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Constraining the occurrence of volcanic lightning at Sakurajima using a multidisciplinary monitoring network

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1. Introduction

The association of lightning with volcanic eruptions has been known since at least the 79AD eruption of Mt. Vesuvius, Italy. In his famous two letters Pliny the Younger describes this eruption in great detail, stating: "Behind us were frightening dark clouds, rent by lightning twisted and hurled, opening to reveal huge figures of flame. These were like lightning, but bigger"[2]. This is probably the first recorded witness of lightning occurring during volcanic eruptions and since then countless other reports of lightning have been made. In recent times the availability of high quality digital cameras has brought the occurrence of lightning during larger eruptions to the attention of many people. Nevertheless, volcanic lightning remains a somewhat mysterious phenomenon and even the most comprehensive reviews on lightning[3] devote only few lines to this phenomenon ("Other types of unusual lightning and lightning-like discharges").

Due to its frequent occurrence during volcanic eruptions, volcanic lightning has moved into the focus of volcanologists, who monitor volcanoes for e.g., mitigating the impact of volcanic eruptions. However, when one wants to use the occurrence of lightning during volcanic eruptions one needs to understand under what circumstances, i.e. dynamic constraints, volcanic lightning occurs.

2. Experimental setup

In Feb. 2018 we installed one Doppler radar at Kurokami Branch Observatory alongside with a camera. This installation was complemented by two thunderstorm detection systems manufactured in May 2018 (one located in Kurokami, one in Harutayama), originally designed to monitor thunderstorm activity. These systems exploit the disturbances caused by lightning in the so-called ELF (extremely low frequency <50Hz) electromagnetic spectrum to determine strength and location of lightning strokes. Our main interest in using this system is to detect lightning in volcanic clouds without using much more complex so-called lightning mapping arrays.

In addition, during our stays at Sakurajima (May 2018 and July 2018) the observations were complemented by thermal and high speed camera observations. The radar was removed in July 2018 due to the start of the typhoon season as the installation of the system would not withstand very strong winds. The thunderstorm detection system kept running for the remaining time.

Here we report on the first results of our exploratory field experiment to constrain conditions of the occurrence of volcanic electric discharges.

3. Results

The data recorded reveal different insights into the eruptions at Sakurajima volcano. The Doppler Radar, running at a temporal resolution of 10 Hz and continuously monitoring the same location about 50-100 m above the vent of Minamidake, allows an easy identi-

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[1] Authors are listed in alphabetical order

[2] http://www.gso.uri.edu/vesuvius/Plinys/Pliny.html

[3] Rakov, V. A. and Uman, M. A. (2007). Lightning - Physics and Effects. Cambridge University Press

fication of eruptions (see Fig. 1).

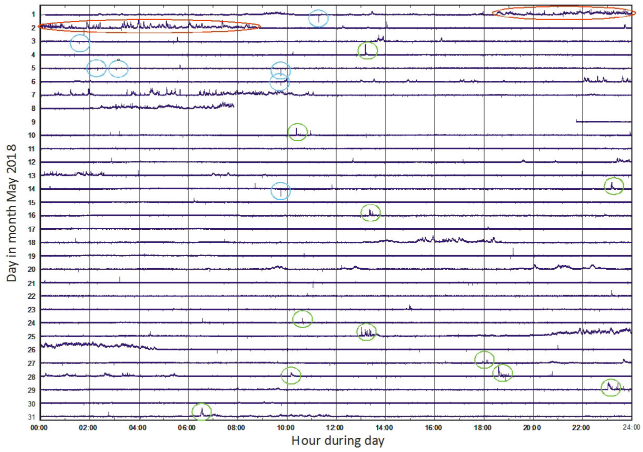

Figure 1: Reflected power recorded by the Doppler radar during May 2018. Display is similar to a drum-plot representation of seismological data. The reflected power shows certain fluctuations. Red indicates rain, blue marks short periods where data are missing and green marks eruptions.

Figure 2 shows an example of an eruption recorded by the radar system on May 25 at around 13:10 UTC. The eruption started at about 13:01:30 (note that 0 s equals 13:00:00 UTC) with a strong initial pulse of material leaving the vent lasting about 30 s.

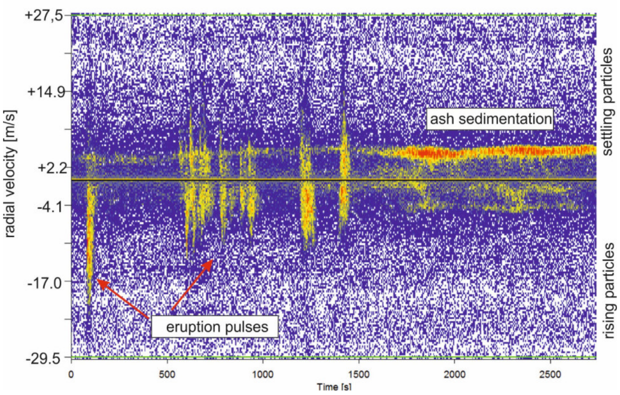

Figure 2: Velocigram of an eruption on May 25th between 13:00:00 and 13:45:39 UTC shown as a function of time and radial velocity. Conversion of the radial velocities to vertical velocities is about 132.75 m/s and -123,75 m/s (minus is here upward, plus downward). Maximum vertical eruption velocities are about 80-85 m/s. Color codes the reflected energy given in dB.

In addition to the clearly visible pulsed activity at the vent of Minamidake crater there is an initially faint signal starting almost immediately with the first pulse at around 80 seconds (see Fig. 2). The signal becomes very strong at about 1600 sec and then lasts for about 1200 sec (20 min). It occurs at a radial velocity of about 4 m/s and is associated with particles moving towards the radar. Based on our experience from other observations at Sakurajima and other volcanoes, this signal is possibly originating from the sedimentation of ash. The signal could alternatively be interpreted as a rain event, but no rain was reported during this time over Sakurajima. Taking into account that the wind speed during that time was about 4 m/s (radiosonde data from 12 UTC, JMA branch Kagoshima) one can estimate that the size of ash particles precipitating is on the order of 0.1 to 1 mm, which is reasonable for volcanic ash.

A comparison of the Doppler radar data with recordings of the thunderstorm detector shows a good correlation between the recorded velocities and the occurrence of the electric discharges and the plume height derived from the thermal observations.

4. Outlook

Because the findings of the exploratory study were very promising in terms using electrical discharges as a monitoring tool we will reinstall the radar system in Feb. 2019. In addition, we will put two additional radar systems in the field to observe the plume under different observation angles. The radar instruments will be complemented by instruments to measure the electric field associated with the eruptions and a third thunderstorm detection system. This data will help to further constrain the dynamic conditions for the occurrence of electric charging and discharging during volcanic explosions. This will help to establish the detection of volcanic lightning as a monitoring tool.