Crustal deformation mapping using PALSAR interferometry conducted by DPRI, Kyoto University

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Abstract
The Disaster Prevention Research Insitute (DPRI), Kyoto University, plans to use interferometric synthetic aperture radar (InSAR) technique as one of the principal tools to monitor and study crustal deformation associated with tectonic strain accumulation, earthquakes and volcano activities. The targets so far analyzed include a mud volcano eruption in East Java, Aysen seismic swarm in southern Chile (Jan. – June 2007), Noto-hanto earthquake (March 2007, Mw 6.6), and an earthquake doublet in Sumatra Island (March 2007, M 6.3 and 6.4). Toward efficient monitoring of crustal deformation using InSAR, development of an integrated system of precise, long-strip and time-dependent processing is under way.
Keywords: PALSAR, crustal deformation monitoring, southwestern Japan.

1. INTRODUCTION

For decades, the Disaster Prevention Research Institute (DPRI) of Kyoto University has conducted researches on seismology and volcanology in southwestern Japan and in other regions in the world. The Research Center for Earthquake Prediction (RCEP), one of the research sections of the DPRI, operates a monitoring system of crustal deformation in southwestern Japan associated with plate motions and (consequent) earthquakes (Figure 1). The Sakurajima Volcano Research Center (SVRC), another research section of the DPRI, performs geodetic and geophysical monitoring of the southern islands in Kagoshima prefecture (Figure 2).

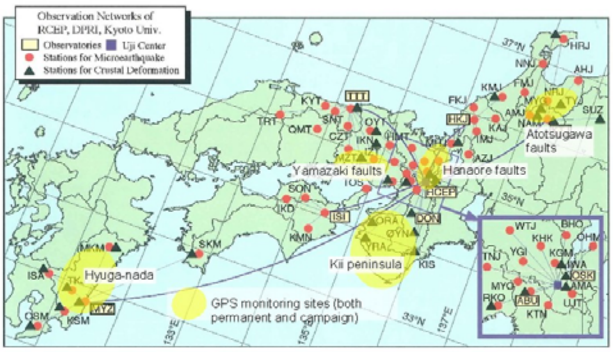

Figure 1. Crustal deformation monitoring network operated by RCEP, DPRI, Kyoto University.

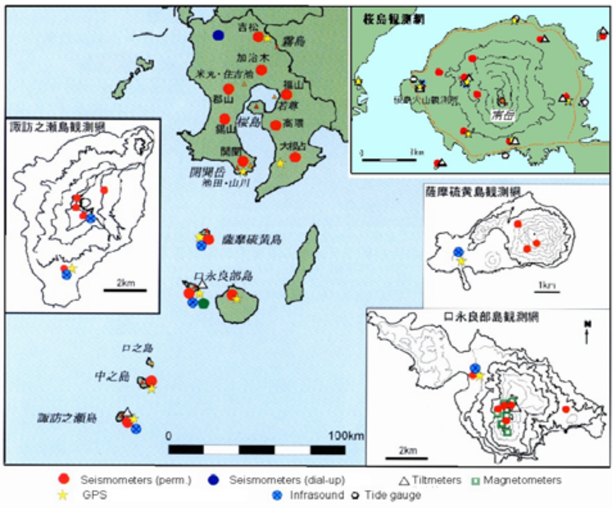

Figure 2. Monitoring network on the southern volcanoes in Japan operated by SVRC, DPRI, Kyoto University.

The potential of interferometric synthetic aperture radar (InSAR) using L-band PALSAR data promises a large contribution in new findings on the seismotectonics and volcanotectonics of our target areas in the southwestern Japan. On the other hand, in order to cover the whole broad region of interest by InSAR, it is essential to have sound knowledge on interferometric processing and then to develop an efficient processing system. On this respect, we started from performing PALSAR interferometric analyses on various targets in the world, which helps us to understand what we can observe as well as to collect technical know-hows. This paper mainly explains the results we have so far obtained. It also contains results of our preliminarly analyses toward an operational crustal monitoring system using InSAR.

2. PROCESSING

We process from raw data (PALSAR L1.0 Fine Beam (FBS or FBD) products) for flexibility in processing. For the target areas specified in the 2nd Research Announcement (RA) contract, the data are provided from JAXA through their AUIG (ALOS User Interface Gateway) system. For other targets, the data are provided from JAXA through a Japanese crustal deformation research consortium PIXEL (PALSAR Interferometry Consortium to Study our Evolving Land surface).

In most of our analyses, we use a commercial software GAMMA in our processing. To interfere FBS and FBD interferograms, Single Look Complex of FBD mode is oversampled, and the common bandwidth in range direction is used. Whereever possible, the processing is automated. For differential interferometry, digital elevation models (DEM) provided from the Geographical Survey of Japan (GSI) (within Japan) or from the Shuttle Radar Topography Mission (SRTM, for global targets; [1]) are used.

3. RESULTS

3.1. Mud Eruption in East Java

On 29 May 2006, a mud eruption started from a gas exploration site in east Java, Indonesia. An approximate location of the eruptive vent is (7.527°S, 112.710°E). The total erupted volume exceeds 10^7 m^3 [2,3], and more than 24,000 habitants are being evacuated. The eruption still continues as of December 2007. PALSAR interferometry clearly detected subsidence associated with this event (Figure 3). Analyses of several pairs indicated a maximum subsidence rate between October to November 2006. The rate gradually decreased but persistently continues. The displacement pattern is best explained by an ellipsoidal source whose top and bottom are located at 200 and 1000 meters beneath the ground surface, respectively.

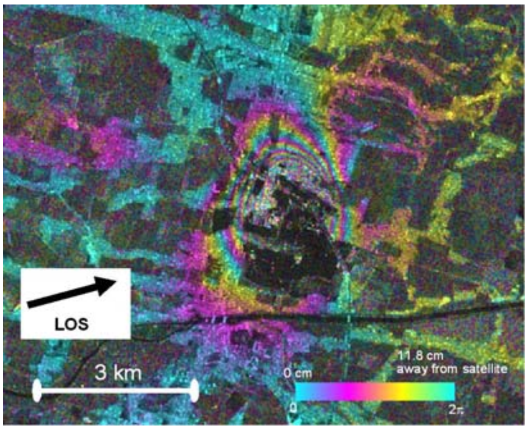

Figure 3. Example of SAR interferograms on a mud eruption site in east Java, Indonesia. This interferogram used images acquired in May and October 2006, and is superimposed on a SAR intensity image. Black area in the center of the figure corresponds to a mud-flooded area. Ellipsoidal fringes indicate at least 80 cm of range increase and are centered at the eruptive vent.

3.2. Aysen Seismic Swarm

Next example is from southern Chile; a seismic swarm started in January 2007 and lasted until June 2007. Most of the earthquakes have been located at shallow depths (less than 10 km) under fijord (approximately 45.37°S, 73.05°W). Significant amount of continuous and coseismic crustal deformation (maximum 10 cm per month) was observed by a GPS network deployed by the Chilean National Emergency Office (ONEMI) and the University of Chile. A Mw 6.2 earthquake triggered slope failures, and the detached materials plunged into fijord. Consequently, a few meters of tsunami was generated, which washed away most of the GPS and seismic stations. Because the swarm area is surrounded by dense forest, C-band interferometry failed to obtain coherent signals associated with the ground deformation (personal communication with Tim Wright and Matthew Pritchard). Being in such a situation, PALSAR interferometry contributed to monitor this unusual phenomenon.

Two interferograms of the off-swarm period did not indicate any ground deformation, implying that the ground deformation was synchronized with seismic activities. Two interferograms during the swarm period, on the other hand, detected significant amount of deformation (maximum 20 cm of range increase and decrease) and showed complex displacement patterns (Figure 4). Such large deformation is considered to be caused by a mixture of magma intrusions in dikes and seismic and aseismic fault slips. Results obtained from our processing were reported to Chilean researchers which helped to keep track of the activities.

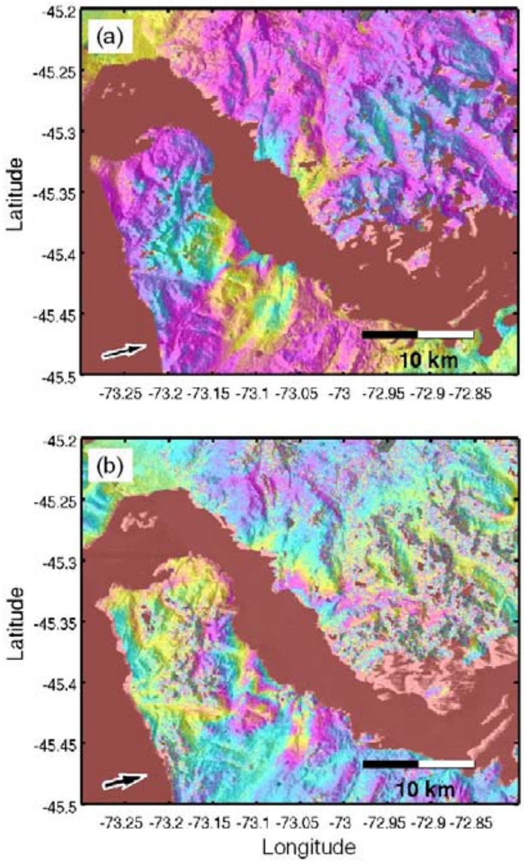

Figure 4. SAR interferograms showing displacements associated with the Aysen seismic swarm, computed from PALSAR FBS and FBD data. Color code is same as that of Figure 3. (a) 15 Feb. – 2 Apr. 2007. (b) 2 Apr. – 3 Jul. 2007. Some phase discontinuities, corresponding to fault movements, are observed. Dark-red area is fijord (sea).

3.3. Noto-hanto Earthquake

In 25 March 2007, a Mw 6.6 earthquake occurred in the Noto peninsula, central Japan. InSAR processing successfully mapped the coseismic displacements from both ascending and descending orbits (Figure 5a and b) in and around the earthquake epicentral region. The line-of-sight displacements toward the satellite from the ascending and descending orbits amount to about 50 cm and 20 cm, respectively.

The interferograms as well as GPS data of the GEONET network operated by GSI are inverted in order to determine the slip distribution on the source fault (work done in collaboration with T. Ozawa, NIED; Figure 5e). The model well reproduces the observed interferograms (Figure 5c and d). The dip and strike angles of the preferred model are 48° and N51°E, respectively, and its fault slip area reaches the seafloor. Details of the analysis is described in [4].

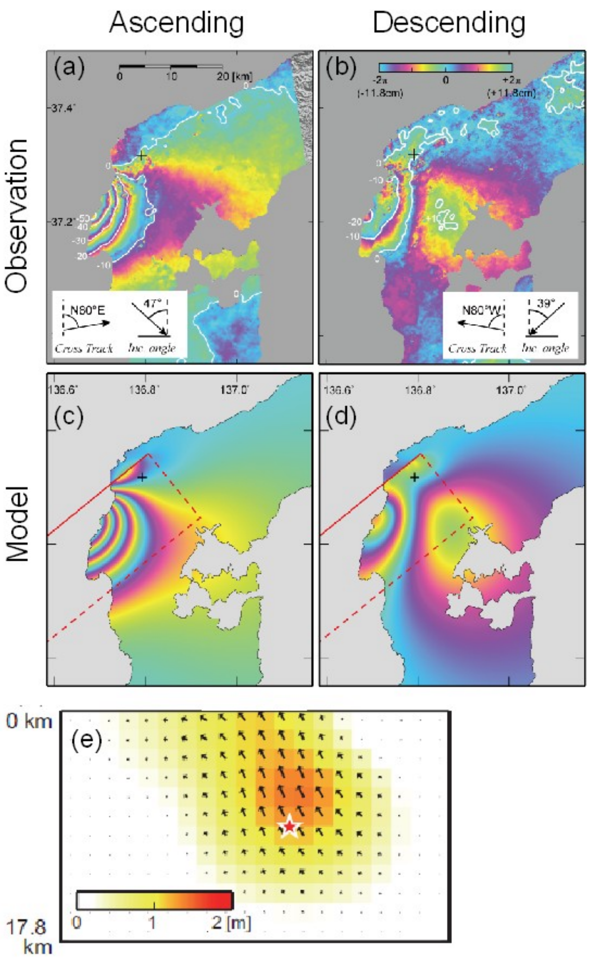

Figure 5. Ascending (a) and descending (b) coseismic interferograms of the Noto-hanto earthquake computed from PALSAR data. The observed interferograms are well explained (c and d) by a fault model (e). The location of the fault is shown in red lines (solid line corresponds to the top). Epicenter of the earthquake (red star in (e)) is located just beneath the area of large slip.

3.4. Earthquake doublet in Sumatra Island

A doublet of earthquakes (M6.3 and 6.4) occurred in March 2007, along the Sumatran fault in Indonesia. The mechanism of the earthquakes determined from seismic body waves (U. S. Geological Survey) was right-lateral strike-slip, consistent with the macroscopic movement of the Sumatran fault. The fault offset of more than 20 cm appeared on the ground, indicating that the coseismic displacements should be observable by InSAR.

A descending interferogram computed from images acquired on 15 Oct. 2006 and 6 June 2007 detected coseismic displacements including phase discontinuities resulting from the surface fault movement (Figure 6a). A reasonable model (right-lateral strike slip) of faults explains the general pattern of fringes (Figure 6b).

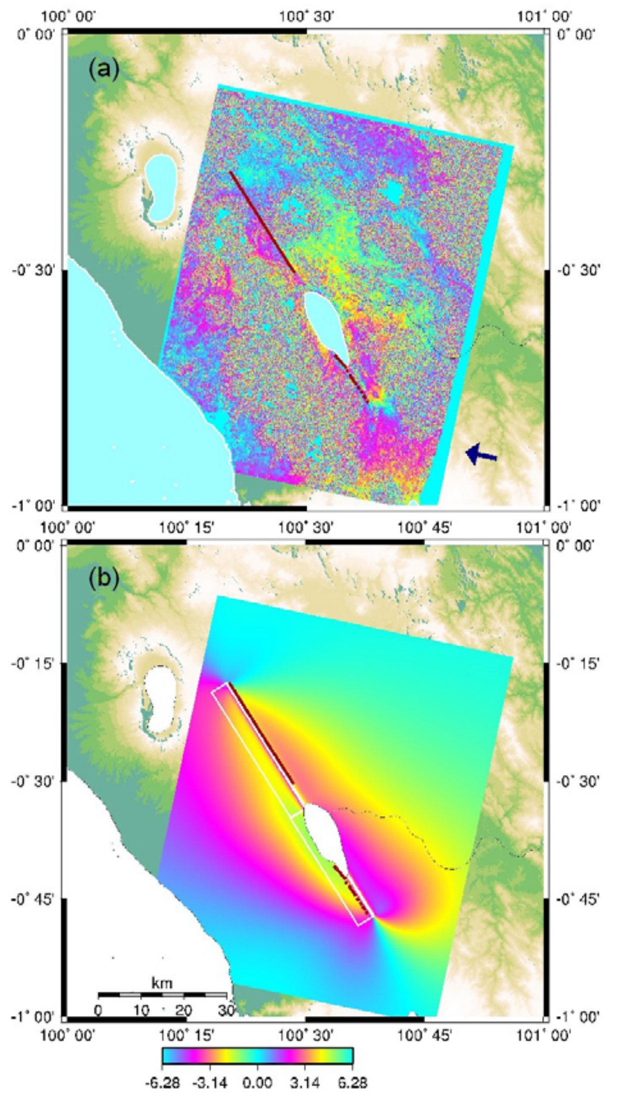

Figure 6. Observed (a) and modeled (b) coseismic interferograms of the earthquake doublet along the Sumatran fault, Indonesia. Dark red lines correspond to surface fault traces. The observed interferogram contains phase discontinuities corresponding to surface fault offsets.

4. TOWARD INTEGRATED PROCESSING SYSTEM

All the examples shown above treated relatively large signals. For earthquake prediction, and for earthquake seismology in general, it is fundamentally important to measure much smaller crustal deformation in an area as wide as possible, as precise as possible, and as frequent as possible. There is hence an intension to develop a system of processing that mitigate noise and produce high-quality interferograms automatically. For this purpose, we have requested strips of data in regions A and B, through the RA contract, shown in Figure 7. These regions include important active faults and subduction earthquake areas. We have made preliminary processings for strip A, which has a 300 km of length (Figure 8), and for B as well. The processing system would eventually include: removal of atmospheric phase delay errors, integration of GPS data (of the GEONET network operated by the GSI), and time-series analysis. Such a system would complement the sparsity of the GPS network and strengthen the crustal deformation detection capabilities. For example, some GEONET GPS data indicate change in the strain rate (Figure 9) that may possibly be related to future earthquake occurrence. InSAR may be able to support such observation and also provide new findings.

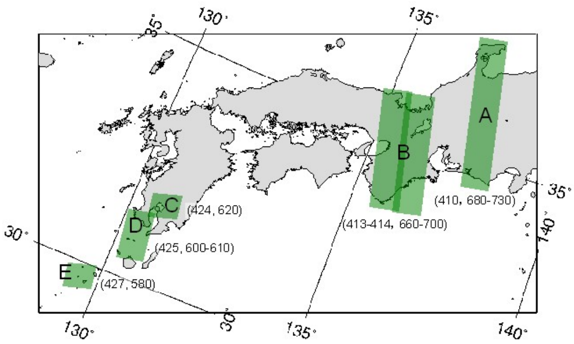

Figure 7. Region on which PALSAR data were requested through the RA constract. A and B include active faults and areas where high rate of strain accumulation (several cm per year) due to plate motions are expected. C, D, and E correspond to active volcanoes that have been monitored by the Sakurajima Volcano Research Center of DPRI.

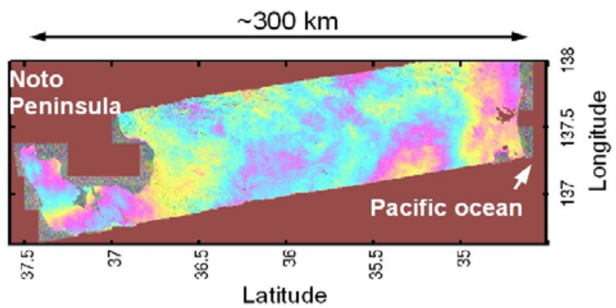

Figure 8. Example of a long-strip interfeogram for the region A of Figure 7. This interferogram probably includes postseismic displacements caused by the Noto-hanto (peninsula) earthquake and some atmospheric noise.

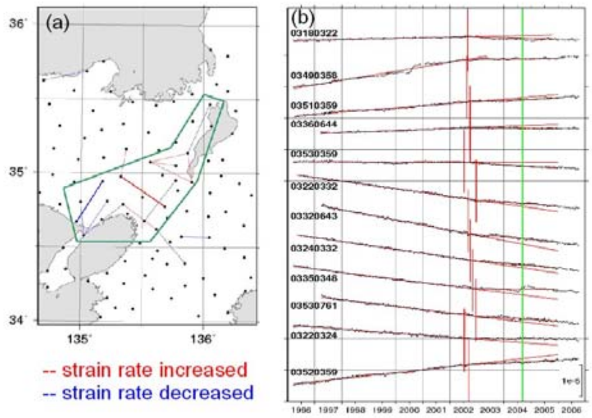

Figure 9. (a) GEONET GPS station pairs that detected change in strain rate. (b) Strain time series for the GPS station pairs on which strain change was observed.

We have also requested data for the volcanoes in southern Japan (Figure 7, regions C, D, and E). Sakurajima volcano (region C) is frequently erupting and GPS is showing long-term inflation for 10 years. Kuchinoerabu-jima, more to the south (region D), is also experiencing unrest, and GPS is showing a few cm of displacements in a few years. We also plan to routinely monitor these volcanoes with InSAR very soon.

Acknowledgement

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