Quantitative detection of debris flow by using tilt and strain meters

*Masato Iguchi[1]

1. Sakurajima Volcano Research Center, Disaster Prevention Research Institute, Kyoto University

Instruments for volcano monitoring are available to detect debris flow at Sakurajima where vulcanian eruptions and debris flow frequently have occurred since 2009. Seismic observation is conventional method to detect debris flows as shown by high-frequency tremor-like waves. However, seismic waves are insufficient to estimate volume of debris flow. Here, I will propose a method to estimate volume of debris flow by using ground deformation associated with debris flows.
Upward tilts of the crater side of Sakurajima have been detected 5 min to 1 day before volcanic eruptions. Upward tilts of the crater side were also detected at the same site associated with debris flows streaming in Arimura river, opposite side of the crater in the view of the tiltmeter, because deposits of debris flows induce downward tilt of the river side. On the other hand, radial strain shows different change patterns between precursory inflation of eruptions and debris flows. Radial strain shows contraction prior to eruptions, but extension of radial strain is recorded associated with debris flows. Such deformations are detected for 65 debris flows in the Arimura river except for 4 minor flows during the period from 2009 to 2016. Amounts of tilt changes ranged from 4 to 409 nano radian. The downward tilt vectors are oriented to the no.1 Sabo dam and it is inferred that the deformation is caused by deposit of debris flow at the Sabo dam. Extension changes of radial strains ranged from 3 to 138 nano strain and are almost 1/3 of the tilt changes. Assuming a point mass applied to the river surface, increase of weight on the river is estimated to 60 thousands ton in case of strain change of 30 nano. Total weight of debris flows is estimated to be 2 million tons during the period from 2009 to 2016.

Keywords: ground deformation, debris flow, Sakurajima

Rainfall-runoff-inundation model application for volcanic debris flow assessment in Mount Merapi

*Magfira Syarifuddin[1], Satoru Oishi[2], Ratih Indri Hapsari[3], Djoko Legono[4], Masahide Muranishi[1], Mariko Ogawa[5], Masato Iguchi[6]

1. Graduate School of Engineering, Kobe University, Japan, 2. Research Center for Urban Safety and Security, Kobe University, Indonesia, 3. State Polytechnic of Malang, Indonesia, 4. Gadjah Mada University, Indonesia, 5. Office of Promoting Regional Partnership, Kobe University, Japan, 6. Disaster Prevention Research Institute, Kyoto University, Japan

Volcanic debris flow or lahar is a hydrometeorological disaster happened in the rainy season in Mount Merapi. Following the 2010 eruptions more than 50 lahar events happened and caused material loss and casualties. Although the frequencies are decreasing, but in 2016 the disaster still happened as the unstable material from the volcano eruption remains at elevation higher than 1200 m above mean sea level (amsl).

Lahar is a Javanese term used to describe a rapidly flowing, high concentration, poorly sorted sediment-laden mixture of rock debris and water from a volcano that goes along river stream. It is a continuum flow type which covers debris flows, hyperconcentrated, streamflow, and mudflows. It comes as series of surges with maximum frontal velocity ranges from 5 m/s to 15 m/s. At Merapi lahar is likely to trigger by rainfall intensity of 40 mm in 2 h. Two types of triggering rainfall are: local stationary or orographic confined to slopes above 1200 m amsl and regional, migratory rainfall that moves from the northwest or the southwest. The latest mention usually leads to large-scale debris flow (>80,000 m^3 of deposits) (Lavigne et al. 2007).

Hydrological model such as rainfall-runoff-inundation (RRI) could be a useful tool for analyzing hydrometeorological disaster. The model uses full dynamic equations that based on diffusion wave assumption which are effective for flood assessment in both mountainous slopes and lowland plains. However, the application on flash-flood and debris flow is difficult because of the short duration and small area. The RRI model relies on satellite-rainfall and rain gauge data, while lahar occurs in a small-scale that constrained the use of coarse resolution of satellite-rainfall or poor resolution rain gauge network.

Previous studies confirmed that rain gauge-rainfall caused uncertainties and underestimated rainfall threshold for debris flow occurrence (Nikolopaulus et al., 2014; Staley et al., 2013; Marra et al., 2014). On the other hand, remote monitoring by weather radar such as an X-band multi parameter (X-MP) radar gives higher spatial and temporal resolution, which is desirable by lahar studies. It offers advantage to monitor rainfall in the initiation area and it could measure debris flow during short duration of storm event (David-Novak et al., 2004; Chiang and Chang, 2009).

In this paper, we improved the RRI model by applying X-MP radar information. A new submodule of debris flow assessment has also been introduced based on Takahashi theory (Takahashi, 2009). The theory considers debris flow initiation criteria depends on average slope, particle size and discharge per unit width. We used the improved model to analyze hydrologic condition in Gendol Catchment for 2 weeks observation in May 2016.

The radar-rainfall based model gave comparable results with the rain gauge-rainfall based model and the

observed water depth information in the downstream area. The discharge information calculated by RRI model were not only useful for direct lahar assessment but could be important boundary information for other numerical model in ungauged sub-basin. Although direct verification in the ungauged upstream area is difficult, but in the future applying the model for real lahar event could be useful to test the improved RRI model performance in small-scale catchment.

Keywords: Rainfall-runoff-inundation model, X-MP radar, volcanic debris flow, rainfall, merapi

Detecting interior structure in Iwate volcano using muon radiography.

*Hideyuki Itoh[1], Hidekazu Kakuno[2], Morio Tsuji[1], Seima Ichikawa[2], Fumihiko Takasaki[3], Shinya Narita[4]

1. Faculty of policy studies, Iwate prefectural University, 2. Department of Physics, Graduate School of Science and Engineering, Tokyo Metropolitan University, 3. HIGH ENERGY ACCELERATOR RESEARCH ORGANIZATION, 4. Department of Physics, Graduate School of Science and Engineering, Iwate University

Recently, radiography for the internal structure of volcanoes using cosmic ray muons has developed and it has produced results in case of Asama volcano and Satsumaioujima (Tanaka et al.2008). We have setup the muon detector in east foot of the Iwate volcano, about 6km from the summit and detected since October 14, 2016. Besides this, our objective is to understand deep underground water flow system on the interior of the volcano, by performing continuous observation of chemical composition of spring water originating from Iwate volcano. And this results of spring water composition compare to the image of the internal structure of Iwate volcano obtained from muography.
The present data taking is stabilized and simple two dimensional image can be obtained.
However, the density length of volcano body obtained from the measurements shows a value considerably different from the actual thickness of the mountain and it is influenced much by the muons coming in from electromagnetic shower or scattering from the surroundings. On the other hand, a comparison of the actually measured density length and distance from the topographic data used a 10m mesh DEM of volcano altitude and from the density distribution, difference of density distribution appeared from the younger volcano body between the elder.
From the chemical composition of the spring water can be divided to two groups as $Ca(HCO_3)_2$ type and the SO_4^{2-} in addition to $Ca(HCO_3)_2$. When tritium dating shows values of 13.9-23.5 years were obtained. Particularly for the Oide and Kanazawa springs, the values were respectively 19.4 years and 23.5 years and this indicates the possibility of the groundwater recharged during 1998-2003 eruption crisis to gush out now onwards.

Keywords: muon, spring water, chemical analysis

Low-temperature fumaroles and diffuse H_2S degassing associated with recent volcanic activity at Iwo-Yama, Kirishima Volcanoes, Japan

*Yoshikazu Kikawada[1]

1. Faculty of Science and Technology, Sophia University

Iwo-Yama is one of active volcano belonging to the Kirishima volcano group (the Kirishima Volcanoes), Kyushu Island, Japan and located in the Ebino Highland, a famous tourist destination. At the volcano, seismic activity increased in December 2013, and volcanic tremors were observed several times in 2015. Also, fumaroles were found at the crater in December 2015 after twelve year’ s absence, and an expansion of thermal and fumarolic activities have been observed around the summit area since then. Meanwhile, the diffuse degassing area with a high H_2S concentration was found at the western outer wall of the mountain. The area lies in the altered zone formed by the past hydrothermal activities. A small acidic spring with high dissolved H_2S content is also found in the altered zone.

The Miyazaki prefectural government started the fix-point observations of the atmospheric H_2S and SO_2 concentrations in and around the fumarolic and degassing areas in March 2016 because the areas are located near a road for tourism and mountain trails, and someone may suffer accidents with gas poisoning. Initially, the atmospheric H_2S concentration at 30 cm height from the ground surface at the center of the diffuse degassing area had not exceeded 200 ppm. However, the concentration has drastically increased in October 2016 and showed 1400 ppm maximum. In response to this, the prefectural government settled policies for setting out restricted areas according to the H_2S and SO_2 concentrations and started the automatic measurement of the atmospheric H_2S concentration at the two fixed point located in and beside the diffuse degassing area in January 2017.

The author has been monitoring the state of changes in the low-temperature fumarolic activity and the diffuse degassing area since March 2016 together with the prefectural government from the viewpoint of safety of tourists. In this presentation, the author would like to discuss the state of diffuse degassing activity with a high H_2S content and report on the approach to volcanic gas disaster prevention by Miyazaki prefecture and the regional community of Ebino Highland.

Keywords: Iwo-Yama, hydrogen sulfide, volcanic gas disaster, low-temperature fumarole, Ebino Highland, gas poisoning

Critical review of disaster mitigation for Hakone Volcano and its eruption occurred in 2015

*Masato Koyama[1]

1. CIREN, Shizuoka Univ.

A critical review was made on the disaster mitigation for Hakone Volcano and its eruption occurred in 2015. Hakone Volcano, one of the active volcanoes in Japan, has repeated phreatic eruptions 5 times since the last magmatic eruption at about 3ka. All these eruptions occurred near Owakudani Valley, which is a famous geothermal area for tourists. A volcanic hazard map, which estimates dangerous areas under a similar situation of the past phreatic eruptions, was made in 2004 by the Hakone Town Office. On the basis of this hazard map, Disaster Mitigation Council for Hakone Volcano made an evacuation plan under each volcanic alert level, which is given by Japan Meteorological Agency. Because all these countermeasures had been prepared before the 2015 eruption, evacuation of tourists and residents was successfully made under the earthquake swarm and abnormal fumarolic activity in the pre-eruption stage. This success, however, was fortunately made under the conditions stated below:
1) The 2015 eruption of Hakone Volcano was a weak phreatic eruption, of which discharge mass was only 100 ton. No base surge and no large lahar occurred. Duration of the eruption was short (about 2 days).
2) There are 10 plus and 11 minus social factors, which affected the development of the systems and urgent actions for disaster mitigation of Hakone Volcano. Through the history since the early 20th Century, the persons or parties, all who concerned the disaster mitigation of Hakone Volcano, suppressed the minus factors and reinforced the plus factors.

Keywords: Hakone Volcano, disaster mitigation, 2015 eruption, critical review, natural and social conditions, plus and minus factors

Review on pre-cursor events of Krakatau1883 caldera-forming eruption —Can we catch the precursor events of caldera-forming eruption?-

*Akira Takada[1]

1. National Institute of Advanced Industrial Science and Technology Geological Survey of Japan

Caldera-forming eruptions, erupted volume more than 10km3, occurred once or twice during 100 years. Indonesia was suffered twice for the last 200 years, and three times within 1,000 years from caldera-forming eruption. I compiled the precursor process to the caldera-forming eruptions of Krakatau 1883 after a dormant period or a long-time low activity stage (Nishimura, 1980, Yokoyama, 1981, Simkin and Fiske, 1983;Carey et al., 1996; Mandeville et al., 1996). During the last a few months, we may have caught geologically the short-term process as the progressive activity to the climax eruption in cases of Krakatau 1883 eruption (Takada, 2010; Takada et al., 2012). For Krakatau eruption, earthquakes increased; wide-range hydrothermal activity occurred; small-scale eruptions increased. However, the problem is to evaluate or predict when the volcano reaches a climax condition, and how much the volcano erupts. The evacuation plan depends on them.

Keywords: Krakatau, caldera-forming eruption, large volume eruption, precursor events, Indonesia

Physical parameters analysis of volcanic ash particles measured by 2D-Video Disdrometer

*Sung-Ho Suh[1], Masayuki Maki[2], Masato Iguchi[3], Dong-In Lee[1]

1. Division of Earth Environmental System Science, Pukyong National University, Korea, 2. Research and Education Center for Natural Hazards, Kagoshima University, Korimoto, Kagoshima, Japan, 3. Sakurajima Volcano Research Center, Disaster Prevention Research Institute, Kyoto University, Sakurajima, Kagoshima, Japan

Weather radar is one of powerful instruments for measuring volcanic ash columns and ash clouds. However, we need fundamental physical properties on ash particles for the quantitative analysis of weather radar data of volcanic ash: necessary information are terminal velocity, axis ratio, and canting angle including density and dielectric constant of target to detect volcanic ash column correctly. In the present study, the basic features of volcanic ash particles are analyzed to develop quantitative ash fall estimations (QAEs).
The data were collected by a number of automatic tephrometers at Sakurajima volcano, Japan and reanalyzed with a 2D-video disdrometer (2DVD) in the large-scale rainfall simulator of NIED. The entire volcanic ash particles were classified as five types based on shape and orientation: Horizontal Oblate (OH), Vertical Oblate (OV), Horizontal Prolate (PH), Vertical Prolate (PV), and Sphere (Sp).
Dominant particle shape was OH (71.5%) and the next was PH (17.0%). It should be noted the horizontally oriented type was 88.7% of all sampled data. The 64.4% data are concentrated on $D < 0.5$ mm. The number of PV and Sp particle is increased with D. The relationships of terminal velocity are dependent on particle shape types: Prolate spheroid (vertical orientation) particles were faster than those of oblate (horizontal). The distribution of γ is from 0 to 1.5 at $D < 2$ mm, but these are concentrated to around 1 for $D > 2$ mm. The deviation of canting angle for OV (OH) is around two times larger (smaller) than raindrops. It is inferred that there would be not much rotating phenomenon.
The features of ZH and dual-pol radar variables (ZDR, KDP, and AH) were analyzed. ZH is around 4.3 dBZ smaller than that of raindrop and there is no resonance effects with radar frequency. There are large variabilities in ZDR depending on the particles shape for $D < 2$mm and these were close to 0 for $D >$ 2mm. KDP and AH are variable with radar frequency but these magnitudes are almost 0 regardless of D. These results will be utilized to develop QAE methods, to detect volcanic ash column and predict its activity.

Corresponding author: M. Maki
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Keywords: Volcanic ash, basic feature, 2DVD

Orographic Effects on the Transport and Deposition of Volcanic Ash - A Sakurajima Case Study

*Alexandros Panagiotis Poulidis[1], Tetsuya Takemi[1], Masato Iguchi[1], Ian Alasdair Renfrew[2]

1. Disaster Prevention Research Institute, Kyoto University, 2. Centre for Ocean and Atmospheric Sciences, University of East Anglia

Introduction

Volcanic ash is a major environmental hazard that acts over both short (hours-days) and long (months-years) timescales and, directly or indirectly, affects life, livelihoods, and infrastructure (Wilson *et al.*, 2015). After an eruption, airborne ash can cause major disruption for international aviation, and in the long term can exacerbate existing respiratory conditions (Hillman *et al.*, 2012). Accurate prediction of the transport and deposition of volcanic ash is therefore vitally important for hazard management and mitigation.

Transport and deposition of volcanic ash are complex processes, depending heavily on the size of the particles (Bonadonna and Houghton, 2005). Heavy ash is deposited quickly within a few 10s of kilometers from the vent, while lighter ash tends to have longer flight times and is more directly influenced by local as well as regional wind fields. Atmospheric flow is heavily influenced by complex terrain creating a number of complex phenomena, such as flow spitting, gravity waves and downslope winds (Smith, 1980). These orographic effects have been seen to affect the deposition of volcanic ash (Watt *et al.*, 2015)

In the study presented we examined the impact of orographic effects on the transport and deposition of volcanic ash from the Sakurajima volcano in Kyushu, Japan. Sakurajima is one of Japan's most active and closely monitored volcanoes. The frequent activity, surrounding mountainous topography, and large amount of observational data make Sakurajima an ideal natural laboratory for the study of these effects.

The August 2013 eruption and ash dispersal modelling

On 18th August 2013 Sakurajima erupted at 1631 JST with a plume height of 5 km - the highest plume height recorded since 2006. Ash was advected W-NW and ashfall was recorded as far as the Koshikijima islands 90 km in the west. This eruption was studied in depth using the Weather Research an Forecasting (WRF) model (Skamarock *et al.*, 2008), coupled with "online" chemistry and aerosol calculations (WRF-chem; Grell *et al.*, 2005). A nested domain setting with high horizontal (12500, 2500, and 500 m) and vertical (90 levels starting at 50 m height increments) resolution was used in order to resolve the orographic effects, while a series of simulations with zero topography were carried out to show the influence of these effects.

Results

Simulations have shown that orographic effects can act in two ways: strong gravity wave activity close to

the volcano act to keep ash afloat, while downslope winds closer to the surface can advect ash downwards and force deposition (Fig. 1; Poulidis *et al.*, 2017). Orographic effects were seen to increase both horizontal and vertical diffusion of volcanic ash. Due to its low residence time, heavy ash was seen to be relatively unaffected by orographic effects: in terms of deposition, the most readily affected size ranges for particles were of grain size between 3-5 ϕ (ie. between 0.125 and 0.03 mm).

Resolving orographic effects over the volcano leads to a “gray area” over the volcano: the initial plume height set at input can be changed due to gravity wave activity over the volcano, leading to a different simulated plume height, something that could affect similar simulations, especially for eruptions with low plume heights.

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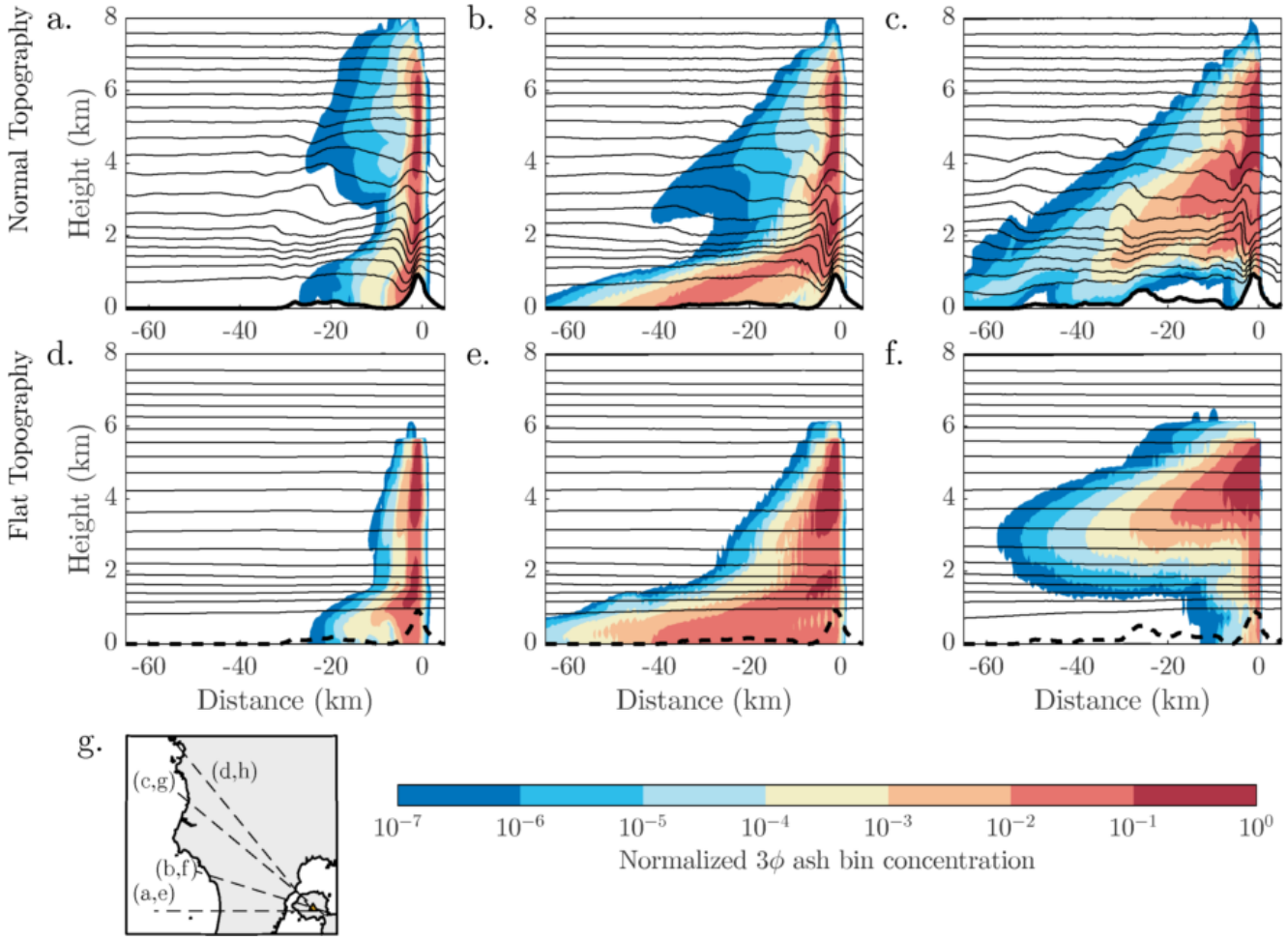
Keywords: Ash dispersal, Sakurajima, WRF, Orographic effects



Attempt of earth and planetary science education by dispersion simulation of pyroclastic materials emitted from the volcanic eruption

*Kazuto Saiki[1]

1. Graduate School of Science, Osaka University

In recent years, simulations of the dispersion of pyroclastic materials released by volcanic eruption have been actively carried out, and they are used for disaster hazard maps. Among them, Tephra 2 (Ref 1, 2), which is often used, is based on advection + diffusion model of pyroclasts in the atmosphere. It does not require much computer resources and its internal processing is easy to understand. Based on this Tephra 2, I made a simulation program called 55Tephra which is more compact, easy to use, easy to read and remodel its code. I am planning to use this 55Tephra (Fig.1) for high school students as a teaching material to teach how to model natural phenomena and the problem on modeling. Because there are some high schools that are interested in simulation of extraterrestrial volcanic eruptions such as on Mars, there is a possibility that it will become a good teaching material for earth and planetary science, that simultaneously cultivates a sense of disaster prevention modeling. In presentation, introduce 55Tephra and present various ideas of utilization.

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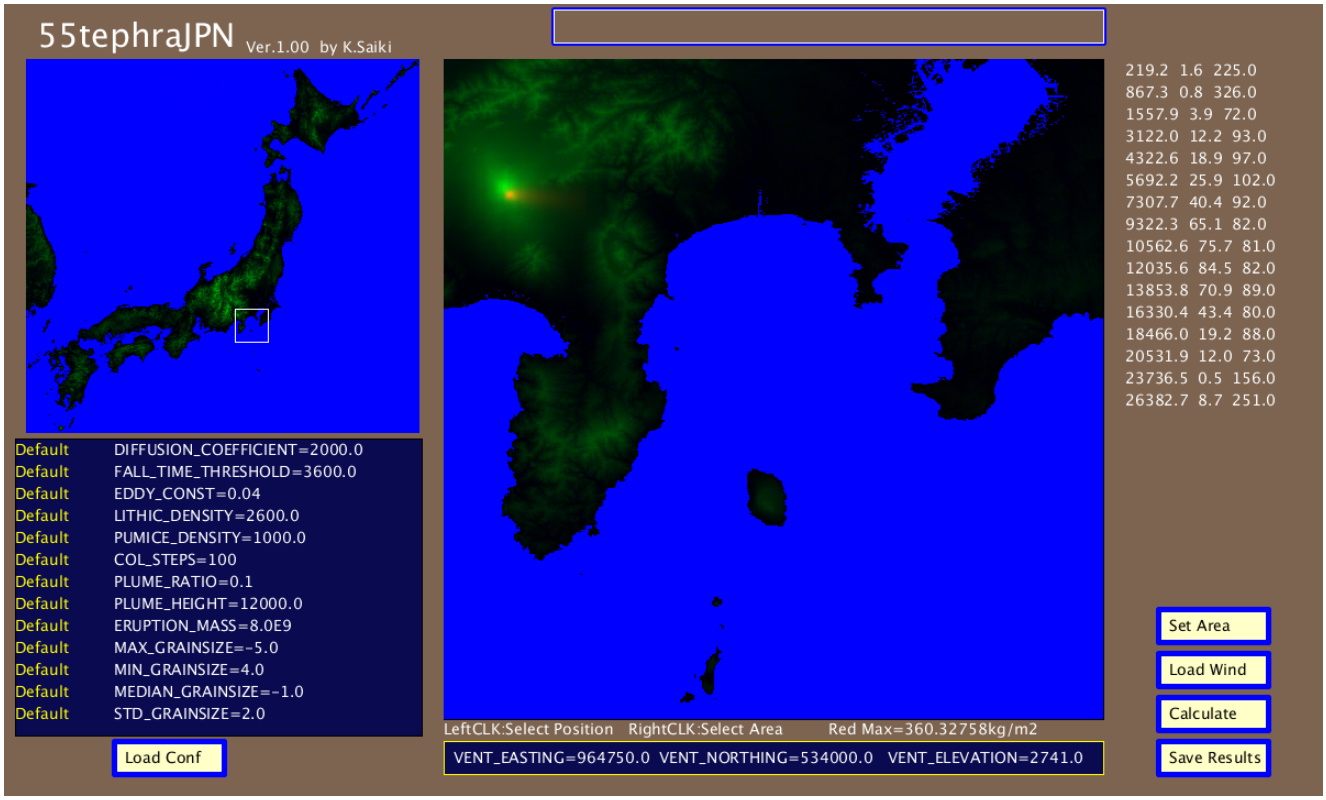
Keywords: tephra, simulation, high school students



Features of Numerical Model “Ballista”; the Ballistic Simulator of Explosive Volcanic Eruption

*Kae Tsunematsu[1], Christopher A Gomez[2], Rebecca Hanna Fitzgerald[3], Ben Mattew Kennedy[3], Koshun Yamaoka[4]

1. Mount Fuji Research Institute, Yamanashi Prefectural Government, JAPAN, 2. Faculty of Maritime Sciences, Kobe University, JAPAN, 3. Department of Geological Sciences, University of Canterbury, New Zealand , 4. Graduate School of Environmental Studies, Nagoya University, JAPAN

Ballistic projectiles are emitted from the vent of the volcano when an explosive eruption occurs. Their sizes range from a few centimeters to several meters, and the landing velocity of these pyroclasts can exceed 100 km/h. Therefore, for hazards and disaster risk management it is essential to estimate the affected area of ballistic projectiles. To reach this goal the ballistic trajectory simulator “Ballista” was developed. This model can calculate the trajectory and deposition condition of multiple ballistic particles in three dimensions using a momentum equation including air friction solved by the Runge-Kutta method, and particles are transported by the Lagrangian method. Ballista was programmed using Java to increase portability and includes complementary modules, such as a topographic effect, which is also taken into account by the simulation. As a result, the model can constrain the ejection angle and direction bearing of ballistic projectiles released during the Ontake 2014 eruption (Tsunematsu et al., 2014), not only using ballistic physics but also realistic terrain data.
In the presentation, we show how local conditions and terrain can affect the model by running the same simulations with and without topography, but also by modifying the resolution of the topography to study these effects. The resolution of the digital elevation model (DEM) only changes the large scale distribution of ballistics on the ground when the grid size is fairly large (> 100 m). Results also show that including topography in the calculation changes the travel distance and the spatial distribution of particles significantly. When examined in detail, in particular locations the high resolution DEM can be used to identify shelter areas where ballistic hazard is reduced, for example, behind large boulders or buildings - risk reduction strategy that proved successful for hikers caught in the 2014 eruption. In our presentation, we discuss such topographic dependency of the Ballista quantitatively.
Finally, we have made the model public by a creating graphical user interface and a user guide in order to contribute to the disaster risk management.

Keywords: Ballistc projectiles, Explosive eruption, Topography, Resolution, Numerical Model, Graphical User Interface

Characteristics of damage caused by lapilli fall of the October 8, 2016 eruption of Aso Volcano, Japan

*Hisashi Sasaki[1], Shino Naruke[1], Tatsuro Chiba[1]

1. Asia Air Survey Co., Ltd.

We examined about characteristics of damage caused by lapilli fall of the October 8, 2016 eruption of Aso Volcano, Japan. Lapilli fall arrived at the remote residential area more than 4 km from the Nakadake crater of the Aso volcano, and the damage to a building or agriculture facilities occurred. In the National Aso Youth Friendship Center (from the Nakadake crater to the northeast approximately 4.5 km), one piece of windowpane and screen door was damaged by lapilli of approximately 3 cm in diameter. It is estimated that the lapilli dropped from the north, but does not agree with the direction of the Nakadake crater. At the roofed passage connecting buildings of the National Aso Youth Friendship Center, the polycarbonate board that ultraviolet rays deteriorated was damaged. The damage of solar panels was confirmed at the point of approximately 6.5 km from the Nakadake crater to the northeast. More than 1500 solar panels were damaged by lapilli fall at this point. As a future problem, it is necessary to investigate relations of collision energy of lapilli fall and strength of glass or polycarbonate board.

Keywords: lapilli fall, damage to buildings, Aso volcano

Safety of wooden buildings roof subjected to ballistic block collision

*KOHEI TATEYAMA[1], KEISHIRO NARITA[2], HIROYUKI YAMADA[3], MEGUMI OKUYA[4], MITSUHIRO YOSHIMOTO[4]

1. Graduate School of Science and Engineering, National Defense Academy, 2. Undergraduate Student of School of Systems Engineering, National Defense Academy, 3. School of Systems Engineering, National Defense Academy, 4. Mount Fuji Research Institute, Yamanashi Prefectural Government

Damages and destruction of as-built wooden buildings caused by volcanic activities are due to various factors. Especially, at the phreatic eruption of Mt. Ontake in September 27, 2014, most of the damages were caused by collision of ballistic block.
In order to prevent these damages, it is suggested that evacuation to a mountain hut is effective. Thus, evaluation of safety for wooden buildings (e.g. mountain hut) against ballistic block collision is necessary. Previously, we reported the protective abilities of as-built wooden buildings, which were reinforced with high performance fabric using aramid fiber. However, the safety of unreinforced as-built wooden buildings has not been clarified.
In this study, safety of wooden buildings roof subjected to ballistic block collision was experimentally investigated.
A collision test was carried out at the velocity of 10 to 90 m/s using a large scale launching system. In this system, a projectile was accelerated by compressed air and then collided with the target. The projectile velocity was measured using two lasers and light receiving parts.
At the volcanic eruption, the diameter of ballistic block was approximately ϕ100 mm under normal circumstances of phreatic eruption. Therefore, abrasive materials similar to the common ballistic block (density: 2400kg/m3, diameter: 90mm, mass: 2.66kg) was used as the projectile.
For the target, typical wooden roof structure (e.g. cedar boards, waterproof sheet, galvalume steel plate and cedar rafter) was used. The thickness of the cedar board, waterproof sheet and galvalume steel plate were 18 mm, 1 mm and 0.4 mm, respectively. The components were fixed with nails and its spacing was approximately 150 mm. The dimensions of the specimen were 600 mm ×600 mm.
From results of collision tests, it was revealed that the penetration boundary energy of the specimen was approximately 1200J. When the collision energy was smaller (440, 818 J) then the penetration boundary, several deformation due to bending at rafters was dominant. On the other hand, when the collision energy was larger (10512 J), local shear failure was observed at the vicinity of the contact surface. It was clarified that fracture mode changed when the collision energy was increased.
In previous study, it was shown the maximum collision energy of volcanic lapillus (ϕ2-64 mm) was 1700 J (in the case of ϕ64mm, 100 m/s), and average collision energy was less than aproximately1200 J in many case. Therefore, it was revealed that the roof of cedar board having a thickness of 18 mm could prevent penetration of volcanic lapillus.

Keywords: Ballistic block, Wooden buildings roof, Collision

