Application of SAR interferometry in Taiwan crustal deformation

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Abstract: The island of Taiwan is a product of the oblique collision between the Luzon arc and the Chinese continent margin. The present-day collision process of Taiwan is vigorous, as revealed by the high seismic activity and the active surface deformation. The deformations generated in this convergent system have been debated from a variety of geological and geophysical observations. In this study, we applied the InSAR technique to determine the coseismic deformation of the central Taiwan area associated with the 1999 Chichi earthquake. The M_w 7.6, Chichi, Taiwan earthquake of 20 September 1999 produced reverse slip with left-lateral component along an 80 km-long surface rupture, the Chelungpu fault. Four ERS2-SAR images acquired before and after the event allow determination of the co-seismic surface displacement. This analysis reveals minor subsidence in the footwall block of the Chelungpu fault, with a maximum displacement of about 25 cm along the radar line of sight.

1. General Geological Setting of Taiwan

Taiwan is situated at the occident extreme of the West Pacific and located at the junction between two subduction systems. East of Taiwan, the Philippine Sea plate subducts northward beneath the Eurasian plate along the Ryukyu subduction system. And South of Taiwan, the Philippine Sea plate overrides the crust of the South China Sea at the Manila trench, which extends northward from the Philippines to about 21.5°N.

The mountain belt of Taiwan is young (3-5 Ma), with active faulting and deformation affecting a broad region. The development of this mountain belt is interpreted as a consequence of the convergence between the Philippine and Eurasian plates (e.g. Ho 1986; Tsai 1986). According to the geodetic measurements for the period 1990-1995 (Yu *et al.* 1997), a steady convergent rate larger than 8 cm yr⁻¹ is detected between the North Luzon arc and the Penghu islands, which belong to the Philippine Sea plate and Eurasia plate respectively.

2. InSAR Observations

Radar interferometry is a technique for extracting surface information of the Earth by using the phase content of the radar signal as an additional information source derived from the complex radar data. The use of InSAR (interferometric SAR) for monitoring earth deformation process has received considerable attention because of its great potential for mapping the movement associated with large earthquakes (e.g. Zebker *et al.* 1994; Massonnet and Feigl 1998).

In Taiwan, the Center for Space and Remote Sensing Research (CSRSR), National Central University has established its ground station in 1993 and then began to use SAR images acquired from European Space Agency (ESA) European Remote Sensing 1 and 2 (ERS1 and ERS2) satellite in detecting deformation linked to the Taiwan crustal activity.

The InSAR result of CSRSR is now abundant, in this paper we would mainly show the interferometric result obtained after the Chichi earthquake. The Chichi earthquake (M_w 7.6), struck central Taiwan on 20th September 1999 (UTC), has caused heavy casualties and widespread damage in Taiwan. However, this earthquake has also generated a great amount of high-quality data and thus provided an unusual opportunity for research towards a better understanding of earthquake mechanics (e.g. Teng *et al.* 2001). Advancements in local instrumentations, which is networked in GPS stations, ground-motion accelerometers and broadband seismometers, have allowed detailed and accurate recording of the crustal deformation during the Chichi earthquake (Ma *et al.* 1999; Shin *et al.* 2000; Yu *et al.* 2001). The integration of these measurements shows that most of the coseismic displacement and crustal deformation occurred in a thrusting movement of the upper plate (i.e. the hanging wall), along a reactivated fault plane named as the Chelungpu fault. In contrast, the lower plate (the footwall area) shows relatively little deformation (e.g. Ma *et al.* 2000; Lee *et al.* 2001; Rubin *et al.* 2001; Yu *et al.* 2001). The characteristics of deformation in the footwall area remained thus relatively poorly understood.

Our interferometric result reveals a relative shortening in the round trip distance between the radar antenna and the ground of the footwall side of Chelungpu fault, during the earthquake. This shortening progressively increases from the west coast to the east and reaches the maximum amount of about 26 cm near the central segment of the Chelungpu fault. The application of SAR interferometry to the footwall deformation of the Chelungpu fault during the Chichi earthquake shows that, with suitable images, the differential interferometry is a useful high-resolution tool for monitoring the earth surface deformation despite the difficulties in a subtropical area like Taiwan. In almost flat areas where main land covers are urban areas or mixtures of nonvegetation and vegetation like agricultural areas, it was proved that interferograms obtained by C-band InSAR bring reasonable displacement information caused by earthquake. The poor result in the hangingwall area suggested also an essential limitation of C-band InSAR in steep mountainous regions with dense vegetation.

3. Conclusion

The resulting SAR interferograms provide an extraordinary spatial sampling density, a competitive precision, and a useful observation cadence. This study cannot be neglected in this context of crustal deformation. It should be combined with GPS geodetic measurements,

geological fieldwork and morphotectonic analysis, resulting in a better knowledge of the active crustal deformation in Taiwan.

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References

- Ho, C. S., 1986, A synthesis of the geologic evolution of Taiwan, *Tectonophysics*, 125, 1-16.
- Lee, J. C., Chen, Y. G., Sieh, K., Mueller, K., Chen, W. S., Chu, H. C., Chan, Y. C., Rubin, C., and Yeats, R., 2001, A vertical exposure of the 1999 surface rupture of the Chelungpu fault at Wufeng, western Taiwan: Structural and paleoseismic implications for an active thrust fault, *Bull. Seis. Soc. Am.*, 91, 914-929.
- Ma, K. F., Lee, C. T., and Tsai, Y. B., 1999, The Chi-Chi earthquake: large surface displacement on an inland thrust fault, *Eos, Trans Am. Geophys. Union*, 80, 50, 605.
- Ma, K. F., Song, T. R. A., Lee, S. J., and Wu, H. I., 2000, Spatial slip distribution of the September 20, 1999, Chi-Chi, Taiwan, earthquake (Mw7.6)--Inverted from Teleseismic data, *Geophysical Research Letters*, 27, 3417-3420.
- Massonnet, D., and Feil, K. L., 1998, Radar interferometry and its application to changes in the Earth's surface, *Rev. Geophys.*, 36, 441-500.
- Rubin, C., Sieh, K., Chen, Y. G., Lee, J. C., Chu, H. C., Yeats, R., Mueller, K., and Chan, Y. C., 2001, Post-earthquake response, 1999 Chi-chi earthquake: evidence for past earthquakes, *Eos, Trans Am. Geophys. Union*, 82, 47, 565.
- Shin, T. C., Kuo, K. W., Lee, W. H. K., Teng, T. L., and Tsai, Y. B., 2000, A preliminary report on the 1999 Chi-Chi (Taiwan) earthquake, *Seism. Res. Lett.*, 71, 1, 24-30.
- Teng, T. L., Tsai, Y. B., and Lee, W. H. K., 2001, Special Issue of the Taiwan Earthquake, Preface to the 1999 Chi-Chi, Taiwan, Earthquake dedicated issue, *Bull. Seism. Soc. Am.*, 91, 5, 1395 pp.
- Tsai, Y. B., 1986, Seismotectonics of Taiwan, *Tectonophysics*, 125, 17-37.
- Yu, S. B., Kuo, L. C., Hsu, Y. J., Su, H. H., Liu, C. C., Hou, C. S., Lee, J. F., Lai, T. C., Liu, C. C., Liu, C. L., Tseng, T. F., Tsai C. S., and Shin, T. C., 2001, Preseismic deformation and coseismic displacements associated with the 1999 Chi-Chi, Taiwan, Earthquake, *Bull. Seis. Soc. Am.*, 91, 995-1012.

Zebker, H. A., Rosen, P. A., Goldstein, R. M., Gabriel, A., and Werner, C. L., 1994, On the derivation of coseismic displacement fields using differential radar interferometry: The Landers earthquake, *J. Geophys. Res.*, 99, 19,617-19,634.