Detecting the surface temperature anomaly of the Anak Krakatau Volcano using Landsat-8 TIRS during 2018 eruption

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Abstract. Geologically, Indonesia is located at the confluence of tectonic plates which causes many active volcanoes to appear in these regions. The existence of these active volcanoes has a consequence that volcanic eruptions will always be a threat to residents who live in volcanic areas. Anak Krakatau volcano is one of the active and dangerous volcanoes located in the Sunda Strait. The volcano will always be a threat to residents who live in coastal areas around the Sunda Strait. With regard to the hazard, it is important to understand the characteristic of the volcanism of Anak Krakatau volcano, especially the physical symptoms that appeared before and during the eruption. This study analyzes the surface temperature anomaly of the peak area of Anak Krakatau volcano in the 2018 eruption. The Brightness Temperature (BT) were measured from channel-10 of Landsat-8 TIRS (Thermal Infra-Red Scanner) time series during 2018. Then, we analyzed the anomalies. The analysis results showed that in the case of Anak Krakatau volcano, a type of submarine volcano in Indonesia, the eruptions that happened during 2018 have demonstrated changes in the surface temperature of the peak area, spatially and temporally. Time-series analysis of brightness temperature data is useful for understanding when the volcano is in its normal active phase and when it is closing to the eruption. Spatial brightness temperature data analysis is useful for detecting the location of the eruption center and the direction of the lava distribution. So, Landsat-8 TIRS data is useful to detect the eruption precursors in Anak Krakatau volcano, a type of submarine volcano in Indonesia, based on the surface temperature changes and anomalies of the peak area derived from this image data.

1. Introduction
Geologically, Indonesia is located at the confluence of tectonic plates which causes many active volcanoes to appear in these regions. The existence of these active volcanoes has a consequence that volcanic eruptions will always be a threat to residents who live in volcanic areas. Anak Krakatau volcano is one of the active and dangerous volcanoes located in Sunda Strait. The volcano will always be a threat to residents who live in coastal areas around the Sunda Strait (figure 1). The Krakatau volcano is famous for its 1883 biggest eruption [1][2]. The paroxysmal eruption of Krakatau Volcano on 27 August 1883, which is considered to be the largest eruption in its eruptive history, shattered a large portion of the cone, ejected around 18 km³ of volcanic material, and generated a 20-meter high
tsunami along the west coast of Banten and the south coast of Lampung which killed around 36,417 peoples [2]. After resting for about 44 years, in 1927, another eruption occurred with the composition of the magma, giving birth to the Anak Krakatau, which grew bigger and higher over time, forming the cone that is today [2]. Based on the history of its eruptions, combined with physical characters, peak landscapes, volcanic structures, and types of eruptions, this volcano can be classified as a submarine volcano (Anak Krakatau Type) [3]. On 22 December 2018, there was a large tsunami in the Sunda Strait which was related to the activities that occurred at Anak Krakatau volcano. Based on the report from the Center for Volcanology and Geological Hazard Mitigation, during 2018, Anak Krakatau volcano recorded at least eight eruptions. With regard to the hazard, it is important to understand the characteristic of the volcanism of Anak Krakatau volcano, a type of submarine volcano, especially the physical symptoms that appeared before the volcano erupted.

One of the physical phenomena that indicated the increase of volcanic activity is changes in heat flow [4]. Thermal remote sensing, specifically the Landsat Thematic Mapper, got reliable as an instrument for considering dynamic volcanoes [5]. The estimation of the total thermal flux of lava has been done by using Landsat TM [6]. The Landsat ETM+ data can be used to comprehend the thermal characteristics of a series of lava flows by analyzing the short-wave infrared (SWIR) signal emitted from the flow surface [7]. This research tried to analyze the surface temperature anomaly of the peak area of Anak Krakatau volcano during 2018. Landsat-8 satellite provided long continuous data on the earth's surface since 2014. The satellite conveys the optical sensor Thermal Infrared Sensor (TIRS) which will quantify surface temperature in two thermal spectral bands with 100 m spatial resolution [8]. The optical sensors have been used for the infrared monitoring of volcanic activity have become fundamental for the monitoring of volcanoes all around the world [9].

![Image of Anak Krakatau complex](https://www.google.co.id/maps) (a) and ![Image of Anak Krakatau volcano captured from Landsat-8](http://landsat-catalog.lapan.go.id/) (b).

2. Methods

2.1. Satellite Image Data

As many as 15 scenes of Landsat-8 TIRS imageries, path/row 123/64 (covering the area of Anak Krakatau), during 2018, were used in this study. The Landsat-8 TIRS was obtained from Google Earth Engine (https://developers.google.com/earth-engine/datasets/catalog/LANDSAT_LC08_C01_T1_TOA) and Remote Sensing Technology and Data Center, LAPAN (http://landsat-catalog.lapan.go.id/). The date of the image data used are 2 January, 23 March, 8 April, 10 May, 26
May, 11 June, 27 June, 13 July, 29 July, 14 August, 30 August, 15 September, 1 October, 17 October, and 20 December (entirely in 2018).

2.2. *Image Data Pre-processing*

The level of available Landsat-8 TIRS data is calibrated Top of Atmosphere (TOA) reflectance. The level data processing method includes converting calibrated Digital Numbers (DNs) to absolute units at sensor spectral radiance and sensor brightness temperature [10][11]. The Landsat-8 TIRS Imagery were converted to Top of Atmosphere (TOA) spectral radiance using the following equation [10][11]:

$$L_\lambda = M_L Q_{cal} + A_L$$  \hspace{1cm} (1)

where $L_\lambda$ is TOA spectral radiance (Watts/(m$^2$*srad*μm)), $M_L$ is a Band specific multiplicative rescaling factor, $A_L$ is a Band specific additive rescaling factor, and $Q_{cal}$ is the Quantized and calibrated standard product pixel values (DN).

The TOA Brightness Temperature of band 10 Landsat-8 TIRS was derived using the following equation [10][11]:

$$T = \frac{K_2}{\ln(K_2/L_\lambda + 1)}$$  \hspace{1cm} (2)

where $T$ is the at-satellite brightness temperature (K), $L_\lambda$ is TOA spectral radiance, and $K_1$ and $K_2$ are Band-specific thermal conversion constants.

2.3. *Image Data Analyzing*

The data analysis method used was multitemporal data analysis of the brightness temperature parameters in the cropping area of the crater region. The cropping area is 105.419° East / 6.098° South (Top Left) and 105.426° East / 6.106° South (Bottom Right). To minimize the influence of the brightness temperature value of the cloud, we choose the maximum value from the pixels in the cropping area. Then, the graph analysis was conducted to understand the dynamics of the volcanic eruption activity of Anak Krakatau volcano, a type of submarine volcano, during the 2018 eruption. One of several physical phenomena that showed the expansion of volcanic action is changes in heat flow [4]. This theory, the relationship between an increase in temperature and the eruption that will occur, is used as a basic concept in conducting the analysis.

3. *Results and Discussion*

3.1. The temporal dynamic of brightness temperature from Landsat-8 TIRS time-series images

The temporal dynamic of brightness temperature represents the temporal dynamic of volcanic activities. Figure 2 showed the dynamic brightness temperature of the Anak Krakatau volcano’s peak area from the beginning of 2018 to the end of 2018. It tends to be seen that generally, the increase in eruption activity that occurred during 2018 shows an expansion in the brightness temperature. Based on the graph, it can be seen that the period between 2 January and 27 June 2018 is a normal active period. Then from 13 July 2018 until 20 December 2018 there was an increase in activity (eruption period). The brightness temperature value during the peak eruption period on 30 August 2018, 15 September 2018, 1 October 2018, 17 October 2018, and 20 December 2018 reached 368 K, 367 K, 368 K, 358 K, and 368 K respectively. Based on the graph, in this case, it looks like the TIRS sensor is saturating at 368 K.
Figure 2. The fluctuation of brightness temperature (in Kelvin) of Anak Krakatau volcano’s peak area from the beginning of 2018 to the end of 2018.

3.2. The spatial pattern of the brightness temperature from Landsat-8 TIRS time-series images

The spatial pattern of the brightness temperature was derived from Landsat-8 TIRS time-series images. The imageries represent surface temperature variations at locations around the peak area of the Anak Krakatau volcano. The location with the highest brightness temperature is the center of the eruption, in the case of the Anak Krakatau volcano is in the crater. The fresh erupted hot lava also appears to have a relatively higher brightness temperature. From the image date of 1 October 2018, it appears that the direction of distribution tends to the South. By looking at the spatial distribution of the brightness temperature around the peak area of Anak Krakatau volcano during the eruption (eruption period), it can be identified that the center of the eruption is in the crater. The crater has the highest brightness temperature. Figures 3 and 4 demonstrated detailed spatial distribution of the brightness temperature around the crater area during eruption periods showing up the expanding of brightness temperature of Anak Krakatau volcano’s peak area during pre-eruption and eruption periods.

![Spatial distribution of the brightness temperature around the peak area of Anak Krakatau volcano before the eruption (pre-eruption period)](image-url)
Figure 4. Spatial distribution of the brightness temperature around the peak area of Anak Krakatau volcano during the eruption (eruption period)

The analysis results described above are sourced from satellite image data analysis. As a comparison, a volcano activity press release (from the Center for Volcanology and Geological Disaster Mitigation) is used which is based on the results of observations from the Anak Krakatau volcano Observer Post. The observations noted that there had been eruptions on 25 June 2018 [12], 16 July 2018 [13], 2 August 2018 [14], 17 August 2018 [15], 23 August 2018 [16], 22 September 2018 [17] and 22 December 2018 [18]. Based on the report released by the Center for Volcanology and Geological Hazard Mitigation, on December 22, the Anak Krakatau volcano experienced an eruption. Visually, an eruption was observed with a smoke height ranging from 300 to 1,500 meters above the crater. Seismically, continuous tremors were recorded with an overscale amplitude (58 mm). At 21.03 WIB, an eruption occurred and most of Anak Krakatau's cone had disappeared and were removed. This landslide from the Anak Krakatau caused a tsunami in several areas on the southern coast of Lampung and the west coast of Banten [18]. The landslide collapses in approximately 60 s and 150 million m$^3$ materials slide into the seawater with a velocity of about 35 m.s$^{-1}$[19].

It is also important to know that increasing the brightness temperature of the volcano’s peak area on Anak Krakatau volcano, a type of submarine volcano, preceding the 2018 eruption is also in line with the Agung eruption case, a volcano with an open crater eruption type [20]. Also, the presence of volcanic material from the 2018 eruption has been observed from the fusion of the Sentinel-1 SAR data on 17 September 2018 and Landsat-8 imagery on 1 October 2018 [21]. The results of this analysis are also in accordance with the results of research from other researchers, namely the increase in surface temperature is associated with an increase in earthquake tremors, which indicates the presence of volcanic fluid rising to the surface and is related to the melting of lava from the eruption that comes out of the crater [22].

4. Conclusion
In the case of Anak Krakatau volcano, a type of submarine volcano in Indonesia, the eruptions that happened during 2018 have demonstrated changes in the surface temperature of the peak area, spatially and temporally. Time-series analysis of brightness temperature data is useful for understanding when the volcano is in its normal active phase and when it is closing to the eruption. Spatial brightness temperature data analysis is useful for detecting the location of the eruption center and the direction of the lava distribution. The brightness temperature value during the eruption period reached 368 K and in this case, the Landsat-8 TIRS sensor is saturating at 368 K. Landsat-8 TIRS data is useful to detect the eruption precursors in Anak Krakatau volcano, a type of submarine volcano in Indonesia, based on the surface temperature changes and anomalies of the peak area derived from this image data. However, considering that in Indonesia, there are many other types of volcanoes, then more research still should be conducted.
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