Remote Sensing of Environment 173 (2016) 122–132

Contents lists available at ScienceDirect

Remote Sensing of Environment

journal homepage: www.elsevier.com/locate/rse

Time-resolved observation of volcanic ash using COMS/MI: A case study from the 2011 Shinmoedake eruption

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ARTICLE INFO

Article history:
Received 29 March 2015
Received in revised form 30 October 2015
Accepted 12 November 2015
Available online xxxx

Keywords:
Volcanic ash
Volcano
Source-receptor
Geostationary satellite
Hybrid algorithm

ABSTRACT

Between January 26 and 27, 2011, Shinmoedake volcano, located in the Krishima complex in Kyushu, Japan, produced a number of explosive eruptions with ash clouds reaching up to 8.5 km above sea level. Volcanic ash (VA) plumes from those eruptions affected the population near the volcano and posed a significant threat to aviation. Since its launch on June 27, 2010, the Meteorological Imager (MI) onboard Korea's first geostationary meteorological satellite, the Communication, Ocean, and Meteorological Satellite (COMS), has provided time-resolved images (less than 27-minute intervals for the full disk) at 1 km spatial resolution for the visible (VIS) channel and 4 km spatial resolution for the four infrared (IR) channels. In this study, MI operational data with one broadband VIS channel (centered at 0.68 μm) and three IR channels (centered at 3.7, 10.8, and 12.0 μm) for eruption events occurring at Shinmoedake were analyzed using the formerly developed hybrid VA detection and retrieval algorithm. We analyzed time-resolved VA plumes produced during three subplinian eruptions and found that spatio-temporal distributions of VA pixels determined by this analysis agreed with the source-receptor regions in meteorological trajectory modeling as well as with the operational products from the Global Ozone Monitoring Experiment-2 (GOME-2), Scanning Imaging Absorption spectrometer for Atmospheric Cartography (SCIAMACHY), and the Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO). For the three subplinian eruptions, VA retrieval results revealed that the maximum total ash mass loadings were 115.1, 1309.7, and 51.3 t, and the maximum height reached by the ash clouds were 5.6 $\pm$ 0.7, 10.2 $\pm$ 2.4, and 5.6 $\pm$ 0.8 km, respectively. These values imply that the second eruption emitted the largest amount of VA into the atmosphere. Overall, this is the first study that has been conducted to detect VA using the COMS/MI observations, which have been determined to provide reliable estimates of VA.

1. Introduction

Over the last few decades, increasing attention has been given to the effects of volcanic ash (VA) clouds on aviation safety, local air pollution, and human health. Notable impacts to the radiation budget have been reported because of a reduction of incoming solar radiation and increased cooling underneath the VA clouds, as noted by several studies of major historical eruptions, such as Mt. El Chichón and Mt. Pinatubo (Dutton & Christy, 1992; Minnis et al., 1993). It is widely accepted in the climate research community that volcanic plumes, including volcanic gases and sulfate aerosols, can affect surface temperatures, global circulation patterns, and the global climate system in general. Also, characterization of optical properties of VA particles can improve the ability to understand climate effects on local and global scales (Derimian et al., 2012; Langmann, 2014). Recently, the eruption of the Eyjafjallajökull volcano in Iceland in April and May 2010 resulted in massive emissions of VA, and plumes covered large areas of Europe. This offered a unique opportunity for monitoring and modeling of VA (Stohl et al., 2011; Langmann, Folch, Hensch, & Matthias, 2012; Matthias et al., 2012; Johnson et al., 2012; Francis, Cooke, & Saunders, 2012; Walker, Carboni, Dudhia, & Grainger, 2012).

In East Asia, the amount of VA released into the atmosphere by the eruption of the Shinmoedake volcano in Japan (31.91°N, 130.88°E, summit elevation 1421 m above sea level [ASL]; Fig. 1) between January and February 2011 (Nakada, Nagai, Kaneko, Suzuki, & Maeno, 2013; Kato & Yamasato, 2013; Marchese, Falconieri, Pergola, & Tramutoli, 2014) must be estimated for the following reasons. First, this eruption was the largest eruption since 1959 (Japan Meteorological Agency, 2013). Second, this eruption was the first significant volcanic event within the observation area of the Meteorological Imager (MI) onboard the Communication, Ocean, Meteorological Satellite (COMS), which is the first Korean geostationary satellite; it has been successfully operated since early 2011 (Kim et al., 2012). Compared to other major volcanic eruptions in history, the Shinmoedake volcano eruption emitted only small amounts of VA, but its impact clearly demonstrates that VA plumes critically impact aviation safety and local air quality. In the first stage

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http://dx.doi.org/10.1016/j.rse.2015.11.014
0034-4257/

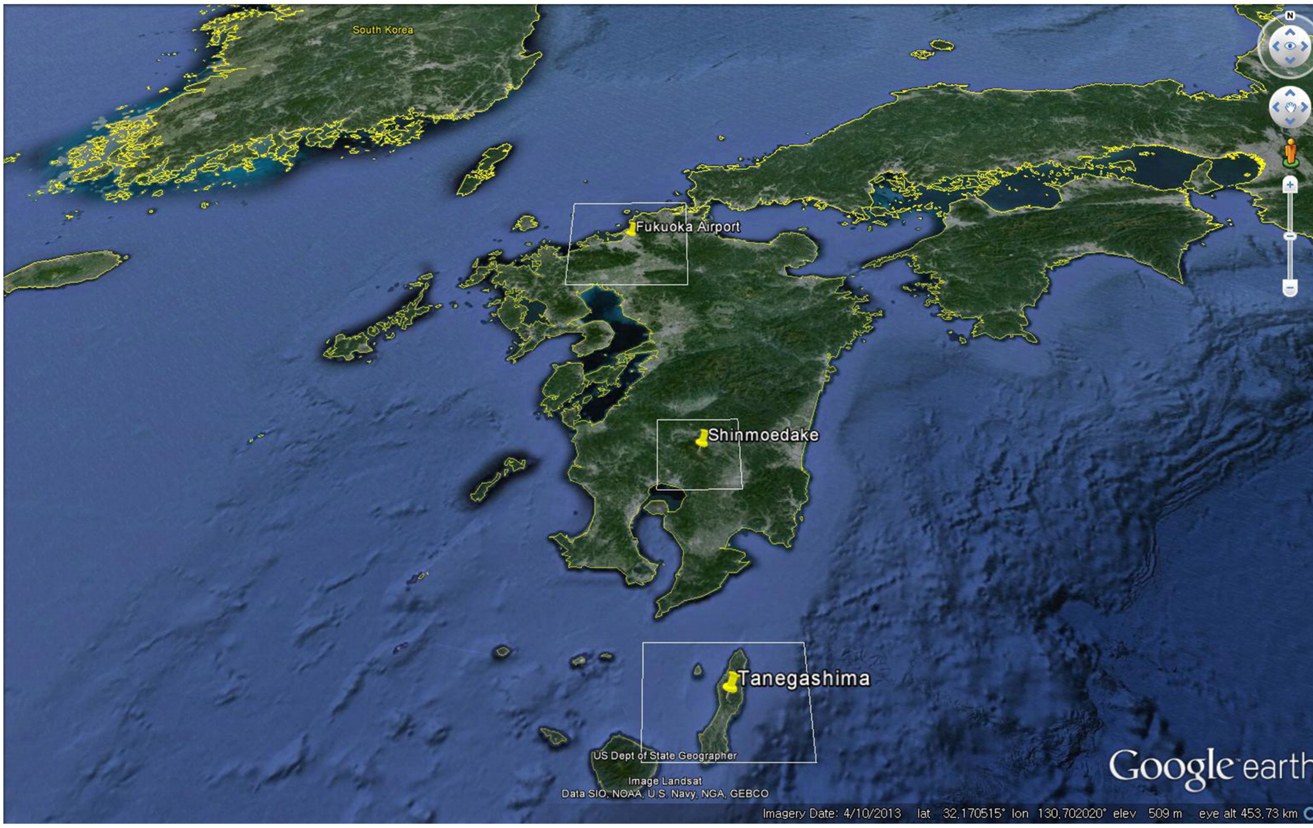

Fig. 1. Geographic location of Mt. Shinmoedake (yellow pins; 31.91°N, 130.88°E). Two Doppler radar stations at Fukuoka Airport (130.45°N, 33.59°E, approximately 190 km away from crater) and Tanegashima Airport (130.98°N, 30.61°E, approximately 190 km away from crater) are also shown.

of the eruption, three volcanic plumes with VA were observed and transported southeast by a westerly wind (Japan Meteorological Agency, 2013). The weather Doppler radars at Fukuoka Airport (130.45°N, 33.59°E) and Tanegashima Airport (130.98°N, 30.61°E; Fig. 1) measured eruption column heights of 6.5–8.5 km ASL (Shimbori, Sakurai, Tahara, & Fukui, 2013). These heights were mid-tropospheric and intersected flight levels of commercial aircraft.

The spatio-temporal variation of VA plumes provides important information for monitoring the hazards and transportation of VA. Continuous observation via satellite is an essential technique for monitoring VA amounts in the atmosphere. Because in situ observation of VA from the ground or from aircraft is limited, remote sensing techniques based on satellites (see Prata & Rose, 2015 and references therein) have been developed to monitor hazardous VA plumes. Among many VA detection techniques from satellite observation data, reverse absorption (RA) using 10.8 and 12.0 μm bands is widely accepted (Prata, 1989b; Simpson, Hufford, Pieri, & Berg, 2000, Simpson, Hufford, Pieri, & Berg, 2001; Rose et al., 2001; Tupper et al., 2004). However, the RA method is affected by residual problems, summarized by Prata, Bluth, Rose, Schneider, and Tupper (2001), that limit its application in an operational scenario. To overcome the limitations of the RA method, an improved VA detection algorithm, the three-bands volcanic ash product (TVAP), which is based on the composite of three infrared bands (3.7, 10.8, and 12.0 μm), was developed (Ellrod, Connell, & Hillger, 2003). This method, however, is limited at night or when the ash cloud is over water. Nevertheless, a lot of satellite remote sensing for VA detection is still based on a combination of mid-infrared and visible channel data (Pergola, Tramutoli, Scaffidi, Lacava, & Marchese, 2004; Pavolonis, Feltz, Heidinger, & Gallina, 2006; Gangale, Prata, & Clarisse, 2010; Pavolonis & Sieglaff, 2010; Lee, Wong, Chung, & Sohn, 2014; Naeger & Christopher, 2014).

The main objective of this study was to estimate VA using highly time-resolved satellite observation data with a forward trajectory modeling approach. While polar orbit satellites have better spectral or spatial resolution, their temporal resolution is poor relative to geostationary satellites. Geostationary satellites have been used for monitoring VA clouds because of their high temporal resolution. It should be noted that many hemispheric estimates of VA detection and retrieval were based on observations by geostationary satellites such as the Geostationary Operational Environmental Satellite (GOES) and the Spin Enhanced Visible and Infrared Imager (SEVIRI), coupled with or driven by radiative transfer simulations (e.g., Pavolonis, Heidinger, & Sieglaff, 2013; Francis et al., 2012; Prata & Prata, 2012; Pavolonis & Sieglaff, 2010; Prata & Kerkmann, 2007; Gu, Rose, Schneider, Bluth, & Watson, 2005; Yu, Rose, & Prata, 2002). To detect and retrieve VA, we used the hybrid algorithm suggested by Lee et al. (2014) for continuous MI observations (15-minute intervals for the North Asian [NA] region). In addition, the Hybrid Single Particle Lagrangian Integrated Trajectory (HYSPLIT; version 4.9; Draxler & Hess, 1998) forward trajectory modeling system was used to understand the spatial distribution of ash plume transport pathways and to identify potential receptor regions where the trajectory lines could fall in the transport pathways from the volcano. Because different transport patterns may play different roles during different eruptions episodes, statistical clustering results were analyzed to reveal the dominant transport pathways that corresponded to elevated VA loadings during each episodes.

This paper is organized as follows. Section 2 briefly describes the study area and data used. Methodology for detection and retrieval of VA from the COMS MI is explained in Section 3. The results of VA detection and retrievals and their consistency with the operational volcanic ash related products by the Global Ozone Monitoring Experiment-2 (GOME-2), Scanning Imaging Absorption spectrometer for Atmospheric Cartography (SCIAMACHY), and Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO) are discussed in Section 4. The conclusion is presented and suggestions are summarized in Section 5.