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Natural hazard monitoring by InSAR analysis

Shuichi Rokugawa
University of Tokyo
Hongo 7-3-1, Bunkyo-ku, Tokyo 113-8656, Japan
Rokugawa@gpl.t.u-tokyo.ac.jp

Takako Nakamura
University of Tokyo
Hongo 7-3-1, Bunkyo-ku, Tokyo, Japan
nakamura@geosys.t.u-tokyo.ac.jp

Hideaki Nakagawa
Institute Of Constraction Environment Co
1-9Sh ｉmanosemaci，Sasebocity，Nagaski
nakagawa@ioce.co.jp

SUMMARY

We have investigated techniques for the efficient early detection of landslides using time series analysis incorporating synthetic aperture radar (SAR) images. The study area, in the Miyazaki, Nagasaki, and Saga prefectures in Kyushu, was determined based on interference fringes detected during interference SAR (InSAR) analysis. We used ALOS/PALSAR data acquired from 2006–2011 to detect early warning signs of landslides that were poorly expressed geomorphologically by conducting time series analysis of InSAR data acquired periodically. Moreover, in order to remove the noise caused by geographical feature stripes or phase retardation, we applied median filtering, histogram extraction processing, and clearisation of the displacement with a Laplacian filter. We evaluated the validity of each filter separately and in combination with other filters and assigned a gradient vector to each pixel value of the SAR picture using altitude data. In order to confirm the assumption that surface-of-the-earth displacement proceeds in the dip direction, we conducted direction analysis and a technique and confirmed the results of InSAR analysis by field survey. Our results prove the effectiveness of InSAR analysis in hazard monitoring over a wide area through the detection of local landslides.

Keywords: landslide, ALOS/PALSAR data, InSAR analysis, hazard monitoring

INTRODUCTION

The many mountainous regions in Japan are often characterised by steep topography such as valleys or cliffs, the presence of which can induce sediment disasters such as mud floods, landslides, and landslips. Recently, large-scale typhoons and abnormal weather have caused local increases in heavy rain, producing conditions that are conducive to large-scale landslides and causing extensive damage. Therefore, it is essential to develop techniques to detect such landslides before their occurrence in order to mitigate their effects. In the present study, we demonstrate the use of interference synthetic aperture radar (InSAR) in detecting early signs of landslides and discuss the production of a new hazard map. In the study area, the Wanitsuka Mountains in Miyazaki Prefecture (Fig. 1), a particularly noticeable large-scale collapse was induced by Typhoon 14 in 2005, although collapses of varying magnitudes occur often in the region. For such areas, it should be possible to obtain information that would be useful in the prediction of landslide disasters, particularly in the detection of precursory phenomenon of large-scale landslides.

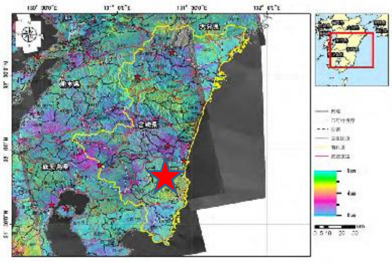

Fig. 1. The area around the Wanitsuka Mountains in Miyazaki Prefecture, indicated by red star

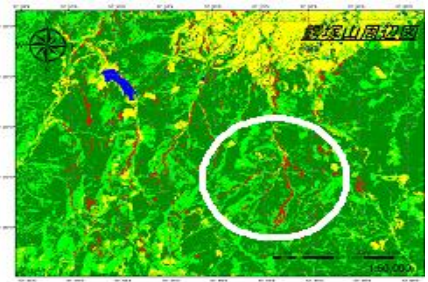

Fig. 2. Image of a disaster situation in the environs of Mt. Wanitsuka. The circled area indicates the area analysed in the present study.

Fig. 3. Image of the landslide disaster that occurred on 24 April 2010 in the Imari area (red star in upper panel) of Saga Prefecture (from Saga Shimbun).

METHODS

InSAR is the most appropriate technique for analysing changes in ground movement with time over large areas. Such monitoring can offer many advantages, particularly in the detection of the precursory phenomena of landslide disasters. We conducted an investigation into landslide disasters occurring between 2008 and 2009 in the region around the Wanitsuka Mountains (Fig. 1), including local InSAR analysis (Fig. 2). We used a high SAR interference pair of the coherence from a PALSAR data 10 scene acquired by December 2010 from April 2008. In the Imari area of northern Kyushu, we used 38 scenes acquired between May 2006 and January 2011 and used a high SAR interference pair of the coherence. Then, we quantitatively evaluated the precision of the InSAR data and conducted time series analysis to clarify variations in local upheaval or settlement in order to assess ground deformation.

The Imari area of Saga Prefecture can be considered a real landslide disaster zone. However, the SAR imagery obtained for this area (Fig. 3) was unclear, making it an ideal location to test our newly developed detection technique. Therefore, we extracted information for a landslide that occurred on 24 April 2010 by applying filters to remove noise and clarify ground movement. As a result, any place other than the point where landslide happened, I was able to detect the point considered that an initial change was caused. During this process, we corrected for the measurement error associated with InSAR and assessed the effectiveness of the technique. However, it proved difficult to remove all noise.

We used a composite filter incorporating three individual filtering techniques.

(1) Median filtering
We calculated a median using a 3 × 3 area comprising a target picture element and its neighbouring picture elements; the value obtained is an object pixel value. This filter was shown to be acceptable for the removal of spot-formed noise in InSAR images.

(2) Histogram extraction processing
We normalised the InSAR displacement data and removed all small displacements from the SAR image. I removed 80% of low order by the ground displacement magnitude detection of the cm unit and, in the case of mm unit, removed low order 60%.

(3) Laplacian filter
We used a 51 × 51 operator derived from a four-dimensional operator that radicalised the surface displacement using a standard second derivative filter to produce a weighted-mean picture element area.

RESULTS AND DISCUSSION

Figures 4a and 4b illustrate the interferogram for the region around the Wanitsuka Mountains and an interpretation of the decay incidence area based on aerial photographs, respectively, confirming the changes in ground movement that were suggested by previous field study. On the basis of the InSAR results, we believe that fluctuations in the ground surface continued after decay. Decay induced by the typhoon of 2005 was not detected in areas ⑦ and ⑨, although evidence suggests that subsidence continued in these areas following the typhoon. Subsidence of approximately 9 cm was found in area ④ over a period of two years and eight months; this represents the greatest fluctuation in ground level detected in the region, although subsidence of 4–6 cm was found in other areas. These results suggest that the newly developed technique is suitable for the assessment of such ground movements. However, problems remain in terms of the interpretation of the consequence of the research technique by the application to more areas and rearranging of the application limit. Therefore, the technique must be verified through further analysis.

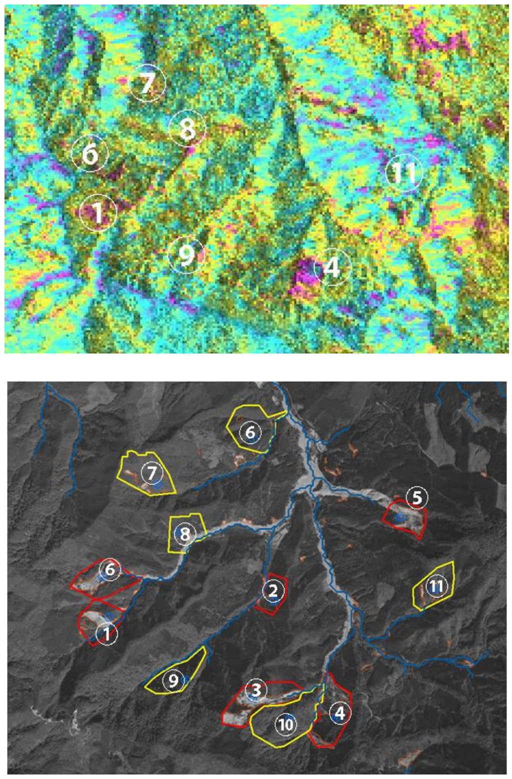

Fig. 4. (a) The interferogram around the Wanitsuka Mountains of Miyazaki Prefecture. (b) Interpretation of decay incidence area based on aerial photographs.

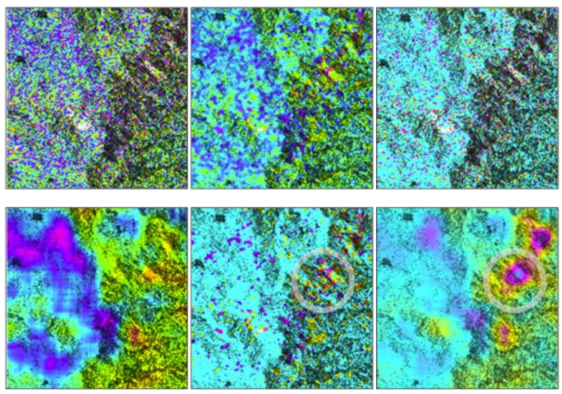

Fig. 5 Effects of filter application to InSAR imagery for the Imari area. Circles indicate areas of landsliding. (a) InSAR image, (b) median filtering, (c) histogram extraction (upper 20% extract of the normalised displacement), (d) Laplacian filter, (e) median filtering and histogram extraction, (f) median filtering and histogram extraction and Laplacian filter.

Figure 5 illustrates the results obtained for an InSAR image of the Imari area using various filter processes. Landslide detection is difficult based on the images in Figs 5a and 5c, because big noise has not been removed from these images. Conversely, the representation of surface displacements is improved in Fig. 5b, from which big noise (but not small noise) has been removed. Figure 5d illustrates the results obtained by radicalising displacement and noise; surface displacements can be detected in this image, indicating that it is desirable to perform Laplacian filtering after removal of noise. Figure 5e illustrates the results achieved by applying both median filtering and histogram extraction and suggests that noise reduction is useful in the acquisition of displacement magnitude. The location of the landslide is clearly indicated in Fig. 5f, for which all filtering techniques were applied. The results presented here indicate that InSAR is effective in detecting microdisplacements that occur during the early stages of landsliding and that detection of these displacements can be improved by application of filtering processes, at least in the Imari area. However, I was able to detect a point considered to have initial fluctuation other than the point where landslide happened as having been shown in (f).

CONCLUSIONS

The InSAR images and time series analyses presented here enable estimation of the incidence device of the landslide and demonstrate the possibility of detecting precursory phenomena related to the occurrence of large-scale landslides. Moreover, the results suggest that the technique evaluated here can offer information that will help the drafting of the first ground movement system of landslide measures (e.g. in deciding where monitoring components such as GPS equipment should be placed). We investigated the effectiveness of the measures described here by performing the monitor after measures sequentially. The results confirm that our techniques are effective in detecting landslide-related ground fluctuations over wide areas. Furthermore, we have demonstrated that it is possible to construct hazard maps for large areas based on the ground movements detected. In this manner, InSAR images may make a considerable contribution to disaster prevention.

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