ERS-TANDEM-INTERFEROMETRIC OBSERVATION OF VOLCANO ACTIVITIES IN ICELAND

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ABSTRACT

Applying SAR-Interferometry in remote areas has shown the high potentials for monitoring of surface changes. ERS-tandem-interferometric observation of the natural phenomena of an volcano activity in Iceland demonstrated once again the powerful ability of SAR-interferometry to detect small surface changes of large areas. With the available data sets from the ERS tandem phase, the topography and the surface changes due to the recent eruption of the Vatnajökull volcano in Iceland are estimated.

Key words: SAR interferometry, ERS-1/ERS-2, volcano, small change detection

1. INTRODUCTION

SAR-interferometry is a powerful technique for the generation of digital elevation models (DEMs) and the monitoring of small surface changes. For the ERS-1 SAR data in a region near Bonn, Germany, the precision of about 4.3 m with a ground resolution of 50×50 m^2 for the DEM estimation of the region with an area of 26×12 km^2 was reached[1]. The ability of SAR-interferometry to detect the small changes was demonstrated for several sites and cases: the monitoring of the Landers earthquake of 28 June 1992[2] and the ice movement in the Antarctic[3,4]. In this paper, ERS tandem interferometric observation of the ice surface changes caused by the recent volcano eruption on Sep. 30, 1996 in the Vatnajökull Glacier in south Iceland will be present.

SAR interferometry is based on the generation of an interferogram by using two SAR images of the same area. The two images are acquired at two different times. In the case of ERS tandem mission, the time interval is 24 hours. The phase of the interferogram contains the topographical information if the two look angles are different, and the information about the surface changes. The following equation describe the relation between the phase Ψ of the interferogram, the topographical elevation Δ z and the surface change δ r in slant range:

$$\Psi(P)-\Psi(P_0) \approx \frac{4\pi}{\lambda}\{\frac{B}{R\cdot\sin\theta}\Delta z+\delta r\}, \tag{1}$$

after the phase of the " flat earth" is removed. In eq. (1), P is a point and P_0 is a reference point, B is the baseline between the two orbits of the two acquisitions, R is the slant range to the point P and θ is the incidental angle.

If there is no surface change between the two acquisitions of the two images, the topographical elevation can be derived from the phase of the interferogram. And if the topographical elevation is known, the surface change in slant range can be also obtained from the phase. In the following sections, we will use two ERS tandem pairs acquired on Dec. 30/31, 1995 and Oct. 21/22, 1996 to estimate the DEM of the Vatnajökull area and its surface changes happened between Oct. 21 Oct. 22., 1996 due to the Vatnajökull volcano eruption on Sep. 30, 1996 and the following seismic activities.

2. 1996 VOLCANO ERUPTION IN VATNAJÖKULL

The recent volcano eruption beneath the biggest glacier in Europe, the Vatnajökull glacier in Central Iceland happened on Sep. 30, 1996, after an earthquake with a magnitude of 5.4 on Sep. 29, 1996. This event continued for more than one month. As a result, a 4 km long fissure beneath the glacier, which is 400-600 m thick in this location, was formed. Around the eruption fissure, an evident ice sinking was observed. A large amount of melt water drained into the Grimsvotn Lake, which is located just in the south of the eruption fissure and about 350 m lower than the eruption location. The ice cover of the Grimsvotn Lake has been raised.

Fig. 1 shows the topography around the eruption location.

3. DEM OF VATNAJÖKULL OBTAINED FROM ERS-INSAR

Because of the immense surface changes caused by the volcano eruption, no repeat INSAR with greater acquisition time interval except for the ERS tandem INSAR can provide an enough coherence to obtain a good quality interferogram. In the eruption duration,

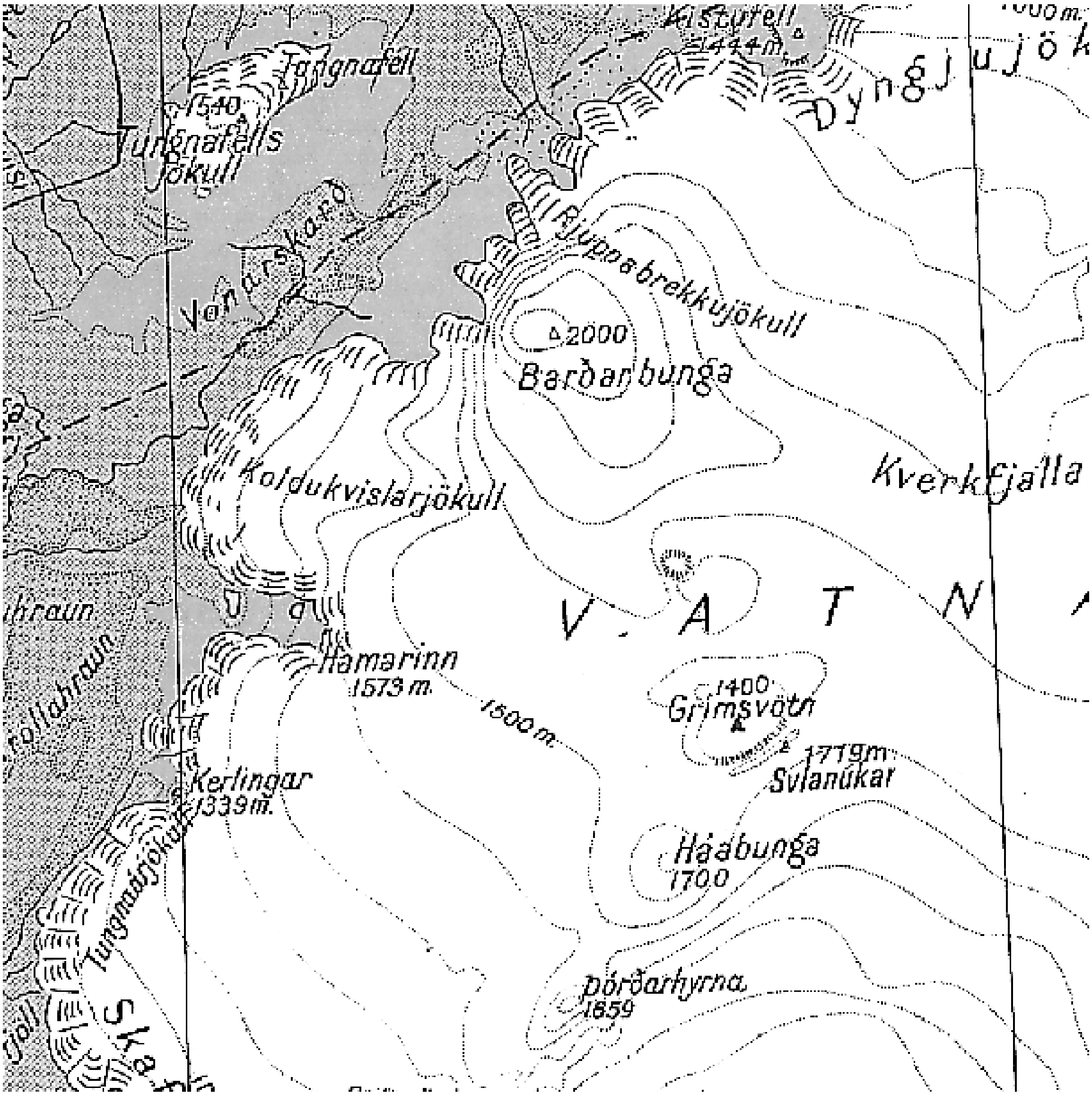

Fig. 1 Topographical map of Vatnajökull of Iceland.

Only the descending pair on Oct. 21/22, 1996 and the ascending pair on Oct. 23/24, 1996 are available. Due to the raining on Oct. 23, the coherence of the ascending pair is too poor to allow to get a useful interferogram. Therefore only the descending pair will be used to detect the surface changes resulting from the volcano activities.

Before the phase of an interferogram can be used to detect the surface changes, the DEM of the area must be known according to eq. (1). One possibility is to use a known DEM. Another alternative is to use an interferogram with no surface changes. The ERS tandem data of Dec. 30/31, 1995 (frame: 2295, orbits: 23315/03642) are used to gain the DEM of the Vatnajökull.

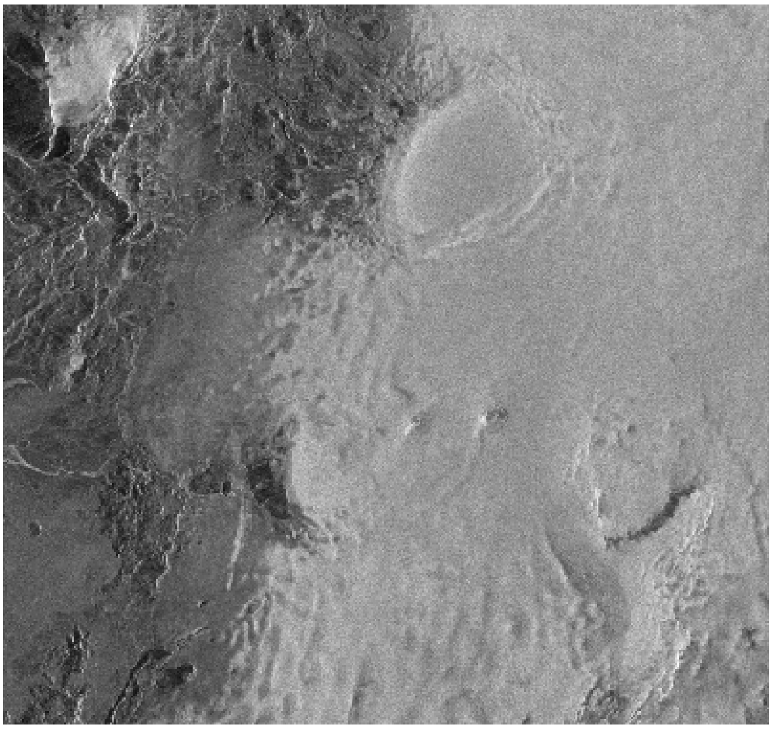

Fig. 2 ERS-1 SAR amplitude image of Vatnajökull from Dec. 30, 1995

Fig. 2 is the amplitude image of ERS-1 SAR obtained from Dec. 30, 1995. Fig. 3 is the phase of the interferogram obtained from the ERS tandem pair of Dec. 30/31, 1995, where the 2π elevation is about 68m. Fig. 4 shows the corresponding coherence image. By comparing the interferogram of Fig. 3 with the topographic map in Fig. 1, we find that they have a good agreement at the three control points: the top of the Tongnafellsjökull (1540 m), the top of the Barð arbungar (2000 m) and the bottom of Grimsvotn (1400 m). The fringes between Barð arbungar and Grimsvotn is 8, which corresponds to 550 m elevation difference. In the map, this elevation difference is 600 m. On the other hand, the fringes between Barð arbungar and Tongnafellsjökull is 7.5, which corresponds about 500 m relative elevation. This has also a good agreement with 460m elevation difference in the map. Therefore the DEM represent by the interferogram in Fig. 3 can be accepted, except for some areas with great surface changes.

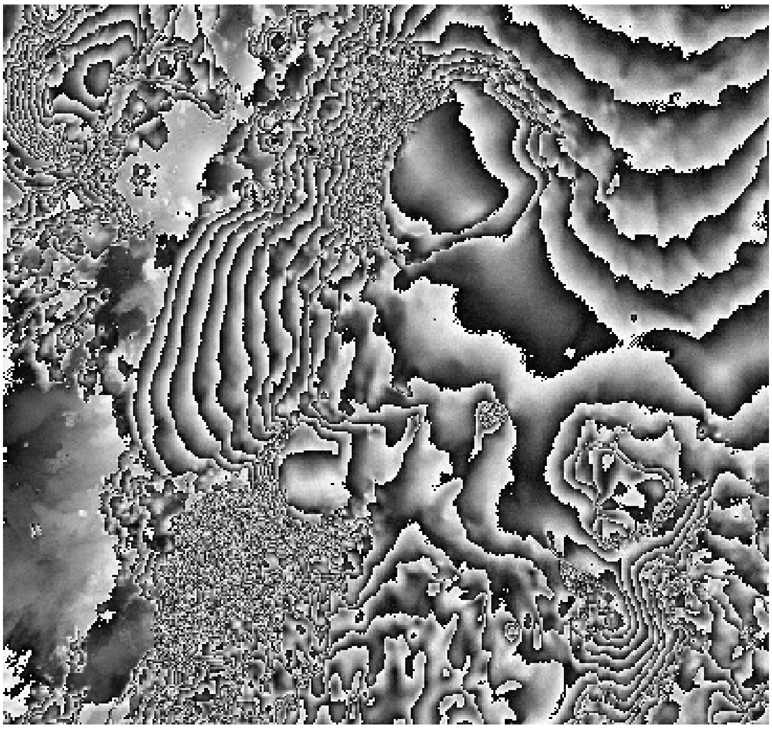

Fig. 3 ERS-1/ERS-2 tandem INSAR phase image of Vatnajökull from Dec. 30/31, 1995 with 2π elevation of 68 m.

These areas include area 1 (refer to Fig. 4) in the west of Hamarinn, where the coherence is low and the fringes are dense and area 2 (refer to Fig. 4) between Barð arbungar and Grimsvotn, which is enlarged in Fig. 5, where the center should be lower than the surrounding for more than 700 m (more than 10 fringes). From the map in Fig. 1, we know this is not correct. Most of the fringes can only be the result of surface changes (about 30 cm surface increase). This suggests that some kind of small seismic activities must have happened during the SAR two data acquisitions on Oct. 21 and 22, 1996. Unfortunately, we have no information about the seismic activities, if any, near Grimsvotn at end of Dec. 1995 to confirm the suggestion.

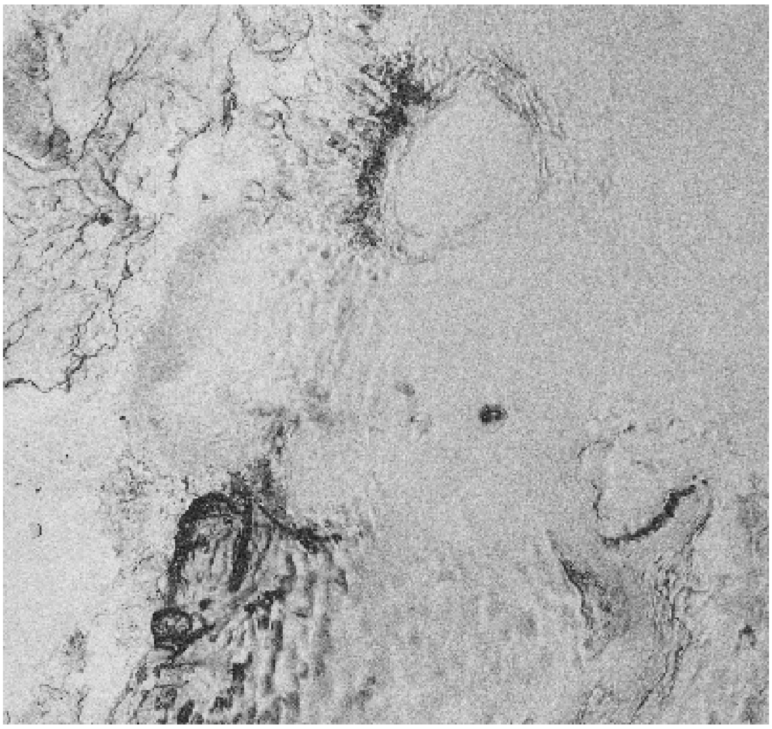

Fig. 4 ERS-1/ERS-2 tandem INSAR coherence image of Vatnajökull obtained from Dec. 30/31, 1995

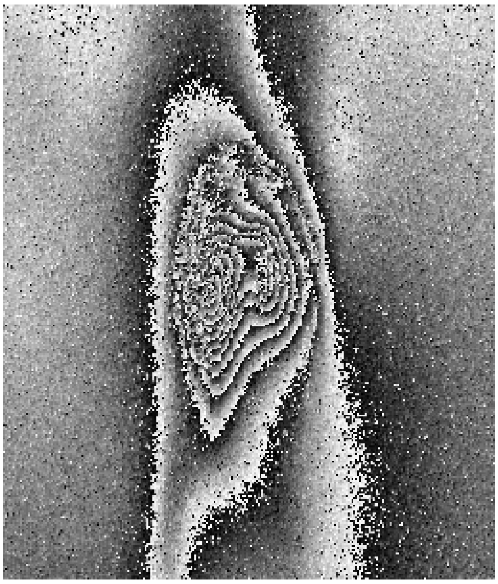

Fig. 5 Surface changes of subregion 2 between Dec. 30 and 31, 1995. One fringe corresponds to 3 cm elevation change.

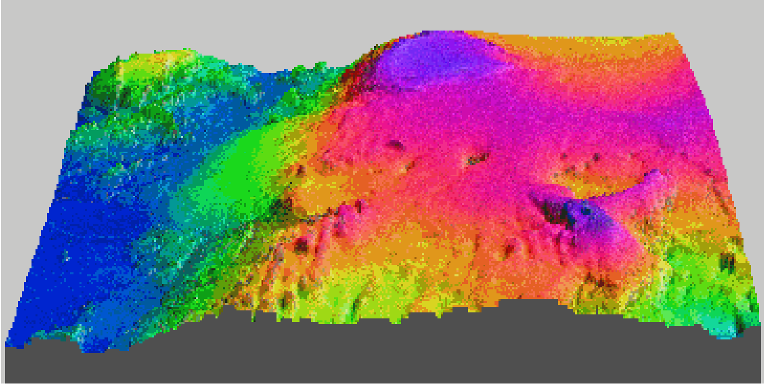

Fig. 6 3D elevation model obtained from the interferogram phase of Dec. 30 and 31, 1995.

4. SURFACE CHANGES OBSERVED BY INSAR

The amplitude image of ERS-1 SAR acquired on Oct. 21, 1996, three weeks after the volcano eruption, is shown in Fig. 7. The most significant difference between the ERS SAR images before (Fig. 2) and after (Fig. 7) the eruption is the new 6 ~ 8 km long eruption fissure between Barð arbungar and Grimsvotn. The other changes can not be clearly and quantitatively determined from these two amplitude images.

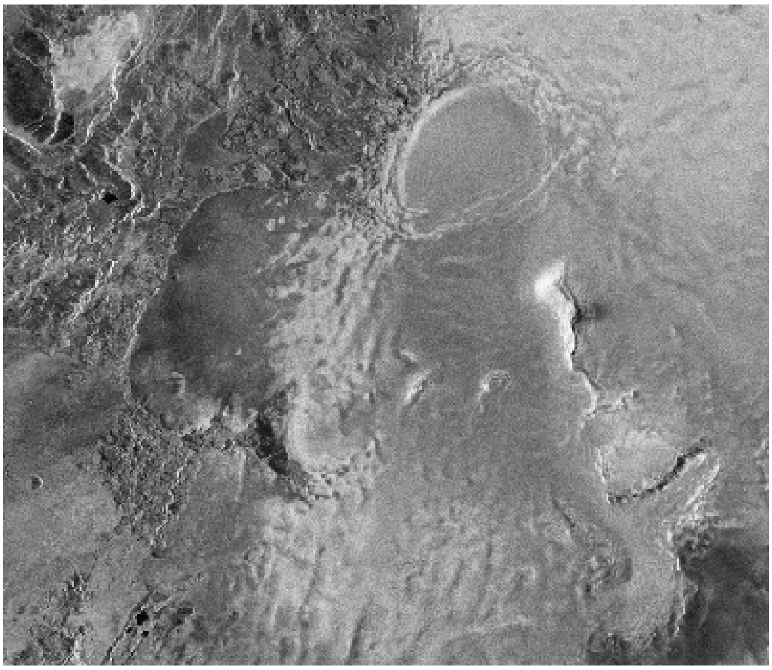

Fig. 7 ERS-1 SAR amplitude image of Vatnajökull from Oct. 21, 1996

But with the help of the coherence image in Fig. 8 obtained from the ERS tandem data of Oct. 21/22, 1996, we can get more information about the effects resulting from the eruption. A pear-formed area around the fissure shows very poor coherence. Just below the area around the Grimsvotn Lake, there is a narrow handle-shaped area with low coherence. The other three low coherence areas around the fissure are a small circle area at the west of the fissure, a small area at the margin of Barð arbungar and north of the fissure and a large area in the east of Barð arbungar. These low coherence areas must have suffered surface changes. The amount of the surface changes can be determined from the interferogram in Fig. 9 and the DEM in Fig. 6.

In order to measure the surface changes between Oct. 21 and 22, 1996 due to the volcano activities according to the interferogramm in Fig. 9, the DEM of this area must be removed from it. Fig. 10 shows the corrected interferogram phase, which is also geocoded in UTM. In Fig. 10 each fringe represents 2.8 cm surface change in slant range. Because the horizontal movement of the ice surface is very small, the surface changes result mainly from the elevation changes. In this case, one fringe represents about 3 cm elevation change.

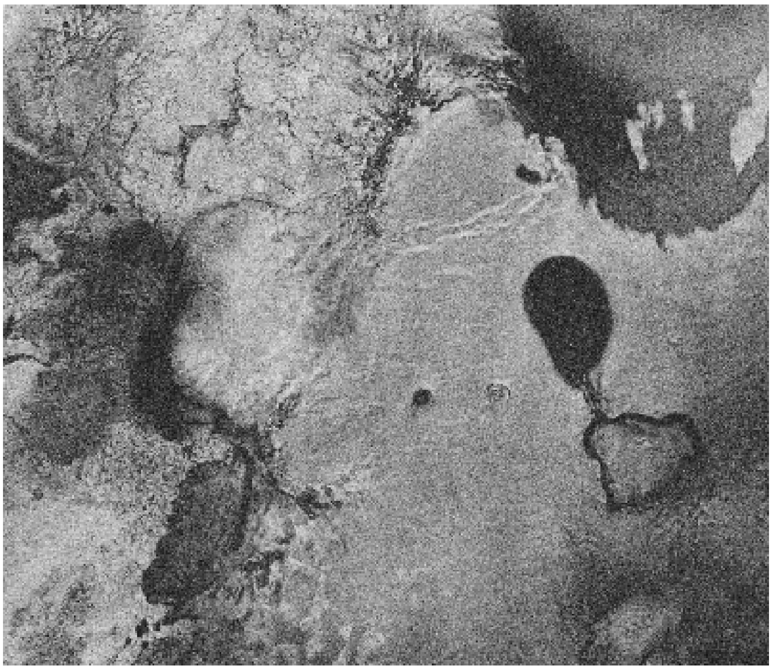

Fig. 8 ERS-1/ERS-2 tandem INSAR coherence image of Vatnajökull from Oct. 21/22, 1996.

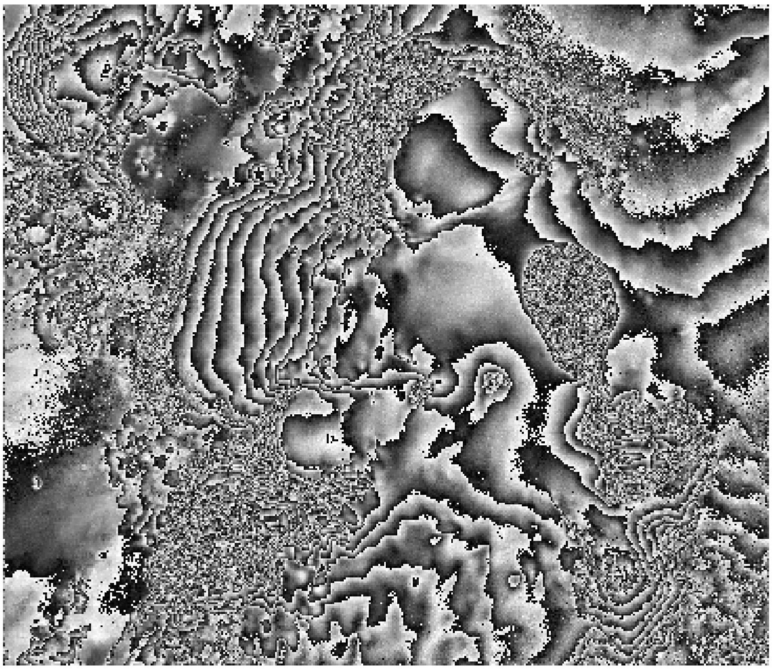

Fig. 9 ERS-1/ERS-2 tandem INSAR phase image of Vatnajökull from Oct. 21/22, 1996 with 2π elevation of 72 m

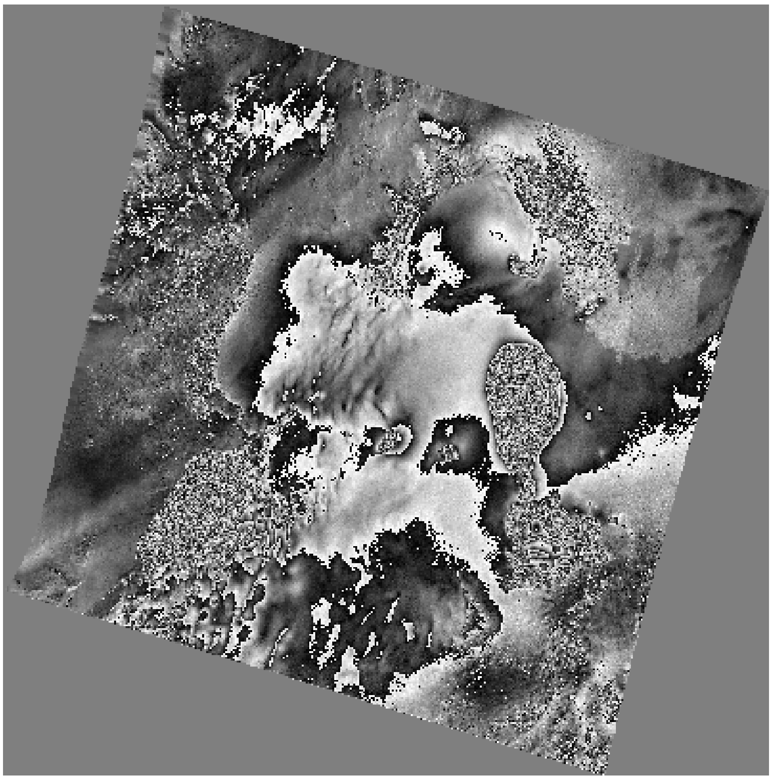

Fig. 10 Geocoded surface changes between Oct. 21 and 22, 1996. One fringe corresponds to 3 cm elevation change.

The largest surface changes happened around the eruption fissure and has a pear form. The changes within one day are so large that the coherence is lost and the fringes in the center of the area is uncountable. Fig. 11 gives an enlarged version of the north part of the pear-formed region. About 20 fringes are clear to count. Therefore the center of the pear-formed region is at least 25 fringes lower than the surroundings, which corresponds to about 80 cm sinking within 24 hours.

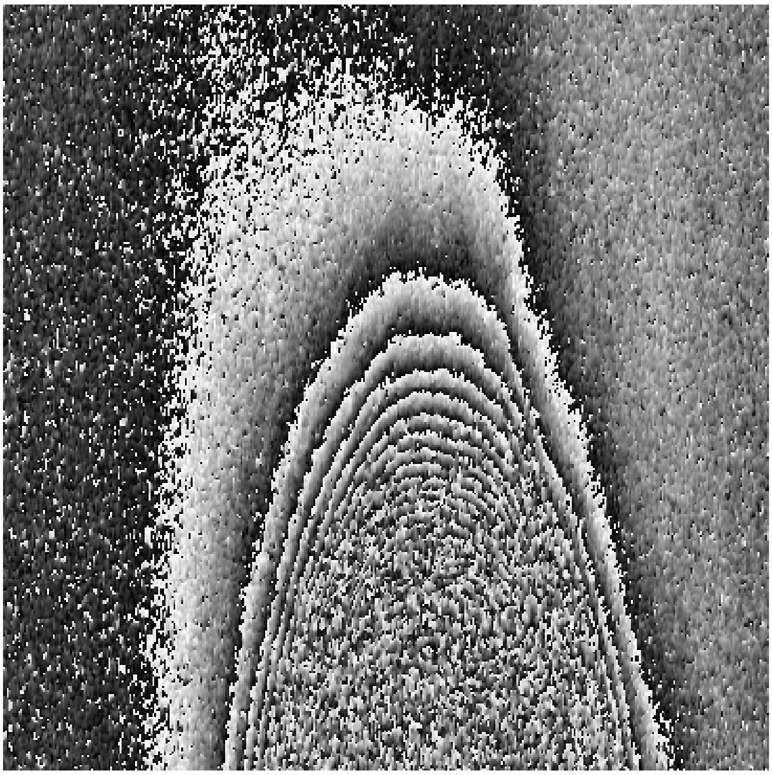

Fig. 11 Enlarged version of the surface sinking of the north part of the eruption region

The melt water flows into the Grimsvotn below, so that the ice cover of Grimsvotn is raised. The rising of the ice surface can be clearly seen in the Fig. 12a and Fig. 12b, which is the enlarged version of one part of Fig. 12a. According to Fig. 12b, the up-right peak in Fig. 12a is 18 fringes higher than the surroundings, which corresponds to 54 cm surface increase. The highest point in Fig. 12 is the middle peak, which is 23 fringes higher than the surroundings, i.e., about 70 cm surface increase. The point with the least increase (27 cm increase or 9 fringes) is located near the bottom of Fig. 12a. Whereas the center of the Grimsvotn has about

40 cm surface increase (13 fringes higher). A measurement with a GPS from Oct. 21 to 25, 1996 shows about 2 meter surface increase, or 50 cm per day surface increase[5], which is in good agreement with the results derived from the INSAR measurement. The unhomogeneous surface increase of the ice cover in Grimsvotn Lake reveals probably the unhomogeneity of the ice thickness, which however must be further confirmed.

The other three areas around the eruption fissure with great surface changes are enlarged and shown in Fig. 13, Fig. 14 and Fig. 15, respectively. The two small regions near Barð arbungar suffered a surface sinking of about 30 cm (10 fringes, Fig. 13), and 6 cm (2 fringes, Fig. 14), respectively, whereas the small region at the west of Grimsvotn Lake has a surface increase of at least 21 cm (7 fringes) at the center.

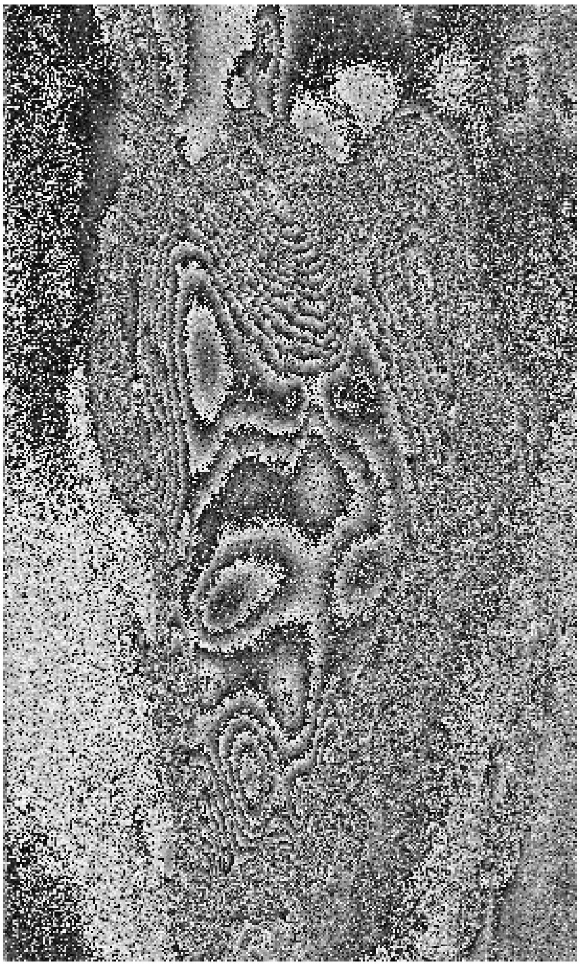

Fig. 12a Enlarged version of the surface increase of the ice cover on the Grimsvotn Lake.

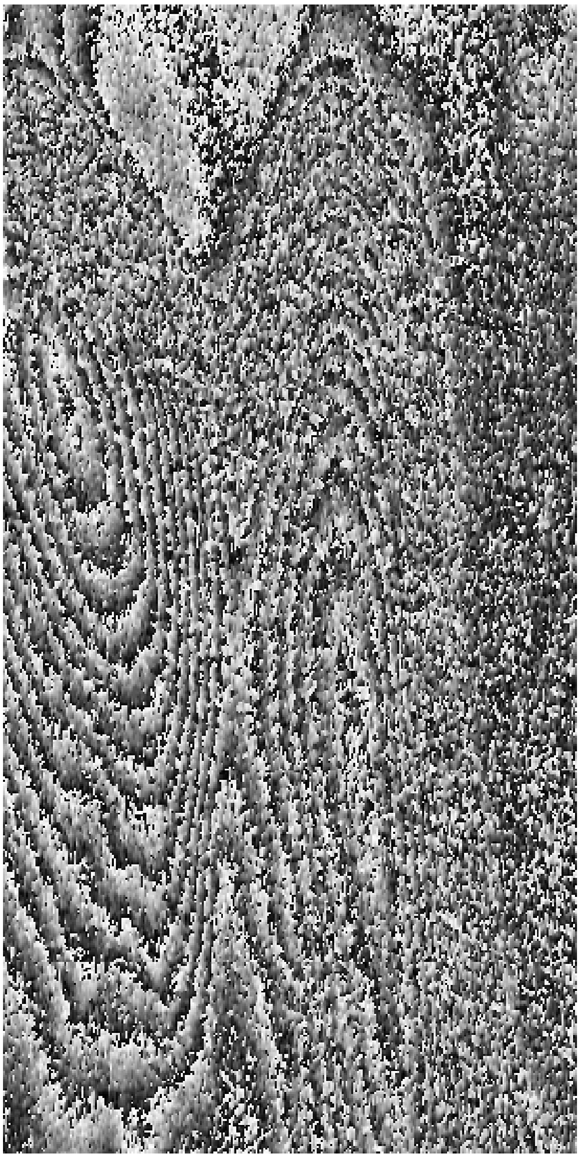

Fig. 12b Enlarged version of the upper part of Fig. 12a.

Another large area with only small surface changes is located at the northeast corner of Fig. 10. The location of the area can be also seen in Fig. 8. The increase of the large area is, however small, only 1 cm (1/3 fringe). The reason, why this area is increased, must be studied further.

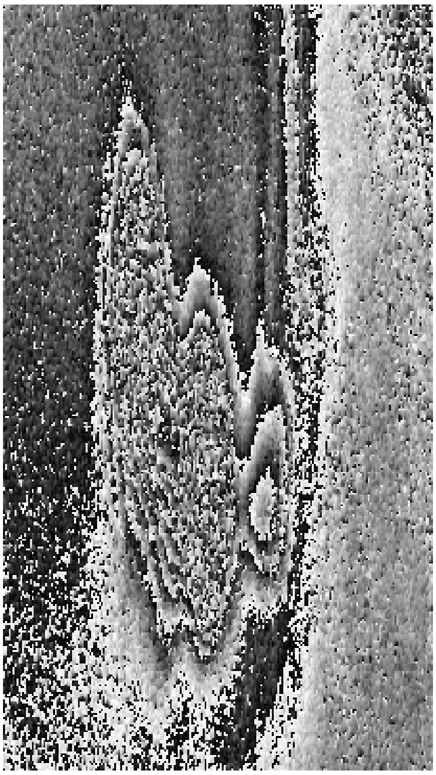

Fig. 13 Enlarged version of the surface sinking of the subregion 1.

Fig. 14 Enlarged version of the surface sinking of the subregion 2.

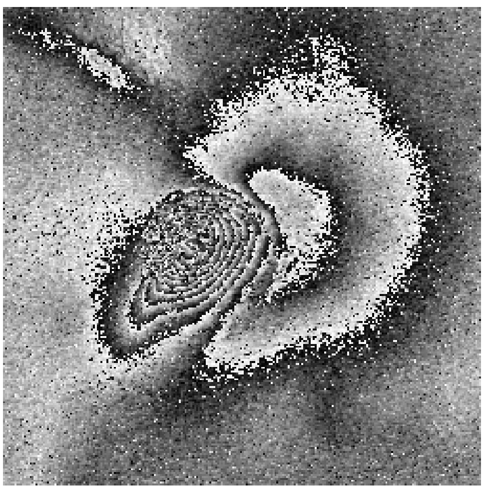

Fig. 15 Enlarged version of the surface increase of the subregion 3.

5. CONCLUSIONS

ERS-1/ERS-2 tandem data with only one day time span allow to observe and measure accurately the ice surface changes of large areas resulting from volcano activities. The INSAR measurement will be valuable information sources to monitor, assess and even predict the effects of volcano activities. It can not be replaced by other techniques such as optical imaging and GPS measurement. It will become one of the most useful remote sensing tools for monitoring the natural phenomena.

6. ACKNOWLEDGMENTS

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7. REFERENCES

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