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InSAR Coherence and Backscatter Images based Analysis for the Anak Krakatau Volcano Eruption

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Abstract: The Anak Krakatau Island and volcano caldera are located at the Sunda Strait between the Java and Sumatra Islands of Indonesia. The volcano started erupting on 22nd December 2018 and collapse of the volcano resulted in Tsunami, the large tidal waves caused mass destruction and life loss in the Java and Sumatra islands. The objective of this study is the interferometric SAR coherence and backscatter images based analysis of the Anak Krakatau Island using Sentinel-1 SAR data. 7 datasets of ESA's Sentinel-1 C-band satellite acquired from 25th November 2018 to 24th January 2019 were used in this study. The InSAR RGB composite images were generated by stacking together the interferometric coherence magnitude images and the sigma nought backscatter images. The Sentinel-2 True Colour Composite (TCC) images before and after volcanic eruption were used to verify the results obtained through InSAR coherence analysis. The sigma nought backscatter image of the 22nd December 2018 clearly indicates the volcano eruption centre and the ocean waves moving away from the Anak Krakatau due to the seismic shock waves caused due to the volcano eruption. The combined interpretation of the results revealed that the severe volcanic eruption on 22nd December 2018 caused a large portion of the volcano to collapse and all the rock debris which submerged to the ocean displaced the ocean water and resulted in the Tsunami at the Indonesian islands.

Keywords: InSAR Coherence, Sigma nought image, Volcano eruption, Tsunami

1. Introduction

SAR Interferometric coherence and backscatter images are very good candidates for understanding the surface deformations [1], [2]. Since Microwave radiations can penetrate the thick volcanic ash and clouds, SAR can be used to get near real-time information about the volcanic activities with the help of the available spaceborne SAR platforms.

The Anak Krakatau Volcano Island "known as the child of the Krakatau" formed over several years after the explosive eruption of the Krakatau Volcano in 1883 [3]. This volcano island is situated in the Sunda Strait between the Java and Sumatra Islands of Indonesia [4]. Anak Krakatau is at the edge of the Indian-Australian and Eurasian tectonic plates which is normally a zone of high seismic and volcanic activity [5]. The volcano is active since 1927 and continued to grow to an elevation of about 300 meters [6]. On 22nd December 2018, the Anak Krakatau erupted and as a resulting tsunami happened in the Java and Sumatra Islands which killed hundreds of people [7].

The datasets acquired by ESA's C-band Sentinel-1 SAR platform and Sentinel-2 optical platform were used in this study to analyse the temporal surface changes to the Anak Krakatau Island due to the volcanic episode of December 2018.

2. Datasets and Method

2.1 Datasets

6 Sentinel-1 datasets acquired from 25th November 2018 to 24th January 2019 were used for this study. The details of the datasets are shown in Table 1. The datasets were acquired in the interferometric wide (IW) mode, where the entire dataset is acquired as three different sub-swaths in TOPSAR mode and each sub-swaths is divided into a number of bursts to ensure uniform Signal to Noise Ratio (SNR) [8].

Table. 1. Metadata of the Sentinel-1A datasets used

Sl. No	Date of acquisition	Polarization used
1	25/11/2018	VV
2	07/12/2018	VV
3	19/12/2018	VV
4	31/12/2018	VV
5	12/01/2019	VV
6	24/01/2019	VV

The Sentinel-2 optical datasets from 16th November 2018 to 02nd February 2019 were used to verify the results obtained from the Sentinel-1 data analysis and the details of the datasets are mentioned in Table 2.

Table. 2. Metadata of the Sentinel-2 datasets used

Sl. No	Sat	Date of acquisition
1	S-2A	16/11/2018
2	S-2A	29/12/2019
3	S-2B	13/01/2019
4	S-2B	02/02/2019

The Red band (band 4), green band (band 3) and blue band (band 2) of the Sentinel-2 datasets were used in this study to generate the True Colour Composite (TCC) images.

2.2 Methodology

The InSAR coherence and backscatter images were generated using the methodology shown in Figure 1[1], [9]. For generating the interferometric coherence magnitude image, the Sentinel-1 datasets acquired on 25th November 2018 is selected as the master image and 5 interferometric coherence magnitude images were generated with respect to the other 5 slave images. The radiometrically calibrated sigma nought images of all the 6 datasets were generated. RGB composite images were generated using the interferometric coherence magnitude images and

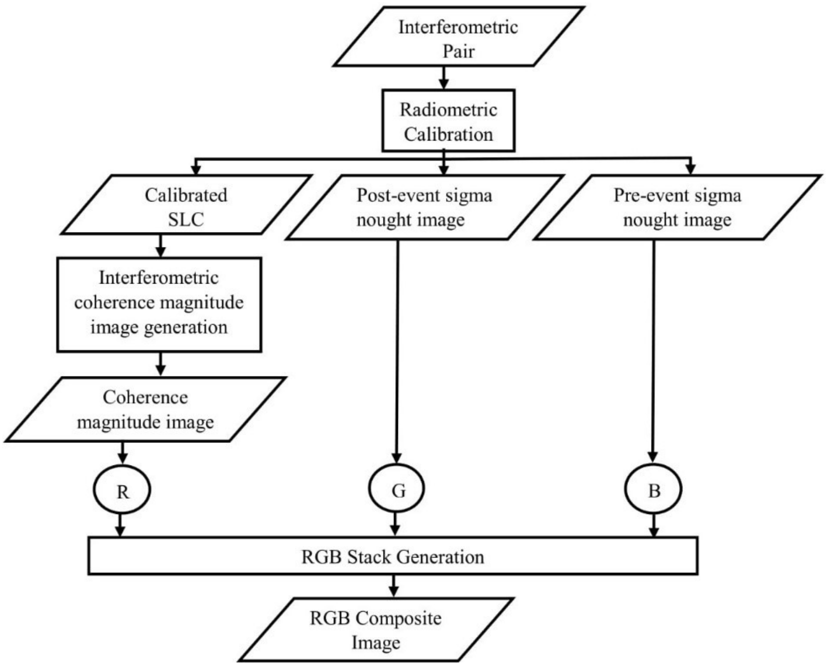


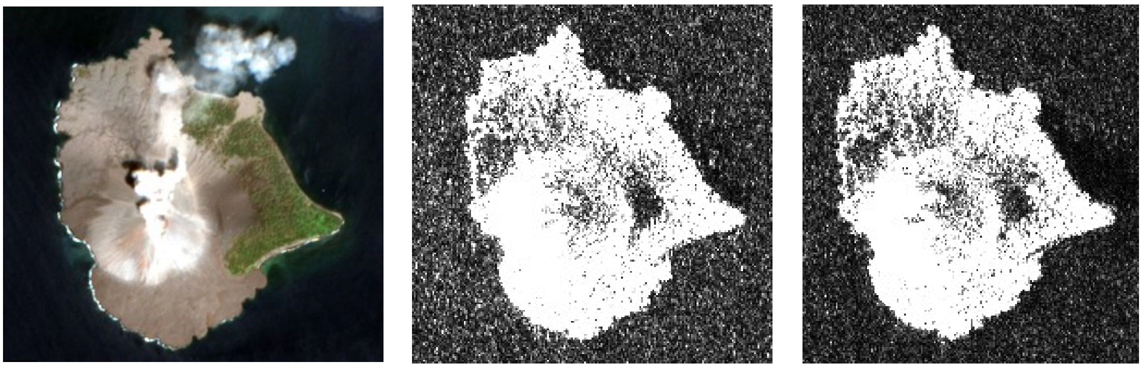
Figure. 1. Methodology flowchart

the two corresponding sigma nought images used to generate the coherence image. InSAR RGB composites can provide better visualization for analyzing and interpreting the results.

The sigma nought images and the interferometric coherence magnitude images were in a linear scale of 0 to 1 so they can be combined together to form the RGB stack. The sigma nought images were radiometrically calibrated images free from system induced radiometric errors so they can be used for quantitative analysis. For generating the RGB composite images, the interferometric coherence magnitude image was used as the red band, the latter date sigma nought image was used as the green band and the earlier date sigma nought image was used as the blue band.

3. Results

The InSAR RGB composite images and backscatter images were generated as per the methodology described in the previous section and the results were discussed in this section.



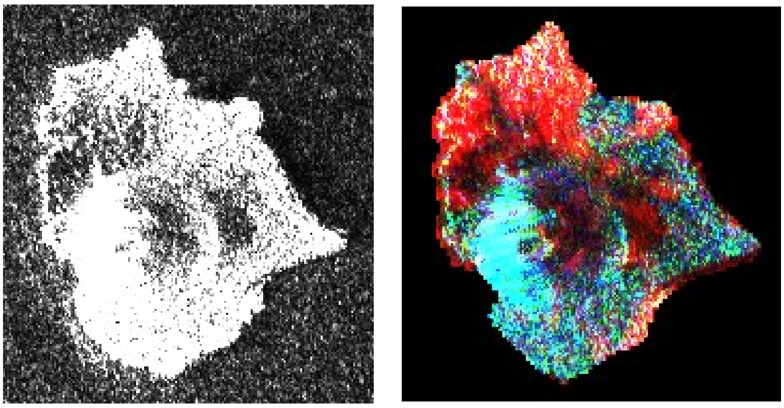
(a) (b) (c)

Figure. 2. Comparision of Sentinel-2 & Sentinel-1 images, (a) Sentinel-2A TCC of 16th November 2018, (b) Sigma nought image of 25th November 2018, (c) Sigma nought image of 07th November 2018

Figure 2(a) shows that smoke is coming out from the volcano caldera, it clearly indicates that the volcano is highly active and there is a change of a volcanic eruption. Figure 2(b) & (c) shows the sigma nought backscatter images of 25th November 2018 and 07th December 2018, by comparing both the images with the Sentinel-2 TCC image in figure 2(a) it can be understood that all the three images are matching to each other in shape and appearance of the volcano island, so there occurred no considerable volcanic activity during this time period.

Figure 3 (a) shows the Sigma nought backscatter image for 19th December 2018, by comparing the image with the sigma nought images of 07th December 2018 (figure 2(c)) and 25th November 2018 (figure 2(b)) it can be seen that there is no change visible which indicates the absence of any considerable volcanic activity. Figure 3(b) shows the InSAR RGB composite generated with 19th November 2018 and 25th December 2018 datasets. The image is generated by stacking together the coherence magnitude image as the red band, the sigma nought image of 19th December 2018 as the green band and the sigma nought image of 25th November 2018 as the blue band. By comparing figure 3 (b) with figure 2(a) it can be seen that the vegetation present at the right side of the island was appearing in cyan colour. This is because the presence of vegetation caused loss of coherence between the interferometric pairs causing low values close to zero in the red band and the similar values in the sigma nought images in the green and blue bands due to no change at the area caused the vegetation to appear in cyan colour. The red regions are the barren lands without any vegetation and free from any surface changes having good coherence between the interferometric pairs. The area surrounding the caldera of the volcano was also appearing in cyan colour, this may be due to the continuous volcanic activity happening at the caldera. Since only red and the cyan colour is present in the InSAR RGB composite image it can be understood that there is no surface deformations happened to the island during this time period.

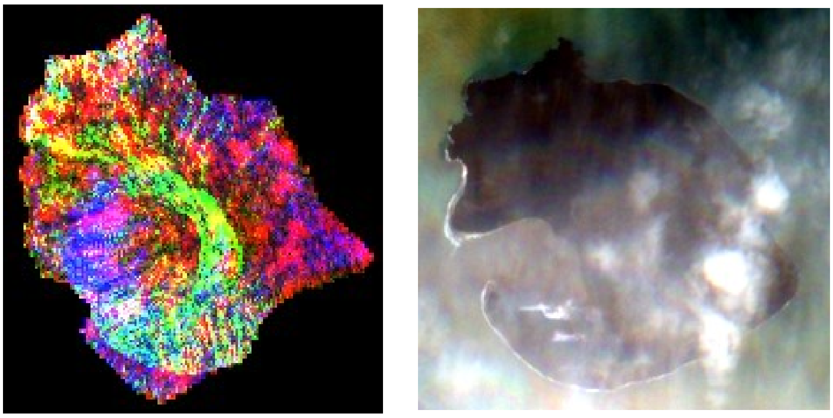
Figure 4 (a) shows the InSAR RGB composite image generated with 31st December 2018 and 25th December 2018 datasets. The image is generated by stacking together the coherence magnitude image



(a) (b)

Figure. 3. (a) Sigma nought image of 07th December 2018, (b) InSAR RGB composite with coherence image of 07th December 2018 with respect to 25th November 2018 in Red band, Sigma nought image of 07th December 2018 in Green band and Sigma nought image of 25th November 2018 in Blue band

as the red band, the sigma nought image of 31st December 2018 as the green band and the sigma nought image of 25th November 2018 as the blue band. Figure 4 (b) shows the Sentinel-2 True Colour Composite (TCC) image acquired on 29th December 2018. By comparing figure 4 (a) with figure 3 (b) it can be clearly understood that after the volcano eruption on 22nd December 2018 there occurred significant deformation to the volcano surface indicated by the loss of cyan and red colour in figure 4 (a). The green coloured regions in figure 4 (a) indicates the new surface which is present on 31st December 2018 and absent on the 25th November 2018 image. Similarly, the blue coloured regions indicate the areas which were present on 25th November 2018 and disappeared on the 31st December 2018 dataset. By comparing figure 2 (a), figure 4 (a) & (b), it can be seen that the south-west portion of the Volcano has collapsed due to the volcano eruption and the portion is filled with the water from the ocean. From figure 4 (a) & (b), it can be understood that the magenta and blue coloured regions in figure 4 (a) indicates the areas lost after the volcano eruption.

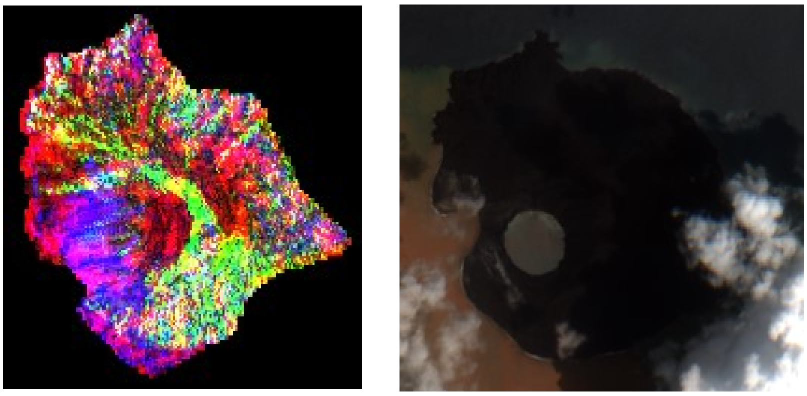


(a) (b)

Figure. 4. (a) InSAR RGB composite with coherence image of 31st December 2018 with respect to 25th November 2018 in Red band, Sigma nought image of 31st December 2018 in Green band and Sigma nought image of 25th November 2018 in Blue band, (b) Sentinel-2 TCC of 29th December 2018

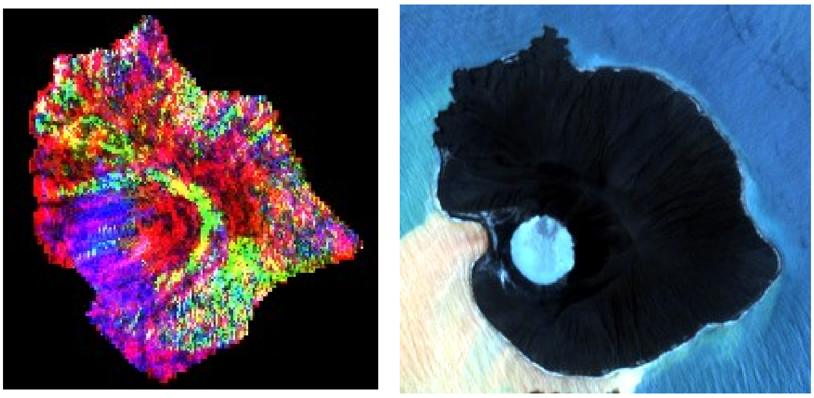
Figure 5 (a) shows the RGB composite generated using the datasets acquired on 12th January 2019 and 25th November 2018. As like the previous RGB composites, the red band represents the coherence image generated between the datasets and the green band represents the sigma nought image of 12th January 2019 and the blue band represents the sigma nought image of 25th November 2018. By comparing figure 5 (a) with figure 4 (a) it can be found that there is no considerable change in both the images indicating the ceased volcanic activity. Figure 5 (b) shows the Sentinel-2 TCC image acquired on 13th January 2019. By comparing the figure 5 (b) with figure 4 (b) it is clearly visible that that land mass has formed at the water entered area at the south-west side of the volcano island isolating the volcano summit from the ocean water.

Figure 6 (a) shows InSAR RGB composite generated using the datasets acquired on 24th January 2019 and 25th November 2018. By comparing it with figure 5 (a), it can be observed that there is no change in both the images indicating the complete ceasing of the volcano activity. The Sentinel-2 TCC image acquired on 2nd February 2019 is shown in figure 6 (b) and it is exactly similar to the figure 5 (b) which validates the ceasing of the volcano activity indicated by the InSAR RGB composite images.



(a) (b)

Figure. 5. (a) InSAR RGB composite with coherence image of 12th January 2019 with respect to 25th November 2018 in Red band, Sigma nought image of 12th January 2019 in Green band and Sigma nought image of 25th November 2018 in Blue band, (b) Sentinel-2 TCC of 13th January 2019



(c) (d)

Figure. 6. (a) InSAR RGB composite with coherence image of 24th January 2019 with respect to 25th November 2018 in Red band, Sigma nought image of 24th January 2019 in the Green band and Sigma nought image of 25th November 2018 in the Blue band, (b) Sentinel-2 TCC of 02nd February 2019

Figure 7 shows the Sentinel-1 backscatter image acquired on 22nd December 2018 which is the same day on which the volcano erupted. By analyzing the image it can be observed that in the ocean water, ripples were moving away from the volcano island indicating the spread of the seismic shock of the volcano eruption moving away from the island. This also indicates the movement of the ocean water towards the Java and Sumatra islands away from the volcano island caused due to the collapse of the volcano wall.

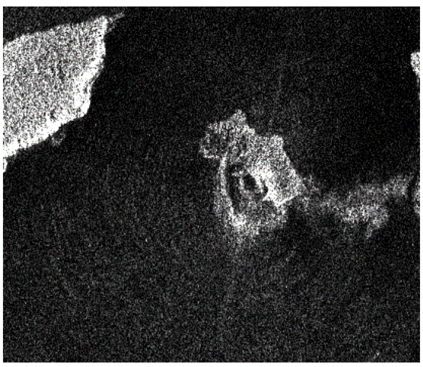


Figure. 7. Sentinel-1 backscatter image acquired on 22nd December 2018 showing water ripples moving away from the volcano

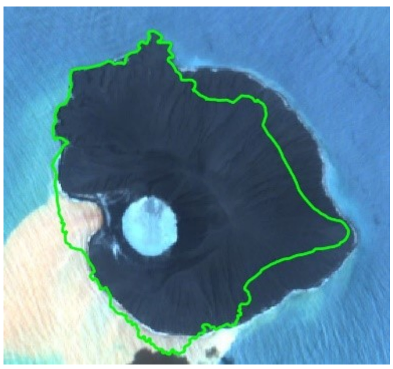


Figure. 8. Outline of the old shape of the volcano before 22nd December 2018 overlaid on top of Sentinel-2 TCC of 02nd February 2019

Figure 8 shows the Sentinel-2 TCC image acquired on 2nd February 2019 with the outline of the shape of the volcano before eruption overlaid on top of it. By observing the outline and the Sentinel-2 image, it can be seen that there occurred considerable change to the shape and size of the volcano island after the volcano eruption. Before volcano eruption, the volcano area was having an area of 2.81 Km^2 and after the volcano eruption, the volcano area increased to 3. 25 km^2 due to the lava deposition.

4. Conclusion

From this study, it is understood that InSAR coherence and SAR backscatter images along with high-resolution optical images are capable of monitoring the surface deformations caused due to volcano eruption. It was found that the volcano eruption on 22nd December 2018 caused the south-west portion of the Volcano island to collapse into the ocean water which caused Tsunami on the Java and Sumatra islands of Indonesia. Even though there occurred the collapse of the volcano wall, there occurred an increase in the area of 0.44 Km^2 to the island. The temporal SAR and optical images of January and February indicated the ceased volcano activity.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. A. Babu and S. Kumar, "SBAS interferometric analysis for volcanic eruption of Hawaii island," *J. Volcanol. Geotherm. Res.*, vol. 370, pp. 31–50, 2019.
2. B. Catherine and O. Andre, "The use of sar interferometric coherence images to study sandy desertification in southeast niger: Preliminary results," in *Envisat Symposium 2007,ESA SP-636*, 2007, vol. 2007, no. SP-636, pp. 1–5.
3. T. Giachetti, R. Paris, K. Kelfoun, and B. Ontowirjo, "Tsunami hazard related to a flank collapse of Anak Krakatau Volcano, Sunda Strait, Indonesia," *Geol. Soc. London, Spec. Publ.*, vol. 361, no. 1, pp. 79–90, 2012.
4. Volcano Discovery, "Krakatoa volcano," 2019. [Online]. Available: https://www.volcanodiscovery.com/krakatau.html. [Accessed: 19-May-2019].
5. M. Abdurrachman, S. Widiyantoro, B. Priadi, and T. Ismail, "Geochemistry and Structure of Krakatoa Volcano in the Sunda Strait, Indonesia," *Geosciences*, vol. 8, no. 4, p. 111, 2018.
6. Deanna Conners, "Anak Krakatau volcano eruption from space | Earth | EarthSky," *EarthSky*, 2012. [Online]. Available: https://earthsky.org/earth/view-from-space-anak-krakatau-volcano-eruption. [Accessed: 19-May-2019].
7. Suyin Haynes, "Tsunami Caused by Volcanic Eruption Kills 429 in Indonesia | Time," *TIME*, 2018. [Online]. Available: http://time.com/5487825/indonesia-krakatoa-volcano-tsunami-sunda-strait/. [Accessed: 19-May-2019].
8. N. Yague-martinez, P. Prats-iraola, S. Member, F. R. Gonzalez, R. Brcic, R. Shau, S. Member, D. Geudtner, M. Eineder, S. Member, R. Bamler, and A. S.- S-, "Interferometric Processing of Sentinel-1 TOPS Data," vol. 54, no. 4, pp. 2220–2234, 2016.
9. D. Das A.S., S. Kumar, A. Babu, and P. K. Thakur, "Coherence and Polarimetric Parameters based Characterization of Flooded Area - Case Study of a Natural World Heritage Site Kaziranga National Park," in *ISPRS Annals*, 2018, vol. IV-5, no. November, pp. 265–272.