RESEARCH ON MONITORING OF VOLCANIC DEFORMATION USING SAR INTERFEROMETRY

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1. INTRODUCTION

Crustal deformation is one of important information for understanding of magma behavior under the volcano. We are monitoring such deformation at volcanic observation stations which have GPS, tiltmeter, strainmeter, and so on. However it is not often enough for its full understanding because of complexity of its spatial distribution. Since constructing denser observation network is not realistic, we want to utilize interferometric synthetic aperture radar technique (InSAR) for covering an insufficiency of the observation density. InSAR is one of tools which can detect specially detailed crustal deformation, and has been used in crustal deformation studies of worldwide volcanoes. However InSAR is usually disturbed by some noise sources, the atmospheric, the ionospheric, and so on. Such noise obscures crustal deformation signal, and sometimes causes a misinterpretation for crustal deformation.

Recently numerical weather model with high precision is available, and the simulation of atmospheric delay using its result came to be able to reduce the atmospheric noise precisely. Ozawa and Shimizu [1] obtained the accuracy of 1.3cm in 1-sigma confidence in a case study of the atmospheric delay simulation in Mt. Fuji, the highest mountain in Japan. However it is not always enough for understanding of volcanic activity. Then InSAR time-series analysis such as small baseline approach (SBAS) [2] is used recently. Especially, SBAS approach can obtain deformation time-series by simple least-square method, and then was used in many researches.

Basically, SBAS approach uses interferograms obtained for single orbit path, and reduces a noise which depends on a condition of observation time by only the effect of smoothing. Then advanced InSAR time-series analysis with additional noise reduction effect will enable us to detect more precise deformation and to understand more detailed magma behavior. Moreover SBAS approach has a problem that interferograms by different observation modes and/or by different SAR sensors cannot be connected directory. For resolving such problem and for improving accuracy of deformation detection, we devised InSAR time-series analysis using interferograms for multiple observation modes. In this study, we propose this new InSAR time-series approach, and demonstrate its usefulness from case studies in Japanese volcanic islands.

2. INSAR TIME-SERIES ANALYSIS

A certain area is included in several SAR scenes by different orbits, different offnadir angles, and different SAR sensors. It means that an area is observed several times in a certain period. The idea of this analysis is estimating deformation time-series from interferograms generated from them. Generally, slant-range changes obtained from InSAR is expressed by an inner product of deformation vector and unit vector of the incidence direction of radar. If slant-range changes by more than three different incidence directions are obtained, three-dimensional displacement vector can be estimated from them. However an observation for most present SAR sensors is carried out transmitting radar to the right-downward direction (right-looking), and the variation of the incidence direction is small in a direction close to north-south. Then sensitivity for its direction is low. Direction which is the lowest resolution is the perpendicular direction of the best fitted plane for all incidence directions (it is called "co-plane" in this paper). Fujiwara et al. [3] estimated two-dimensional component of deformation associated with M6.1 earthquake which occurred near the Mt. Iwate from JERS-1 interferograms for ascending and descending orbits. Our approach estimates their two-components by the least-square analysis. One of their components is horizontal component in co-plane, and it is almost east-west direction (it is called quasi-east-west (QEW) component in this report). Another one is vertical component, and it inclines 10 degree from the vertical to the south (it is called quasi-up-down (QUD) component in this report) in a case that interferograms for right-looking SAR is used. In this analysis, we estimate two-components of deformation for each epoch, dividing a whole estimating period by the specified time step. Additionally, apparent slant-range change due to error of a digital elevation model (DEM) appears on an interferograms. Then we can estimate time-series of slant-range change and DEM error from the least-square analysis. In a case that time-series of slant-range change is estimated from interferograms for single orbit path, it is the same as SBAS approach. In the analysis of this study, we estimate time-series of QEW and QUD components from multiple orbit interferograms. If many SAR images are available for all epoch, they can be estimated precisely by simple least-square analysis. But it is actually not. Therefore we use constraint that temporal change of deformation is smooth, and its strength is determined by minimizing Akaike Baysian Information Criterion [4]. Additionally, we strongly fix deformation in the first epoch to be zero to stabilize the solution.

3. A CASE STUDY IN IWO-TO

First, we present a result in a case study in Iwo-to volcano. Iwo-to is a caldera volcano located to 1200 km south from Tokyo (Fig. 1). It has a caldera with 10km diameter, and the resurgent dome appears on the sea surface. From geological research, 120m uplift in recent 100 years is suggested, and such huge uplift characterizes volcanic activity of Iwo-to [5]. Continuous GPS observation revealed that such huge uplift occurs in period when volcanic activity increases. Such an increase of volcanic activity started from mid-2006, and uplift reached to 1m in 2 years (Fig. 1). To gather information about such an increase of the volcanic activity, emergent observations and high frequent observations have been carried out by cooperation between Coordinating Committee for Prediction of Volcanic Eruption and JAXA. We applied InSAR to these data, and detected crustal deformation related to an increase of the volcanic activity. Obtained interferograms were adjusted to GPS displacements to reduce a long wavelength noise. Reference site is Haha-jima, located to 220km north-northeast from Iwo-to, and then obtained interferograms also shows crustal deformation relative to Haha-jima. Figs. 2 show obtained interferograms. Slant-range extension representing slight subsidence is found throughout Motoyama just before the increase of volcanic activity. On the other hand, slant-range shortening throughout the island is found on the interferogram after that. We estimate deformation time-series from these interferograms applying InSAR time-series analysis.

Fig. 3 shows obtained result, showing QUD and QEW components for 46 days in each epoch. In the first two epochs, uplift exceeding 20cm/46 days was obtained. After that, uplift rate decreases with time, but it re-accelerated from end of 2007. On the other hand, horizontal component is much smaller than vertical component. The uplift in the center is slow, and its shape is like a bowl. Along the west coast, steep gradient of uplift can be seen, and its location corresponds to the active fault. Actually, cracks were found in roads crossing the fault in this period. In this case, crustal deformation is very large, exceeding 1m in 2 years. Then this crustal deformation must be detected without noise reduction by time-series analysis. So, in next case study, we attempt to detect smaller crustal deformation.

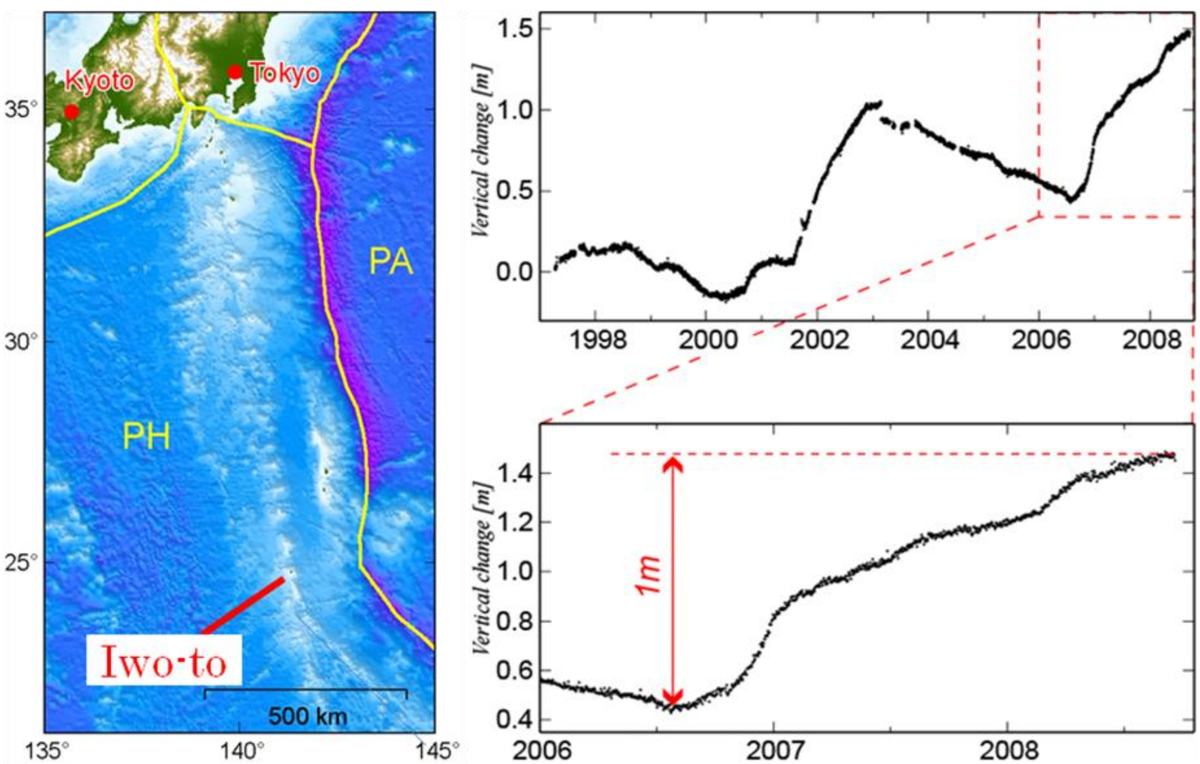

Fig. 1 Location of Iwo-to and uplift observed at 960604, GEONET site

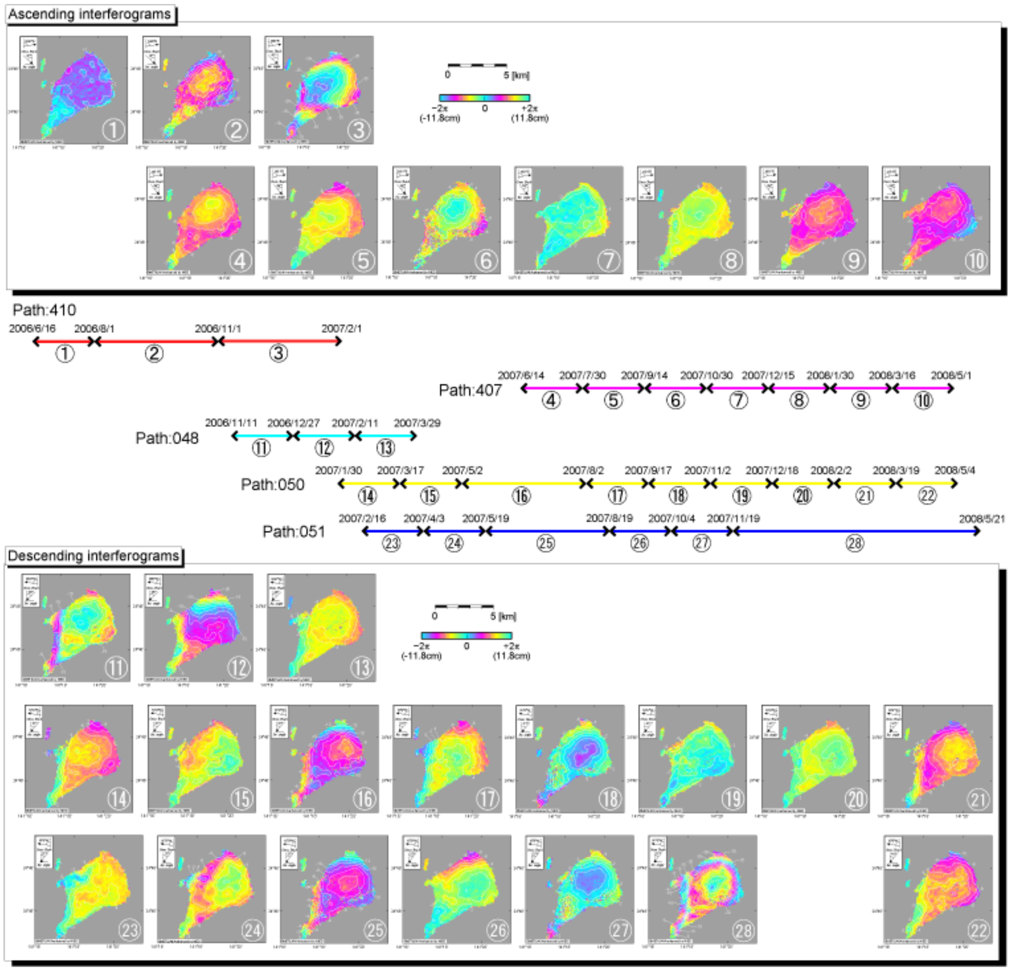

Fig. 2 Interferograms of Iwo-to generated from PALSAR data

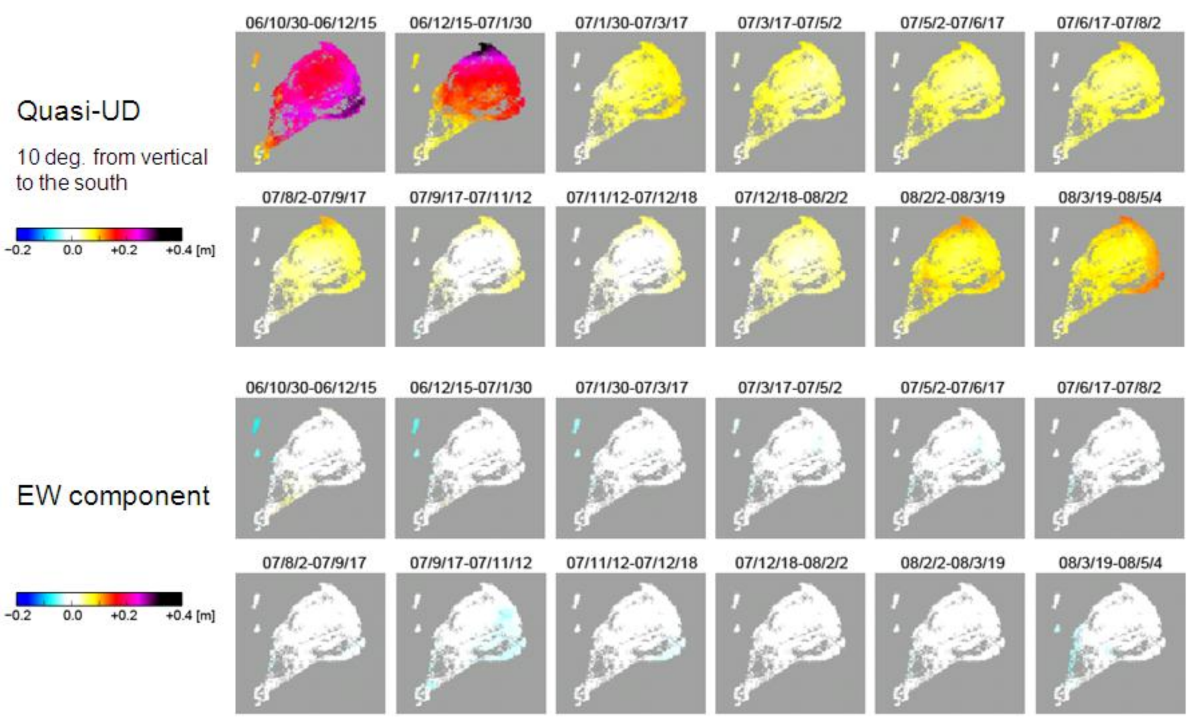

Fig. 3 Estimated time-series of QUD and QEW components.

4. A CASE STUDY IN MIYAKE-JIMA

In this section, we present a result in a case study in Miyake-jima volcano. Miyake-jima is located to 180 km south of Tokyo. In 2000 eruption, the summit suddenly collapsed just before the eruption, and a caldera with 1.6km diameter was formed. After that, a large amount of volcanic gas has been emitted from the caldera. Associating such volcanic activity, crustal deformation with a few cm/yr has been observed. In this case study, we attempt to detect time-series of such crustal deformation. In this analysis, we use SAR data observed from six orbit paths. Offnadir angles are 34.3 and 41.5 degree. In the generation of interferogram, we reduce the atmospheric noise using the simulation of atmospheric delay from the numerical weather model with 10km mesh released by Japan Meteorological Agency. Furthermore, we adjust interferograms to GPS displacements to reduce a long wavelength noise. Reference site is Mikura-jima, located to 20km south-southeast from Miyake-jima, and then obtained interferograms also shows crustal deformation relative to Mikura-jima. Fig. 4 shows a part of obtained interferograms. Actually, we use 232 interferograms in InSAR time-series analysis. From these interferograms, we

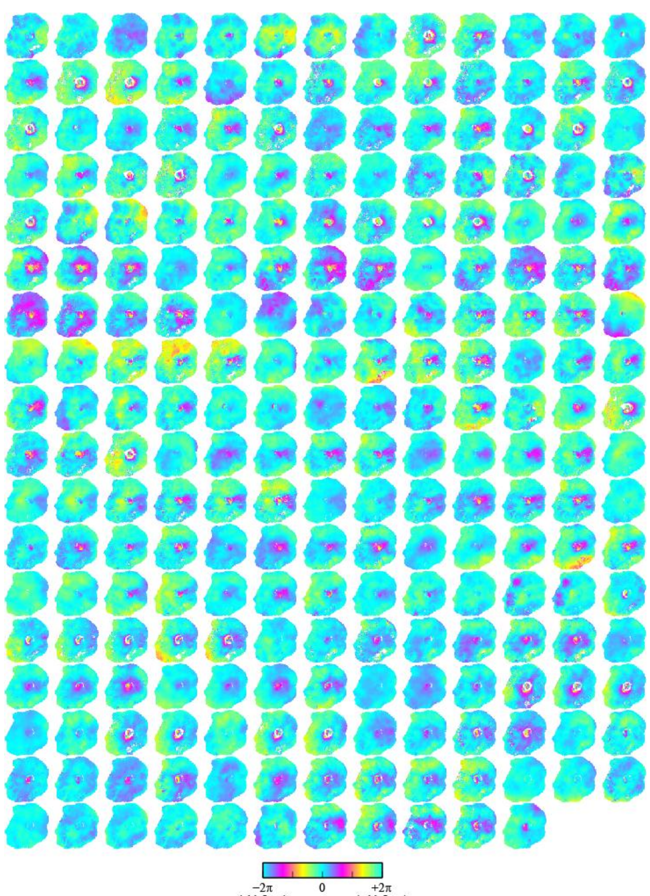

Fig. 4 Interferograms of Miyake-jima generated from PALSAR data

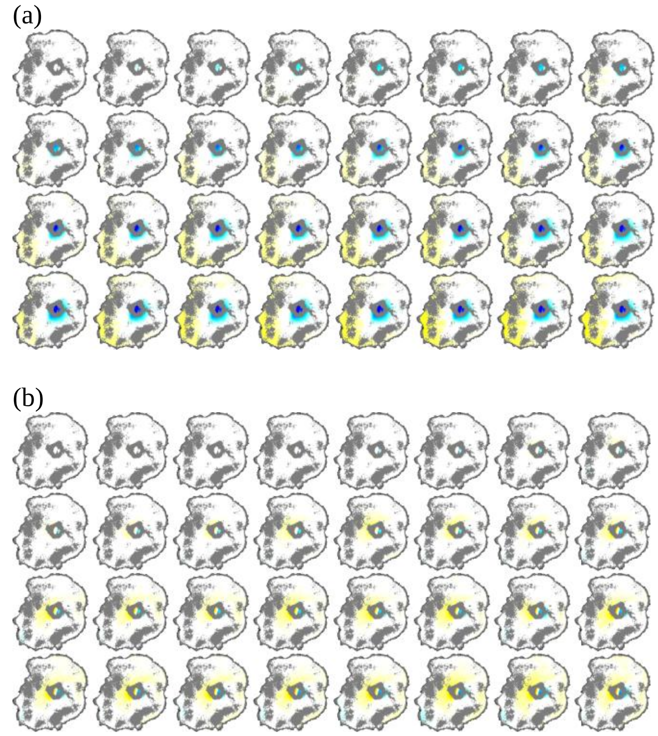

Fig. 5 Estimated time-series of deformation from July 2006. Time step is 46 days. (a) QUD component (b) QEW component

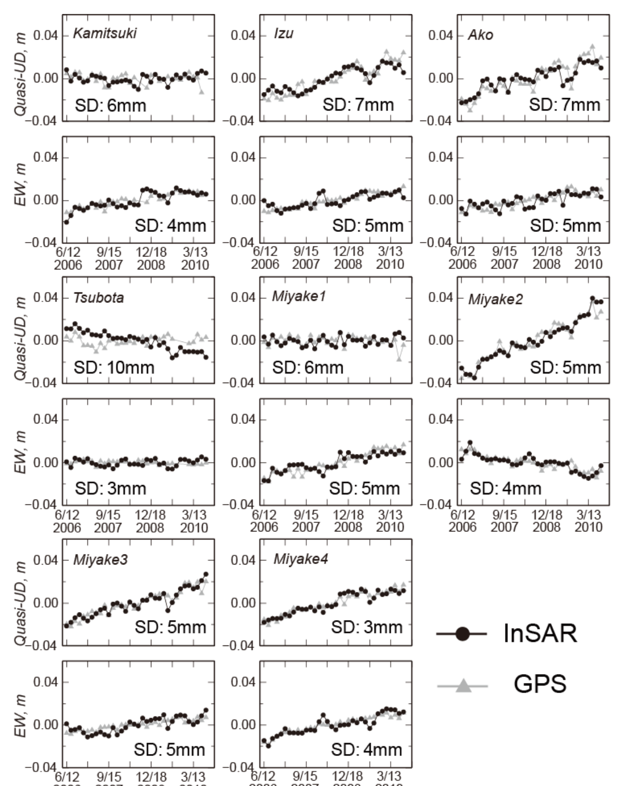

Fig. 6 Comparison between InSAR (Solid circle) and GPS (Grey triangle) displacements.

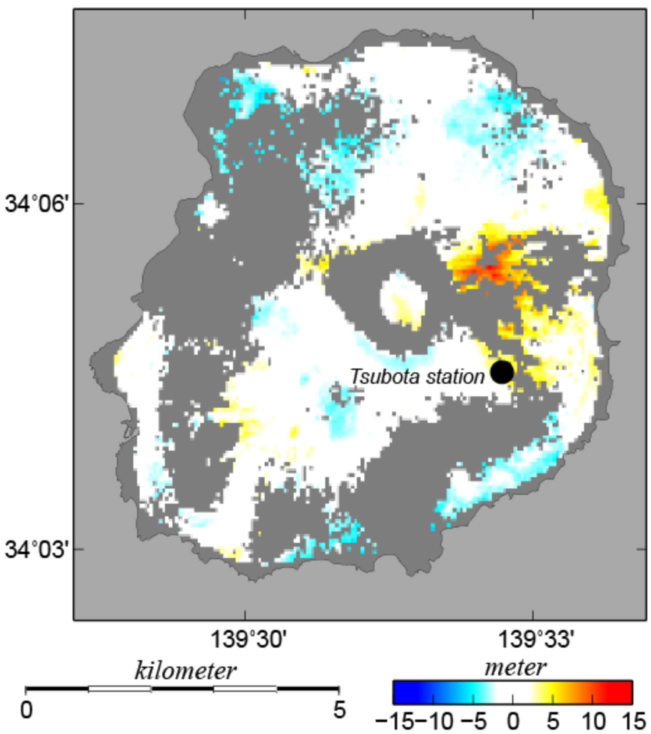

Fig. 7 Uplift observed by Iwo-to 1, GEONET site

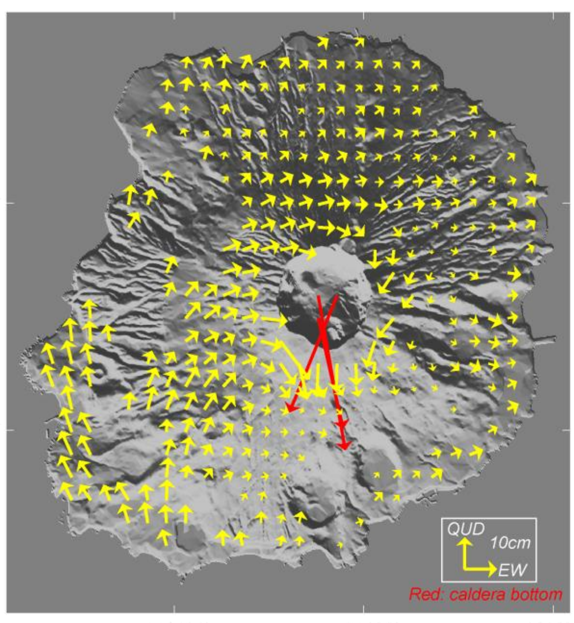

Fig. 8 Uplift observed by Iwo-to 1, GEONET site

estimated time-series of QUD and QEW components. Fig. 5 shows a result showing that crustal deformation increases as time progresses. Fig. 6 shows the comparison between InSAR and GPS displacements. At most of sites, these are consistent within 1cm (Fig. 6). At Tsubota station, the

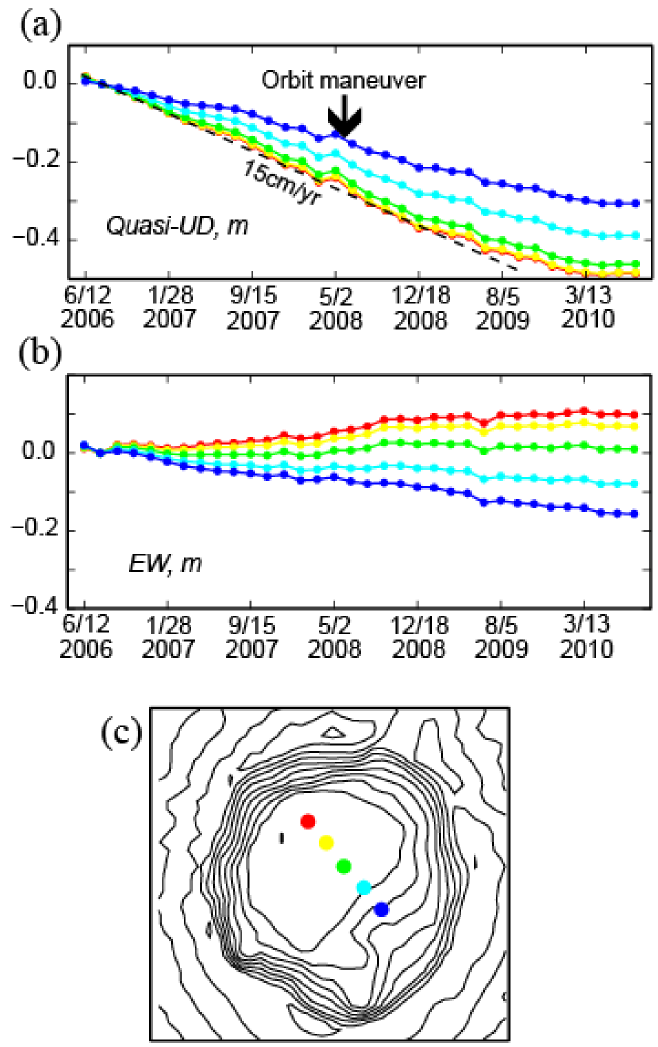

Fig. 9 Uplift observed by Iwo-to 1, GEONET site

trend doesn't agree. Its site is located the area where 10m DEM error was estimated (Fig. 7). Around this area, vegetation is dead due to volcanic gas, and the land slide has occurred in large area. InSAR must have detected such surface movement. On the other hand, GPS was fixed on ground, and therefore, we think that InSAR and GPS detected different movement.

Fig. 8 shows obtained crustal deformation for 4 years. Horizontal component of an arrow indicates QEW component, and vertical component indicates QUD component. Though eastward movement is seen in the whole of the island, it may be relative motion with respect to fixed point, Mikurajima. Pacific plate subducts beneath the Phillipine sea plate in 200km east of Miyake-jima, and we think it is its effect. Remarkable subsidence with contraction is found around the caldera, and uplift with 5cm is found around the west coast. Its temporal change is linear. Fig. 9 shows temporal change of deformation in the caldera bottom. The center of subsidence is shown by the yellow circle. Its speed was about 15 cm/yr until 2008. But it decelerated from early 2009, and it stops recently. It seems that its tendency is also seen in east-west component. According to earthquake observation by NIED, low-frequency earthquakes increased from the same period. We suspect that it relates to deceleration of subsidence, but more investigations are necessary to understand it.

5. SUMMARY

We estimate deformation time-series from interferograms obtained from multiple orbit paths. In the case study in Iwo-to, we detected a bowl-shaped uplift distribution. In the case study in Miyake-jima, estimated time-series agrees with GPS displacement within 1cm. And we found the remarkable subsidence around the caldera. Subsidence speed was constant until 2008, but it decelerated from early 2009. As mentioned in this report, ALOS/PALSAR mission is much contributing for understanding of volcano activity. In the future, monitoring of such deformation is important. Then we wish continuous L-band SAR mission PALSAR-2 and its follow-on.

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6. REFERENCES

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