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Short Communication

Remote sensing and the search for surface rupture, Haiti 2010

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Abstract Minutes after the 12 January 2010 Haiti earthquake most geologists and seismologists assumed that from its shallow teleseismic location, and its largely strike-slip mechanism that a significant rupture must have occurred on the transform plate boundary south and east of Port au Prince. Within hours, plans were being made by geologists to map the anticipated rupture, and if possible to trench it to obtain a record of paleoseismic slip. However, remote sensing images available a day or two after the earthquake revealed puzzling departures from simple strike-slip displacement, and we now know that shallow slip was transpressive and that no surface rupture occurred. A week after the earthquake it was clear that scientific visits to the region would be much delayed by the continuing needs of emergency response teams and military support who had commandeered access to the airport at Port au Prince. Serendipitously on 20 January, one of the authors accompanied a film crew on a chartered flight from nearby Santo Domingo with the quest to record the tectonic reasons for the disaster, and to document the details of structural damage. At the time there was still no clear idea of whether the transform boundary had a surface rupture, but there was abundant evidence for surface deformation from from Google Earth images showing raised corals and collapsed coastlines along the Lêogáne coast. This article briefly describes communications between remote geologists, and the ground based crew who were guided to critical areas in the search for surface deformation using remote sensing data.

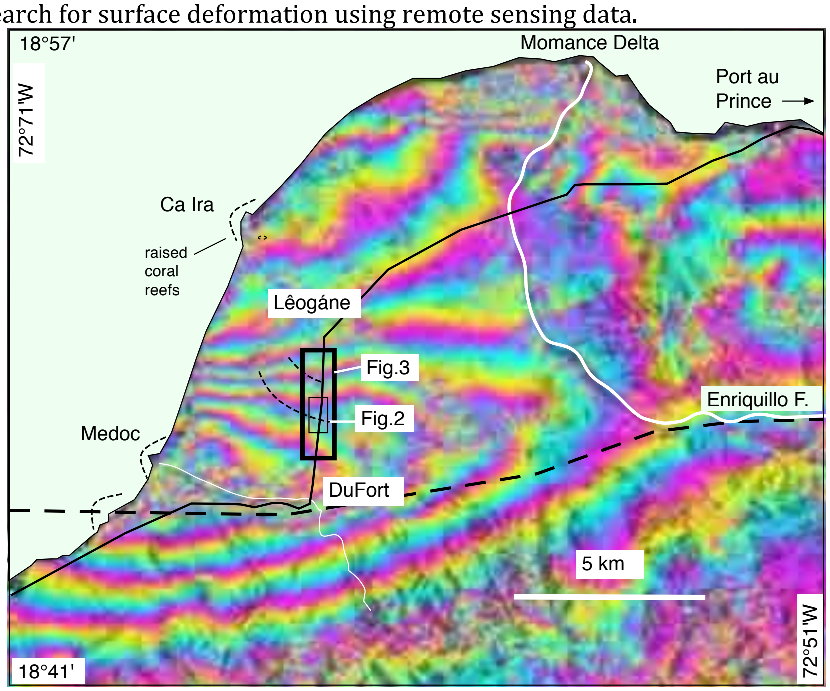

Figure 1 ALOS/PALSAR interferogram south of Lêogáne. Remotely coordinated (but unsucessful) searches for surface cracks were undertaken in fields near where maximum interferometric strain was evident. Ground inspection, however, quantified distributed shear and dilational strain along the DuFort/ Lêogáne road (Fig. 3).

On 20 January the Haiti capital was still in a state of chaos, and although an engineering visit (Eberhard et al., 2010; Bilham,2010a) had hastily installed a few seismometers during the first week, no geologist had set foot in the region. Most of Haiti's 85,000 dead had by then been buried in mass graves outside the capital, and although in the following year official counts continued to inflate the actual count without basis, the much repeated final fatality count of 300,000 exeeds the most conservative estimates documented by critical investigative reporters (Mellison, 2010) by more than a factor of three.

On arrival, the film crew (carrying food, water and tents) camped at the airport with the plan to charter a helicopter and to follow the plate boundary searching for rupture. On 21 January, pending the availability of a suitable helicopter, two vehicles were chartered to document damage in Port au Prince and to search for surface disturbances in the Lêogáne region. An armed escort of commandos accompanied the film team, a precaution adopted in view of rumours of kidnapping and looting, which we subsequently learned were much exaggerated.

Guiding the search for rupture 20-25 January was a substantial body of remote sensing data. These data were made available to the field crew by the transmission of images and coordinates from scientists who were processing images in laboratories in Menlo Park and Pasadena. Those in processing laboratories, and on the ground in Haiti, were in contact daily thanks to the availability of broadband wireless services rapidly repaired after the disaster. As a result, annotated Google Images could be viewed graphically in the mezoseismal area (on an I-phone) shortly after acquisition, with corresponding verbal feedback on findings, and discussions of where to look next. Remarkably, it was possible to head directly to within 10 m of potential ground cracks using these images, supplemented by coordinates entered into a handheld GPS unit.

Ground truth at the epicenter

Despite the exchange of high quality imagery to the field team no surface rupture was identified along the Enriquillo/Plaintain-Garden fault, nor was unique surface rupture identified elsewhere (Bilham, 2010b; Prentice et al., 2010; Rathje et al., 2010; Hayes et al., 2010). In fact, were it not for the 25 January interferometry data (Figure 1), which showed no tell-tale dislocations along the transform valley, there is little doubt that the search for surface rupture would have continued for many weeks.

Notwithstanding the absence of discrete surface rupure it was possible to confirm the JAXA ALOS PALSAR (Japanese Aerospace Exploration Agency Advanced Land Observation Satellite Phased-array L-band Synthetic Aperture Radar) interferometry observation of distributed surface strain south of Lêogáne. Specifically, we had noted during early traverses that a freshly-surfaced north/south road crossing the epicentral region south of Lêogáne had been cracked in numerous places. With one exception all the cracks dissected the road in clean fissures running east-west, manifesting both opening and sinestral shear. The unweathered tarmacadam fractures were devoid of wind blown dust or sand suggesting their recent development presumably at the time of the earthquake.

Fissuring is typical of strong ground motion and is rarely worth quantifying in the epicentral region after an earthquake since it is often attributable to lateral-spreading or lurching. In this case, however, the cracks were confined to a 2.7 km segment of road north of DuFort (Figure 2) where maximum strains were subsequently evident in remote imagery. The line-of-sight length change along this cracked segment of the road amounted to four 11.8 cm amplitude fringes. A digital caliper was available, and it was possible to measure precisely the shear offset, and the width of 65 cracks, on each side of the north-south road surface. Some of the cracks could be followed into the adjoining fields and dwellings, but this was rare because dense impenetrable tropical vegetation made visual tracking difficult. The road cracks were recorded to a precision of 0.01 mm, and an accuracy of ±0.5 mm. Since the film crew provided limited time for science, each was photographed rapidly with caliper offset and handheld GPS coordinates in the same view. Crack positions were subsequently plotted on LIDAR imagery (Figure 2). In one location it is possible to discern a subtle offset in the

PALSAR interferogram extending ≈1 km NW into the fields. Although the image exhibits low nearby coherence we estimate that the offset approximates one fringe (11.8 cm in the radar line-of-sight (LOS) for PALSAR). The radar LOS for this descending scene is about 38 degrees from the vertical looking roughly west. Left-lateral slip on a fault with this orientation would project to about half into the radar LOS. Thus at most, a few tens of cm of slip may have occurred in the fields, compared to the ≈50 mm sinestral crack observed near the end of the apparent PALSAR dislocation where it crossed the road.

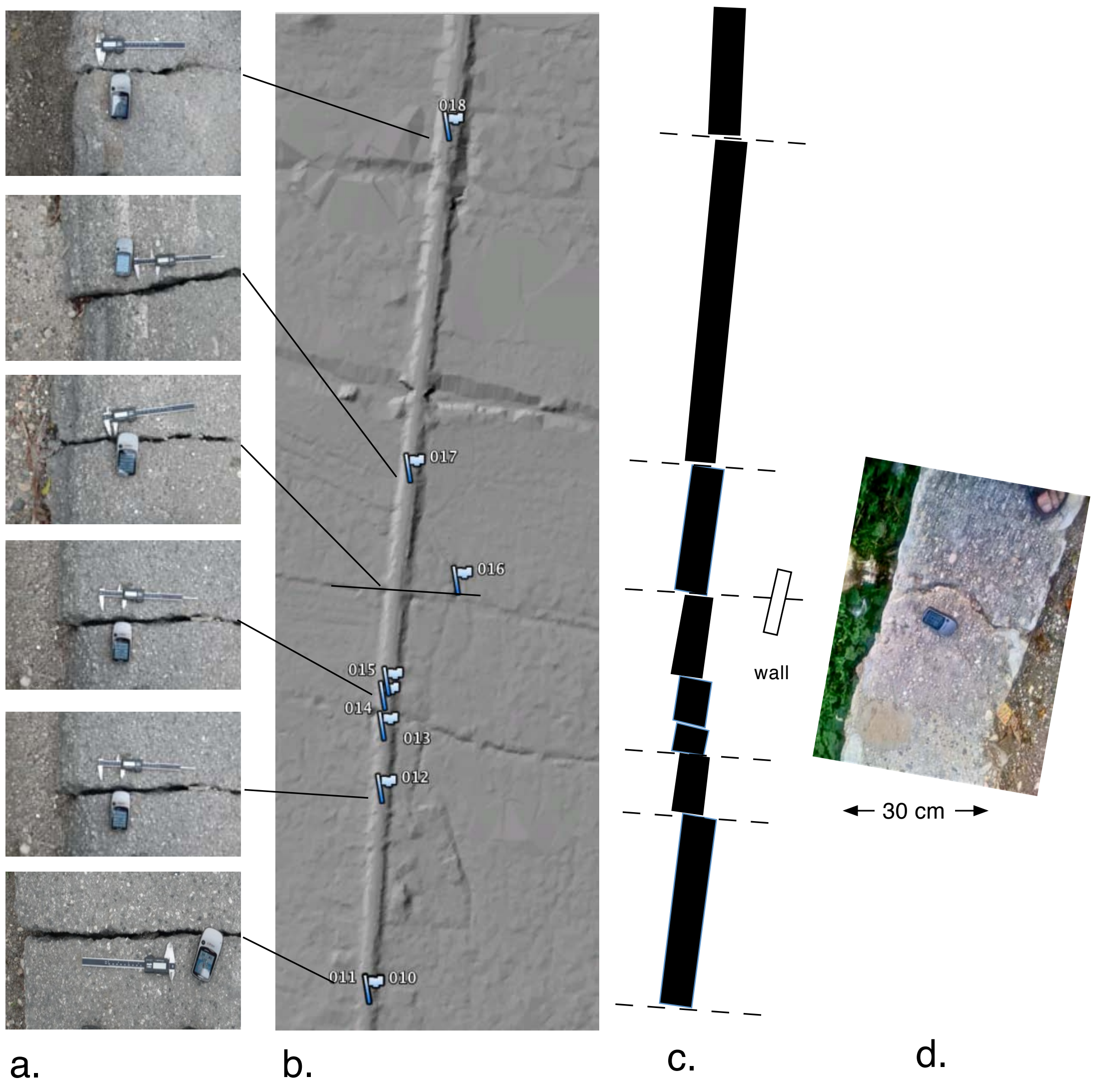

Figure 2 Composite figure shows (left) Lidar with a subset of roadcracks flagged, (center left) photographs of cracks, (center right) cartoon of corresponding road segmentation indicating east and west extension, or sinestral shear (thick black line with offsets) and right, a close up of a house foundation offset by some of the cracks in January showing no additional opening in March 2010.

The edges of the cracks indicated no evidence for pounding as sometimes occurs in lateral spreading, suggesting instead simple separation accompanying coseismic anticlinal uplift. This doming was evident in exposed corals viewed in a helicopter traverse along the coast (Prentice et al., 2010; Hayes et al., 2010). Cumulative opening and shear along the cracked road surface is quantified in Figure 3. The average opening amounted to 45 cm in a distance of 2.7 km, with a minimum of 32 cm of left-lateral shear. Almost certainly this left-lateral shear is a minimum estimate because it was not possible to quantify block rotation between road fissures. The corresponding spatial strains are

1.7x10^{-4} extension and 1.2x10^{-4} sinestral shear, respectively, similar to the ≈1.75 x 10^{-4} strain recorded by the PALSAR interferometry.

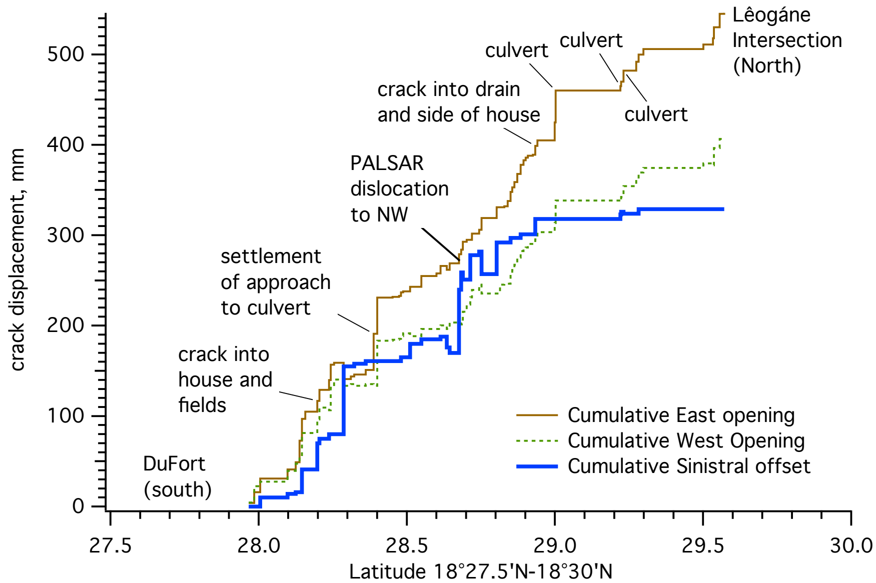

Figure 3 Cumulative crack extension and left-lateral shear on 65 cracks along each side of the road surface between DuFort and Lêogáne. Cracked length =2.97 km. Cumulative average extension equals 45 cm (170 μstrain), and sinestral shear exceeds 32 cm (120 μstrain). In the same distance PALSAR interferometery indicates ≈175 sinestral μstrain (≈38° inclination N85°W line of sight).

Conclusions

Access to remotely-sensed interferometric and space-based imagery following the Haiti earthquake permitted an efficient search for surface deformation by a road- and helicopter- based film crew in the epicentral area. The availability of this imagery to crews on the ground confirmed the absence of slip on the transform boundary, but confirmed its presence in the form of distributed shear in regions of high strain gradient evident in interferometric imagery. The cumulative offset of fresh road cracks on a recently paved road crossing the epicenter confirmed that surface sinestral shear strain south of Lêogáne exceeded 10^{-4}.

Acknowledgements

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