INTERFEROMETRIC ANALYSIS OF ALOS/PALSAR DATA FOR LAND SUBSIDENCE MONITORING AND CRUSTAL DEFORMATION DETECTION

PI No. 134

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1. INTRODUCTION

Spaceborne synthetic aperture radar interferometry (InSAR) technique is powerful tool to detect the earth's surface topography and its deformations as land subsidence.

The main purpose of this study is the examination of the correlation properties of ALOS PALSAR data pairs for interferometric applications. Fringe continuity on the interferogram is important for DEM generation and earth2.1. surface's change mapping. Correlation properties of the radar echoes are important to extract continuous fringes. Previous studies show the importance of baseline distance, stability of the land surface, observation interval and topographic features. For interferometric application of ALOS PALSAR data, it is necessary to prove the effect of these factors.

For the first step of this research including a term before ALOS launch, we analyze JERS-1 and ERS-1,2 SAR data for preliminary study. After ALOS launch, we evaluate the aptitude for interferometric analysis of ALOS PALSAR data by comparison with the result of interferometric analysis for other satellites' SAR data.

We also aim to land subsidence monitoring using PALSAR data. Evaluation of the effects of atmospheric factors in interferogram is important for detecting earth's surface changes including land subsidence. We plan to examine the cloud perturbation on interferogram with AVNIR-2 data that are simultaneously obtained with PALSAR data[1][2][3].

2. JERS-1 SAR DATA ANALYSIS

2. 1. Methodology

Several JERS-1 SAR data pairs were analyzed for preliminary studies. Main test site is Kanto plain and a region including Sendai city. Differential interferograms were extracted using JAXA/SIGMA-SAR.

2. 2. Extracted Interferogram

Perpendicular baseline distance is important for extracting continuous fringe from JERS-1 SAR data. It is difficult to extract inferferometric fringe from the data pairs of which perpendicular baseline distance is more than 1000m. Fig. 1 and 2 are extracted interferograms and coherence maps from the data pairs for a region including Sendai, Japan. Orbital direction for Fig. 1 is ascending and that for Fig. 2 is descending. Perpendicular baseline

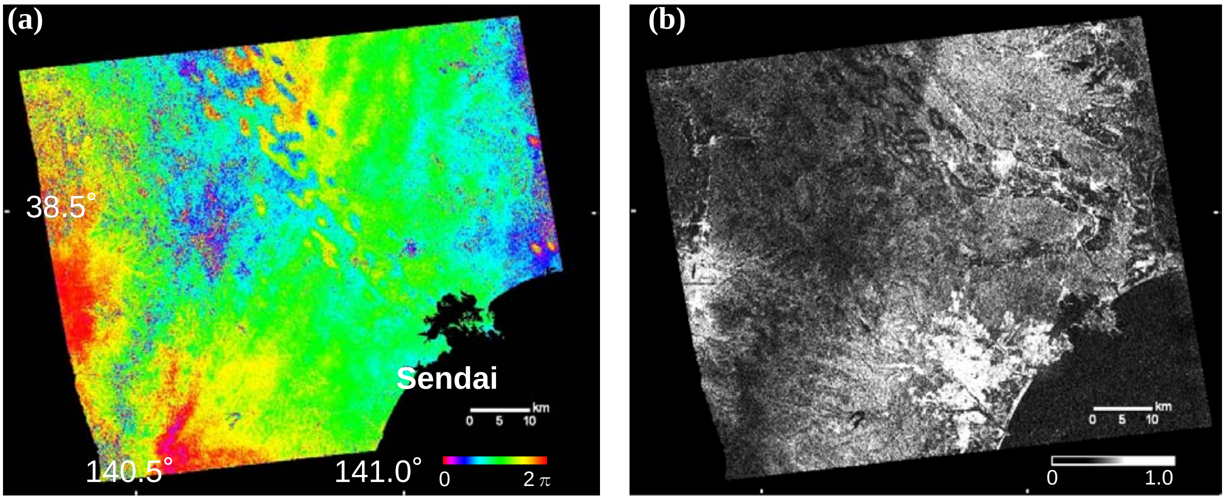

Fig. 1 (a) JERS-1 SAR interferogram and (b) coherence image for a region including Sendai, Japan from images obtained on 2 March 1998 and 15 April 1998.

distance from orbital information for Fig. 1 is 48m and that for Fig. 2 is 98m. Obvious fringe discontinuity and decorrelation is found in Fig. 2(a). Its long observation interval (3 years) is one of the possible reasons for the decorrelation.

Some of the interferograms include fringe features which are independent from actual deformations and topography (Fig.s 1(a), 2(a)). Similar patterns clearly appear to the coherence patterns (Fig.s 1(b), 2(b)). Signal processing or registration errors are possible to cause these patterns, but there is no conclusive evidence.

3. ERS SAR DATA ANALYSIS

3. 1. Methodology

We analyzed ERS SAR data pairs covering the Kanto Plains, which is a region including Tokyo, Japan. Large urban and agricultural zones occupy the major part of this area.

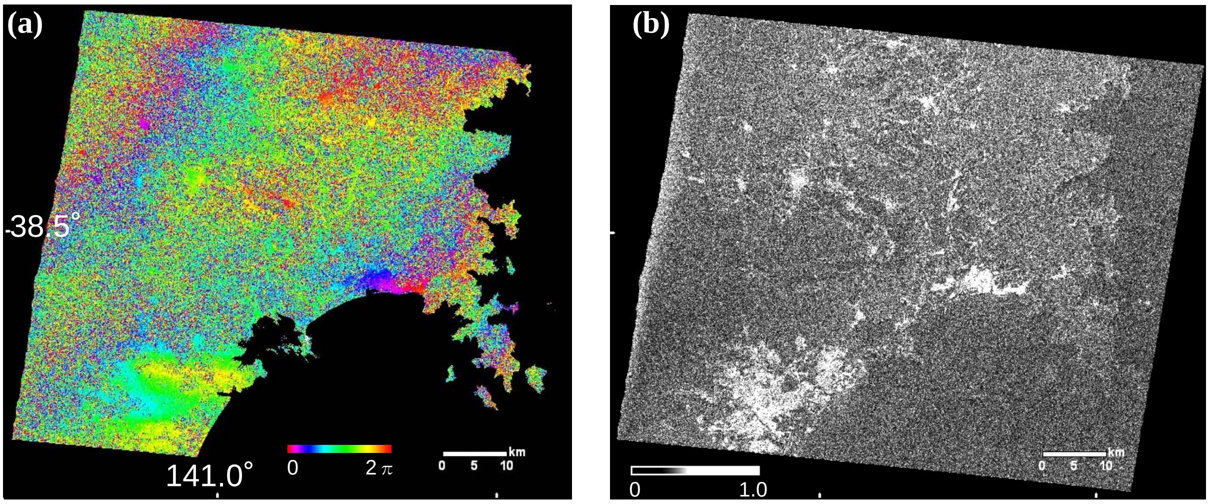

Fig. 2 (a) JERS-1 SAR interferogram and (b) coherence image for a region including Sendai, Japan from images obtained on 14 December 1994 and 4 November 1997.

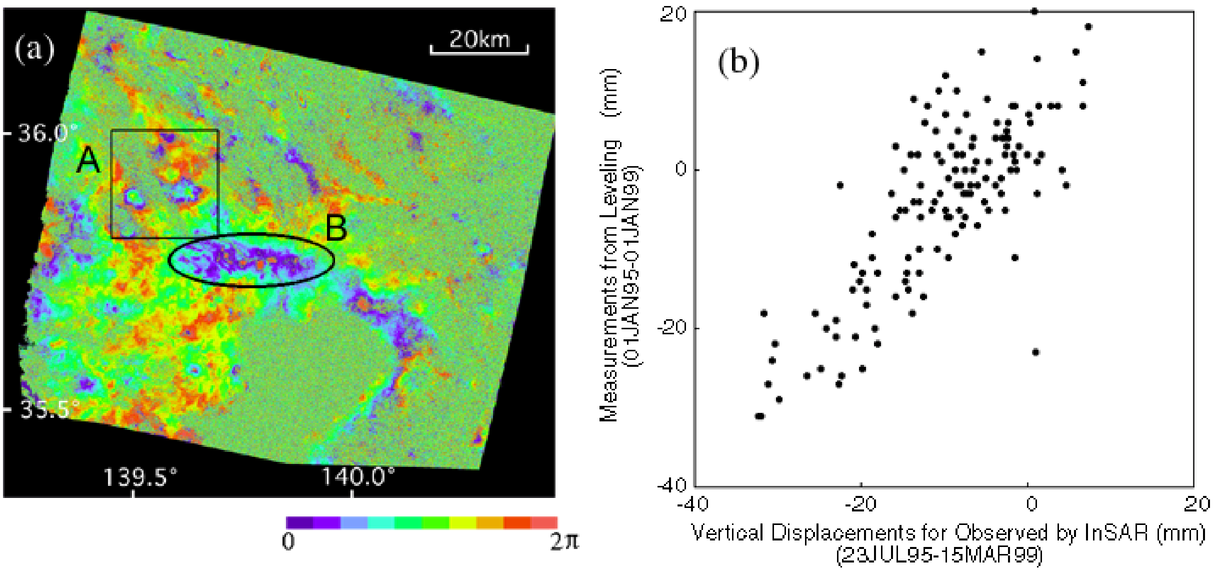

Fig. 3 (a) ERS-2 Interferograms from images obtained on 23 July 1995 and 15 March 1999. Rectangle A outlines the area where the common circular concentric fringe patterns appear. Ellipse B shows the feature that is interpreted as being produced by atmospheric contributions. (b) Comparison between vertical displacement derived from the interferograms and annual leveling data. InSAR data represent displacements within rectangle area A on Fig. 3(a) that corresponds to the leveling station locations. Observation periods are 23 July 1995 and 15 March 1999 (interferogram) and 1 January 1995 and 1 January 1999 (leveling).

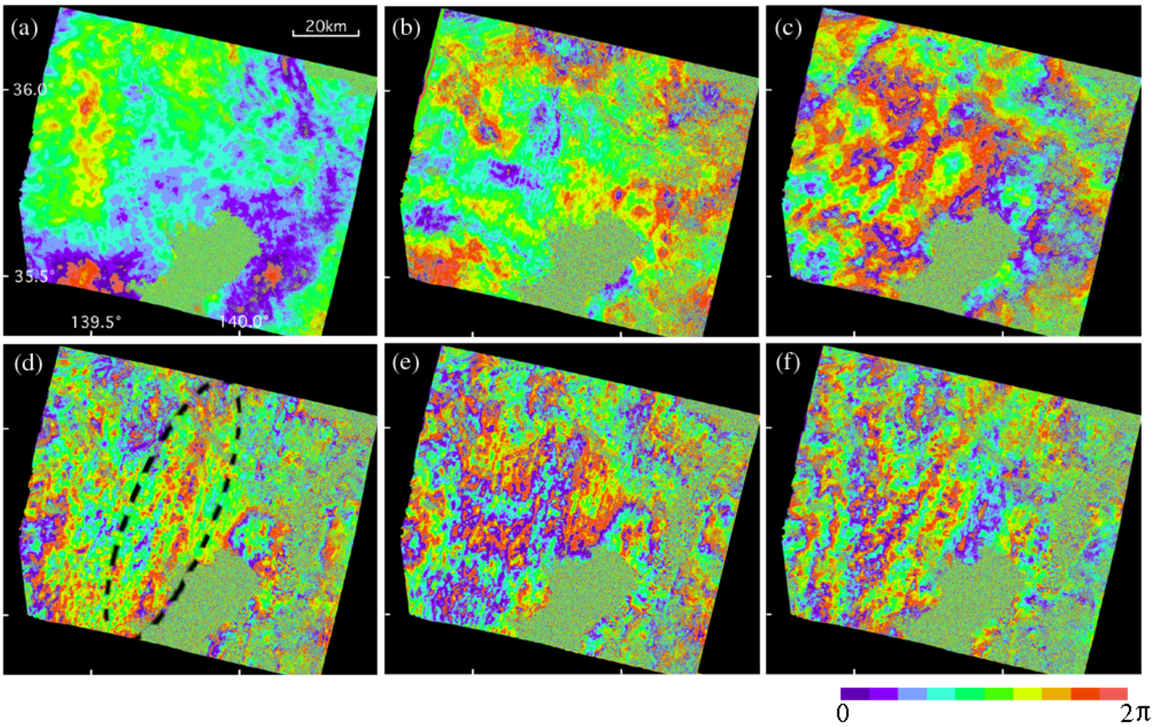

Fig. 4 ERS-1,2 Interferograms for the Kanto Plains, including Tokyo, Japan: (a) 8 February 1999 and 15 Marc 1999, (b) 8 February 1999 and 24 May 1999, (c) 24 May 1999 and 28 June 1999, (d) 8 February 1999 and August 1999, (e) 24 May 1999 and 2 August 1999, and (f) 28 June 1999 and 2 August 1999. The dashed line i Fig. 4(d) indicates "typical features".

The raw data were processed using a 3dSAR processor from Vexcel Corporation. When processing two data sets, the older one was fixed as a master data for extracting an initial interferogram. The topographic effect on the fringe pattern was removed using a 50 m grid Digital Elevation Model (DEM) from the Geographical Survey Institute, Japan. Orbital and systematic atmospheric fringes were removed manually using simulated patterns by assuming perpendicular baseline changes. More than 60 interferograms have been extracted.

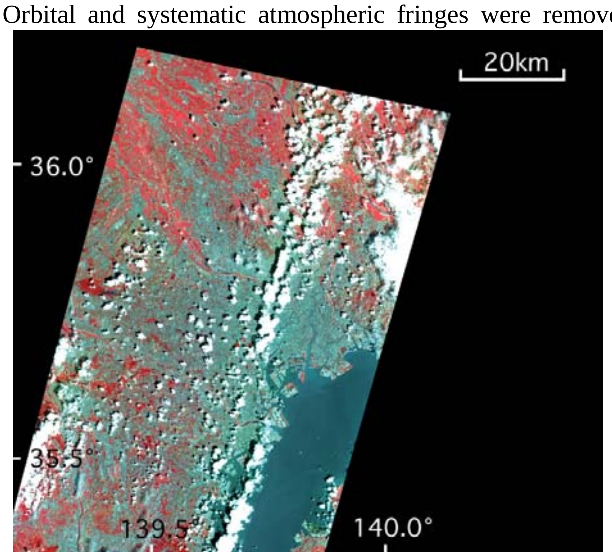

Fig. 5 SPOT HRV image obtained on 2 August 1999 a 01:40 UT, and registered to the images in Fig. 4(d).

3. 2. Land Subsidence Detection

Continuous fringe patterns were extracted from the urban area. However, fringe pattern is discontinuous on mountainous and covered by vegetation area.

The interferograms were unwrapped and all slant range displacements were converted to vertical displacements. Annual leveling of the land has been conducted by the Saitama-prefecture since 1965. The relative vertical displacements around Saitama city were compared with those obtained from the leveling results (Fig. 3). The observed amount of leveling strongly supports InSAR measurements.

3. 3. Cloud perturbation

The interferograms derived from data pairs acquired in 1999 include fringe features that are independent of land deformations (Fig. 4). Typical features are found from the interferogram from the 8 February 1999 and 2 August 1999 data (Fig. 4(d)). Patterns related to monotonic phase differences of greater than 0.5 cycle are seen. The phase differences increase towards the core of the dimples, suggesting that the phase of the August data is delayed relative to that for the February data in the dimpled zone.

The short observation intervals - less than 0.5 years - suggest that these patterns are independent of surface movement. These patterns can be attributed to radar signal delays caused by the troposphere.

A SPOT HRV image (Fig. 5) with a ground resolution of 20 m obtained 18 minutes after the August SAR observation strongly supports the assumption that the phase delay was caused by cloud. The features in the central part of the interferograms of the August data are very similar to the cloud distribution patterns in the SPOT HRV image. GMS-5 visible-channel images suggest that the air flow direction at the time of the SPOT HRV and ERS SAR data acquisitions was from SSW to NNE.

4. PALSAR DATA ANALYSIS ON SENDAI PLAIN

4. 1. Methodology

We have analyzed PALSAR data pairs covering Sendai, Japan. This area is downwind side of Oou mountain Range. The atmospheric gravity waves are commonly observed over this area.

PALSAR observes the same area with different off-nadir angle. There are datasets acquired from descending orbit with off-nadir angle 21.5°, 34.3°, 41.5°, and 50.8° on the study area. AVNIR-2 simultaneously observed the study area for several times [5][6].

Differential interferograms were extracted from the same off-nadir angle data pairs using JAXA/SIGMA-SAR.

4. 2. Fringe continuity

Several interferograms extracted in this study are shown on Fig.s 6 and 7. PALSAR interferograms generally show good fringe continuity in each off-nadir angle dataset. Fig. 6 show interferograms from the data pair of which off-nadir angle is 34.3°. Perpendicular baseline distance from orbital information for Fig. 6 (a)～(f) is 2190m, 2554m, 95m, 550m, 565m and 505m, respectively. Fig. 7 show interferograms of which off-nadir angle is 41.5°. Perpendicular baseline distance from orbital information for Fig. 7 (a)～(f) is 323m, 1155m, 943m, 1110m, 882m and 234m, respectively. Fig. 6 and 7 show that possibility for extraction of continuous fringe on mountainous area

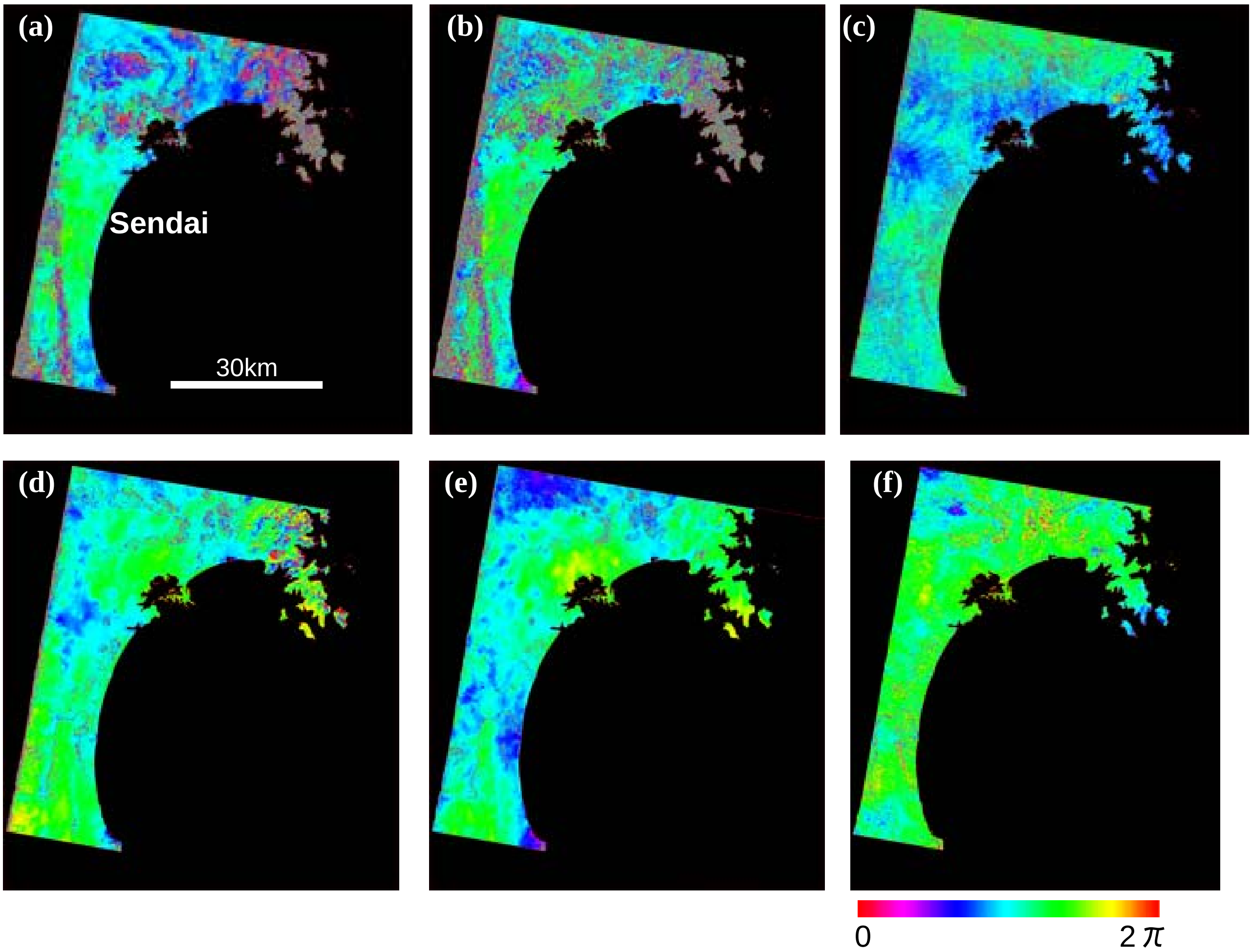

Fig. 6 PALSAR Interferograms for the areas including Sendai, Japan.: (a) 24 September 2006 and 25 December 2006, (b) 24 September 2006 and 12 August 2007, (c)25 December 2006 and 12 May 2007, (d) 25 December 2006 and 12 August 2007, (e) 12 May 2007 and 12 August 2007, and (f)12 August 2007 and 27 September 2007. Observation off-nadir angle is 34.3°

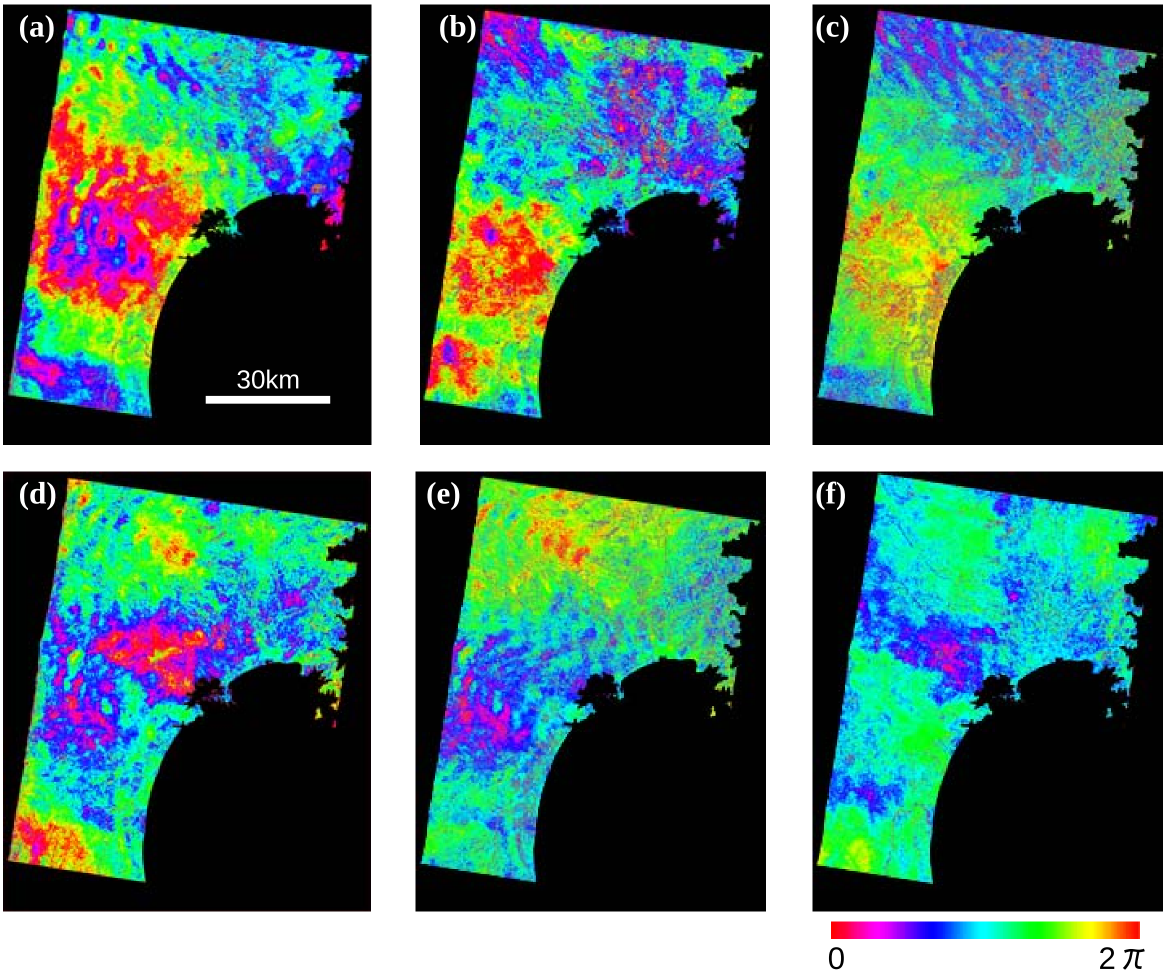

Fig. 7 PALSAR Interferograms for the areas including Sendai city, Japan.: (a) 19 June 2006 and 4 August 2006, (b) 19 June 2006 and 19 September 2006, (c) 19 June 2006 and 4 November 2006, (d) 19 September 2006 and 4 August 2006, (e) 4 August 2006 and 4 November 2006, and (f) 19 September 2006 and 4 November 2006. Observation off-nadir angle is 41.5°

covered by vegetation from data pairs of which perpendicular baseline distance are less than 1200m. Continuous fringe patterns were extracted from the urban and agricultural area on the data pairs of which perpendicular baseline distance are more than 2000 m. Fringe extraction from long baseline distance (more than 1000m) data pairs is difficult from the JERS-1 SAR data set. And continuous fringe extraction from mountainous area is difficult on the ERS-1,2 SAR data analysis. PALSAR show good property for interferometric application by short observation interval (less than one year) data pairs compare to these previous spaceborne SAR sensors.

4. 3. Comparison with AVNIR-2 image

Most of the interferograms generated in this study show fringe features that are independent from actual surface movement. These patterns are not corresponded with geographical features.

We compared these fringe patterns with the simultaneously observed AVNIR-2 images. Fig. 8 is AVNIR-2 images acquired on the simultaneous with the PALSAR data for the interferograms on Fig. 7. Several patterns appeared on the PALSAR interferograms corresponds to the cloud distribution patterns shown in AVNIR-2 images. For example, rippled fringe patterns are appeared on Fig. 7(a), (b) and (d). These interferograms are extracted from data on 4 August 2006. The rippled pattern corresponds with the thin cloud distribution pattern appeared in AVNIR-2 image observed on 4 August 2006 (Fig. 8(a)). Cloud distribution pattern shown in AVNIR-2 image possible to demonstrate effect of atmospheric turbulence.

4.4. Off-nadir angle difference

We examined the interferograms by the data pairs with different off-nadir angle. Generally, larger off-nadir angle data pair shows the larger phase difference patterns. For example, phase change cycles appeared in Fig. 6 is smaller than those in Fig. 7. Slant range increase with the off-nadir angle. Atmospheric phase delay increase is consistent with the slant range increase.

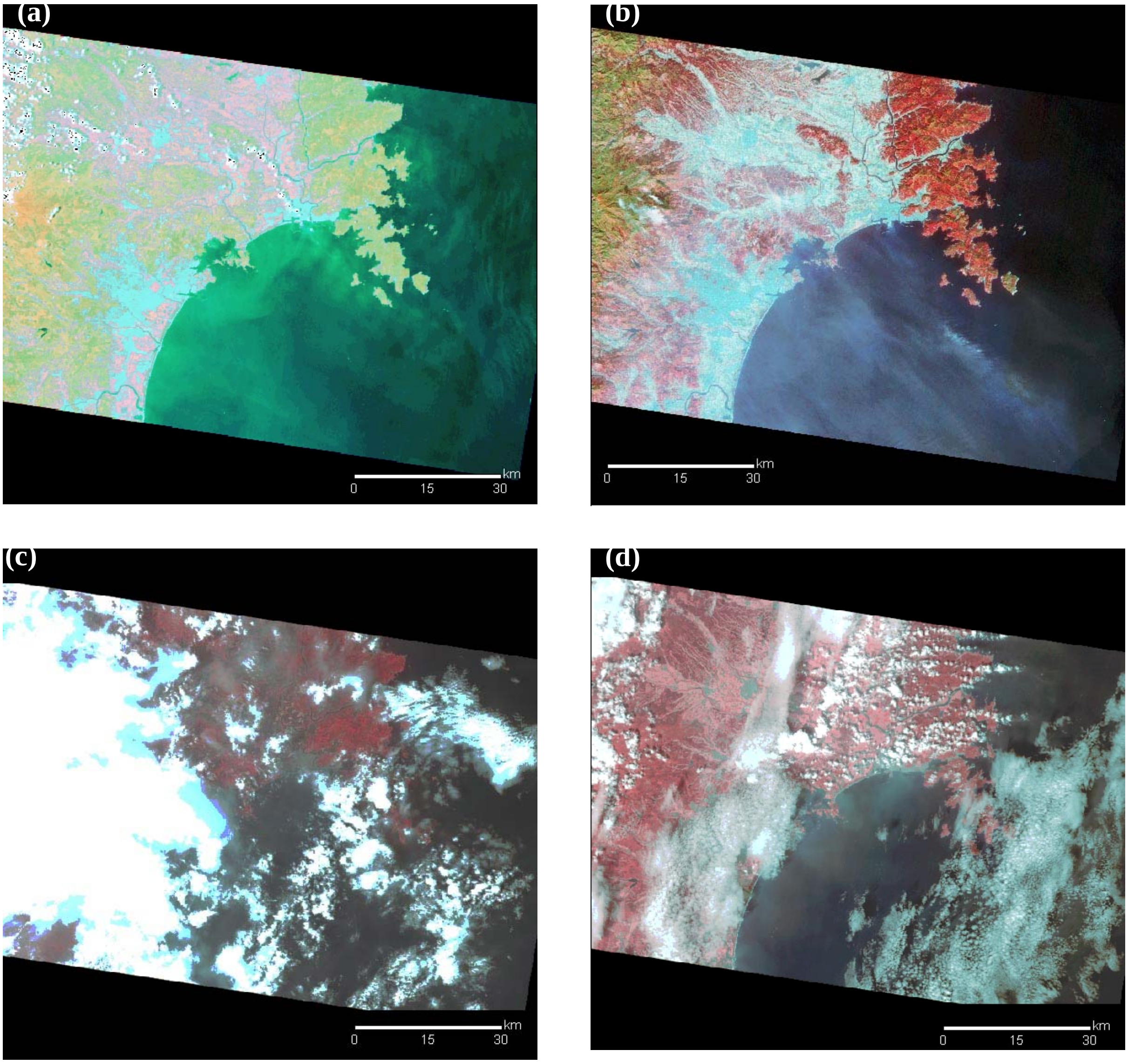

Fig.8 AVNIR-2 images: (a) 4 August 2006, (b) 4 Novemer2006,(c) 19 June 2006 and (d)19 September 2006 .

5. PALSAR DATA ANALYSIS ON LAND SLIDE AREA, TSURUOKA CITY

5. 1. Methodology

A landslide had been occurred from February 2009 at Shimekake in Tsuruoka city, Japan. Its width and length are 400 x 700 m and 2 m scale subsidence in some area has been observed. Several PALSAR data pairs observed before and after the landslide have been analyzed.

PALSAR observes the same area with different off-nadir angle. We analyzed one datasets acquired from descending and three datasets from ascending orbit with off-nadir angle 34.3° on the study area. Differential interferograms were extracted from the same off-nadir angle data pairs using JAXA/SIGMA-SAR.

5. 2. Extracted Interferogram

Fig. 9 is extracted interferograms from the data pairs observed on 14 June 2009 and 9 June 2007 for a region including Tsuruoka, Japan. Orbital direction for Fig. 9 is ascending. Perpendicular baseline distance from orbital information is 1019 m. Several fringe continuities are observed in the figure, which may be due to crustal movement. But no obvious fringe discontinuity related to the landslide is observed. We could not detect landslide pattern from another data pair analyzed in this study. Small size of the landslide or/and low coherence may be the reason for failure of the detection. Long temporal or perpendicular baseline distance may cause the low coherency.

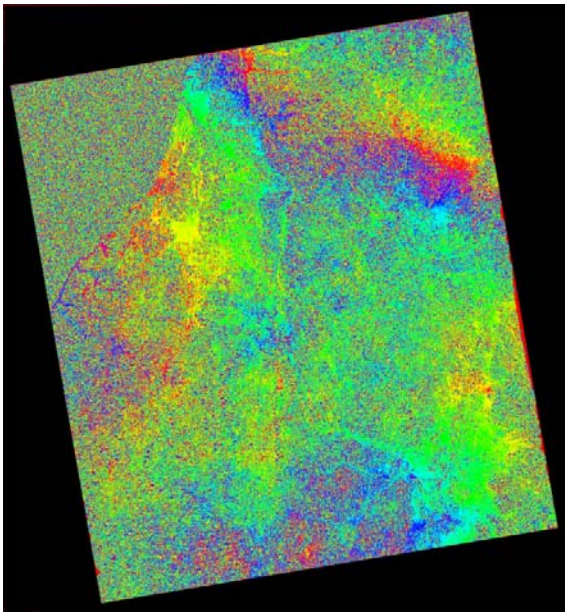

Fig. 9 Interferograms derived from the data pairs observed on 14 June 2009 and 9 June 2007 for a region including Tsuruoka, Japan.

6. PALSAR DATA ANALYSIS OBSERVING DAMAGES CAUSED BY THE IWATE-MIYAGI NAIRIKU EARTHQUAKE ON 2008

6. 1. The Iwate-Miyagi Nairiku Earthquake

An earthquake hit inland area of Iwate and Miyagi prefectures in Japan at 8:43 AM (JST) on June 14, 2008. Magnitude as determined by the Japan Meteorological Agency is Mj 7.2. The earthquake is named Iwate-Miyagi Nairiku Earthquake. Epicenter is located on the south of the inland part of Iwate prefecture. Seismic intensity by Japanese meteorological agency is 6-plus in Oushu city, Iwate and Kurihara city, Miyagi. The earthquake caused massive landslides on mountainous area. Thirteen people were died and 10 people were missing by this earthquake and most of the victims were killed by the landslides. The landslides caused dam up of rivers, collapse of artificial dams and closure of roads.

6.2. Methodology

ALOS obtained many data immediately after the earthquake. We analyzed AVNIR-2, PRISM and PALSAR data observing the damaged area. Interferogram was generated from PALSAR data using

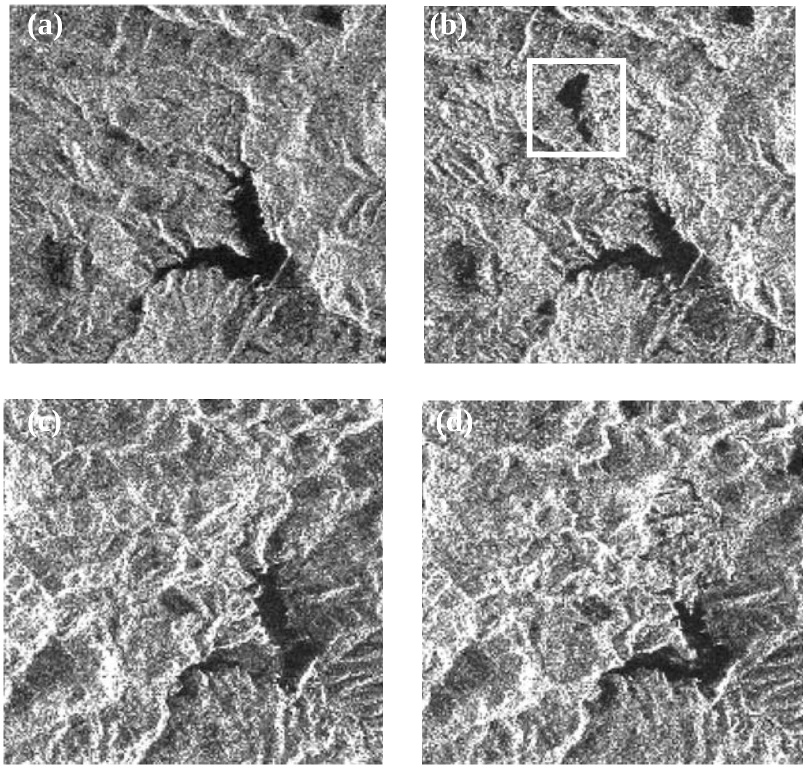

Fig.10 ALOS PALSAR intensity imageries of Aratozawa-dam in Miyagi prefecture for (a) 21 June 2007, (b) 23 June 2008, (c) 2 August 2006 and (d) 22 June 2008. Polarization is HH. (a) and (b) were observed from ascending orbit with off-nadir angle of 34.3°. (c) and (d) were observed from descending orbit with off-nadir angle of 21.5°. Box on (b) shows radar shadow region.

JAXA/SIGMA-SAR. Damaged area was also extracted by visual interpretation [7][8][9].

6. 3. Observed landslides by PALSAR

Landslide at north of Aratozawa-dam clearly appears on AVNIR-2 imagery. Land coverage of damaged area had been forest, and it changed to bare land by the landslide. Influent sediment to the dam is possible to be recognized. Pan-sharpen imagery by PRISM and AVNIR-2 is useful to distinguish detail of land features.

The sediment influent in the dam and land features change by the landslide appears on PALSAR intensity imageries (Fig.10). Decreasing of backscattering is found on northwest side of the landslide area in ascending orbit imageries. This decrease appears in all of the imageries obtained after the earthquake on ascending orbit with 47.8°and 34.3°off-nadir angle. This decrease of backscattering is caused by radar shadow. Radar shadow occurs at terrain slop facing away from the radar beam by relationship between terrain slope and radar incidence angle. Descending intensity imageries do not contain this radar shadow. SAR intensity imagery is capable to extract huge land features change. SAR imageries from different orbit direction or optical sensor imageries are helpful to examine the actual change.

6. 4. Extracted Interferogram

Fig. 11 presents interferograms derived from the data pairs observed on 19 June 2006 and 24 June 2008 near epicenter. Orbital direction is descending and off-nadir angle is 41.5° . Clear crustal movement is observed around epicenter, while phase information is destroyed near the epicenter due to a sudden change of the ground surface. The fault plane is estimated as 20 km in length and 12 km in width, the average slip is 3.5 m from simulation based on GPS observation. Maximum uplift observed by GPS is 2.1 m. Extracted interferogram support this simulation.

7. SUMMARY

The objective of this study is to discuss applicability of ALOS PALSAR data for interferometric analysis. ALOS PALSAR is L-band SAR and has been expected to detect land surface elevation and deformation using interferometric technique.

In this study, we examine the correlation properties of ALOS PALSAR data for the purpose of extraction of continuous land surface deformation by long interval data pairs. Continuous fringe pattern is appeared from both flat and mountainous area on data pairs of which observation interval is less than 1 year even their perpendicular baseline distance is approximately 1000 m. Crustal deformation pattern caused by an earthquake is extracted from a data pair with two years temporal baseline. However, we could not detect small scale landslide from the data pair with two years observation interval and more than 1000 m perpendicular baseline. It is difficult to

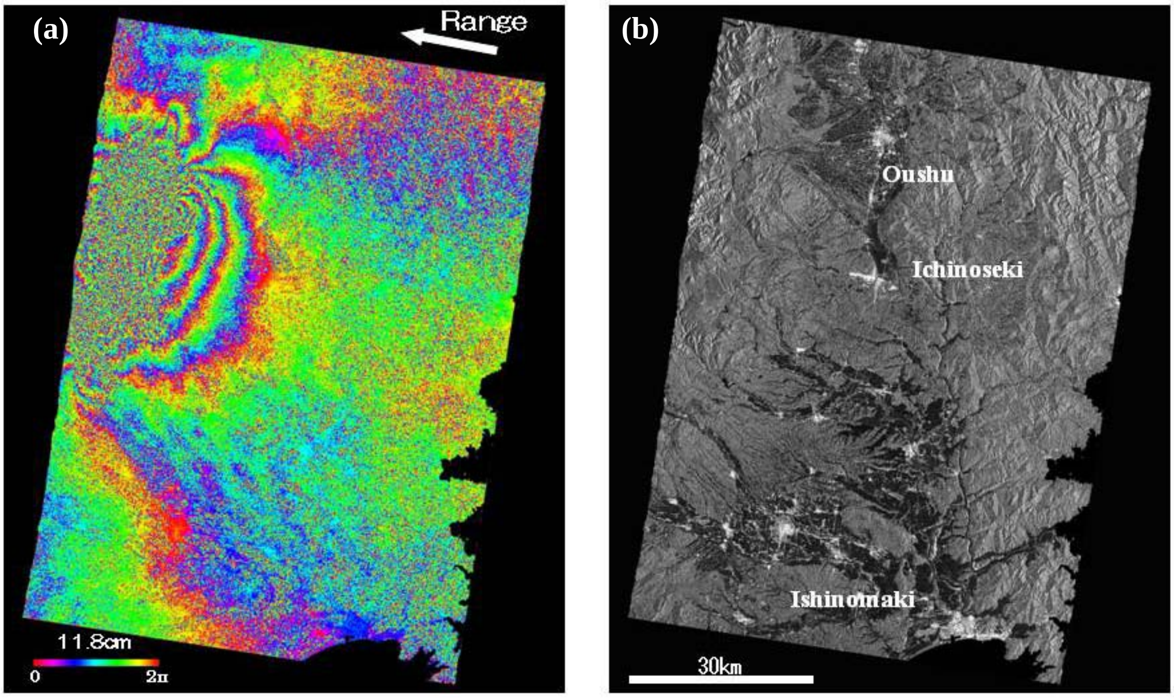

Fig. 11 (a) Interferograms derived from the data pairs observed on 19 June 2006 and 24 June 2008 near epicenter . (b) Intensity image on 24 June 2008.

extract deformation pattern from phase variation caused by low coherency.

Atmospheric effect for phase delay is a problem for crustal deformation detection. Simultaneous observation data AVNIR-2 with PALSAR suggests a possibility for atmospheric disturbance. To remove this effect, quantitative evaluation is necessary.

Acknowledgement

We thank JAXA SIGMA-SAR software (M. Shimada 1999) to generate our interferograms.

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