Deformation monitoring using the PALSAR and the related activity (JAXA PI-194)

Masanobu Shimada, Osamu Isoguchi, and Yousuke Miyagi
Earth Observation Research Center (EORC)
Japan Aerospace and Exploration Agency, (JAXA) Sengen 2-1-1, Tsukuba, Ibaraki, Japan, 305-8505, Voice 81-29-868-2474,
Fax: 81-29-868-2961, shimada.masanobu@jaxa.jp

Abstract PALSAR is an L-band synthetic aperture radar, which is being operated onboard the ALOS since March 2006. During the last one-year and a half, PALSAR acquired more than 500,000 scenes using different modes (FBS, FBD, SCANSAR, POL) and almost collected 5 times global coverages in mainly 34.3 degrees off nadir angle. Since the operation termination of the JERS-1 SAR on Oct. 12 1998, L-band SAR has been long waited because L-band SAR is only capable of monitoring the deformation of even the vegetated or forested region. Out of the PALSAR image pairs, we conducted the performance evaluation of the L-band SAR interferometry, especially the coherence and the phase detection performance depending on the incidence angle. This paper summarizes the PALSAR InSAR potential and the current results acquired for the crustal deformation monitoring. L-band SAR potentially contains higher coherence for the longer temporal and spatial separation. The PALSAR data showed that it has quite high performance for detecting the deformation even in the dense forest region.

Keywords PALSAR, ALOS, InSAR, DinSAR

I. Introduction
The Advanced Land Observing Satellite (ALOS), JAXA’s flagship Earth-observation satellite, was launched on January 24, 2006 to an altitude of 691.5km in a Sun synchronous orbit with a 46-day repeat cycle. It carries two high-resolution optical sensors and one radar for land monitoring (JAXA web). PALSAR is an L-band synthetic aperture radar onboard the satellite, with a high resolution, a high-quality imaging capability allowing an average ground resolution of 10m, a high transmission power of 2Kw, and the ability to change the incidence angle (from 7.7 degrees to 60 degrees). PALSAR has five observation modes, 1) Fine-Beam Single mode (FBS), with a high slant range resolution of 5m, a 70km imaging swath, and single polarization, 2) Fine-Beam Dual mode (FBD), with a medium-range resolution of 10m with a 70km swath, and two orthogonal polarizations for reception, 3) Polarimetry mode (PLR) with a 35km swath, 10m slant range resolution, and full polarizations for transmission and reception, 4) SCANSAR mode (SCAN) with 100m resolution, a 350km swath, and single polarization, and 5) Direct Single downlink mode (DSN) with 10m resolution, and a 70km swath with single polarization. The PALSAR has been radiometrically and geometrically calibrated using the corner reflectors deployed worldwide (Shimada et al., 2006).

The radar wavelength is 23.6cm, almost the same as the one used by GPS, so the Synthetic Aperture Radar (SAR) can observe the Earth’s surface penetrating the aboveground biomass of tree trunks and canopies, independently of the weather and day-night conditions. Thus, an interferometric SAR analysis is advantageous and robust for providing quantitative deformation and height maps for even the highly vegetated land areas. With regard to the calibration of the PALSAR, it has been conducted successfully [3],[4].

II. Data acquisition
PALSAR data is being acquired systematically following the basic observation scenario, which was established to harmonize the majority of the data users, and scientific researchers [1]. Current status of the PALSAR data is summarized in Table 1, and it shows that the roughly the five times global coverage of the earth land was acquired already. The basic observation is the 34.3 degrees of off-nadir angle.

Table 1 PALSAR data amounts

<table>
<thead>
<tr>
<th>Off-nadir</th>
<th>Number of images</th>
</tr>
</thead>
<tbody>
<tr>
<td>FBS-21.5</td>
<td>11997</td>
</tr>
<tr>
<td>FBS-34.3</td>
<td>124370</td>
</tr>
<tr>
<td>FBS-41.5</td>
<td>143503</td>
</tr>
<tr>
<td>FBD-34.3</td>
<td>144916</td>
</tr>
<tr>
<td>POL-21.5</td>
<td>75212</td>
</tr>
<tr>
<td>SCANSAR (WB1)</td>
<td>17212</td>
</tr>
<tr>
<td>SCANSAR (WB2)</td>
<td>579</td>
</tr>
<tr>
<td>Total</td>
<td>545833</td>
</tr>
</tbody>
</table>

Note: The statistics covers the period of May 16 2006 ~ Oct. 22, 2007

III Incidence angle dependency of the InSAR coherence and the phase difference
Interferometric coherence defined in Eq. (1) measures the quality of the interferometric performance of the SAR.

\[ C_{ij} = \frac{\langle m_i \cdot s_j \rangle}{\sqrt{\langle |m_i|^2 \rangle \langle |s_j|^2 \rangle}} \] (1)

where, mi is the pixel of the master image, is the corresponding pixel in the slave image, <> is the ensemble average. Cij is a complex value representing the coherence and the phase difference between two images.
In order to evaluate the incidence angle dependence of the InSAR coherence, we prepared five image pairs in the Hawaii Island of the Hawaii islands, USA, which are listed in Table 1. Five incidence angles are prepared at 9.9, 21.5, 34.3, 41.5 and 50.8 degrees. The images were selected such that the perpendicular baseline is more than 2 km since possibility to detect the vegetation height using the SRTM DSM for correcting the topography is also desired.

<table>
<thead>
<tr>
<th>Case</th>
<th>Off-nadir</th>
<th>Date1</th>
<th>Date2</th>
<th>Bperp</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>9.9</td>
<td>20060723</td>
<td>0060607</td>
<td>1.89km</td>
</tr>
<tr>
<td>2</td>
<td>21.5</td>
<td>20060728</td>
<td>20060612</td>
<td>1.74km</td>
</tr>
<tr>
<td>3</td>
<td>34.3</td>
<td>20060802</td>
<td>20060502</td>
<td>0.054m</td>
</tr>
<tr>
<td>4</td>
<td>41.5</td>
<td>20061107</td>
<td>20060622</td>
<td>2.39km</td>
</tr>
<tr>
<td>5</td>
<td>50.8</td>
<td>20060817</td>
<td>20060702</td>
<td>2.34km</td>
</tr>
</tbody>
</table>

Note: Case 3 of 34.3 degrees off nadir has small baselines of 54m.

Figs 1 to 5 show the results. The images are coherence and deformation maps terrain corrected using SRTM 90 and projected onto the UTM.

III-1) 9.9 degrees
Fig. 1a and Fig.1b show the coherence map and deformation pattern. While the coherence of the target is quite low, the deformation pattern looks clearer. Since the near range is deformed severely by the foreshortening or the layover, this incidence angle does not bear the further data analysis.

III-2) 21.5 degrees.
The coherence is slightly better than 9.9-degree case, however the quality cannot be satisfied. The phase information looks fine.

III-3) 34.3 degrees
The coherence is improved so much. This is because the electric performance of this off-nadir is designed best. The baseline of 89 m is not suffered from the spatial decorrelation. The surface siren of the Kilauea volcanic area is easily confirmed by the PALSAR.

III-4) 41.5 degrees
This off nadir angle gives great performance of the coherence and the surface deformation. The circular pattern in this area shows the surface rise of the region due to the volcanic activity.

III-5) 50.8 degrees
This case was provided by the maximum off nadir angle that the PLASR offers. Surprisingly the coherence recorded the high value while the amplitude image looks dark.

In terms of the coherence, the larger off-nadir angle gives the higher coherence and thus the fringe quality is improved. In terms of the SNR, the smaller angle exceeds the one in the larger off nadir. However the truth is this.
IV. PALSAR Interferometric Path processing

One interesting challenge is to generate the interferometric path image. This may detect more global scale land movement than the scene-by-scene interferometry while the memory limitation always is against. By modifying the SIGMA-SAR processor [2], which the JAXA SAR imaging and InSAR processor, for allocating the memory size within 2 GB. One example over the Peru is shown in Fig. 6, which has around 900km in length and the 70 km in width. Coherence looks high and the deformation pattern still contains high fringes at the south of the image. This may be explained by the ionospheric irregularity appeared at this area. Other than this figure, we succeeded more than 2000km length InSAR recently. Thus, the path interferometry can be available soon.

V. The other examples

Here, we introduce more samples that were derived from the PLSAR DinSAR.

a) Kilauea Volcanic activity

Kilauea of the Hawaii Island is one of the very active volcanoes. The PALSAR first detected the surface rise of the Kilauea volcano using the 92 days separated but 54m specially separated PALSAR image. The analysis shows that the area is uplifted around 12 cm at maximum.

b) Peru earthquake

Two-path mosaic of the surface deformation at the Peru is shown in Fig. 7. The image dimension is around 500km in north south and 200km in east - west. We can confirm the border between two paths. Two adjacent paths are acquired 17 days in separation. During these days, post seismic deformation might have occurred. This could make the border of the fringes.

c) Solomon island case

On April 2 2007, M. 8.1 earthquake occurred at the Solomon Islands as the Australian plate and the pacific plate collided. Three path DinSAR were mosaicked without orbital tuning. Any stripe can be visible between the each of two neighboring paths. This means that the orbital accuracy of the ALOS is enough good for DinSAR analysis, and that the image has high coherence although the land is covered by dense forest.
IV Conclusion
We analyzed the incidence angle dependence of the PALSAR INSAR for five different off nadir angle of 9.9, 21.5, 34.3, 41.5, and 50.8 degrees. High incidence angle gives higher coherence. Although the high incidence has a demerit in SNR and range ambiguity, the results overcome this disadvantage. In the future satellite, the high incidence angle may give us the good signal for obtaining the coherence and the surface imaging (less foreshortening and the lay over as well.

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References

Fig. 7 Two path mosaic of the surface deformation cause by the Peru earthquake of Aug. 2007.

Fig. 8 Solomon Island deformation, which was made using three path DinSAR results.

References