ESTIMATION OF GROUND MOVEMENT CAUSED BY THE 2000 ERUPTION OF USU VOLCANO, FROM THE GEOMORPHIC IMAGE ANALYSIS OF LIDAR DEMS

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Commission VIII, Working Group 1

KEY WORDS: Volcano, DEM, Image Matching, Monitoring, LIDAR

ABSTRACT:

The efficient measurement of the small-scale ground deformation caused by an eruption over a large area is difficult. Mukoyama (2009) developed a new method for extracting the vector of ground displacement by applying the image-matching analysis technique to the visual image of the geomorphic quantity. In this study, we used the particle imagine velocimetry (PIV) method for image-matching analysis in a volcanic field. For image matching, we created a slope gradation map from a 10m DEM before (30 Mar 2000) and after (22 Jun 2000) the eruption. We used this to estimate the small displacement in the large-scale ground deformation. It became clear that the center of the movement in the horizontal direction was located at the northwestern foot of Mt. Nishiyama. The deformation that spread radially from there was also detected. This tendency was also seen in photogrammetric analysis data (Suto et al., 2002) and in matching SAR images (Tobita et al., 2001). An advantage of this technique during a time of disaster is that analysis can be conducted quickly. Analysis of this object range (2.5km × 3.3km) required approximately 1 minute. When a volcano is active, the data needed for a specific place may not be immediately available. As such, the improvement of prior data and the construction of a network and its effective utilization are important. We are confident that this method is effective for tracking the transitional deformation of volcanic edifices, etc.

1. INTRODUCTION

1.1 Background

When a volcano is in an active phase, one can observe various surface phenomena in the behavior of the magma in the basement. When measuring the ground deformation in three dimensions, it is very common to find a change in the arbitrary point by using GPS observation and photographic measurement. Using these techniques, a local change in the arbitrary point is compassable but it is difficult to determine the surface ground deformation over a large area.

Using the SAR interferometry method, several-centimeter precision in the surface ground deformation is compassable. However, data on large-scale deformation that exceeds the detection limit is difficult to extract. Tobita et al. (2001) extracted the surface ground deformation by matching the SAR image to overcome the problem of the aforementioned SAR interferometry method. Because of the revisit time required for the SAR images and other technical problems, however, the data may not be available when needed (Table 1).

Given these issues, the development of a technique that can quickly determine the ground deformation on the basis of either a SAR image or other surface deformation data is necessary.

1.2 PIV method (numerical geomorphic image velocimetry)

Mukoyama (2009) developed a new technique called numerical geomorphic image velocimetry that uses the particle imaging velocimetry (PIV) method (Figure 1). It can extract the vector of ground displacement by applying the image-matching analysis technique to the visual image of the geomorphic quantity.

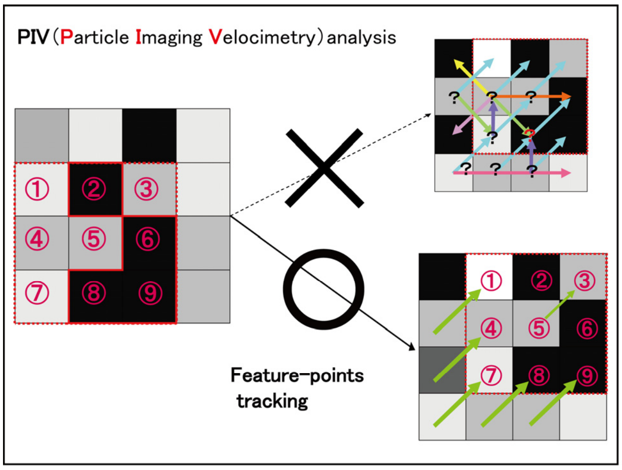

Figure 1. PIV method

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Table 1. Comparison with similar study (limited to the active volcano area)

	Ground control point survey	Aerial photogrammetry	SAR	This study*
Data type	Point data	Multipoint data	Surface data	Surface data
Ground control point	○ Necessary	○ Necessary	× Unnecessary	× Unnecessary
Large ground deformation analysis	○ Possible	○ Possible	× Impossible	× Impossible
Large ground displacement analysis	○ Possible	○ Possible	○ Possible	○ Possible
Advantages	○ Consecutive ground deformation is compassable.	○ If there is a landmark object that can be distinguished in a photograph, the fluctuation vector of the point will be analyzable. ○ Even if the volcano is active, one does not have to enter the field.	○ It can measure a wide area with high density. ○ Not affected by the climatic conditions (clouds or fog) or volcanic fumes. ○ Even if the volcano is active, one does not have to enter the field. ○ It permits periodic cyclic observation. ○ A three-dimensional component of ground deformation is acquirable.	○ It can measure a wide area with high density. ○ Even if the volcano is active, one does not have to enter the field. ○ If there is DEM, it can analyze it within one hour. ○ A three-dimensional component of ground deformation is acquirable.
Disadvantages	× If the GPS is destroyed by the eruption, measurement is not possible. × GPS installation cost is very high. × If the volcano is active, installation of GPS or field measurement is difficult.	× It is easily affected by climatic conditions (clouds or fog) or volcanic fumes, vegetation changes and sedimentation of ash.	× A geometric distortion occurs to the image × Revisit time is a few days. × It is easily affected by vegetation change or the sedimentation of ash.	× Affected by climatic conditions (clouds or fog) and volcanic fumes. × It is easily affected by vegetation change or the sedimentation of ash.
Data resolution	Several mm～Several dozen cm	Several m～About 10m	About several m	Several dozen cm～About several m
Data verification	△ Need time.	○ If the original photograph is saved, it is possible to conduct verification again.	○ Using the image information, it is easy to extract and inspect the error.	○ Using the image information, it is easy to extract and inspect the error.

* In case of using a DEM generated from LiDAR Data

The distinct advantages of this technique are as follows:

- Neither mapping for the measurement nor selection of specific characteristics for tracking is needed. Moreover, the ground displacement can be calculated from many points at random.
- In image-matching analysis, the displacement of approximately one-tenth the size of a pixel is usually calculated by subpixel interpolation (Figure 2).
- Analysis of this object range (2.5km × 3.3km) required approximately 1 minute.

This technique was applied to the measurement of the ground deformation at the Iwate-Miyagi Nairiku earthquake (2008). A slope map made from 2m mesh DEMs before and after the earthquake was used for image matching (Figure 3).

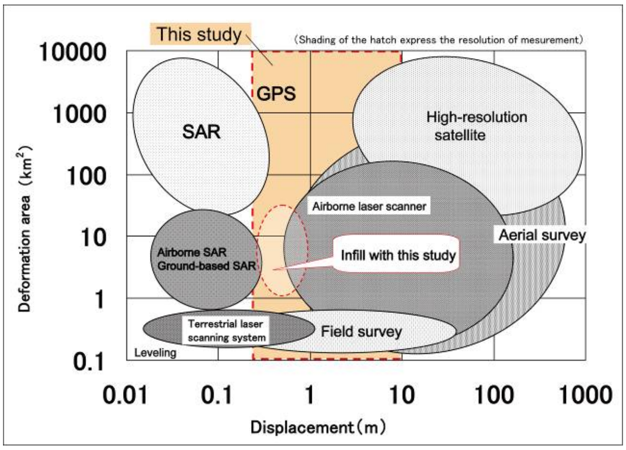

Figure 2. Comparison with general measurement technique

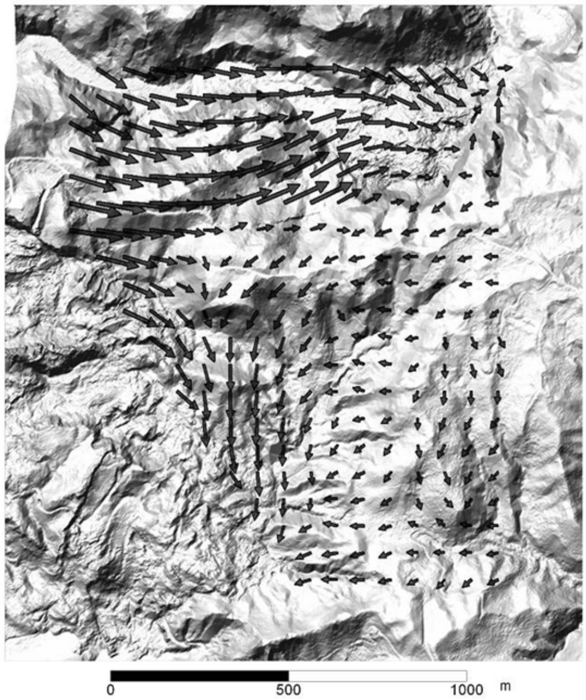

Figure 3. Estimation of ground deformation caused by the Iwate-Miyagi Nairiku Earthquake 2008 (Mukoyama, 2009)

Using this, the small movement of a large-scale mass movement was able to be estimated. Additionally, the movement direction of the ground surface was correctively calculated by adding the reference point data of wide-area crustal deformation. In the northern part of the investigation area, a large horizontal movement component was recognized in the southeast–east direction. The maximum quantity of displacement was approximately 5.2m. Mukoyama (2009) assumed a grid size of 2m × 2m to one pixel in this technique. Therefore, it can be speculated to calculate a displacement of approximately 20cm. The error of the topography measurement, however, is approximately ±30cm. Considering other errors, it is able to extract the quantity of displacement as approximately ±50cm.

1.3 Measurement in an active volcanic field

In general, when measuring surface deformation in an active volcano field, it is necessary to carefully consider the following points:

- Because it is difficult to install ground control points, the remote-sensing technique is needed.
- In the case of observation in an emergency, low-cost measurement and quick results are expected.
- Detailed topography data from before and after the eruption are necessary to examine surface deformation.

We believe that the PIV method overcomes these problems. As a case study, we apply this method to the measurement of the ground deformation in the 2000 eruption of the Usu volcano in northern Japan. Using this technique, we examined whether or not it could determine the regional ground deformation as a result of the volcanic activity and then compared the results with a similar study.

2. THE USU VOLCANO 2000 ERUPTION

2.1 Outline of Usu volcano

The Usu volcano is situated on the southern rim of the Toya caldera in western Hokkaido (Figure 4). Its highest peak is approximately 700m above sea level. Its base is approximately 6km in diameter. Two lava domes, Mt. Kousu and Mt. O-usu, are located within the summit crater, which has a diameter of approximately 2km. The Usu volcano has a lava dome, cryptodome growth, and strong precursory seismicity.

2.2 The 2000 eruption

On the afternoon of March 27, 2000, the number of small earthquakes under the Usu volcano began to increase. This seismic activity rapidly intensified and reached a peak on March 30. The eruption started at the northwestern foot of the volcano on the afternoon of March 31 under a decreasing trend in seismicity. The majority of earthquakes took place more than 4km below the southern part of the Usu volcano.

Localized upheaval around the crater area continued for about four months and resulted in a new hill that that was 70m higher than the original topography. A comparison of aerial photographs taken before and after the eruption revealed that the total upheaval due to the intrusion of the cryptodome was 60 to 75m (Suto et al., 2002; Koarai et al., 2002). The position of the center of upheaval was initially at the southwestern bottom of Kompirayama (from 30 Mar. to 3 Apr. 2002). The location of the source producing the displacement field was also examined. The center of upheaval moved to the west from 3 Apr. to 26 Apr. 2000 (Suto et al., 2002). Miura and Niida (2002) suggested by means of aerial photograph interpretation that the formation of the cryptodome was due to two-stage growth, consisting of the initial dike intrusion and subsequent shallow inflation and lateral extension of magma from the dike tip.

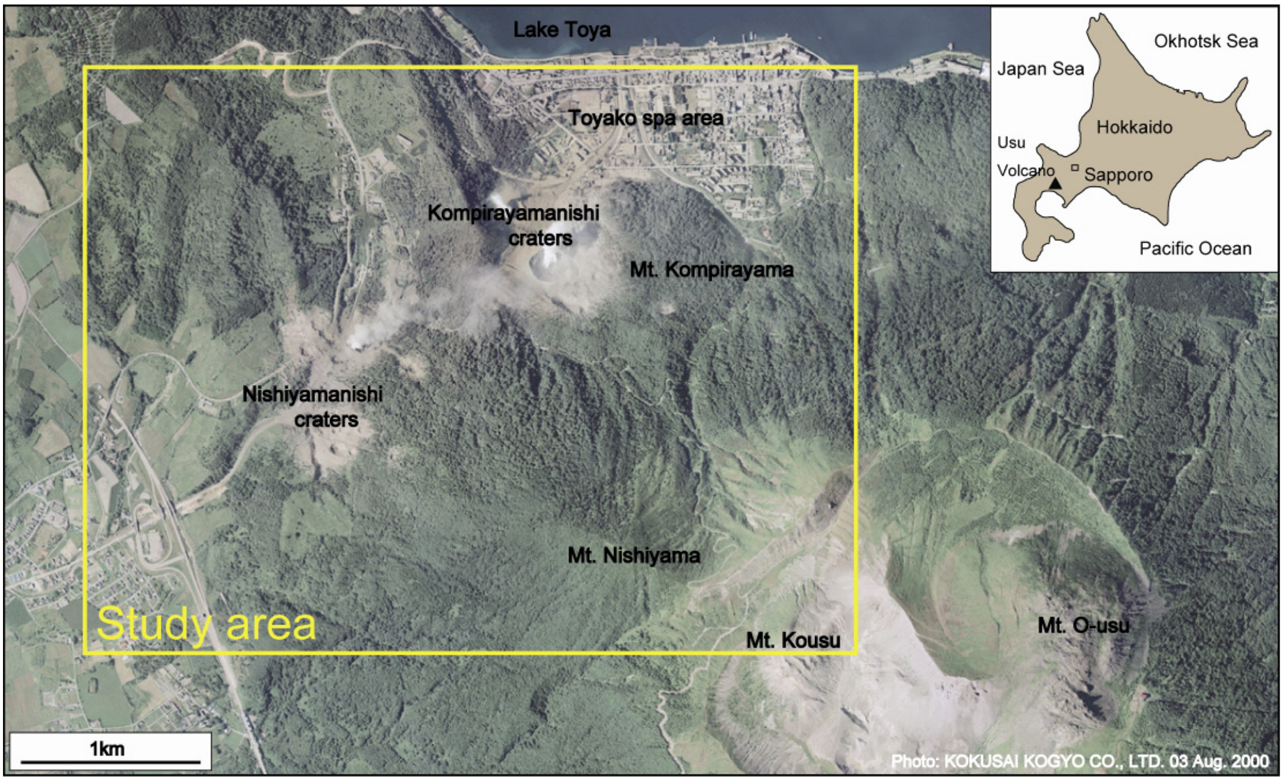

Figure 4. Location of the Usu volcano

Table 2. A summary of the 2000 eruption of the Usu volcano (after Ui et al., 2002)

Active phase	Time period	Activity features
Precursory phase	27 - 31 Mar. 2000	Earthquakes were felt frequently. After the peak, the seismic activity decreased on 31 Mar. A normal fault appeared in the crater floor and at the foot of Mt. Nishiyama; a small fault appeared lakeside
Start of eruption	31 Mar. 13:07 - 4 Apr. 2000	The first and largest phreatomagmatic began at the northwestern flank of Mt. Nishiyama. It began with the intermittent release of black smoke mixed with volcanic ashes and then shifted into a Cock's tail type smoke. A small pyroclastic surge was occurred from the base of the volcanic column. A group of two craters formed; volcanic bombs were ejected from one and were projected 1.2km. A fault begins to form around the Nishiyama crater group.
Growth of the cryptodome	4 Apr. - Mid-Apr. 2000	Smoke of Cock's tail type was intermittently discharged and a hot mudflow occurred from the crater. A hot mud flow overflowed into the western part of Lake Toya-ko hotsprings from April 9 to 10. The crater group was gradually distributed over the northwest side. The amount of ash fall decreased rapidly. The area around the Nishiyama crater group rose quickly while forming a fault complex.
Eruption decline phase	Mid-Apr. - Aug. 2000	Explosion and infrasonic fumes were high at the crater bottom. No new craters were made. The upheaval slowed and finally stopped.
Geothermal active phase	After Aug. 2000	Steam continues to emerge from three craters. Geothermal activity continues to be remarkable in parts of the Nishiyama crater group until spring 2001.

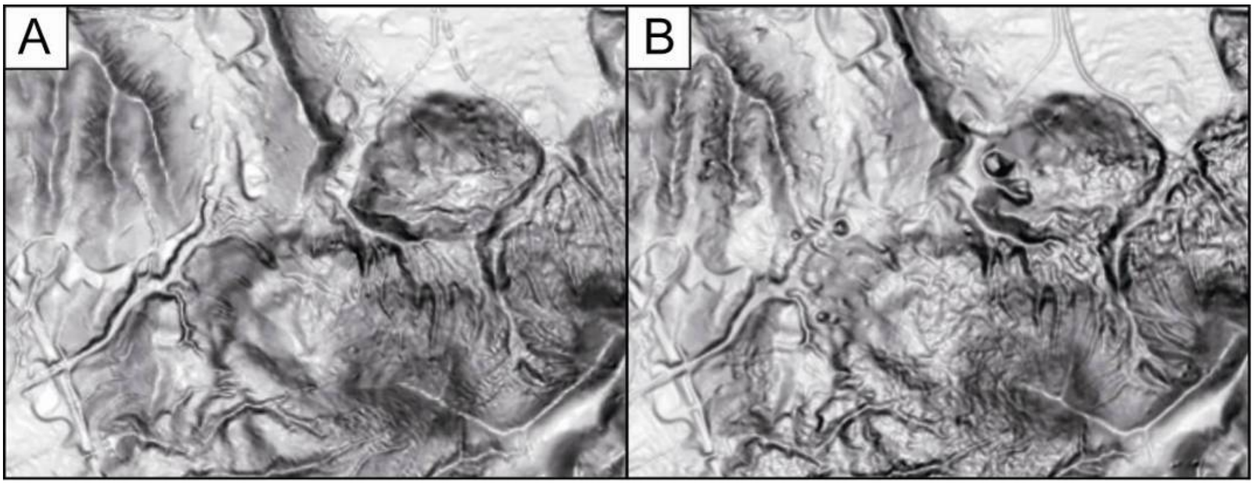

Figure 5. A pair of slope gradation maps made from two periods of DEMs for PIV method image-matching analysis
(A: Made from an aerial photograph taken 30 Mar. 2000 and 1/5,000 topographical maps
B: Made from airborne laser scanner data taken 22 Jun. 2000)

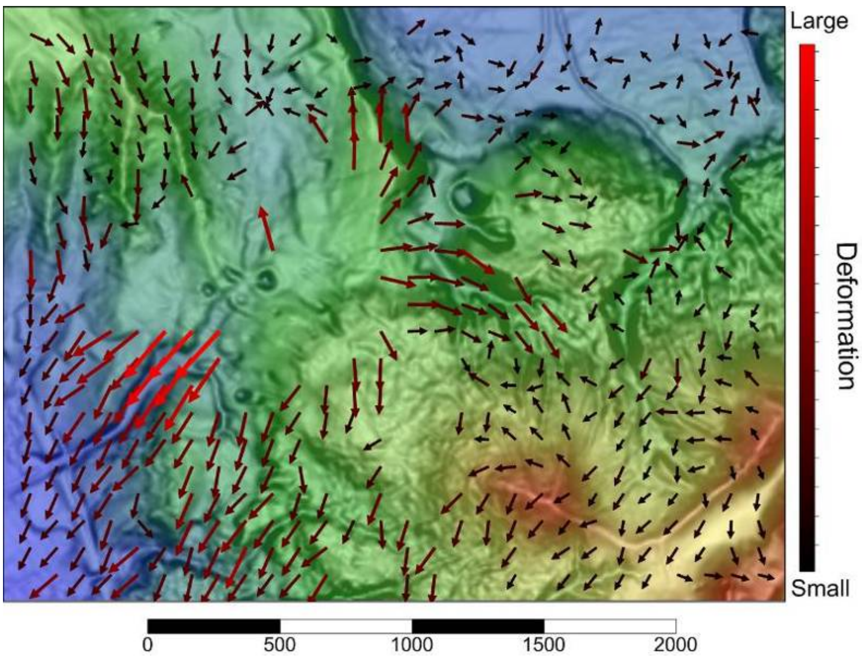

Figure 6. Movement vector of the ground surface calculated by PIV image analysis

3. ANALYSIS

3.1 Geomorphic data

The DEM data before the eruption was based on an aerial photograph taken 30 Mar. 2000 and 1/5,000 topographical maps (Figure 5A). The data after the eruption, based on airborne laser scanner data (with a grid size of 2m), was taken 22 Jun. 2000 (Figure 5B). We made a slope gradation map from 10m DEM before and after the eruption for image matching and conducted PIV analysis.

3.2 Result

The small displacement in the large-scale ground deformation was able to be estimated. It became clear that the center of the movement in the horizontal direction was located in the northwestern foot of Mt. Nishiyama. The deformation that spread radially from there was also detected. The maximum deformation in the horizontal direction was 31m. This tendency was also seen in photogrammetric analysis data of 3 April 2000 and 26 April 2000 (Suto et al., 2002) and the result of image matching SAR images of 3 April 2000 and 27 April 2000 (Tobita et al., 2001).

4. CONCLUSION

High-resolution DEM is very useful as basic data for investigation and has multiple purposes. In the near future, the area covered by high-resolution DEM will likely continue to increase by airborne laser survey, etc. When a volcano is active, the data on a certain place may not be immediately available. As such, the improvement of prior data and the construction of a network and its effective utilization are important. We believe that this method is effective for tracking the transitional deformation of volcanic edifices, etc. Further investigation is required in the future to determine the most suitable analysis image (image type and resolution) to analyze ground deformation.

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