Article

Mount Semeru Eruption on December 1, 2020: A volcanic ash cloud assessment using TIR imagery with 8.5-12.0 μm spectral bands

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Abstract. Mount Semeru is one of the most active volcanoes in the Java Island. This article presents the results of observations and detections of volcanic ash cloud after Mt Semeru eruptions on 1 December 2020 at 01:23 AM. Volcanic ash cloud detection was conducted by analyzing thermal infrared (TIR) satellite images acquired by the NOAA-20 and SNPP with MODIS and VIIRS instruments. The TIR instruments have detected the presence of volcanic ash cloud. The results show increasing ash cloud brightness temperature (BT) from 240 to 270 Kelvin (K) several hours after eruptions. Increasing BT indicated the development of volcanic Cumulonimbus (Cb) at lower altitude. Northeast movements of 270 K BT clouds were observed at 06:12 AM. Presences of volcanic Cb and SO_2 were confirmed using IR bands of 12.0-10.8 μm, 11.0-8.5μm and 11.0 μm. This Cb cloud was observed moving northeast directions. The data acquired from the TIR imagery resulted from this study is thought be used in future to support and complement ground-based observations and detections of active volcanoes mainly in Java Island.

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1. Introduction

A volcanic activity was characterized by its infrared region of the spectrum since this activity transfers heat from within the earth to the surface. This observed activity expressed in the thermal signature ranges from a fresh lava flow or an active lava lake to degassing surface or warmed crater-lake. Then observations emphasizing more on infrared region are useful when examining volcanic activity (Blackett 2017, Oppenheimer 1998). Volcano emits varied temperatures with fresh lava ranges of 1073-1273 Kelvin (K) with lava lake temperature can be at up to 1473 K and cooler active surfaces may reach 673 K (Fink et al. 2008, Oppenheimer & Yirgu 2002). At these temperatures, the chief radiant emissions are in the thermal infrared (TIR), middle infrared (MIR) and shortwave infrared (SWIR) portions of the spectrum. The wavelength ranges of TIR, MIR and SWIR were 5.5-15.5 μm, 3.0-5.0 μm and 1.0-2.5 μm correspondingly.

Various earth-observing satellites have sensors capable of observing these infrared emissions and as such are routinely used for volcanic observations. TIR was equipped in NASA Television Infrared Observation Satellite (TIROS) series launched in 1960. Since this time, TIR has observed wildfires to

active volcanoes including 2006's eruption of Bezymianny volcano and Redoubt Volcano. In Indonesia, TIR observations have been used to determine lava extrusion rates and discriminating different types of lava dome activity of Merapi volcano in Java island (Carter et al. 2008, Carter et al. 2009, Carr et al. 2016, Wessels et al. 2013).

Infrared observation was pioneered by launches of satellite with its TIR instruments included NOAA with AVHRR, NASA GOES (geostationary satellite), Meteosat with SEVERI, NASA EOS with ASTER and MODIS (aqua and terra) and JPSS (NOAA 20 and SNPP), a joint satellite of NASA and NOAA with VIIRS instrument. SNPP is the first satellite mission to acquire a wide range of land, ocean, and atmospheric measurements while simultaneously addressing operational requirements for weather forecasting. VIIRS instrument has succeeded to detect ash cloud from Kamchatka eruption on 03/26/2015 based on false color imagery using combinations of 8.55 µm, 10.76 µm and 12.01 µm spectral bands. It also has detected a thermal anomaly indicating increased volcanic activity at Mt Sakurajima, 14 hours before an eruption on August 18. Rapid developments of TIR instruments have an advantage for monitoring the volcano activities mainly in countries that located in the ring of fire including Indonesia.

Semeru is one of active volcano in Java island and has been reported erupted several times. The recent eruption was started at 01:23 AM on 12/01/2020. A visual observation has reported a volcanic ash released several times form the mountain. Regarding this situation, this paper aimed to assess the volcanic loads of recent Mt Semeru eruption using TIR imagery acquired by VIIRS instruments. Understanding active volcano in this study Mt Semeru is clearly useful in determining Mt Semeru's status and as such in predicting future activity. Making an early accurate assessment and detection remotely and at a safe distance is also notably advantageous.

2. Methodology

2.1. Study area

The study area was 3676 meter Mount Semeru (Mt) located in East Java. The geocoordinate of Mt Semeru were 8°6'28.8"S and 112°55'12.0"E . The observation was made after the eruptions of Mt Semeru on December 1, 2020 (12/01/2020) started from 01:23 AM.

2.2. TIR image acquisition

The TIR image acquisition was following methods developed by Dubuisson et al. (2014), Ellrod et al. (2003), Pavolonis (2010) and Pavolonis et al. (2006, 2013, 2015, 2018). All TIR image were acquired from following satellites include GOES-EAST, GOES-WEST, NOAA-20 and SNPP with MODIS and VIIRS instruments.

2.2.1. VIIRS

VIIRS stands for Visible Infrared Imaging Radiometer Suite, an instrument developed to collect visible and infrared imagery and global observations of land, atmosphere, cryosphere and oceans. This sensor is currently flying on the SNPP satellite mission. VIIRS provides critical environmental products about snow and ice cover, clouds, fog, aerosols, fire, smoke plumes, dust, vegetation health, phytoplankton abundance and chlorophyll. VIIRS has 22 channels ranging from 0.41 µm to 12.01 µm with 5 of these channels are high-resolution image bands or I-bands. Another 16 bands serve as moderate-resolution bands or M-bands. VIIRS also hosts a unique panchromatic day/night band.

2.2.2. MODIS

MODIS stands for Moderate Resolution Imaging Spectroradiometer is on-board the two polar orbiting satellites Aqua and Terra. Data acquisition of MODIS is in 36 channels with 3 channels in the infrared window (8.6, 11.0 and 12.0 µm) at 1×1 km^2 spatial resolution. MODIS has viewing swath width of 2330 km and it capable of retrieving aerosol properties (Remer et al. 2005).

2.2.3. Data acquisition

Volcanic ash was assessed based on infrared channels (IR) at 11 µm and combinations of 12.0-10.8 µm (red), 11.0-8.5 µm (green) and 11.0 µm (blue). Measured variables to assess the volcanic ash are including ash height presented as brightness temperature/BT (K), presence of volcanic Cumulonimbus (Cb), SO_2 and reflectance (%). Those variables were measured after eruption occurred.

3.Results and Discussion

Figure 2 shows the presence of volcanic ash detected using infrared (IR) of 10.8 µm after eruption of Mt Semeru. The image was acquired at 05:24 AM and 06:12 AM on 12/1/2020 several hours after eruptions. The volcano ash was clearly detected at 06:12 AM while at early observation at 05:24 AM the ash was not occurred. At 06:12 AM, it was clear that the brightness temperature BT has higher value than value observed at 05:24 AM. Figure 3 presents the 10.8 µm (BT) displayed with a color enhancement. Using color display, the coverage areas of volcanic ash were apparent and can be distinguished from non volcanic ash areas. The volcanic ash was observed covering and moving towards northeast area at 06:12 AM. Volcanic Cb and SO_2 were presented in Figure 4 since as detected at 12.0-10.8 µm, 11.0-8.5 µm and 11.0 µm. SO_2 was already observed at 05:24 AM and volcanic Cb was developed at 06:12 AM. This Cb cloud was observed moving northeast directions. The volcanic reflectance (%) is displayed with a grayscale enhacement (Figure 5). Ash cloud at 06:12 AM was detected has high reflectance compared to the observation result at 05:24 AM.
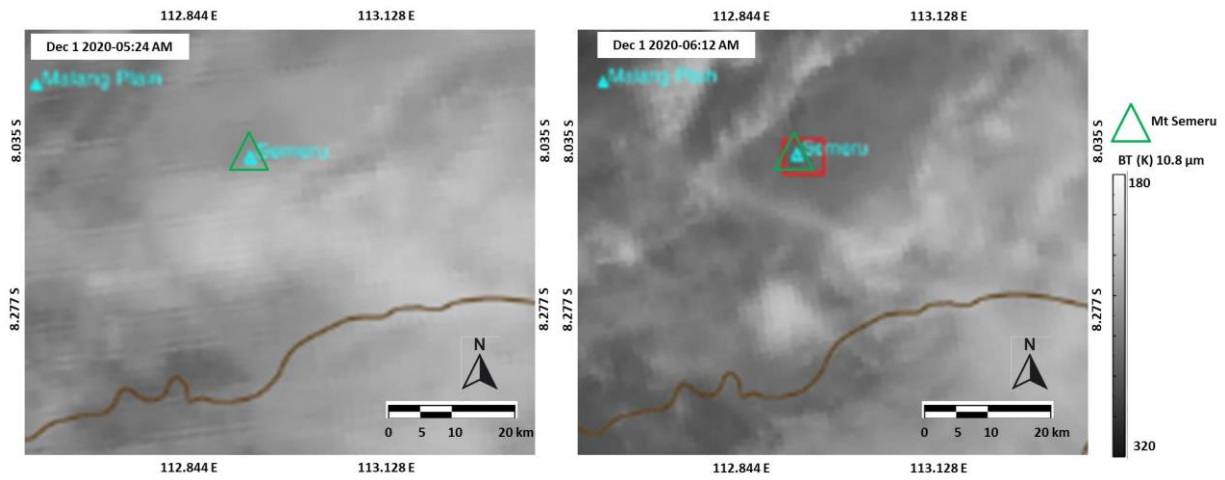
Figure 2. Infrared (10.8 μm) images, with NOAA-20 and Suomi NPP VIIRS taken at 05:24 AM (left) and 06:12 AM (right) on December 1, 2020 in Mt Semeru
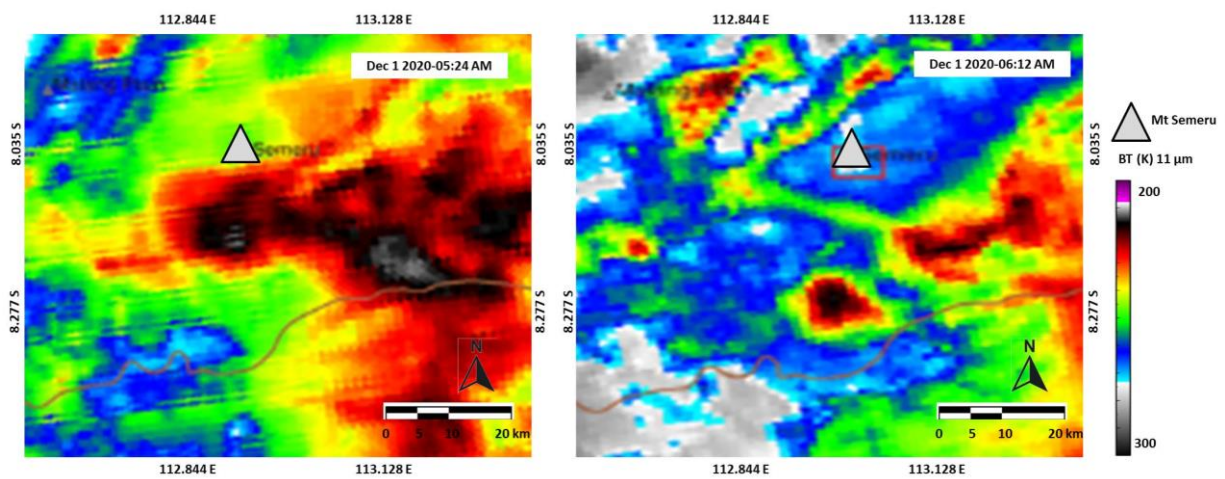

Figure 3. Color enhanced (11 μm) images, with NOAA-20 and Suomi NPP VIIRS taken at 05:24 AM (left) and 06:12 AM (right) on December 1, 2020 in Mt Semeru
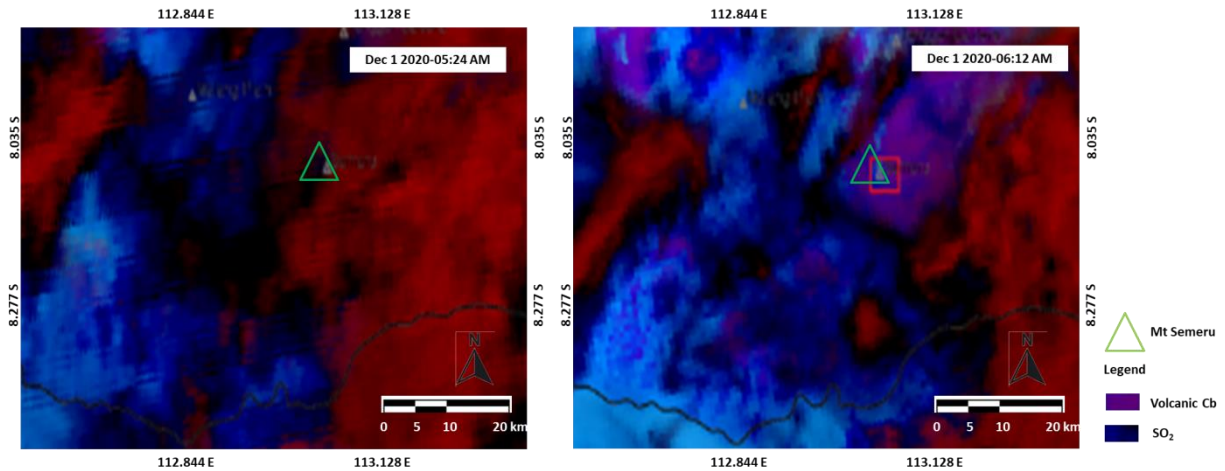
Figure 4. False color image 12.0-10.8 µm (red), 11.0-8.5µm (green), 11.0 µm (blue) , with NOAA-20 and Suomi NPP VIIRS volcanic Cb and SO₂ products taken at 05:24 AM (left) and 06:12 AM (right) on December 1, 2020 in Mt Semeru
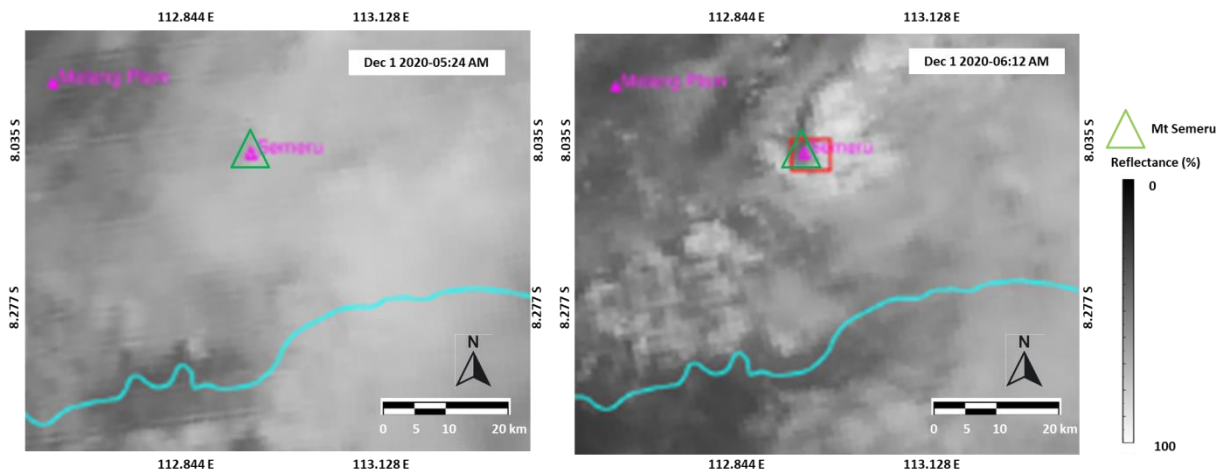

Figure 5. NOAA-20 and Suomi NPP VIIRS volcanic reflectance (%) products taken at 05:24 AM (left) and 06:12 AM (right) on December 1, 2020 in Mt Semeru

The use of TIR instruments to observe thermal activities have received attentions including in Indonesia. Zubaidah et al. (2019) have utilized VIIRS Image for forest and land fire detections in Indonesia. The used VIIRS channel composite combinations included spectral bands of 1.61 µm, 0.86 µm, 0.44 µm and 0.49 µm, 0.44 µm, 0.41 µm. The composite combinations have detected the presences of ash originated from forest fire in yellowish white and brownish white smoke. While the detection of SO₂ contents emitted from Mt Sinabung volcano has been studied by de Laat et al. (2019) and Artaning et al. (2020) using the Sentinel 5P, TROPOMI and Himawari imageries. The Sentinel 5P has detected the presence and movements of SO₂ contents from volcano crater to surrounding areas. Those studies have indicated that monitoring thermal objects mainly related to the volcanic eruptions are important.

Despite growing studies on volcano ash monitoring, uses of VIIRS to monitor volcanic ash in Indonesia are still limited. Here, this study has provided empirical evidences of VIIRS uses to detect the volcanic ash presence, BT, volcanic Cb, SO_2 and reflectance.

Brightness temperature (BT) value measured using VIIRS with 10.8 μm is comparable with BT from other eruptions. BT of Mt Calbuco, Chile was 260 K and 270 K for Mt Tecapa, El Salvador. At 05:24 AM, Mt Semeru was covered by <220 K BT cloud, showing it was cloud at high altitude (Lin et al. 2011). While, cloud covers at 06:12 AM on the top Mt Semeru was replaced by >260 K BT low altitude clouds indicating the presence of volcanic Cb. SO_2 was observed near Mt Semeru and overlapped with the cloud BT more than 220 K and less than 240 K indicating SO_2 contained in high altitude atmosphere layers. According to BT values where SO_2 was observed, stratosphere level is atmosphere layer that may contribute to SO_2 through photolysis/oxidation of SO_2.

One of TIR imagery advantages is its capability to detect the volcanic Cumulonimbus (Cb) cloud. This Cb is a convective cloud that can produce hazardous weather. A deep convection, such as a mature Cb, is oftenly accompanied by rapidly changing weather on different spatial and temporal scale (Henken et al. 2009). Cb is a cloud that feeds directly from the heat and smoke of an intense fire. In this study, volcanic Cb was detected using VIIRS and it is comparable from other studies. Rosenfeld et al. (2014) reported VIIRS can provide a fine detail of the billowing volcanic Cb clouds that occur directly over the volcano crater. By using IR 10.7 μm and SLIR combinations to assess Mt Montserrat eruption, cirrus, low cloud and an isolated deep convective cloud or Cb have been successfully distinguished.

4.Conclusion

Indonesia is one of countries that were located in the ring of fire and this situation has increased the volcanic activities. One of active volcano is Mt Semeru that recently has erupted on 12/01/2020. Eruption of a volcano may release volcanic ash leads to the development of volcanic Cb and SO_2 releases. This study has provided evidences of volcanic ash detections using TIR imagery acquired from NOAA-20 and SNPP satellites with MODIS and VIIRS instruments. VIIRS sensors have detected a volcanic ash moving northeast at 06:12 AM. Simultaneously, volcanic Cb and SO_2 contents were also observed. These results have strengthened the capability of TIR image to deliver accurate detection of volcanic ash properties.

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