FAULT DISPLACEMENT OF WENCHUAN EARTHQUAKE OBSERVED BY ALOS PALSAR

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ABSTRACT: Wenchuan earthquake (Mw 7.9) occurred in Sichuan province, China, May 2008 had resulted in a huge fault displacement around the Lungmenshan fault. Preliminary results of the fault displacement observed by ALOS PALSAR interferometry are presented. The surface deformation by the Wenchuan earthquake was reported up to 10 m consisting of thrust- and right-slip compnents. A significant reduction in ionospheric density was also reported. Twenty differential interferograms and twenty multiple aperture SAR interferometry (MAI) pairs were produced over four ALOS tracks. It was observed from differential interferograms that i) LOS deformation decreases steadily from north-northwest of the Longmenshan fault to the fault, ii) the LOS deformation sharply increases at areas around the fault, and iii) the decrease of the LOS deformation is observed from the Longmenshan fault to the south-southeast of the fault. Horizontal movement of the reverse fault displacement can better be observed by MAI technique, and the MAI phases show that i) the south-southeast directional reverse fault displacement (negative along-track deformation for an ascending track) of the north-northwest block gradually increases to the Longmenshan fault, ii) the reverse fault movement of the south-southeast block is sharply reversed to the north-northwest of the fault, and iii) the north-northwest movement gradually decreases to the south-southeast of fault. Although the Lonmenshan Fault line is a center of earthquake epicenter, the boundary of surface movement exists to the north-northeast of the fault. Since the ionosphere was not stable even forty days after the mainshock, MAI phases were seriously corrupted by ionospheric effect. It is necessary to acquire more data when the ionosphere recovered to a normal state.

KEY WORDS: Fault displacement, earthquake, Sichuan China, ALOS PALSAR, radar interferometry,

1. INTRODUCTION

An earthquake mainshock (Wenchuan earthquake) occurred on 12 May 2008 in Sichuan Province, China, with an epicenter at 80 km west-northwest of Chengdu with a depth of 19 km. The surface deformation by the Wenchuan earthquake was reported larger than 3 m. On 25 May 2008, a major aftershock (Mw 6.0) hit the northeast of the original epicenter, in Qingchuan Country.

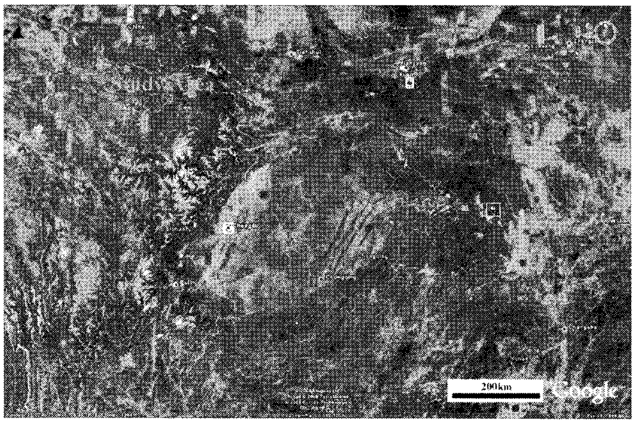


Figure 1. Study area with locations of the earthquake epicenter. (The background image is from Google image.)

The earthquake of 12 May probably reflects long-term uplift with slow convergence and right-slip, of the eastern plateau relative to the Sichuan Basin (Burchfiel et al., 2008). It was reported that rupture occurred over a length of about 270 km along a north-northeast-striking west-dipping Longmenshan thrust belt (USGS, 2008). Coseismic slip, estimated at up to about 10 m, consists of thrust- and right-slip components, with initial rupture occurring at about 10-20 km depth (Ji, 2008). GPS-determined rates in the vicinity of the 12 May event suggest an average recurrence interval of about 2,000-10,000 yr. (Burchfiel et al., 2008). Another interesting event associated with the earthquake is a reduction of ionospheric density. It was measured and reported on May 11 by Taiwan's Formosat-3 that ionospheric density over Sichuan had dropped by one half to 600,000 charged particles (Stone, 2008; The Earth Times, 2008).

On 25 May 2008, a major aftershock (Mw 6.0) hit the northeast of the original epicenter, in Qingchuan Country. The first 25-day period of aftershock activity ($M \geq 4$) is mostly confined within the mainshock rupture area (Parsons, et al., 2008). The aftershock magnitude–frequency distribution suggests a potential moment deficiency in the M=5–6.5 range, although variability is high and the number of events is small. The 12 May 2008 $M > 7.9$ earthquake, yet its legacy includes possible large aftershocks in the near future because it increased failure stress on important faults within and around the Sichuan basin (Parsons et al., 2008).

Preliminary results of the coseismic displacement in Sichuan, China, observed by ALOS PALSAR interferometry are examined. For this study, twenty differential interferograms and twenty multiple aperture SAR interferometry (MAI) pairs were produced over four ALOS tracks. Since the coseismic displacement consists of thrust- as well right-slip components along t north-northeast-striking Longmenshan fault, the MAI pairs are effective for observing the thrust components while the differential synthetic aperture radar interferometry (DInSAR) pairs for the right-slip components.

2. MULTIPLE APERTURE RADAR INTERFEREOMETRY (MAI)

Conventional DInSAR has been successfully applied to observations of large-scale surface deformations by measuring crustal movements at the surface. However, the DInSAR technique can only measure one-dimensional deformation along the antenna's line–of-sight (LOS) direction. A significant improvement in measuring along-track deformation was made with a new approach, multiple aperture SAR interferometry (MAI) (Bechor and Zebker, 2006). The MAI imaging configuration is as shown in Fig. 2.

A further improvement of measurement accuracy can be achieved by correcting flat Earth phases caused by variation of baseline between the two data (Jung and Won, 2008). Forward- and backward-looking MAI pairs have different perpendicular baselines, which play a key role in phase distortion; Consequently, an orbital deviation of only a few centimeters could result in a significant flat Earth phase.

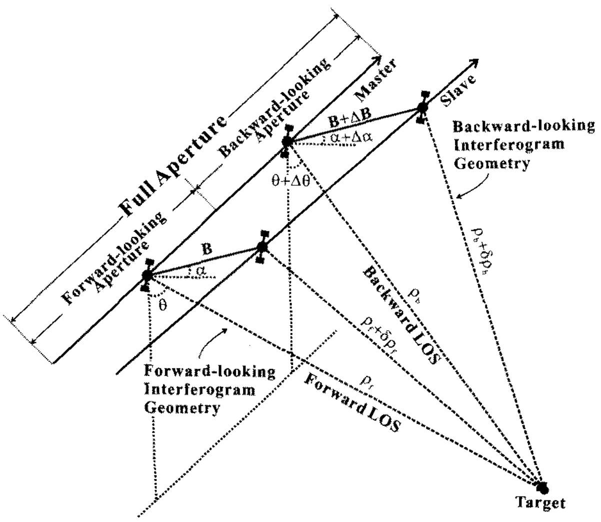


Figure 2. MAI geometry in which forward- and backward-looking interferograms are produced by means of sub-aperture processing with different squint angles. The B is the baseline length, θ and α are look angle and baseline orientation, respectively, and ΔB , $\Delta\theta$, and $\Delta\alpha$ are the deviations of the baseline length, look angle, and baseline orientation between the forward- and backward-looking pairs.

The difference of perpendicular baseline ($\Delta B_{\perp}$) from the starting point to the ending point causes the flat Earth and topographic phase distortions. The flat Earth phase and topographic phase are respectively defined by

$$\frac{\partial\varphi_{MAI}}{\partial\rho} \approx \frac{4\pi}{\lambda}\cdot\frac{\Delta B_{\perp}\cdot\cos\theta}{\rho\cdot\sin\theta} \text{ and} \tag{1}$$

$$\phi_{MAI} - \phi_{MAI,f} \approx -\frac{4\pi}{\lambda\rho}\cdot\frac{\Delta B_{\perp}}{\sin\theta}\cdot\left(r - r_e\right), \tag{2}$$

where λ and ρ are the wavelength and the slant range distance, θ is the look angle and r_e is the radius of the Earth spheroid (Jung and Won, 2008). This phase distortions can be corrected by a data-based approach.

3. RESULTS AND DISCUSSION

3.1 Results

Twenty differential interferograms and twenty multiple aperture SAR interferometry (MAI) pairs were produced.

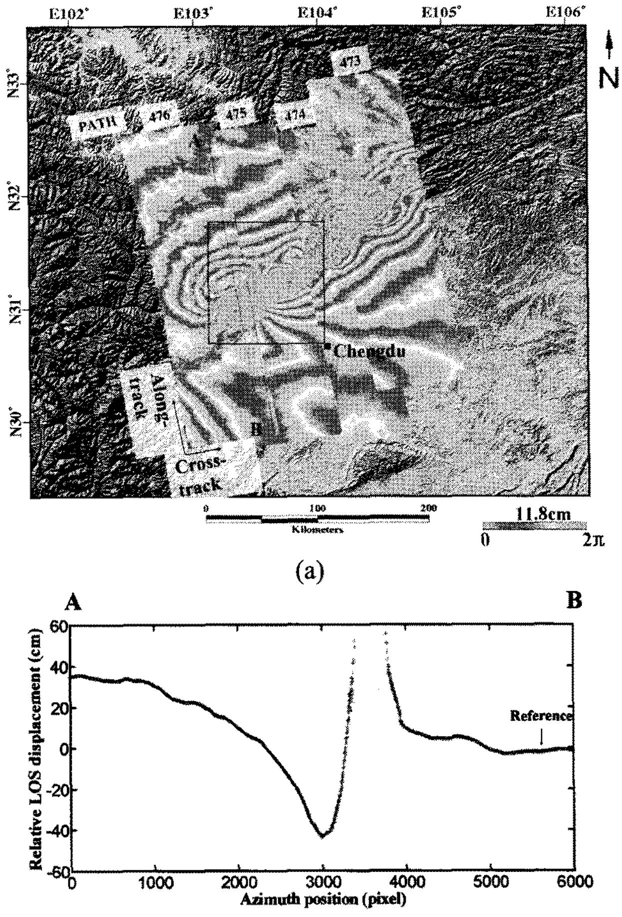
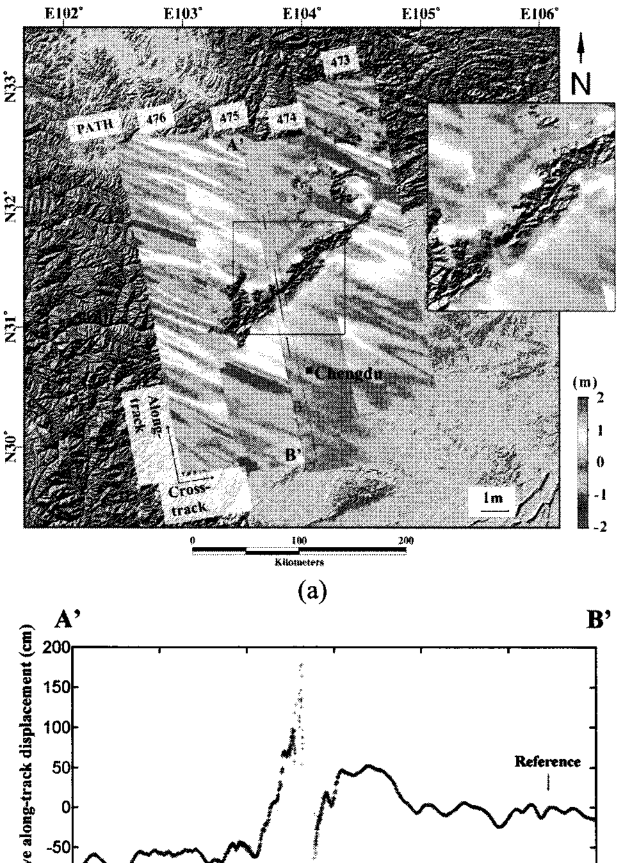
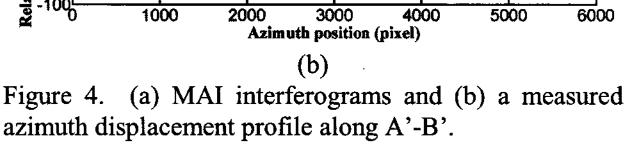


Figure 3. (a) DInSAR interferograms and (b) a measured LOS displacement profile along A-B.

First we examined differential interferometric pairs to review the LOS displacement. As seen in Fig. 3, the thrust and strike-slip displacements are well recorded by DInSAR interferograms. It was observed from differential interferograms that i) LOS deformation decreases steadily from north-northwest of the Longmenshan fault to the fault, ii) the LOS deformation sharply increases at areas around the fault, and iii) the decrease of the LOS deformation is observed from the Longmenshan fault to the south-southeast of the fault. In the profile A-B, the LOS surface deformation gradually decreases from about 40 cm to -43cm and then increases sharply. And then it decreases again to about 0 cm. Along the fault line, the coherence of interferogram is very low because of the large deformation. For this reason, the maximum LOS deformation could not be estimated (Fig. 4(b)).



(a)



(b)

Figure 4. (a) MAI interferograms and (b) a measured azimuth displacement profile along A'-B'.

Horizontal movement of the reverse fault can better be observed by MAI technique. Unfortunately, the MAI interferogrmas were severely corrupted by ionospheric interference. The MAI phases show that: i) the south-southeast directional reverse fault displacement (negative along-track deformation for an ascending track) of the north-northwest block gradually increases to the Longmenshan fault; ii) the reverse fault movement of the south-southeast block is sharply reversed to the north-northwest of the fault; and iii) the north-northwest movement gradually decreases to the south-southeast of fault. Although the Lonmenshan Fault line is a center of earthquake epicenter, the boundary of surface movement exists to the north-northeast of the fault.

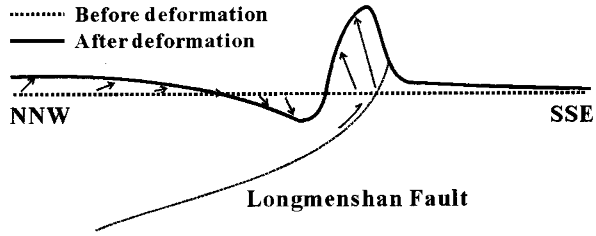


Figure 5. Idealization of cross section A-B as a reverse fault slip based upon a combined interpretation of LOS and azimuth radar measurements.

In the profile A'-B' (Lower figure in Fig. 4), the along-track surface deformation is about -50cm and increases greatly to about 190 cm around the fault line. Then it decreases steadily to zero level. Although the Lonmenshan Fault line is a center of earthquake epicenter, the boundary of surface movement exists to the north-northeast of the fault.

A preliminary interpretation along the profile A-B is displayed in Fig. 5. The interpretation was made based upon both LOS and azimuth displacement measured by PALSAR. The result is summarized as follows: Sharp surface uplift with horizontal movement to NNW direction near the Longmenshan fault can be inferred. 2) In NNW block of the Longmenshan fault, surface subsidence with horizontal movement to SSE direction can be inferred.

3.2 Discussion

In the hours before the Wenchuan earthquake, a Taiwanese meteorology satellite reportedly detected a decrease in density of charged particles in the ionosphere above Wenchuan (The Earth Times, 2008). Although some researchers speculate that it may have been due to radon seeping into the air, Huang notes that a link between earthquakes and ionosphere anomalies is controversial (Stone, 2008). However, it is apparent that ionosphere has been unstable since the main event of Wenhucan earthquake until recently. Since the ionosphere has not been stable even forty days after the mainshock, MAI phases were seriously corrupted by ionospheric effect. Corrections for the ionospheric delay in MAI inteferogram are required. It is still controversial in InSAR community that the NW-SE stripped noise in MAI and other interferemetric phase is resulted from ionospheric effects or other causes such as data processing problem. However, it is clear that the stripped noise in MAI phase is not observed in other sites so that the noise was from inherent problem of ionosphere in the Sichuan region. It is also necessary to acquire more data when the ionosphere recovered to a normal state. Validation of surface deformation observed by differential and multiple aperture SAR interferometry needs to be carried out using in-situ data and earthquake modeling.

As Parson et al.(2008) pointed out, there exists a potential of large aftershocks in the near future because it increased failure stress on important faults within and around the Sichuan basin. It is also well known that delays of years to decades between mainshocks and large aftershocks are commonly observed (Stein, 1999). GPS data and earthquake focal solutiosn show eastward movement of upper crust away from the central Tibetan plateau and into the eastern plateau region at rates of about 15-20 cm/yr (Burchfield et al., 2008). However, little of the northeastward crustal motion measured in the eastern plateau reaches the Longmenshan (Zhou et al., 2007). GPS sites west of and within the Longmenshan are not sufficiently dense to determine where the deormation is localized. Therefore it is important to identify potential future rupture zones and to keep continuously monitoring the region by space-borne SAR systems as well as various ground observation.

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