Remote Sensing Monitoring of Fuego Volcano in Guatemala December 2022

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ABSTRACT

The monitoring of basaltic is important for their spontaneous change in behavior from being passive to explosive. Near the study site, Fuego volcano, there are villages and farms which are vulnerable. The Fuego volcano had activity from the 10th to the 11th of December of 2022 which would be good to examine as PDCs went down some gullies and a lava flow was developed. The program ENVI was used to estimate the NDVI around the volcano, see geomorphological changes, and d combination of bands to highlight recent deposits. The NDVI detected the effect of the ash on the vegetation around the volcano. Slight geomorphological changes were observed, and the vent did not change shape. In conclusion, the activity was able to be detected and the effect of the ash on the vegetation was more noticeable by shortening of distance and being in the zone of ashfall. The behavior displayed was Strombolian by comparison to prior observations. The use of Shortwave infrared bands proved to be essential.

Keywords: physical volcanology, monitoring, remote sensing, NDVI, false color

INTRODUCTION

The Fuego volcano is the subject of study as it is continuously active which is good as it raises the probability that there will be images for remote sensing monitoring (Aldeghi et al., 2019). Several volcanic hazards are generated by the volcano and the heavy rains that occur by the tropical climate, and communities live near the volcano. The volcano is located towards the Southwest of Guatemala, and it has an elevation of 3,763 m (Aldeghi et al., 2019; Naismith et al., 2019) (**Fig.1**).

The intensity of eruptions at the Fuego volcano is variable and the volcanic activity mostly produces lava flows, moderate ash explosions, and paroxysms which generate widespread ashfall (Liu et al., 2020). The most dangerous hazard of this volcano is the pyroclastic density currents (PDCs) as they can be catastrophic and take numerous lives by their high velocity and variable reach (Walker, 1983; Brown et al., 2017). The PDCs at Fuego are produced during paroxysms or when there are slight changes to above-background explosive eruptions (Liu et al., 2020). Extensive lava flows, constant eruption columns, and frequent PDCs were generated during paroxysms (Liu et al., 2020). A total of three categories or stages have been identified for a paroxysm in the Fuego volcano which are waxing phase, "paroxysm" itself, and the waning phase (Lyons et al., 2010)

A special volcanology bulletin of Instituto Nacional de Sismología, Vulcanología, Meteorología e Hidrología de Guatemala (INSIVUMEH), a government agency, is available in their website for the activity that was present from 10th to the 11th of December of 2022. The volcano was entering an eruption phase at the time the first report was being written. This date was chosen as the activity is the most recent reported and if there are deposits these will not be affected greatly so changes in the areas near the vent or flanks will be less difficult to detect. On the 10th of December of 2022 the Fuego volcano increased in its volcanic activity with a range of explosions in its vent, there was lava fountain that reached a height of 500 m and the eruptive column had a height of 16,404 ft (INSIVUMEH, 2022a). A lava flow in the Ceniza gully maintained its longitude of 800 m and the front of it was producing avalanches (INSIVUMEH, 2022a). The eruptive activity was maintained until the 11th of December, and PDCs were spontaneously going down different gullies, especially Las Lajas and Ceniza (INSIVUMEH, 2022b) (**Fig.2**). The lava fountain and PDCs are expected to produce new deposits as seen in Aldeghi et al., 2019. Other noticeable events were not chosen as these produced more prominent ash plumes and more extensive ash fall, this would make it more difficult to find the new deposits and observe changes in the vent during the activity.

The main aim of the project is to calculate the Normalized Difference Vegetation Index (NDVI) with Planet Scope and OLI/TIRS images before, during and after the activity in late November 2022. The NDVI will show how the vegetation was affected by the ash fallout and how the vegetation recovers. Another goal is to highlight new deposits by combining different bands with the Planet Scope images and Operational Land Imager/TIRS images, and if these can be identified then estimate the area that they cover. An additional objective with the project is to observe if the shape of the vent changes over time. The contrast with Sentinel 2 images from the Copernicus hub and Sentinel hub websites was not done as these images cut in half the area of the volcano and using a mosaic of images of different dates is not appropriate for calculating NDVI and doing other visual procedures. Sentinel images have a resolution of 10-60 meters and a cadence of 5-10 days.

METHODOLOGY

Planet Labs has a CubeSat constellation of small satellites around 150 and these are called "Doves", the images they produce are Planet Scope images have a daily cadence, and the spatial resolution is 3 meters. The range of the wavelengths of the bands goes from 445 to 860 nanometers. OLI/TIRS are the sensors utilized which are in the satellite Landsat 8 and 9. Landsat 8 and 9 images have a spatial resolution of 15-30 meters and a cadence of 16 days, and they have a total of 11 bands. The range of the wavelengths of the bands goes from 0.43 to 12.51 micrometers.

The program Environment for Visualizing Images (ENVI) is used to create the NDVI images and combine bands and observe geomorphological changes in the Fuego volcano. The formula for the NDVI is (NIR-Red)/(NIR+Red), for the Space Scope images NIR= band 4 and Red= band 3 and for the OLI/TIRS images NIR= band 5 and Red= band 4. Before working with the OLI/TIRS images, the NNDiffuse Pan Sharpening tool must be utilized to change the spatial resolution to 15 m using the panchromatic band. To calculate the NDVI, the NDVI tool within the Toolbox is used. The NDVI was also calculated with the Band Math tool in the Toolbox. There were no changes detected between the NDVI tool and the Band Math tool. When creating the mask for the NDVI images using Build Raster Mask, one must use the option of data range and put the maximum and minimum values (Planet Scope images 0.45-1 and OLI/TIRS images 0.2-1). Next the NDVI can be saved as a ENVI file in the File tab by choosing Save As, later the respective mask must be chosen and the value to ignore should be 1.1.

The combinations of bands were done utilizing the Data Manager tool. The vent and deposits were highlighted using the Annotations tool using the polygons. The area of polygons utilizing the Mensuration tool as it gives it and one can choose the units. With the Annotation tool the north arrow, title, graphical scale, color bar for the values, and grid lines can be added. The image of the map can be saved by going to the File tab, choosing Chip to View and selecting File (there is an option to change from saving ENVI to JPEG format).

RESULTS AND DISCUSSION

For the Planet Scope images, the dates found for the project were 7th, 10th, 11th, 15th, and 16th of December. No more Planet Scope images were found as the majority had a high percentage of clouds, and even those used for the project have. The Landsat images that were found were of the dates 19th of November and 5th, 13th and 29th of December. Additional images were not found as these a lot of cloud coverage and the cadence for the images also affects. The contrast with the Sentinel satellite images was not done as these would not cover the volcano completely and a mosaic could not be done as the other following images were days later. This would probably affect the estimate of the NDVI.

There are a total of 32 images which includes the subsets, NDVI and false color images, and a deposit highlight (**Fig.3 - 33**). By looking at the NDVI images (**Fig.4 & 16**) of the 7th and 16th of December, one can observe a slight decrease in vegetation. Contrasting the NDVI images of the 5th and 29th of December (**Fig.23 & 31**), one can observe a slight decrease in NDVI in the areas that are visible. Observing the false color images of the 5th, 13th and 29th of December (**Fig.25, 29 & 33**) one can observe the direction of where the volcanic activity is occurring which was mostly towards the Southwest. Additionally, one can observe the location and shape of the vent of the volcano. As we compare the true color image of the 7th of December (**Fig.3**) and the false color image of the 10th of December (**Fig.8**) one can observe the shape and position of the crater.

Two tables (**Table 1 & 2**) were created to show the coordinates chosen and the NDVI values at different dates. **Table 1** show the values for the Planet Scope images, in general one can observe that the values decrease from 0.8 to 0.6 from the 10th to the 11th of December and then increases to 0.7 from the 15th of December. **Table 2** shows the values for the OLI/TIRS images, in general one can observe that the values decrease from 0.4 to 0.3 or 0.2 from the 19th of November to the 13th of December and then it generally stays at 0.3 from 29th of December.

As for geomorphological changes around the vent, one can observe that some areas in the Ceniza gully are filled and near the vent a deposit is disrupted (**Fig.3 & 15**). The zone where the PDCs flowed down could not be depicted as the two images have different colors so it is difficult as some colors can be confused. The old deposit measured (**Fig.34**) had an area of 0.0393 km^2 (39,339.4631 m^2, 198 m) and the perimeter is 1.3554 km (1,335.4459 m).

CONCLUSIONS

The use of a satellite that passes through an area daily is imperative for a tropical study site as clouds a constant obstacle, this is if remote sensing will be utilized and multispectral satellite images are to be examined. In the research this proved to be challenging and an obstacle as it can also affect the estimate of vegetation indices. Taking into consideration the products of the project, one can say that remote sensing techniques can detect volcanic activity from the 10^{th} to 11^{th} of December by using vegetation indices and combining bands that the satellite images have.

The visual inspection of the true color and false images (**Fig.3**, **8, 25, 29 & 33**), one can suggest that the vent maintained its very circular shape. If there were changes to the shape of the vent it would have occurred on the 11^{th} of December during the early morning. Some areas of the Ceniza gully were filled as PDCs went down that gully and in Las Lajas gully or another explanation is that avalanches being developed in front of the lava flow moved material and went down the topography.

Knowing that the NDVI values diminished after the volcanic episode by looking at **Table 1 and 2**, one can say that the ash did influence the vegetation and that later it was recovering slowly. The observations of the NDVI images (**Fig.4, 16, 23 & 31**) show that within the ashfall zone estimated by INSIVUMEH and being closer to the volcano the effect of ash on the NDVI values is more noticeable. Also, the trend for the ash to fall towards the East or West can be appreciated visually.

The observations with the Shortwave infrared images of OLI/TIRS correlate with the descriptions of INSIVUMEH in their special bulletins (**Fig.25, 29 & 33**). This occurs as these bands are more sensitive to change in temperature. The activity seen from the 10^{th} to 11^{th} of December can be classified as Strombolian if compared to observations by Aldeghi et al., 2019 and Naismith et al., 2019.

RECOMMENDATIONS

For future work, the Planet Scope images used in this project can be studied using the Shortwave infrared bands. Other higher resolution images can be utilized like those from the satellite IKONOS. Additional vegetation indices can be calculated with the images used in the research like the Normalized Burned Ratio (NBR) and Normalized Difference Moisture Index (NDMI). The Land Surface Temperature (LSS) can be estimated for all these satellite images. A Principal Component Analysis can be done to identify the ash plume for the images.

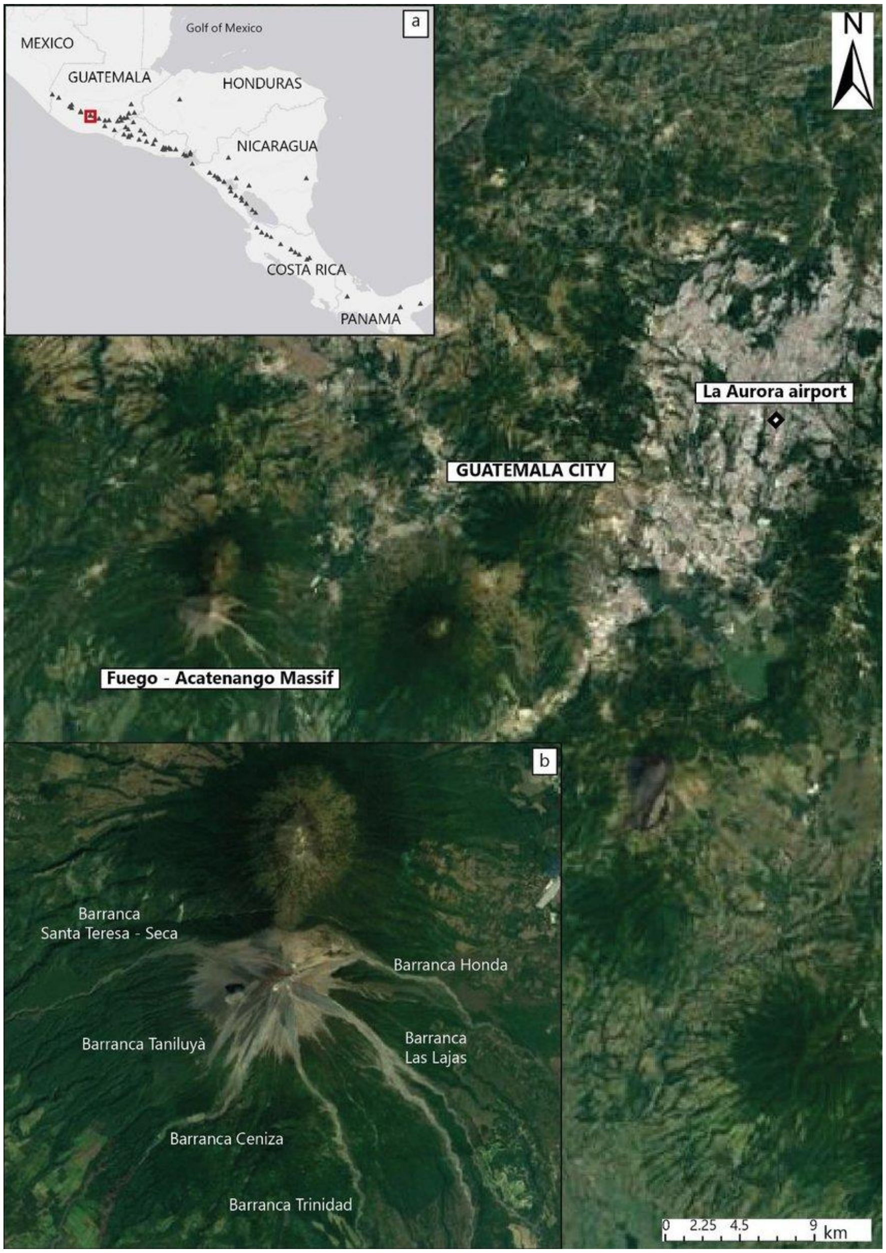

Figure 1 – Location of the Fuego volcano in Central America and major cities that are near, and the names of seven gullies around it (*from* Aldeghi et al., 2019).

Figure 2 – Map displaying the zones were the ash was scattered on the Fuego volcano in the 11th of December of 2022 (*from* CONRED on Twitter: "¡ENTÉRATE! INSIVUMEH comparte mapa de dispersión de ceniza del volcán de Fuego, se dispersa en dirección Oeste, Noroeste y Noreste, Este y Sureste a una distancia de hasta 45 kilómetros con probabilidadde aumentar. https://t.co/BOkz5xEMbn" / Twitter).

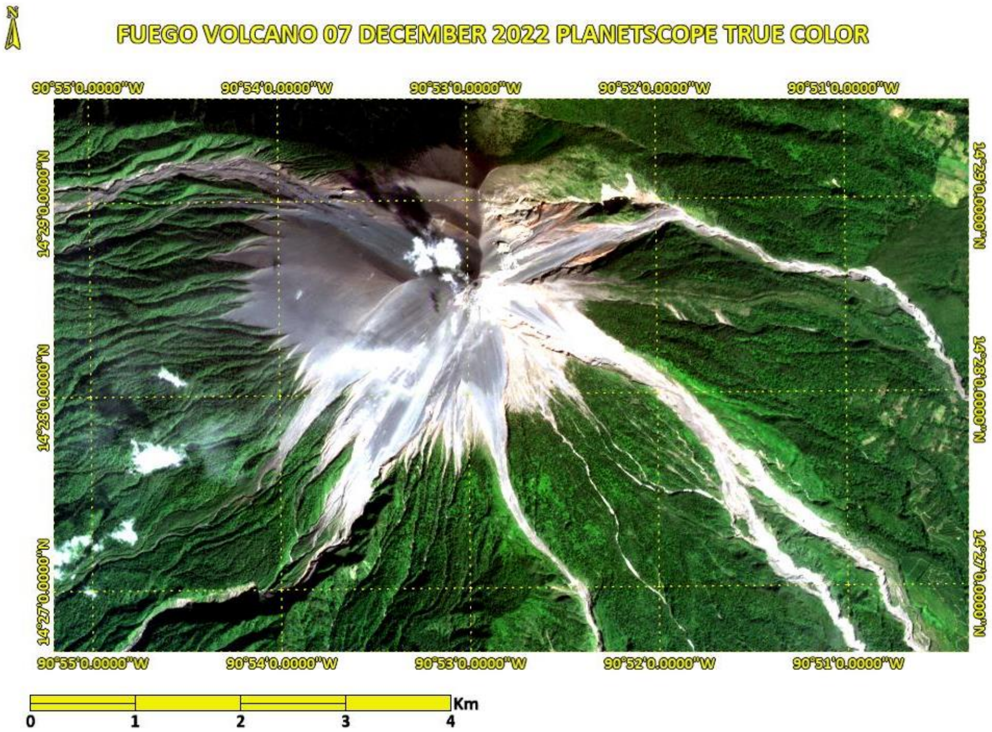

Figure 3 – Planet Scope image of the Fuego volcano on the 7th of December of 2022.

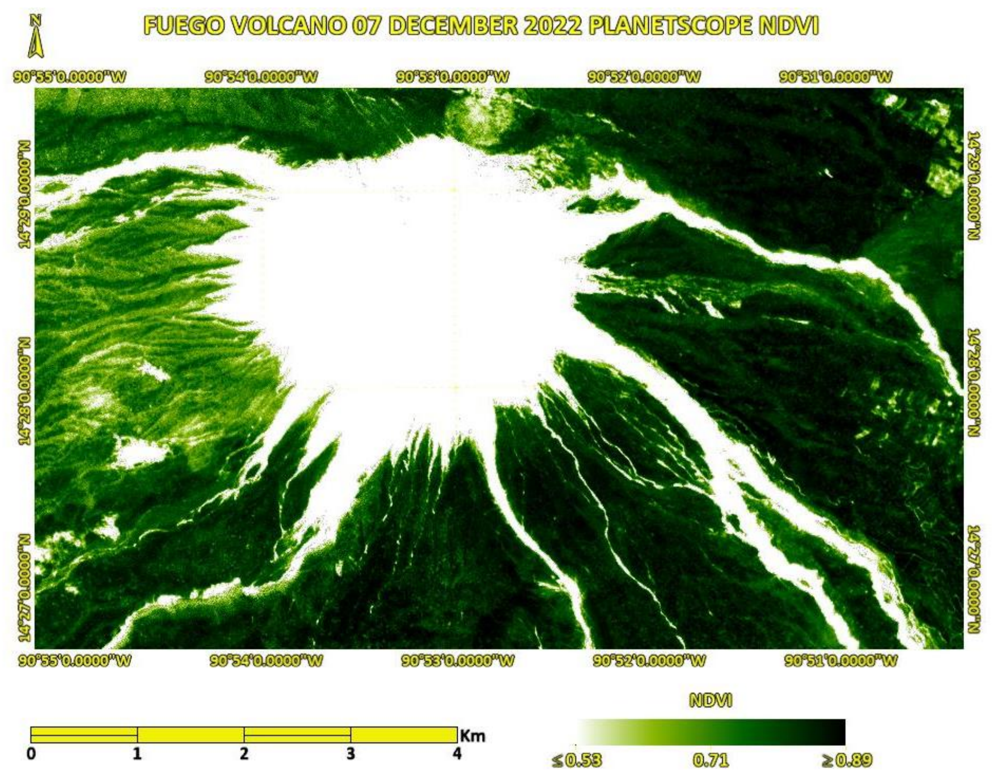

Figure 4 – NDVI for the Fuego volcano in 7th of December of 2022 using a Planet Scope image.

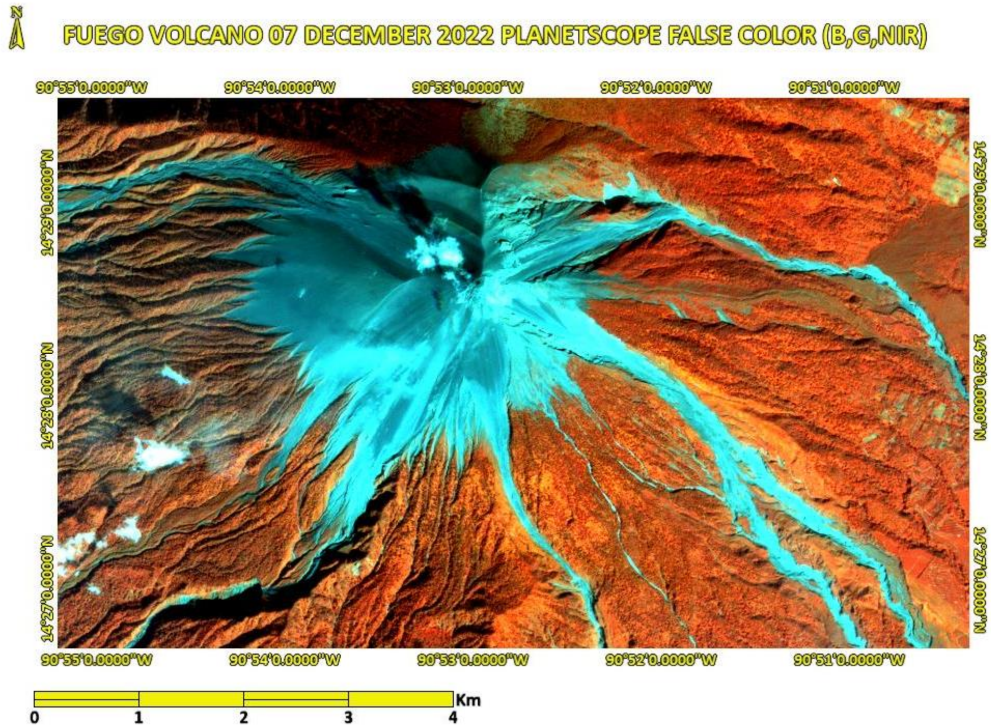

Figure 5 – B,G,NIR Planet Scope image of the Fuego volcano on the 7^{th} of December of 2022.

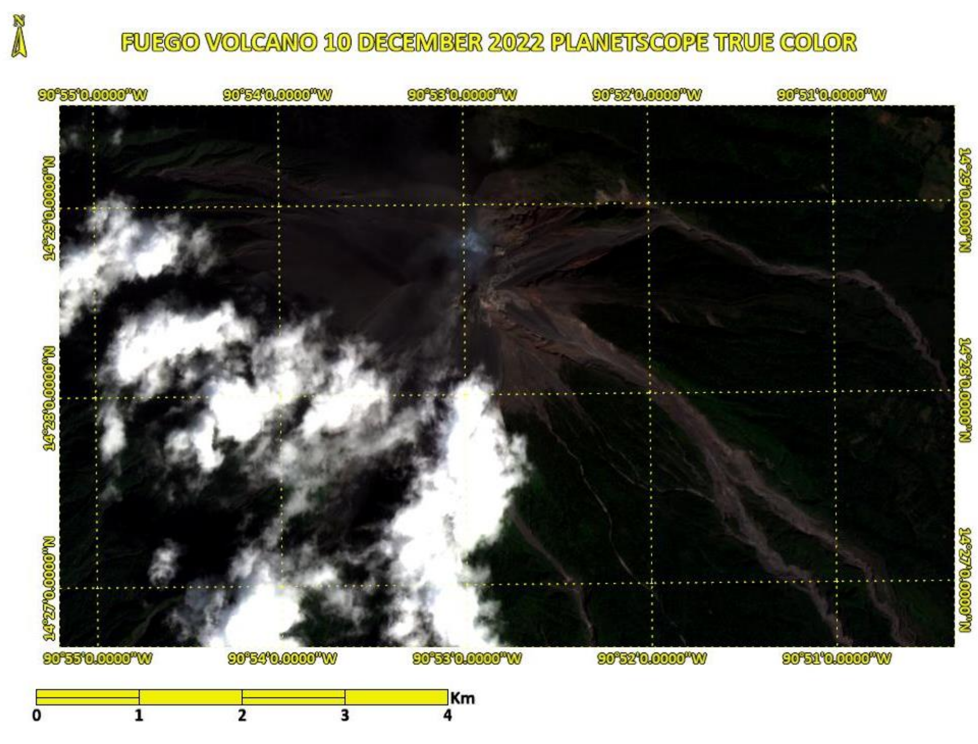

Figure 6 – Planet Scope image of the Fuego volcano on the 10^{th} of December of 2022.

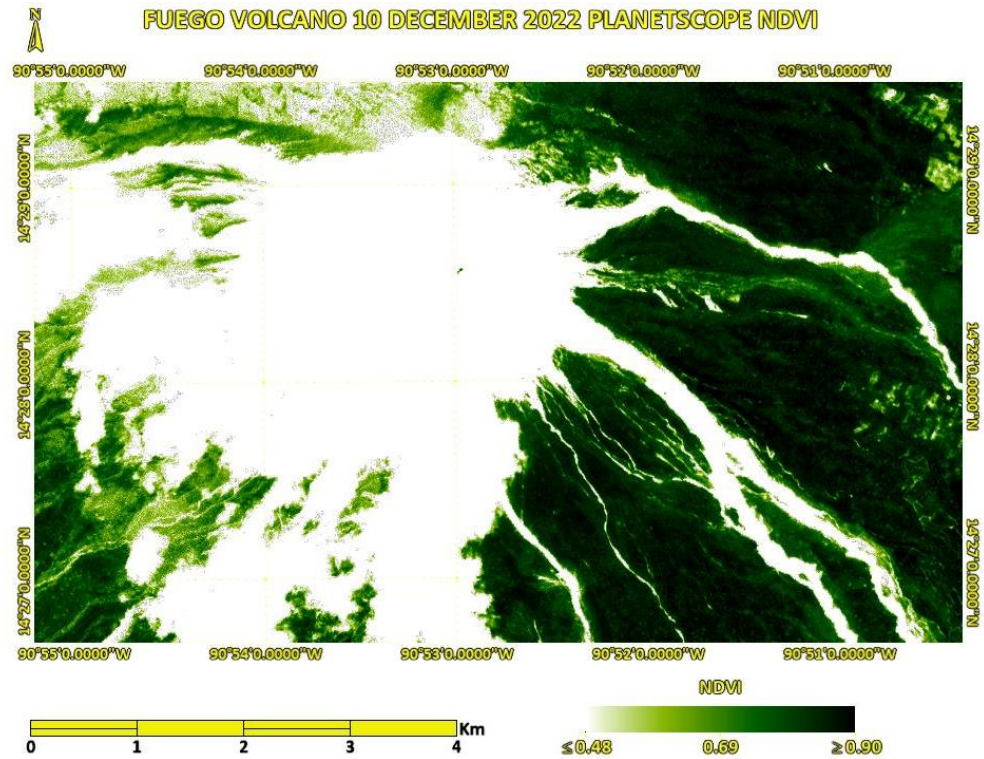

Figure 7 – NDVI for the Fuego volcano in 10th of December of 2022 using a Planet Scope image.

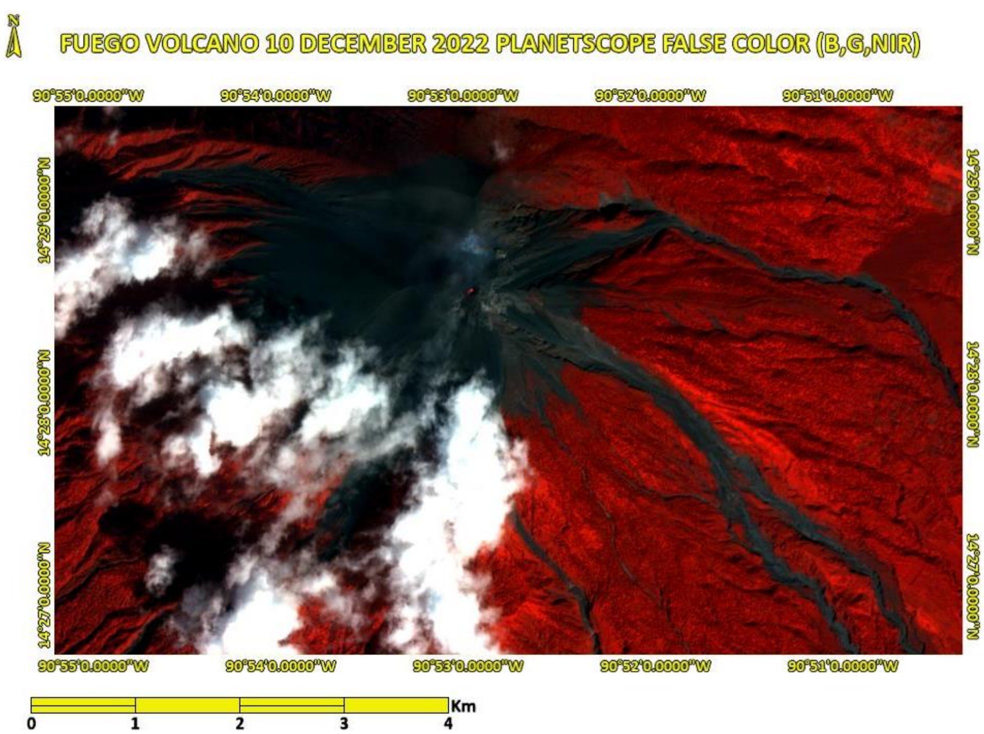

Figure 8 – B,G,NIR Planet Scope image of the Fuego volcano on the 10th of December of 2022.

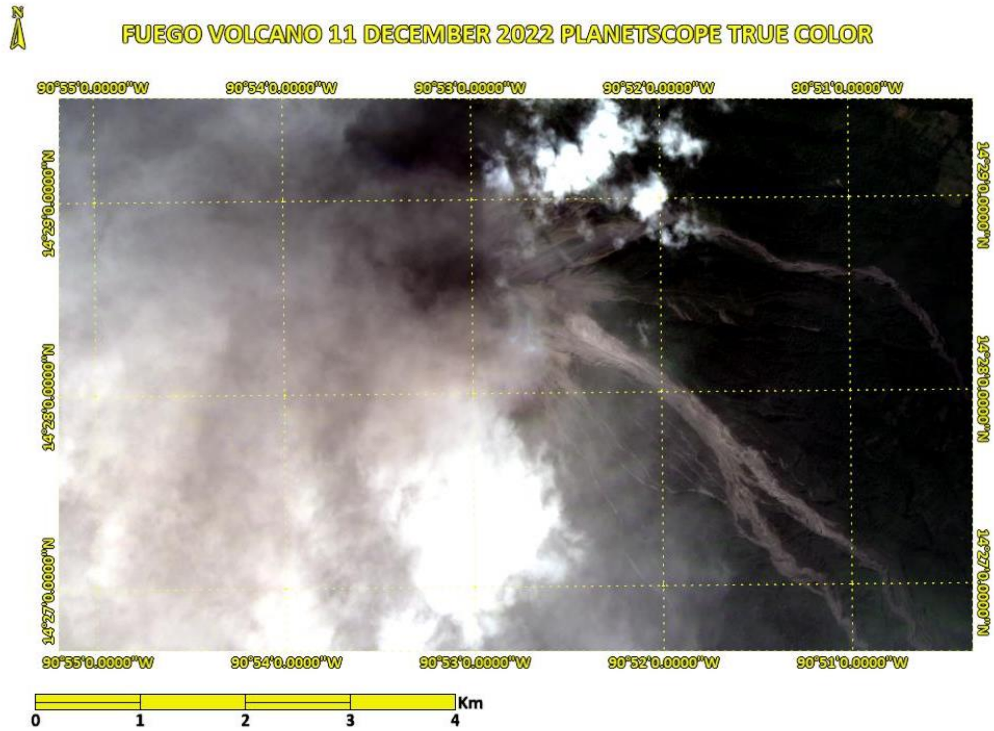

Figure 9 – Planet Scope image of the Fuego volcano on the 11th of December of 2022.

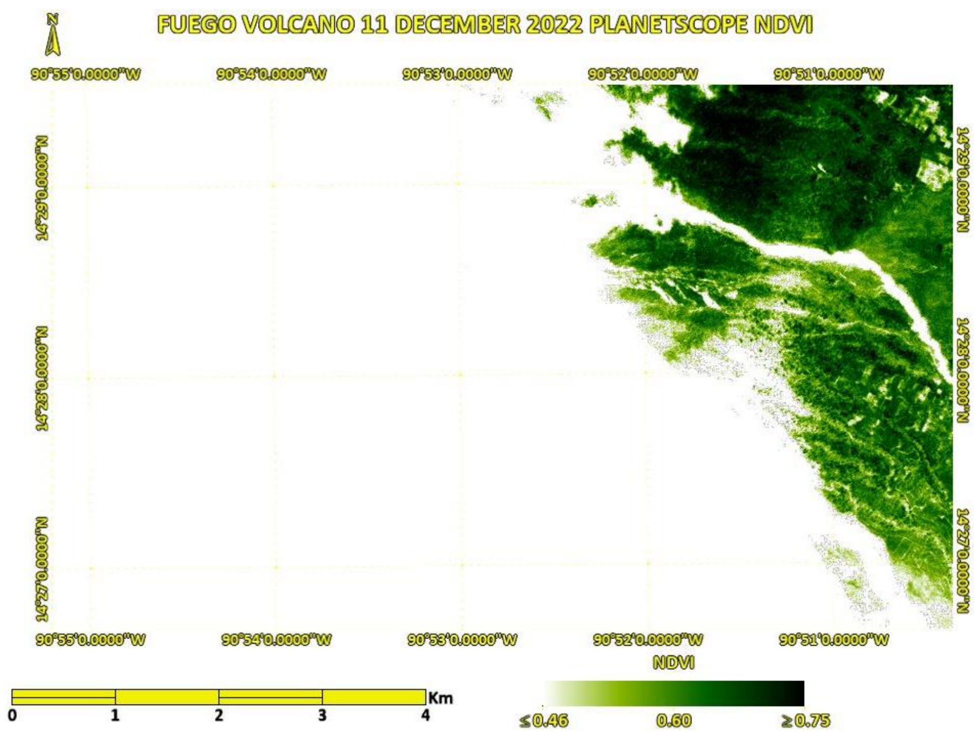

Figure 10 – NDVI for the Fuego volcano in 11th of December of 2022 using a Planet Scope image.

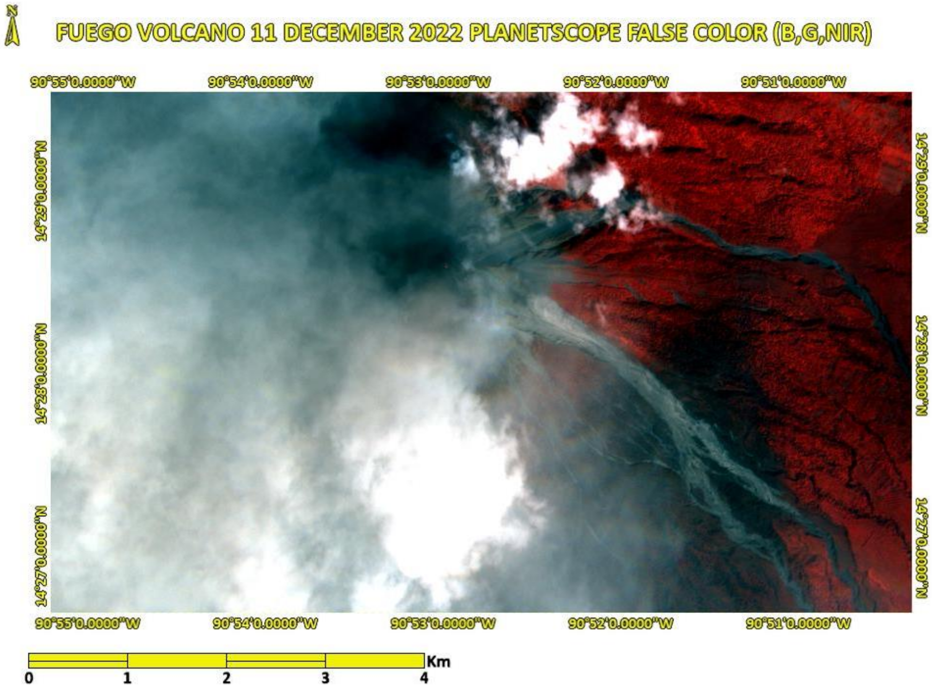

Figure 11 – B,G,NIR Planet Scope image of the Fuego volcano on the 11th of December of 2022.

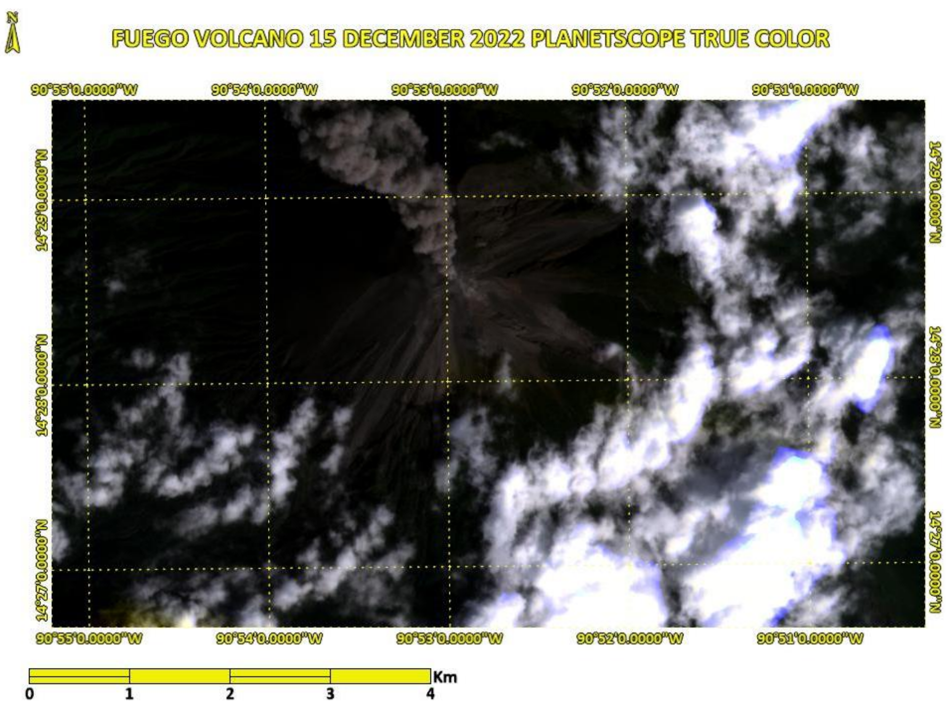

Figure 12 – Planet Scope image of the Fuego volcano on the 15th of December of 2022.

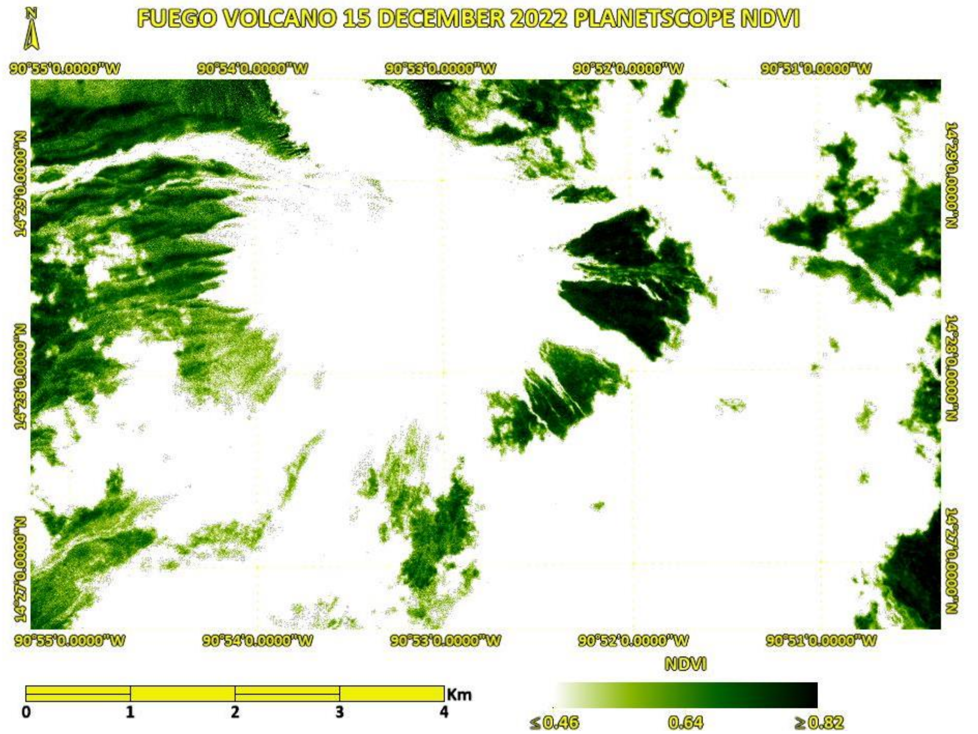

Figure 13 – NDVI for the Fuego volcano in 15th of December of 2022 using a Planet Scope image.

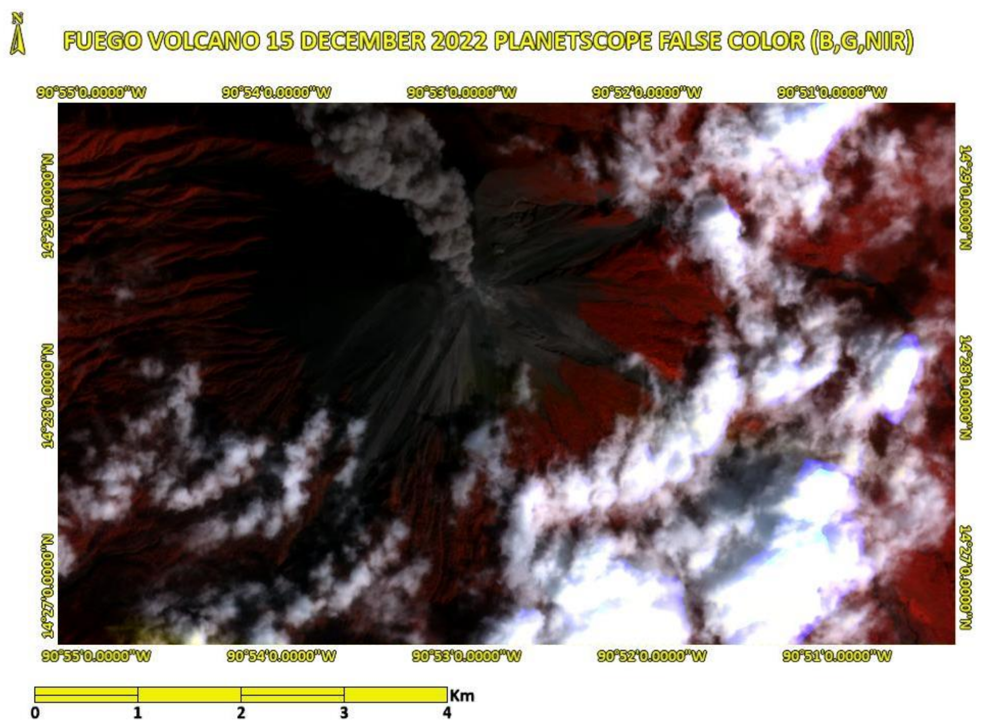

Figure 14 – B,G,NIR Planet Scope image of the Fuego volcano on the 15th of December of 2022.

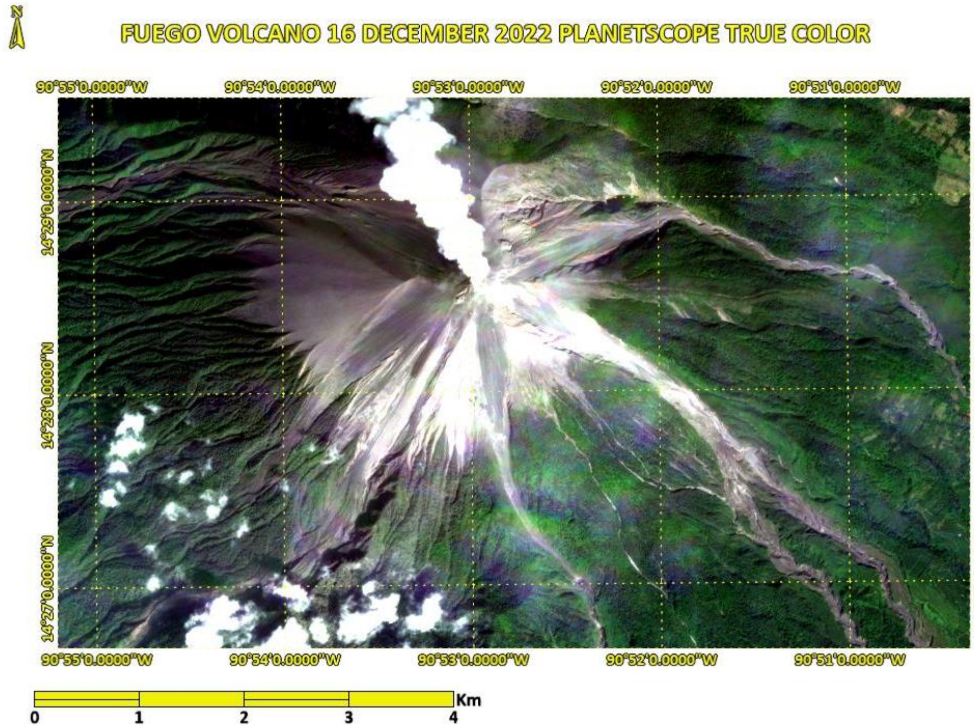

Figure 15 – Planet Scope image of the Fuego volcano on the 16th of December of 2022.

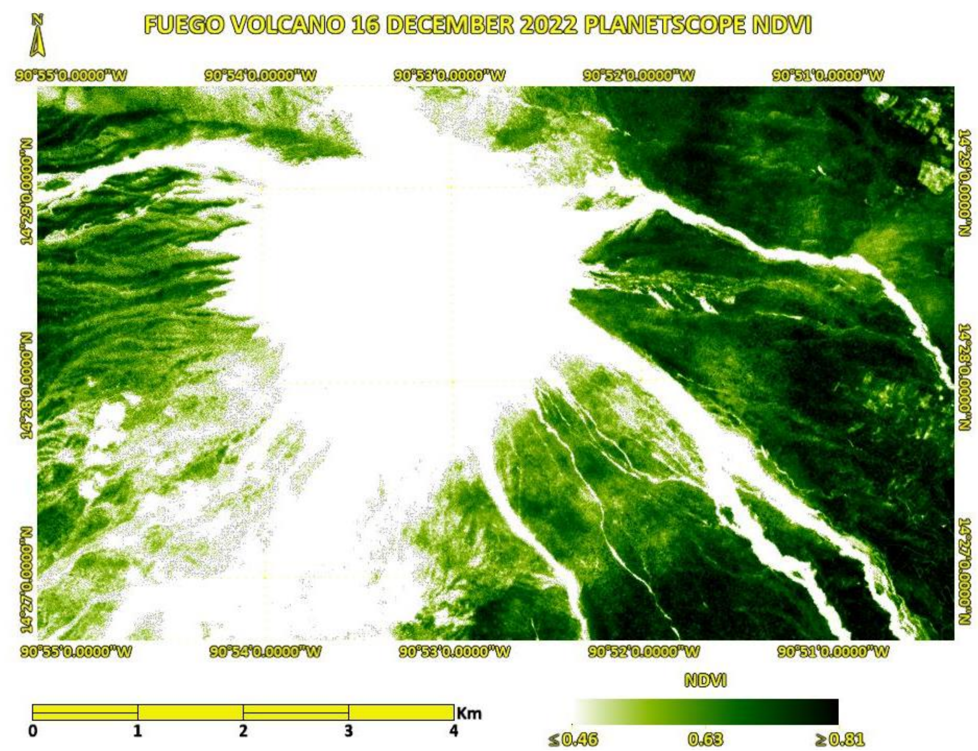

Figure 16 – NDVI for the Fuego volcano in 16th of December of 2022 using a Planet Scope image.

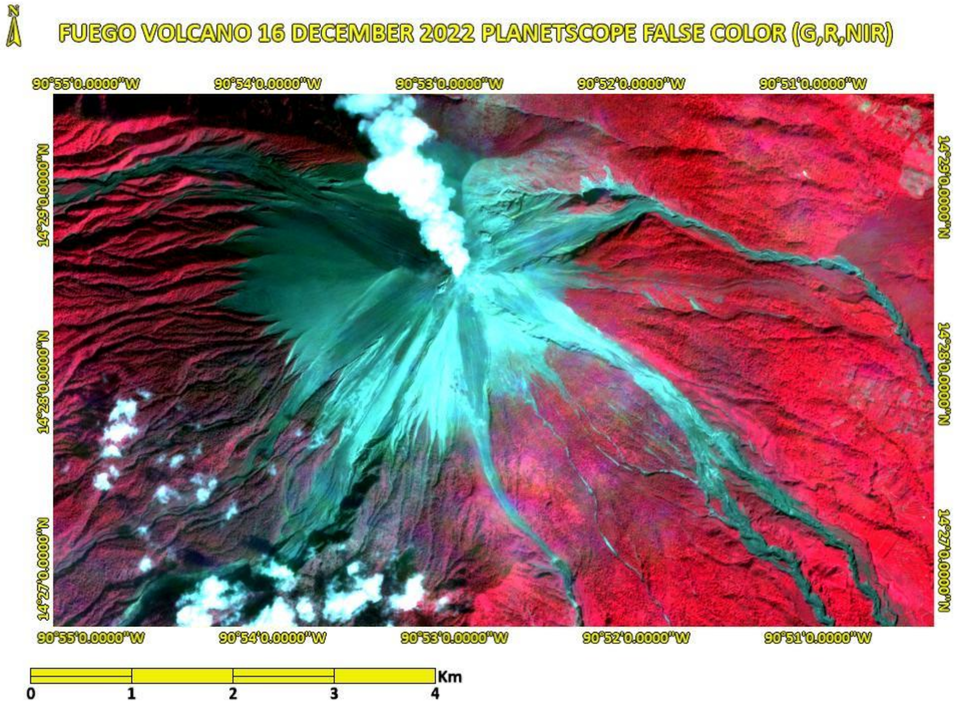

Figure 17 – B,G,NIR Planet Scope image of the Fuego volcano on the 16th of December of 2022.

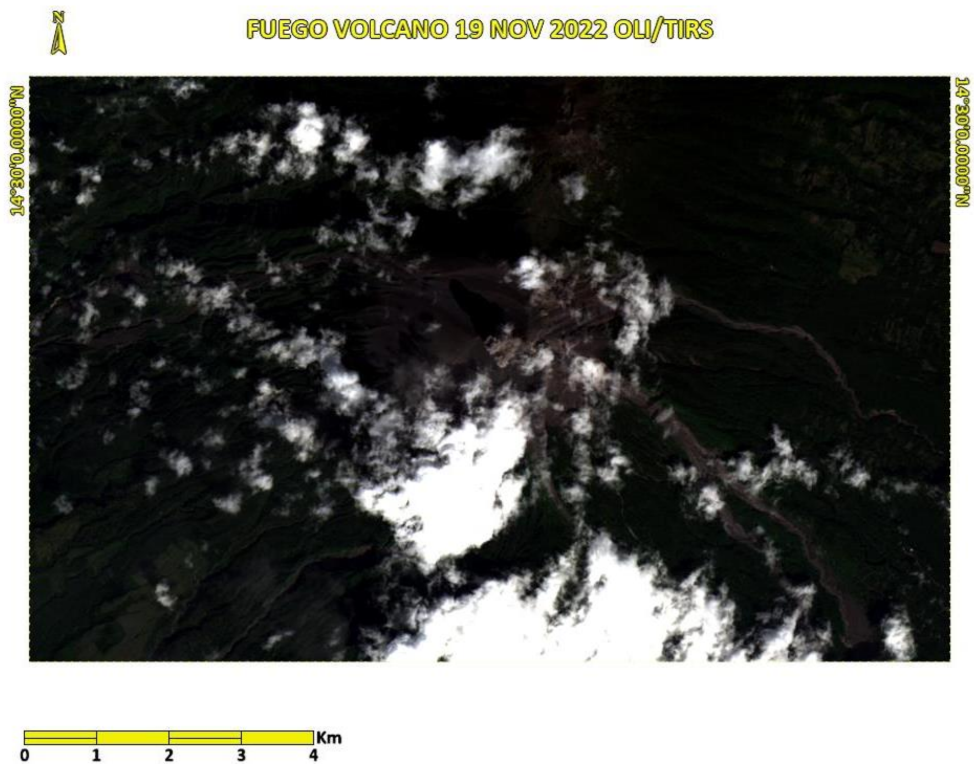

Figure 18 – OLI/TIRS image of the Fuego volcano on the 19th of November of 2022.

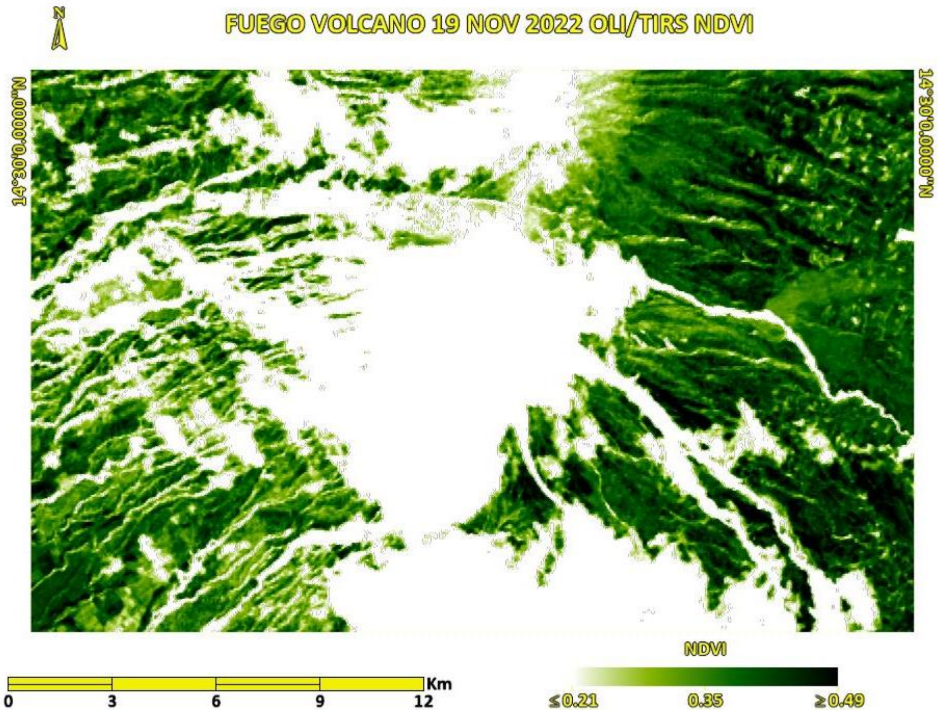

Figure 19 – NDVI for the Fuego volcano in 19th of November of 2022 using an OLI/TIRS image.

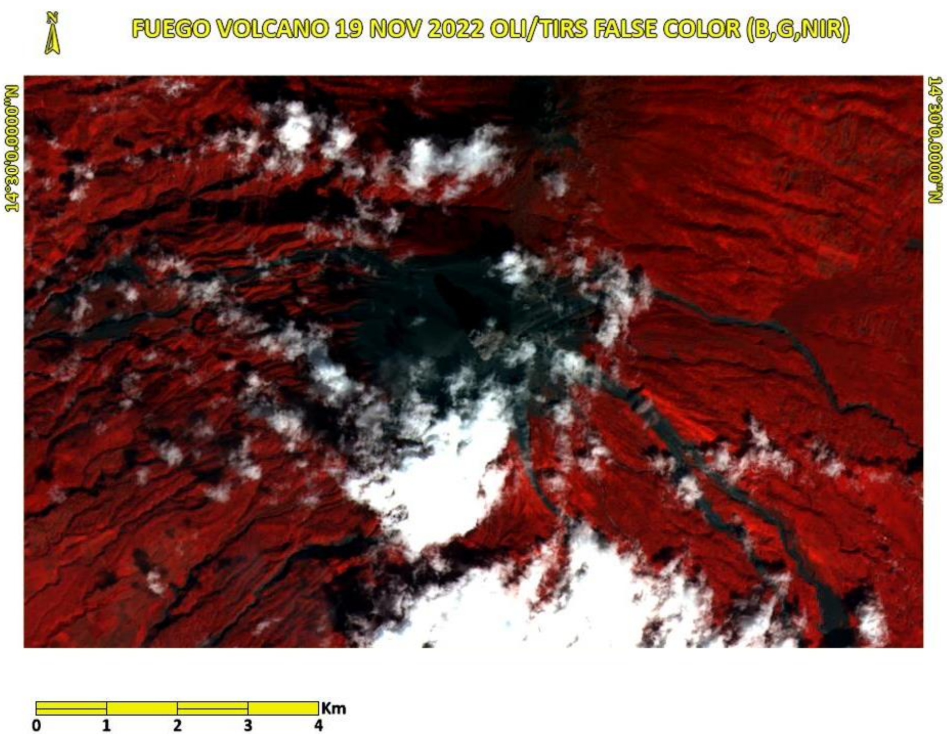

Figure 20 – B,G,NIR Planet Scope image of the Fuego volcano on the 19th of November of 2022.

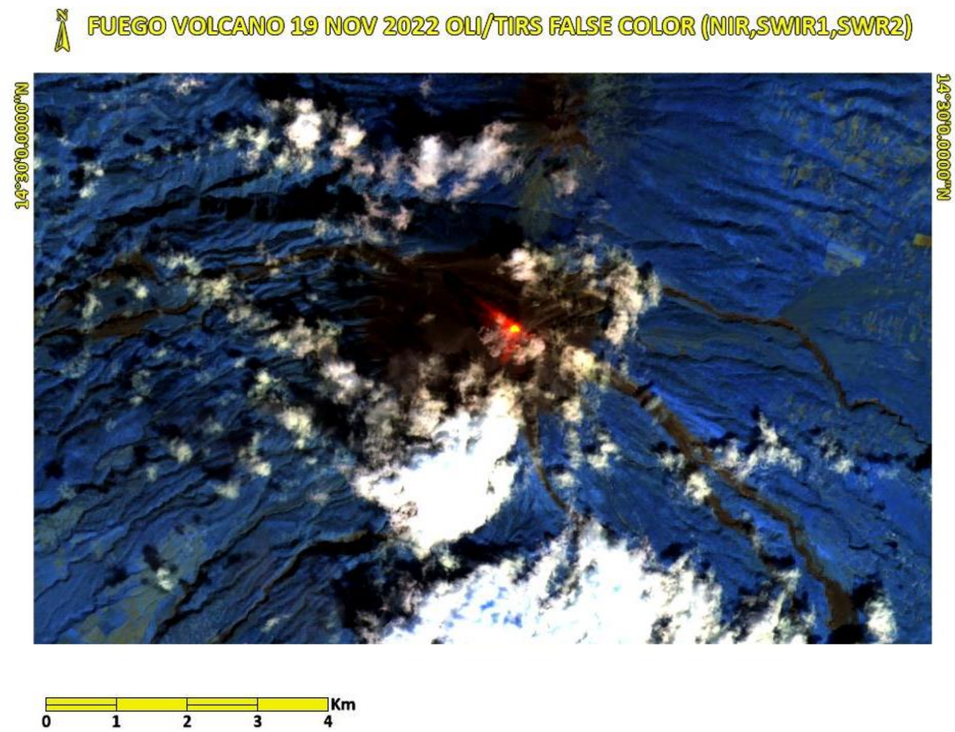

Figure 21 – NIR,SWIR1,SWIR2 Landsat image Fuego volcano on the 19th of November of 2022.

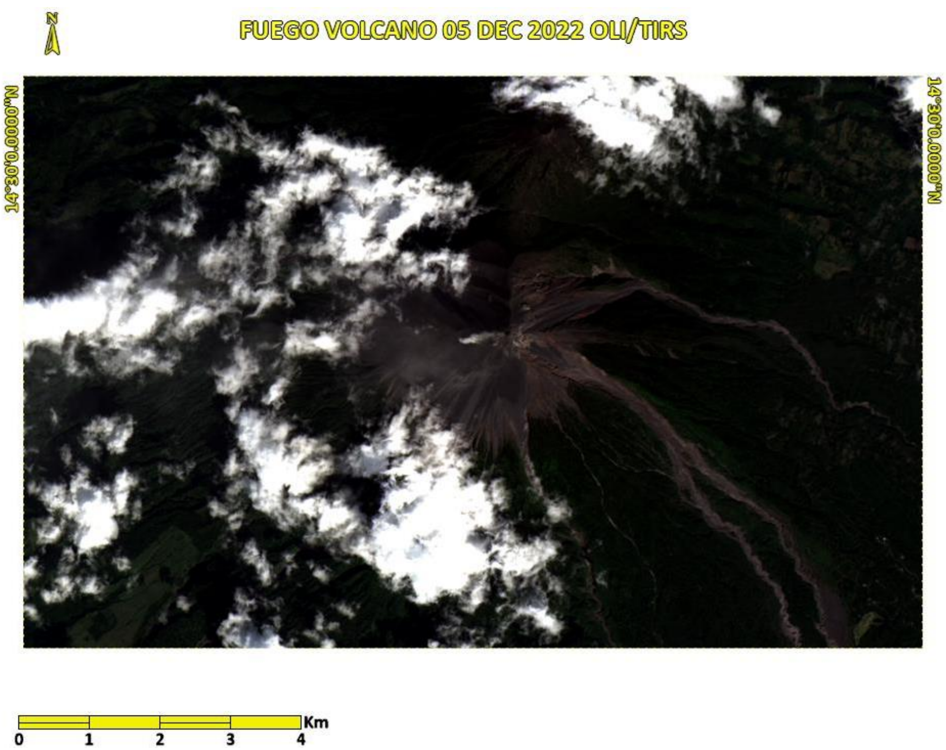

Figure 22 – OLI/TIRS image of the Fuego volcano on the 5th of December of 2022.

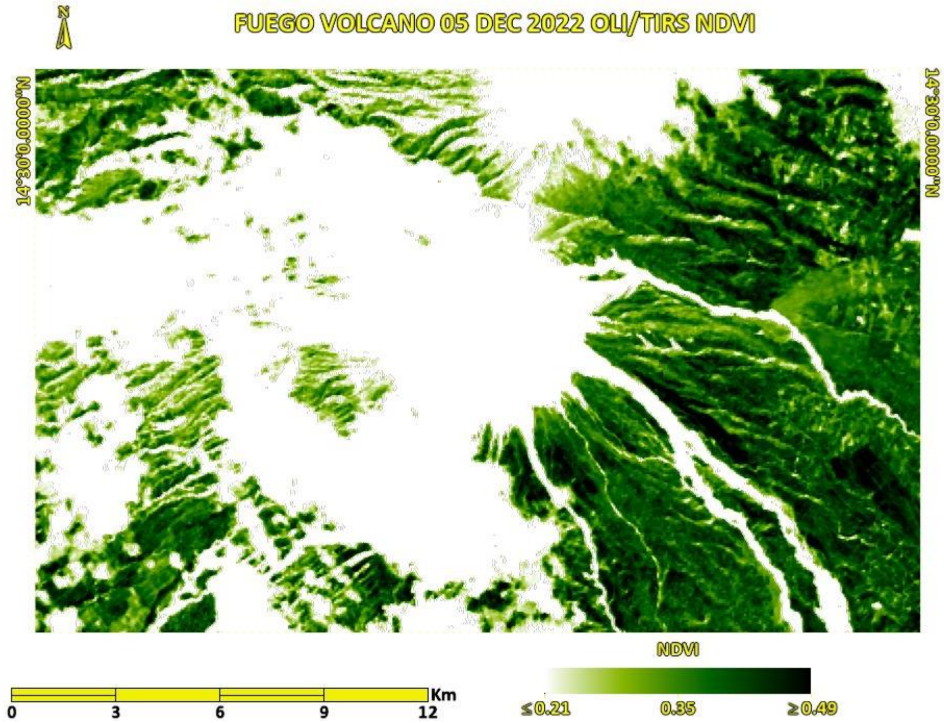

Figure 23 – NDVI for the Fuego volcano in 5th of December of 2022 using an OLI/TIRS image.

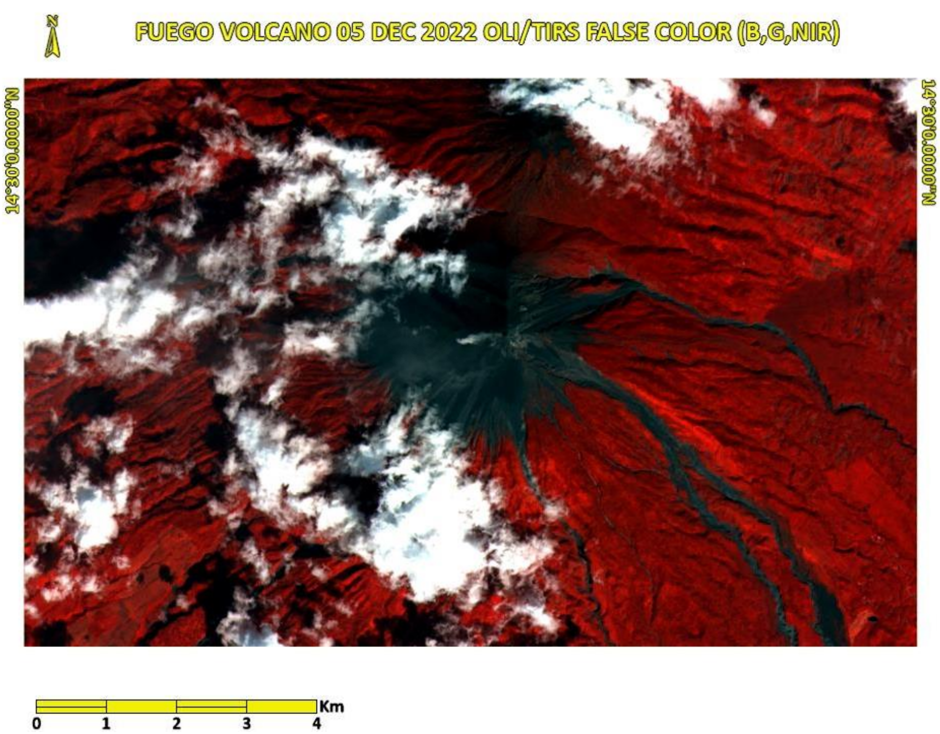

Figure 24 – B,G,NIR Planet Scope image of the Fuego volcano on the 5th of December of 2022.

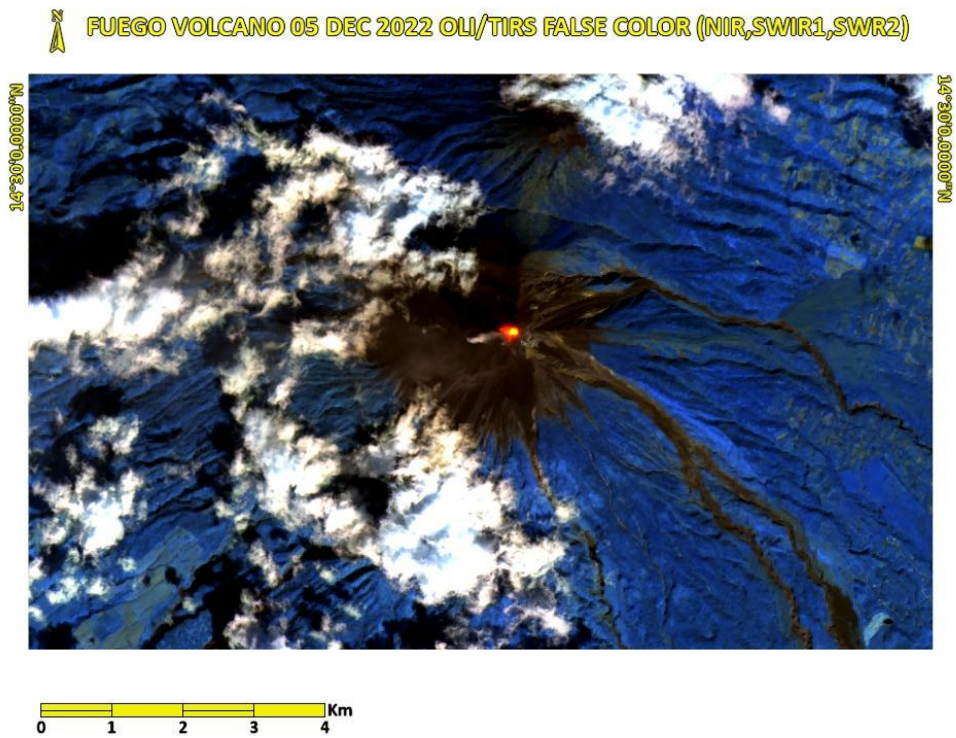

Figure 25 – NIR,SWIR1,SWIR2 Landsat image Fuego volcano on the 5th of December of 2022.

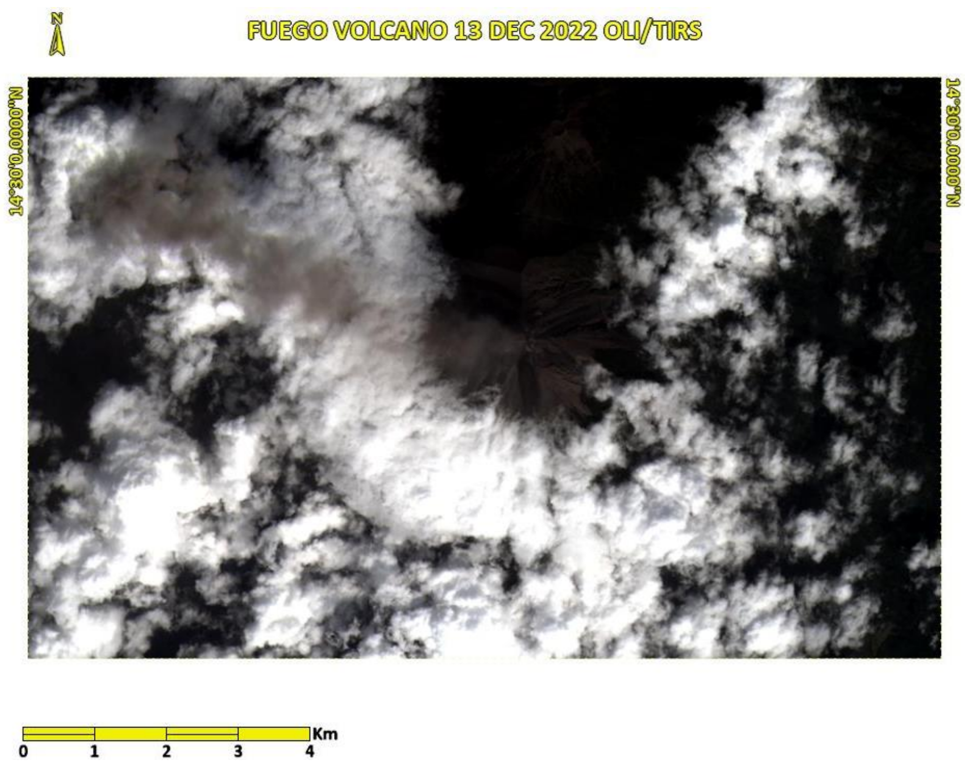

Figure 26 – OLI/TIRS image of the Fuego volcano on the 13th of December of 2022.

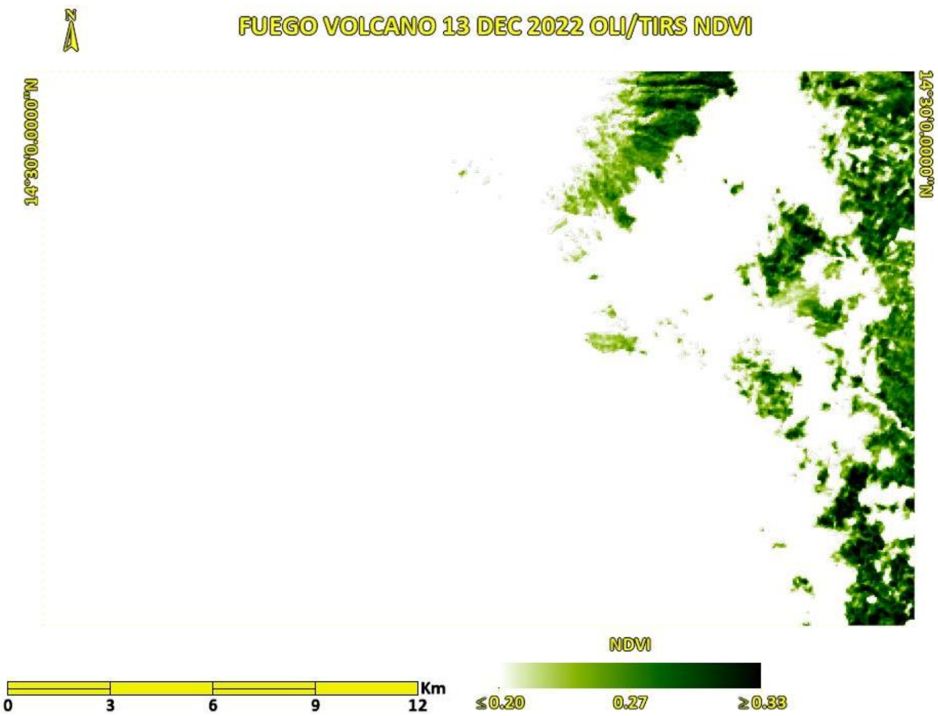

Figure 27 – NDVI for the Fuego volcano in 13th of December of 2022 using an OLI/TIRS image.

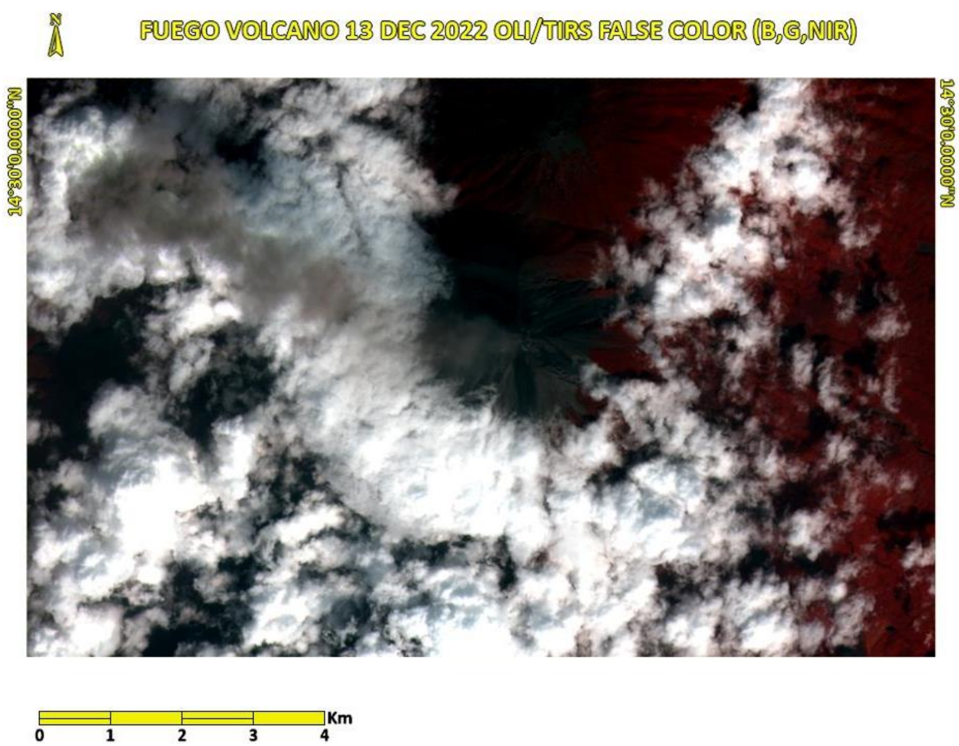

Figure 28 – B,G,NIR Planet Scope image of the Fuego volcano on the 13th of December of 2022.

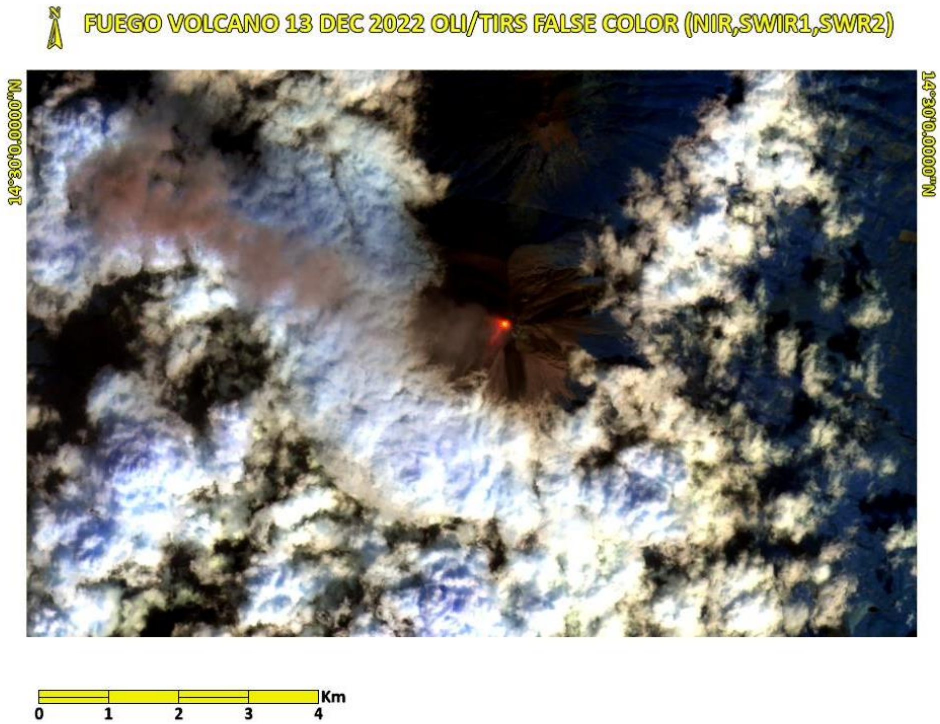

Figure 29 – NIR,SWIR1,SWIR2 Landsat image Fuego volcano on the 13th of December of 2022.

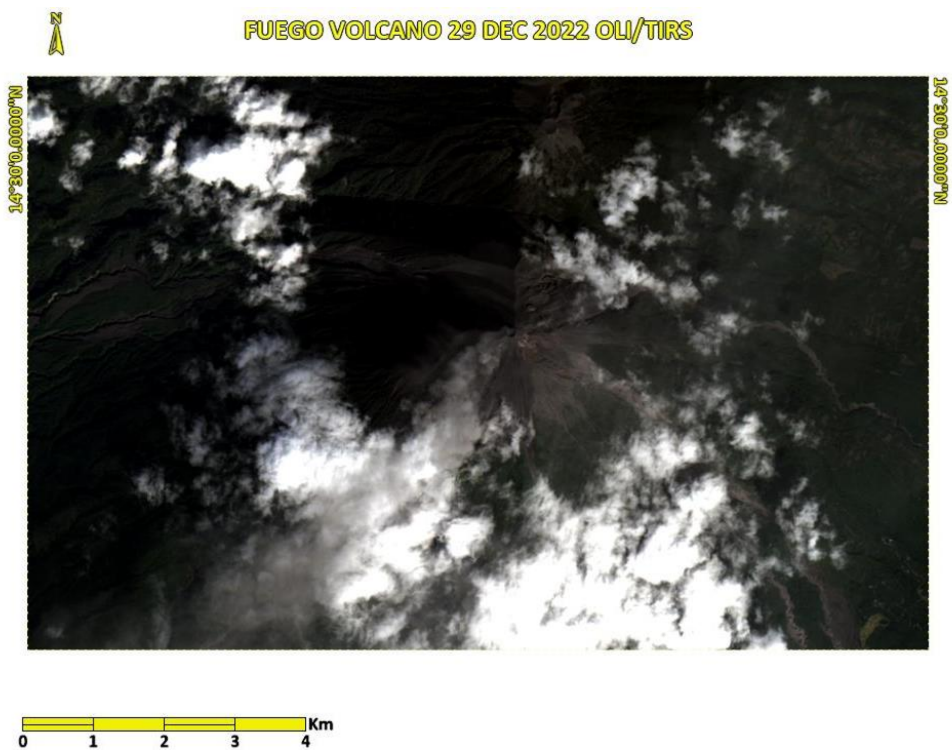

Figure 30 – OLI/TIRS image of the Fuego volcano on the 29th of December of 2022.

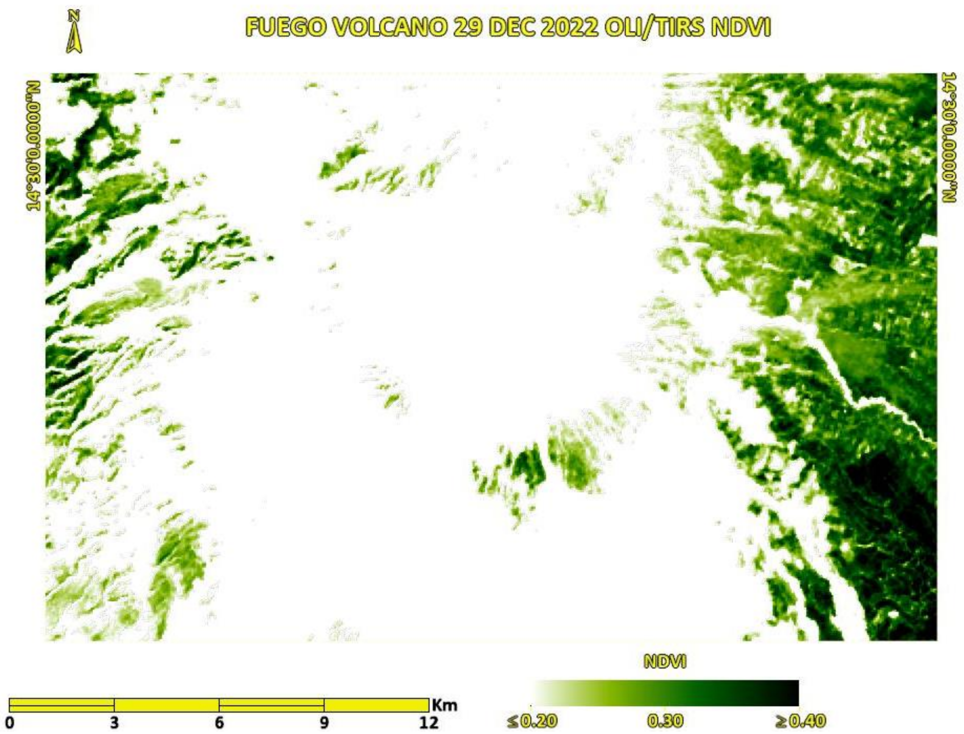

Figure 31 – NDVI for the Fuego volcano in 29th of December of 2022 using an OLI/TIRS image.

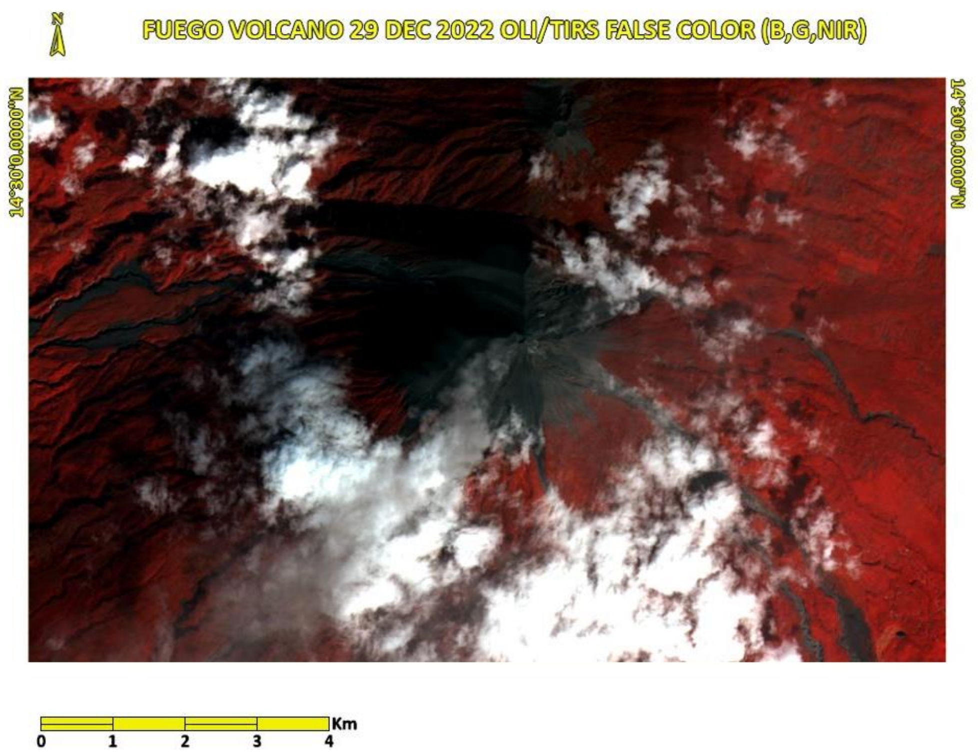

Figure 32 – B,G,NIR Planet Scope image of the Fuego volcano on the 29th of December of 2022.

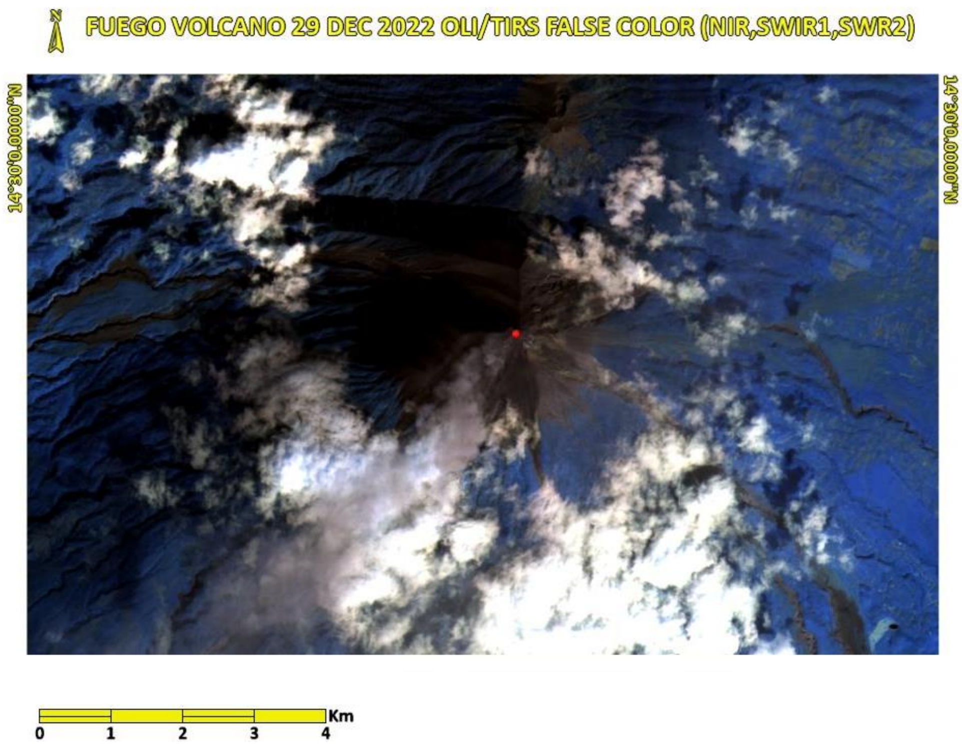

Figure 33 – NIR,SWIR1,SWIR2 Landsat image Fuego volcano on the 29th of December of 2022.

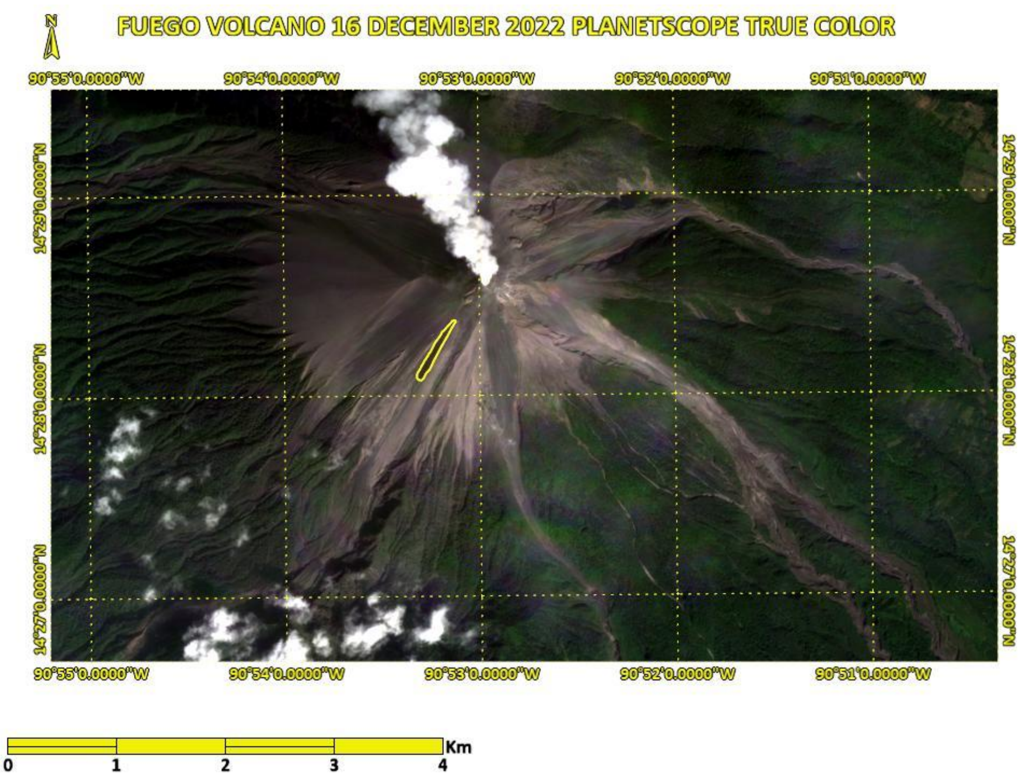

Figure 34 – PS image of the Fuego volcano on the 16th of December of 2022 with deposit marked.

Table 1 – Coordinates of points selected and the NDVI value for the Planet Scope images for the 7th, 10th, 11th, 15th and 16th of December of 2022.

Coordinates	NDVI (7th Dec)	NDVI (10th Dec)	NDVI (11th Dec)	NDVI (15th Dec)	NDVI (16th Dec)
14°28’35.31’’N, 90°51’57.13’’W	0.81	0.85	0.60	0.79	0.72
14°28’30.50’’N, 90°51’38.90’’W	0.85	0.86	0.67	0.80	0.77
14°29’20.95’’N, 90°50’27.68’’W	0.85	0.84	0.64	0.74	0.74
14°28’23.62’’N, 90°50’24.26’’W	0.84	0.84	0.66	0.72	0.67
14°26’57.66’’N, 90°50’22.71’’W	0.86	0.87	0.61	0.82	0.76
14°28’39.38’’N, 90°50’54.31’’W	0.88	0.88	0.69	0.81	0.69
14°28’34.52’’N, 90°50’30.52’’W	0.79	0.78	0.59	0.68	0.63
14°27’41.76’’N, 90°50’19.11’’W	0.84	0.83	0.64	0.76	0.73
14°28’23.83’’N, 90°50’47.31’’W	0.73	0.74	0.59	0.57	0.63
14°28’39.08’’N, 90°50’21.73’’W	0.81	0.82	0.67	0.78	0.69

Table 2 – Coordinates of points selected and the NDVI value for the OLI/TIRS images for the 19th of November of 2022 and the 5th, 13th, 29th of December of 2022.

Coordinate	NDVI (19th Nov)	NDVI (5th Dec)	NDVI (13th Dec)	NDVI (29th Dec)
14°26’57.06’’N, 90°50’10.04’’W	0.40	0.38	0.32	0.35
14°26’4.90’’N, 90°49’45.35’’W	0.42	0.39	0.33	0.38
14°27’14.71’’N, 90°49’37.89’’W	0.42	0.43	0.32	0.36
14°27’55.35’’N, 90°49’42.34’’W	0.41	0.40	0.28	0.34
14°29’3.82’’N, 90°50’34.01’’W	0.34	0.32	0.26	0.24
14°28’28.76’’N, 90°50’20.78’’W	0.43	0.40	0.29	0.32
14°26’39.96’’N, 90°49’58.58’’W	0.36	0.42	0.33	0.39
14°26’56.11’’N, 90°50’9.08’’W	0.43	0.43	0.33	0.38
14°27’9.26’’N, 90°50’1.20’’W	0.48	0.48	0.36	0.41
14°28’25.54’’N, 90°49’39.14’’W	0.37	0.35	0.27	0.30

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