SPATIO-TEMPORAL ANOMALIES IN SURFACE BRIGHTNESS TEMPERATURE PRECEDING VOLCANO ERUPTIONS DETECTED BY THE LANDSAT-8 THERMAL INFRARED SENSOR (CASE STUDY: KARANGETANG VOLCANO)

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Abstract. Indonesia's geological as part of the “ring of fire” includes the consequence that community life could be affected by volcanic activity. The catastrophic incidence of volcanic eruptions in the last ten years has had a disastrous impact on human life. To overcome this problem, it is necessary to conduct research on the strengthening of the early warning system for volcanic eruptions utilising remote sensing technology. This study analyses spatial and temporal anomalies of surface brightness temperature in the peak area of Karangetang volcano during the 2018-2019 eruption. Karangetang volcano is an active volcano located in North Sulawesi, with a magmatic eruption type that releases lava flow. We analyse the anomalies in the brightness temperature from channel-10 of the Landsat-8 TIRS (Thermal Infrared Scanner) time series during the period in question. The results of the research demonstrate that in the case of Karangetang Volcano the eruptions of 2018-2019 indicate increases in the surface brightness temperature of the crater region. As this volcano has many craters, the method is also very useful to establish in which crater the center of the eruption occurred.

Keywords: *Surface brightness temperature, Karangetang Volcano, magmatic eruption, Landsat-8 TIRS*

1 INTRODUCTION

Karangetang volcano (also known as Api Siau) is a volcano with a magmatic eruption type that releases lava flow (Kusumadinata, 1979; Pratomo, 2006). It is one of the active volcanoes located in North Sulawesi, more precisely in Siau Islands Tagulandang Biaro Regency (Figure 1-1). Based on the history of its eruptions, and combined with its physical characteristics, peak landscapes, volcanic structures, and types of eruption, the volcano can be classified as an active volcano type with lava flow (Sangeangapi Type) (Pratomo, 2006). MAGMA Indonesia-Pusat Vulkanologi dan Mitigasi Bencana Geologi (Centre of Volcanology and Geological Hazard Mitigation) (2020) reported that on 25 November 2018 the volcano erupted, causing danger to those living on its slopes. Because of the associated hazards, it is important to understand the volcanic characteristics of Karangetang.

Surface temperature derived from satellite images is a key component of numerous aspects of environmental research (Mazzeo et al., 2021). Thermal remote sensing is currently a developing technique for monitoring dynamic volcanoes around the world (Mia et al., 2017). Thermal remote sensing, in

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particular the Landsat Thematic Mapper, is reliable as a tool for studying active volcanoes (Wright et al., 2004). Estimation of the total thermal flux of lava has been made using Landsat TM (Harris, 1998). In addition, Landsat ETM+ data can be used to understand the thermal characteristics of a series of lava flows by analysing the short-wave infrared (SWIR) signals emitted from the flow surface (Wright et al., 2001).

The application of optical data for temperature analysis related to volcanic activity is increasing, along with the development of more advanced analytical techniques such as subpixel analysis and multichannel thermal infrared sensors, such as MODIS (Wright & Flynn, 2003; Wright et al., 2004; Marchese et al., 2010; Lacava et al., 2014; Suwarsono et al. , 2015), NOAA-AVHRR (Patrick et al., 2005), VIIRS (Trifonov et al., 2017), ASTER (Pieri & Abrams, 2004), and Landsat-8 (Blackett, 2014; Marchese et al., 2019).

This research attempts to analyse the surface brightness temperature anomaly both spatially and temporally of the peak area of the Karangetang volcano during the 2018-2019 magmatic eruption. The Landsat-8 satellite has provided continuous data of global volcanic activity since 2014. One of the advantages of the satellite is that it is a medium resolution type, and carries a thermal sensor with 16-day re-recording, making it very useful for monitoring volcanism activity. The Thermal Infrared Sensor (TIRS) quantifies surface brightness temperature in two thermal spectral bands with 100 m spatial resolution (Irons, 2012). The optical sensors used for the infrared monitoring of volcanic activity have become fundamental around the world. Landsat-8 TIRS has advantages over its predecessor TIR, Landsat sensors, in that its images are captured in a push-broom (compared to a whisk broom), which reduces the signal-to-noise ratio, and its TIR bands have a larger dynamic range and the collected TIR images are combined with OLI images to form a registered image (Irons et al., 2012; Schott et al., 2012).

According to the Indonesian Volcano Data Base, Center for Volcanology and Geological Hazard Mitigation, Geological Agency, Karangetang Volcano is very active. Based on the Geological Map, the peak area of Karangetang volcano is a lava dome with an andesite-basaltic composition (Budianto, et al., 2000). The volcano has a very short rest period of several months before becoming active again. In general, volcanic activity begins with an eruption of smoke or ash and usually lasts 2 or 3 months. This activity continues in the form of a magmatic (explosive) eruption, followed by a lava discharge (effusive). In some cases, the effusive eruption also occurs without being preceded by an explosive eruption. Explosive eruptions are sometimes followed by hot clouds, but what often happens is that the melting of lava always creates hot clouds of avalanche. These hot clouds result from the accumulation of lava at a certain point, or at the end of the flow and collapse due to gravity. This condition is different from the hot clouds of avalanches in the case of the Merapi volcano. Hot clouds of the avalanche in the case of Merapi occurred due to the collapsed dome. The lava from Karangetang Volcano almost always flows, although at one point, it forms a dome. One of the characteristics of the volcano is the major role of local tectonic earthquakes in driving an eruption.

The novelty of this research is the understanding of the spatial and temporal anomalies in surface brightness temperature preceding eruptions of active volcanoes in Indonesia associated with lava flow (Sangeangapi Type), which can be detected by Landsat-8 TIRS. It is hoped that the results of the research based on the case study of Karangetang volcano will be able to be applied to all volcanoes in Indonesia of the Sangeangapi Type.

2 MATERIALS AND METHODOLOGY

2.1 Data

The study used 25 scenes of Landsat-8 TIRS images, path/row 111/58, from 2018-2019, covering the peak area of Karangetang Volcano. The images were obtained from Google Earth Engine and from the Remote Sensing Technology and Data Center, LAPAN, via http://landsat-catalog.lapan.go.id/.

2.2 Methods

2.2.1 Brightness Temperature

In this study, we used the brightness temperature (BT) parameter, not that of land surface temperature (LST). This decision took into account the saturation level of the detection by the TIRS sensor in measuring radiation from objects that emit very high heat, and by considering that the nature of the object being detected is the material resulting from the volcanism process, especially incandescent lava, which has a very high temperature (reaching 1000° C). In using band 10 Landsat-8 TIR images in the case of Mt. Paluweh in Flores, Blackett (2014) noted that saturation occurred at a BT value of 360 K. In principle, on an object at a certain location, the variation in LST over time can be represented by BT parameters. However, the LST value, apart from being influenced by the amount of radiation from the object received by the sensor, is also affected by the emissivity of the surface object (land surface emissivities) and atmospheric conditions (atmospheric transmittances) at the time of the acquisition. It is more important that the focus of the analysis is not the absolute value of the LST, but rather the thermal trend dynamics over time. However, to minimise errors, we made the analysis based on data from cloud-free pixel values.

Figure 2-1: (a) Location of Karangetang volcano (red box) in North Sulawesi (source of background map: https://www.google.co.id/maps); (b) Karangetang volcano seen from Landsat-8, 8 August 2018.

2.2.2 Data Processing

The level of Landsat-8 TIR band 10 data is calibrated top-of-atmosphere (TOA). The calibration coefficients are extracted from the image metadata; the level data processing method refers to Chander et al. (2009). The method includes converting calibrated Digital Numbers (DNs) to absolute units of at-sensor spectral radiance and at-sensor brightness temperature. These conversions provide a basis for standardised comparison of data in a single scene or between images acquired on different dates or by different sensors. In this case, the Landsat-8 TIRS images were processed to obtain the brightness temperature (BT) of the peak region of Karangetang volcano, especially in the crater area (Top left 125.401952 E / 2.782131 N - bottom right 125.410905 E / 2.772477 N). The data were used to provide temperature characteristics, especially in the crater area, before, during and after the eruption, both spatially and temporally.

The Landsat-8 TIRS imagery was converted to top of atmosphere (TOA) spectral radiance using the following equation (Chander et al., 2009; Zanter, 2015):

$$L_\lambda = M_L Qcal + A_L \tag{2-1}$$

where L_λ 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 $Qcal$ is the quantised and calibrated standard product pixel values (DN).

Subsequently, the band 10 Landsat-8 TIRS imagery was converted to a TOA BT. The band 10 TOA BT was derived using the following equation (Chandler et al.; Zanter, 2015):

$$T = \frac{K_2}{ln(\frac{K_1}{L_\lambda}+1)} \tag{2-2}$$

where T is the at-satellite brightness temperature (K); L_λ is TOA spectral radiance; and K_1 and K_2 are band-specific thermal conversion constants.

2.2.3 Data Analysis

The data analysis method employed was spatial data and temporal (time series) data analysis of the brightness temperature band 10 of Landsat-8 TIRS. Spatial and temporal investigation of the brightness temperature data of the crater region was conducted to understand the dynamics of the volcanic eruption activity. One of physical phenomena that indicates increasing volcanic activity changes in heat flow (Marshak, 2013). Therefore, a rise in brightness temperature on the crater is one of the precursors of volcano eruption.

3 RESULTS AND DISCUSSION

3.1 Surface Brightness Temperature Temporal Anomaly

The dynamic of the surface brightness temperature channel-10 (BT10) also represents the surface temperature dynamic. Figure 3-1 shows the dynamic of the surface brightness temperature of the Karangetang volcano peak area from the beginning of 2018 to late 2019. The anomalies took place from November 2018 (2018 eruption) to February 2019 and from July to November 2019 (2019 eruption). The graph shows that the surface brightness temperature increases (positive anomalies) preceding the 2018 and 2019 eruptions. The brightness temperature values on 30 November 2018, 13 August 2019, 29 August 2019, 30 September 2019, 1 November 2019 and 30 November 2019 were 367.1 K, 355.3 K, 360.0 K, 344.9 K, 330.3 K, and 331.8 K respectively.

This physical phenomenon of the occurrence of an increase in crater temperature before an eruption is in accordance with the concept put forward by Marshak (2013), that one of the physical phenomena that indicates an increase in volcanic activity is changes in heat flow. Generally, the characteristic of increased surface brightness temperature in the volcano peak area is also in line with the case of the Agung eruption, a volcano with an open crater eruption type (Suwarsono et al., 2020), and of Anak Krakatau, a type of submarine volcano (Suwarsono et al., 2021).

3.2 Surface Temperature Spatial Anomaly

Based on the Landsat-8 TIRS data, the temperature around the peak area was spatially represented by the data from the BT10 images. Figure 3-2 shows the spatial distribution of the brightness temperature around the crater area during eruption periods. The images indicate the rising brightness temperature of the Karangetang volcano peak area during eruption periods. The surface brightness temperature has a spatial pattern, that is, the closer to the crater (the center of the eruption) the higher the temperature. What is very interesting here is that before the eruption the increase in surface brightness temperature was centred in the south crater, but the large eruptions that occurred were centred in the north crater. Therefore, the north and south craters have an interrelated volcanic mechanism. This spatial analysis can explain the location of the main source of the eruption, where the lava material will be released. Furthermore, it can estimate which locations will be affected by the eruption. This information is very useful in supporting disaster mitigation efforts, in order to minimize the impact that occurs due to incandescent lava

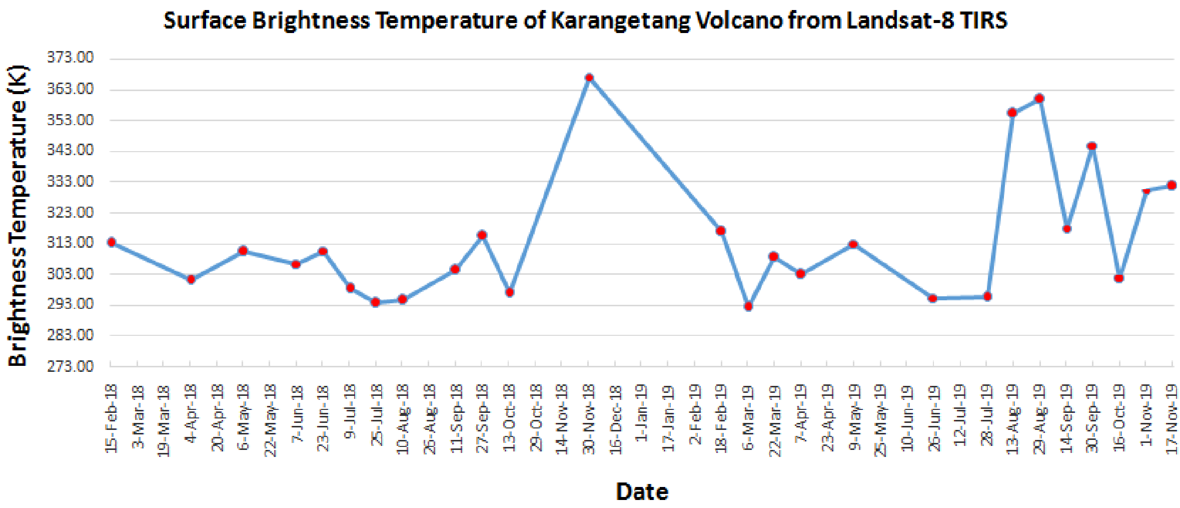

Figure 3-1: Variation in the surface brightness temperature of the Karangetang volcano peak area from the beginning of 2018 to late 2019

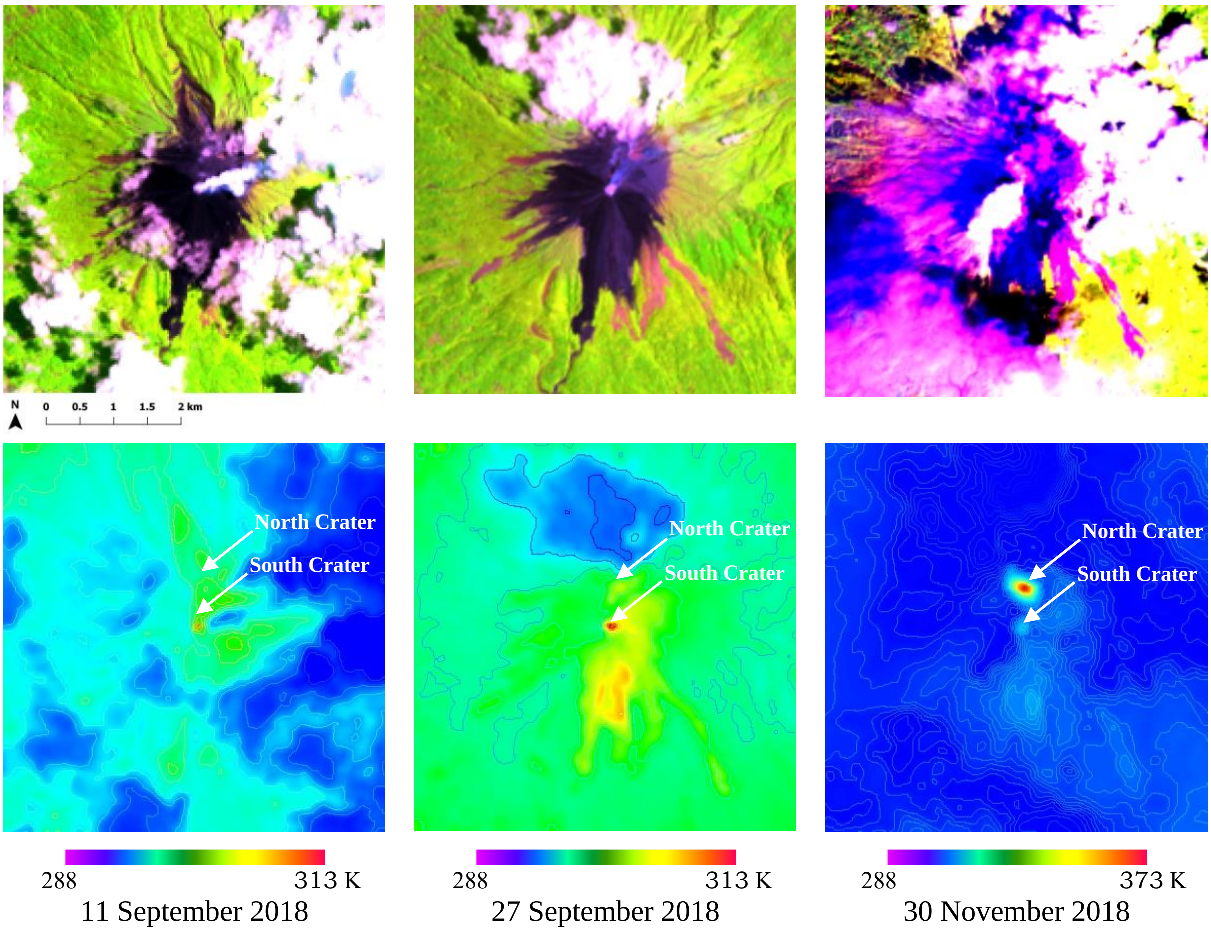

Figure 3-2: Spatial pattern of the brightness temperature of the Karangetang volcano crater before (11 and 27 September 2018) and during (30 November 2018) the 2018 eruption.

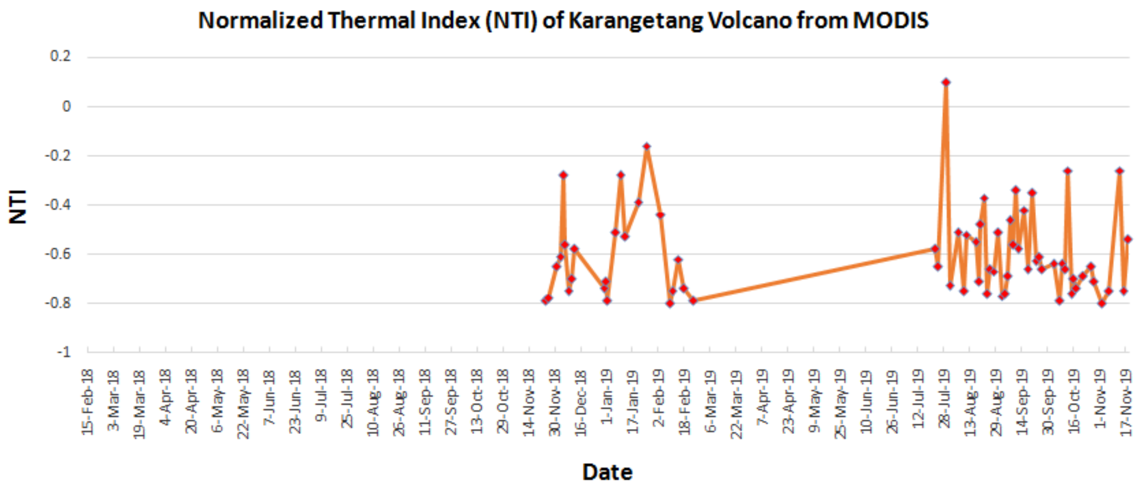

Figure 3-3: Number of volcano hotspots from MODVOLC during the period late 2018 to late 2019.

3.3 Comparison with information from MAGMA Indonesia, GVP and MODVOLC

MAGMA Indonesia–Pusat Vulkanologi dan Mitigasi Bencana Geologi (Centre of Volcanology and Geological Hazard Mitigation) (2020) notes that Karangetang volcano experienced a significant and rapid increase in seismic activity with high frequency content (deep and shallow volcanic) since 22-23 November 2018. This increase in seismicity was followed by a marked decrease in high frequency seismic activity on November 24 2018. Since then, lava effusions accompanied by the growth of lava domes, avalanches, and hot clouds of avalanches have continued.

The results of the monitoring records of Karangetang volcano by the Global Volcanism Program (GVP) (2013) show that on 25 November 2018 there was a volcanic eruption measured at 2 VEI (Volcanic Explosion Index) (https://volcano.si.edu/volcano.cfm?vn=267020). Furthermore, information from MODVOLC (2021) (http://modis.higp.hawaii.edu/) confirms the analysis. From the monitoring results from the Normalized Thermal Index (NTI) derived from MODIS data on this platform, it is known that from November 2018 to February 2019 and from July to November 2019 (2019 eruption), there was an increase in NTI at the summit of Karangetang (Figure 3-3). Therefore, information about the occurrence of eruptions of Karangetang from MAGMA Indonesia, the Global Volcanism Program and MODVOLC confirmed the analysis.

4 CONCLUSION

In the case of Karangetang volcano, which is a magmatic eruption type that releases lava flow, the eruption stage shows a rise in brightness temperature. The eruptions that took place between 2018 and 2019 demonstrate the changes in the surface temperature of the peak area. The surface brightness temperature has a spatial pattern, that is, the closer to the crater (the center of the eruption) the higher the temperature. Anomalies in brightness temperature occurred on 30 November 2018, 13 August 2019, 29 August 2019, 30 September 2019, 1 November 2019 and 30 November 2019, with levels of 367.1 K, 355.3 K, 360.0 K, 344.9 K, 330.3 K, and 331.8 K respectively. Karangetang is a volcano with more than one crater, and the north and south craters show an interrelated volcanic mechanism. The Spatio-temporal anomalies analysis is very useful to establish in which crater the center of the eruption was located. The surface temperature changes in the peak area, which can be identified from Landsat-8 TIRS multi-temporal images, can be utilized as a precursor during an eruption period for this volcano type. More research needs to be conducted on utilizing TIRS Landsat-8 TIRS data integrated with other recent satellite imagery data, to analyze the precursors of other types of volcano in Indonesia.

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AUTHORS CONTRIBUTION

Suwarsono (conceptualisation, data curation, formal analysis, investigation, methodology, validation, visualisation, writing of the original draft, review writing and editing); Djoko Triyono (conceptualisation, methodology, supervision, review writing and editing); Muhammad Rokhis Khomarudin (conceptualisation, data curation, methodology, supervision, review writing and editing); and Rokhmatuloh (conceptualisation, funding acquisition, methodology, supervision, review writing and editing).

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