



# TERRASCOPE SENTINEL-1

## ALGORITHM THEORETICAL BASE DOCUMENT (ATBD)

**S1 Sigma0 GRD V101**

**Reference:** *Terrascope Sentinel-1 Algorithm Theoretical Base Document S1 – Sigma0 GRD V110*

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## LIST OF ACRONYMS

<b>ACRONYM</b>	<b>EXPLANATION</b>
ATBD	Algorithm Theoretical Base Document
DEM	Digital Elevation Model
DN	Digital Number
EO	Earth Observation
ESA	European Space Agency
GDAL	Geospatial Data Abstraction Library
GEOTIFF	Geospatial Tagged Image File Format
GIS	Geographical Information System
GRD	Ground Range Detected
IW	Interferometric Wide Swath
LUT	Lookup table
PDF	Product Distribution Facility
S1A/B	Sentinel-1A/B
SAR	Synthetic Aperture RADAR
SLC	Single Look Complex
SNAP	Sentinel Application Platform
SRTM	Shuttle RADAR Topography Mission
VV/VH	Vertical-Vertical/Vertical-Horizontal polarization mode

## 1. Introduction

The Sentinel-1 satellites provide essential EO data of the Earth. They operate a C-band Synthetic Aperture RADAR (SAR), which is able to provide regular observations with a 6 day repeat cycle for the combination of S1A and S1B. Because the system uses microwave radiation, which is not blocked by clouds, a new observation is guaranteed at every overpass.

SAR data have been notoriously difficult to use by all but a small number of RADAR specialists, and this has resulted in little uptake in many EO communities. By providing the  $\sigma_0$  product as described below, Terrascope aims to change this. The product is delivered in a familiar file format (GEOTIFF), and is corrected to make it directly useable in GIS software and for time series analyses.



## 2. Description

The Sentinel-1 Level1 GRD sigma0 product is an orbit corrected and calibrated version of the original ESA Level-1 GRD product, corrected for geometric distortions which come with the generation of SAR images.

The product algorithm takes the ESA Level-1 GRD product (as it is also provided by the Terrascope PDF) as input. These GRD images are first corrected based on more precise orbit information than what is available in the original image. Next, radiometric noise is removed from the edges of the image, followed by the removal of thermal noise from the product. The fourth step in the processing workflow is the radiometric calibration, resulting in the sigma0 backscatter image. From this backscatter, the geometric distortions are removed, originating from the SAR way of creating the data. Next, the terrain corrected backscatter is converted into a standard SNAP BEAM-DIMAP output file. All these steps are performed using SNAP (the ESA Sentinel Application Platform). The resulting output file is subsequently converted into GeoTIFF, for both the VV and VH polarizations, as well as the incidence angle. This is done using gdal tools.

The backscatter images are provided in their original backscatter intensities (cfr. Sect. 5)

### 3. Added value and use cases

The purpose of creating this new GRD product (compared to the GRD images delivered by ESA) is to lower the threshold for users that want to work with Sentinel-1 backscatter images. In order to get any useable results out of the original ESA Level-1 data, some basic processing is required, which is provided in this new product. Calibrated sigma0 backscatter also allows to compare acquisitions at different times, and between different sensors.

Users that want to do basic calculations with Sentinel-1 backscatter will be helped by this product, since they won't have to install SAR-software to process the original data. On the other hand, users who have software to do some more advanced processing can also benefit from this product, if they want to gain time by not having to do the basic processing steps themselves.

## 4. Product naming scheme

**COLLECTION NAME:**

**CGS\_S1\_GRD\_SIGMA0\_L1**

**PRODUCT REFERENCE SCHEME:**

**<mission\_identifier>\_<mode>\_<product\_type>\_<PP>\_<start\_date>\_<orbit\_direction>\_<relative\_orbit>\_<product\_unique\_identifier>\_<product\_version>**

Template	Description
mission_identifier	S1A or S1B
mode	Always IW: <a href="#">interferometric wide swath</a>
product_type	GRDH_SIGMA0: Ground Range Detected, Sigma0 , H = High resolution
PP	PP = polarisation mode (is always DV: dual polarisation, VV-VH)
start_date	Product start date in the format yyymmddThhmmss
orbit_direction	ASCENDING or DESCENDING, always the same for a given relative orbit
relative_orbit	relative orbit number
product_unique_identifier	We reference the unique identifier of the base product, to establish a 1 to 1 relationship with ESA products.
product_version	VITO product version

**Example:**

**S1B\_IW\_GRDH\_Sigma0\_DV\_20180813T054334\_DESCENDING\_139\_B621\_V000**

## 5. Note on the use of original intensities as opposed to decibels

It is of extreme importance that the user of this product is aware that the backscatter intensities in our sigma0 product are **NOT expressed in decibels**, as opposed to how it is generally done by other providers. While it is true that conversion to decibels turns backscatter intensities in a quantity that is more user-friendly, has a higher value visually, and is a generally accepted method of communicating radar data, we have chosen specifically to not do this for the following reasons:

- In the growing world of datacubes, including the work we do with Terrascope services, ingesting decibel backscatters imposes serious error-prone complexities, as any kind of analysis that would be done on these data would require an on-the-fly removal of the decibel unit.
- Providing decibel backscatters to end users would require the user to convert to original intensities when doing any kind of analysis that requires mathematical operations.
- Calculating overview levels on the GeoTIFFs based on decibels results in wrong values that cannot be used in any analysis.

This all comes back to the basic mathematical principle that no mathematical operations such as calculating an average value can be done directly on the (logarithmic) decibels. Doing so results in mathematically incorrect results, of which users are often not aware. To prevent this as much as possible, our sigma0 product is provided in original backscatter intensities. Users that do want to convert to decibels, can apply a simple conversion function:

$$\sigma_{0,dB} = 10 \log_{10}(\sigma_0)$$

where  $\sigma_0$  is the sigma0 backscatter in original intensity as provided in our product, and  $\sigma_{0,dB}$  is the sigma0 value in decibels.

## 6. Algorithm description

### 6.1. Algorithm input

The algorithm uses the original Sentinel-1 GRD product as distributed by the [Copernicus Open Access Hub](#) in its native format.

### 6.2. Algorithm output

The outputs from this algorithm are a VV backscatter (not in decibels), a VH backscatter (not in decibels), and an incidence angle (degrees) image, all provided as GeoTiff. The two backscatter images are stored in "float32" format, while the incidence angle image is a scaled "int16" image. Metadata of the product is described here:

[https://www.vito-eodata.be/collections/srv/eng/main.home?uuid=urn:eop:VITO:CGS\\_S1\\_GRD\\_SIGMA0\\_L1](https://www.vito-eodata.be/collections/srv/eng/main.home?uuid=urn:eop:VITO:CGS_S1_GRD_SIGMA0_L1)

### 6.3. Format

Product format:

- Cloud optimized GEOTIFF (256x256 internal tile size)
- DEFLATE compression
- Not all overview levels are generated to save disk space, but higher level overviews really speed up visualization in e.g. Qgis
- TIFFTAG\_DATETIME is set to the product date, as some software also uses this.
- For the incidence angle, a scale and offset is applied:
  - Offset = 29
  - Scale = 0.0005
  - Scaling is chosen to be an easy number, while preserving sufficient precision.

Product layout for the example product:

#### **S1A\_IW\_GRDH\_SIGMA0\_DV\_20180513T055838\_DESCENDING\_110\_E24E\_V110:**

- S1A\_IW\_GRDH\_SIGMA0\_DV\_20180513T055838\_DESCENDING\_110\_E24E\_V110\_angle.tif (incidence angle, approximately 100MB)
- S1A\_IW\_GRDH\_SIGMA0\_DV\_20180513T055838\_DESCENDING\_110\_E24E\_V110\_VH.tif (VH backscatter band, approximately 1.6GB)
- S1A\_IW\_GRDH\_SIGMA0\_DV\_20180513T055838\_DESCENDING\_110\_E24E\_V110\_VV.tif (VV backscatter band, approximately 1.6GB)
- S1A\_IW\_GRDH\_SIGMA0\_DV\_20180513T055838\_DESCENDING\_110\_E24E\_V110.xml (metadata)

**Total average product size: 3-4GB**

## 6.4. Methodology

The following algorithm steps are performed using [SNAP](#), more specifically using the command line "gpt" tool of SNAP. For each process in the workflow, the description of what the operator in SNAP does is given, what it needs as input, and what it delivers as output. Following these SNAP algorithms, a few more gdal steps are required. The first one will make sure the No Data values are handled correctly and the result is saved to GTIFF. The second one will apply an additional border noise mask on products prior to 13<sup>th</sup> of March 2018, and the last steps will set some metadata information in the files.

### 6.4.1. The SNAP Part of the processing

The SNAP processing steps in Terrascope are performed using **SNAP 6.0** and the **Sentinel-1 Toolbox (S1TBX) version 6.0.3**.

Previous versions cannot be used as some of the processes will not work or result in unreliable output. See <http://forum.step.esa.int/t/grd-border-noise-and-thermal-noise-removal-are-not-working-anymore-since-march-13-2018/9332/25> for more information on this. In summary, on the 13<sup>th</sup> of March 2018, Sentinel-1 data processing switched to IPF 2.90 which changed the way noise profiles are annotated in the metadata. Only up-to-date versions of the Sentinel-1 toolbox in SNAP are able to handle this update.

Part of the information provided in the steps below is taken from operator descriptions in SNAP. We refer the reader to these documents for additional information on the processes involved.

#### 6.4.1.1. Apply orbit correction

The orbit state vectors provided in the metadata of a SAR product are generally not completely accurate and can be refined with the precise orbit files which are available days-to-weeks after the generation of the product. The orbit file provides accurate satellite position and velocity information. Based on this information, the orbit state vectors in the abstract metadata of the product are updated.

For Sentinel-1, Restituted orbit files and Precise orbit files may be applied. Precise orbits are produced a few weeks after acquisition. Orbit files are automatically searched and downloaded from <https://qc.sentinel1.eo.esa.int>. To refine the orbit state vectors, the following steps are performed by SNAP.

- Get the start time of the source product;
- Find orbit file with user specified type and the product start time;
- For each orbit state vector, get its zero Doppler time;
- Compute new orbit state vector with 8th order Lagrange interpolation using data for the 9 nearest orbit positions around the zero Doppler time.

The Sentinel-1 precise orbit determination operations provide restituted orbit information within 3 hours from sensing which is nominally used for the systematic processing of Fast24 products. The quality of the restituted orbits has proven to be better (twice as good) than expected in 95% of the cases, resulting in the very good absolute geolocation accuracy of Sentinel-1 products. Given the timeliness of the product, the high absolute accuracy already with restituted orbits, and the high additional load and complexity of reprocessing every image once the precise orbit becomes available, we currently provide our sigma0 product based on **restituted orbit files**.

#### **6.4.1.2. GRD border noise removal**

The Sentinel-1 Instrument Processing Facility (IPF) is responsible for generating the complete family of Level-1 and Level-2 operation products. The processing of the RAW data into Level-1 products features a number of processing steps, leading to artefacts at the image borders.

These processing steps are mainly the azimuth and range compression and the sampling start time changes handling that is necessary to compensate for the change of the Earth curvature. The latter process is generating a number of leading and trailing "no-value" samples that depend on the data-take length which can be several minutes long. The former process creates radiometric artefacts that complicate the detection of the "no-value" samples. These "no-value" pixels are not null but contain very low values which complicates the masking based on thresholding.

This operator implements an algorithm proposed in [1] allowing the masking of the "no-value" samples efficiently with a thresholding method.

However, the method is not perfect and remaining border noise is present. Setting the parameters more aggressively is, however, discouraged since this might exclude many valid pixels as well.

For the sake of enhanced user experience, we apply an additional inward buffering method that effectively removes any remaining border noise in the provided sigma0 product for products acquired prior to March 13, 2018. Cfr. Section 6.4.2 for more information.

[1] Masking "No-value" Pixels on GRD Products generated by the Sentinel-1 ESA IPF, Reference MPC-0243, Issue 1.0, Date 2015, June 25.

#### **6.4.1.3. Thermal noise removal**

Thermal noise correction can be applied to Sentinel-1 Level-1 SLC products as well as Level-1 GRD products which have not already been corrected. The operator can also remove this correction based on the product annotations (i.e. to re-introduce the noise signal that was removed). Product annotations will be updated accordingly to allow for re-application of the correction.

Level-1 products provide a noise LUT for each measurement data set. The values in the de-noise LUT, provided in linear power, can be used to derive calibrated noise profiles matching the calibrated GRD data. Bi-linear interpolation is used for any pixels that fall between points in the LUT.

#### **6.4.1.4. Radiometric calibration to sigma0**

The objective of SAR calibration is to provide imagery in which the pixel values can be directly related to the radar backscatter signal of the scene. Though uncalibrated SAR imagery is sufficient for qualitative use, calibrated SAR images are essential to quantitative use of SAR data.

Typical SAR data processing, which produces level 1 images, does not include radiometric corrections and so a significant radiometric bias remains. Therefore, it is necessary to apply the radiometric correction to SAR images so that the pixel values of the SAR images truly represent the radar backscatter of the reflecting surface. The radiometric correction is also necessary for the comparison of SAR images acquired with different sensors, or acquired from the same sensor but at different times, in different modes, or processed by different processors.

For converting digital pixel values to radiometrically calibrated backscatter, all the required information can be found in the product. A calibration vector is included as an annotation in the product allowing simple conversion of image intensity values into sigma or gamma nought values. The objective of SAR calibration is to provide imagery in which the pixel values can be directly related to the radar backscatter of the scene. To do this, the application output scaling applied by the processor must be undone and the desired scaling must be applied. Level-1 products provide four calibration Look Up Tables (LUTs) to produce  $\beta_{0i}$ ,  $\sigma_{0i}$  and  $\gamma_{0i}$  or to return to the Digital Number (DN). The LUTs apply a range-dependent gain including the absolute calibration constant. For GRD products, a constant offset is also applied.

In this processing chain we choose to calibrate the raw signals in the product to the widely used calibrated **sigma<sub>0</sub>** backscatter intensities.

#### **6.4.1.5. Range doppler terrain correction**

Due to relief variations of a scene and the tilt of the satellite sensor, distances can be distorted in the SAR images. Image data which is not directly at the sensor's Nadir location will have some distortion. Terrain corrections are intended to compensate for these distortions so that the geometric representation of the image will be as close as possible to the real world.

The process needs a DEM based on which the correction is applied. The more accurate the DEM, the better the correction. Below 60° latitude, SRTM 1Sec can be auto-downloaded by SNAP and provides a sufficiently accurate DEM for correction in Belgium. Furthermore, we can define the map projection (~ellipsoid) based on the which the correction will be done. Here we use **WGS 84 / UTM zone 31N** with a pixel spacing of **10m**, in accordance with the Sentinel-2 data in Belgium as also provided by Terrascope.

#### **6.4.1.6. Export to file**

The final processed product is exported by SNAP to the BEAM-DIMAP output format. While direct export to GTIFF is supported by SNAP, the processing is much slower than the export to a native format. Therefore, we need to convert the output to GEOTIFF in a separate step.



## 6.4.2. The GDAL part of the processing

A Python script performs the following steps, using the GDAL library.

### 6.4.2.1. Convert nodata values

The output from the SNAP processing chain is a file in BEAM-DIMAP format (standard SNAP format) containing three bands: "Sigma0\_VH", "Sigma0\_VV", and "incidenceAngleFromEllipsoid". The no-data value for backscatter bands is set to nan and .

### 6.4.2.2. Additional border noise removal

Since the SNAP border noise removal tool is not able to fully eliminate border noise for products acquired **before 13 March 2018**, we have implemented a more aggressive approach. This is needed because this Sigma<sub>0</sub> product is ingested in our datacubes and any remaining faulty values near the product borders would result in unreliable time series retrievals.

Our method is based on a simple clipping of the images based on manually delineated swath polygons that correspond to the real swath excluding border noise. While this approach may result in the loss of some correct values near the borders of the image, it ensures reliable data which is more important than the loss of a few values.

### 6.4.2.3. Adding metadata to final GeoTIFF products

The file name, description, creation date, copyright info and scale and offset is added to the metadata.

### 6.4.2.4. Conversion of Incidence angle band to UInt16

The "incidenceAngleFromEllipsoid" band can be stored in the "UInt16" GeoTiff format without significant loss of information. The float values are converted to the appropriate integer value within the UInt16 range, of which the resulting scale and offset values were given in Sect. 6.3.

### 6.4.2.5. Generating Cloud Optimized Geotiffs

Cloud optimized geotiffs are generated as the last step, as GDAL requires this. Appropriate overviews are added to the geotiffs.

## 7. Quality assessment

It should be noted that a quantitative assessment of a radar product is difficult, since measurements are extremely sensor/location/time specific. No ground truth data are available to compare with radar backscatter intensities.

To verify the consistency of our product, we have chosen to compare it to the Sigma0 product that is available within the [Google Earth Engine](#) archive, which gives the advantage that it has been thoroughly evaluated by the community, while their processing steps are - for the test images - identical to what is processed with our processing workflow. It should be mentioned that Google Earth Engine automatically determines the most appropriate UTM zone in which the S1 image is processed. For the test images, it has been verified that this corresponds to our UTM31 (EPSG:32631) which we use for all processed S1 imagery over Belgium. For some other images we generate (e.g. near eastern Belgium), Earth Engine will provide images in UTM zone 32, and slight differences with our output will occur, mostly due to different results in the geometric terrain correction step.

Google at first decided to save on storage and produce VV/VH backscatter in UInt16. To retain the required precision, they had to clamp the original values and remove the 1st and 99th percentiles. This has resulted in numerous discussions with the community and Google is now reprocessing the entire archive to Float32, because the removed 1st and 99th percentiles actually contain important information for some users. This is why we process the backscatters here to Float32, so no information loss occurs. In the comparison mentioned here, and the provided reference data from Earth Engine, we already use their new Float32 collection, so we don't expect any differences due to this issue.

In our comparison, we have randomly taken 10,000 points in the following Sentinel-1 Sigma0 images: **S1A\_IW\_GRDH\_SIGMA0\_DV\_20171024T173238\_ASCENDING\_161\_F229\_V110\_VV** and **S1A\_IW\_GRDH\_SIGMA0\_DV\_20171024T173238\_ASCENDING\_161\_F229\_V110\_VH**. Next, we have extracted the exact same points from the Google Earth Engine corresponding Sigma0 image. The scatterplots in Figure 1 and Figure 2 show the very close correspondence between both sources of Sigma0.

These images confirm that the output provided by the Terrascope processing chain is within expectations of what other providers deliver, although especially designed to work over Belgium, and additionally cleaned near the borders.

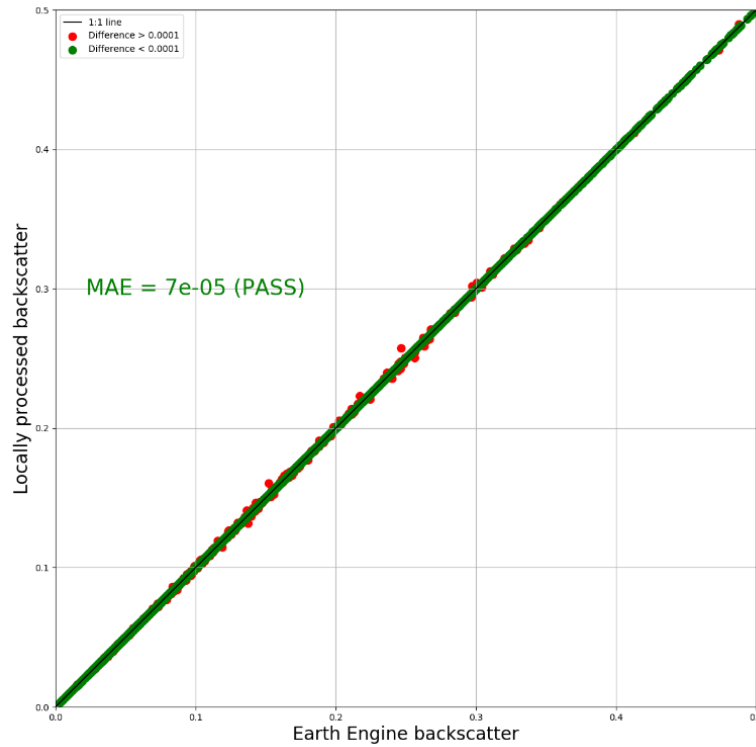


Figure 1: Comparison of 10,000 randomly extracted pixel values of the Terrascope Sigma0 product and the Google Earth Engine Sigma0 product shows an almost perfect agreement between both for the VV band.

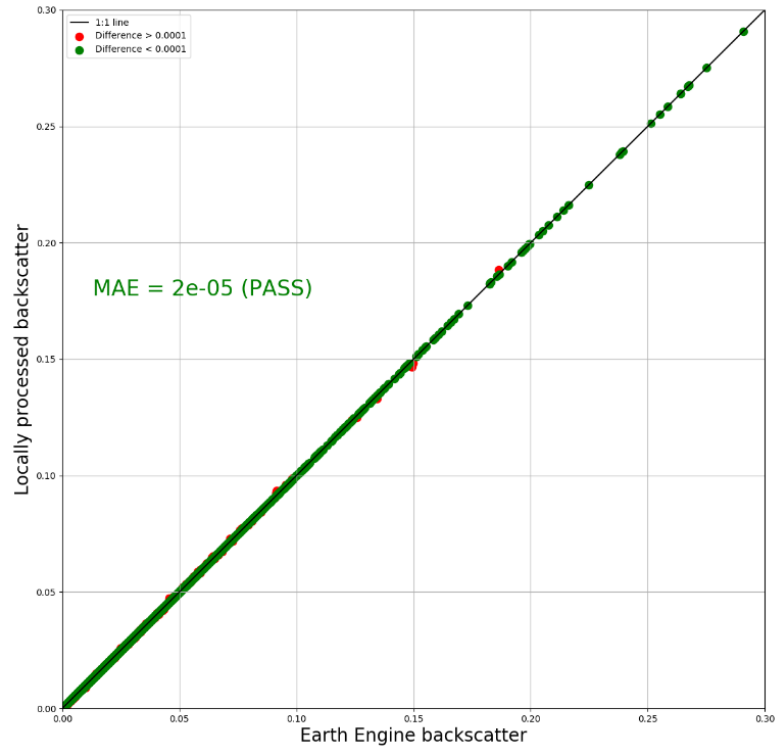


Figure 2: Comparison of 10,000 randomly extracted pixel values of the Terrascope Sigma0 product and the Google Earth Engine Sigma0 product shows an almost perfect agreement between both for the VH band.

## 8. Example Sigma0 image

An example of the Sigma0 product as provided by Terrascope is shown in Figure 3 for the product **S1A\_IW\_GRDH\_SIGMA0\_DV\_20171024T173238\_ASCENDING\_161\_F229\_V110\_VV**. Note that the image shown is not in decibels. The user can transform the values to decibels as desired.

