" application: it takes as input the list of all previously images filtered with the asymmetric filter 24 or 48 (configurable) days before the date (and including it) where we want to compute the MTSF. Input and output data are shown in Table 3-15 and the parameters are defined in Table 3-16.

Table 3-15. Input and output data for the Outcore computation step

Input data	Description	Default value [format]
bck_orb_tnr_{cal}_deb_tr_ts _{tile}_{epsg}_AF	Radiometric calibrated and orthorectified backscattering time series with asymmetric filtering; {cal} = sigma or gamma naught; {tile} = S2 tile name; {epsg} = EPSG code	[GeoTIFF]
Output data	**Description**	**Default value [format]**
outcore_{cal}_{tile} _{epsg}_{date}	Outcore; {cal} = sigma or gamma naught; {tile} = S2 tile name; {epsg} = EPSG code	[GeoTIFF]

Table 3-16. Parameters for the Outcore computation step

Parameters	Description	Default value [format]
outcore_windows_days	Window in days for the computation of the outcore. 24 for 6 days between images (6 days coverage) or 48 for 12 days	24 or 48 [days]
mtsf_window_radius	Spatial averaging windows radius	7 [integer]

```
otbcli_MultitempFilteringOutcore
   -progress false
   -inl list_im_outcore_{outcore_windows_days}
   -wr mtsf_window_radius
   -oc outcore_{cal}_{tile}_{epsg}_{date}
```

Code 3-5. Outcore computation

3.4.3.3 Multi-Temporal Speckle Filtering

Once the outcore is computed, we can apply it to the orthorectified (and optionally asymmetric filtered) image. The advantage of multi-temporal filtering is that it preserves or even enhances the level of geometric detail and increases the signal to noise ratio. This step is achieved using the OTB "*MultitempFilteringFilter*" application, which implements the Quegan speckle filter for SAR images (Code 3-6). It applies the outcore to an image. Input and output data are shown in Table 3-17.

Table 3-17. Input and output data for the MTSF step

Input data	Description	Default value [format]
bck_orb_tnr_{cal}_deb_tr_ts _{tile}_{epsg}_AF	Radiometric calibrated and orthorectified backscattering time series with asymmetric filtering; {cal} = sigma or gamma naught; {tile} = S2 tile name; {epsg} = EPSG code	[GeoTIFF]
outcore_{cal}_{tile} _{epsg}_{date}	Outcore; {cal} = sigma or gamma naught; {tile} = S2 tile name; {epsg} = EPSG code	[GeoTIFF]
mtsf_directory	Directory where filtered files shall be stored.	[string]
Output data	**Description**	**Default value [format]**
bck_orb_tnr_{cal}_deb_tr_ts _{tile}_{epsg}_AF_**filtered**	Radiometric calibrated and orthorectified and filtered backscattering time series; {cal} = sigma or gamma naught; {tile} = S2 tile name; {epsg} = EPSG code	[GeoTIFF]
enl_file	Number of images averaged	[GeoTIFF]

```
otbcli_MultitempFilteringFilter
   -progress false
   -inl bck_orb_tnr_{cal}_deb_tr_ts_{tile}_{epsg}_AF
   -wr mtsf_window_radius
   -oc outcore_{cal}_{tile}_{epsg}_{date}
   -filepath mtsf_directory
   -enl enl_file
```

Code 3-6. Multi-Temporal Speckle Filtering — Quegan method

3.4.4 Step 4: Pixel Conversion and Compression – optional

The last (optional) step consists in reducing the size of the resulting MTSF product by converting FLOAT32 pixel values of the MTSF product to UINT16 values with a scaling factor of 1000 and compressing it. This is achieved by using GDAL (Code 3-7).

Table 3-18. Parameters for Convert and Compress step

Parameters	Description	Default value [format]
ot	Output pixel type	UInt16
v0min v0max v1min v1max	Source minimum and maximum and target minimum and maximum values	- [float]
-co	Gdal options	

```
gdal_translate
   -ot UInt16
   -scale {v0min v0max v1min v1max}
```

```
-co COMPRESS=DEFLATE
-co PREDICTOR=2
bck_orb_tnr_{cal}_deb_tr_ts_{tile}_{epsg}_AF_filtered
bck_orb_tnr_{cal}_deb_tr_ts_{tile}_{epsg}
```

Code 3-7. Image conversion and compression — *gdal_translate* command

3.5 Sentinel-1 backscattering gamma naught pre-processing

Coming in the next version

In the next version, an indicator of the topography will be developed using a DEM to decide if the conversion needs to be done until beta naught (and then gamma naught). If this indicator is below a certain threshold, which means that the relief in the stratum is relatively flat, the calibration will be in sigma naugth. On the contrary, if the indicator is higher than the threshold, which will be the case in mountainous regions, then the DN will have to be converted to beta naught so that the terrain flattening step may be applied after (and produce gamma naught).

When land cover classification is applied to terrain that is not flat, inaccurate classification result is produced. The terrain flattening method proposed by Small[8] removes the radiometric variability associated with topography while leaving the radiometric variability associated with land cover. Ellipsoid-based or sigma naught (σ^0) based incident angle approximations fail to reproduce the effect of topographic variation in their sensor model. The gamma naught (γ^0) backscatter is converted directly from beta naught (β^0) to a newly introduced terrain- flattened γ_T^0 normalization convention.

The SNAP XML snippet of this step is shown in Figure 3-8, while the associated parameters are listed in Table 3-19.

Table 3-19. Parameters used in Terrain Flattening

Parameters	Role	Default value [format]
demName	Digital Elevation Model used in computing local illuminated area	SRTM 3Sec
demResamplingMethod	Resampling method used in getting elevation from DEM	BILINEAR_INTERPOLATION
additionalOverlap	Additional Overlap Percentage: To perform terrain flattening to a given tile, pixels from adjacent tiles are generally needed due to the topography in the image area. The overlap percentage is automatically computed using the DEM. However, if the computed overlap is not enough, then tiling effect can be observed in the terrain flattened image. In this case, user can increase the Additional Overlap Percentage.	0.1
oversamplingMultiple	Oversampling Multiple: The Terrain Flattening algorithm requires that the DEM resolution is higher than the image resolution. Therefore, the DEM is generally oversampled by a factor automatically computed based on the DEM and image resolution. However, if the automatically computed oversampling factor is not large enough, then artefacts can be observed in the terrain flattened image. In this case user can	1.5

[8] David Small, "Flattening Gamma: Radiometric Terrain Correction for SAR imagery", IEEE Transaction on Geoscience and Remote Sensing, Vol. 48, No. 8, August 2011

	increase the oversampling factor by multiplying it with this coefficient.	

```xml
<node id="Terrain-Flattening">
    <operator>Terrain-Flattening</operator>
    <sources>
      <sourceProduct refid="TOPSAR-Deburst"/>
    </sources>
    <parameters>
      <sourceBands/>
      <demName>SRTM 3Sec</demName>
      <demResamplingMethod>BILINEAR_INTERPOLATION</demResamplingMethod>
      <externalDEMFile/>
      <externalDEMNoDataValue>0</externalDEMNoDataValue>
      <externalDEMApplyEGM>false</externalDEMApplyEGM>
      <outputSimulatedImage>true</outputSimulatedImage>
      <additionalOverlap>0.1</additionalOverlap>
      <oversamplingMultiple>1.5</oversamplingMultiple>
    </parameters>
</node>
```

Figure 3-8. XML snippet — Terrain Flattening

3.6 Sentinel-1 coherence pre-processing

The coherence pre-processing chain generate coherence images at a 6- (or 12-) day interval. The coherence product at time *t* is computed using the S1 SLC acquisitions at time *t* and at time *t-6* (or *t-12*).

The coherence pre-processing chain is done into 5 steps (Figure 3-9):

1. Apply Orbit File
2. Back Geocoding;
3. Coherence computation;
4. Deburst;
5. Terrain Correction.

Input and output data are summarized in Table 3-20.

Table 3-20. Input and output data for the coherence processing step

Input data	Description	Default value [format]
s1_raw_{date_t-6}	S1 IW SLC raw at date *t*-6	[BEAM-DIMAP]
s1_raw_{date_t}	S1 IW SLC raw at date *t*	[BEAM-DIMAP]
Output data	**Description**	**Default value [format]**
cohe_{date_t}_{tile}	Coherence at date *t*; {tile} = S2 tile name	[GeoTIFF]

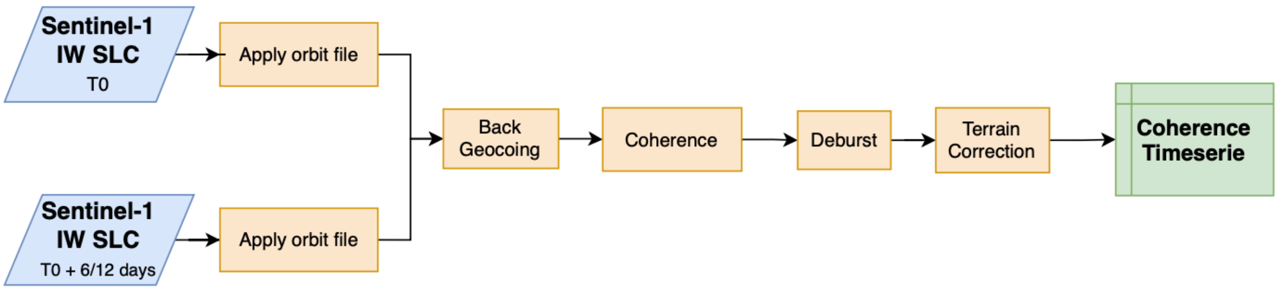

Figure 3-9. Coherence pre-processing workflow

3.6.1 Apply Orbit File

Same as section 0.

3.6.2 Back Geocoding

The S1 Back Geocoding operator co-registers the two products (master and slave) based on the orbit information added in the previous step and on information from a DEM which is downloaded by SNAP (Figure 3-10). Associated parameters are shown in Table 3-21. Before running this operator, user should first run S-1 TOPS Split operator to both master and slave products to get the same sub-swath and same polarization data for co-registration (e.g. IW1 - VV).

Table 3-21. Parameters used in Back Geocoding

Parameters	Role	Default value [format]
demName	DEM used in computing local illuminated area	SRTM 1Sec HGT
demResamplingMethod	Interpolation method for obtaining elevation values from the original DEM file	BICUBIC_INTERPOLATION
resamplingType	Interpolation methods for obtaining pixel values from the source image	BISINC_5_POINT _INTERPOLATION
maskOutAreaWithoutElevation	Checkbox indicating if areas without elevation should be masked out from co-registration. *It is recommended to select this checkbox to avoid artefacts along the coast in the co-registered images.*	true
outputRangeAzimuthOffset	/	false
outputDerampDemodPhase	Checkbox indicating if deramp and demodulation phases should be output as separated bands	false
disableReramp	/	false

```xml
<node id="ProductSet-Reader">
    <operator>ProductSet-Reader</operator>
    <sources/>
    <parameters>
      <fileList> s1_raw_{date_t-6},s1_raw_{date_t}</fileList>
    </parameters>
</node>

<node id="Back-Geocoding">
    <operator>Back-Geocoding</operator>
    <sources>
      <sourceProduct refid="ProductSet-Reader"/>
    </sources>
    <parameters>
      <demName>SRTM 1Sec HGT</demName>
      <demResamplingMethod>BICUBIC_INTERPOLATION</demResamplingMethod>
      <externalDEMFile/>
      <externalDEMNoDataValue>0.0</externalDEMNoDataValue>
      <resamplingType>BISINC_5_POINT_INTERPOLATION</resamplingType>
      <maskOutAreaWithoutElevation>true</maskOutAreaWithoutElevation>
      <outputRangeAzimuthOffset>false</outputRangeAzimuthOffset>
      <outputDerampDemodPhase>false</outputDerampDemodPhase>
      <disableReramp>false</disableReramp>
    </parameters>
</node>
```

Figure 3-10. XML snippet —Back Geocoding

3.6.3 Coherence computation

This step allows to compute the coherence between two S1 SLC images (6 or 12 days apart). Coherence expresses the similarity of the radar reflection between these two images. In this way, even very subtle changes in the scene from one image to the next is detected. The SNAP XML snippet of this step is shown in Figure 3-11, while the associated parameters are listed in Table 3-22.

Table 3-22. Parameters used in Coherence

Parameters	Role	Default value [format]
cohWinAz	Coherence azimuth window size	3
cohWinRg	Coherence range window size	10
substractFlatEarthPhase	The flat-earth phase is the phase present in the interferometric signal due to the curvature of the reference surface. The flat-earth phase is estimated using the orbital metadata information and subtracted from the complex interferogram.	true
srpPolynomialDegree	Degree of “Flat Earth” polynomial	5 [integer]
srpNumberPoints	Number of “Flat Earth” estimation points	501 [integer]

orbitDegree	Orbit interpolation degree	3 [integer]
squarePixel	/	true
substractTopographicPhase	Flat terrain should produce a series of regularly spaced, parallel fringes. Any deviation from a parallel fringe pattern can be interpreted as topographic variation.	true
demName	DEM used to remove the topographic phase	SRTM 1Sec HGT
tileExtensionPercent	/	100 [integer]

```
<node id="Coherence">
    <operator>Coherence</operator>
    <sources>
      <sourceProduct refid="${sourceProduct}"/>
    </sources>
    <parameters>
      <cohWinAz>3</cohWinAz>
      <cohWinRg>10</cohWinRg>
      <subtractFlatEarthPhase>true</subtractFlatEarthPhase>
      <srpPolynomialDegree>5</srpPolynomialDegree>
      <srpNumberPoints>501</srpNumberPoints>
      <orbitDegree>3</orbitDegree>
      <squarePixel>true</squarePixel>
      <subtractTopographicPhase>true</subtractTopographicPhase>
      <demName>SRTM 1Sec HGT</demName>
      <externalDEMFile/>
      <externalDEMNoDataValue>0.0</externalDEMNoDataValue>
      <externalDEMApplyEGM>true</externalDEMApplyEGM>
      <tileExtensionPercent>100</tileExtensionPercent>
    </parameters>
</node>
```

Figure 3-11. XML snippet — Coherence computation

3.6.4 Deburst

Same as section 3.4.1.4

3.6.5 Terrain Correction

Same as section 3.4.1.5

3.6.6 Conversion and Compression – optional

Same as section

4 Output

4.1 Sentinel-2 L2A surface reflectance time series

For each S2 tile within the site defined by the user, BOA L2A reflectance images for each of the 10 spectral bands acquired during the selected season are collected via SciHub.

For each of these images, a validity mask is generated either via Fmask, Sen2Cor or a combination of both.

4.2 Landsat-8 L2A surface reflectance time series

Coming in the next version

4.3 Sentinel-1 Backscattering time series

For each S2 tile within the site defined by the user, a sigma naught (or gamma naught) backscattering time series (inside the selected season) is generated from the S1 SLC products. These time series are radiometric calibrated, orthorectified and filtered.

4.4 Sentinel-1 Coherence time series

For each S2 tile within the site defined by the user, a coherence time series (inside the selected season) is generated from the S1 SLC products at a 6- (or 12-) day interval.