The InSAR and field observation of the Match-2011 Myanmar earthquake

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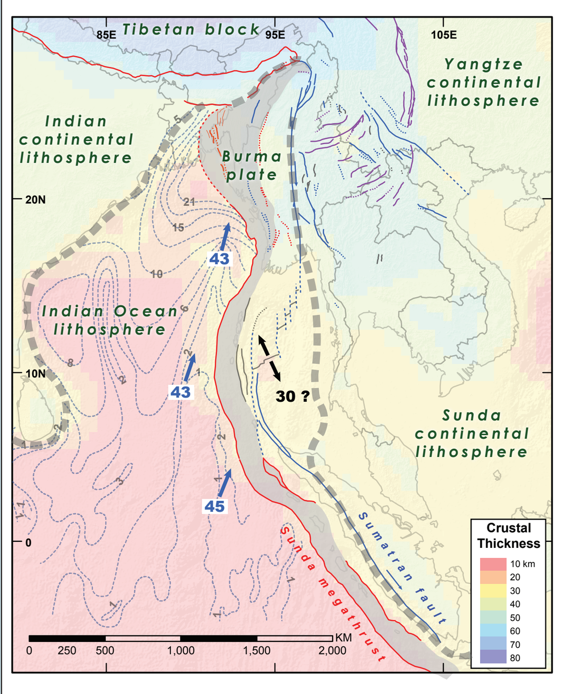
Summary

We use L-band ALOS PALSAR data to infer the distribution of subsurface fault slip during the Tarlay earthquake in eastern Myanmar. Our result indicate that the total length of the surface rupture is ~30 km, with nearly 2 m maximum surface offset along the westernmost section of the Nam Ma fault (the Tarlay segment). The inversion result using both InSAR and pixel-tracking data suggests that the maximum amplitude of slip exceeded 4 m at the depth between 3 and 5 km on the sub-vertical Nam Ma fault.

Comparison between the field observation and the range-offset near fault deformation suggests 10 -80 % of deformation occurred in a 1-km-wide region along the fault. This distributed deformation may be able to explain the shallow slip depict that we observed in this event, as the physical-based simulation study suggested. Our inversion model also shows a narrow and shallow slip patch during the earthquake, which we hypothesize are the result of partial rupturing of the seismogenic patch in the continental crust. Similar situations are also reported in other earthquake events including the Bam earthquake in 2003, where the rupture during the mainshock only ruptures part of the seismogenic patch in the crust.

Tectonic background



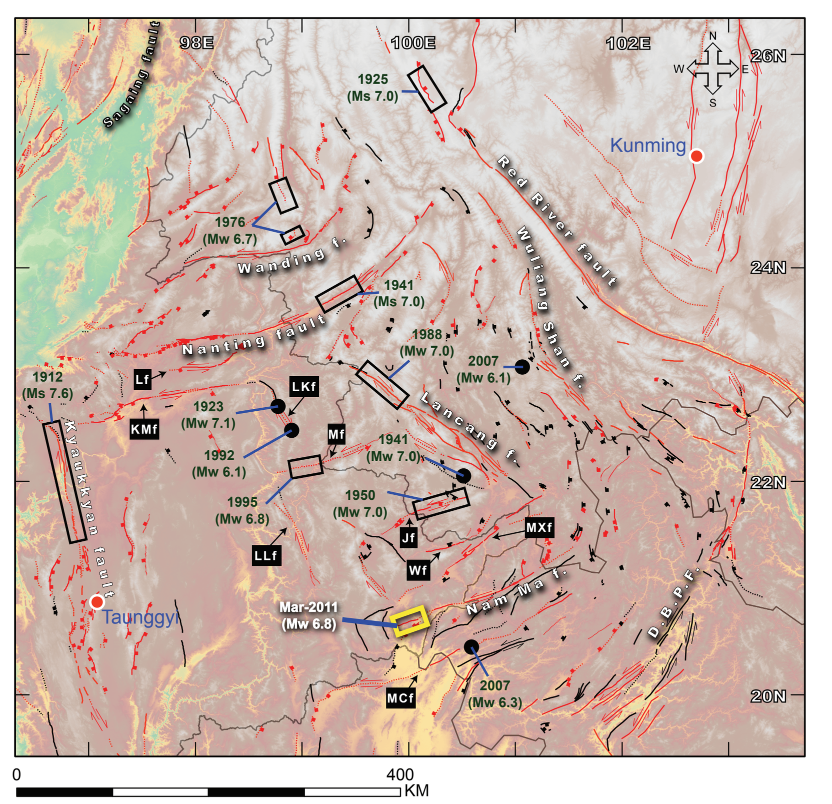


Figure 1 (up). Major neotectonic elements around the western SE Asia. The Shan fault system (up-right figure) is one of the three major fault systems that dominate the active tectonics of the Myanmar region. Its predominantly southwest-striking left-lateral faults (purple lines) span a 700-km section of the Chinese border with Vietnam, Laos, Thailand and Myanmar. The crustal thickness map shows the fault system mainly developed in the northern Sunda continental lithosphere where the crustal thickness is generally more than 30 km thick. The crustal model is from CRUST 2.0 model. Thick-dashed line marks the boundary of continental lithosphere. Blue arrow shows the plate motion between Sunda and Indian in mm/yr from MORVEL-2010. Red-line is the active thrust fault; Blue-line is the right-lateral fault; Purple line is the left-lateral fault.

Figure 2 (up-right). Neotectonic and historical seismic context of the Shan fault system from China to Myanmar. The active faults are based upon analysis of SRTM topography and ASTER imagery. The historical ruptures are inferred from post-seismic accounts of shaking intensity and ground failure records (mainly from the Chinese record) (black-boxes). The earthquake where we can't locate its surface rupture is shown in black-circle, which is the epicenter from the global seismic catalog. The yellow-box shows the location of Tarlay earthquake (Mw 6.8) in 24-March 2011, which ruptured a segment of fault near the western termination of the Nam Ma fault. The detail fault mapping and aftershocks are shown in Figure 3 (right).

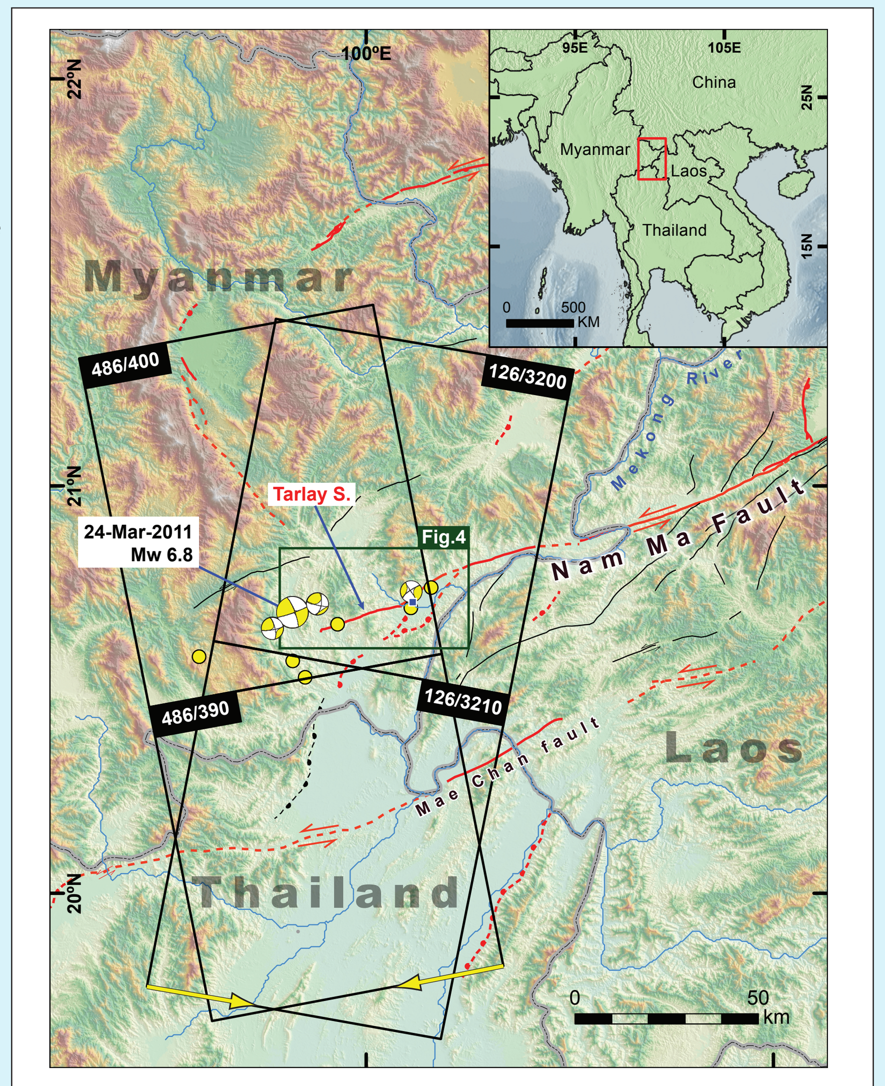
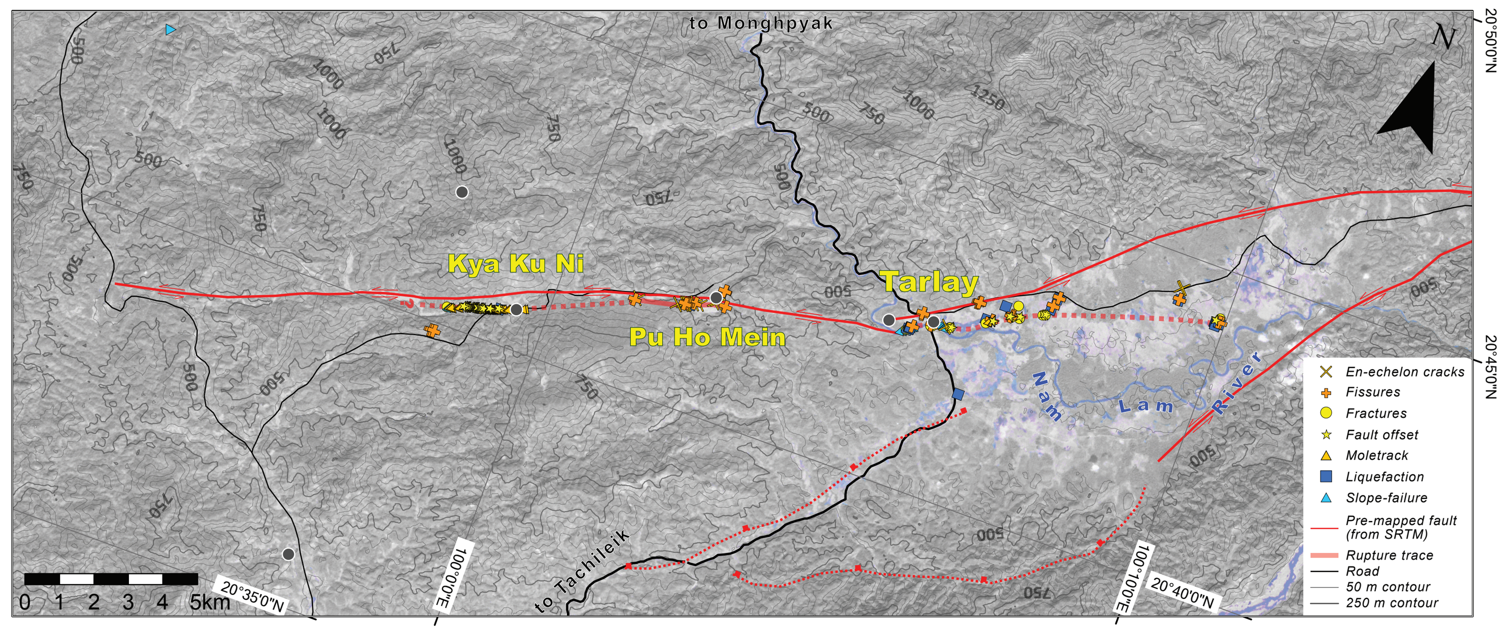
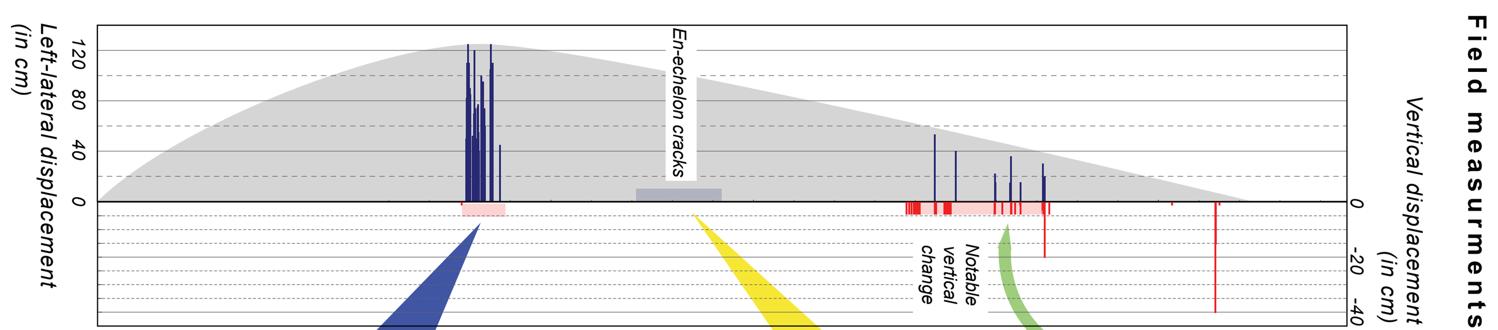


Figure 3 (right). Map of active faults in the region of the Nam Ma Fault, based on geomorphological analysis of optical imagery and SRTM topography. The surface rupture occurred along the Tarlay section, which is one of the fault segment in the horse-tail structure of the western Nam Ma fault. Yellow circles are the epicenters of aftershock from global seismic catalog (NEIC database). The moment tensors are from Global CMT solution. The distribution of the aftershocks and the CMT solution well agree with the fault section that mapped from the SRTM topography, showing the Tarlay segment is the cause of the earthquake. Back-box marks the footprint of the ALOS data that we used in this study.

Field survey result

Figure 4 (below). The surface rupture and surveyed locations for the 24 March 2011 Tarlay earthquake along the westernmost section of the Nam Ma Fault. Myanmar scientists conducted a post-earthquake field survey within a week after the earthquake along the Tarlay segment to document the ground deformation during the mainshock. Their result shows the rupture mainly follows the pre-mapped fault trace, where the maximum surface offset is 125 cm near the Kya Ku Ni village.





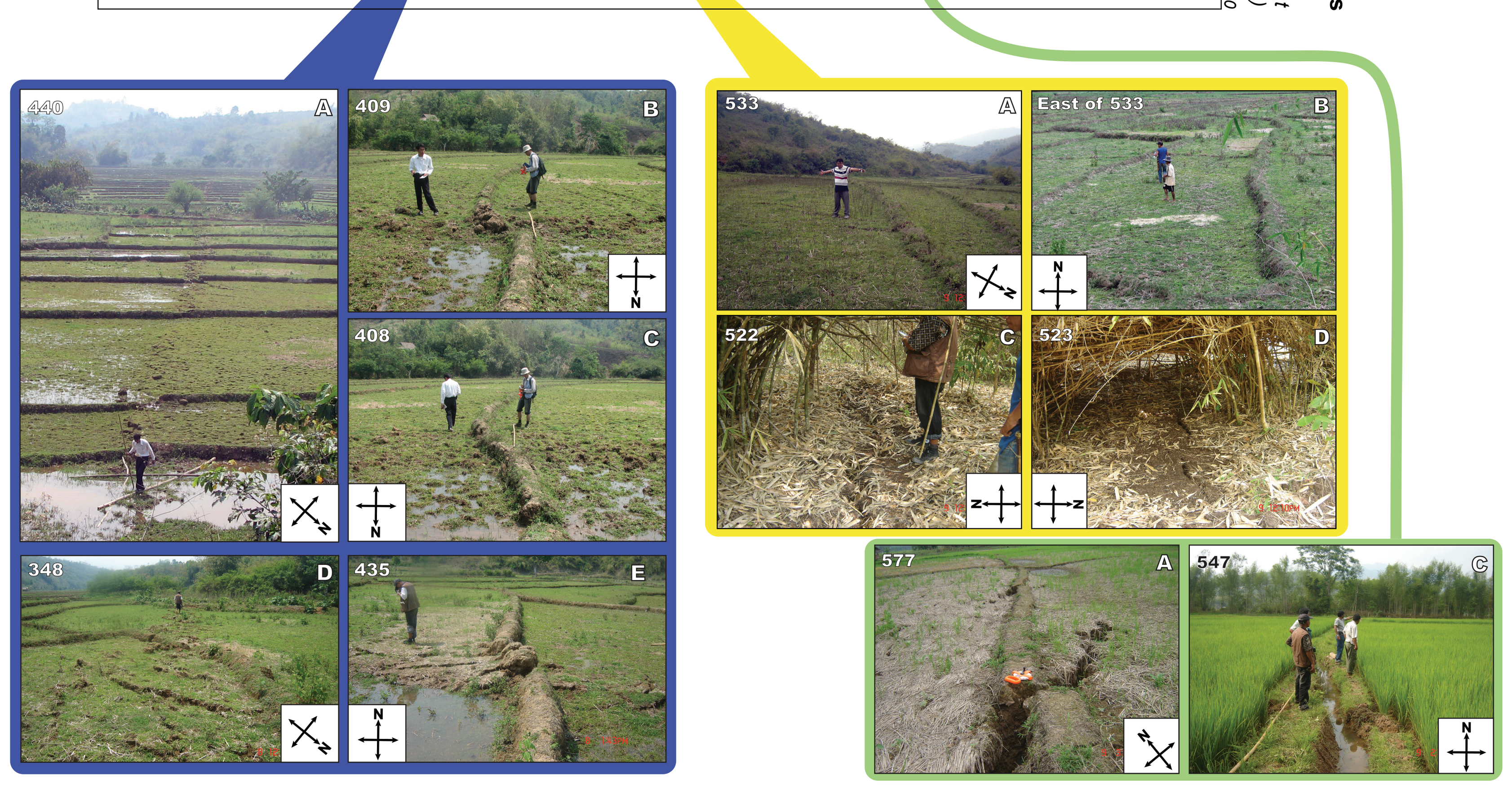


Figure 5 (up). The fault surface rupture are three different section of the Tarlay segment, showing different rupture behavior along the fault. (Blue) The surface rupture near the Kya Ku Ni village where Myanmar survey team measured up to 1.25 m left-lateral offset along the fault. A. Overview of the rupture, looking southwestward. The right-stepping Riedel shears, the moletrack and the small vertical component of slip implied by the water on the south (left) side of the fault rupture are clear along this section of the fault. B. 85-cm sinistral offset of the paddy boundary at Waypoint 409. C. 90-cm sinistral surface warping across the fault zone at Waypoint 408, just west of Waypoint 409. The paddy boundary is clearly warped across the rupture zone. D. 3-m-wide right-stepping Riedel shears zone at Waypoint 348. E. 72-cm left-lateral offset of a paddy divider near Waypoint 435. (Yellow) Three locations in the valley near Pu Ho Mein that may have experienced sinistral tectonic rupture. A. Right-stepping en echelon fractures across a dry paddy field at Waypoint 533. B. A long fracture and sand blows in paddy fields east of Waypoint 533. C & D. Right-stepping en echelon fractures at Waypoint 522 suggest a few cm of sinistral slip. Note that the ground fractures are distributed along the fault trace. (Green) Photographs of left-lateral displacements near Tarlay that appear to be tectonic. A. Dual traces of the fault rupture offset a paddy field by 22 cm (in the foreground) and 15 cm (in the background) at Waypoint 577. B. 15-cm left-lateral offset and unmeasurable warping of the paddy field boundary near Waypoint 609.

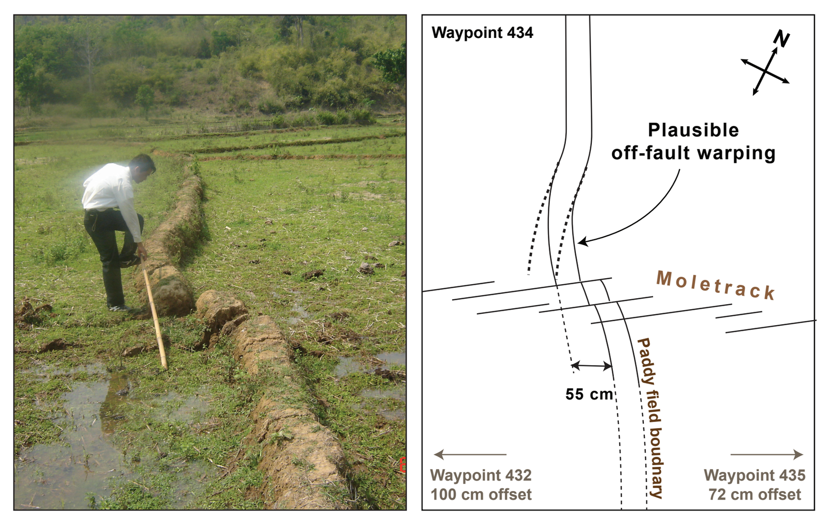


Figure 6. The offset berm between paddy fields shows plausible off-fault warping north of the surface rupture at Waypoint 434. The schematic illustrates the relationship of off-fault warping and offset based on the field photos. We believe the off-warping over a short distance from fault explains at least part of the offset variation along this section of the surface rupture, which is shown in the right-hand-side figure. The others may reflects the true slip variation over the short-distance along the fault.

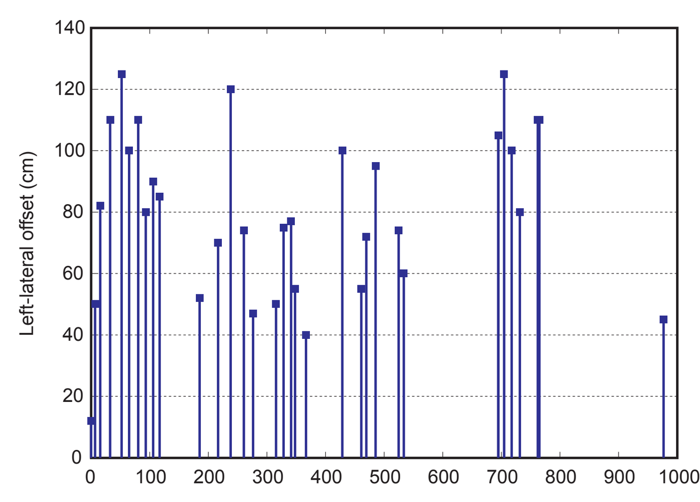


Figure 7. Graph of 34 sinistral offsets at Kya Ku Ni as a function of distance from the westernmost measured offset, showing that the offsets range from 12 to 125 cm. The tape measured result has 1-order difference along this 1-km-long section. We suggest at least part of the variation is resulting from the off-fault deformation. Others may cause by the slip variation along the fault.

InSAR and inversion result

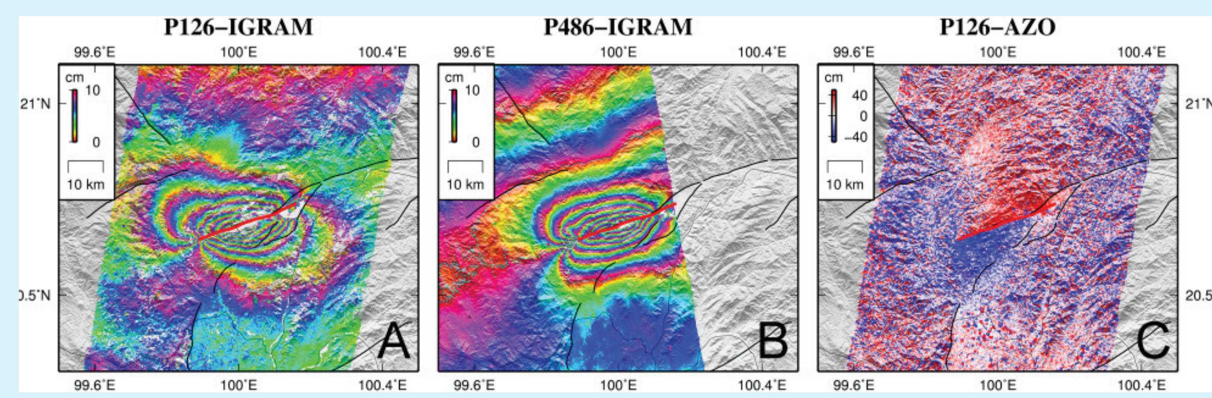


Figure 8. The ALOS L-band InSAR and Pixel-tracking analysis result. The InSAR and Pixel-tracking result show the surface rupture is relatively simple along the Nam Ma fault. They also show the western and the eastern termination have different behavior along the Tarlay segment, where the eastern one seems to contain more distributed strain than the western termination. Red line shows the trace of Tarlay segment that we mapped from SRTM and LANDSAT imagery. Black-line shows the regional fault that did not rupture during this earthquake.

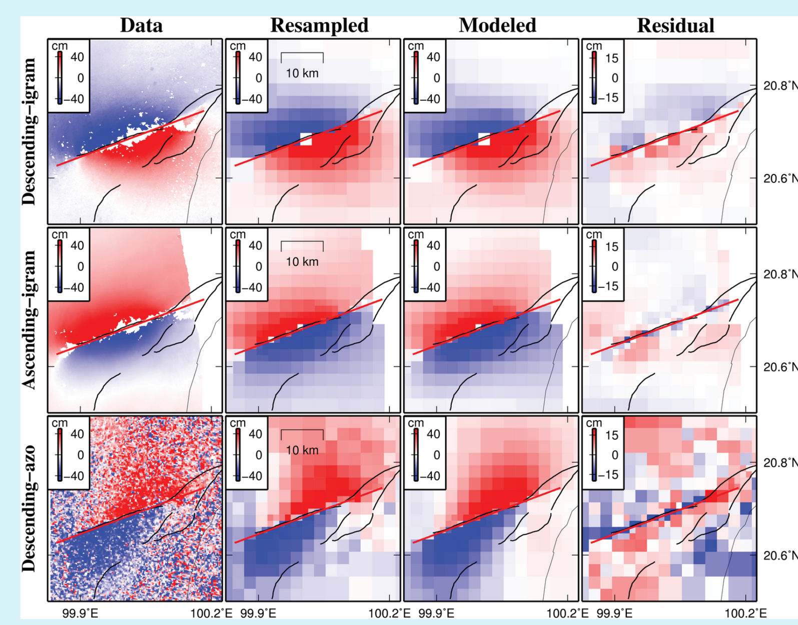


Figure 9. We resample all three ground deformation fields before using PCAIM to invert the fault slip distribution. Generally, the deformation fields from our model match to our observation from the InSAR and the pixel-tracking results with a single fault rupture on the Tarlay segment. The average residual of our preferred model is about 2 cm to 7 cm.

Range-offset data

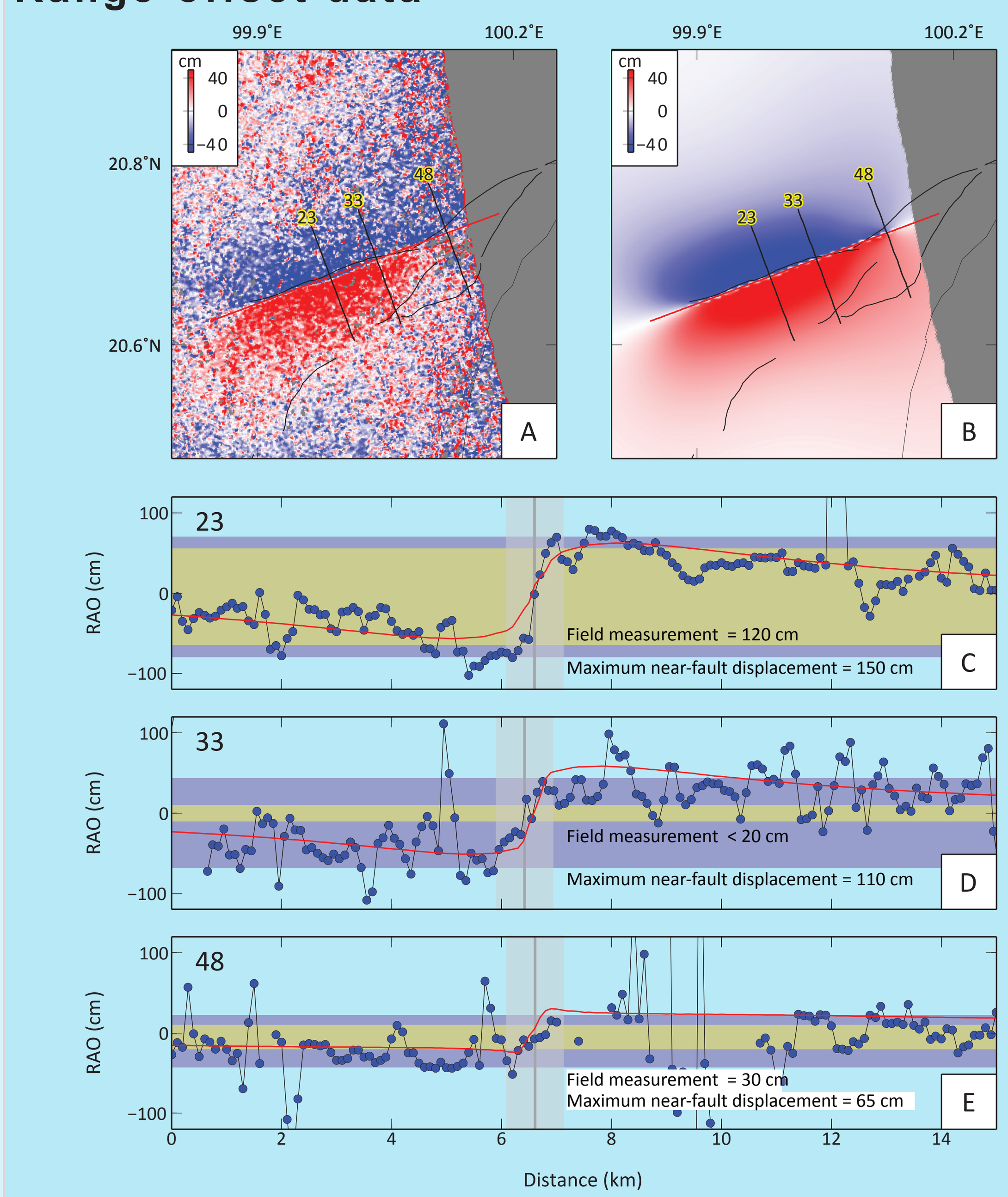


Figure 10 (Left). The comparison between the Range-offset data and the field measurement along three different section of the fault.

Within these profiles, the profile 23 demonstrates one of the end members where most of the deformations concentrate at the fault surface rupture (Fig.4C). The measured offset from this profile is almost identical to the offset value from the nearby field survey point. The sharp change over a short distance in the profile also suggests that most of the ground deformation occurred very close to the fault. Nevertheless, we still find 10 to 30 cm difference between the field measurement and pixel-tracking data, revealing a plausible 10 to 20% off-fault deformation over the distance of ~800 m across the rupture. Such off-fault deformation are likely preformed as the gentle warping and bending on the surface, as the field survey only found one very narrow rupture zone along this section [Soe Thura Tun et al., submitted].

Toward the east, profile 33 shows a completely different type of deformation near the fault trace where the strain is distributed within an at least 1-km-wide zone across the fault (Fig. 4D). Field observation reports series of en echelon cracks on the ground along this section of the fault, suggesting the fault slip is not more than 10 or 20 cm near the surface [Soe Thura Tun et al., submitted]. The profile from the pixel-tracking data also shows a much gentle deformation pattern, even though the overall displacement across the fault remains large (~ 1.1 m). Such gentle deformation curve suggests either the rupture were failed reaching to the surface, or the disturbed slip occurred along the shallow section of the fault. Here, we argue the later (distributed slip) is the explanation for at least part of the deformation pattern, as the field investigation found several plausible tectonic fissures within a range of several hundreds of meters away from the fault near this profile.

Further east, profile 48 in the western side of the basin also shows plausible off-fault deformations within a 500-m-wide zone along the fault. The offset that measured from the offset paddy field boundaries near the profile shows 20 – 30 cm left-lateral offset, whereas the near-fault displacement from the profile are 37 – 65 cm (Fig. 4E). This profile also performs the gentle deformation pattern across the fault as the pattern of profile 33. Thus, we suggests the off-fault deformation along the profile 48 may up to ~30 cm within the zone of ~1 km along the fault, which is about 50% of the total displacement at the western part of the basin.

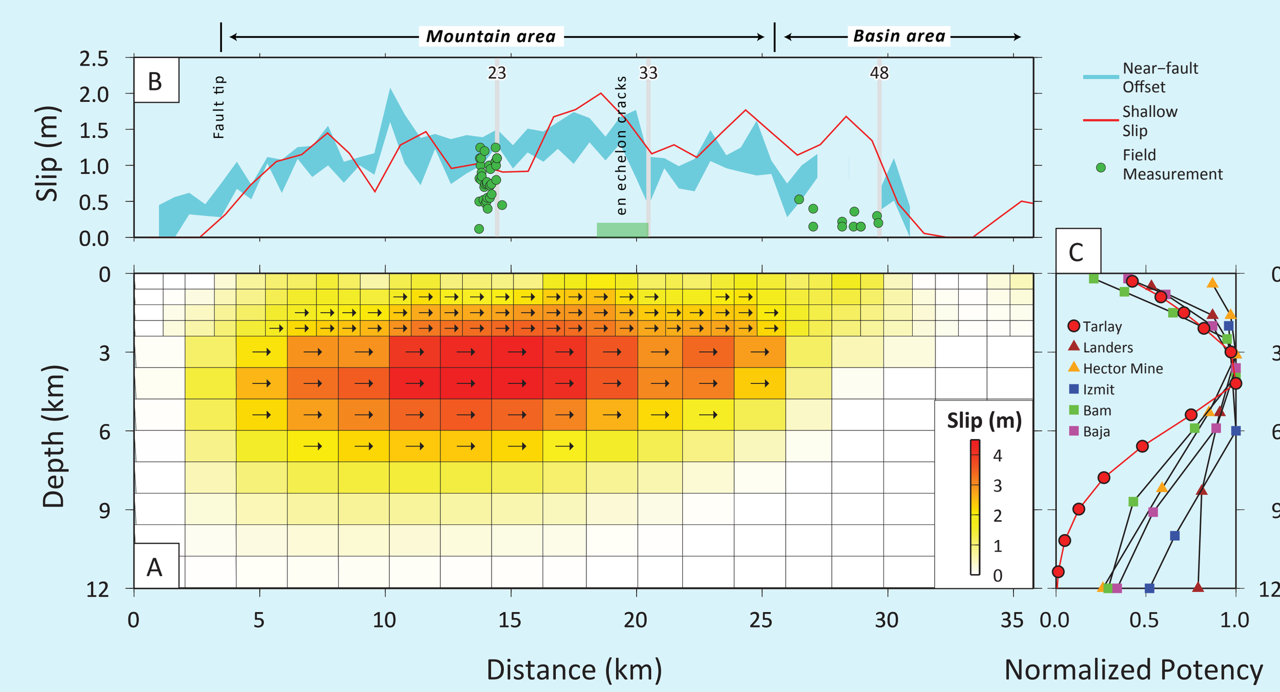


Figure 11. (A) The comparison between field measurements (red dots) and the upper 600 m fault slip (black line) along the Tarlay segment. This figure shows generally good match between the model result and the field investigation result at the central part of the fault. To the east, the field measurements are significantly smaller than the model result. This suggests the near-fault warping when the fault entering the transtensional basin. (B) The fault-slip distribution along the Tarlay segment. The maximum fault slip in our model is about 4 m at 3 – 5 km deep, where most of the slip occurred shallower than 10 kms. The degree of the shallow slip decipt is similar to the Landers and Baja earthquake; however, our model shows a very shallow rupture comparing with all other examples in this chart.

Vertical segmentation ?

Comparing to the result of fault slip distribution during the Kobe earthquake in 1995 and the slip history of associated faults, we proposed the idea of vertical segmentation along the Tarlay segment at the Nam Ma fault. Since the rupture of Tarlay earthquake only slip the upper-half of the seismogenic zone, the lower-half of the fault patch may slip with the nearby patch, or active indepently, as the rupture pattern of the Kobe earthquake in 1995.