Volcanic ash plume observation by weather radars

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In spite of the existence of many eruption cases observed by weather radars (e.g. Sawada (2003), Marzano et al. (2013)), the quantitative ash estimation (QAE) technique is not established yet. One of the reason is an uncertainty of reflectivity. Roughly speaking, the parameter represents both size and number of clutters, however, we can't separate it into the components. In other words, only with reflectivity, we can’t determine the particle size distribution (PSD) of targets.
In such a circumstance, it is expected that polarimetric weather radar can obtain information about the PSD inside volcanic ash plume. Generally, polarimetric radars transmit horizontal and vertical radio waves at the same time, and receive the backscattered waves, thus, we can get the ratio and the correlation coefficient of two components. We think these parameters are effective for QAE.
Another way we think effective for observing volcanic ash plume is a fast-scan radar. As fast-scan radars can get a 3D image of a volcanic ash plume in a moment, we believe that this kind of radars can contribute to better understanding of dynamics of volcanic ash plume.
Meteorological Research Institute (MRI) installed an X-band multi-parameter (polarimetric) radar (MRI-XMP) and a Ku-band fast-scan radar (MRI-Ku) near Sakurajima volcano, and started observation from March, 2016. In this presentation, we will present some cases of volcanic ash plume observed by these radars, and discuss the problems and the prospects of the future.

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Keywords: volcanic ash plume, weather radar, polarimetric radar, fast-scan radar, Sakurajima volcano

Development of a Volcanic Ash Data Assimilation System for Atmospheric Transport Model

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In the Japan Meteorological Agency (JMA), there are two major operations related to volcanic ash forecasting: the Volcanic Ash Fall Forecast (VAFF) and the Volcanic Ash Advisory (VAA). The VAFF provides information for local governments and residents who may be affected by ash fall from volcanoes (Hasegawa et al., 2015). The VAA is issued to airline companies and aviation authorities for safe aviation services.

In these operations, the forecasts are calculated by atmospheric transport models including advection process, gravitational fall process and deposition process (wet/dry). The most important and uncertain factor of the models is the initial condition of volcanic ash. In operations, the initial condition is based on the empirical model of Suzuki (1983). Since it includes many assumptions and empirical research, it often fails to reproduce actual plumes of volcanic eruptions.

On the other hand, in recent years, research of observation techniques of volcanic ash by weather radar and satellites have advanced. The Meteorological Research Institute (MRI), one of the facilities of JMA, has started observation using two different types of weather radar. Besides, in 2015, the Himawari-8 geostationary meteorological satellite was put into operation. Himawari-8 has sixteen observation bands as against five in its predecessor, MTSAT-2. Using this abundant observation data of new-generation satellite, physical quantities of volcanic ash clouds (including top height, mass loading and particle radius) can be retrieved (Hayashi et al., JpGU2016).

In the present study, using both radar and satellite observation, we are developing a volcanic ash data assimilation system to improve initial conditions of the atmospheric transport models.

We have adopted the three-dimensional variational data assimilation scheme (3D-Var), which has low computational cost and is suitable for creating initial conditions immediately after an eruption occurs. Analysis variables are concentration of ash and size distribution parameters (median particle size and dispersion) which are mutually independent. It is assumed that observation error covariance matrix is diagonal, and background error covariance matrix has the relationship between correlation and distance and has the Gaussian form (Ishii et al., JpGU2016).

From the radar observation, it is expected that we can obtain three-dimensional ash concentration in the atmosphere and parameters of ash particle size distribution in the atmosphere. On the other hand, the satellite observation is expected to provide only two-dimensional parameters of ash clouds such as mass loading, top height and particle radius. Currently, we are trying to estimate the thickness of ash clouds using vertical wind shear.

Here, we show two case studies of data assimilation system. One is the February 14th, 2014 eruption case of Kelut in Indonesia for an experiment of data assimilation with virtual radar observation, and the other is the May 29th, 2015 eruption case of Kuchinoerabujima in Japan for an experiment of data assimilation with actual satellite observations.

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Keywords: data assimilation, atmospheric transport model, volcanic ash

Observations of volcanic eruption columns using Himawari-8 Super-Rapid Scan 30-sec imagery

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Japan Meteorological Agency (JMA) began operation of the new-generation geostationary meteorological satellite, Himawari-8, on 7 July 2015. The imager on board is called Advanced Himawari Imager (AHI), whose observation performance is highly improved compared to that of the predecessor geostationary meteorological satellites MTSAT-series. For example, the number of observation bands is increased from 5 (1 visible band and 4 infrared bands) to 16 (3 visible bands, 3 near-infrared bands, and 10 infrared bands), the spatial resolution is almost doubled (1 km to 0.5-1 km for visible and near-infrared bands and 4 km to 2 km for infrared bands), and the full-disk observation frequency is improved from hourly to every 10 minutes. Furthermore, for the small regions including Japan (two areas coverage of the 2000 km (E/W) and 1000 km (N/S) rectangle over the North-Eastern and South-Western Japan) and a target area (1000× 1000 km), high-frequency observation as much as every 2.5 minutes is carried out. These high-resolution and high-frequency data enable us to observe relatively small-scale and quickly changing phenomena, such as volcanic eruption clouds. The increase in number of the observation bands improves the capability of volcanic ash clouds detection and estimation of various parameters, such as amount and particle size of ash (Hayashi *et al*. 2016), and can be expected to estimate an amount of sulfur dioxide in volcanic clouds. Furthermore, the imagery at two Landmark areas of the 1000 km (E/W) and 500 km (N/S) rectangle can be obtained at every 30 seconds (Super-Rapid Scan observation). The main purposes of this observation are the navigation of satellite, image registration, and moon observation for calibration of AHI (Bessho *et al*. 2016). In recent times, the landmark areas are used experimentally for observation of phenomena such as rapidly developing cumulonimbus clouds and volcanic eruptions, and these set at the areas which contains the active volcanoes such as Sakurajima, Aso, and Asama volcano.

We start the study on the dynamics of eruption columns just after the start of eruption by using the Super-Rapid Scan data. In this paper we talk about the comparative studies of Himawari-8 band 3 (0.64 μm, spatial resolution 0.5 km) Super-Rapid Scan imagery of the eruption column of Sakurajima volcano with the observational data obtained by weather radars (Sato *et al*. 2017) and video data captured by volcano monitoring cameras of JMA.

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Keywords: Himawari-8, Super-Rapid Scan, eruption column, volcanic eruption, geostationary meteorological satellite, Sakurajima volcano

A sequence of plinian eruption preceded by dome destruction at Kelud volcano, Indonesia, on February 13, 2014: insights from tephra fallout and pyroclastic density current deposits

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A plinian-style eruption with a radially spreading umbrella cloud occurred on February 13, 2014, at Kelud volcano, Indonesia. We present the sequence of this plinian event based on a geological study of the eruptive products, analysis of satellite images of the eruption plume, and surface features of the volcanic edifice before and after the eruption. The eruptive deposits were divided into four major depositional units (Units A, B, C, and D) and used to determine the sequence of events. The plinian phase was preceded by partial destruction of the existing lava dome and generation of high-energy pyroclastic density currents (PDCs) with a maximum runout distance of ~6.8 km mainly towards the NE. The PDCs produced a series of depositional subunits (Units A_{0-2}) and caused surface damage (blown-down trees and vegetation) over an area of 12 km^2 (stage 1). The main phase of the eruption was characterized by a strong eruption plume that produced widespread fallout tephra (Unit B) over East and Central Java (stage 2). The winds above the volcano significantly affected the tephra dispersal process. In stage 3, the plinian column collapsed, generating dense PDCs that flowed down the volcano valleys, producing pumiceous lobate deposits (Unit C). The declining phase of the eruption produced fine-rich fallout tephra layers (Unit D_{1-2}) from low-level eruption plumes and/or ash lofted from PDCs. The eruption sequence constructed from field observations is supported by geophysical observations, including remote seismic and infrasound signals, total electron content variation, lightning strokes, and satellite observations. The initial high-energy PDCs and fallout tephra contained juvenile pumice and dome-derived lithic clasts, and isolated crystals originated from the fragmentation of porphyritic magma. The deposit features and componentry suggest that newly ascended magma triggered the destruction of the lava dome and the generation of high-energy PDCs, and during the subsequent climactic phase the dome was completely destroyed. Thus, the pre-existing lava dome significantly affected the course of the eruption. This type of eruption sequence has not been previously documented in the historical records of Kelud volcano activity. The total volume of erupted material was estimated as 0.25–0.50 km^3 (bulk deposit volume), corresponding to 0.14–0.28 km^3 in DRE, and the mean eruption rate as $6.5 \pm 2.8 \times 10^7$ kg/s. The scale of the 2014 eruption had a VEI of 4, and was one of the largest eruptions at Kelud volcano over the past century. The eruption sequence and estimated physical parameters of the 2014 eruption will help assess future volcanic activity and potential hazards at Kelud volcano.

Keywords: Plinian, pyroclastic density current, blown-down tree, lava dome, Kelud

A One-dimensional Steady State Model of a Buoyancy-generating Turbulent Plume and its Application to Volcanic Eruption Columns

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I will talk about a one-dimensional steady state model of turbulent plumes in which the buoyancy flux significantly increases with height. This model clearly suggests the importance of the formulation of the increase in buoyancy flux due to thermal expansion of entrained air to appropriately describe the fundamental features of volcanic eruption columns. An analytical solution of a simple form is specifically derived for an idealized axisymmetric turbulent plume of a linearly increasing buoyancy flux in a uniform environment. The solution predicts that the upward velocity of the plume is constant along the height, in contrast to the upward velocity of a common incompressible plume, the velocity of which decreases inversely proportional to the third root of the height. More realistic plumes in both uniform and density-stratified environments are also investigated by modifying the one-dimensional model. The model yields several scaling parameters, some of which are used to estimate the terminal height of an eruption column. Numerical investigations using the parameters indicate that the thermal energy in an eruption column is exhausted for heating and expanding entrained air before reaching the terminal height. Numerical investigations also imply that the buoyancy flux in an eruption column may be less than half of that predicted by the conventional theory of an incompressible plume. The discussion based on the present model also sheds new light on the physical background of the superbuoyant behavior of an eruption column.

Keywords: Eruption column, Turbulent plume, One-dimensional model, Buoyancy flux, Thermal expansion

Backscattering characteristic of volcanic eruptions based on LIDAR observation around Sakurajima Volcano

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Increases in aerosol due to eruptions have been detected by lidars distant from erupting volcanoes. Backscattering coefficient and depolarization ratio are examined related with volcanic ash particles (eg. Sassen et al.,2007). A lidar is installed on the flank of Sakurajima volcano and lidar observation is conducted for volcanic ash plume above the craters of the volcano to obtain spacio-temporal distribution of backscattering intensity and depolarization ratio. Sakurajima volcano is the most active volcano and has continued eruptions at the Showa crater since 2006 and white plume is emitted from the Minamidake crater continuously.

Depolarization ratio of white plume is almost the same as water cloud (0.05-0.1). On the other hand, depolarization ratio of volcanic ash cloud is much higher (0.40-0.45) than the white plume and water cloud. The highest value of depolarization ratio (0.72) was obtained only just above the crater immediately after eruptions for short-term. The high depolarization ratio is caused by larger density of volcanic ash particle with non-spherical shape.

Keywords: Volcanic smoke colored white, Volcanic smoke include volcanic ash, LIDAR, Backscattering intensity, Depolarization ratio, Sakurajima Volcano