Topographic Change of the Summit Crater of Asama Volcano during the 2004 Eruption Derived from Airborne Synthetic Aperture Radar (SAR) Measurements

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Abstract

An active volcano, Mt. Asama, located in the central part of the Honshu island of Japan, erupted on September 1, 2004. Since then, thick volcanic fumes have prevented monitoring of the topography on the summit crater floor by standard optical methods. To detect geomorphic changes of the volcano, GSI repeatedly carried out Airborne Synthetic Aperture Radar (AirSAR) measurements including interferometry between September 2004 and March 2005. The comparison of AirSAR results with a digital elevation model (DEM) by Airborne Laser Scanning measurements in October 2003 revealed that a pancake shape lava mound had formed on the crater floor, and the volume of the lava mound amounted to 2.1×10^6 m^3*. From this, AirSAR measurement is recognized as an effective method for monitoring the topographic change of active volcano craters, and for foreseeing crises.*

1. Topographic Observation using AirSAR

AirSAR is a high resolution imaging radar attached to an aircraft which acquires terrain imagery by transmitting microwaves and receiving their reflection from the earth's surface. The transmission is made in the range direction downwards from the aircraft.

GSI's AirSAR system (GSI-SAR) has two receiver antennas attached to the frame such that each antenna receives the same reflection signal at a slightly different position from each other (Photo 1). Operating interferometric measurements using both receivers' observations, it generates a digital elevation model (DEM) of the area.

Concerning terrain observation from an aircraft, the introduction of SAR technology has the following advantages and disadvantages.

1) Observation through clouds, mists, or volcanic smoke is available.

SAR uses microwave radiation for observation. Microwaves can penetrate through clouds and mist, which ordinary optical devices such as a camera cannot. Also, as it is an active sensor that transmits the radiation by itself, it can acquire information about terrain with or without sunlight (Fig. 1). This wide ability of observation provides a big advantage to SAR devices in cases like the monitoring of active volcanoes when observation by ordinary photography or laser scanning is impossible.

2) Observation conditions can be determined flexibly

Compared to Satellite SAR systems, AirSAR has an advantage in the determination of observation conditions such as flight altitude, flight direction, and timing. These are very important abilities for efficient observation of volcano activities (Sato *et al*, 2002).

3) Distortion and radar shadow

The output image of SAR is generated using the results of distance measurement between the radar and the terrain surface. So the image carries distinctive characteristics of the radar measurement such as distortions and shadows caused by steep mountains (Fig. 1).

Reflected microwave signals are processed to be allocated on an image from the near side according to the trip time between the antenna and the terrain. Thus, the tops of mountains are shifted in the range direction to the near side of the image from their proper position. No distortions exist in the azimuth direction of the aircraft.

The transmitted microwaves cannot reach the opposite side of mountains, so they cause a shadow area on the image where no signals come back from the terrain. Because of the use of an aircraft as the platform, AirSAR observation can be made from various directions toward the target, so the shadow area is reduced to the minimum even at obstructed targets like volcanic craters.

Photo 1 Assembled airborne SAR equipment used for the repeated measurements over the Asama volcano on September 16, October 22 and December 15, 2004 (left). The aircraft (Cessna 208) with onboard SAR instruments mounted (right).

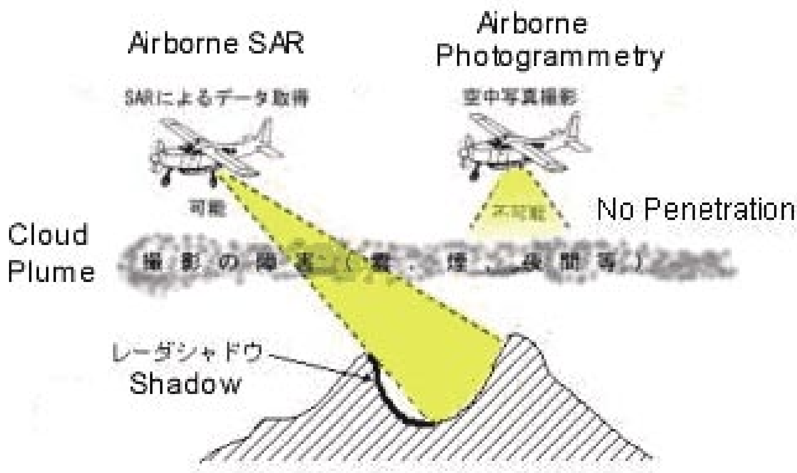

Fig. 1 A schematic illustration of AirSAR measurements over a volcano. SAR is advantageous in measurements during night or through cloud, mist and volcanic fumes.

2. Observation of the Summit Crater of Asama Volcano using AirSAR

Since the major eruption of Asama volcano on September 1, 2004, GSI has repeatedly carried out AirSAR measurements around the summit crater, and observed its topographic change. The measurements were carried out considering the AirSAR characteristics described above. The results of the measurements were analyzed by interpretation from the output images, and comparison of the DEM generated using interferometric processing of SAR data and the DEM derived from a laser scanner measurement taken before the eruption by Tonegawa River Basin Sabo Office, Kanto Regional Development Bureau. From the DEM comparison, the volume of lava eruptions was also calculated.

2.1 Outline of measurement

The measurement was set to have the most suitable altitude and off-nadir angle for observing inside the crater, and the flight courses were planned to circulate the summit so the measurements would cover all directions. Based on this plan, four sets of measurement flights were repeatedly carried out. Among the flights, the first three measurements were operated using an X-band (9.5GHz) microwave SAR system, and the last measurement was operated using a Ku-band (16.7GHz) SAR system. The conditions of measurements are shown in Table 1.

Table 1 Specifications of Repeated AirSAR Measurements over the Asama Volcano during the 2004 Eruption

Date	Direction	Distance Between Scene Center and flight Path	Off-Nadir Angle at Scene Center	Altitude Of Aircraft	Freq. band (frequency)	Across Track Spatial Resolution At Scene Center	Along Track Resolution
Sept. 16	NESW NESW	2 km 3 km	49 deg 60 deg	4,250 m	X (9.6GHz)	2.0 m 1.7 m	1.5 m 1.5 m
Oct. 22	NESW	2 km	49 deg	4,250 m	X (9.6GHz)	2.0 m	1.5 m
Dec. 15	SWN	2 km	49 deg	4,250 m	X (9.6GHz)	2.0 m	1.5 m
March 10	NESW	2 km	49 deg	4,250 m	Ku (16.7GHz)	0.4 m	0.3 m

2.2 Interpretation of SAR images

Using images produced from the acquired SAR measurements, the authors carried out interpretation of details on the bottom of the crater. Fig. 2 shows the produced SAR images and sketches of the interpretation results.

2.3 Analysis of interpretation results

In the images produced from the measurement on September 16, an obvious circle shaped mound is recognized at the north-eastern part of the crater bottom. According to the previous DEM, this part had been a sunken place before the eruption. It is considered that a dome of lava was formed by the volcanic activity on September 1. Also, from the facts that the reflection level is comparatively low and that concentric circles are shaped on the mound, the authors conjecture that there were frequent evacuations of lava during the eruption. It seems the lava was rather viscous, and the mound was formed in multiple layers.

In the images of the measurement on October 22, the dome of lava recognized on the previous measurement had disappeared, and was replaced by a basin whose diameter is about 50m. Japan Meteorological Agency reported there were two medium class eruptions between this measurement and the one of September 16, and the basin is considered to have been formed by these eruptions (Japan Meteorological Agency, 2005).

At the 3rd measurement on December 15, the ejecta of the volcano was still covering the bottom of the crater. The north-eastern part of the bottom was slightly raised; however, the total shape of the crater bottom was rather a shallow basin. It is considered that this change of terrain was caused by another eruption after the previous measurement.

There was no big change in the bottom terrain when the most recent measurement was taken on March 10. However, the radar shadow caused by the crater wall had grown slightly. This means the crater bottom had subsided. This measurement was carried out using a Ku-band SAR system which provides higher resolution images. On observing the Ku-band SAR image, it first became clear that a bowl-like terrain was formed around the fumarole.

2.4 Calculation of height change of the crater bottom and erupted lava amount

In order to investigate the movement of the crater terrain, we compared DEMs generated from the SAR measurements after the eruption with a DEM generated from the laser scanner measurement before the eruption. Fig. 3 shows a combined chart of the cross section of the crater (from northeast to southwest) modified by using the results of each measurement.

The chart of the September 16 measurement shows that the highest point of the lava mound is about 2,380m, which is about 120m below the lowest point of the crater wall. By subtraction of DEMs, the amount of lava ejected at the eruption was calculated as approx. 9×10^5 m^3, and the thickest part of the lava mound was approx. 65m.

With the chart of the October measurement, the amount of lava ejecta was recognized to be increased to 2.1×10^6 m^3, pushing up the lava thickness to 75m. The peak of the lava mound was 2,430m, approx. 70m below the crater wall edge. It is also calculated the amount of lava ejection during those measurements in September and October was approx. 1.2×10^6 m^3.

The chart of the December 15 measurement shows a small part of the crater bottom was raised by about 20m, however, the other part was sunken by 10 to 15m. It is also recognized that the lowest point of the bottom is 2,360m, that is approx. 10m lower than the measurement on October 22.

In order to evaluate the accuracy of DEM generated from SAR measurement, we compared a SAR DEM with a laser scanner DEM of the outer slope of the crater where no terrain change is recognized. The results of evaluation are shown in Table 2. According to this evaluation, the relative accuracy of height measurement by SAR is estimated as approx. 2 to 4m. This is considered to be accurate enough for the detection of terrain in a volcano crater.

Table 2 Difference between DEMs by AirSAR Interferometry and Laser scanner measurement

Date	S.D. of difference (SAR v.s. Laser scanner)
September 16	2.03m
October 22	4.16m
December 15	2.91m

3. Summary

By the series of measurements of Asama volcano, it is proved that AirSAR is effective in observing terrain under volcanic fumes, where ordinary photography is unavailable. Also, repetition of measurements provided useful information about the gradual change of crater condition, and this will make possible prediction of a critical situation. Fortunately, this volcanic event of Mt. Asama has not become very serious; however, it is necessary to continue observing its activities by using AirSAR.

References

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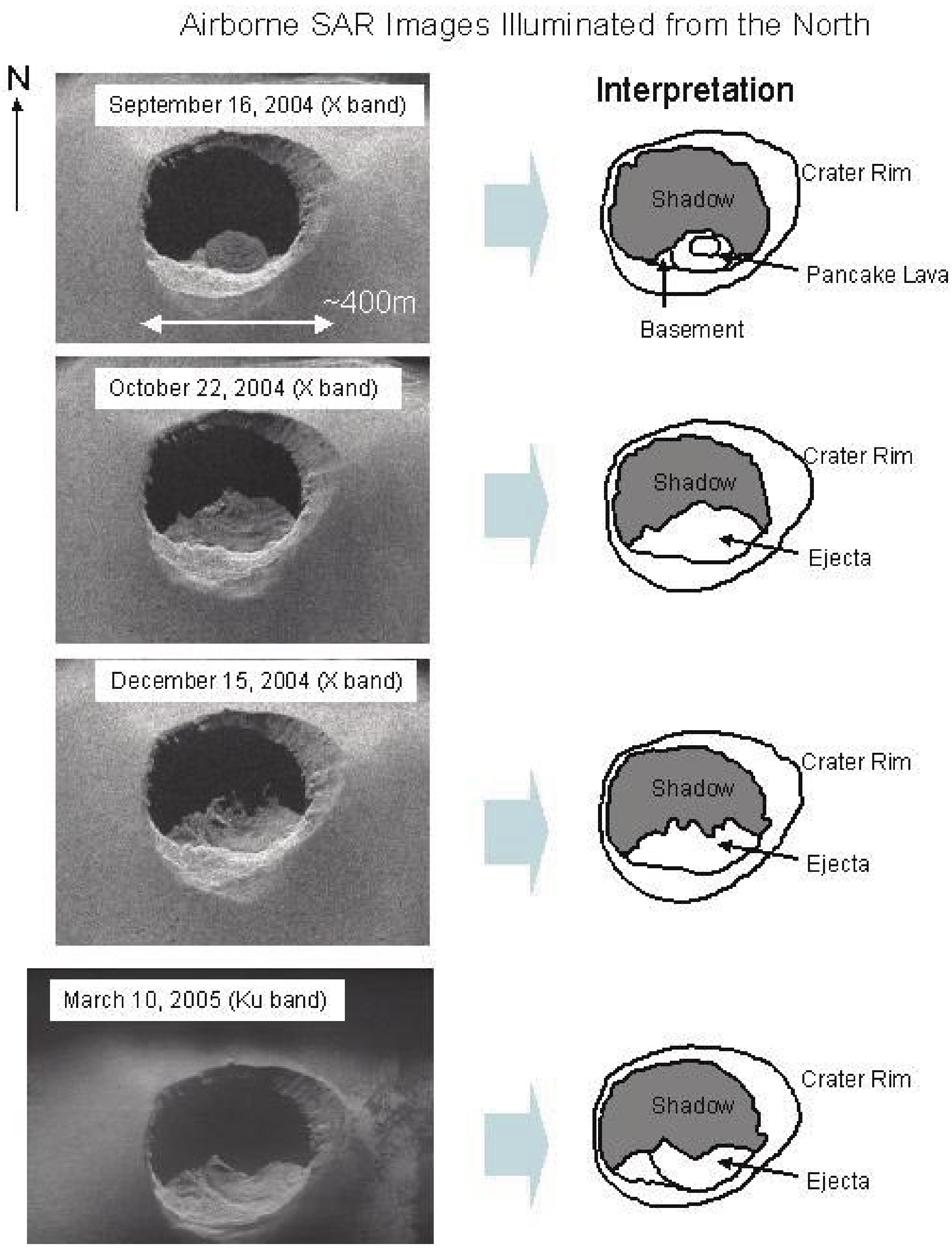

Fig. 2 Backscatter amplitude images in and around the summit of the Asama volcano obtained from Airborne SAR measurements on September 16, October 22, December 15, 2004 and March 10, 2005 (left) and schematic interpretations (right) .

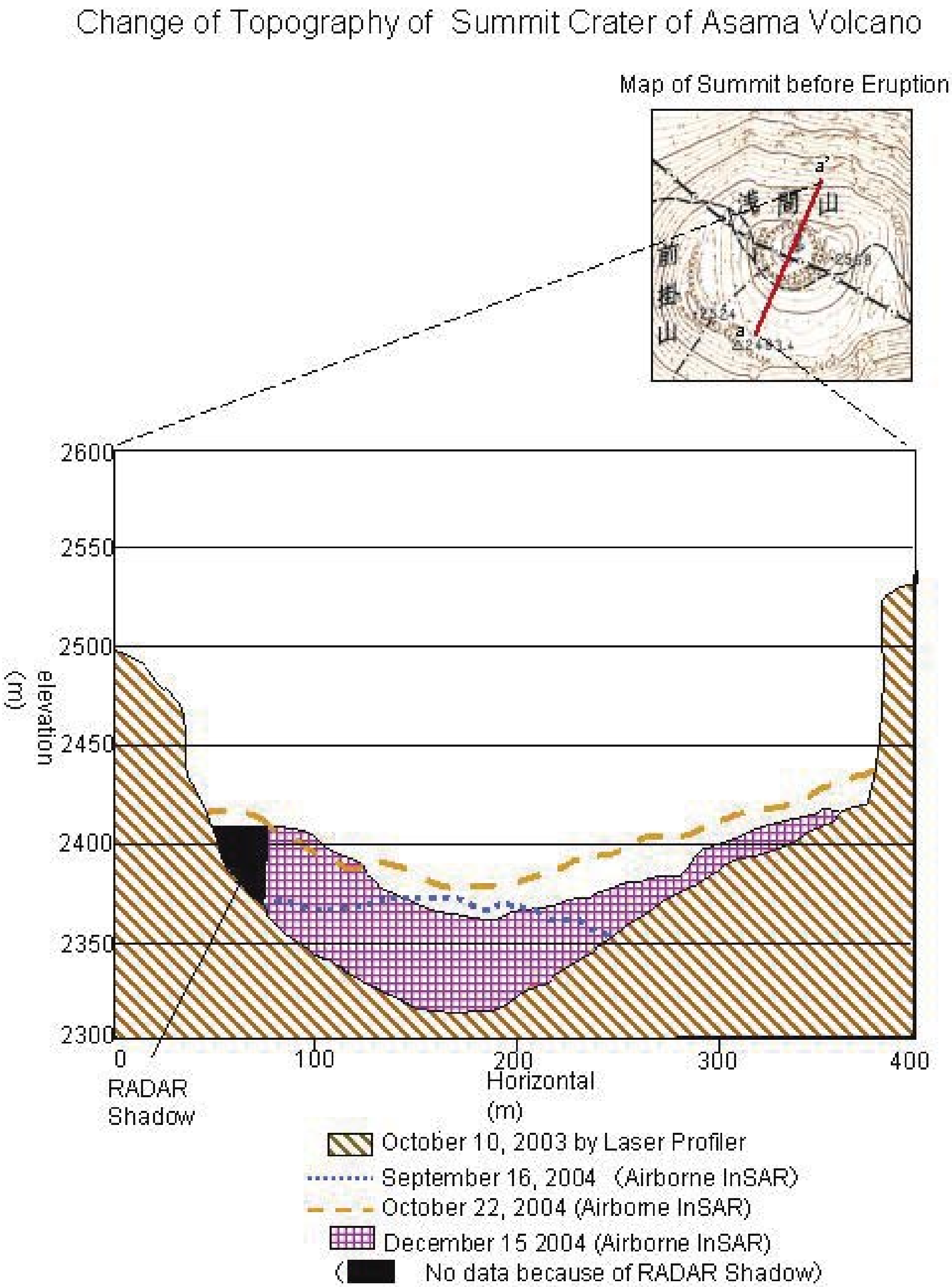

Fig. 3 Change of topography in the summit crater of the Asama volcano derived from DEMs obtained by the repeated AirSAR Interferometry and laser scanner measurement of October 2003.