An experiment in numerical prediction of volcanic gas transportation

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1. Introduction

The amount and composition of volcanic gas observed in the vicinity of a volcano are closely related to underground hydrothermal processes or gas escaping from magma. Therefore, it is important to estimate the release rate and composition of volcanic gas as precisely as possible in order to monitor and predict the volcano's activity. Since the SO_2 included in volcanic gas is sensitive to uprising of magma, SO_2 measurement is one of the most important aspects in the monitoring of volcanoes.

The Japan Meteorological Agency (JMA) has categorized 111 domestic volcanoes as active, and continuously monitors 50 of them. The release rate of SO_2 is monitored and made available to the public for Mt. Asama, Miyakejima Island, and Mt. Aso by the JMA, and for several other volcanoes by domestic organizations including research institutions, universities, local governments, and also the JMA. In general, the SO_2 release rate is estimated based on a traverse measurement of SO_2 column concentration, using an ultraviolet spectrometer system. However, the applicability of this method is limited by whether or not a traverse route is available for the target volcano, and the frequency of measurement is restricted by the cost of operation. To perform the estimation of SO_2 release rate for more volcanoes with lower operational costs, we are developing an alternative approach, combining a fixed-point measurement of SO_2 column concentration and a numerical model with fine grid spacing. For the first step of the development, a numerical prediction system for volcanic gas transportation has been constructed, based on a numerical weather prediction (NWP) model and a passive tracer trajectory model. This report will provide a description of the system and preliminary results.

2. Numerical prediction system for volcanic gas transportation

The system for numerical prediction of volcanic gas transportation has two components: a numerical weather simulation and a tracer trajectory simulation. The former is performed using the JMA's Non-Hydrostatic Model (JMA-NHM; Saito et al., 2006).

Hashimoto et al. (2017) reported on an ongoing weather prediction experiment, for the purposes of meteorological research and of collaboration with other research fields. This experiment has a 2250 × 2250 km computational domain, with a 5-km horizontal resolution, around Japan. For simulations of volcanic gas transportation, this domain is extended to the south and west by 250 km (Domain-1 in Fig. 1a), and a new domain with a 1-km horizontal resolution (Domain-2) is embedded within Domain-1 (Fig. 1a). This domain covers 17 active volcanoes, which include 9 continuously monitored volcanoes in Kyushu and on remote islands. Another domain with a 200-m horizontal resolution (Domain-3) is further embedded into Domain-2 so as to cover Suwanosejima Island (Fig. 1b).

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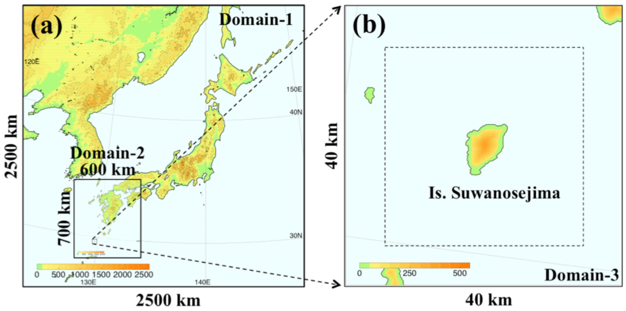

Fig. 1. Computational domains (a) Domain-1, Domain-2 and (b) Domain-3 for weather prediction simulations by 5km-NHM, 1km-NHM and 200m-NHM, respectively. The dotted line shows the domain for the volcanic gas transportation simulation.

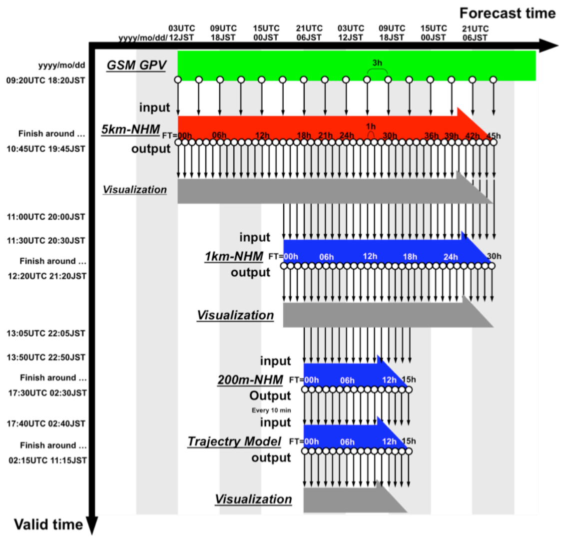

Fig. 2. Schedule for weather prediction, with the initial time of 1200 JST. Thin black arrows indicate the data flow.

The numerical prediction is conducted twice a day. Each time, a simulation is performed in order of Domain-1 (5km-NHM), Domain-2 (1km-NHM), and Domain-3 (200m-NHM). For all the simulations, the Lambert conformal conic projection is adopted, with 30.00 and 60.00°N for the first and second standard latitudes, and 140.00°E for the standard longitude. The vertical grid arrangement and the procedure of time integration in the 5km- and 1km-NHM are the same as those described in Hashimoto et al. (2017).

For the 200-m NHM, the top height of the model domain is 17.7 km. Vertical grid spacing is stretched from 40 m at the

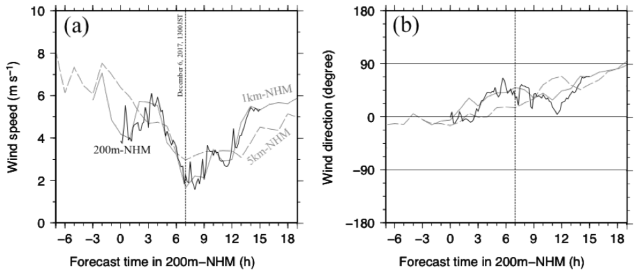

Fig. 3 Time series of (a) surface wind speed and (b) direction at Suwanose Airport, predicted by the 5km- (gray broken line), 1km- (gray solid line), and 200m- (black solid line) NHM. The time interval of the plotted data is one hour for the 5km- and 1km-NHM, and ten minutes for the 200m-NHM. The gray dotted line shows the time of 1300 JST on 6^{th} December 2017.

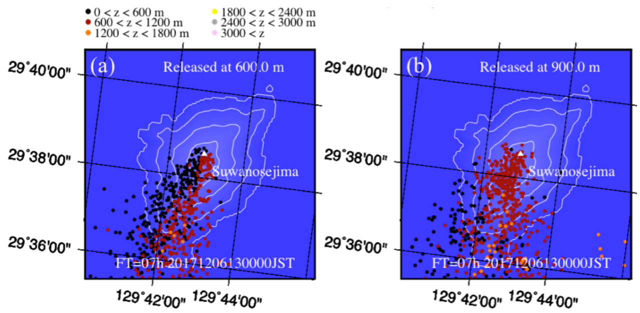

Fig. 4 Distribution of tracers at 1300 JST on 6^{th} December 2017, which were released at (a) 600 m and (b) 900 m above the vent. The colors of the dots show the heights of the tracer positions. White contours show the topography.

surface to 199 m at the top of the domain in a terrain-following coordinate system. The total number of vertical layers is 150. The integration time is 15 h, with a timestep of 1 s. The initial and boundary conditions are obtained from the 1km-NHM. The initial time of the 200-m NHM is 3 h later than that of the 1km-NHM (Fig. 2). The boundary condition is provided every hour. Figure 2 shows the schedule and data flow in the numerical prediction, with an initial time of 1200 JST.

The 200-m meshed wind field is output at 10-min intervals within the sub-domain (dotted line in Fig. 1b), in order to perform a simulation of volcanic gas transportation using the passive tracer trajectory model. The simulation period covers the eight days from 3^{rd} to 11^{th} December 2017, in accordance with the measurements of SO_2 column concentration carried out on Suwanosejima Island during the same period (Mori et al., 2018). In the simulation, the wind field is at first temporally interpolated into a one-second timestep. The wind vector at the position of the tracer is then determined by interpolation of the grid values at the 8 nearest points. The movement of the tracer is predicted by assuming this wind vector is equal to the transfer vector of the tracer. The tracer position is tracked for 15 h unless it goes out of the domain (dotted line in Fig. 1b). In this simulation, 10 tracers are released every 30 s at each of 8 different levels above the vent (from 600 to 1300 m above sea level, at intervals of 100 m).

3. Results and discussion

3.1 Sensitivity of predicted surface wind to a horizontal resolution

Figure 3 shows the surface wind speed and direction at Suwanosejima Airport, predicted by simulations with different horizontal resolutions. The 1-km and 200-m NHM show almost same temporal change of the wind. However, wind prediction with the 5km-NHM is clearly different from the others. As the area of Suwanosejima Island is 27.61 km^2, and its width is about 8 km at most, the 5km-NHM is not able to resolve the topography, which means that the applicability to SO_2 transportation of a wind field of the 5km-NHM is quite limited. Although the results from the 1km- and 200m-NHM show good agreement, it is still unclear if these horizontal resolutions are sufficiently fine to provide accurate wind fields for volcanic gas transportation, because the topography in the model is smoothed so as to stabilize the numerical simulations. To resolve this issue will require more systematic observations of the surface wind, as well as more sensitivity simulations.

3.2 Application to volcanic gas measurement activity

Figure 4 shows a part of the prediction results for SO_2 transportation. The direction and width of the gas plume change depending on the release height. This is due to vertically-sheared environmental wind and topographic effects. In field observations (Mori et al., 2018), it was hard for the crews to determine the main axis of the gas plume, or how broad it was. The numerical prediction system is a useful tool to update crews with concrete predictions of the gas plume, although these predictions have potential errors originating from uncertainties in the release height and other factors. Combining a numerical prediction with well-designed observations, it would be possible to constrain this uncertainty.

4. Summary

A numerical prediction system was established, based on the JMA-NHM, for predicting SO_2 transportation. This report has described the procedure of numerical prediction, and presented preliminary results. The predicted surface wind changes depending on the horizontal resolution. By combining a fixed-point measurement of SO_2 column concentration with the numerical prediction of SO_2 transportation, a new approach to evaluating the SO_2 discharge rate can be developed.

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