Results of the eruptive column model inter-comparison study

*Yujiro Suzuki[1], Antonio Costa[1,2]

1.Earthquake Research Institute, The University of Tokyo, 2.Istituto Nazionale di Geofisica e Vulcanologia, Bologna

Plume heights developed during explosive volcanic eruptions are key observable data for estimating crucial parameters such as mass eruption rate, and they are commonly used as input for dispersal models of tephra particles. Therefore, the accurate description of the relationships between plume heights and eruption conditions has been required. In the past decades, several volcanic plume models have been developed, including the more recent sophisticated computational fluid dynamics models. In this study, we presents results of the volcanic plume model inter-comparison study promoted by the IAVCEI Commission on Tephra Hazard Modelling.

This study compared empirical parameterizations (0D), and simulations of one-dimensional (1D) and three-dimensional (3D) numerical models in a set of inter-comparison exercises to evaluate model capabilities and highlight aspects requiring improvement and future research. The study involved four 0D, nine 1D models based on different extensions of the Buoyant Plume Theory (Morton et al,, 1956), and four 3D models describing the transient dynamics of volcanic plumes. The exercises were designed as tests in which a set of common input parameters was given for two reference eruptions, representing a strong and a weak eruption column, under different meteorological conditions.

Despite their different formulations, the 1D and 3D models provide reasonably consistent predictions of maximum height of plume. Variability in plume height, estimated from the standard deviation of model predictions, is within ~20% for the weak plume and ~10% for the strong plume. Predictions of neutral buoyancy level where the plume density is equal to the atmospheric density, are also in reasonably good agreement among the different models with a standard deviation ranging from 9 to 19%. There are important differences amongst models in terms of local properties along the plume axis, particularly for the strong plume. Our analysis suggests that the simplified treatment of air entrainment in 1D models is adequate to resolve the general behavior of the weak plume. However, it is inadequate to capture complex features of the strong plume such as large vortices. There is a need to more accurately quantify entrainment rates, improve the representation of plume radius, and incorporate the effects of column instability in future versions of 1D volcanic plume models.

Keywords: explosive volcanism, eruptive plumes dynamics, fluid dynamic models, model inter-comparison, eruption source parameters

Consideration of Wind Effects on the Eruption Source for the Lapilli Fall Prediction

*Toshiki Shimbori[1], Yosuke Hayashi [2], Akira Sugai [1,2], Hidekuni Kuroki [2], Shomei Shirato [2], Kenji Fujiwara[3], Kensuke Ishii[1], Eiichi Sato[1], Keiichi Fukui[1]

1.Meteorological Research Institute, 2.Japan Meteorological Agency, 3.Kagoshima Local Meteorological Office

When volcanic eruption occurs under strong wind condition, lapilli falling relatively in a short time are transported to a distant place. In several cases of recent eruptions in Japan, a few cm-sized lapilli fall were observed at resident area located a dozen km away from vent and caused human or property damage such as broken windshields of cars (e.g. JMA, 2013). For the purpose of mitigation of lapilli-fall disaster, the Japan Meteorological Agency (JMA) has been issued Volcanic Ash Fall Forecasts (VAFFs, Hasegawa et al., 2015; Sugai et al., 2015). In the scheduled and preliminary VAFFs, potential areas of lapilli fall are indicated with volcanic-ash fall area or quantity. The VAFFs are based on the calculations by the JMA Regional Atmospheric Transport Model (JMA-RATM), however, effects of wind are not considered in the eruption source which is the initial condition of the RATM. Then there is a problem which tends to underestimate the predicted volcanic-ash and lapilli fall areas.

In order to address this problem, we observed the wind around Sakurajima volcano with Aerological Observatory’s Doppler LIDAR (Hoshino et al., this volume) and have been improving of the eruption source of the RATM in the joint research of the Meteorological Research Institute and the Kagoshima Local Meteorological Office (FY2014-16). Instead of currently used empirical model of eruption source by Suzuki (1983), we consider the effects of wind especially for weak plume case based on the following methods; (i) not change the vertical distribution (i.e. Suzuki distribution) of volcanic ashes and lapilli, and (ii) shift only the horizontal distribution of them with wind GPVs according to Ida (2014). In this presentation, we will show the verifications of volcanic-ash and lapilli fall predictions for case studies of the eruptions at Sakurajima volcano in 2013, Kuchinoerabujima volcano in 2015 and so on.

Researches on the eruption column considering wind effects have been done by more sophisticated models, for example, BENT (Bursik, 2001), SK-3D (Suzuki and Koyaguchi, 2015) and JMA-NHM (Hashimoto et al., this volume). In order to apply the results of these physical models to the initial conditions of the operational RATM, under various weather conditions, it is required to make an eruption source immediately from observables for any active volcanoes in Japan. Therefore we consider that the eruption source including wind effects in this research is impermanent and provide a bridge from empirical models to physical ones. Furthermore improvements of eruption source make more accurate first guess in the volcanic-ash data assimilation system (Ishii et al., this volume) inputted the data observed by weather radars (e.g. Sato et al., this volume) and Himawari-8 (e.g. Hayashi et al., this volume).

References

Bursik, M., 2001: Effect of wind on the rise height of volcanic plumes. Geophys. Res. Lett., 28, 3621-3624.

Hasegawa, Y., A. Sugai, Yo. Hayashi, Yu. Hayashi, S. Saito and T. Shimbori, 2015: Improvements of Volcanic Ash Fall Forecasts issued by the Japan Meteorological Agency. J. Appl. Volcanol., 4: 2.

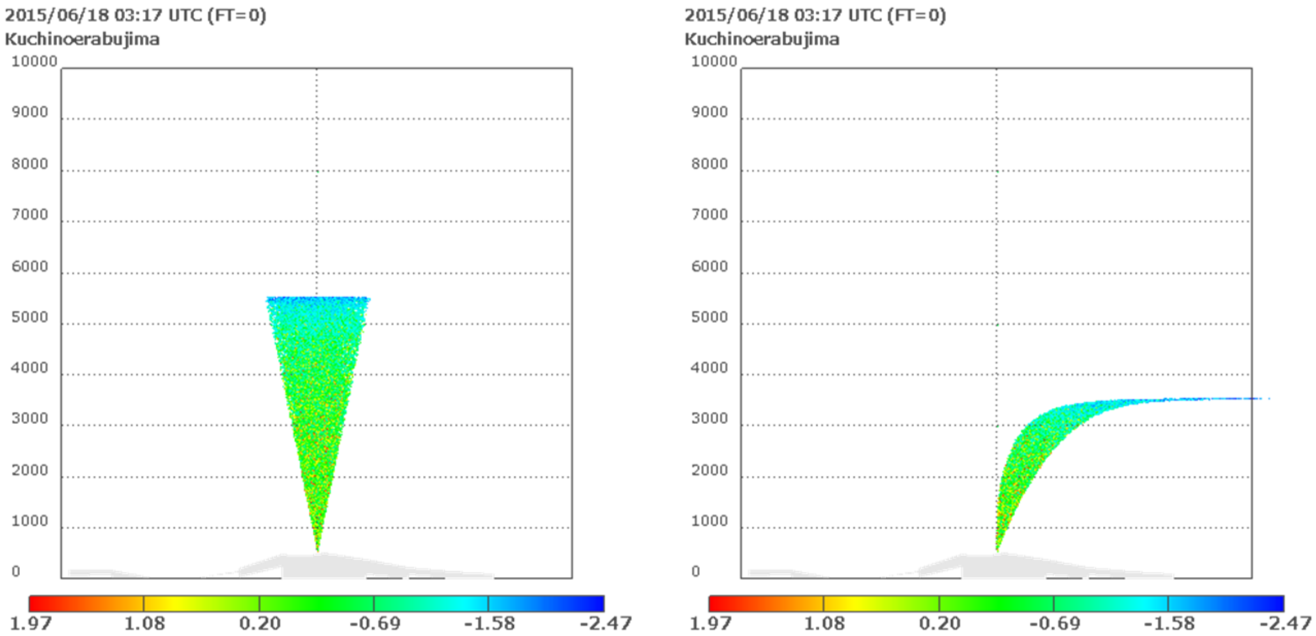
Ida, Y., 2014: Introduction to Simulation of Natural Disasters. Asakura Pub., pp. 139-154.

JMA, 2013: Report of the Working Group on Advanced VAFF, p. 259.

Sugai, A., H. Kuroki, Yo. Hayashi and T. Shimbori, 2015: New operation of the Volcanic Ash Fall

Forecasts (VAFFs). Proc. Volcanol. Soc. Japan, 155.
Suzuki, T., 1983: A theoretical model for dispersion of tephra: Arc Volcanism. TERRAPUB, pp. 95-113.
Suzuki, Y. J. and T. Koyaguchi, 2015: Effects of wind on entrainment efficiency in volcanic plumes. J. Geophys. Res., 120, 6122-6140.

Keywords: Atmospheric Transport Model, eruption source parameter, effects of wind, lapilli, volcanic ashes, Volcanic Ash Fall Forecast



Examples of eruption sources (vertical cross-sections of initial tracers) in the JMA-RATM. Left: without wind effects based on Suzuki distribution. Right: with wind effects in this research. Colors indicate the logarithmic grain-sizes of tracers.

Bayesian Estimation of Volcanic Ash Plume Height by Weather Radar Network

*Eiichi Sato[1], Keiichi Fukui[1], Toshiki Shimbori[1], Kensuke Ishii[1], Akimichi Takagi[1], Akira Sugai[2], Hidekuni Kuroki[2], Masayuki Maki[3]

1.Meteorological Research Institute, 2.Japan Meteorological Agency, 3.Kagoshima University

In order to make an initial condition of volcanic ash fall forecasts, Japan Meteorological Agency (JMA) basically uses volcanic ash plume height observed by highly sensitive cameras. This method has a disadvantage that, in the case of poor visibility, volcanic ash plume height would not be determined by the visual observation. In such a circumstance, volcanic ash plume detection methods using remote sensing technology such as weather radars are desired. Since weather radar uses a radio wave, volcanic ash plume can be detected in the case of cloudy weather. However, it should be noticed that single polarization radars, such as JMA weather radars, are not useful at rainy conditions.
The authors analyzed a case of the eruption at Mt. Ontake, and concluded that JMA radar echo height showed an over-estimated value compared to the ash plume height deduced from a photo taken at Mt. Aino. Since the data observed by Tokyo radar had a bias because of an anomalous propagation, the composite radar echo height was over-estimated.
To estimate volcanic ash plume height more accurately, the authors introduce a Bayesian estimation method. The procedure to estimate a volcanic ash plume height is as follows: 1. assume that a probability density function (PDF) of each radar echo height follows a normal distribution; 2. multiply the prior probability by the PDFs; 3. normalize the composite PDF. Moreover, Bayesian updating can make the prior probability better. Using the Bayesian method, we can eliminate effects of anomalous propagations. The disadvantage of this method is that, in the case of fewer radar coverage, we can't get accurate estimation. In such a case, the prior probability become more important.
In this presentation, preliminary results of the method will be shown.

Keywords: Volcanic Ash Plume Height, Weather Radar Network, Bayesian Estimation

Real-time data assimilation of radar-based volcanic ash data in an atmospheric transport model

*kensuke ishii[1], Toshiki Shimbori[1], Keiichi Fukui[1], Eiichi Sato[1], Akihiro Hashimoto[1]

1.Meteorological Research Institute

Improving the forecasting accuracy of volcanic ash and speeding up the issuing of volcanic ash advisories is vital not only for world aviation but also for people living in volcanic areas. In Japan, the Tokyo Volcanic Ash Advisory Center (VAAC) is responsible for atmospheric volcanic ash forecast in civil aviation flight paths. For this purpose, we developed an atmospheric transport model: the JMA-GATM.

The JMA-GATM uses the volcanic ash source function of Suzuki (1983), which uses assumptions of size distribution, shape of ash clouds, etc. The model shows good performance, but still has the room for improvement in volcanic ash source as initial condition.

We plan to start radar observation of volcanic plume of the Sakurajima volcano from March 2016. The observational data will be assimilated into the model to improve the initial conditions which is essential for realistic forecast.

We have selected the three-dimensional variational method (3D-var) from several data assimilation methods. The 3D-var is a low-costs and speedy methods, and can create initial conditions soon after an eruption occurs.

In this system, analysis variables are density of ash and size distribution parameters (median particle size and dispersion) which are independent of each other. It is assumed that observation error covariance is diagonal. Another important parameter is background error covariance, where the relationship between correlation and distance has the gaussian form.

We use the eruption source model or forecast value as the first guess in 3D-var. Because there is no value of size distribution parameters at the grid points where there is no ash, near first guess or observation values are interpolated.

Currently, we are validating the assimilation system using hypothetical radar observation data, we are developing and checking validation of the data assimilation system.

Acknowledgments
This study was supported by the Earthquake Research Institute Cooperative Research Program.

Keywords: data assimilation, Atmospheric Transport Model, radar, volcanic ash, numerical simulation

An algorithm for detecting the onset of volcanic eruption from digital images

Masanori Saito[1], *Keiko Matsumoto[2], Yasuhiro Yanagida[2], Miwa Kuri[3]

1.Department of Geophysics, Graduate school of Science, Tohoku University, 2.Department of Earth Science, Graduate School of Science,Tohoku University, 3.International Research Institute of Disaster Science, Tohoku University

Near real-time monitoring of active volcano is necessary for understanding of eruption mechanisms and mitigating of volcanic disaster. However, volcanic eruptions usually restrict access to the near-crater, which prevent scientists from setting or repairing observation devices. We aim for realizing volcanic plume observations using digital images taken from an unmanned-copter-portable device, which could be placed at a new observation point around crater in spite of dangerous volcanic activities. In this study, we developed an algorithm for detecting the onset of volcanic eruption and discriminating volcanic plume from the images. We also validated the algorithm on the images of the Aso volcano eruption on 14 September, 2015.

This algorithm is organized in two steps: detection of eruption onset and discrimination of volcanic plume areas. First, newly defined three parameters that represents scattering properties on the sky (the intensity index, small particle index, and molecular index) are calculated from the RGB (red-green-blue) digital counts of digital images with JPEG format. Empirical thresholds of six parameters including the three indices and RGB counts can roughly discriminate cloud parts, clear sky parts, and volcanic plume parts from the images. The time derivative of the volcanic plume area calculated from the succeeding images can detect an onset of eruption. Second, once an onset of eruption is detected, the pixels detected as volcanic plume gives the most appropriate threshold for detecting volcanic plume part based on statistical features in the six parameters. The detection of volcanic plume with optimized threshold is more accurate than the first discrimination based on empirical thresholds, since optimal thresholds can avoid misclassification of volcanic plumes and perform well under various solar conditions.

We applied the algorithm to the images of Aso volcano eruption captured by JMA (from 09:04 to 10:08 JST in 2 minutes, on 14 September, 2015). Until 09:44, continuous white plumes have been observed, and all the area of analyzed images have been illustrated as blue color indicating normally active. On the other hand, the algorithm detected the onset of eruption at 09:46 when explosive gray plume was observed, and the volcanic plume part and the other parts were shown as red and white, respectively. These continued as long as the volcanic plume part was above sequential calculated threshold. When the volcanic plume covered the image, the time derivative of volcanic plume part fell below the threshold, resulting in blue. This analysis shows that the algorithm appropriately detected the change of eruption style from the continuous white plume to the explosive gray plume based only on digital images. Additionally, the analysis time is a second per an image, which is applicable for near real-time monitoring.

We have already developed the device equipped with a digital camera which can be load on an unmanned multi-copter. Therefore, we plan to analyze the images captured by the device using the algorithm and validate the volcano observation system.

Keywords: volcanic plume, digital camera, near real-time

Numerical simulations of a two-layer shallow-water model for pyroclastic flows by column collapse

*Hiroyuki SHIMIZU[1], Takehiro KOYAGUCHI[1], Yujiro J. SUZUKI[1]

1.Earthquake Research Institute, The University of Tokyo

Pyroclastic flow is one of the most hazardous volcanic phenomena. During explosive volcanic eruptions, a mixture of volcanic particles and gas is ejected from the volcanic vent and develops an eruption column. When the eruption column collapses, the mixture falls to the ground and produces pyroclastic flows that propagate as gravity currents. Pyroclastic flows are characterized by strong density stratification, consisting of a dilute flow in the upper region and a dense flow in the lower region. The dynamics of pyroclastic flows is affected by physical processes within each of the dilute and dense parts, such as basal friction and entrainment of ambient air in the interfacial surface. It also depends on the particle transport between the dilute and dense parts. We aim to understand these effects on pyroclastic flow dynamics using numerical simulations.
We have developed a two-layer model to describe the gravity current which has a strong density stratification. In this model, each of dilute and dense parts is assumed to be uniform in any vertical section and is formulated as shallow-water equations. The equations are numerically solved by the finite volume method using the HLL scheme. In the dilute part, the effects of settling of particles, entrainment, and the interfacial drag between the dilute and dense parts are taken into account. In the dense part, the effects of basal friction, sedimentation, and the particle supply from the dilute part are included. In addition, to reproduce the dynamics of gravity current, the balance between the driving force and the resistance of ambient at the flow front should be correctly expressed in the model. In the dilute part, the balance is solved as a boundary condition with the Froude number proposed by Huppert and Simpson (1980). In the dense part, the balance is approximately calculated by setting a thin artificial bed ahead of the front.
We performed numerical simulations for a release of stationary fluid consisting of the dilute part in the rectangular-lock domain on a horizontal ground surface. As a result, the expansion of dilute part, the development of dense part below the dilute part, and the deposition of particles on the ground were reproduced. In addition, the behavior of pyroclastic flows is classified into two regimes: the regime where the dilute part always reaches the head of the flow and governs the total propagation of the flow, and the regime in which the dense part outruns the parent dilute part. The results of our parameter study indicate that which regime can occur mainly depends on particle size. When the currents contain fine-grained particles, the total propagation is dominated by the dilute part. This is because the lower particle-settling velocity of fine particles reduces particle transport from the dilute part to the dense part so that the development of the dense part is limited. When the currents contain coarse-grained particles, owing to a higher particle-settling velocity, particle transport from the dilute part to the dense part becomes substantial, so that the development of the dense part is enhanced. When the dense part becomes thick, it can outruns the parent dilute part. The difference of these regimes determines which one of the two parts forms the lowermost part of the deposits, because the lowermost part of the deposits is formed by the preceding flows. Therefore, the difference may explain the diversity of depositional facies formed by pyroclastic flow.

Keywords: pyroclastic flows, shallow-water model, two-layer model, numerical simulation, volcanic column collapse, pyroclastic flow deposits

