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VERIFICATION OF INSAR CAPABILITY FOR DISASTER MONITORING - DETECTION OF VOLCANIC DISASTER BY MT.UNZEN -

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ABSTRACT: The authors conducted a verification study on the capability of interferometric SAR (InSAR) technology for disaster monitoring. The target of this study is the pyroclastic flows caused by the volcanism of Mt.Unzen, which continued to erupt and bring large physical and human damages to the surrounding areas from 1991 to 1995. JERS-1/SAR repeat-pass pairs acquired from Oct., 1992 to March, 1997 were used as the test data for interferometric analysis. We generated time sequential coherence images from JERS-1/SAR pairs with the time interval of one to six repeat cycles. From those coherence images, it was proved that the coherence in the regions during pyroclastic flows occurred are significantly lower than those after pyroclastic flows ceased. Therefore the coherence information obtained by InSAR was proved to be an effective parameter to detect pryroclastic flows as well as other disaster damages such as building collapse by an earthquake, which was already proved. In addition, we attempted to detect surface deformation patterns caused by pyroclastic flows. The detection of deformation in the pyroclasic flow areas was considered to be difficult in general because of significantly low coherence. However, for the data pairs with relatively short time interval, some deformation patterns were detected in the pyroclastic flow areas. In addition, the subsidence patterns around the lava dome were also detected by the data pairs observed after the pyroclastic flows ceased. From these experiments, InSAR technology can be recognized to have a high potential for disaster monitoring by satellite remote sensing.

1. INTRODUCTION

Recently the interferometric SAR (InSAR) technology has been widely recognized to be an effective and important tool to detect crustal deformation caused by volcanic eruption or earthquakes. In addition, the coherence information obtained by InSAR also has been proved to be effective to detect urban damages by earthquakes (Takeuchi *et al*, 2000, Yonezawa and Takeuchi, 2001). We conducted a verification study on the capability of InSAR for detecting damages caused by a volcanic eruption as the follow-on study of that on Chi-chi Earthquake in Taiwan presented at the last ACRS conference. Mt.Unzen (actually the name of volcano is Mt.Fugen) in Kyushu of Japan was selected as the target volcanic eruption. We examined the capability of the coherence information for detecting pyroclastic flows caused by the volcanic eruption and also the possibility for detecting surface deformation caused by the pyroclastic flows and by cooling and shrinking of the lava dome created by the eruption.

2. OUTLINE OF VOACANIC ERUPTION OF MT.UNZEN

The volcanic activity of Mt.Fugen, the main peak of Mt.Unzen, started with an earthquake swarm lasted for one year and followed by a phreatic eruption on Nov. 17, 1990. Phreatomagmatic eruption thereafter continued for half a year (Nov. 1990 - May 1991), and then a large amount of lava was successively extruded over a period of 3 years and 9 months to form a huge lava dome (May 1991 - Feb. 1995). This lava dome was very unstable and frequently collapsed to bring about many times of pyroclastic flows, whose number amounted to several thousands. Total 44 peoples were killed and 820 houses were burned by these pyroclastic flows. The extrusion of lava ceased finally in February, 1995, and followed by cooling and shrinking of the lava dome, the magma conduit and sinking down of the dome.

Fig. 1 shows the geology of Unzen Volcano and its surrounding area (the Shimabara Peninsula). The red colored region indicates the areas for the pyroclastic and debris flow deposits. Fig.2 shows the bird's eye view image of Unzen Volcano created from JERS-1/OPS image acquired on Dec. 9, 1993 combined with 50 meters DEM issued by Geographical Survey Institute (GSI) of Japan. The areas where the pyroclastic flows occurred are clearly indicated as very bright colors from the north-east to the south-east slopes of Mt.Fugen together with the lava dome created by the eruption.

3. TEST DATA

JERS-1/SAR repeat-pass data pairs were used as the test data for interferometric analysis. The data pairs used for the study are shown in Table 1. Total eleven data pairs with one to six repeat cycles from Oct. 1992 to Mar. 1997 were used.

Table 1. JERS-1/SAR data pairs used for the study.

No.	observation date combination	Observation interval	Baseline length*
1	1992/10/31 – 1993/04/25	176 days	363 m
2	1992/12/14 – 1993/01/27	44 days	404 m
3	1993/03/12 – 1993/04/25	44 days	463 m
4	1993/04/25 – 1993/07/22	88 days	718 m
5	1993/07/22 – 1993/12/01	132 days	11 m
6	1994/01/14 – 1994/02/27	44 days	336 m
7	1995/05/13 – 1995/06/26	44 days	116 m
8	1995/05/13 – 1995/09/22	132 days	123 m
9	1996/06/12 – 1997/01/18	220 days	44 m
10	1996/06/12 – 1997/03/03	264 days	108 m
11	1997/01/18 – 1997/03/03	44 days	152 m

*Actual baseline length indicates its perpendicular component to slant range direction.

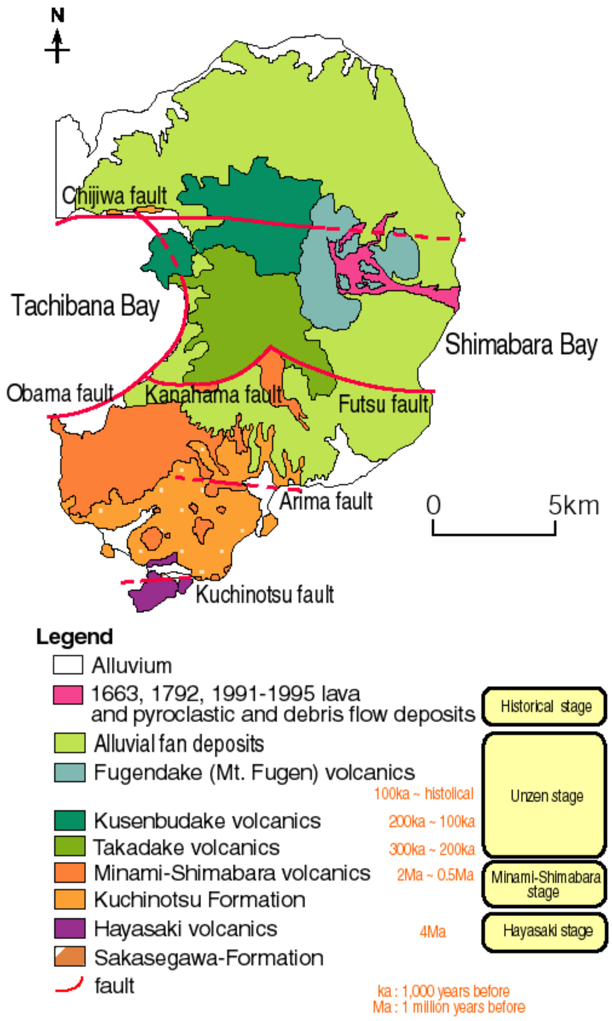


Fig.1. Geology of Unzen Volcano and its vicinity.
(Web site of Internet Museum of Kyushu University)

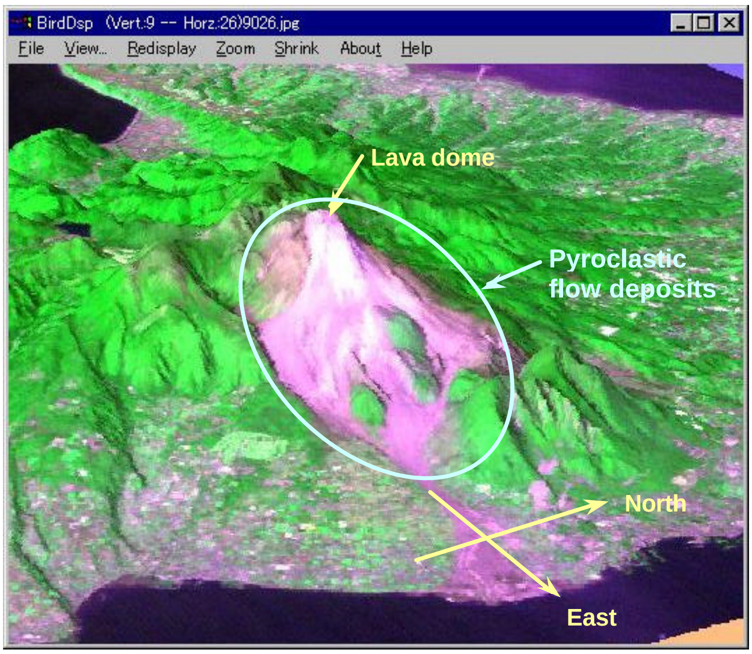


Fig.2. Bird's eye view image of Unzen Volcano by JERS-1/OPS on Dec. 9, 1993 combined with 50 meters DEM by GSI.
(JERS-1 data : MITI/NASDA retains ownership of data.)

4. DETECTION OF PYROCLASTIC FLOWS USING COHERENCE INFORMATION

Fig.3 (a) to (j) show the coherence images obtained from the data pairs in Table 1 from Pair-1 to 11 excluding Pair-9. These time sequential coherence images clearly indicate that relative coherence values in the pyroclastic flow deposit areas (indicated by a circle) change from lower values to higher values according to the time. In the period from Oct. 1992 to Dec. 1993, every coherence images even by one repeat-cycle data pairs ((b) and (c)) indicate that the areas corresponding to pyroclastic flow deposits shown in Fig.1 are significantly lower values of coherence than those in other landcovers, even in forest areas. On the other hand, four coherence images ((g) to (j)) after May 1995 indicate that the coherence values in the pyroclastic flow deposits are all higher than those of surrounding areas, even in the image by the longest time interval ((i) by six repeat cycles).

On the other hand, Fig.4 (a) to (d) show the time sequential intensity images of JERS-1/SAR data from Oct. 1992 to Mar. 1997. It is rather difficult to find the changes due to pyroclastic flows in these time sequential intensity images. This contrast between the coherence and the intensity images by JERS-1/SAR strongly suggests that the coherence information is very effective to detect the existence of pyroclastic flows. The reason why the coherence changes due to pyroclastic flows is considered to the fact that the landcover conditions when pyrocloastic flows often occurred were very unstable, while the landcover conditions became stable after the pyroclastic flows ceased.

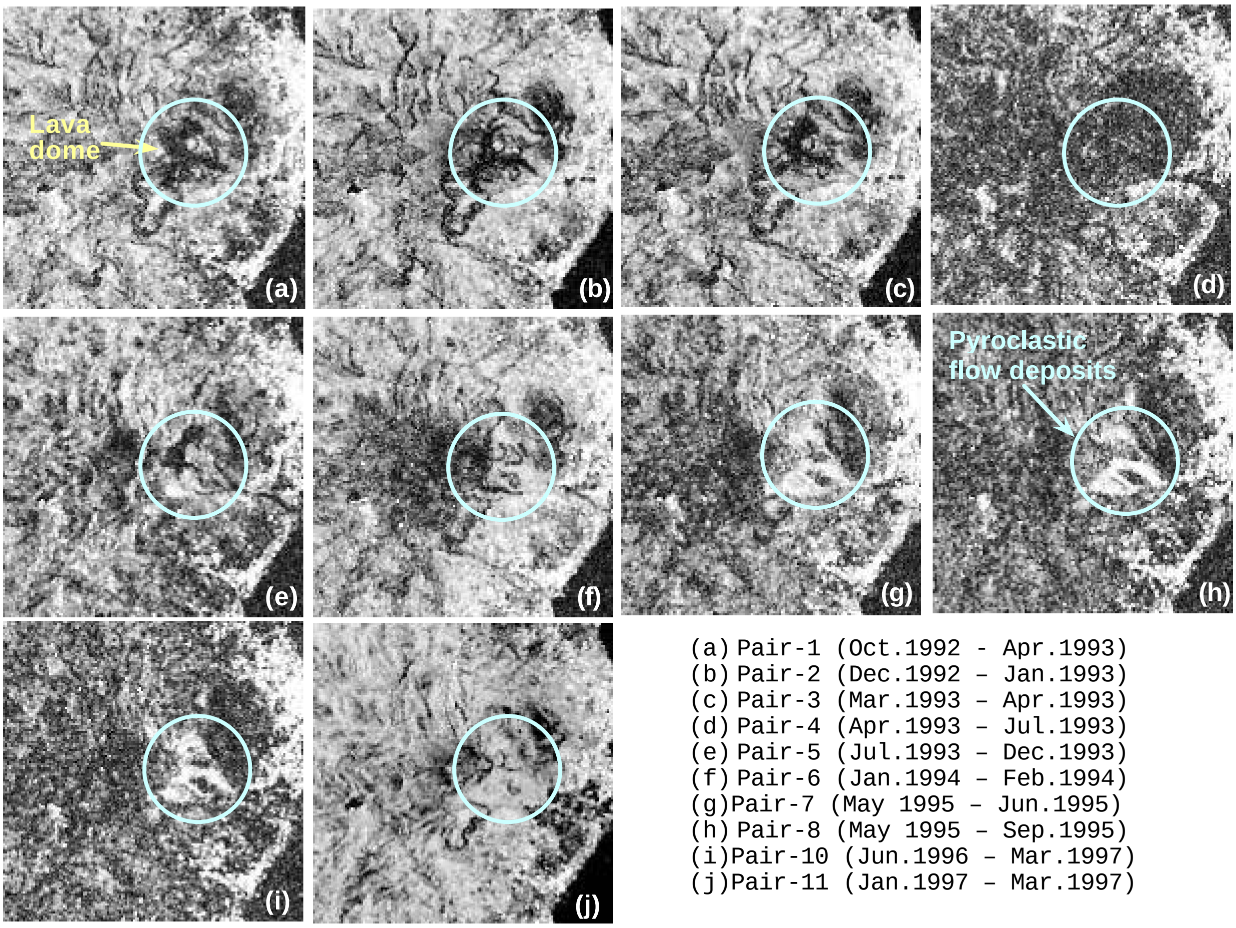
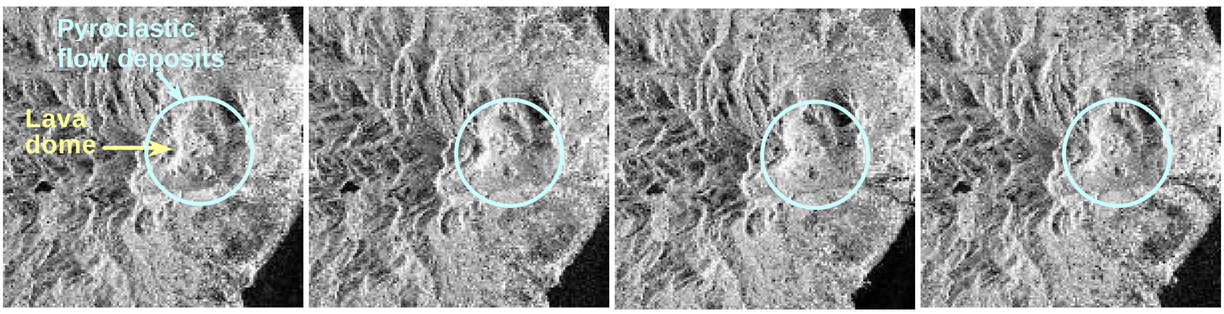


Fig.3. Time sequential coherence images by JERS-1/SAR data pairs (1 to 8 and 10 to 11) shown in Table 1.



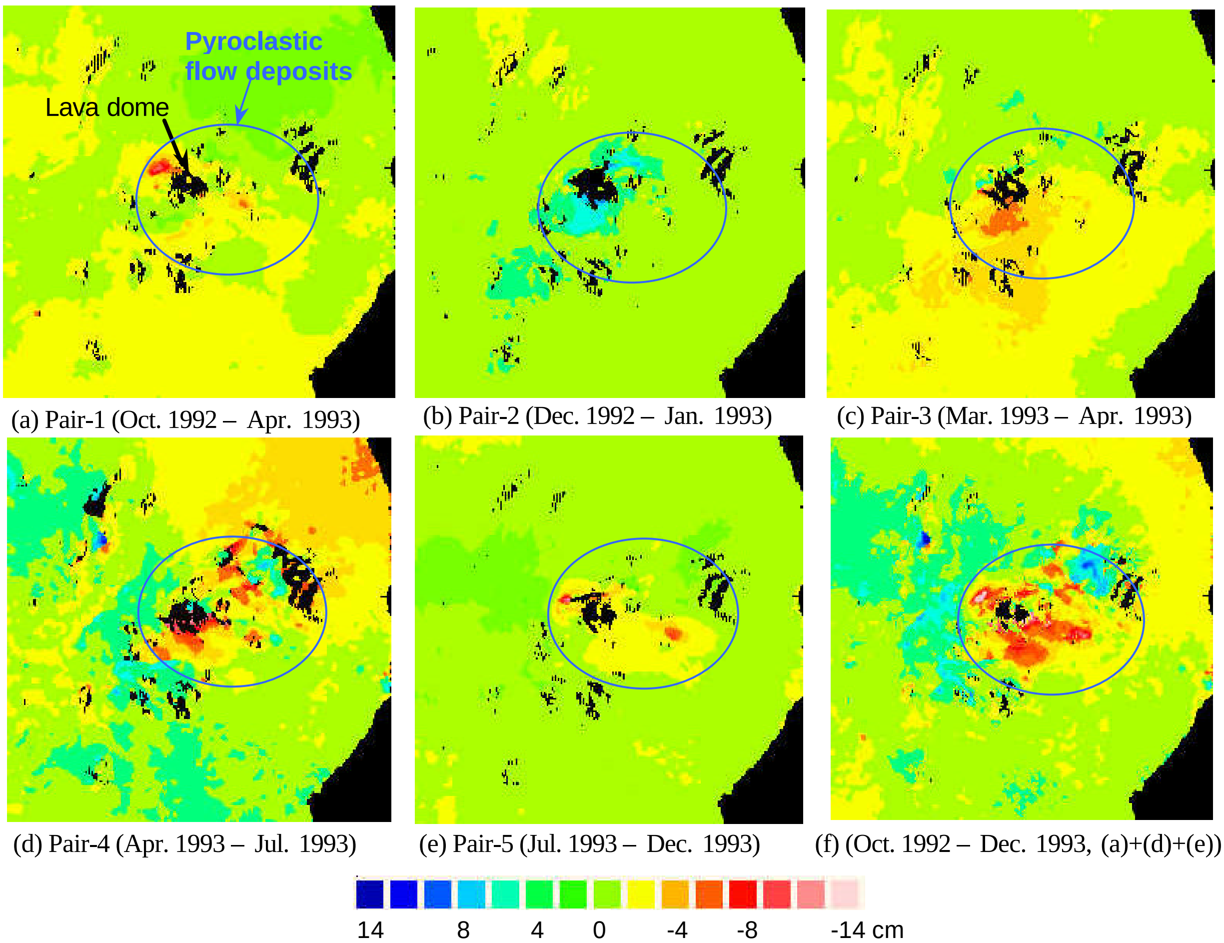
(a) Oct. 1992 (b) Dec. 1993 (c) Sep. 1995 (d) Mar. 1997

Fig.4. Time sequential intensity images by JERS-1/SAR from Oct. 1992 to Mar. 1997.

5. DETECTION OF SURFACE DEFORMATION BY DIFFERENTIAL INTERFEROMETRY

We tried to detect the surface deformation caused by the pyroclastic flows and by the post crustal movement after the pyroclastic flows ceased. As indicated in Fig.3, the areas where the pyroclastic flows occurred are generally in low coherence, and therefore, it is considered to be difficult to detect the surface deformation because of poor coherence. In addition, the principal idea to detect deformation by InSAR is that the surface backscatter is identical between the two times of repeat-pass observation, and if pyroclastic flows often occur during two observations, the landcover conditions are always changing and SAR backscatter is not identical any more. However, even in low coherence conditions, there might be some possibility to detect deformation by relative short interval data pairs. We tried to detect the surface deformation using five data pairs (Pair-1 to 5 in Table 1) through the common procedure for two-pass differential interferometry (DInSAR) using 3dSAR Processor by Vexcel Co. in U.S.A.. The 50 meters DEM by GSI was used to remove the topographic phase patterns from the differential interferograms. The effect by ground height sometimes remained in the deformation patterns even after the removal of the topographic phase, which might be caused by the radar phase delay by water vapor. This effect was removed again by using the result of regression between the deformation patterns and the height patterns.

Fig.5 (a) to (f) show the results of deformation patterns detected by DInSAR. The final one (f) was generated by accumulating the deformation patterns in (a), (d) and (e), which corresponds the partial periods of the total period from Oct. 1992 to Dec. 1993 respectively. In Fig.5 the lave dome is always indicated as black color, which means no deformation data is available due to extremely poor coherence. However, at the surrounding areas of the lava dome, some deformation patterns are recognized. Among the five data pairs from (a) to (e), the biggest deformation patterns are detected in (d) in the period from Apr. to July, 1993. From the report on Unzen volcanic activity (Kyushu Univ., 1999), this period corresponds to the period when the pyroclastic flows were most active during 1993, and the flows expanded to the north-east slopes as well as the east to south-east slopes (see Fig.6). The deformation patters in (d) indicates the coincident patterns as those in Fig.6.



[Deformation in slant range direction. Plus denotes the forward direction to satellite and minus the reverse.]

Fig.5. Surface deformation patterns detected by DInSAR from Oct. 1992 to Dec. 1993 during the pyroclastic flows were active.

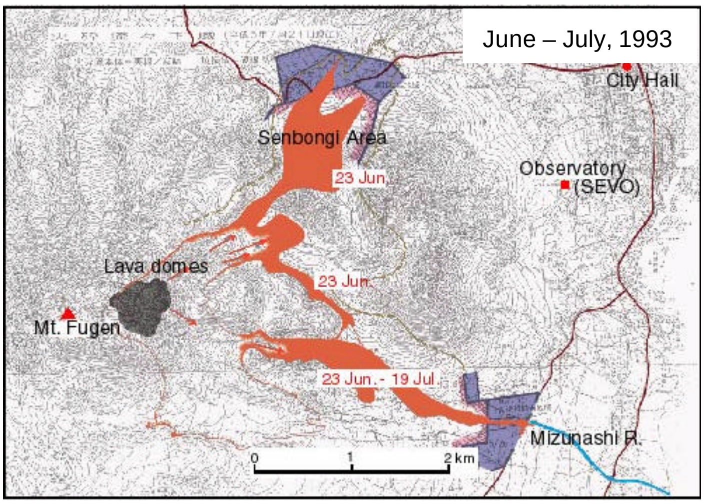
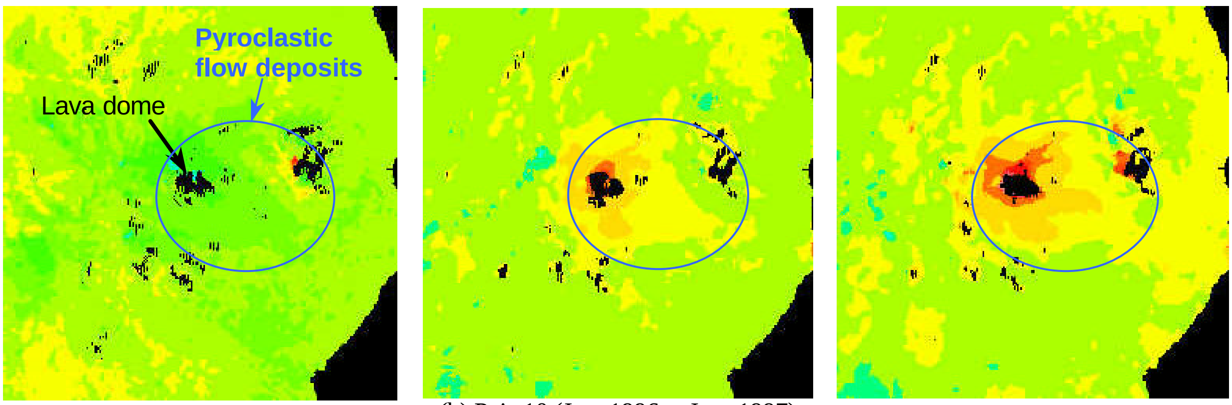


Fig.6. Areas for the pyroclastic flows from June to July, 1993. The areas are indicated as brown colors.
(Web site of Internet Museum of Kyushu University)

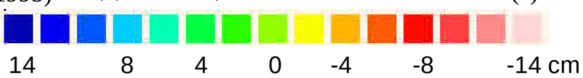
Also it is interesting that in Fig.5 (b) the deformation is almost positive, while in (c), successive period of (b), a part of the deformed regions changed to negative deformation (south slopes of the lava dome). This change of deformation might indicate the process of deposit and then erosion on the land surface due to pyroclastic flows.

The surface deformation patterns detected by DInSAR in Fig.5 might be different from so-called crustal deformation by volcanic activity, the latter one has been successfully detected by DInSAR in many studies on volcanic eruption until now. The physical meaning of the deformation in Fig.5 should be investigated in detail. However, the result in Fig.5 is very interesting because it suggests that it is still possible to detect surface deformation even in the case that landcover conditions are not stable between two repeat-pass observations. The similar result was also reported by a study to detect the surface erosion at Mt. Sakurajima (Tomiyama *et al*, 2000).

Fig.7 (a) to (c) show the results of deformation patterns by the data pairs observed after the pyroclastic flows ceased. It is remarkable that from May to Sep. in 1995, just after the flows ceased, no deformation patterns are detected, while more than one year after, some deformation patterns around the lava dome are detected. However, these deformation patterns are clearly different from those in Fig.5, during the period when the pyroclastic flows were active. The deformation patterns in Fig.7 (b) and (c) suggest the overall sinking of the lava dome, although at the lave dome itself any deformation could not be detected due to still poor coherence of the lava dome. This poorness might be caused by the steep and complicated slope structures of the dome.



(a) Pair-8 (May 1995 – Sep. 1995) (b) Pair-10 (Jun. 1996 – Jan. 1997) (c) Pair-11 (Jun. 1996 – Mar. 1997)



[Deformation in slant range direction. Plus denotes the forward direction to satellite and minus the reverse.]

Fig.7. Surface deformation patterns by DInSAR from May 1995 to Mar. 1997 after the pyroclastic flows ceased.

The surface deformation patterns detected in Fig.7 (b) and (c) might be reasonable because it is reported that the height of the peak of the lava dome gradually decreased from the beginning of 1996 to 1997 (Meteorological Agency, 1997). However, the actual amount of sinking of the peak was much bigger than that in Fig.7, at least several meters order. Also during Jan. to Apr. in 1994, a big (almost 70 meters) rise of the dome peak was recorded (Meteorological Agency, 1997). This surface change of the dome could not be detected by the data pair-6, which should include the period of the rising. This is considered due to the significant decorrelation at the lave dome which is seen in any data pairs by JERS-1/SAR. These facts suggest the essential limitation of DInSAR for detecting crustal deformation in the most active areas of volcano eruption, where the amount of deformation is generally too big, the surface conditions are unstable and topographic features are steep and complicated, all of which are unsuitable conditions for the application of DInSAR.

6. CONCLUSION

In this paper the authors evaluated the capability of interferometric SAR (InSAR) for detecting pyroclastic flows and surface deformation caused by volcanic activity of Mt.Unzen. As to the detection of the pyroclastic flows, the coherence information obtained by InSAR was proved to decrease significantly when the pyroclastic flows were active, while the coherence became much higher after the flows ceased. This result strongly supports that the coherence is an effective parameter for detecting pyroclastic flows caused by volcanic activity. The results of this study together with the previous studies (i.e. Yonezawa and Takeuchi, 2001) also supports that the coherence is generally much sensitive to the change of landcover conditions caused by volcanic eruption as well as by earthquakes compared with SAR backscattering intensity. Therefore, InSAR can be recognized to be an effective and important approach for detecting different kinds of landcover changes caused by different disasters such as volcanic eruption or earthquakes.

As to the surface deformation, some essential limitation by InSAR was indicated possibly due to a steep and complicated topographic structure of the lava dome. However, InSAR partly worked to detect the surface deformation in the areas where the pyroclastic flows were active and also the surface deformation around the lava dome due to the sinking of the lava dome itself. This result suggests some possibility of InSAR application to the studies on the crustal conditions caused by volcanic eruption and also some promising applications of ALOS/PALSAR, coming L-band space-borne SAR launched in 2003 by Japan, for the purpose of disaster monitoring.

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