Creep Motion Monitoring along the North Anatolian Fault by using DInSAR and Time Series Analysis

Tomonori Deguchi, JAPAN

Key words: DInSAR, time series analysis, PALSAR, fault creep, NAF, Ismetpasa

SUMMARY

North Anatolian Fault (NAF), which is well-known as a destructive fault, has several records of a huge earthquake occurrence in the 20th century. NAF is a right-lateral fault, and it extends for 1,200 km from the eastern part of Turkey to the Aegean Sea in parallel to the Black Sea. Four tectonic plates (Eurasian, Arabian, African and Anatolian plates) are complicatedly connected in the surrounding of the Anatolia peninsula.

Two destructive earthquakes (the M7.3 1944 and the M6.9 1951 earthquake) ruptured the Gerede and Ismetpasa segments. Nevertheless no large-scale earthquakes have taken place near Gerede-Imapetpasa after the 1951 earthquake, some offset damages at surface constructions that had been built after 1951 are observed. This phenomenon is interpreted as a creep displacement. The fault with creep deformation is aseismic and never generates the large scale earthquakes. The understanding and monitoring of the fault behaviors around the active fault give the important information to the risk assessment of a seismic hazard.

The purpose of this study is to investigate the distribution of spatial and temporal change on the ground motion due to fault creep in the surrounding of the Ismetpasa segment. DInSAR is capable to catch a subtle land displacement less than a centimeter and observe a wide area at a high spatial resolution. I applied InSAR time series analysis using PALSAR data in order to measure long-term ground deformation from July, 2007 until January, 2011. As a result, the land deformation that the northern and southern parts of the fault have slipped to east and west at a rate of 7.5 and 6.5 mm/year in line of sight respectively were obviously detected. In addition, it became clear that the fault creep along the NAF extended 61 km in east to west direction. Next works are i) investigation of the deformation history using ERS-1/2 and ENVISAT data obtained between 1992 and 2012, ii) integration of results using PALSAR and ENVISAT data for the measuring of 2.5 dimensional displacement, iii) DInSAR analysis on the other segments of NAF, and iv) continuous monitoring using RADARSAT-2.

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1. INTRODUCTION

A sequence of eight earthquakes in the 20th century, which magnitude is over 7, ruptured the most of NAF. Especially, two earthquakes, the M=7.3 1944 Bolu-Gerede earthquake and the M=6.9 1951 Kursunlu earthquake, destructed the one segment of NAF between Gerede and Ismetpasa (Barka and Kadinsky-Cade, 1988). Though no large-scale earthquake have taken place near this region after that, an offset wall at the railway station that had been built in 1957 observed with naked eye. This phenomenon was construed as the fault creep.

Because most of active faults are locked at the surface, strain has been accumulated over a long period and therefore causes a large scale earthquake. On the other hand, the creep fault normally releases strain throughout the seismogenic layer and never generates a large earthquake. In some cases, however, a fault creep appears to happen within a shallow depth at a slower rate than the overall slip rate and produces moderate-to-large scale earthquake (Cakir et al., 2005). Hence, the understanding and monitoring of the rate and the extent of fault behaviors are quite important to an assessment of a seismic hazard. In this study, we measured land deformations around Ismetpasa segment by InSAR time series analysis using PALSAR data obtained between 2007 and 2011.

2. STUDY AREA

Four tectonic plates (Eurasian, Arabian, African and Anatolian plate) are complicatedly connected in the surrounding of Turkey (Figure 1). The Arabian plate makes a left-lateral slip at the Dead Sea Rift Valley on the boundary with the African plate resulting from the extension in north to south direction of Red Sea. The Arabian plate moves northward relative to the African plate and collides with the Eurasian plate over the Zagros Mountains. The Anatolia plate is pushed westward by the collision zone between the Arabian and the Eurasian plate. In addition, it is pulled westward by the Hellenic subduction zone in the Aegean Sea.

The right-lateral NAF extends for 1,200 km from Iran to the Aegean Sea in an arc parallel to the Black Sea. The region along NAF is tectonically quite active and several destructive earthquakes are recorded. A series of strike-slip earthquakes of magnitude greater than 7 have ruptured the most of NAF during the twentieth century. The trench survey in Gerede segment suggested that the amount of displacement was approximately 5 m and the annual average of creep displacement was deduced 20 mm/yr from the time interval of past earthquakes. Based on the result of instrumental measurements and trench investigation, seismic-coupling of Gerede segment is indicated nearly 100 % and earthquakes is probable to occur quasi-regularly.

Two destructive earthquakes (the M=7.3 1944 and the M=6.9 1951 earthquake) ruptured the Gerede and Ismetpasa segments. Nevertheless no large-scale earthquakes have taken place near Gerede-Imapetpasa after the 1951 earthquake, some offset damages at surface constructions that had been built after 1951 are observed (Figure 2). This phenomenon is interpreted as a creep displacement. The fault with creep deformation is aseismic and never generates the large scale earthquakes. The understanding and monitoring of the fault behaviors around the active fault give the important information to the risk assessment of a seismic hazard.

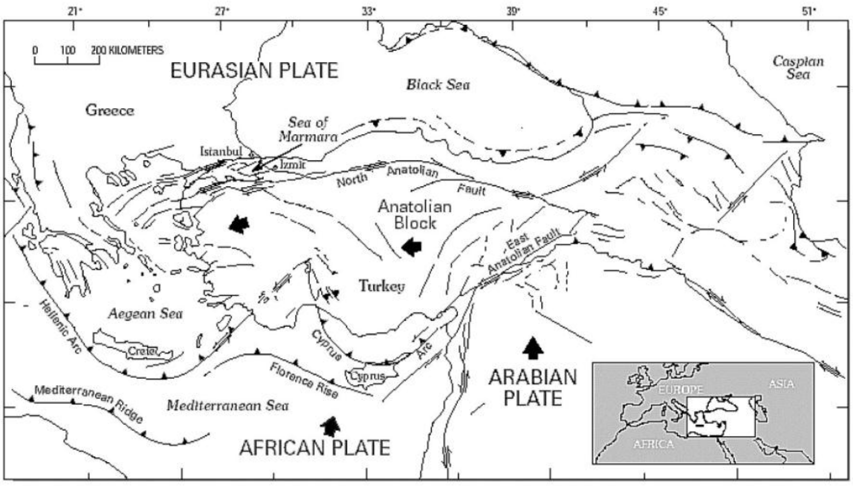

Figure 1. Tectonic motion around The Republic of Turkey (Barka and Kadinsky-Cade, 1988).

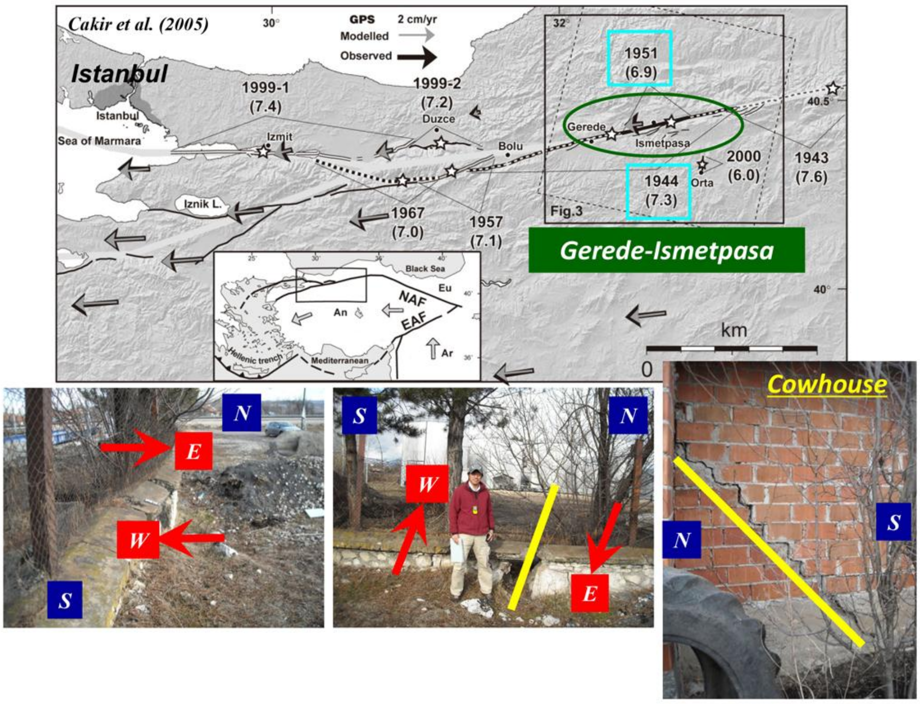

Figure 2. Examples of damage to the surface constructions.

3. METHODOLOGY

DInSAR is an unique methodology for measuring ground motions by analyzing phase differences on two SAR images taken at two different times. The phase difference $\Delta\Phi$ after the removal of the orbit fringe ($\Delta\phi_{orbit}$) and the topographical fringe ($\Delta\phi_{topo}$) using orbit records and DEM includes not only the displacement component ($\Delta\phi_{def}$) but also the noise component (ε) due to atmospheric phase delay, ionospheric disturbance and elevation errors (Δh) in the DEM data.

$$\Delta\Phi = \Delta\phi_{def} + \varepsilon + \frac{4\pi B_{perp}}{\lambda\rho\sin\alpha}\Delta h \tag{1}$$

where B_{perp} is the perpendicular component of the orbit distance between two observations, λ is the wavelength, ρ is the slant range length, and α is the incidence angle.
Consider a case where M pairs of interferograms are derived from N+1 scenes of SAR imagery over a single area. Suppose that the land deformation from the first observation (0-th recurrence) is an unknown vector, t_n(n=1…N), and that the interferogram of the m-th pair (m=1⋯M) is obtained from the SAR images on the i-th and j-th recurrence (i=1⋯N-1, j=2 ⋯N, j>i). A smoothness constraint is added to hypothesize that the time wavelength of land deformation is sufficiently longer than the satellite's recurrence period. Specifically, a smoothness constraint condition represents the minimization of the second order difference for t_n. By rendering the phase difference of each interferogram, the optimal solutions to t_n and Δh, the variables used to provide the minimum value of S, can be estimated based on the least squares method.

$$S = \sum_{m=1}^{M} w\left\{\Delta\Phi_m - \left(t_j - t_i\right) - \frac{4\pi B_{perp}}{\lambda\rho\sin\alpha}\Delta h\right\}^2 + \mu^2 \sum_{n=1}^{N}\left(t_n - 2t_{n-1} + t_{n-2}\right)^2 \tag{2}$$

The variable w in the first term on the right side of Equation (2) is the weighting function from Tukey's biweight. The variable μ^2 in the second term is a parameter used to control the smoothness of land deformation, and is fixed to 1.0. The t_n finally obtained is regarded as a vector representing the land deformation in the line of sight after separating noise components. The value is output as a total of the long-term land deformation from the first observation.

4. THE RESULT OF DATA ANALYSIS

I used 30 PALSAR scenes acquired between 2007 and 2011. Top-left (a) and Top-right (b) image of Figure 3 present land deformation maps on the path 603 and 602 respectively. The red and blue in the image represent the deformation away from the sensor and toward the sensor respectively. The areas colored in red and blue will be recognized to eastward and westward displacement respectively on the assumption that ground surface deforms in the horizontal direction only. This interpretation corresponds to tectonic motion of NAF. The average velocities of an eastward and westward deformation in a northern and southern part of NAF are 7.5 mm/yr and 6.5 mm/yr respectively, the southern block of NAF is moving westward at 14 mm/yr, supposing that the northern block is stable relatively (Figure 4).

A closer examination of Figure 3 (a) and (b) reveals a sudden change in interferometric phases in the north-south direction out of the phase changes around NAF. Phase differences indicative of ground subsidence or atmospheric phase delays generally tend to be smooth over wide areas. Thus, by detecting a sudden spatial change in phases, a location of creep deformation can be identified and this leads to determine if the phase difference around the site results from the creep deformation. To this end, the first differentiation was applied to the deformation maps from InSAR time series analysis in the north-south direction for edge detection. The white line shows a steep gradient of phases detected through the first differentiation. This line expands in the east-west direction parallel to NAF, its length is estimated 61 km.

Cakir et al. (2005) summarized the history of creep motion along NAF, so that it was described that the surface creep had ceased its decreasing trend. According to Kutoglu et al. (2008), the annual rate between 2002 and 2007 was twice larger than that observed between 1992 and 2002 and seems to have turned back at the 1970’ level. From this study, the rate of creep was measured 22 mm/yr. It is considered that the increasing trend of creep rate has still continued (Figure 5).

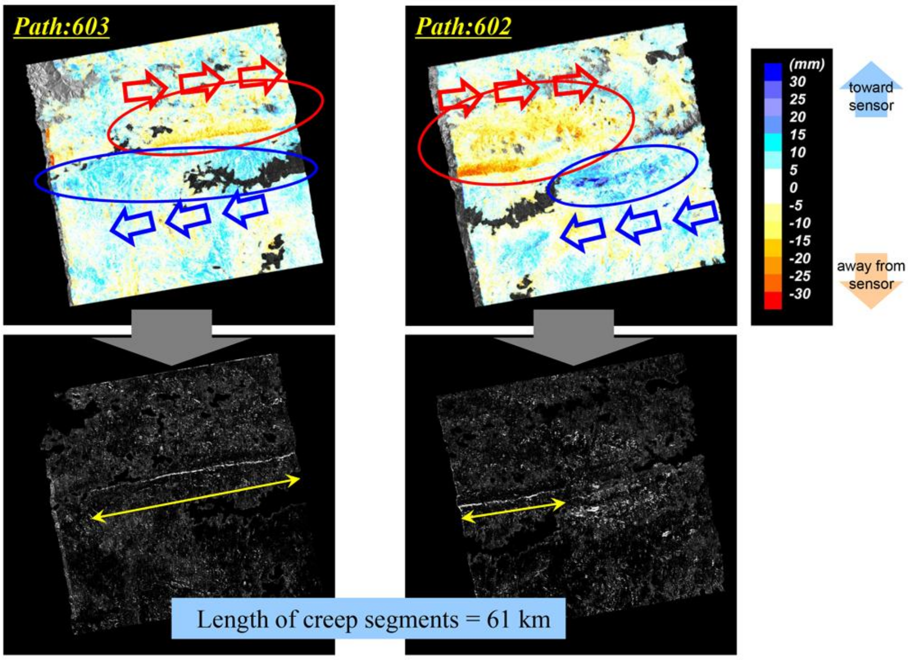

Figure 3. a-b): Deformation map generated by InSAR time series analysis using PALSAR data. The red and blue in the image represent the deformation away from the sensor and toward the sensor respectively. c-d): Results of edge detection using the first differentiation.

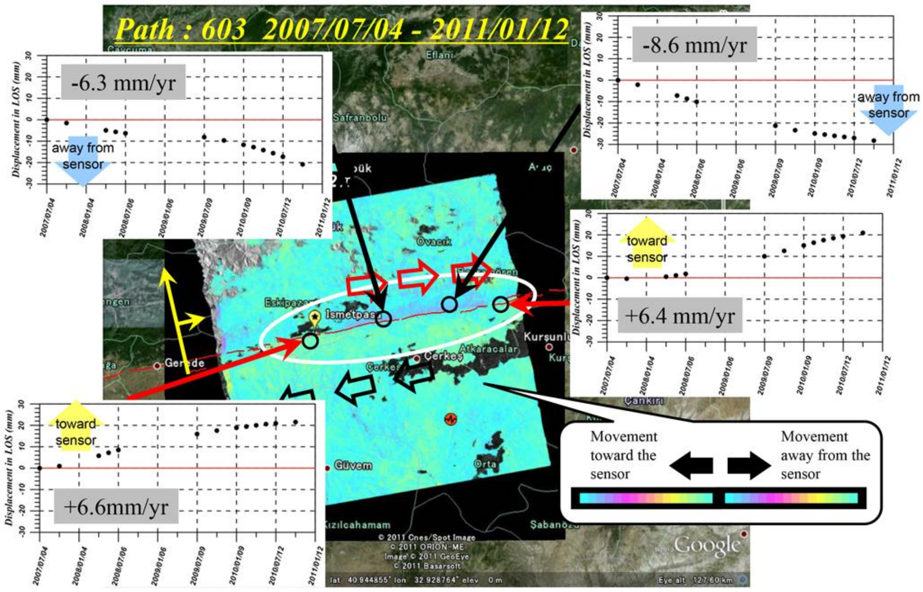

Figure 4. Long-term dispalcement along the North Anatolia Fault measured by DInSAR

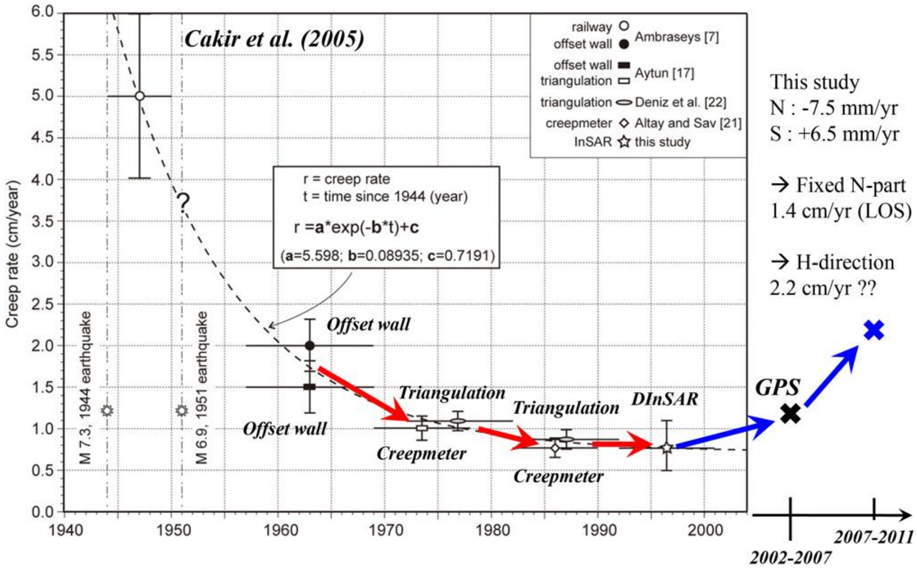

Figure 5. Comparison between the result of this study and the deformation history by Cakir et al. (2005).

5. CONCLUSION

In this study, we measured land deformations around Gerede-Ismetpasa segment of NAF, a

fault line running from east to west along the northern edge of the Anatolian plate in the Republic of Turkey, by means of an InSAR time series analysis using PALSAR data.
A further examination of the link between creep deformations and the occurrence of the earthquake will be required, next works are the following topics, i) investigation of the deformation history using ERS-1/2 and ENVISAT data obtained between 1992 and 2012, ii) integration of results using PALSAR and ENVISAT data for the measuring of 2.5 dimensional displacement, iii) DInSAR analysis on the other segments of NAF, and iv) continuous monitoring using RADARSAT-2.

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BIOGRAPHICAL NOTES

I was graduated from Faculty of Engineering, Kyoto University in 1997. My study paper was on the modeling and inversion technique of the resistivity method. While the working for Nittetsu Mining Consultants from 1997 until 2003, I had engaged in the geophysical exploration for the survey field on geothermal, mining, oil, active fault and others. In the period of temporal working to Earth Remote Sensing Data Analysis Center (ERSDAC) from 2004 until 2007, I started the research on remote sensing technique, especially SAR data analysis. Then, I acquired Ph.D. degree from School of Engineering, the University of Tokyo in 2009.

CONTACTS

Tomonori Deguchi
Nittetsu Mining Consultants Co., Ltd.
2-3, SHIBA 4-CHOME, MINATO-KU, TOKYO, 108-0014 JAPAN
Tel.: +81-3-6414-2766
Fax: +81-3-6414-2772
Email: t_degu@nifty.com