Measuring land displacement in Boso Peninsula Japan by Differential Interferometry SAR Technique

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Abstract

The Philippine Sea plate is subducting beneath the Boso peninsula, central Japan, with the Pacific plate underlying the Philippine Sea plate and the complicated tectonic setting is occurred here, followed by numerous seismic events. In order to detect the temporal and spatial pattern of surface deformation in this area, we use the benefit tool of Interferometric Synthetic Aperture Radar (InSAR) method. The raw SAR data which is from 2 C-band acquired by the ERS-1 SAR satellite from 1992 to 1996 are analyzed by using GAMMA, EarthView-3 software commercial software and SIGMA_SAR software respectively. We explored the ability for producing the best interferogram between them. In SIGMA_SAR software, by using Goldstein-Wagner filter, we are successfully increasing Signal Noise Ratio (SNR) on the interferogram image. The DEM 50 m Japan is used to remove the topography effects from InSAR fringes. Our InSAR mapping suggests that subsidence occurs around Mobara region (at the center InSAR image), and the uplift area was detected both in northeast and in Chiba city extending to the northwest of its city. We estimated that our InSAR image has peak amplitude of ~ 5 to 8 cm in line of sight (LOS) direction during 1992-1996 time period. To compare our result, we also analyzed 3 interferograms of JERS-1 data from 6 scenes L band SAR data (1993-1996). Even though the coherency of ERS-1 interferogram is higher than JERS-1 data pair, in general, we got almost the same pattern displacement from both ERS-1 and JERS-1 data. We also present evidence of the subsidence area from leveling data which recorded during 1993-1997. The radar observations of land subsidence are in good agreement with leveling data. However, the radar data provides a more detailed mapping of both the amplitude and spatial extent of land subsidence.
Key words: Boso Peninsula, InSAR, subsidence, leveling

1. INTRODUCTION

The Philippine Sea plate is subducting beneath the Boso peninsula, central Japan, with the Pacific plate underlying the Philippine Sea plate (see Fig. 1). Because of the complicated tectonic setting, shown in figure 1, seismic events are numerous off the coast of the Boso p eninsula. The coupling rate off the east coast of the Boso peninsula is estimated at between 1 and 2 cm/year with the southern part showing a higher coupling rate between the Philippine Sea plate and the overriding North American plate **(Sagiya T., 1997.)** There were several earthquakes that have been reported off the Boso peninsula such as slow slip event in May 1996 which has peak GPS displacement of 15 mm **(Ozawa *et al.,* 2003,** and **Sagiya, 2004)** , October 2002 and recently earthquake on August 27, 2007. Moreover, the rapidly subsiding areas north of Tokyo and in the eastern part of the Boso peninsula have also reported due to the product of ground water pumping and natural gas extraction, respectively **(Geographical Survey Institute, 1999).**

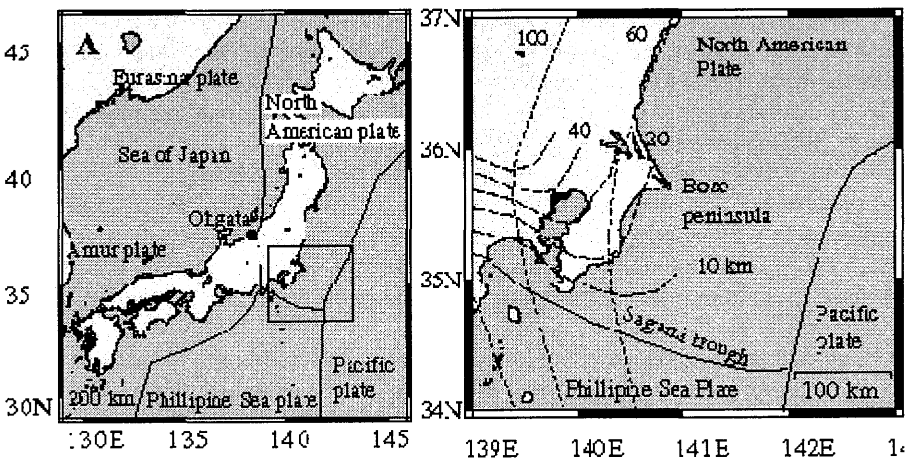

Figure 1. Tectonic map in and around the Boso peninsula, central Japan

Investigating of land displacement associated with either earthquake or aseismic activity can be detected by Global Positioning System, leveling data and Interferometry Synthetic Aperture Radar (InSAR) method. Permanent GPS observation sites (GEONET) set up by the Geographical Survey Institute of Japan (GSI) have been in operation since 1994. Unfortunately there was few GPS receiver around Boso peninsula (only 3 sites). As a result, measurement land displacement using GPS observation in large spatial area could not be performed. Therefore we use the benefit InSAR method to estimate land displacement during 1992 – 1996 period in Boso peninsula area.

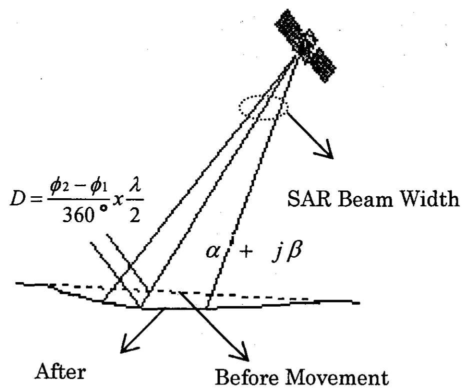

Figure 2. Image acquisition geometry of SAR. φ_1 and φ_2 are the phase differences obtained from the two image scenes related to slant range change D and λ is the wavelength. $\alpha+j\beta$ is the Cartesian representation of amplitude and phase recorded by the SAR

Spaceborne radars on the ERS and JERS-1 satellites have been successfully used for surface deformation studies, including coseismic deformation associated with earthquakes **(Massonnet *et al.*, 1993; Zebker *et al.*, 1994; Murakami *et al.*, 1996)**, volcanic deflation **(Massonnet *et al.*, 1995; Rosen *et al.*, 1996)**, and glacier motion **(Goldstein *et al.*, 1993)** with centimeter- to millimeter-scale precision, and this became a key result to promote many studies on InSAR application for disaster monitoring due to earthquakes or volcanic eruptions.

A single SAR image does not contain enough information to say anything about the movement or relative height change of the imaged scene **(Soren, N.M, H.A. Zebker, and J.Martin, 1992)**. InSAR combines two complex and co-registered images of the same scene from almost identical perspectives into a so-called interferogram. The phase difference for each picture element (pixel) in the interferogram is a measure of relative change in distance between the ground (scatterer) and the SAR antenna as shown in Figure 2.

In general, the phases corresponding to differential range change in the interferogram will contain topographical information as well as movement information. Thus, there is a need for two interferometric pairs (4 images), so that the first two images can be used to generate an accurate topographical model or Digital Elevation Model (DEM) and then this model can be used to remove the topographical phases from the subsequent pair to obtain movement information. This technique is called differential interferometry. In principle, phase relating to range change can be written as

$$\Delta\varphi = \Delta(\varphi Topography) + \Delta(\varphi displacement) + \Delta(\varphi error) \qquad (1)$$

The two interferometric pairs (4 images) are required to generate the movement-only interferogram, assuming there is no other way to get the topographical information of the scene **(Gabriel, A.K., R.M. Goldstein, and H.A. Zebker, 1989)**. If the external Digital Elevation Model (DEM) is exist, only one pair interferometry (2 images) is needed to measure ground deformation between image acquisition times.

Although the principle of InSAR for detecting land displacement is very simple as shown above, the actual procedure is much complicated because it is necessary to remove the first and third fringe components (equation 1) from the original fringe patterns perfectly. For the second one, conventional digital elevation data (DEM) are usually used because it is rather easy to remove the second one (topographic fringe) by simulating precise topographic fringe patterns by using DEM and, in addition, the sensitivity of topographic fringe for the height differences is much lower than that for land displacement.

Another problem is that phase unwrapping is finally necessary to obtain absolute displacement values and this phase unwrapping is much sensitive to phase noises and easily fails in degraded phase patterns. The phase noises are generated by incomplete interferometry, which is brought by spatial and temporal decorrelation of SAR signals. The former is brought by large baseline length and therefore the data pairs with baseline length as short as possible are preferable for interferometric analysis. The latter is actually the most significant factor to achieve InSAR successfully for displacement detection especially for C-band SAR data, because the temporal decorrelation is bigger for shorter wavelength than the longer one. The temporal decorrelation is also much affected by land cover types. It is large for vegetated land covers and small for non-vegetated, because the surface of vegetation is unstable in the scale of wavelength order of SAR signal. Therefore, the result of InSAR using C-band SAR is much affected by land cover types, and forest and agricultural areas are difficult to apply C-band InSAR in general.

2. Data and Result

In this study we use ascending C band ERS-1 SAR data which acquired on March 3, 1992 as master data and November 11, 1996 as slave data. The perpendicular baseline of two SAR data is 20 m. In order to compare InSAR image derived from ERS-1 data, we use also SAR data from two passes of JERS-1 which launched on February 11, 1992. The data were provided by National Space Development Agency of Japan (NASDA). The JERS-1 revolves on circular orbit with 568 km in altitude, illuminating the Earth surface with L band radar which microwave frequency is 1275 MHz. The orbit is Sun synchronous and sub recurrent, with a repeating period of 44 days. **(Mukarami., M., *et. al.* 1996)**

Table 1. SAR data used for monitoring land displacement in Boso peninsula region

Pair	Master	Slave	Baseline (m)	Perpendicular Baseline (m)	Period (days)
Pair 1	1993/02/22	1996/05/25	1168.42	1037.83	1188
Pair 2	1993/02/22	1996/08/21	594.04	389152	1276
Pair 3	1993/02/22	1996/11/17	389.93	387.88	1364
Pair 4	1993/04/07	1996/11/17	1758.80	1368.53	1320

Figure 3 shows a location map of these interferograms. The Synthetic Aperture Radar pair covers a larger area in rectangular box. Table 1 summarizes the JERS-1 data pairs and spatial baselines relevant to region interferometry.

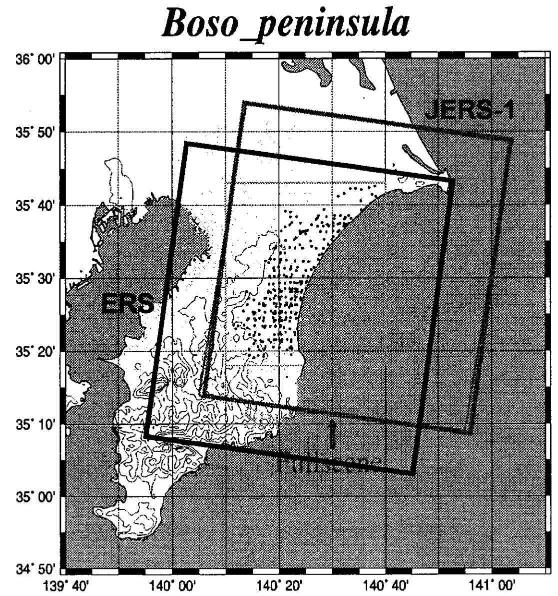

Figure 3. Map location research area.

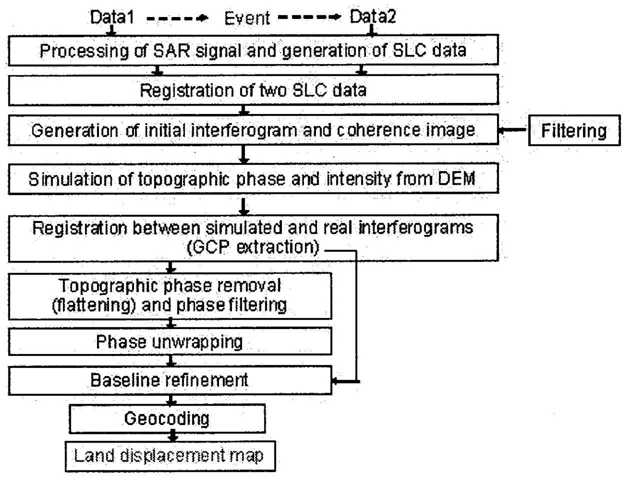

Figure 4. Flow chart for two-pass differential interferometry to detect land displacement patterns

The ERS-1 data, we processed with commercial GAMMA software, EarthView software and SIGMA_SAR packed software made by JAXA Japan. The procedure, called two-pass differential interferometry, to obtain land displacement patterns is shown by figure 4. Mainly, data processing was started from single look complex (SLC), which then continued by resampling SLC (co-registration), creating interferograms and image coherency, filtering, unwrapping interferogram and geocoding process.

In order to remove fringe related to topographic effect we use digital elevation data from Geographical Survey Institute (GSI) with resolution 50 m. We improved signal to- noise ratio of each differential interferogram using a weighted power spectrum filter as discussed in **Goldstein and Werner (1998)**.

The result of InSAR application by ERS-1 data for Boso Peninsula region for monitoring land displacement can be seen in Figure 6a-6c. In this figure, the fringe patterns are detected very clearly in Chiba city extending to northwest direction and in the eastern of Boso (Mobara region) region where in this area water pumping and natural gas extraction were intensively done **(Geographical Survey Institute, 1999)**. Figure 6a, 6b and 6c were processed by commercial GAMMA software, SIGMA_SAR software and EartView respectively. The interferograms reveal that the spatial pattern of subsidence almost does not change. However, the map displacement which had processed by EarthView a little bit noisily even the subsidence can be detected.

The dominant signal in the interferograms is a bowl-shaped pattern of apparent line-of-sight (LOS) displacements in the Mobara region. We interpret the cycle elliptical-shaped fringes in Figure 6a-6c as indicating land subsidence in Mobara region.

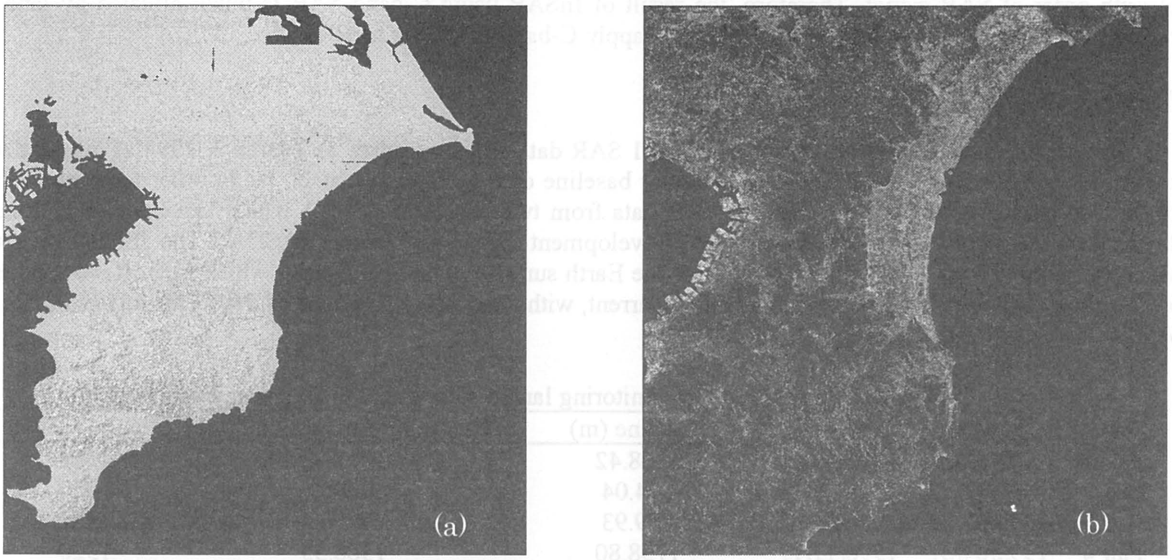

Figure 5. (a) GSI DEM with 50m resolution (b) Topographic phase from simulated DEM, one cycle equal to 160 m

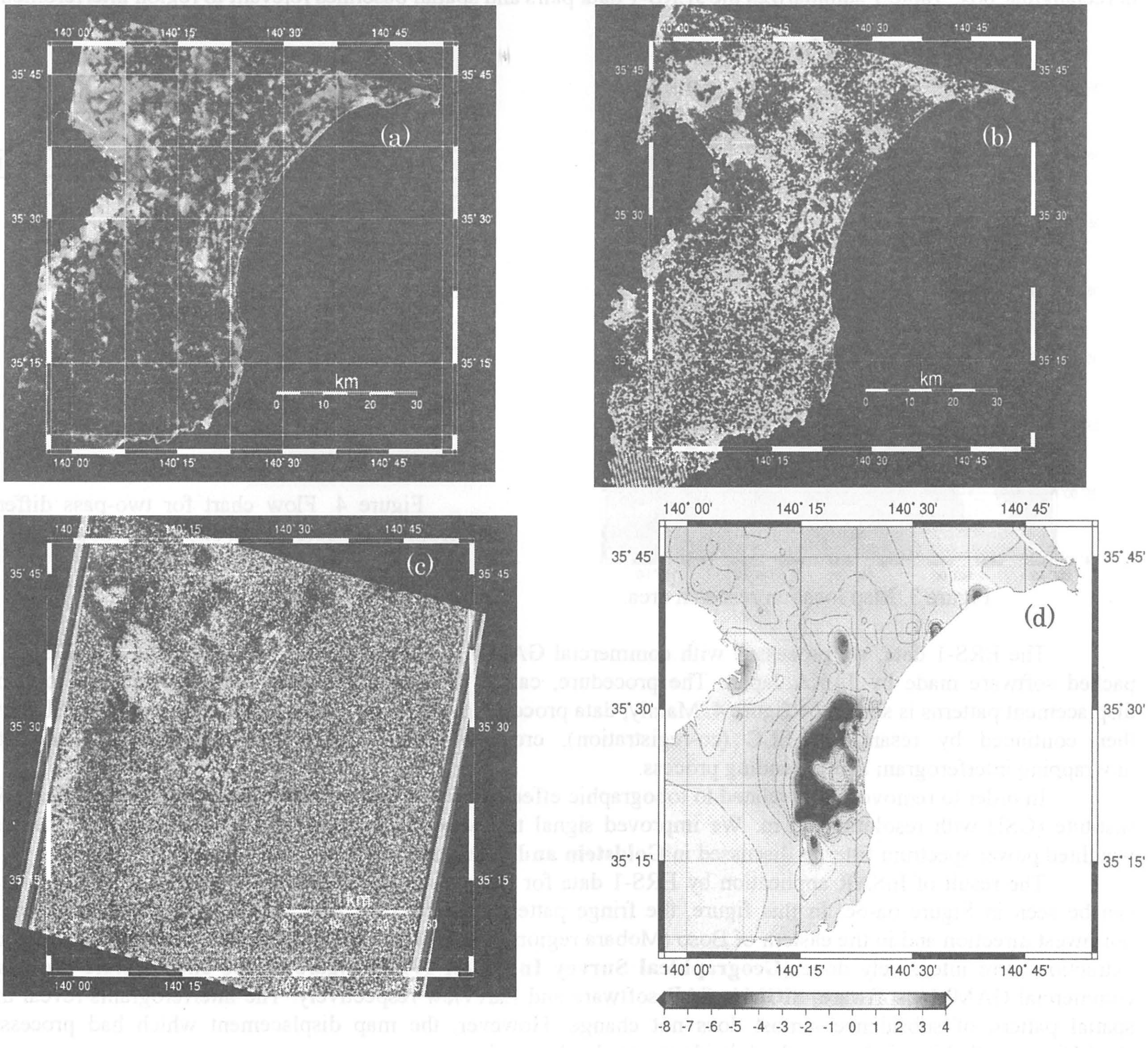

Figure 6. Result of land displacement patterns detected by ERS-1. (a) Land displacement derived by GAMMA software. (b) Land displacement processed by SIGMA_SAR software. (c) Land displacement using EarthView software, one palette scale is equal to 2.58 cm. (d) Map of leveling data, scale in cm

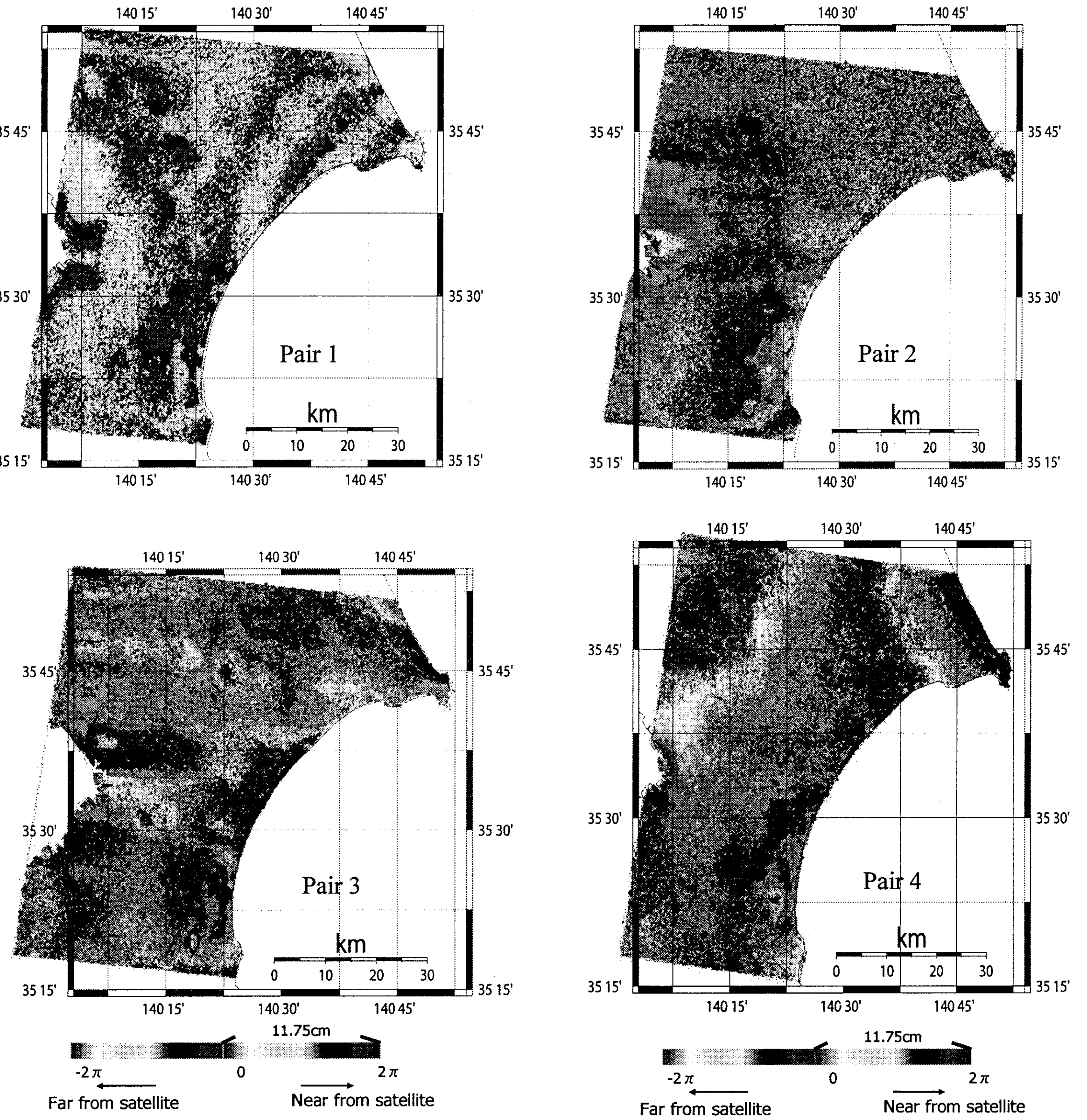

Figure 7. Result of land displacement patterns detected by JERS-1

In general the correlation of pair ERS-1 data is higher than pair JERS-1 data. Though the time interval for our first interferogram is about four years, the coherence value is still very high and the interferometric fringes are very clear. Phase unwrapping was uncritical. The correlation of InSAR data depends on several factor, i.e. local slope (steep slope), properties of surface being imaged (vegetated or moving surface such as ice glacier) and baseline between master and slave SAR data. Our JERS-1 data have baseline more than 300 m, so we note that this phenomenon leads poor correlation in comparison to ERS-1 data. The problem in data processing is the inaccuracy of the ERS-1 orbit parameters. In addition, the passes in the illumination interval, usually about 16 s, are not exactly parallel to each other. To solve this problem, we attempted DEFLT precision orbital data records in GAMMA software to refine orbit parameter.

Figure 7, pair 1, pair 2, pair 3 and pair 4, illustrates the land displacement in Boso peninsula from JERS-1 data. In all of pairs, the dominant signal in the interferograms is a bowl-shaped pattern of apparent line-of-sight (LOS) displacements in the Mobara region. The same fringe pattern can be traced in all of the interferometric pairs even covering different time interval. Due to the loss of coherent signal, it is difficult to assess exactly the maximum amount of subsidence in the long-term interferograms, but the data suggest that the subsidence for this time interval is approximately has amplitude 5 - 7 cm in LOS direction. The instability interferogram was detected in interferogram of pair 1 and pair 4 which may be caused long baseline master and slave of both pair interferograms. The interferogram pair 2, there is loss phase detected in northeast of Boso peninsula due to low signal noise ration in this region .In general, four interferograms which have been constructed from Table 1, there is no significant seasonal variation is observed in the InSAR measurements during the 1993-1996 time interval.

Since in this region there was no available GPS data in 1992 and GEONET was initiated in 1994 with 3 sites in the region, we could not make comparison to validity our result using GPS data. We present evidence of the subsidence area from leveling data which recorded during 1993-1997 (Figure 6d). The radar observations of land displacement are in good agreement with leveling data. However, the radar data provides a more detailed mapping of both the amplitude and spatial extent of land subsidence.

3. CONCLUSIONS

We have applied Interferometric Synthetic Aperture Radar (InSAR) for monitoring land displacement in Boso Peninsula. We estimated that during 1992-1996 the land displacement in Boso peninsula region has amplitude of ~ 5 to 8 cm in line of sight (LOS) direction. For both ERS-1 and JERS-1 data, even though the coherency of ERS-1 interferogram is higher than JERS-1 data pair, the same pattern of displacement from both ERS-1 and JERS-1 data was obtained. Our results also match well with in situ, leveling data observation. Finally, from radar measurement we can calculate accurately land displacement around Boso Peninsula. In 2006, the new satellite, DAICHI (Advanced Land Observing Satellite: ALOS) was launched by Japan Aerospace Exploration Agency (JAXA), so for the next future we can easy to conduct disaster monitoring in Boso Peninsula due availability data around the world.

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