Estimate of crustal deformation around Azumayama Volcano by using SAR data

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Azumayama Volcano is located along the border of the Yamagata and Fukushima Prefecture. The volcanic alert level of Azumayama has been raised to Level 2 since Dec. 2014, which is the highest in the Fukushima prefecture. Level 2 means a probability of an eruption which can damage the area near the crater.

The Advanced Land observing Satellite2 (ALOS2) / Phased Allay L-band Synthetic Aperture Radar (PALSAR2) observes the large area. The technique of interferometric SAR (InSAR) analysis can estimate the ground displacement with the cm-level resolution.

In this research, we examined a crustal deformation around Azumayama. We analyzed the ALOS2/PALSAR2 data observed from September 2015 to November 2016 using the technology of InSAR, comparing the results with the measurement from the 6 GNSS stations around Azumayama. If the crustal deformation obtained by the InSAR analysis of ALOS2/PALSAR2 data is consistent with the measurement by GNSS observation at the corresponding locations, we could integrate the two methods to estimate the crustal deformation of the whole area around Azumayama, spatially- and time-continuously which should complements each other.

As a result, we detected the local crustal deformation around Azumayama by InSAR. The crustal uplift had occurred at Oana crater through 2014/9/9-2015/6/2. No crustal deformation was observed from 2015/6/2 to fall 2015. The subsidence at the west of Azumayama since fall 2015 seemed to be detected for the first time by InSAR.

The InSAR estimates showed very good agreement with the GNSS observations within their errors except for a few cases where phase propagation delays through the ionosphere or troposphere should limit the accuracy of InSAR.

No GNSS station is located at the west of Azumayama. InSAR analysis can contribute to estimate the crustal deformation in the whole volcanic area. By integrating the two different methods of InSAR and GNSS, we would be able to monitor the deformations around Azumayama Volcano multi-dimensionally. It will be an important step toward prevention and/or mitigation of natural disaster.

Keywords: Mt. Azuma, crustal deformation, interferometric SAR, prevention and reduction of natural disaster

3-D deformation mapping by exploiting ALOS-2 InSAR from four different viewing directions –case of Sakurajima volcanic activity in 2015 -

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InSAR can measure surface displacement with high spatial resolution and precision, and has contributed to estimating underground crustal deformation caused by earthquakes and volcanic activities which is difficult to observe directly. One of the limitations of InSAR is its one dimensional measurement capability, i.e., change of distance between the satellite and the ground. Whereas three dimensional (3-D) displacement can be retrieved from multiple InSAR measurements acquired from three or more different viewing directions, it had been unlikely to occur because almost all of satellite SAR acquisitions were right-looking. Although combination with a pixel offset method or multiple aperture interferometry (MAI), which provide displacement along azimuth direction, has been applied to resolve 3-D deformation, it would sacrifice of an inherent capability of InSAR because spatial resolution and precision of a pixel offset method and MAI are lower than that of InSAR.
In Sakurajima, a lot of volcanic earthquakes occurred and extensive deformation was detected by tiltmeters, extensometers and continuous GNSS observations on 15 August 2015. In order to measure the deformation caused by the volcanic activity, emergency observations have been conducted by ALOS-2 shortly afterward. The observations were not only right-looking but also left-looking, resulting in InSAR results from four different viewing directions (i.e., ascending/descending and right-/left-looking) in just nine days.
We estimated 3-D deformation caused by the volcanic activity in Sakurajima and its errors using four interferograms acquired from different viewing geometry. Horizontal expansive displacement of 15 cm at maximum with northeast-southwest direction around Showa crater and uplift of 12 cm at maximum around southeast of Showa crater were detected. The estimated errors of east-west (EW), north-south (NS) and up-down (UD) components are 0.8, 3.4, and 0.7 cm, respectively. The reason why the error of the NS component is larger than that of the other components is that the satellite has a polar orbit. Still, the error is much smaller than the displacement, hence the detected displacement is significant. The RMS errors of EW, NS and UD components between the 3-D deformation and GNSS observations at seven stations installed in Sakurajima are 1.2, 1.6 and 0.7 cm, respectively, which means the 3-D deformation and the GNSS observations are consistent taking into account the error of 3-D deformation.
We also tried to utilize azimuth displacement derived from MAI. However, its precision is much lower than that of InSAR and the estimated 3-D deformation is hardly improved by the MAI result.

Keywords: ALOS-2, InSAR, 3-D deformation, Dike intrusion, Sakurajima

Effect of atmospheric-related noise reduction using numerical weather model –Application to the 2015 Sakurajima dike intrusion event -

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One of the cause of phase errors for InSAR is an effect of atmosphere. An error reduction approach using a correlation between phase change and elevation is often employed. Kobayashi et al. (2014) have developed an error reduction tool using numerical weather model, named AtmDeRay. In this presentation, I report the effect of the atmospheric-related noise reduction using numerical weather model, which is demonstrated by the analysis for the 2015 Sakurajima magma intrusion event. The magma intrusion got started on August 15, 2015. The intrusion was inferred to occur beneath the summit area based on seismicity and geodetic observations. The anomalous activity stopped on the same day, and no remarkable crustal deformation was observed. Emergency observations of ALOS-2 satellite were done for the volcanic activity. The observations are from the east side by ascending/left-looking (path 125) and descending/right-looking (path30) orbits, and from the west by ascending/right-looking (path131) and descending/left-looking (path 23) orbits. The first interferogram produced by the data acquired on August 16 has been strongly affected by atmosphere, in which there are a strong elevation-correlated phase change of about 9 cm in and around Kirishima volcano. In this interferogream, a clear crutal deformation signal with a LOS shortening of about 16 cm is observed in and around Nabeyama which is located in the east of the Sakurajima volcano, and in addition, it should be noted that a LOS shortening signal of about 7 cm is clearly identified at the Minamidake summit. The phase change estimated from AtmDeRay is about 8 and 6 cm at maximum in Kirishima volcano and Minamidake summit, respectively. On the other hand, the predicted phase change around Nabeyama is up to 1 cm at most. Using this phase error model, the phase changes in and around Kirishima and Minamidake summit are suppressed in the range of about 1cm, while the phase change in and around Nabeyama remains as it is. In other inteferograms obtained by the observations from the east side (path 23), there is little effect of atmosphere in and around Kirishima area, and we cannot identify any significant LOS shortening signals at the Minamidake summit. It suggests that the phase change corrected by AtmDeRay possibly reflects the true crustal deformation. The atmospheric noise has a serious effect on the source modeling. When inverting GNSS data and/or other three noise-less interferograms except for path 125, a dike opening beneath the Showa crater is obtained as the possible model. This model cannot account for the LOS shortening at the Minamidake summie seen in the original interferogram of path 125. If using the interferogram before the noise reduction for the source modeling, a crack opening with a low dip angle is determined as the best model, and the model fitting gets rather bad. It suggests that atmospheric noise reduction is indispensable for InSAR-based volcano observations, otherwise there is a possibility that we misinterpret the deformation source and wrongly assess volcanic activity.
Acknowledgements: ALOS-2 data were provided from the Volcano Working Group under a cooperative research contract with JAXA (Japan Aerospace Exploration Agency). The ownership of ALOS-2 data belongs to JAXA. Numerical weather model data were provided from JMA (Japan Meteorological Agency) under a cooperative agreement with JMA.

Keywords: InSAR, Atmospheric-related noise, numerical weather model

Interpretation of InSAR images by FEM: Effects of topography

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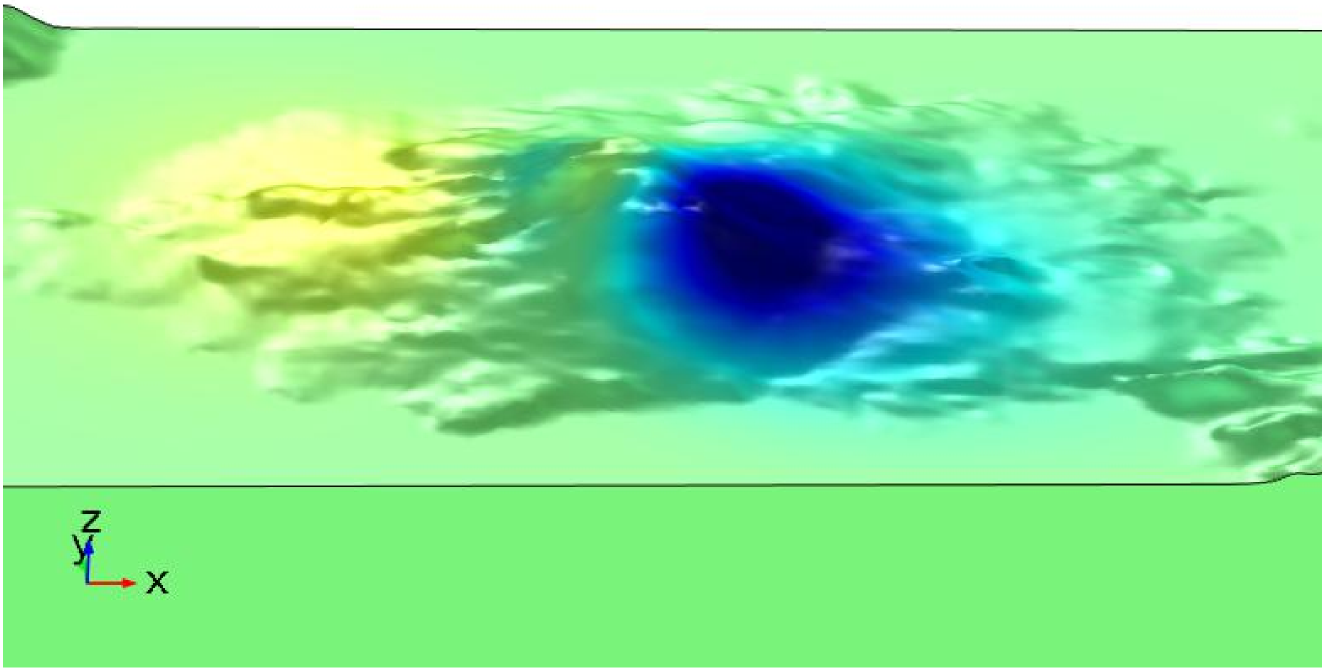
Synthetic Aperture Radar (SAR) plays very important role in detecting volcanic deformation all over the world. Recently, in Japan, volcanic deformation associated with eruption and/or dike intrusion at Mt. Sakurajima, Mt. Kirishima, and Mt. Ontake etc. has been elaborated by using SAR interferometry. The spatial resolution of SAR satellites has been increasing with time, by which we can grasp more detailed surface deformation at the flank and the summit of volcanic edifices. Also, airborne SAR technique is developed to attain higher spatial resolution.
To quantitatively interpret the SAR images of higher resolution, we need improved numerical modelling scheme. Especially for volcanoes with steep edifice, the surface deformation due to shallow dike intrusions should be affected by surface topography. In this study, I develop an improved model of dike intrusion considering realistic topography, and apply it to the InSAR images of Mt. Sakurajima to evaluate the effect of surface topography.
On August 2015, the Japan Meteorological Agency raised volcanic alert level for Mt. Sakurajima to 4, following increased volcanic activities. The InSAR images of Mt. Sakurajima acquired by ALOS2 indicate clear Line-of-Sight (LOS) length change in the island exceeding the noise level. The displacement pattern seems well explained by crack opening. The crack locates in the central part of the island where surface altitude is high. As the crack sits quite shallow depth, it is very likely for InSAR images to be affected by surface topography. I calculated surface deformation by finite element method using COMSOL Multiphysics fully considering the surface topography derived from SRTM (Shuttle Radar Topography Mission) data (Figure). I set a rectangular crack in an elastic medium corresponding to a dike. Given crack opening, the finite element model well explains the InSAR image of surface deformation during August 10 and 24, 2015.
Next, I ran the calculation setting surface altitude as 0 m everywhere, and noticed that the surface deformation gets too large. To explain the InSAR image without considering realistic topography, we have to increase the crack depth by over 500 m. The calculated LOS displacement with such “flat topography” correction still differs from the finite element analysis about 1cm around the summit area. The difference shows positive and negative pairs, which may be identified by further noise reduction. In the presentation, I mention on the model application to other InSAR pairs, and expected topographic effects for shallower crack.

Keywords: SAR, FEM, Sakurajima, Surface topography

Finite element model and dLOS of Sakurajima



Ground-based radar interferometer observation system for monitoring of surface deformation around the volcanic crater

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Ground-based radar interferometer (GBRI) transmits a microwave from an antenna installed on the ground and receives its backscatter from the target. Then change of distance between an antenna and a target is obtained from temporal phase change at each pixel. In previous researches using spaceborne SAR and GNSS, local deformations around craters had been detected in many volcanoes. For researches on volcanic mechanism and on eruption prediction, monitoring of such deformation is important. Then we started the research on GBRI to monitor surface deformation around a volcanic crater and are installing GBRI observation system around the Asama volcano now.

This system is composed by two GBRI sensors; the synthetic aperture radar type (LiSA mobile k09 of LiSALab) and the real aperture radar type (GPRI2 of Gamma Remote Sensing). These GBRIs use the 17GHz microwave with 200-300MHz bandwidth, and then resolution of the range direction is better than 1 meter. LiSA mobile k09 transmits a microwave while the antenna moves on the rail of 3m, and high resolution for the cross-range direction can be obtained by synthetic aperture processing. On the other hand, GPRI2 uses the antenna with 2.5m width for cross-range direction, and comparable resolution for cross-range direction with LiSA mobile k09 can be obtained.

GPRI2 was already installed in the Asama volcano observatory of the Earthquake Research Institute, the University of Tokyo, and we started test observation. At February 2016, observation area is covered by snow. In such situation, coherence during 1-hour was stable in most time. However, non-deformation component such as tropospheric delay has often reached to 2cm in 1-hour, and then reduction of such component is one of big issues in this research. In the presentation, we will show investigation results for longer observation data. Furthermore installation of the LiSA mobile k09 will be finished in March. We will also show its initial observation result in the presentation.

Keywords: Ground-based radar, volcano, deformation

GB-SAR technology and its deployment

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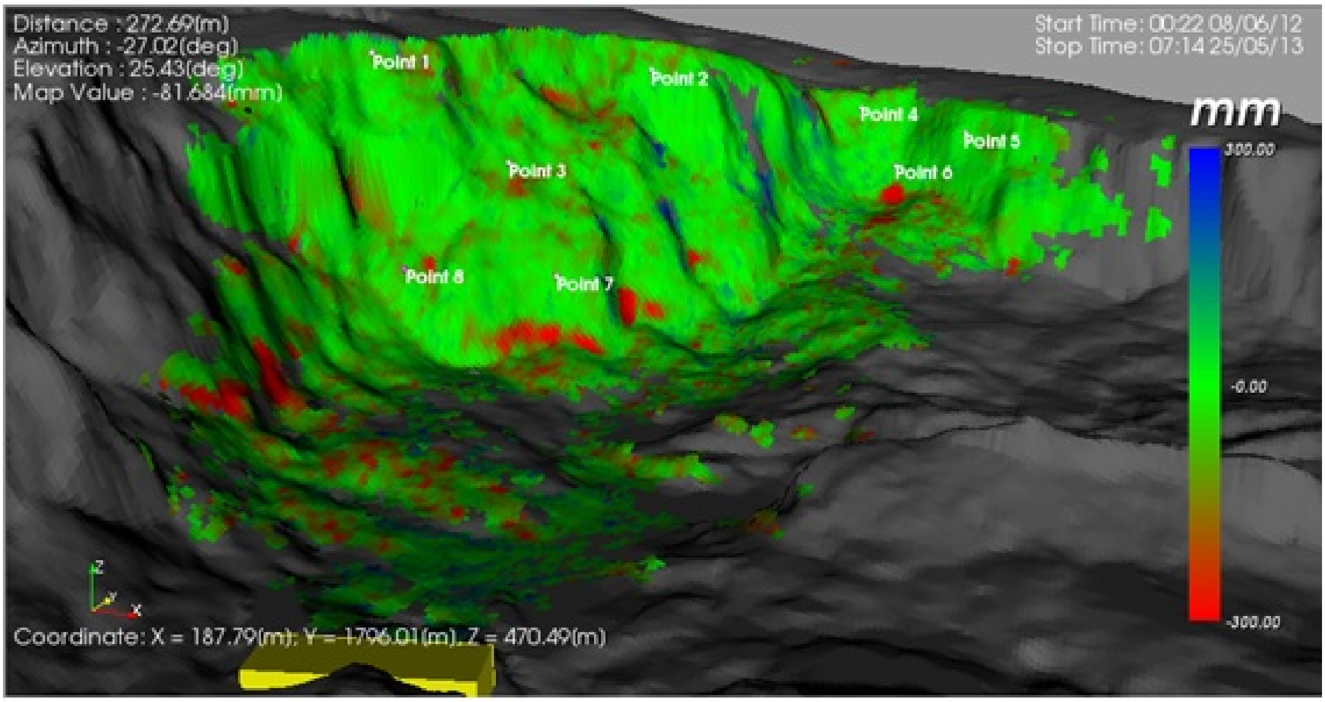
GB-SAR (Ground Based Synthetic Aperture Radar) is one kind of Synthetic Aperture Radar (SAR), whose platform is fixed on the ground surface. GB-SAR is useful for monitoring slow varying phenomena such as ground deformation due to landslide and volcanic activities. One GB-SAR system can monitor wide area with high resolution, therefore we do not have to select discrete positions to be measured, which is common for conventional methods such as GPS and strain meter. GB-SAR technology has been developed since 1980s, where most pf the system employed a vector network analyzer (VNA) as a transmitter and a receiver. Then in 1990, commercial systems have been deployed, which can acquire much faster than VNAs. These GB-SAR systems used a liner rail to move a radar unit with a pair of transmitting and receiving antennas. Recently, multiple fixed antennas can also be used for realize GB-SAR systems.
Frequency allocation is an important problem in practical use of GB-SAR. In European Union, 17GHz has been used for GB-SAR, and the same frequency is widely used also in Japan. GB-SAR information changes dependent on the operation frequency. Different frequencies should be studied for useful use of GB-SAR.
Compared to space borne SAR systems, GB-SAR normally images near range targets. Therefore, SAR processing algorithm used in space borne SAR systems cannot be used, and generally the SR processing of GB-SAR data required relatively larger computation for the size of the data sets. In order process the data faster, we are proposing a method to use fractional Fourier transformation. Then in order to obtain higher resolution, we are using CS (Compressive Sensing) approaches.
Even though the targets are located relatively short range, for example, a few hundred meters to 1km, we found that the atmospheric effect is very strong in interferometric analysis. Atmospheric correction is quite important for accurate measurement in SAR interferometry.
Tohoku University is operating 3 sets of GB-SAR systems using 17GHz. One of the systems is fixed at Arato-zawa landslide site located in Miyagi prefecture since November 2011. Interferometric SAR images are obtained in real time and transferred to the university through internet. This is a social demonstration of real time warning system, which is a collaboration of Tohoku University and Kurihara city. This type of observation is strongly required in Japan. We are now planning to use it for observation of volcanic activities.
Then we are now testing GB-SAR for vibration observation of bridges and other social infrastructures and buildings.

Keywords: GB-SAR, Landslide, vibration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Elevation : 25.43(deg)
Map Value : -81.684(mm)
Start Time: 00:22 08/06/12
Stop Time: 07:14 25/05/13
Point 1
Point 2
Point 3
Point 4
Point 5
Point 6
Point 7
Point 8
mm
300.00
-0.00
-300.00
Coordinate: X = 187.79(m), Y = 1796.01(m), Z = 470.49(m)

Antarctic ice shelf and ice sheet through ALOS-2 / PALSAR-2 satellite

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After the two years of launch of ALOS-2 satellite, PALSAR-2 collected the fine data on Antarctic continent and surrounding ice shelves. We would like to report the first two years of results using ALOS-2 / PALSAR-2 data. Our study focus on two subjects, one is 3pass or 4pass DInSAR (DDInSAR) analysis for detection of marginal zone between ice sheet and ice shelf, known as "grounding line". It is very few 3pass InSAR pairs even after two years of data accumulation, we introduce the intermidiate report of the analysis through the comparison of grounding lines made by ERS-1/2 and ALOS / PALSAR data respectively. The other is time series analysis of ice shelf change on Prinsesse Ragnhild Kyst. This area is located on East Antarctica, where its climatological change is said to be relatively calm. We investigate the variation of the ice shelf trough the time series SAR backscatter image analysis.

Keywords: ALOS-2, InSAR, Time series analysis

InSAR measurement of ground subsidence at permafrost areas: preliminary results

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Permafrost thawing due to global warming can not only change any local hydrological and biological systems but also generate methan gasses that could further contribute to enhance gobal warming. Moreover, ground subsidence associated with permafrost thawing is another natural hazard to social infrastractures such as roads and pipelines in high-latitude regions. However, a comprehensive mapping of on-going permafrost thawing and refreezing is challenging, because of their remote and wide spatial coverage.
Liu et al. (2015, JGR-ES) suggested that satellite synthetic aperture radar interferometry (InSAR) could reveal on-going subsiding signals around thermokarst, which could tell us the dynamic processes and thus the mechanisms responsible for on-going permafrost thawing, using satellite remote sensing.
Meanwhile, at Yamal Peninsula, northern Siberia, four caldera-like collapsed topographies were discovered, whose maximum diameter and depth reach 37 meter and 70 meter, respectively. These sudden collapses are attributed to the rapid thawing of permafrost due to the anomalously high air-temperature in recent years.
Given these backgrounds, we have performed InSAR measurements over Yamal Peninsula to examine if any ground deformation has been on-going. We will report and disucss our preliminary results and isssues.

Keywords: permafrost, InSAR, thermokarst, ground subsidence, ionosphere

Phase shift observed over a forest stand with PALSAR-2 SAR interferometry in Hakone

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Volcanic activity has increased in Owakudani Park, Hakone, Japan, since April 26, 2015, including a small eruption that occurred on May 29. Several Phased Array type L-band Synthetic Aperture Radar-2 (PALSAR-2) observations were conducted to detect crustal movement near the crater area. A phase shift of about 90° over a Japanese cedar forest stand located near Owakudani Park was clearly observed for the interferometric pair on March 1 and May 10, 2015. However, no clear phase shift was observed for the adjacent broadleaf forest stand. Except for the pair, no clear phase shift was observed over the forest stands.

Watanabe et al. [1] used L-band Synthetic Aperture Radar (SAR) to determine that the dielectric constant corresponding to moisture in a tree trunk often increases after rainfall and induces sigma-0 increase. Rainfall of 10.5 mm/h was observed 6 h prior to the observation on March 1, which may have affected the ground phase beneath the cedar forest stands.

A model describing the phase delay due to water vapor in the atmosphere [2] is introduced in the present study to describe the phase delay due to the moisture change in a forest layer. It is indicated that the estimated phase shift due to the moisture variation of trees is 109° assuming a 20% refractive index variation, which was actually observed in trees in Tsukuba and Tomakomai. This result implies that the possible cause of the phase shift observed over the Japanese cedar forest stand was caused by moisture change in the forest layer after the strong rainfall.

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[2] M. Shimada, “Correction of the satellite’s state vector and the atmospheric excess path delay in the SAR Inerferometry—An application to surface deformation detection,” J. Geodetic Soc. Japan, 45(4), 327-346, 1999

Keywords: Moisture

Detection of slope failure using ALOS and ALOS-2 data –Application to Mt. Fuji

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Synthetic aperture radar (SAR) has an advantage for acquiring information in wide area with high spatial density, and this advantage would be effective for slope failure detection. However, some slopes are difficult to be monitored because of low coherence due to slope angles or surface coverings. In this study, we applied InSAR analysis to Mt. Fuji, which has been recently paid attention to its slope failure, and clarified slopes that can be monitored by InSAR analysis. Some case studies of slope failure detection were also done.
Our InSAR results using ascending and descending data showed the slopes opposite to radar illumination exhibits low coherence likely due to the shadow effect. Accordingly, it is possible to monitor most of slopes using either ascending or descending data. However, the western slopes of Mt. Fuji constantly showed low coherence in both ascending and descending data. This is attributed to the layover effect in ascending data and the shadow effect in descending data. Compared with ALOS and ALOS-2 data analysis, ALOS-2 results have larger high coherence areas compared with ALOS result. We also found the slope failure in the Houei crater. These results show the effectiveness of slope failure monitoring using InSAR analysis of ALOS and ALOS-2 data.

Keywords: SAR interferometry, Slope failure, Mt. Fuji

Preliminary Analysis of Airborne SAR Interferomery Using Pi-SAR-L2 Data

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1. Introduction
Synthetic-aperture radar (SAR) is a powerful tool for volcano monitoring that enables all-weather non-contact remote sensing covering wide area on the globe. Space born SAR like PalSAR2 onboard ALOS2 already becomes a standard method for volcanology, whereas airborne interferometric SAR remains at an experimental stage for a long time, owing to many obstacles coming from difficulties to keep flight trajectories of paired observations close enough to each other. Recent progress in airborne SAR technology, the capability of the instrument is improving. Here process Pi-SAR-L2 data to evaluate the technological possibility of L-band airborne SAR interferometory.
2 Interferometry of .Pi-SAR-L2 data and Results
Pi-SAR-L2 is equipped with a precise INS-GPS hybrid type navigation system so that high level trajectory control is achievable. In reality, a perfect identical routing of the flight is still difficult because of unpredictable aeronautical conditions during the flight. As a result, the distribution of the phase of the interferogram suffers from phase undulations caused by the entangled nature of the geometric configuration of the trajectories. An appropriate removal of those phase undulation caused by the complexity of the wake is the key factor for an effective detection of crustal deformation information. Here we try a relatively simple approach based on surface fitting for the removal of this unwanted phase undulations. As a test target area we selected Sakurajima region where a magmatic intrusion event took place in August, 2015 and crustal deformation is already confirmed by ALOS2 InSAR and GNSS analyses. The Pi-SAR-L2 data were granted by JAXA. For interferometric analysis we used RINC (ver. 0.36) software developed by Dr. Taku Ozawa at NIED. We processed a pair acquired on 2013/9/13 and 2014/8/7 spanning over a period when no crustal deformation was detected. We obtained initial interferogram by simple differentiation of two data sets (SLC) following a standard process of RINC software. At this stage the phase distribution is a mixture of several components coming from different origins, such as incompatibility of repeating trajectories, topography, propagation medium inhomogeneity and crustal deformation on the ground surface. For the detection of crustal deformation, we at least have to remove phase undulation caused by the incompatible trajectories. In this study we removed this undulation using a simple surface fitting technology. As a first step we found the entire interferogram can be devided into 3 parts separated by 2 range lines across which phase continuity is lost. Because in each of the patches we confirmed that the phase change is smooth, we carried out surface fitting assuming quadratic function for each patch separately. Then we subtracted the best fit surface component from the original interferogram. As the next step we also subtracted the best fit component proportional to ground undulation. We applied these processes separately for each of 3 patches of the original interferogram and finally we combined all the results. We found that the distribution of remaining phase is within +/- half wave length range which corresponds to about +/- 6 cm. This indicates the possibility of the air-borne interferometry for the detection of crustal deformation similar to the 2015 intrusion event beneath Sakurajima.
Acknowledgement: The airborne sar data were provided by JAXA. We used RINC(ver.0.36) developed by Dr. Taku Ozawa at NIED. We also used digital elevation model by GSI.

Keywords: Crustal Deformation, Volcanology, Remote Sensing, Airborne SAR

PALSAR-2 ScanSAR Interferometry - Full Aperture processing and Specan processing -

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PALSAR-2 has wide observation capability using the ScanSAR with the amplitude image and the ScanSAR-ScanSAR interferometry. This paper describes the sensitivity of the PALSAR-2 ScanSAR and compares the performances between Specan SAR and full aperture SAR data.

Keywords: PALSAR-2, ALOS-2

