QUANTITATIVE VOLCANIC ASH ESTIMATION BY OPERATIONAL POLARIMETRIC WEATHER RADAR

Masayuki Maki\(^{(1)}\), Takeshi Maesaka\(^{(1)}\), Tomofumi Kozono\(^{(1)}\), Masashi Nagai\(^{(1)}\), Ryuta Furukawa\(^{(2)}\), Setsuya Nakada\(^{(3)}\), Tomoki Koshida\(^{(4)}\), Hideyoshi Takenaka\(^{(4)}\)

\(^{(1)}\)National Research Institute for Earth Science and Disaster Prevention (NIED),
\(^{(2)}\)National Institute of Advanced Industrial Science and Technology (AIST),
\(^{(3)}\)Earthquake Research Institute, the University of Tokyo,
\(^{(4)}\)IDEA Consultants, Inc.

ABSTRACT

Operational weather radar data from 27 big eruptions of the Mt. Shinmoedake volcano in the Kirishima range in Kyushu, Japan in the period from January to March 2011 are analysed to examine the possibility of using radar for quantitative volcanic ash estimation. It is concluded from analysis of the radar data that operational weather radar has the potential ability to quantitatively estimate the amount of volcanic ash expelled in volcanic eruptions. The distribution of accumulated reflectivity factor during the eruption of 26-27 January was similar to that of collected ground ash data. Differential reflectivity over the volcano crater fluctuates in space and time, while showing significant spatiotemporal variation in the downwind regions, which suggests the presence of ash particles aggregation and sorting mechanism.

1. INTRODUCTION

The volcanic ash released by volcanic eruptions cause damage to farm crops, land transportation, aviation, the organs of respiration, etc. Ash that accumulates on the ground has the potential to cause volcanic mudflows, which in turn cause damage to downstream houses and roads. Big eruptions spew large amounts of volcanic ash and gas into the stratosphere. When such ash remains in the stratosphere on a global scale and for prolonged periods of time, it blocks the sun’s rays and has the potential to decrease the air temperature in the lower atmosphere. To overcome these problems, it is necessary to establish a method of detecting volcanic eruptions and to formulate a quantitative ash estimation algorithm.

The success of weather radar observation of a volcanic eruption was probably 1980’s in U.S. and 1990’s in Japan ([1], [2]). Studies using research Doppler radar named VOLDORAD have been started since 2000 in France. Physical approaches using C-band radar and X-band polarimetric radar have been conducted since 2005s in Italy ([3], [4],[5]). A comprehensive review on this topic has been done by [6]. The present research will add new observational findings and confirm the previous studies.

2. DATA

Operational weather radar data from 27 big eruptions of the Mt. Shinmoedake volcano (1,421 m above sea level) in the Kirishima Mountain Range in southern Kyushu, Japan in the period from January to March 2011 are analyzed. The radars used in the analysis are C-band polarimetric radars located at Kunimiyama and Shakadake, both of which are operated by the Ministry of Land, Infrastructure, Transport, and Tourism (MLIT). The eruption time period, maximum and accumulated horizontal reflectivity factor \((Z_H)\) and differential reflectivity \((Z_{DR})\) were collected for each eruption. Note that the MLIT did not save Doppler velocity data for some reason. It should be also mentioned that the Kunimiyama radar cannot measure differential phase shift because it is not fully polarimetric.

The locations of the radars and of Mt. Sinmoedake are shown in Fig. 1(a). The Kunimiyama radar (KNM) and the Shakadake radar (SKD) are located 67.8 km south and 141.4 km north of Mt. Sinmoedake, respectively. The maximum range of both radars is 300km, and the spatial resolution is 256 sector × 200 range bins (i.e. 1.5 km range). The antenna scan mode is 2 tilts PPI (the antenna elevation angles are 0.4° and 0.8° for KNM and 0.3° and 0.8° for SKD) at a rotation speed of 1 rpm. Fig. 2 shows the relationship between the beam center height and the range. In the case of KNM, the beam heights above Mt. Sinmoedake are 300 m and 700 m for the elevation angles 0.4° and 0.8°, respectively. For SKD, the beam heights are 1,800 m and 3,000 m above Mt. Sinmoedake for the elevation angles 0.3° and 0.8°, respectively.

3. RESULTS

3.1. Field survey of ash amount

After the prominent eruptions on 26-27 January, 2011, a field survey was conducted by a team from AIST, JMA, CRIEPI, and Nippon Koei Co. to collect ash samples and to measure the ash amount distribution at over 110 points in an area extending about 70 km east to west by about 80 km north to south, where there was a possibility of volcanic ash falling to the ground. The
amount of volcanic ash around the volcanic crater was estimated by airborne imagery. Fig. 3 shows the distribution of ash amounts obtained by the field survey following the 26-27 January eruptions. The largest amount of ash was observed near Mt. Sinmoedake. Ash was observed about 50km downwind from the crater.

Figure 1. Location of Mt. Sinmoedake and the observation areas of the C-band operational weather radars. KNM: Kunimitama radar. SKD: Shakadake radar.

Figure 2. Beam center height (km) vs. range (km).

3.2. Effect of clutter filtering on ash detection

Weather radar generally uses a filtering technique to remove ground clutter from the received signals. Both KNM and SKD adopt a non-coherent MTI filter. To examine the effect of the filter on the detection of volcanic ash, $Z_H$ and $Z_{DR}$ with and without the filter were compared using radar data from the big eruption of January 26, 2011.

KNM was significantly affected by ground clutter because its beam height was close to the peak of Mt. Sinmoedake: the radar could not identify volcanic ash which was contaminated with clutter echoes. The MTI effectively separated the ash echoes from the clutter. SKD did not suffer from severe clutter contamination because the minimum radar beam height was 1,800 m above Mt. Sinmoedake. Thus, SKD could detect the volcano ash without utilizing MTI. The ash detection area without MTI is slightly larger than that with MTI. From these results, we conclude that MTI is necessary for ash detection while its effect on the quantitative estimation of ash is insignificant.

3.2. Accumulated reflectivity factor ($Z_H$)

Accumulation of $Z_H$ of KNM was calculated for 27 volcanic eruptions. Of the 27 Mt. Sinmoedake volcanic eruption events in 2011, the most pronounced was that of January 26. This eruption started at 15:30 LST and continued intermittently for about 3 hours. A maximum $Z_H$ of 65.7 dBZ was observed at 17:15 LST above the crater. Fig. 4 shows the distribution of accumulated $Z_H$ measured by KNM from 15:30 to 19:10 LST. The accumulation time was determined from the information on the eruption time and the ash echo detected by the radar. The maximum accumulated $Z_H$ was located above
the crater and decreased in the downwind area. Fig. 4 clearly shows that volcanic ash was swept downwind by the wind at the middle atmosphere. The distribution pattern is quite similar to that shown in Fig. 3.

![Figure 4. Accumulated Z_H measured by PPI scans at EL=0.4° during 15:30-19:10 LST, January 26, 2011.](image)

Fig. 5 shows the time change of Z_H at points A, B, C, D, and E in Fig. 4. Z_H is at its maximum at A and it decreases at the downwind points: the maximum Z_H is 65, 55, 50, 35, 30 dBZ at A, B, C, D, and E, respectively. It is interesting that the time change of Z_H at A, after the radar started to detect ash, is substantially different from that at B, C, D, and E: while the Z_H at A retained a high value, the Z_H at other points are small and increase gradually. It is also interesting that the ash detection time period is shorter depending on the distance from the crater. These results suggest an ash particle sorting mechanism.

### 3.4. Differential reflectivity (Z_{DR})

Differential reflectivity (Z_{DR}) measured by KNM and SKD were examined (Fig. 6). As mentioned above, the observation heights of the radars were different: KNM and SKD observed at heights of approximately 0.3 km and 1.8 km above Mt. Sinmoedake, respectively. Although the KNM PPI image of Z_{DR} measured at 17:30 LST does not show any typical echo pattern as precipitation, Z_{DR} shows a random pattern and a large value above and near the crater. It is also noted that Z_{DR} tends to be positive in the downwind area located at about 40 km from KNM. A larger Z_{DR} in this area may suggest that the flatter ash particles fall with small canting angles. The Z_{DR} observed by SKD shows a small positive value (from 0 to 0.5 dB). The difference between the KNM and SKD Z_{DR} patterns may be due to the difference in observed heights.

![Figure 6. Z_{DR} measured by (a) KNM (EL=0.4°) and (b) SKD (EL=0.3°).](image)
Fig. 7 shows the time change of $Z_{DR}$ at the points from A to E shown in Fig. 6. Generally, temporal fluctuation of $Z_{DR}$ is a common feature at all points. The variation range of $Z_{DR}$ is large at A. Positive $Z_{DR}$ is pronounced at B, especially after 17:00 LST. Negative $Z_{DR}$ may be pronounced at C. Negative $Z_{DR}$ is found at C from 16:10 to 16:20 LST, and positive $Z_{DR}$ is pronounced after 17:00 LST. The temporal change of $Z_{DR}$ at different points is interesting. However, more detailed analysis is necessary to answer the question “Do these temporal and spatial variations of $Z_{DR}$ have any physical meaning?” The other useful polarimetric radar variable may be the co-polar correlation coefficient which represents an irregularity of target shapes.

4. SUMMARY

It is concluded from analysis of the radar data that operational weather radar has the potential ability to quantitatively detect the amount of volcanic ash expelled in a volcanic eruption. Conversely, the radar could not detect eruptions of ash where the ash particle size is too small to be detected by the radar: i.e. the reflectivity of the ash is lower than the minimum detectable signal of the radar receiver. Naturally, it is also impossible to detect eruptions of ash when their height is below the radar beam height. It is also hard to detect eruptions in rainy conditions, when erupted ash particles are contaminated with precipitation particles.

Differential reflectivity, which is one of the parameters of polarimetric radar, fluctuates in space and time over the volcanic crater while it shows significant distributions over regions downwind from the crater. This suggests the presence of ash particle aggregation and sorting mechanisms.

Co-polar correlation coefficient $\rho_{HV}$ may be useful information to discriminate ash particles from rain particles: $\rho_{HV}$ is around 1 in case of rain, it decreases when irregular shape particles are contaminated in the radar sampling volume. This research topic will be a future work.

REFERENCES


