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Active tectonics of the onshore Hengchun Fault using UAS DTM combined with ALOS PS-InSAR time series (Southern Taiwan)

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Abstract. Geometry, characterization and quantification of active faults are major concern in Taiwan, especially following the major Chichi earthquake of September 21st, 1999. Among the targets that still remain poorly known in terms of active tectonics, are the Hengchun and Kenting faults (Southern Taiwan). From the geodynamic point of view, the latter affects the outcropping top of the Manila accretionary prism of the Manila subduction zone that runs from Luzon (N. Philippines) to Taiwan. In order to settle the location, characterization and quantification of the Hengchun fault, we needed to up-date the Chinese Petroleum Corporation (CPC, 1993) and Central Geological Survey (Sung, 1991) existing geological maps using GIS mapping and photo-interpretation of both UAS's acquisition : 1). the very high precision (<50 cm) and resolution (<10 cm) Digital Terrain Model, and the 2). the georeferenced aerial photograph mosaic of the studied area. Moreover, the superimposition of the resulting structural sketch map with the new PSI interferometric data acquired through the SAR ALOS 1 images, validated by GPS data, helps to give motions, characterisation and quantification of the displacements along the LOS during the monitoring time-series (2007-2011). We therefore focus herein on the geometry, the characterization and the quantification of the Hengchun Fault which is an active left-lateral transpressive fault. Finally, as the Hengchun ridge faces one of the last major earthquake of Taiwan (Dec. 26th 2006, depth: 44 Km, M_L=7.0), it is needed to better constrain the active Hengchun Peninsula tectonics in order to prevent major destructions in the near future.

1 Introduction

The island of Taiwan is the place of the so rapid NW-SE trending oblique Eurasian versus Philippine Sea Plates convergence (e.g. Ho, 1986, 1988). A Southwest propagation of the Taiwan deformation is proposed by Suppe (1981; 1984). It is confirmed for instance by the instantaneous discrete GPS measurements that highlight displacements in the Southern Taiwan of about 40 ± 2.3 mm y^{-1} (e.g.: Yu et al., 1997, Chang et al., 2003). This shortening rate is about the maximum range of

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compression in the world. We focus herein in the Southern Taiwan (so called the Hengchun Peninsula), that is geodynamically interpreted as the Taiwan incipient collision zone (Lallemand et al., 2001) which is the transition of the Manila subduction area toward onshore Taiwan. The Hengchun Peninsula is interpreted also as the summit of the outcroping onshore Manila accretionary prism (Malavieille et al., 2002; Chang et al., 2003). Fig. 1 illustrates the modified geological context of the study area. From the lithological point of view, it is a geologically complex area, as it is composed of (1) turbidites (Huang et al., 1997, 2006; Chang et al., 2003 and 2009; Zhang et al., 2016) as well as the "Kenting Melange" close to the Fault zone (shale and large blocks of various lithologies), and (2) five incompatible different 1/50000 scale geological maps had been drawn independently and none are geologically compatible! Two major fault zones trend along the 15km long Hengchun valley (Hengchun and Kenting Faults) and had been recognized by previous authors as potentially active (Bonilla, 1976; Hsu and Chang, 1979; Huang, et al., 1997, 2006; Lee, 1999; Lin et al., 2000; Chang, et al., 2003, 2009; among others)... As the Hengchun Peninsula is the place of sensitive industries to the active tectonics, such as the TAIPOWER Nuclear Power Plant N°3, it is a major concern to better decipher the neotectonics and the active tectonics of the place. Consequently, we herein decided to better localize, characterize and quantify the Hengchun Fault which is the southernmost onshore active fault in Taiwan.

Below, we first focus on the acquisition of the high resolution Digital Terrain Model (DTM below) and the orthorectified image of the Hengchun Fault Zone acquired from Unmanned Aircraft/aerial System (UAS). From the terminological point of view, we used herein the UAS acronym that encompasses all the aspects of deploying those aircrafts and which is less restrictive than Unmanned Aircraft/Aerial Vehicle (UAV) that corresponds only to the platform itself. Then following the classical photo-interpretation techniques, we carefully map and interpret the morphostructures in term of geological mapping as well as revealing the active tectonic structures. We then compare our result to the PSinSAR results of the place that give us the interseismic displacement along the Line of Sight (LOS herein) through the time series using the so interesting long wavelength ALOS 1 JAXA Radar images. The latter is validated by two E-W trending precise leveling lines across the Hengchun Fault and few GPS stations. Finally, the discussion leads us to propose a simple geodynamic and tectonic model for the Hengchun Fault that fits with all the available data.

2 High resolution Digital Terrain Model (DTM) acquired from UAS

An unmanned aircraft system (UAS), commonly known as a drone, is an aircraft without human pilot on board and flies autonomously, and is now been used wildly for many aspects because of its convenience, high resolution, etc. (Fernandez Galarreta et al., 2015 ; Giordan et al., 2015 ; Tokarczyk, 2015 ; Bühler et al., 2016; Deffontaines et al., 2016B). The UAS used in this study is a modified version of the already-available Skywalker X8 delta-wing aircraft reinforced by carbon fiber rods and covered partially by Kevlar fiber sheets. The drone is launched by hand, flies and takes photos autonomously, then glides back down to the ground by using a pre-programmed flight plans organized by ground control system, and controlled by the ground control station and remote controller. The autopilot system is composed and modified from the open source

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APM (Ardupilot Mega 2.6 autopilot) firmware and open source software Mission Planner, transmitted by ground-air XBee telemetry. In order to generate high resolution digital terrain model (DTM below) and mosaic orthorectified images, total 3767 photos were gathered by Sony ILCE-QX1 camera mounted on the crafts, during 5 fly missions, for a total coverage area of 33 Km^2 with 8 cm Ground Sampling Distance (GSD). The coverage of the adjacent photos is kept at least for 85% overlap and 45% sidelap. The data sets generate in this study, orthoimages and DTMs, with a grid spacing of 10cm, where the raw images are process by Contextcapture and Pix4Dmapper software mutually. Prior to the morphotectonic analysis (Deffontaines et al., 1991, 1993, 1997, 2016A; Pubellier et al. 1994...), the quality of the data set (see whole data set on Fig. 2) needs to be evaluated. 18 ground control points used in this study are extracted from airborne LiDAR dataset. The quality of the DTM, compared with airborne LiDAR data, the RMSD of 4 cm with maximum error of 40 cm for the open bar ground area (Huang & Chang, 2014). The Fig. 3 illustrates some case examples of the quality of both the DTM as well as the orthorectified image of the Hengchun Fault. The morphostructures analyses based on photo interpreted are studied accordingly.

3 Geology of the Hengchun area

From a geologic and geodynamic point of view, the Hengchun Peninsula is interpreted as the northern tip of the Manila accretionary prism (Malavieille et al., 2002; Chang et al., 2003). It is mainly composed of several lithological formations that are described below from the older to the younger ones (see location on the cross-section of Fig. 1C).
The Mutan Formation is farther the larger outcropping formation of the Hengchun Peninsula. Middle to late Miocene in age, it is composed of classical turbidites deposits such as interbedded sandstones (channels and levees) and shales (Sung and Wang, 1986). The Mutan Formation is a very thick pile (locally several thousands of meters) and highly deformed turbidites (locally even overturned, Chang et al., 2003).
The complex Maashan formation, late Miocene, Pliocene up to Quaternary in age, is a mixed of submarine erosion and depressions fill-in of both Mutan and Kenting formations (Cheng and Huang, 1975; Page and Lan, 1983; Lin and Wang, 2001; Huang, 2006). The Maashan formation outcrops partly in the South of the Hengchun Basin (CGS geological map (Sung, 1991), see panorama of the Hengchun Basin on Fig. 4). We believe that the Maashan formation compose partly the basement of the Hengchun Basin and the offshore Manila accretionary prism to the south (Lundberg et al., 1992 and 1997; Reed, et al., 1992).
The Kenting Mélange, which is only outcropping east of the Hengchun Basin, is known as a tectonic Mélange (Huang, 1984; Pelletier and Stephan, 1986; Huang et al., 1997, Chang et al., 2003, 2009; Deffontaines et al., 2016B, among others...). Previous authors interpret it as a large tectonic breccia of composite ages as it mixes various sizes of different blocks and different turbiditic and shale bodies (Page and Lan, 1983; Lin and Wang, 2001, Chang et al., 2003). To our point of view this shaly/blocky tectonic Mélange is intruded within the major fault zones south of Taiwan due to both the plate convergence

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and high pressure of fluids at depth (see also Deffontaines et al., 2016B). Future scientific work is definitely needed in order to precise both its role and origin that are still poorly known (work in progress).

From a structural point of view, the Hengchun Fault geological map is the result of (1) field studies (Figs. 4 and 5 taken Jan. 3rd, 2007), (2) the previous geological mappings of the CPC (1993), the CGS-Sung (1991), Chang et al., (2003), Chen et al. (2005) and more recently the Giletycz et al. (2015); and (3) a detailed photo-interpretation of both the orthorectified mosaic of the UAS aerial photograph as well as the hill-shading of the high resolution UAS-DTM (Fig. 5). The detailed structural photo-interpretation of the Hengchun Fault area checked in the fields, takes into account the basic morphostructural principles (Deffontaines et al., 1991, 1993, 1997; Pubellier et al., 1994...) such as the geometry of the drainage pattern (bayonet tracks, curves and alignments), the alignments of small scarps present in the flat Hengchun Basin (Fig. 6, index 5) that helps to get the morphotectonic features (Fig. 6, faults that affect the topography, index 2 for instance). We also added on these local geological and geomorphological mapping places where paleo-surfaces are easily recognized and preserved from erosion on this shaly environment. Paleo-surfaces show particular planar texture and structure, and correspond to slightly folded plateau east of the Hengchun Fault. Those tilted and folded paleo-surfaces are witnesses of the vertical uplift of the tectonic activity of the Hengchun Fault. It remains uneasy to extract fold axes from those paleo-surface. It should be interesting to date these paleo-surfaces in order to get the middle to long-term activity of the deformation. We select also the chevrons from the morphostructural analysis of the high resolution UAS-DTM (Fig. 6, index 6). Chevrons correspond to the top of harder rocks tilted structural surfaces. They reveal tilted strata consequently the presence of folds (anticlines as well as synclines, index 7) close and parallel to the Hengchun Fault zone compatible with the results deduced from the interferometric result (see below). Some tectonically offset and eroded mud volcanoes are also identified and mapped herein especially in the South Hengchun Basin and close to the Taipower Nuclear Power Plant N°3. We interprete these mud volcanoes as the outcropping traces of the shale intrusions within the major fault zones south of Taiwan very probably due to fluids overpressure at depth in relation to the intense tectonic stress (see also Deffontaines et al., 2016B).

The Hengchun Fault is recognized as active (Bonilla, 1976; Hsu and Chang, 1979; Lee, 1999; Lin et al., 2000; Deffontaines et al. 2001). Geological mapping in the fields reveals many active cracks within anthropic concrete dykes. These cracks highlight the clear transpressive and thrusting component of the Hengchun Fault (Fig. 5 both above and below). As the concrete dykes are manmade and very recent, it is easy to reconstruct and inverse the deformation following the Angelier's methodology settled along the Longitudinal Valley Fault (see also Lee et al., 1998, 2000, 2001, 2003, 2005, 2006). One may note that we cannot recognize clearly in the topography the trace of the Hengchun Fault as a unique straight line thrusting (see Fig. 6) contrasting to the CGS geological mapping (Sung, 1991) or its sinusoidal shape on the CPC geological mapping (1993). We only highlights herein locally aligned segments of faults that affect the eastern part of the very recent Hengchun Basin deposits (cf. Fig. 6).

From the dating of the deformation point of view, the long-term slip rate has been settled from marine terraces study and estimated of 6.3 mm y^{-1} at Haikou and 3.8~6.1 mm y^{-1} at Nanwan (Chen and Liu, 1993). Other marine terrace studies from WS Chen (CGS reports in Chinese) show similar long-term slip rate. Further datings ought to be undertaken in order to

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better characterize the ages of the terraces and the different deposits of the Hengchun Basin in order to inverse the tectonic history (Liew and Lin, 1987).

4 Inputs of PS-InSAR interferometry on the Hengchun Fault

In order to get the tectonic activity of the Hengchun Fault, we processed the 13 radar images (ALOS PALSAR data in L-Band - λ = 23.6 cm, acquired between Jan. 2007 and Jan. 2011 so with 4 years monitoring), through the STAMPS software (Hooper, pers. com). Stack of interferograms were calculated by the phase difference of two Synthetic Aperture Radar images with respect to one « Super Master » image situated in the mid-time series (Pathier et al., 2003; Fig. 7). The selected pixels (higher than 20.000 PS points see Fig.8A and 8B) are characterized by an high amplitude and a stable phase over the whole study time period. The 12 interferograms that we have calculated lead us (1) to extract the topographic displacements toward the Line Of Sight (LOS below) and consequently (2) to re-construct those displacements through the time series.
The results (Fig.8A and B) show an impressive density of PS (more than 140 PS Km^{-}) in this area where both human activity and luxuriant vegetation prevail. The PS reveal a clear continuous discontinuity in LOS velocities across the Hengchun Fault (HF below) where the Hengchun valley (western side HF) is subsiding with values ranging from -5 to -10 mm y^{-1} and the westernmost Hengchun ridge is uplifting, contrasting on the eastern side of the HF to the uplifting of the Kenting Mélange. We note the great coherence in between the PS and the GPS measurements (colored large dots put into the radar geometry). Consequently, this PS-InSAR reveal a more precise mapping of the active interseismic splays of the Hengchun Fault and reveal both characterisation and quantification within the time series of the tectonic displacements. No differential PS displacement along the LOS is registered by our radar dataset TIME SERIES on the Kenting Fault. As from the analysis of the Chang et al. 2003 geological mapping it is a low dipping thrust fault due to its sinusoidal geometry and intersections with the topography, this fault be may locked at the surface or have a tectonic activity that we do not observe on this INSAR dataset.
The two PS profiles (Fig. 9, see location Fig. 8) that run transverse to the Hengchun Fault one north of the Hengchun valley close to the Checheng city, and the second one southward (close to Hengchun city), both show LOS displacement less than 10 ± 2.5 mm y^{-1}.
We compare our projected PS result to topographic data and especially leveling data acquired during the same period of time (between March 2008 to April 2011 during 3 campaigns of measurement) in order to validate the PS results. Consequently, we convert the GPS points into the Line Of Sight (LOS) value. The yellow triangles on Figure 10 represent LOS velocities for GPS stations close to the leveling profiles. One may note the good coherence of the leveling and the PS results.
The creep estimation of the Hengchun Fault from north to south gives an interseismic LOS velocity offset more than 7 ± 2.5 mm y^{-1} that reveal the clear tectonic activity of the Hengchun Fault (Fig. 11). One may note the excellent coherence of the yellow triangle zone of the GPS projected in the INSAR geometry with the resulting processed PS (see Fig. 11). This is a

major result from this study as it gives the average annual interseismic displacement toward the LOS of the Hengchun Fault. The following Times series show the total slip vector. It shows neither specific behaviour nor seasonal variations (Fig.12).

5 Discussion: up-dated Hengchun active tectonic model

Many different tectonic models had been proposed on the active Hengchun Fault zone (thrust, left-lateral strike-slip...). But nobody were able to gave arguments and prove the validity of one of those all along the Hengchun Fault (e.g. Liew and Lin, 1987; Chen and Liu, 1993, 2000; Chang et al., 2003, 2009; Central Geological Survey and CPC geological mappings -1991 and 1993 respectively; Chen et al. 2005).

The simplest tectonic model that fits with both the oblique NW trending Taiwan geodynamic convergence (Suppe, 1984), the E-W displacements shown on the GPS data (Yu et al., 1997), the geometry of the geological dataset and geological mapping (CPC-1993 and CGS- Sung, 1991; Chang et al., 2003 and 2009, Giletycz et al., 2015), our detailed UAS DTM photo-interpretation and field work (Fig. 6) and our interferometric 2009-2011 PS LOS displacements monitoring (Fig. 8A and 8B), is given (Fig. 13) for the westward onshore Hengchun Peninsula.

From the interferometric point of view, if we generalize, the westernmost Hengchun Peninsula is slowly uplifting toward the LOS (less than +1 cm y^{-1}) contrasting to the slow subsidence of the eastern part of the Hengchun Peninsula (-0.25 cm y^{-1}). So as the average topographic displacements deduced from the interferometric processing across the Hengchun Fault is continuous across the Hengchun Fault zone, that show the existence of its clear average interseismic creeping component of 0.8 mm y^{-1} along the LOS. The variation of displacements on both sides of the Hengchun Fault zone reveals also the progressive folding of the Hengchun Fault zone: the eastern hanging wall is progressively uplifting acting as a growing anticline which contrasts to the progressive subsidence of the Hengchun Basin (Foot Wall and growing syncline - see Fig. 9 and 10). The interferometric results show that the fault is only locally outcropping and active folding on both sides occurs increasing progressively stress and strain at depth.

Consequently due to the structural geometry, the Hengchun Fault appears to act as an active left lateral transpressive strike-slip fault with an active uplifting of the Hanging Wall (eastern bloc) contrasting to the active subsidence of the western footwall (western bloc and that correspond to the easternmost part of the Hengchun Basin). Moreover the fault is not outcropping as the deformation is continuous that may explain the reason why we saw so little active fault segments at the surface. One may note that the left lateral strike-slip motion had been deduced from the obliquity of the GPS arrows evidenced by Chang et al., (2003). Therefore the figure 13 shows the transpressive left-lateral N160°E trending active Hengchun Fault zone and the active hanging wall overthrusting at depth and actively folding the topographic surface above the footwall Hengchun Basin that is subsiding probably due to a parallel to the fault syncline axis that helps for the lagoonal deposition of the Pleistocene/Holocene Hengchun Basin deposits (Chen et al., 1991).

abitrary! unclear ?? why? (!) What a mess! unclear! ?

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One may note that many faults in Taiwan present both displacements such as the active displacement we deduced herein for the Hengchun Fault (left-lateral strike-slip and overthrusting) such as the Chelungpu Fault (reactivated during the 921 Chichi earthquake Sep. 21st, 1999).

Dealing with the amplitude of the Hengchun Fault deformation, the interferometric displacement toward the LOS (0.8 ± 0.2 cm y^{-1}) correspond to the instantaneous interseismic slip rate that could be a bit different than the vertical long term slip rate deduced from the marine terraces datings 6.3 mm y^{-1} at Haikou and 3.8~6.1 mm y^{-1} at Nanwan (Chen and Liu, 1993). From this slight difference in between the long term and the instantaneous slip rates, we may deduce the fact that the Hengchun Fault is not only a creeping fault (work in progress).

6 Conclusions and perspectives

First, the flights of UAS lead us to settle through photogrammetry, a high resolution Digital Terrain Model of the Hengchun Fault area with a less than 7 cm ground resolution and less than 40 cm precision. However for some places, e.g. for the lakes, the texture is changing rate higher than image capture rates, so the water surfaces causes noises in DTMs. Concerning data interpretations, especially for the active geological structures, the terrain is easily to be modified by human activity in Taiwan. The cities and the farmer land are developed some areas thus conceal detail morphotectonic study. Fortunately, the orthomosaic images helps to recognize those artefacts. Overall, the autonomous UAS and well developed photogrammetry generates high detail topographic information conveniently, and helps to carry on long term scale morphotectonic study. Integrating of PS-inSAR data showing the short term active movement of the Hengchun Fault and UAS demonstrates longer term topographic deformations and anomalies, thus providing one of different tectonic deformation terms to get active tectonics features.

Then with these so useful high resolution topographic data, we undertook a classical geological and geomorphological photo-interpretation that lead us to up-date and refine the pre-existing CPC-1993 and CGS-1991 geological maps, especially on both side of the Hengchun Fault. The latter lead us to precise the structural geometry of the Hengchun Fault in the Peninsula (Fig. 6). Moreover, the PS-InSAR interferometric processing that we carried out over the Hengchun Peninsula from 2007 to 2011 with more than 12 coherent interferograms reveal displacements proving the interseismic activity of the Hengchun Fault. Moreover, our interferometric results confirmed by GPS data (transform into the radar geometry) reveal the active deformation of the eastern hanging-wall of the Hengchun Fault of about 0.8 ± 0.2 cm y^{-1} toward the Line of Sight (LOS) due to an active anticline folding. Furthermore the footwall is submitted also to a complentary active subsidence due to the development of an active syncline that parallels the Hengchun Fault. These displacements are a cumulative vector taking into account both planimetric and tvertical components of the deformation. Our results are fully coherent with both two leveling lines E-W trending across the Hengchun Fault and three continuous GPS stations. Moreover the interferometric Persistent Scatterers density (more than 140 PS Km^{-2}) is so superior to that offered by the GPS measurements, allowing us a global and whole coverage and mapping of the active Hengchun Fault deformations.

So, we deduce that the highly dipping Hengchun Fault act as an interseismic creeping left-lateral strike-slip fault with a clear transpressive component of 0.8 cm.y-1 displacement to the LOS that is associated with active foldings. One consequence of this interpretation is that due to the continuous PS interferogram spectrum across the Hengchun Fault, it is actively folding. This signs the slow continuous increase of tectonic stress at depth which is a major clue for a future earthquake in that area. Unfortunately, the active differential displacement on both side of the Kenting Fault is much more difficult to highlight with our interferometric processing, due (1) to the low dipping of that fault deduce from its mapping geometry, and also (2) due to the ductile rheology of the underlying formation (Mutan clay turbidites - MT). It is needed to much better map the Kenting Fault in order to better understand its rheology and active behaviour (work under progress).

Anyway, the shallow seismicity (Deffontaines et al. 2016B) confirms the high onshore shallow tectonic activity that hits the Hengchun Peninsula. The deep offshore major Hengchun earthquake (Dec. 26th 2006, depth: 44 Km, M_L=7.0) also participate to the active deformation of the Peninsula.

Finally, due to the homogenous 0.8 cm y^{-1} displacement toward the LOS all along the 15 Km of the Hengchun Fault studied area, it is definitely needed to better constrain the Hengchun peninsula active tectonics in order to prevent major destructions and major failure in the near future as for example for the present so sensitive energy industries (e.g. the Taiwan Nuclear Power Plant N°3 situated along the southern tip of the Hengchun Fault).

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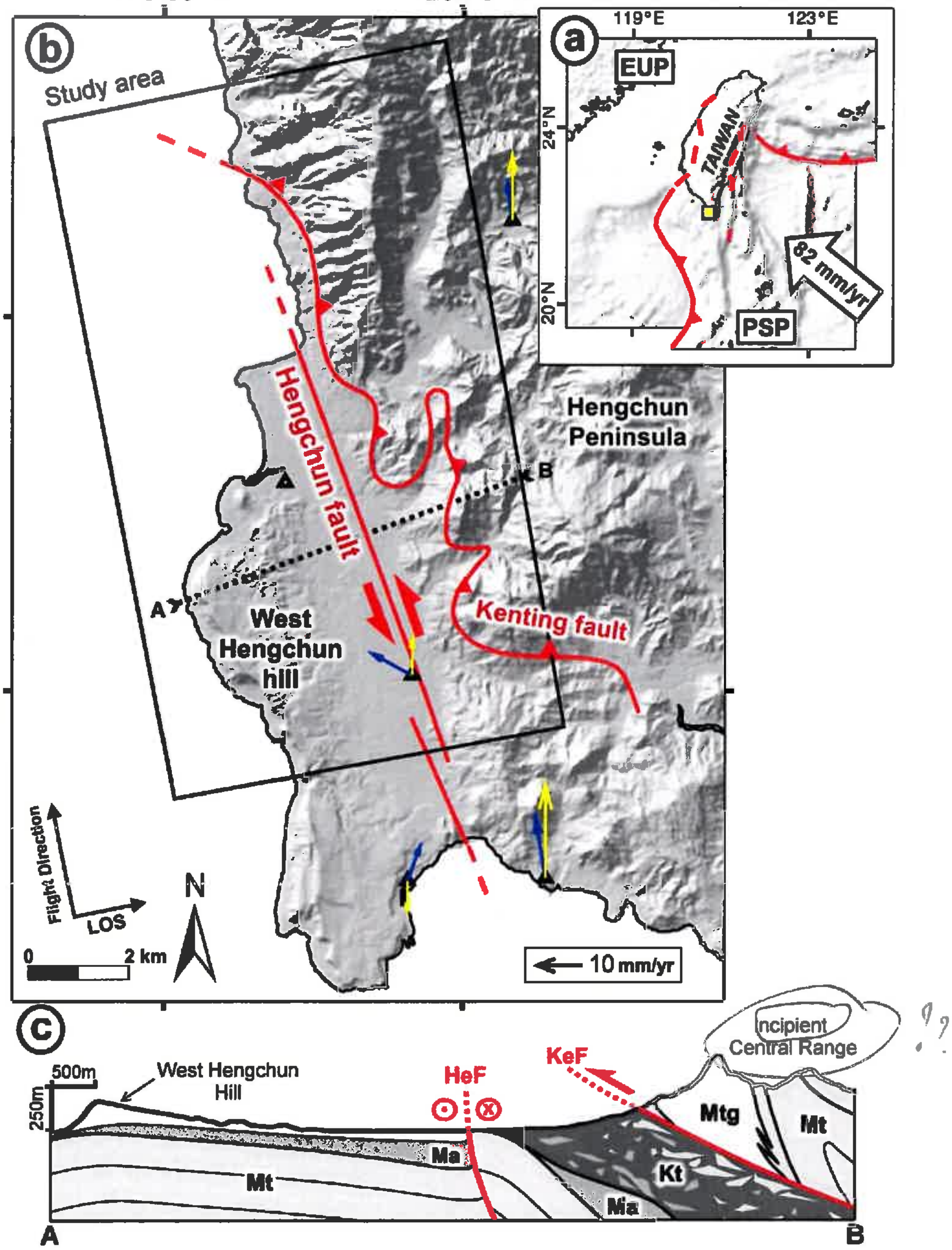

Figure 1: Location of the Hengchun and Kenting Faults (heavy red lines) within Southern Taiwan. Fig. 1a: location of the Hengchun Peninsula (yellow quadrangle), EUP Eurasian Plate; PSP: Philippine Sea Plate. 82 mm y^{-1} is the rate convergence of the Philippine Sea Plate toward the Penghu Islands (Yu, et al. 1997). Fig.1b: blue and yellow arrows horizontal and vertical GPS displacements respectively; Black Triangle: used GPS stations; A-B location of Fig.1C geological cross-section; Fig.1c: W-E

not on the map
Eurasia

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trending synthetic geological cross-section, modified from Zhang et al. (2016), Ma: Maanshan formation, Mt and Mtg: different facies of Mutan formation, Kt: Kenting Melange.

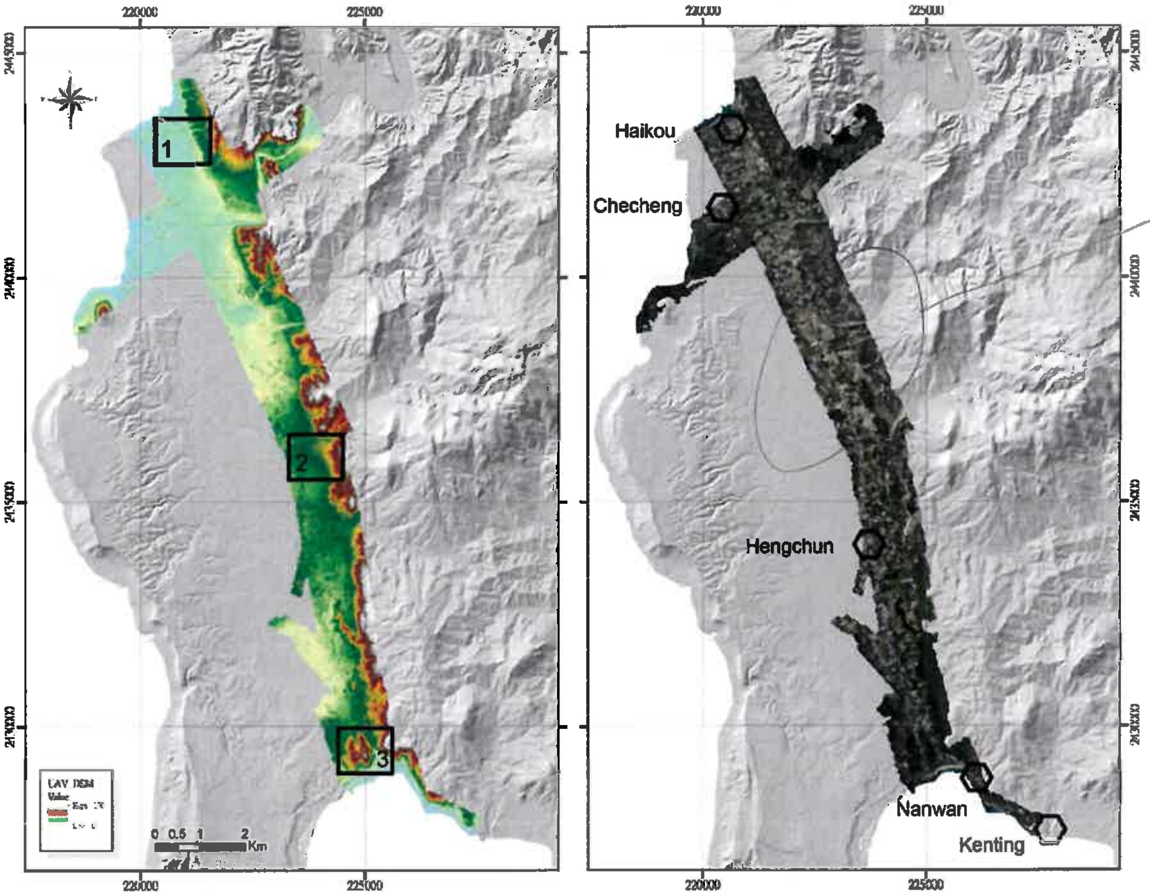

Figure 2: Digital Terrain Model (DTM) of the Hengchun Fault area on left side (altitude in meter, black rectangles location of the three detailed sites of Fig. 3). right: Mosaic of orthorectified images, the black hexagons denote the cities. One may notice the contrasting relief on both side of the Hengchun valley : its western part is slightly tilted contrasting to the highly eroded eastern part.

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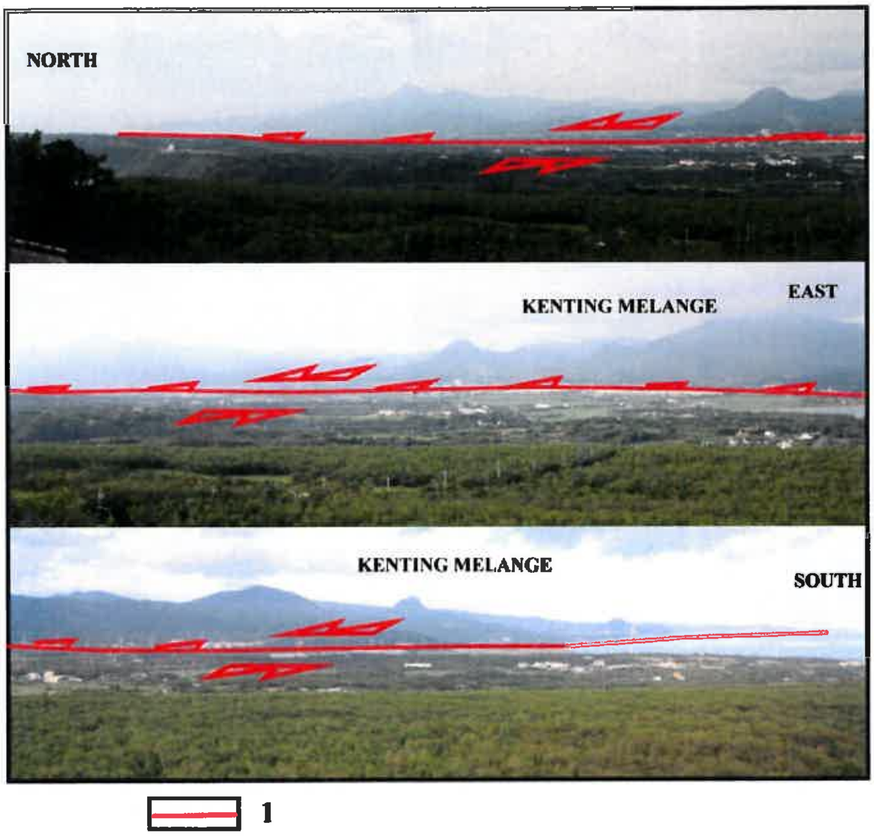

Figure 4: Panorama of the Hengchun Fault observed from the SW part of the studied area. 1: red lines correspond to the left lateral compressive Hengchun Fault. ~~One may~~ note the isolated summits within the Kenting Melange that correspond to a tectonic breccia with various blocks surrounded by highly deformed shales.

↳ Main blocks could be olistolith...

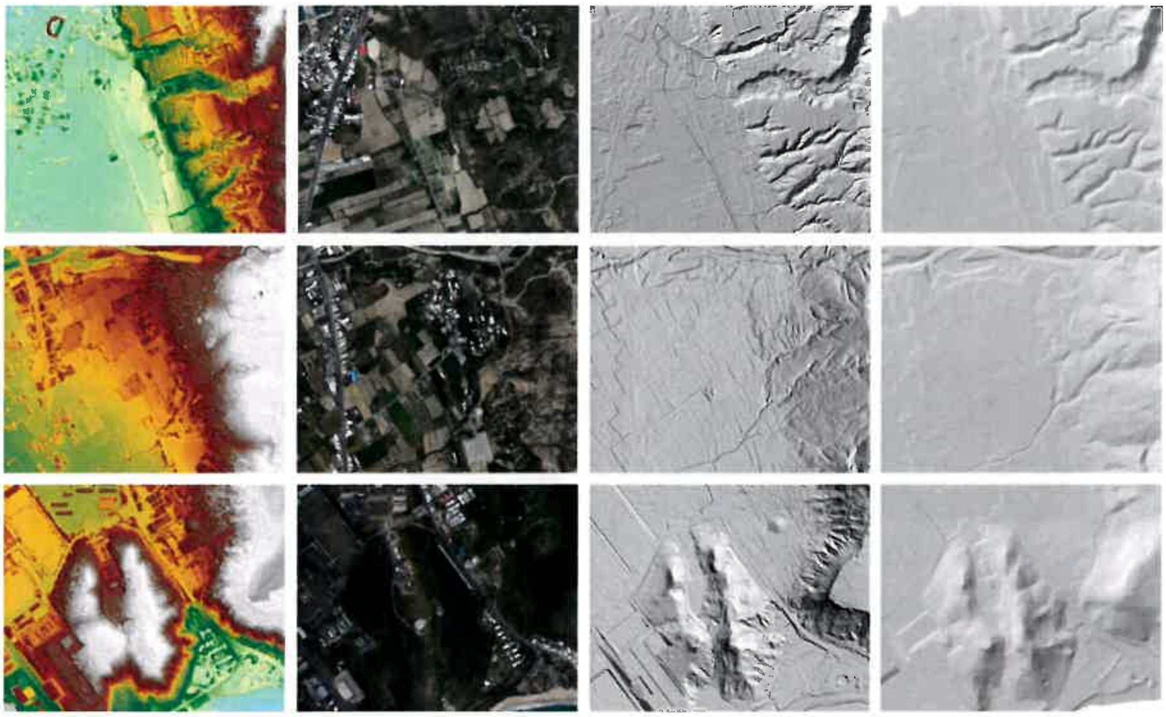

Figure 3: Three case examples taken from North to South of the UAS Digital Terrain Model (DTM) - left column : hypsometric color images (see legend in Fig.2) and third column to the right: for the black and white hill-shading relief) and the associated orthorectified images mosaic (2nd color column) acquired from UAS compared to the reference 5m ground resolution DTM (last right column). The first line of images highlights the active tectonic scarp of the Hengchun Fault which differentiates 2 blocks with erosion to the east and sedimentation to the west. the second line highlights the left lateral offset of tributaries on a glacis. The last line of 4 images of Fig. 3. show a deformed elongated mud diapir close to the Taiwan Nuclear Power Plant N° 3 (see infrastructures on the lower left corner of the deformed mud volcano).

unclear to me!

I do not see any legend in Fig 2...

Can you explain?

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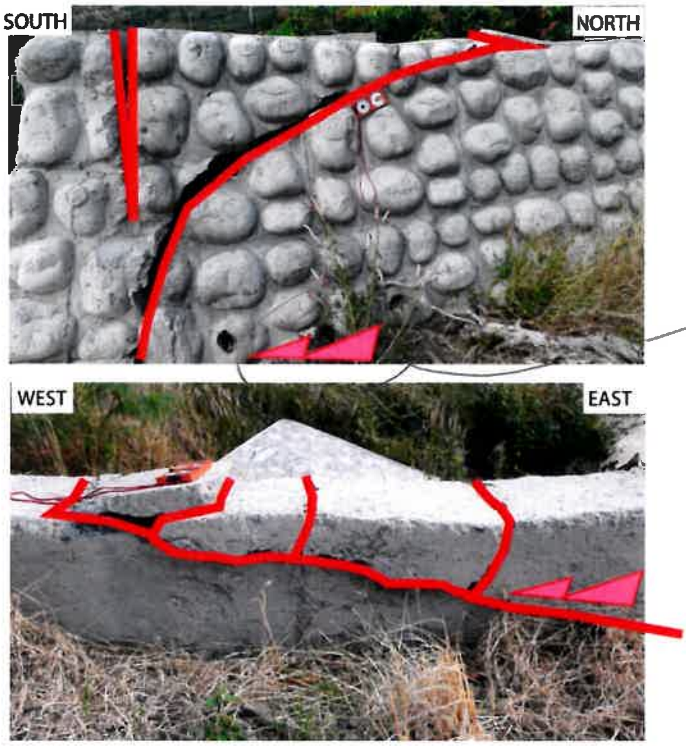

Figure 5: Field work images of compressive features affecting recent concrete dykes after the Hengchun earthquake (Dec. 26th 2006, M_L=7.0), see location on Fig. 1 near the Fang-Shan village (22.26°N, 120.66°E). The red compass give the scale of the outcropping deformation (20 cm). Above: extrados and tension joints due to the compression; below: thrust detachment associated with three back-thrusts highlighting a small pop-up (below the compass). The red arrow reveal the thrusting component that affects the new concrete dykes.

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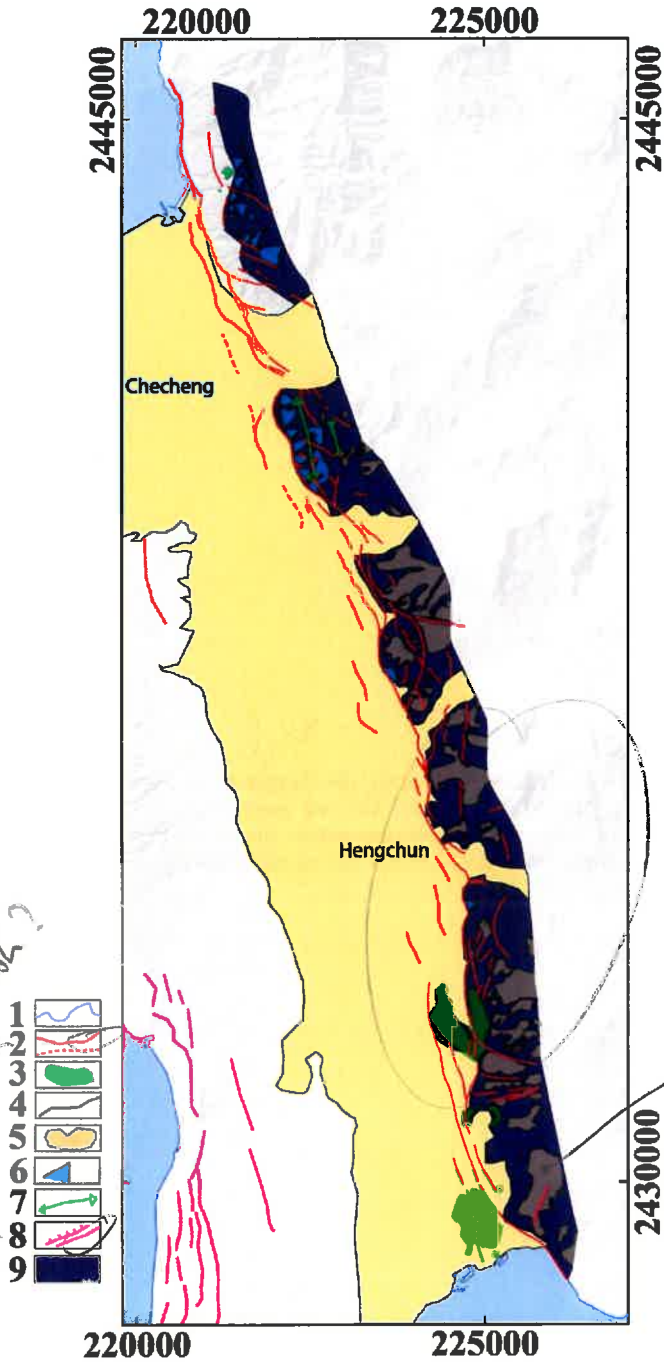

Figure 6: Morphostructural map of the Hengchun Fault: 1. Shoreline ; 2. Faults (certain, inferred); 3: Mud-volcano ; 4: Lithological boundaries; 5: Paleo-surfaces ; 6: Chevron corresponding to tilted structural surface, 7: Fold axes; 8: Landslide and extrados fault (see Deffontaines et al., 2016B); 9: Kenting Mélange.

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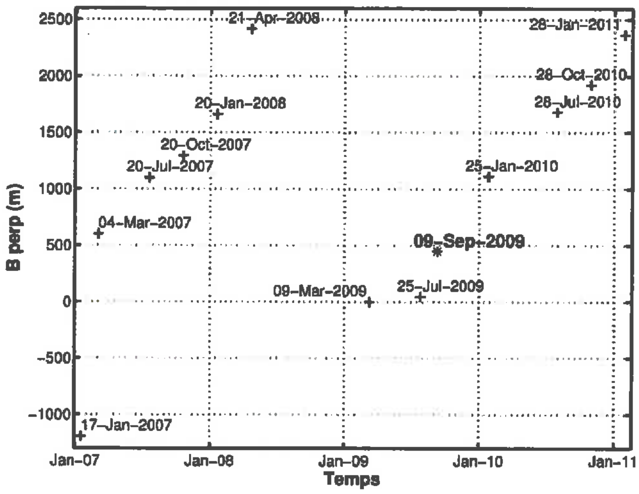

Figure 7: Times series of the processed ALOS SAR radar images and their associated perpendicular baselines. All slave images are linked to the best master image chosen in the middle of the time series to shorten perpendicular baselines that decrease radar geometric artefacts.

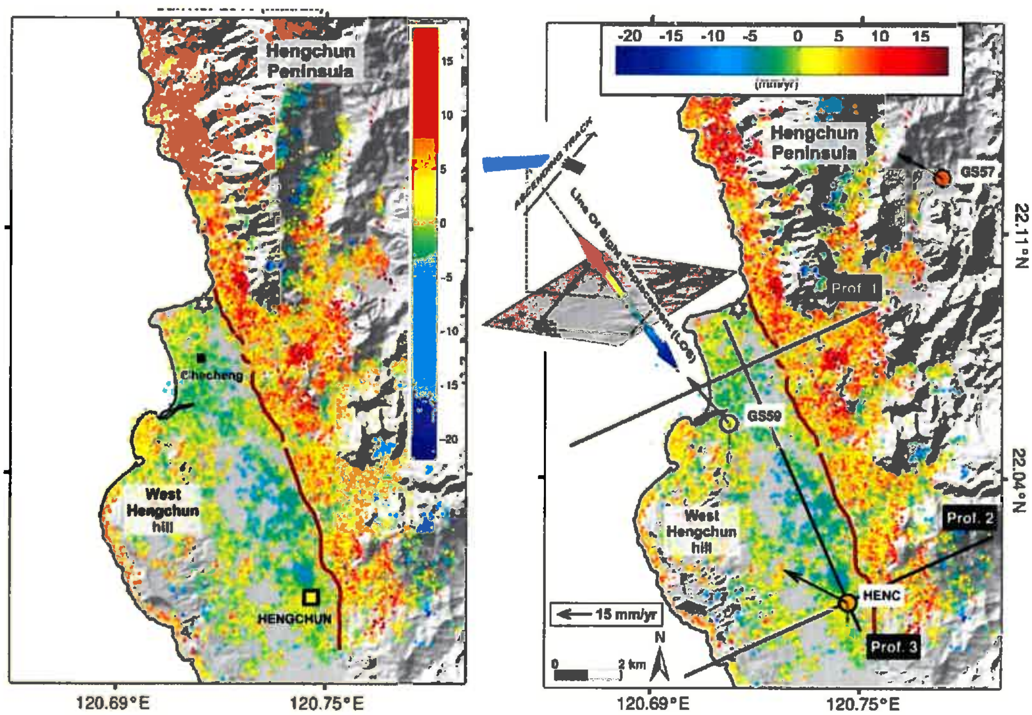

Figure 8A left, 8B right: PS result superimposed to the Digital Terrain Model 40m ground resolution and the GPS points with the associated speeds (Black arrow). Red line: Hengchun Fault. Location of profile 1 and 2 (see Fig. 9).

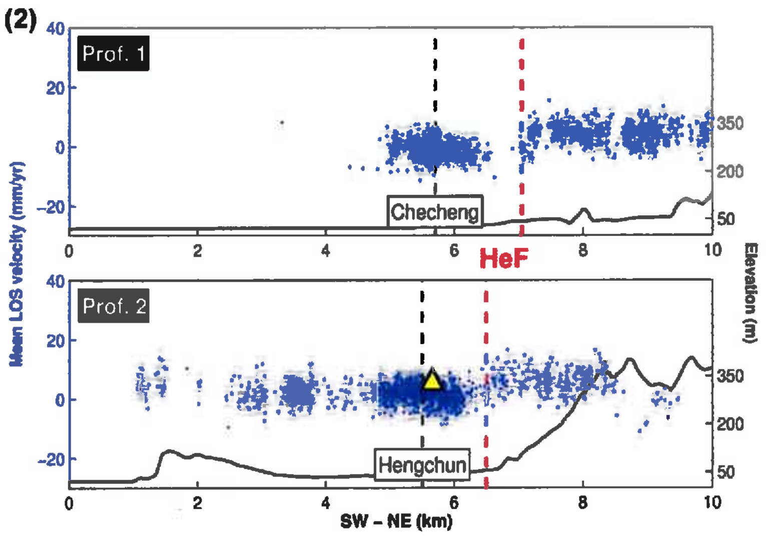

Figure 9: E-W projection of Mean LOS velocity in mm/y (blue dots with error bars, E on the right) on transverse profile to the Hengchun Valley, Black line: topography, Yellow triangle GPS point, HeF: Hengchun Fault.

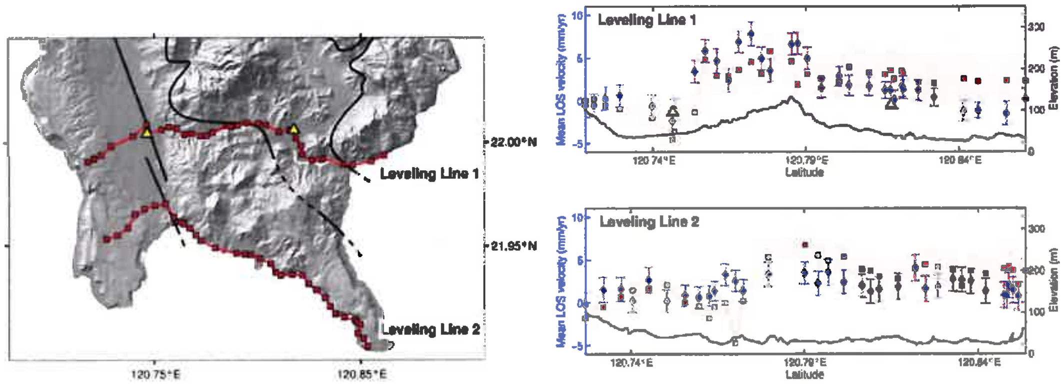

Figure 10: (A) Location of the leveling on the Hengchun Peninsula, (B) associated PS (blue dots) leveling data (red square) and GPS stations (yellow triangle). One may note the general coherence of the topographic displacements.

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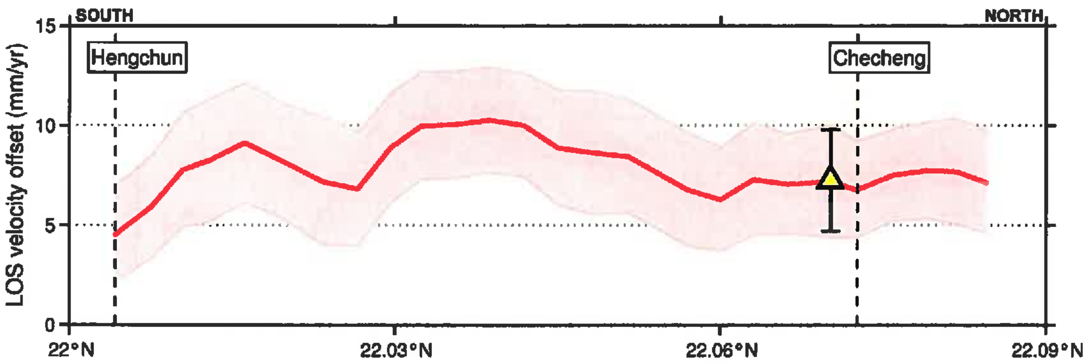

Figure 11: Hengchun Fault along strike variation of LOS velocity displacement (in mm/y). One may note the active interseismic displacement that highlights definitively that Hengchun Fault is an active Fault of Taiwan.

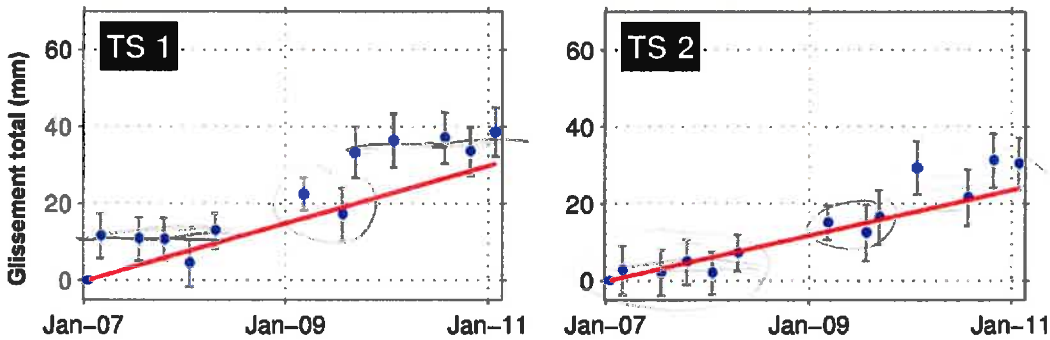

Figure 12: Average continuous slip vector of the time series where no particular seasonal effects prevail. Further studies and PS monitoring ought to be developed in the near future to up-date and precise this aspect.

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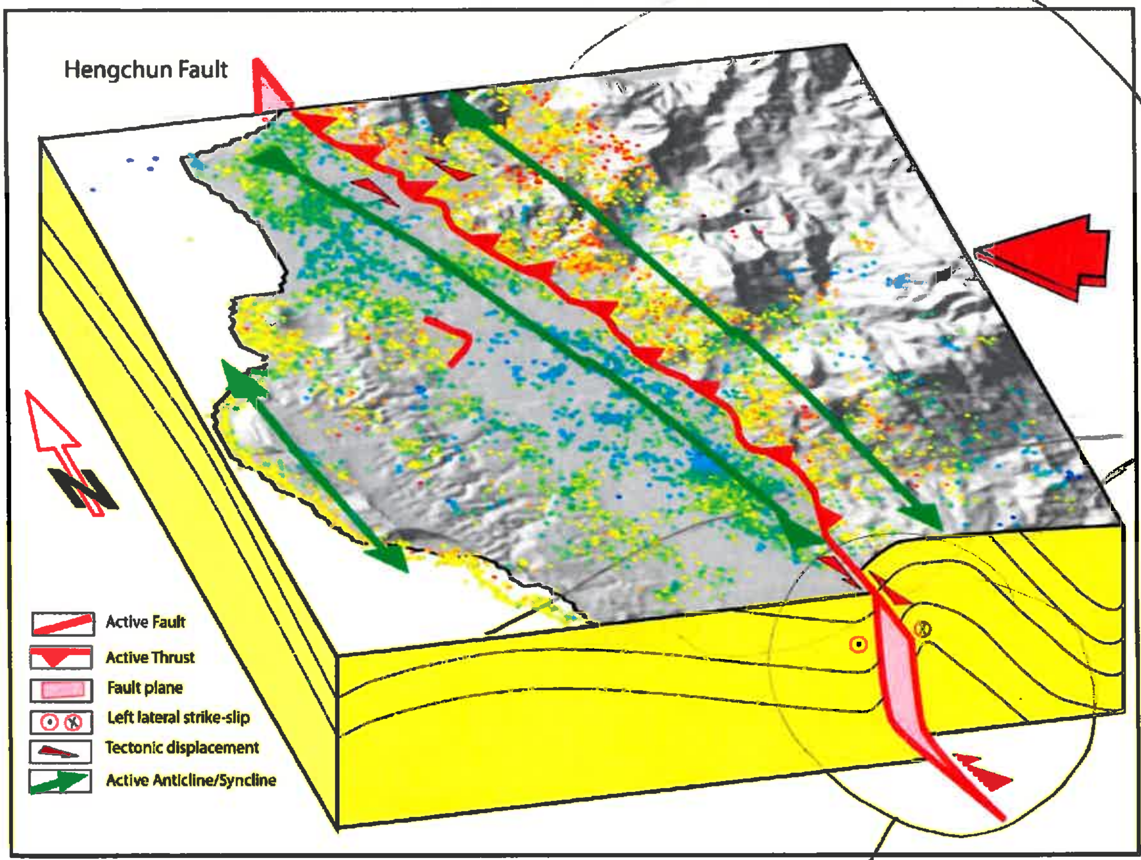

flat topography?

Figure 13: Simplest model of active inter-seismic tectonic deformation of the Hengchun Fault compatible with the oblique geodynamic convergence (large red arrow on the right), GPS and interferometric active displacements and the detailed UAS DTM photo-interpretation. The Hengchun Fault act as a left-lateral transpressive strike-slip fault with an actively folding and uplifting anticline (hanging wall) contrasting with the aligned active subsidence of the syncline that trend parallel to the Hengchun Fault.

which constraint is given on the left-lateral and vertical motion by this model

I am not convinced by this geometry of fault that does not fit the map surface fault trace.