

DOCUMENT

Radiometric Calibration of S-1 Level-1 Products Generated by the S-1 IPF

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1 INTRODUCTION

The Sentinel-1 (S-1) Instrument Processing Facility (IPF) is responsible for generating the complete family of Level-1 and Level-2 operational products [AD- 1, AD- 2, AD- 3]. An important aspect for users is the ability to easily derive the radar cross-section of both distributed and point targets for ground range detected (GRD) and slant range complex (SLC) products generated by the S-1 IPF.

This document describes and gives an example of how the radar cross-section can be easily calculated.

2 DOCUMENTATION

- AD-1 *S-1 Product Definition, S1-RS-MDA-52-7440
- AD- 2 *S-1 Product Format Specification, S1-RS-MDA-52-7441
- AD-3 *Sentinel-1 Level 1 Detailed Algorithm Definition, S1-TN-MDA-52-7445
- RD-1 *Definition of the TOPS SLC deramping function for products generated by the S-1 IPF, ESA-EOPG-CSCOP-TN-0002.

(*) Latest version of these documents is available on the S-1 product handbook web pages: <u>https://sentinel.esa.int/web/sentinel/user-guides/sentinel-1-sar/document-library</u>

3 CALIBRATION LOOK UP TABLES

3.1 Calibration LUT Description

The L1 products are provided with dedicated Calibration Annotation Data Set (CADS) providing the necessary information to convert the radar reflectivity into physical units. The CADS provides four Look Up Tables (LUTs):

- A_{β} : to transform the radar reflectivity into beta β^{o} where the area normalization is aligned with the slant range
- A_σ: to transform the radar reflectivity into radar cross-section σ^o where the area normalization is aligned with ground range plane
- A_γ: to transform the radar reflectivity into gamma γ^o where the area normalization is aligned with a plane perpendicular to slant range
- A_{dn}: to revert for the final pixel scaling. The final products are coded in 16 bits integers (signed for SLC and unsigned for GRD). Those final products are generated from the same internal SLC product coded in floats. In order to best use the limited



integer dynamic range, the internal SLC is scaled. A_{dn} defines the final scaling from internal SLC to the final product. The use of single calibration constant K for all the final products is ensured by properly considering the final scaling in the equations as shown in Section 3.2.

The Earth model used in the CADS is the ellipsoid inflated with an average height such that the area normalization factor can be simplified to:

- $sin(\alpha)$ in the σ^{o} case
- $tan(\alpha)$ in the γ^{o} case

where α is local incidence angle of the Earth Model used.

The LUT available in the CADS are provided as function of the pixel index and regularly updated in azimuth time to accommodate for the platform roll steering, effectively changing the angel of view around the orbit.

The CADS is located in the calibration XML files located in *annotation/calibration* folder. The L1 Annotation Data Set (LADS) is the located in the annotation folder instead. For example:

S1A_EW_GRDM_1SDH_20150519T125352_20150519T125456_005990_007B81_52BE.SAFE/

unioution
calibration
calibration-s1a-ew-grd-hh-20150519t125352-20150519t125456-005990-007b81-001.xml calibration-s1a-ew-grd-hv-20150519t125352-20150519t125456-005990-007b81-002.xml
noise-s1a-ew-grd-hh-20150519t125352-20150519t125456-005990-007b81-001.xml noise-s1a-ew-grd-hv-20150519t125352-20150519t125456-005990-007b81-002.xml
s1a-ew-grd-hh-20150519t125352-20150519t125456-005990-007b81-001.xml s1a-ew-grd-hv-20150519t125352-20150519t125456-005990-007b81-002.xml
— manifest.safe — measurement s1a-ew-grd-hh-20150519t125352-20150519t125456-005990-007b81-001.tiff s1a-ew-grd-hv-20150519t125352-20150519t125456-005990-007b81-002.tiff — preview

Figure 1: Representation of the product folder tree, with in red the CADS and in blue the LADS

3.2 **Calibration LUT Definition**

The calibration LUTs provided in the CADS are defined to radiometrically calibrate distributed targets. As per the radar equation the calibration of S-1 products follows the same generic formulation as Envisat ASAR. In the case of radar cross-section σ^{0} :

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$$\sigma^{0} = \frac{DN^{2}}{A_{dn}^{2} \cdot K} \cdot \frac{1}{G_{eap}^{2}} \cdot \left(\frac{R}{R_{ref}}\right)^{3} \cdot \sin(\alpha)$$

where:

- $\frac{1}{G_{eap}^2}$ is the elevation antenna pattern (EAP) correction (2-way)
- $\left(\frac{R}{R_{ref}}\right)^3$ is the range spreading loss (RSL) correction
- A_{dn} is the product final scaling from internal SLC to final SLC or GRD
- *α* is the local incidence angle.

In the case of Sentinel-1, the EAP and RSL corrections are by default applied by the S-1 IPF such that the above formula simplifies to:

$$\sigma^0 = \frac{DN^2}{A_{dn}^2 \cdot K} \sin(\alpha)$$

Consequently, the radar cross-section LUT (A_{σ}) is defined as:

$$A_{\sigma} = \sqrt{\frac{A_{dn}^2 \cdot K}{\sin(\alpha)}}$$

Similarly the other LUTs are derived as:

$$A_{\beta} = \sqrt{A_{dn}^2 \cdot K}$$
$$A_{\gamma} = \sqrt{\frac{A_{dn}^2 \cdot K}{\tan(\alpha)}}$$

It can be seen that the calibration LUTs essentially contains the area normalisation factor and the calibration constant. These have a smooth evolution in range. The calibration LUTs are therefore provided as sub-sampled range vector. The LUTs can therefore be safely interpolated to each pixel without any risk of interpolation artefacts.

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With the introduction of the calibration LUT, it is not necessary to compute anymore the incidence angle as it is built-in the LUT. However if necessary it can simply be retrieved by:

$$\cos(\alpha) = \frac{A_{\gamma}^2}{A_{\alpha}^2}$$

Similarly, the calibration constant K is built-in the LUTs and is just provided for completeness.

3.3 Mapping with Product Specification

The table below provides the mapping between the above variables and the product annotations (within the Calibration Annotation Data Set (CADS) and L1 Annotation Data Set (LADS)).

A_{β}	/calibration/calibrationVectorList/calibrationVector/betaNought	CADS
A_{σ}	/calibration/calibrationVectorList/calibrationVector/sigmaNought	CADS
A_{γ}	/calibration/calibrationVectorList/calibrationVector/gamma	CADS
A_{dn}	/calibration/calibrationVectorList/calibrationVector/dn	CADS
K	/calibration/calibrationInformation/absoluteCalibrationConstant	CADS
Δ_a	/product/imageAnnotation/imageInformation/azimuthPixelSpacing	LADS
Δ_r	/product/imageAnnotation/imageInformation/rangePixelSpacing	LADS

4 RADIOMETRIC CALIBRATION OF DISTRIBUTED TARGETS

As defined in the product specification [AD- 2], it is possible to calibrate the data using straight away the calibration LUTs using the following relations:

$$\sigma^{0} = \frac{DN^{2}}{A_{\sigma}^{2}}$$
$$\beta^{0} = \frac{DN^{2}}{A_{\beta}^{2}}$$
$$\gamma_{0} = \frac{DN^{2}}{A_{\gamma}^{2}}$$

where DN is the pixel Digital Number being in the case of:

- GRD: the pixel amplitude directly taken from the measurement file
- SLC: the pixel amplitude defined SQRT(I² + Q²) where I and Q are the real and imaginary values from the measurement file.

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The LUTs provide the σ^{0} , β^{0} and γ^{0} in natural values. It is possible to access dB as following (e.g. for σ^{0}):

$$\sigma_{db}^0 = 10.\log_{10}\sigma^0$$

In order to improve the accuracy, the average backscatter coefficient over an area of interest can be used instead:

$$\sigma^0 = \frac{\langle DN \rangle^2}{A_{\sigma}^2}$$

As the calibration LUTs are regularly updated in azimuth time, it is necessary to select the closest LUT in time to the range line of the distributed target.

4.1 Numerical Example

A numerical example of calculating the normalized radar cross-section σ^{0} , as described in Section 4, is given for a small uniform region in an S1A_IW_SLC product.

For a small uniform region, the average product intensity, $< DN^2 >$, has a value of 22142.71. Using the closest σ^0 calibration vector in the L1 CADS to that of the selected region (i.e. in azimuth time) at range position 8720, as shown in Figure 2, directly derives the normalised radar cross-section:

$$\sigma_{db}^{0} = 10.LOG10 \left[\frac{22142.71}{319.946^2} \right] = -6.65 \text{ dB}$$

As the region is small a single LUT value has been used – for larger regions in range a spread of LUT values would need to be used.

```
<calibrationVector>
        <azimuthTime>2015-05-04T22:45:51.243650</azimuthTime>
        line>5300</line>
        <cpre>cpixel count="514">0 40 80 120 160 200 240 280 ... 8600 8640 8680
            8720 8760 8800 8840 ...
...
        <dn count="514">2.370000e+02 2.370000e+02 2.370000e+02 2.370000e+02
            2.370000e+02 2.370000e+02 2.370000e+02 ... 2.370000e+02
            2.370000e+02 2.370000e+02 2.370000e+02 2.370000e+02
            2.370000e+02 2.370000e+02 2.370000e+02 2.370000e+02
            2.370000e+02 2.370000e+02 2.370000e+02 2.370000e+02
            2.370000e+02 ...
...

...

...

...

...
```

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•••

<gamma count="514">3.079890e+02 3.079099e+02 3.078309e+02
3.077520e+02 3.076731e+02 3.075944e+02 3.075157e+02 3.074371e+02 ...
2.927296E+02 2.926659E+02 2.926021E+02 2.925384E+02 2.924748E+02
2.924112E+02 2.923477E+02 ...

Figure 2. Example DN, σ^{o} and γ^{o} LUTs

It is important to derive the average product intensity, $\langle DN^2 \rangle$, by converting the pixel amplitude to intensity before calculating the average. Thus using the following equation for a region of L by M pixels with a total of N pixels:

$$< DN^2 > = \frac{1}{N} \sum_{i=1}^{i=L} \sum_{j=1}^{i=M} DN_{i,j}^2$$

5 RADIOMETRIC CALIBRATION OF POINT TARGETS

5.1 **Point Target Calibration for GRD Products**

The basic equation to calculate the radar cross-section (σ) for point targets using GRD imagery is:

$$\sigma = \frac{I_P}{A_{dn}^2 C_F} \frac{P_A}{K} . \sin(\alpha)$$

where

- I_P is the total power in the point target Impulse Response Function (IRF) mainlobe
- C_F is the relative power in the point target sidelobes
- P_A is the product pixel area
- K is the calibration constant
- *α* is the point target incidence angle.

Parameters IP, CF and PA are described in Sections 5.3 to 5.5.

Considering the definition of the LUT defined in Section 3.2. The following equation relying on the A_{σ} LUT can be used instead:



$$\sigma = \frac{I_P}{C_F} \frac{P_A}{A_\sigma^2}$$

5.2 **Point Target Calibration for SLC Products**

The corresponding basic equation for SLC data is:

$$\sigma = \frac{I_P}{A_{dn}^2 \cdot C_F} \frac{P_A}{K}$$

Note that for SLC data, deramping needs to be performed before the point target radar cross-section can be calculated. This step is described in [RD-1].

5.3 Total Power in Mainlobe (I_P)

To calculate this parameter, it is necessary to remove the background radar cross-section contribution from distributed target on which the point target is superimposed. The following steps should be carried out in association with Figure 3:

- Extract a sub image centred on the point target (e.g. of 256 by 256 pixels)
- Convert the pixel values to intensities by squaring
- Choose four areas of size e.g. 10 by 10 pixels around the point target, positioned in such a way that they exclude pixels attributable to the point target or any other point target responses, to get a representative sample of the background intensity
- Square each of the background sample pixels, sum them, and divide by the number of pixels (e.g. 400) to derive a mean pixel intensity due to the background
- Interpolate the intensity background corrected sub-image by a factor of 8
- Subtract this mean from each pixel in the sub image
- Integrate this interpolated and background corrected image over the size of 2 by 2 resolution cells, centred on the point target, to give I_P (i.e. over a size of 2x by 2y where x and y are the spatial resolutions in range and azimuth respectively where the spatial resolution is the 3dB width of the point target mainlobe).





Figure 3. Definition of point target response area and background areas for IRF analysis.

5.4 Relative Power in Sidelobes (C_F)

This is defined by:

$$C_F = \frac{1}{(1 + ISLR)}$$

where the integrated sidelobe ratio (ISLR) is the ratio of the energy of the sidelobes within an area of 20 by 20 resolution cells excluding the mainlobe to the energy of the mainlobe (2 by 2 resolution cells) – see Figure 3.

5.5 Pixel Area (PA)

Extract the pixel spacing in both the range and azimuth direction and multiply these values, i.e.

$$P_A = \Delta_a \cdot \Delta_r$$

where:

- Δ_a is the the azimuth pixel spacing in meters
- Δ_r is the the range pixel spacing in meters

5.6 Numerical Example

A numerical example of calculating the radar cross-section σ of a point target, as described in Section 5.1, is given for a bright point target in an S1A_S1_GRDF product.

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The first step is to calculate the total power in the mainlobe, I_P as described in Section 5.3. Figure 4 shows the original image (the blue cross shows the selected peak of the IRF and the four background boxes), the interpolated image and slices through the peak of the IRF (red for azimuth and black for range). The interpolated image and slices are shown before background subtraction for illustrative purposes only.



Figure 4. Point Target Impulse Response Function

To determine I_P the half-power (3dB) width of the IRF slices is required to determine the azimuth and range spatial resolutions and hence the size of the mainlobe. For this example, the azimuth spatial resolution is 8.11m and the range resolution is 8.82m. Note that as the pixel size is 4m in both azimuth and range, the product is adequately sampled (i.e. at least two pixels per resolution cell).

The sum of the pixel intensities in the interpolated image within the half-power width of the IRF gives the total power I_P . For this example, the total power in the mainlobe is 99.94 dB.

The next step is to calculate the relative power in the sidelobes C_F as described in Section 5.4. This requires the integrated sidelobe ratio which for this example is -13.30 dB and hence C_F is -0.20 dB. The pixel area P_A is extracted from the L1 Image Annotation Data Set as shown in Figure 5 which for this example is 12.04 dB.

Thus the point target radar cross-section is calculated:

 $\sigma_{db} = 99.94 + 0.20 + 12.04 - 10 \log 10 [270.7972 * 270.7972] = 63.53 \, dBm^2$

where 270.7972 is the σ° LUT value for range position 2320 shown in Figure 6.

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Figure 5. Product Pixel Spacing

<	calibrationVector> <azimuthtime>2014-09-09T05:42:38.412186</azimuthtime> <line>21829</line>
	<pre><pixel count="516">0 40 80 120 160 200 240 280 2200 2240 2280 2320 2360 2400 2440</pixel></pre>
	<pre><dn count="516">1.600000e+02 1.600000e+02 1.600000e+02</dn></pre>
•••	
	<pre><sigmanought count="516">2.757337e+02 2.756456e+02 2.755578e+02 2.754700e+02 2.753824e+02 2.752949e+02 2.752074e+02 2.751201e+02 2.710446E+02 2.709620E+02 2.708796E+02 2.707972E+02 2.707150E+02 2.706329E+02 2.705508E+02</sigmanought></pre>
•••	
	<pre><gamma count="516">2.675622e+02 2.674658e+02 2.673696e+02 2.672736e+02 2.671777e+02 2.670818e+02 2.669859e+02 2.668903e+02 2.624129E+02 2.623219E+02 2.622311E+02 2.621403E+02 2.620496E+02 2.619590E+02 2.618685E+02</gamma></pre>

Figure 6. Example DN, σ^{o} and γ LUT

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