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An Analysis of Black Fill Artefacts Noise Removal on GRD Products Sentinel-1 Data

Haris Suka Dyatmika[#], Katmoko Ari Sambodo[#], Rahmat Arief [#]

[#] *Remote Sensing Technology and Data Centre – LAPAN, Jakarta, 13710, Indonesia*
E-mail: haris.suka@lapan.go.id; katmoko_ari@lapan.go.id; rahmat.arief@lapan.go.id

***Abstract*— Synthetic Aperture Radar (SAR) is an active remote sensing satellite which is able to acquire cloud free images in all weather conditions. It is also capable of night time operation. Sentinel-1 data is one of SAR data which is good for monitoring natural resources in area with high cloud cover throughout the year. Processing the data until mosaic product needs good methods and right procedure. An highlight processes to remove noise through border of GRD data scene necessary to do because the processing chain from raw data into L1 GRD (Ground Range Detected) products were leading to artefacts at the near and far range image borders. The artefacts were not visible at a glance in the raw data but, observable clearly after performing mosaic a sets of data. Some methods to fix the problem are available to use such as common noise removal methods. This paper analysed methods to do noise removal i.e. using a tool in ESA's provided Sentinel-1 software (Sentinel Application Platform - SNAP) and proposed noise removal method using simple thresholding and segmentation process. The mosaic products results from both method shown good results visually but the detailed histogram shown that the S-1 Remove GRD Border Noise results still have a very low value pixels in the black-fill area while the Random Noise Removal removed all of the noise. PSNR of raw data mosaic, GRD Border Noise and Random Noise Removal results sequentially 8.5, 18.6 and 19.7 dB indicated that Random Noise Removal get the highest similarity to reference data.**

***Keywords*— sentinel-1; Synthetic Aperture Radar (SAR); noise removal; ground range detected; border noise.**

I. INTRODUCTION

Sentinel-1 data is one of SAR data which is suitable for monitoring natural resources in area with very high cloud cover throughout the year. Sentinel-1 data have been utilized widely because of the distribution policy which provide free, full, and open access to the data [1].

The processing chain from raw data into L1 GRD (Ground Range Detected) products were leading to artefacts at the near and far range image borders. The processing steps contain sampling window start time (SWST) changes, range, and azimuth processing i.e. azimuth and range compression. The SWST changes induced black-fill of the compressed range lines. The SWST determines the range origin of echo data. The change of Earth radius necessitate the sampling start time changes during the acquisition. The sampling window start time (SWST) changes in 10 micro second step at least every 30 second. SWST decreases when the Earth radius increases (since the ground distance is kept almost constant at 400 km in the near range) [2], [3]. The compression processes could induced radiometric artefacts on the black fill/ "no value" pixels on GRD products Sentinel-1 data [4], [5].

The radiometric artefacts were not visible at a glance in the raw data but, observable clearly after performing mosaic a sets of data. Mosaic process merge several scene into one unit data. A seam line was separated each scene in mosaic products. Even, the line could be observed visually. These line is quite disturbing and changing the mosaic data products. Some research have been done to fix the problem. The noise can be removed significantly using thresholding and segmentation [6].

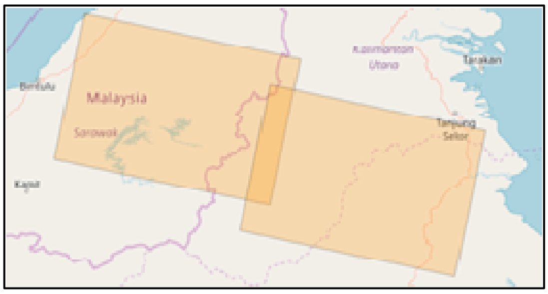
Some approach to masking the noise have been done in many study. Spatial filtering is a basic way to remove noise from image data based on the pixels values. There are mean filtering, adaptive median filtering, decision base algorithm, and many other methods to remove the noise without any attempt to explicitly identify it. Some noisy signal could be applied a de-noising processes by soft-thresholding with statistical decision theory and wavelet transform bases and their properties [7], [8], [9], [10], [11].

High demand of a good mosaic products trigger to improve and evaluate several methods to simplify the data utilization. The work analysed here was an analysis of the method for Masking "no-value" pixels on GRD Products Sentinel-1 Data. The analysed methods uses tool (S-1 Remove GRD Border Noise) in ESA's provided Sentinel-1 software (Sentinel Application Platform - SNAP) and noise removal methods using simple thresholding and segmentation process.

II. Material and Method

A. Data and Problem Setting

The data used to analysed the methods were dual polarization i.e. VV and VH polarization Sentinel-1 data, acquired on December 11th and December 18th 2015 with Interferometric Wide (IW) swath mode. Figure 1a shows data coverage area. Figure 1b shows the GRD raw data, the noise are highlighted with red mark i.e. in the left and right side of the scene. The red highlighted area in Figure 1b were pixels with selected values (red highlighted in histogram in Figure 1c). That area should be the black-fill area with “no data” value pixels but proved in histogram contain random low value as the noises.



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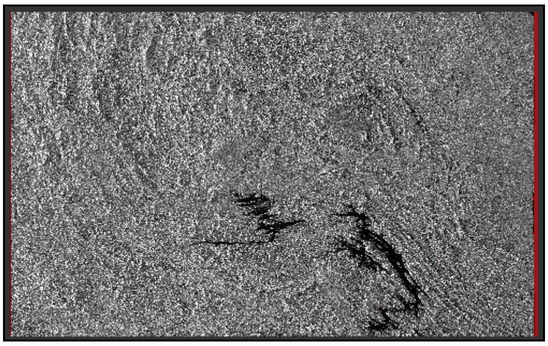

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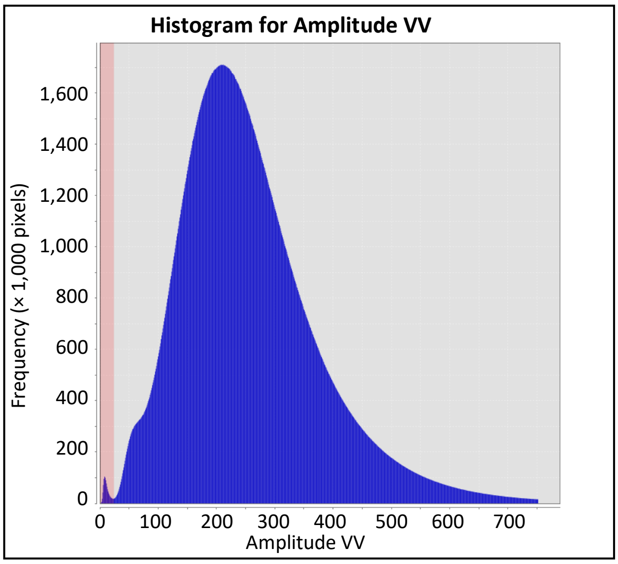
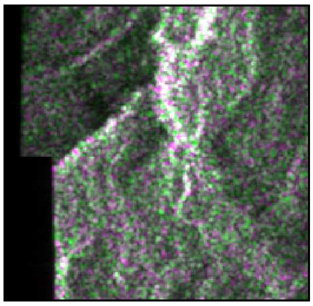


c.

Fig. 1 GRD raw data; a. data coverage, b. sample scene, c. histogram of the scene.

The sampling window start time changes were creating the black-fill “no-value” pixels and different starting of range line as shown in Figure 2a. In the other hand, the azimuth and range compression affected the black-fill area. That area would contained very low values as like random noise that should be as “no-value” pixels data. The noise only observable when the brightness stretched into the noise value, observed in Figure 2b. Before do a mosaic processes the data must be geometrically corrected. The selected method to the geometric correction was range Doppler terrain correction using SNAP. After all processes, the noise were strongly influenced the mosaic product as shown in Figure 2c [12],[13],[6].



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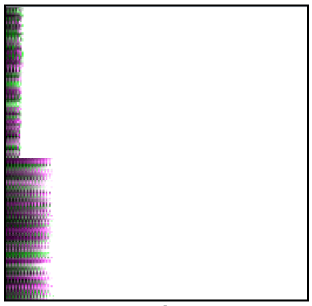

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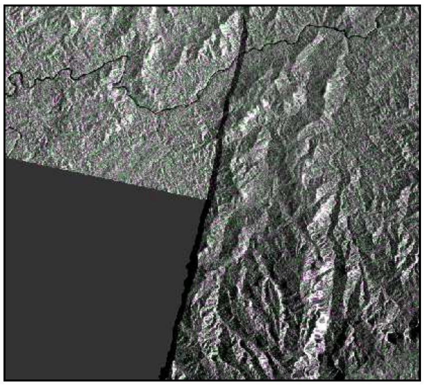
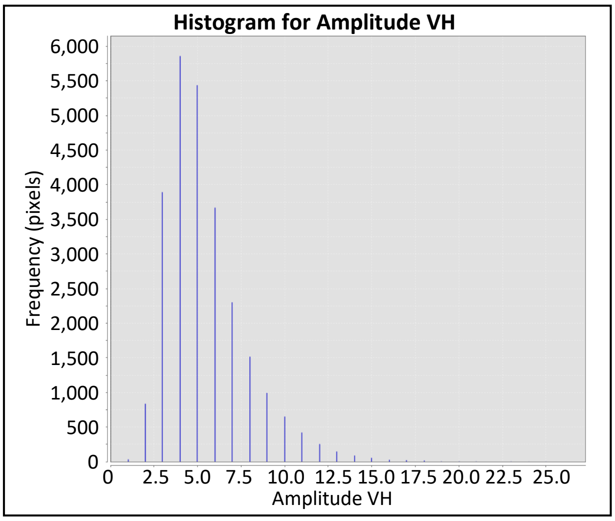


c.

Fig. 2 Example of highlighted data and mosaic of GRD raw products; a. different starting of range line, b. stretched image, c. mosaic of GRD raw product.

The black-fill area have a very low value compare to the normal backscatter value. Cropping small region as a sample in the black-fill area could identified characteristic of the noise such as noise range of values. Figure 3 shows histogram of the noise sample. The sample were shown that the VV noise value are higher than the VH value. The analysis of the sample could help the determining of the threshold for the proposed method.



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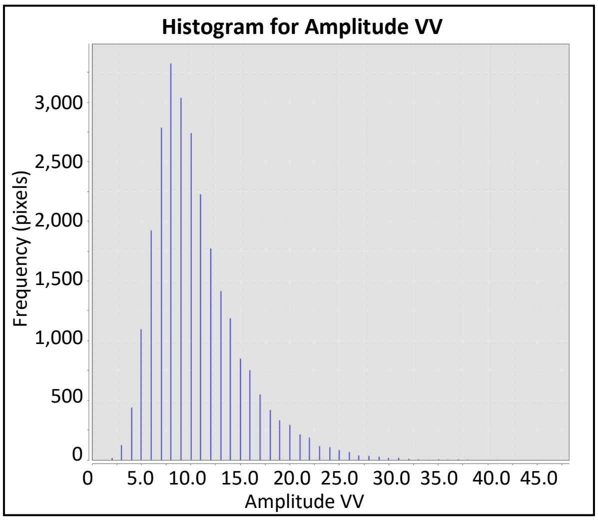


b.

Fig. 3 Amplitude histogram sample of noise; a. VH, b. VV.

Finally, the mosaic of data without noise correction, using S-1 Remove GRD Border Noise – SNAP, and Random Noise Removal in python program would be analysed using linear spectral profile (vertical and horizontal). One of the data would be analysed with detail histogram.

B. S-1 Remove GRD Border Noise

SNAP is a comprehensive software to do processing from the calibration, speckle filtering, terrain correction, analyses, until batch processing, and others. SNAP have a tool to remove the noise on the “no-value” pixels called S-1 Remove GRD Border Noise. The software relies on the usage of de-noising vectors for masking the “no-pixel” values for GRD products. The S-1 Remove GRD Border Noise used de-noising vectors on the Sentinel-1’s metadata for identified the noise pixels then set to zero for make it easier their masking. The metadata contains the thermal noise as a function of the pixel index. The identification preferable to use the co-polarization channel because the brightness intensity usually higher than the cross-polarization. In the fact, the signal-to-noise ratio (SNR) in co-polarization is expected to be higher than in cross-polarization. However, recent studies confirm that cross-polarized signals from satellites will enable the retrieval of strong wind speeds while co-polarized data has saturated. The mask identified on the co-polarization data used to applied on the cross-polarized channel without re-identification [5], [14], [15], [16].

- The SNAP software processing step could be summarized as follows:
- Step 1: Selecting the noise annotation data sets.
- Step 2: Reading the noise vector.
- Step 3: De-noising at near range.
- Step 4: Masking at near range [5].

C. Random Noise Removal

The approach was combination of some de-noising tree algorithm then, named Random Noise Removal to remove the "no-value" pixels noise on GRD products Sentinel-1 data. The noise identification relies on thresholding and segmentation.

Processing whole scene of GRD products would be ineffective because the noise were only on the small region in the left and right side merely. The first step would be restrict the working area. This step reduce many computation load and processing time. The boundary area defined as all pixels for which in restricted column (pixels) both in the left and the right border.

The second step, the noise was classified by set of backscatter amplitude threshold to differ the noise and the real data. Thresholding an image is a kind of quantization that separates some pixels values in two classes even more, depend upon a given threshold value that is usually constant [17]. It would be hard to set the threshold to differ the noise and the data. If the threshold is too high, many pixels data contained information would be erase, especially on the dark object such as water but, if the threshold is too low, many noise would be unclassified. The threshold would be different between each polarization depend on the sample. The noise define as all pixels greater than the noise threshold.

The classified noise by simple thresholding generated suspected noise pixels in the boundary area. The suspected pixels still contain error from overlapping backscatter value between noise and the data. Therefore the results would be re-classified based on the size of segmentation area. The purpose is to separate the noise from the background image used set of criteria such as histogram, similarity, homogeneity, and connected components [18],[19]. The noise usually spread randomly in the border area. The noise were pixels in the segmented area with size less than segmented area size threshold.

The Random Noise Removal method could be summarized as follows:

- Step 1: Limit the noise suspected pixels area around the border (left and right side) of the scene
- Step 2: Perform a simple thresholding process to the backscatter amplitude of the Sentinel-1 data
- Step 3: Perform a segmentation to noise suspected area

- Step 4: Perform a simple thresholding process with the segmented area size
- Step 5: Mask the noise
- Step 6: Remove the masked noise [6].

D. Accuracy Assessment

Both the de-noising for the GRD raw single data and the mosaic results quality were evaluated using several methods. Single data de-noising results were evaluated using histogram. Histogram represents relative frequency of occurrence for various value pixels in the image. An image with L range levels value pixels, the histogram would follow $h(g_k) = n_k / N$, $k = 0, 1, 2, ..., L-1$ wherein n k represent the number of pixels with value g_k as a fraction of the total number of pixels N [18].

Evaluating the mosaic product were performed with both of direct measurement on each method and comparing the mosaic results to a reference image. Visual assessment involve subjective factors and personal preference that can influence the results of the evaluation [20]

Direct measurements performed with visual assessment, horizontal and vertical profile analysis. The horizontal and vertical profile are better than visual assessment to illustrate and compare the similarities and differences between morphometric [21]. The horizontal profile of image was obtained by averaging all pixel intensities in each image column and the vertical profile of the image was obtained by averaging all pixel intensities in each image row [22].

Each fraction of the mosaic results i.e. mosaic of raw data, S-1 Remove GRD Border Noise, and Random Noise Removal results data would be compared to the reference data. The reference data was one of the raw data before mosaic process that didn't contain the noise. The evaluation used peak signal-to-noise ratio (PSNR). In that fraction only one of the data was contain the noise. PSNR gives the similarity score of the processed image against reference image based on mean square error (MSE) of each pixel, could be the simplest reference quality metric, computed by averaging the squared pixels value differences of reference and processed image pixels [23],[24]. PSNR increases with the increasing subjective similarity of a specified content [25].

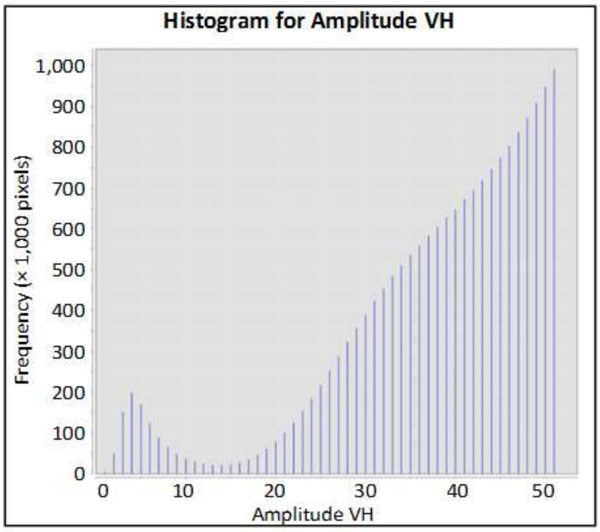
III. Results and Discussion

The experimental data have been proceed with determined procedure and methods above. The results and analysis divided into two section i.e. single scene data and mosaic products analysis.

A. Single Scene Data

One of the GRD raw data directly proceed with two methods above i.e. S-1 Remove GRD Border Noise and Random Noise Removal. Observing visually, the results were the same even with the raw data. So, the evaluation continued with analyzing the histogram distribution especially around the noise amplitude values. Histogram represent the global feature composition of an image that very useful for indexing and retrieving images [26]. The left peak in Figure 4a and 4b indicated the most noise value as the sample taken in Figure 3 with peak on amplitude value around 5 (VH) and 9 (VV) then valley could be the end of the noise value range, so the rest amplitude value would be the data value.

Frequency of noise range value decrease significantly as the results for GRD Border Noise processing. But there were still remained very low frequency, observed from the histogram in Figure 4c and 4d. While Figure 4e and 4f were shown that the frequency of the noise range value have been disappear as the results for Random Noise Removal processing. This results mean that the Random Noise Removal removed the amplitude on the noise predicted value more than the GRD Border Noise.



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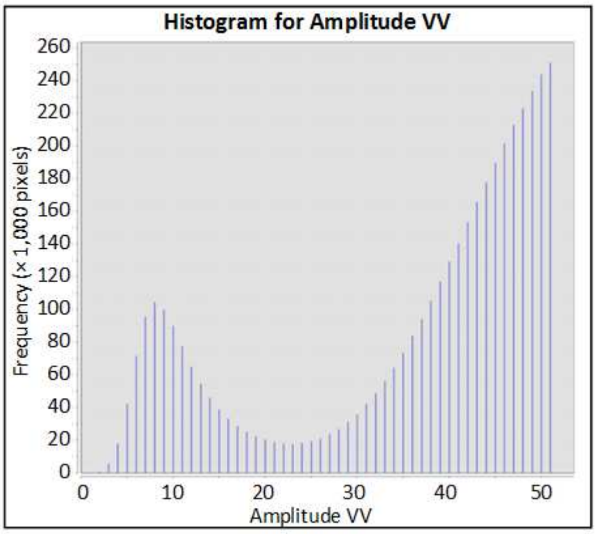

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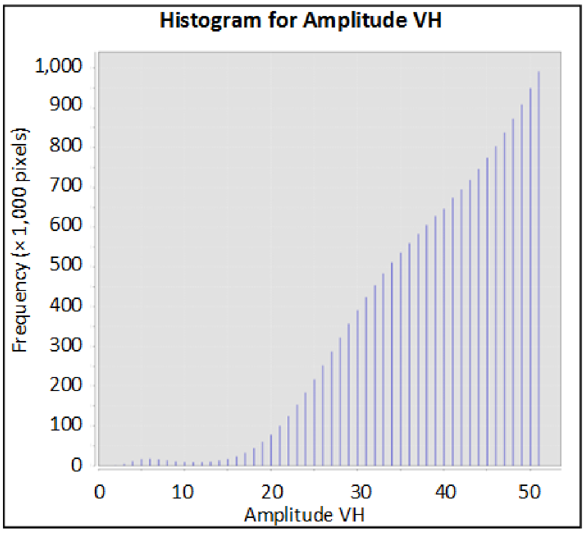

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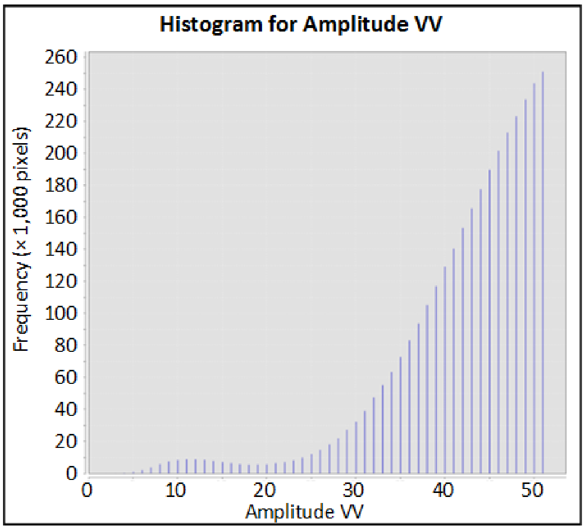

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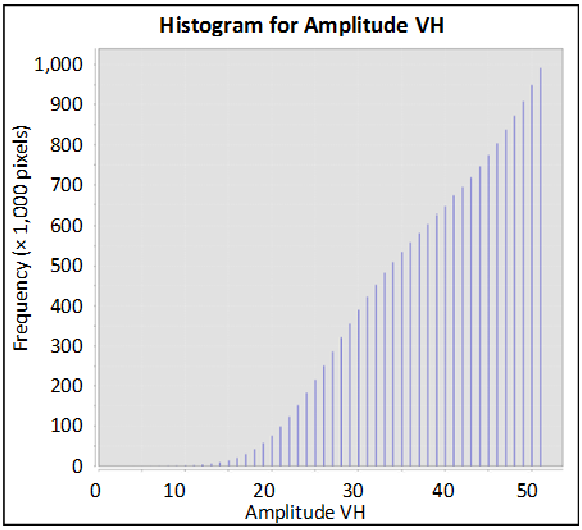

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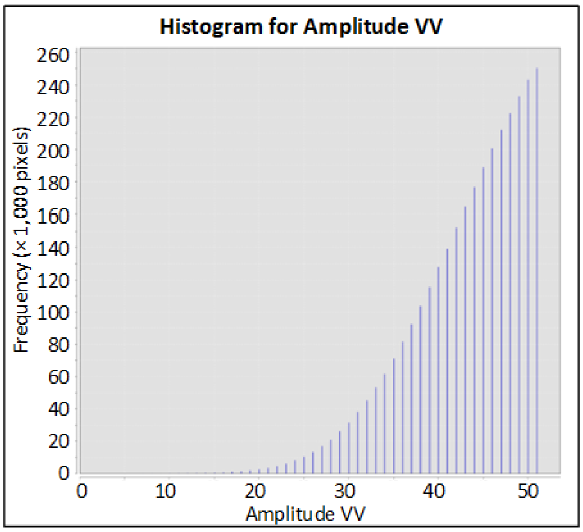

f.

Fig. 4 Histogram of the; a. VH, b. VV GRD raw data, c. VH, d. VV S-1 Remove GRD Border Noise results, e. VH, f. VV Random Noise Removal results.

B. Mosaic Products

Both of the GRD raw data proceed with two methods above i.e. S-1 Remove GRD Border Noise and Random Noise Removal then performed a terrain correction before the mosaic. So there would be three mosaic output i.e. GRD raw data, S-1 Remove GRD Border Noise and Random Noise Removal mosaic.

With visual assessment, the noise effect observed clearly on the GRD raw data mosaic (Figure 5a and 5b). The noise affected overlap area of the mosaic image become a dark line because the “no-value” area didn’t ignored, but still taken into account to the mosaic image. So there were a dark line with low value pixels on the overlap area affected by the noise. While both the S-1 Remove GRD Border Noise (Figure 5c and 5d) and Random Noise Removal (Figure 5e and 5f) mosaic become seamless. Explaining the amplitude value, the GRD raw data mosaic, horizontal and vertical profile were decreasing on the marked red line that is the area affected by the noise (Figure 5a and 5b). On the marked red line (the noise affected area sample), the GRD Border Noise and Random Noise Removal mosaic, horizontal and vertical profile processed image were more stable than the GRD raw data mosaic. But, it was quite hard to differ the difference between the GRD Border Noise and Random Noise Removal mosaic on the visual assessment nor the horizontal and vertical profile.

The results indicated that both GRD Border Noise and Random Noise Removal mosaic have good results for image visualization. The mosaic image have no seam line separate the image border (seamless).

The analysis was continued with PSNR calculation. Digital analysis using digital number (DN) need more precision image to have a good results. A small difference in set of digital number can be distinguished with digital analysis rather than visual analysis. Although visual analysis also have some advantages. PSNR

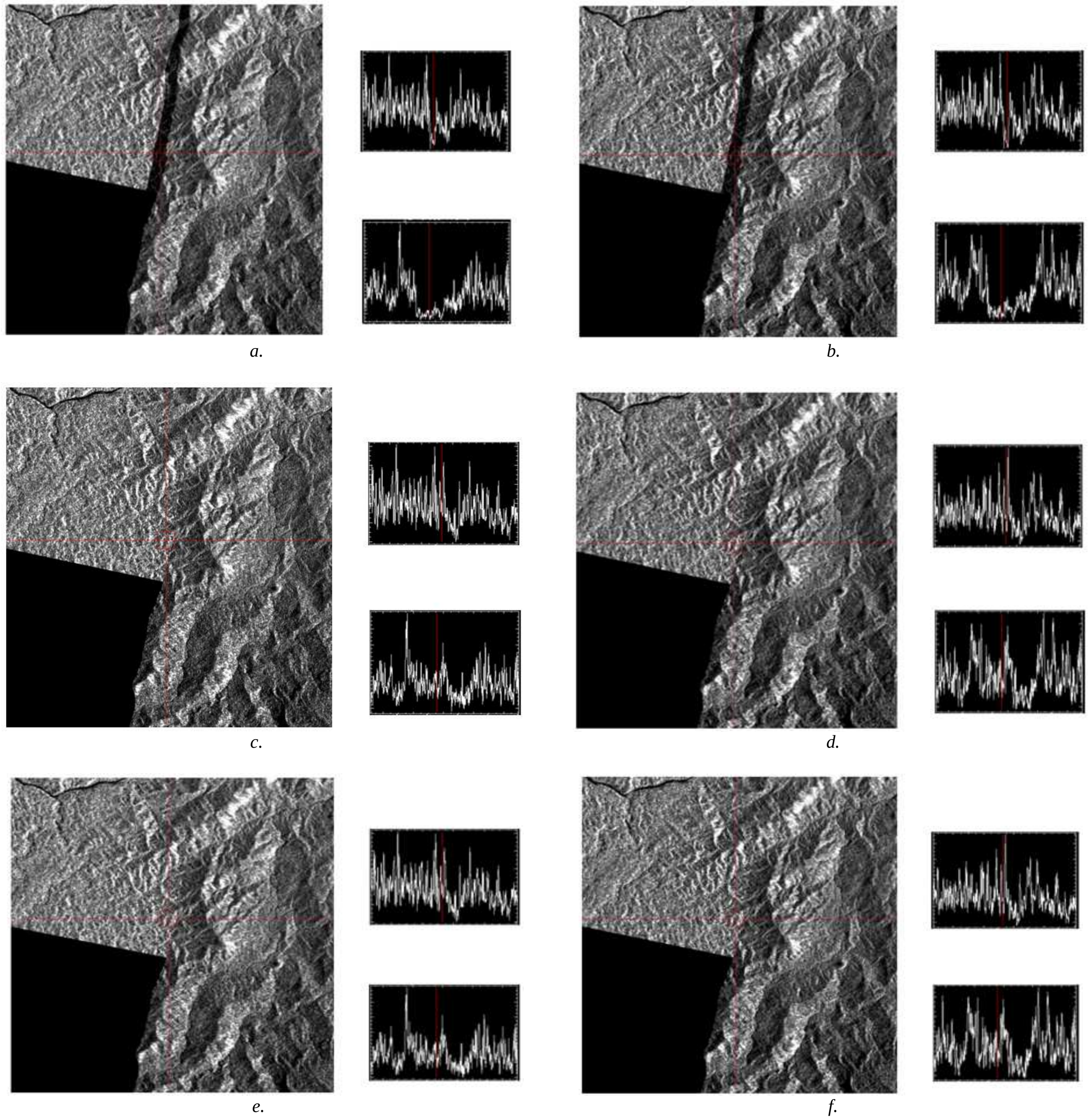

Fig. 5 Mosaic products, horizontal and vertical profile; a. VH, b. VV GRD raw data, c. VH, d. VV S-1 Remove GRD Border Noise results, e. VH, f. VV Random Noise Removal results.

Table 1 shows the PSNR value between the mosaicked image and the reference image on the noise affected area sample.

TABLE I
PSNR VALUE OF VARIOUS METHODS

Method	VH PSNR (dB)	VV PSNR (dB)
GRD raw data	17.93	12.24
S-1 remove GRD border noise	27.99	22.25
random noise removal	29.09	23.19

The table indicated an improvement of the mosaic quality by the Random Noise Removal from the other. The PSNR increased about 1 dB from the S-1 Remove GRD Border Noise method. While from the GRD raw data mosaic the PSNR increased significantly i.e. more than 10 dB. For a comparison, Thompson suggested an acceptable image quality of JPEG2000 compressed image’s PSNR to be above 20 dB [27].

IV. Conclusions

In this paper, some methods for masking "no-value" pixels on GRD Products Sentinel-1 Data have been analyzed. The detailed histogram were shown that the S-1 Remove

GRD Border Noise still had a very low value pixels in the black-fill area but the Random Noise Removal removed all the noise. The Random Noise Removal and Remove GRD Border Noise product PSNR value reach the acceptable value i.e. greater than 20 dB, but the Random Noise Removal product attain the highest PSNR value i.e. 29.09 dB for VH and 23.19 for VV.

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