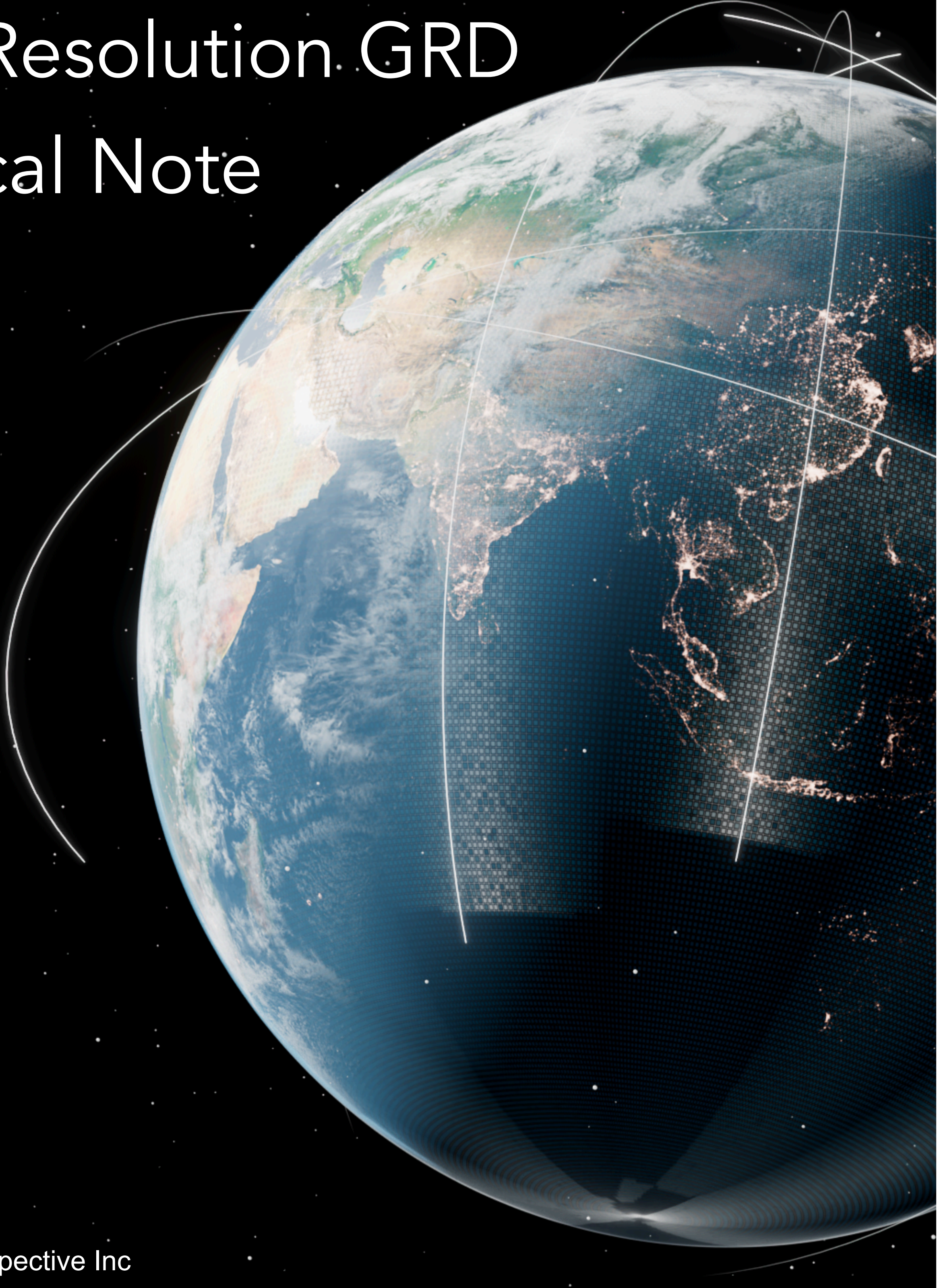
Synspective SAR DATA Super-Resolution GRD Technical Note



Version 2.1
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Revision History

Version	Date	Description
1.0	May 9, 2023	- First edition
2.0	Aug 1, 2023	- Added SR-GRD products for Sliding Spotlight mode
2.1	May 23, 2025	- Changed the cover pages and header coloring

1 INTRODUCTION

Due to geometric and radar constraints SAR imaging is characterized by limited spatial resolution. Therefore, one point-like target appears as a small, smeared circle surrounded by a cross. The circle and the cross represent the *Impulse Response Function* (IRF) of the acquisition system; the circle is referred to as the *mainlobe* of the IRF whereas the cross as the *sidelobes*.

The leftmost panel of Figure 1.1 shows a closeup over a corner reflector as imaged by SAR; the mainlobe and the sidelobes are clearly visible. The finite extent of the mainlobe and the presence of the sidelobes prevent SAR images to be easily interpreted, for this reason many algorithms have been created for improving the quality of the SAR imaging; these algorithms can be generically referred to as *super-resolution* algorithms. The Spatially Variant Apodization (SVA) algorithm presented here can be regarded as one super-resolution algorithm. SVA does not modify the extent of the mainlobe, it rather aims at removing the sidelobes. The rightmost panel shows the same corner after the SVA filter is applied. Most of the energy gathered by the sidelobes was removed while preserving the mainlobe extent and power.

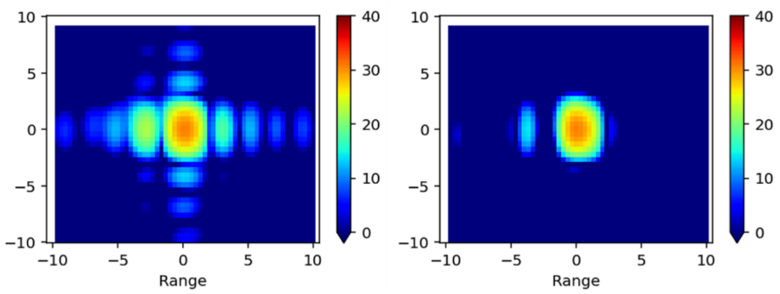

Figure 1.1 Example of sidelobe suppression by SVA.

The SVA filter explores a small neighborhood of the image at a time and determines whether the pixels belong to mainlobe or sidelobes; if they are classified as sidelobes, they are set to zero; they are left unchanged otherwise. In order to determine whether the pixels belong to the mainlobe or to sidelobes it is important that the resolution of the image is exactly double (or any integer multiple; two is used in current Synspective products) of the sampling step along both directions. For this reason, the SLC needs to be upsampled before applying the SVA. As a consequence, the size (in terms of pixels, GigaBytes) of a SVA processed SLC is larger than the original SLC image.

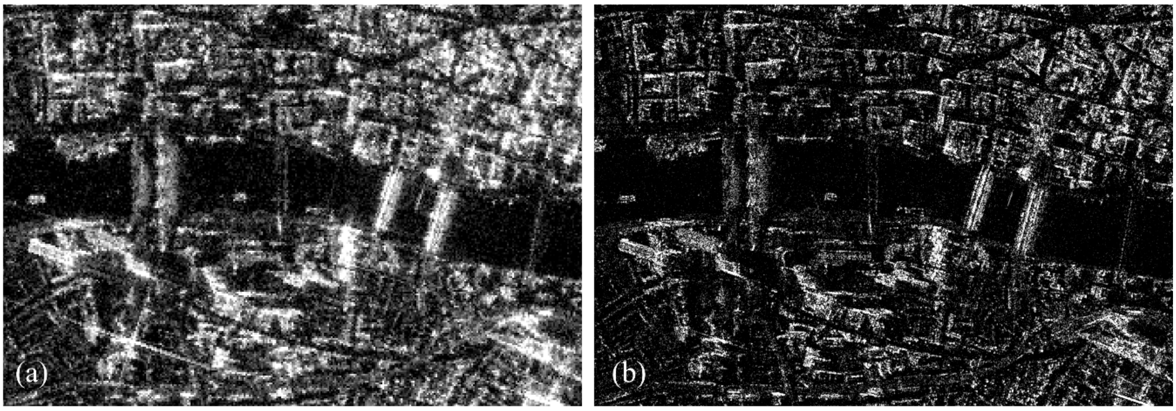

Figure 1.2 Comparison between GRD (left) and SR-GRD (right) products.

Once the SVA filter is applied to the SLC image, the SVA-processed SLC is projected on the Earth ellipsoid to create one Super-Resolution GRD (SR-GRD) image. Unless otherwise stated the examples in this document refer to Stripmap mode. The procedure for creating SR-GRD products from Sliding Spotlight mode is identical up to resolution and consequently, pixel spacing.

The performance of SVA is analyzed in section 2. The projection on the Earth ellipsoid is discussed in section 3.

2 SIDELOBES SUPPRESSION BY SVA

The effectiveness of the SVA algorithm was assessed by analyzing one Stripmap image gathered on the Rosamond site. Several corner reflectors were installed in this area; also, the low clutter level makes it a proper site for assessing SAR image quality.

Figure 2.1 shows the SAR backscattered intensity gathered over the corners in the Rosamond area. Letters are present at the left of each corner further analyzed in this document. The cross-shaped artifact surrounding each corner is clearly visible, especially for the biggest ones.

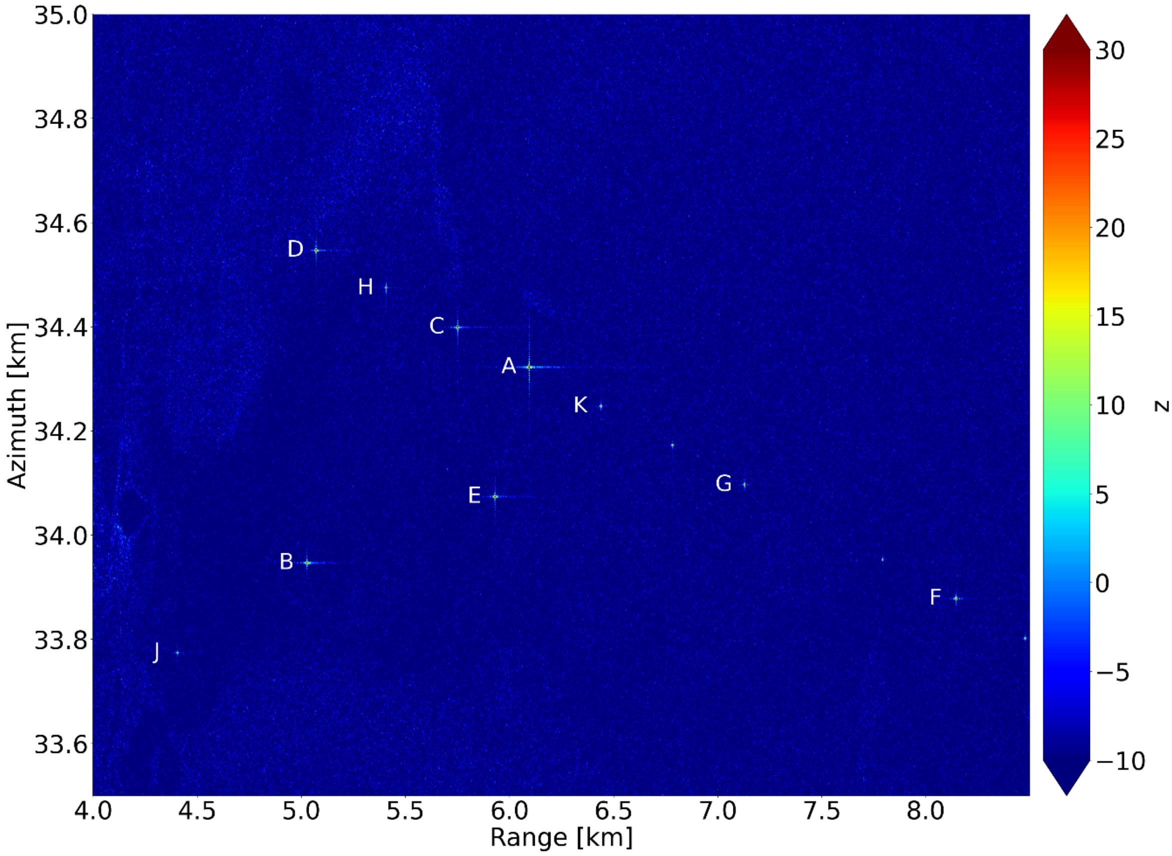

Figure 2.1 Rosamond area with several corner reflectors before SVA filtering.

Figure 2.2 shows the same Rosamond region as in Figure 2.1 but after applying the SVA filter. Globally the image appears less bright; the cross-shaped artifacts have been canceled.

It must be remarked that whenever SVA classifies one pixel as "sidelobe" it sets its value equal to zero. Exactly zero is not physically consistent and special care must be paid when interpreting such values. Furthermore, when converting the amplitude image to decibels, an error is returned whenever a zero is encountered (as the logarithm of zero is not defined). For these reasons it was decided to modify the SVA algorithm so that the values returned by SVA is one small value, still not exactly zero. In order to cope with both calibrated and not calibrated SAR images, the small value to be used for replacing the sidelobes was drawn from the image itself: it was set as the minimum value encountered in the image greater than zero.

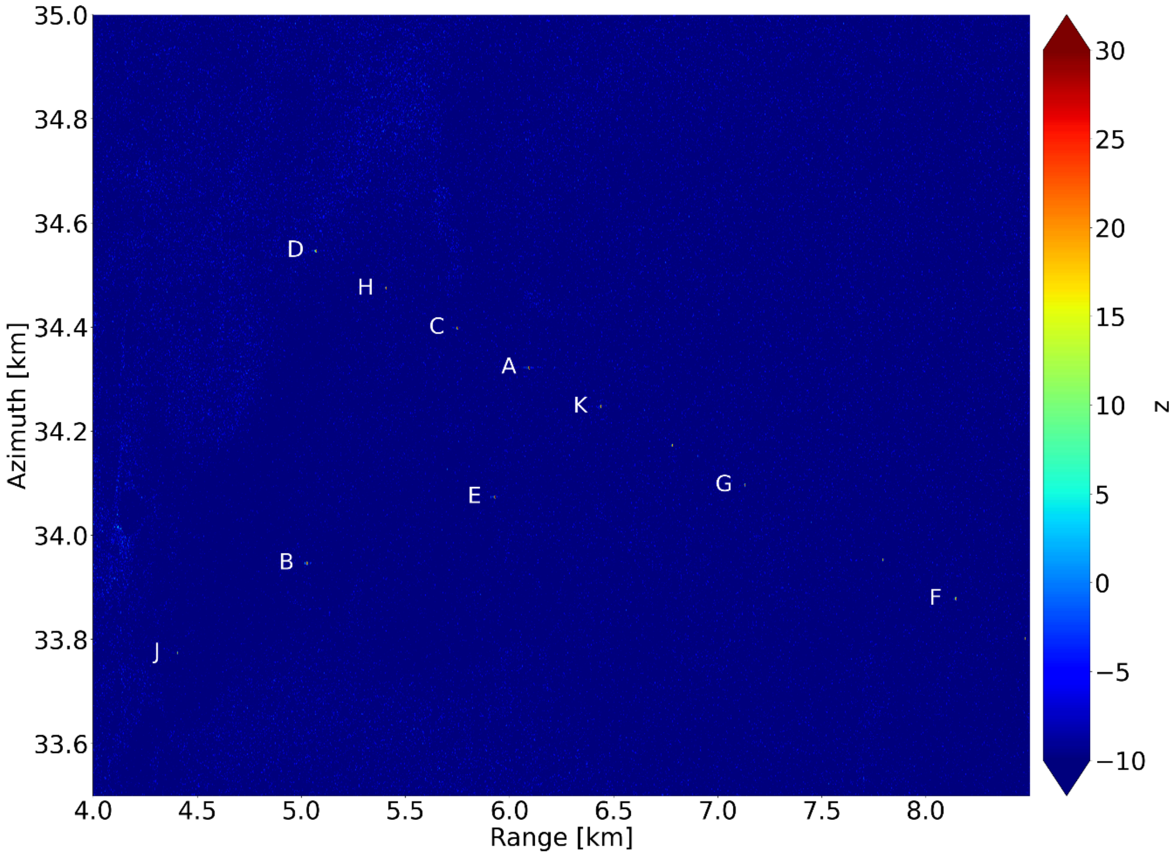

Figure 2.2 Rosamond area with several corner reflectors after SVA filtering.

Figure 2.3 shows the ten corner reflectors chosen for further analyses. They are identified by one capital letter as in figures 2.1 and 2.2.

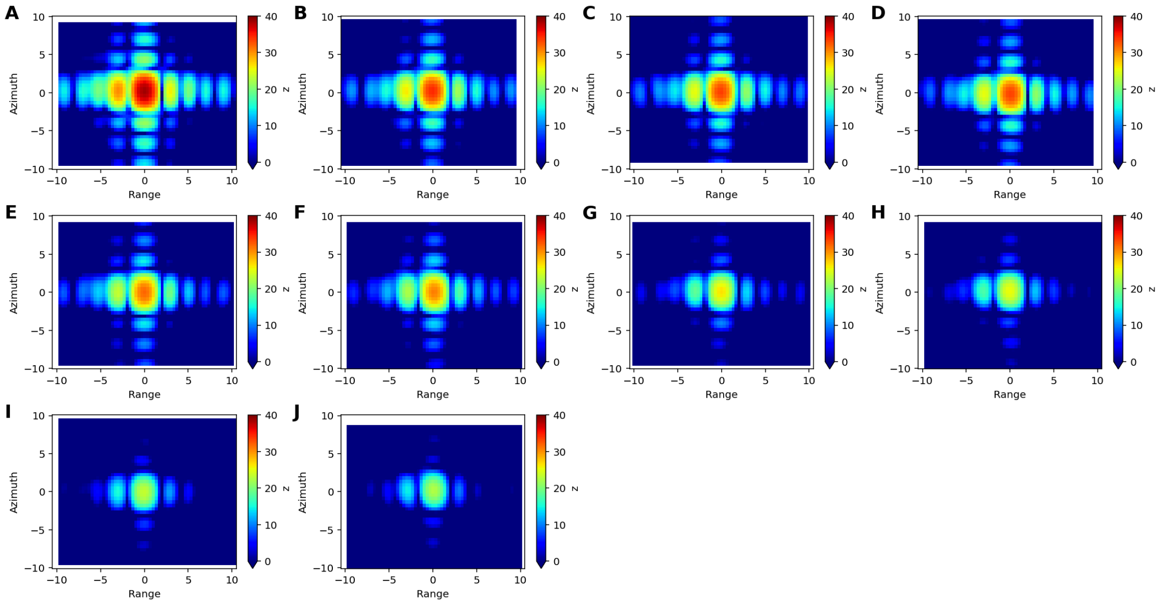

Figure 2.3 Images of the 10 corner reflectors in the Rosamond site before filtering with the SVA algorithm.

Figure 2.4 shows the zoom on the corners after SVA processing. The sidelobe removal in the azimuth direction is almost total. Concerning the range direction, one small (less than 20dB below the mainlobe) sidelobe is still visible next to the mainlobe for all the corner reflectors. This residual sidelobe is probably due to the oscillations of the spectrum in the range direction. As a matter of fact, SVA requires the spectrum to be flat for optimal performance when recognizing the sidelobes. StriX acquisitions are characterized by almost flat spectrum, however the chirp used during focusing sometimes oscillates. The compensation of these oscillations is currently being implemented. It is expected that the sidelobe removal will be even more effective by then.

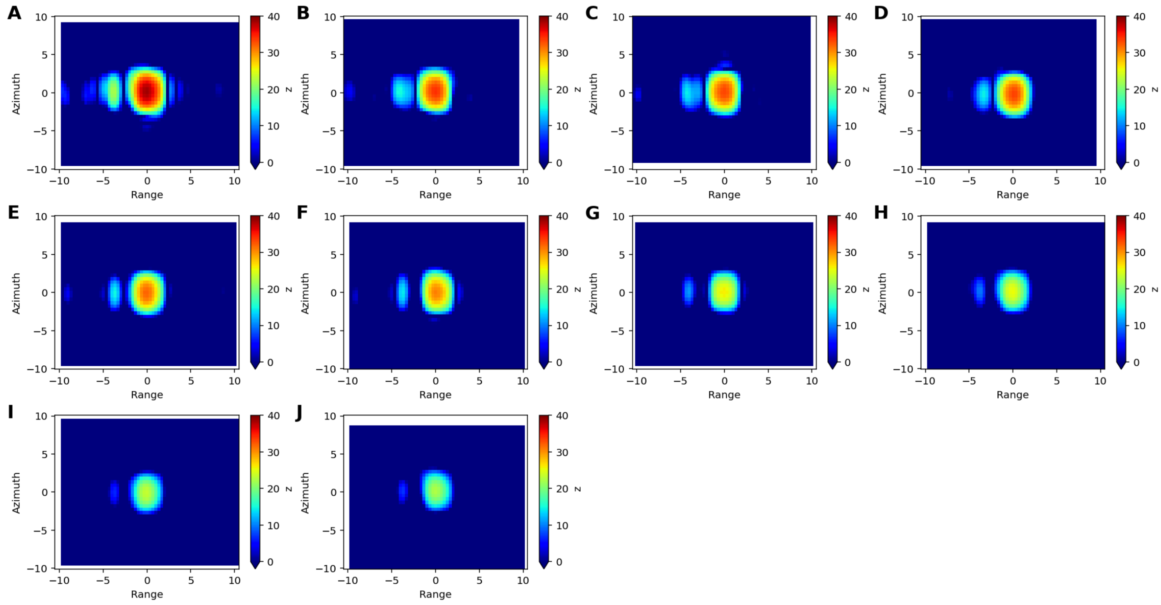

Figure 2.4 Images of the 10 corner reflectors in the Rosamond site after filtering with the SVA algorithm.

Figures 2.5 and 2.6 show the range and azimuth cuts in correspondence of the 10 corners. In blue, the original SLC is shown, in red the SVA-processed SLC.

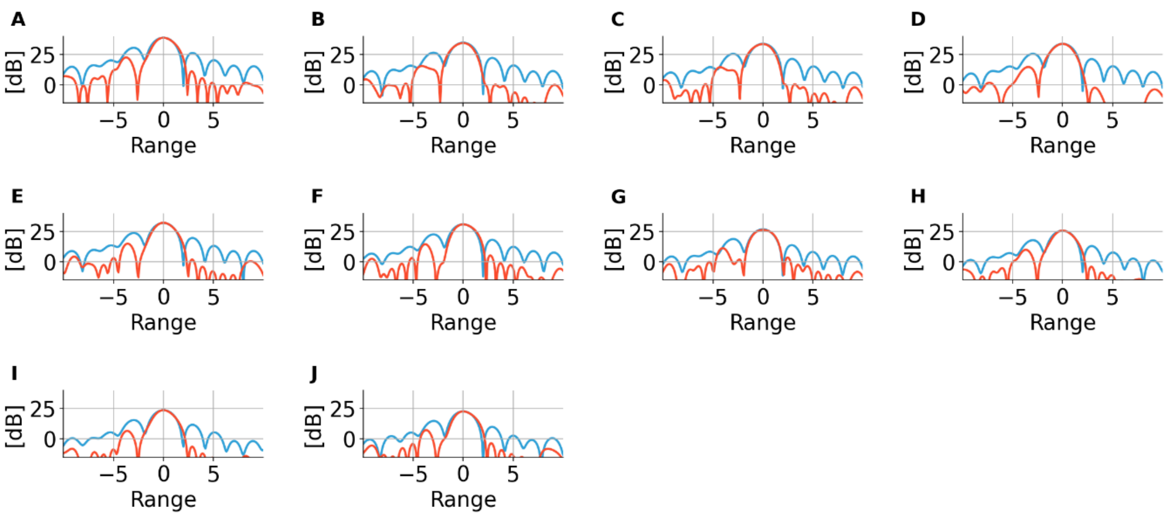

Figure 2.5 Range cuts of the 10 corner reflectors in the Rosamond site. In blue the SLC image, in red the SVA-processed SLC.

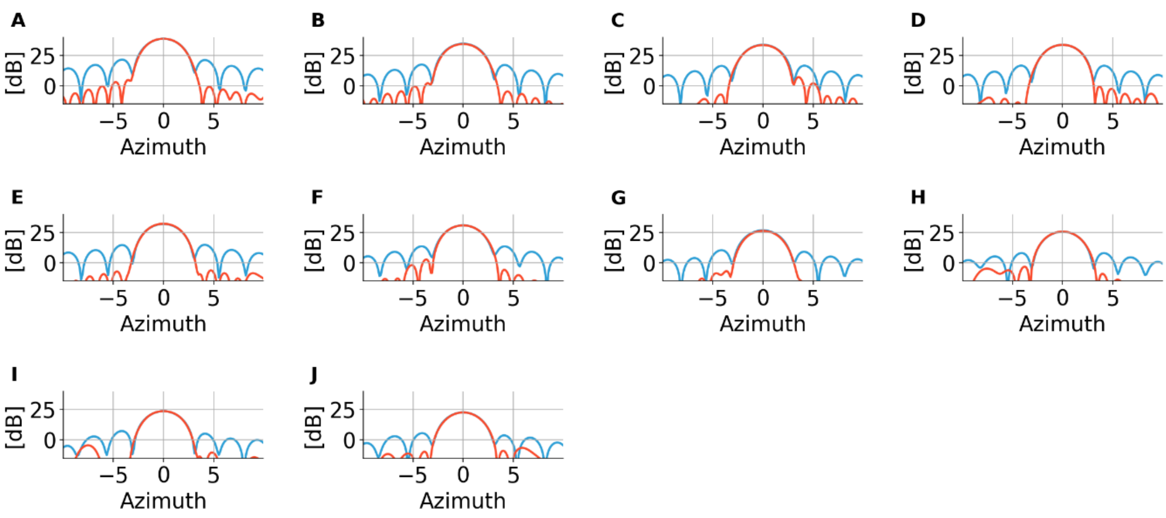

Figure 2.6 Azimuth cuts of the 10 corner reflectors in the Rosamond site. In blue the SLC image, in red the SVA-processed SLC.

The dramatic reduction of the sidelobe level due to the SVA algorithm is clearly visible. It must be remarked that the mainlobe is untouched.

3 SR-GRD BY PROJECTING SVA-PROCESSED SLC ON THE EARTH ELLIPSOID

The creation of Synspective GRD products starting from SLC images follows these processing steps:

1. Intensity computation (squared absolute value)
2. Multi-looking (spatial average)
3. Interpolation on the ground (creation of one intermediate product)
4. Interpolation on the UTM grid (final product)

Several possibilities exist for the implementation of these processing steps, they are discussed in the following sections. The differences between standard GRD products and SR-GRD products are highlighted.

Intensity Computation

The real and imaginary parts of the SLC image are squared and then summed up together. After this operation the phase information of the SLC image is lost and only the information regarding radar intensity is preserved. The sampling grid of the image is unchanged though and matches the one of the SLC. This operation is identical for GRD and SR-GRD products.

Multi-Looking (spatial average)

The interpolation process needed for the projection of the SLC image on the ground is easier whenever a smooth image is provided as an input. For this reason, the spatial average operation often anticipates the interpolation step. However, multi-looking deteriorates the sharpness of SAR images so that avoiding it is preferred when working with SVA-processed images. For this reason, the multi-looking currently implemented for the generation of the GRD images is disabled whenever SR-GRD are requested.

Interpolation on the ground (creation of the intermediate product)

The intermediate product is defined on a grid regularly sampling the Ellipsoid surface (that is ground range rather than slant range) but still oriented as the satellite orbit. Free parameters here are:

1. The interpolator kernel
2. The sampling step of the grid

At this stage, the interpolator kernel can be set as bilinear or nearest neighbor. For GRD products it is set as bilinear; the same choice was made for SR-GRD images. The sampling step was modified though.

Several combinations of interpolator kernel and sampling step were tested. Figure 3.1 shows the configuration chosen for creating the intermediate products out of SVA-processed SLC Stripmap images; that is bilinear kernel and 1m x 1m grid spacing. Top left panel shows the SLC samples (sparse dots) in the presence of one SVA-processed corner. This latter is oversampled by a factor 2 in both azimuth and range directions and set to zero by SVA outside from the mainlobe. Since the grid of the intermediate product has a different spacing, then it is assumed that the sample closest to the peak of the corner can be located with equal probability in one square $\pm\ \Delta/2$ meters wide, centered on the peak (with Δ length of the sampling step of the intermediate product). The output value produced by the bilinear interpolator is shown in the top right panel for each position here simulated. Whenever the sample of the intermediate grid is very close to the peak as sampled by the SLC then a very high value is obtained; this value decreases as the sample moves away from the peak. Since these values are equally probable, the statistics and the average can be immediately computed; they are shown in the bottom panels of Figure 3.4.1. It is important to note that such a fine grid enables us to sample the corner even with spatial average. The drawback is an increase in the image size. The grid spacing in case of Sliding Spotlight images was set equal to 50cm x 50cm.

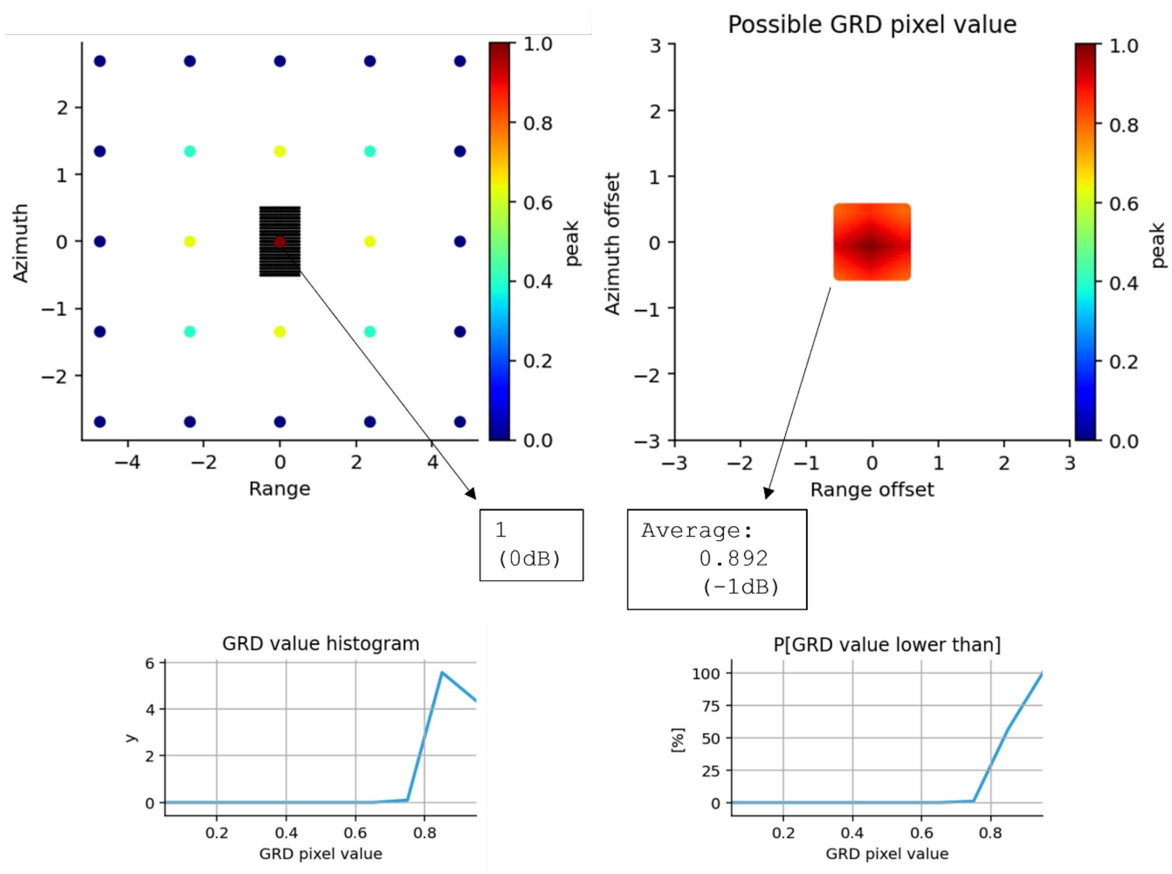

Figure 3.1 Analysis for the parameters controlling the production of the intermediate product.

Interpolation on the UTM grid (final product)

The interpolation of the intermediate product on the UTM grid can be carried out according to different interpolation kernels and grid spacing. Now the choice of the interpolation kernel is wider; still, it was chosen to maintain the nearest neighbor interpolation kernel just as for standard GRD images. In case of Stripmap mode, the sampling step was greatly reduced though: from 5m x 5m to 1m x 1m. This choice produces a difference in file size between GRD and SR-GRD by a factor 25. For Sliding Spotlight mode, the sampling step was changed from 1m x 1m to 50cm x 50cm resulting in 4 times bigger GRD images.

4 REFERENCE DOCUMENTS

[1] Stankwitz, H. C., Dallaire, R. J., & Fienup, J. R. (1995). Nonlinear apodization for sidelobe control in SAR imagery. *IEEE Transactions on Aerospace and Electronic Systems*, 31(1), 267-279.

[2] Smith, B. H. (2000). Generalization of spatially variant apodization to noninteger Nyquist sampling rates. *IEEE Transactions on Image Processing*, 9(6), 1088-1093.

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