# SEISMIC HAZARD ASSESSMENT IN TAOYUAN-HSINCHU AREA: INSIGHTS FROM INSAR PERSISTENT SCATTERERS


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**ABSTRACT:** We study recent tectonic activity in the Taoyuan-Hsinchu area in northwest Taiwan. Using the latest technique of radar interferometry, InSAR persistent scatterers and GPS, we are able to demonstrate that uplift in Shuanglienpo syncline is due to the growth of a blind fault system; and, Hukou fault is slowly accumulating strain. Information about these subsurface structures is vital to seismic hazard assessment since they are proved to be active.


## 1 Introduction

In this study, the area of interest, Taoyuan-Hsinchu, is located at the outer fold-and-thrust belt of Western Foothills, formed mainly of Neogene clastic sediments (Ho, 1986) or terrace gravel/alluvium (Figs 1 & 2a), in northwest of Taiwan. This is an unmetamorphosed and slightly deformed region in front of Taiwan orogeny (foreland basin). It has been inferred as a transition zone between the active shortening of the Miaoli Domain and active extension of the Taipei Domain (Shyu et al., 2005). In terms of level of seismic activity, there are few earthquakes, with no recorded destructive earthquake ever been documented (Fig. 2b) in the study area. Nevertheless, two large destructive earthquakes, namely the 1909 Taipei (ML=7.3, focal depth approximately 80 km) and 1935 Hsinchu-Taichung (ML=7.1, focal depth 5 km) earthquakes, occurred in the close proximity (Fig. 2a). Besides the prominent 1999 Chi-Chi earthquake happened in central part of Taiwan, the 1935 Hsinchu-Taichung earthquake caused the largest casualties in the twentieth century in Taiwan: 3,276 deaths, 12,053 injured, 17,907 houses totally destroyed, 11,405 partially destroyed and 25,376 damaged. The absence of destructive seismic event in the Taoyuan-Hsinchu-Miaoli region since at least third quarter in the century should not be interpreted as evidence of seismic quiescence, but rather indicates strain deficit and suggests continuing accumulation of elastic stress (Ng et al., 2009). Taoyuan-Hsinchu-Miaoli area has high potential of occurring next possible large earthquake (Ng, 2010) in the coming decade provided that the time-predictable model (Shimazaki and Nakata, 1980) is applicable in Taiwan. In this paper, we are going to examine present-day surface deformation using short-term geodetic measurements both from InSAR persistent scatterers (PSI) and continuous GPS (CGPS).

## 2 Local Geology

An obvious geomorphologic lineament, namely Shuanglienpo lineament, which approximately extends 10 km from Poukongkang tableland, via Shuanglienpo of Pingchen tableland and ends in northwest of Jhongli city, Taoyuan county, Taiwan (Shih et al., 1983), has long been observed. It is a convex-shaped lineament with the maximum curvature pointing towards northwest. Northwest of Shuanglienpo lineament, it is a flat coastal plain and its elevation lies between 0 and 70 m. It is a relatively tectonic stable region. Many shallow seismic reflection profiles have already revealed that sediments layers are nearly horizontal and continuous (Wang et al., 2001). It is, however, valid only because the depth of those shallow seismic reflection profiles is about 1 km. They reveal clearly very shallow structures such as Shuanglienpo syncline and Pingchen anticline (Fig. 2b) but not intermediate- or deep-depth structures. Southeast/South of Shuanglienpo lineament, regional tectonics becomes more complicated. There are several active faults and anticlines, for example, Hukou fault and Hukou anticline (Fig. 2b). Going further southeast, it is the inner fold-and-thrust belt of Western Foothills. The deformation front of the Taiwan orogeny in this region is lying somewhere between the flat coastal plain and Hukou fault. Hukou fault, or so-called Yangmei south fault, which trends ENE, is another important fault in the area. It approximately runs 23 km. Together with an anticline, namely Hukou anticline, to its south, the mechanism of folding has been proposed as fault-bend folding (Suppe, 1983).

Having analyzed the whole region, Wang (2003) concluded the regional tectonics was a dual opposing folds-and-blind faults system (Figure 62, Wang, 2003). Morphology of Pingchen anticline was mainly controlled by a south-facing backthrust, opposite to the direction of plate convergence. A wedge structure also exited in the south limb of Pingchen anticline which was backthrusting. Hukou fault, nonetheless, was most likely to be a hinge-break fault and was not a seismogenic fault. We will take advantage of Wang's (2003) study and use his profile to explain our PSI observations.

## 3 Methodology and Data Acquisition

### 3.1 From radar interferometry to InSAR Persistent Scatterers (PSI)

Radar interferometry and its subsequent advancements have been proved their capabilities in monitoring crustal deformation (Massonnet et al., 1993; Pathier et al., 2003; Chang et al., 2004) and other geophysical applications. This relatively new geodetic technique calculates the interference pattern generated by the difference in phase between two images acquired by spaceborne synthetic aperture radar mounted on satellite such as ERS1/2 and Envisat at distinct times. The resulting interferogram is a contour map of the change in slant range distance. Radar interferometry is also called Synthetic Aperture Radar (SAR) interferometry or Interferometric SAR (InSAR). InSAR Persistent Scatterers (PSI) is the latest new analytical method which overcomes the problem of decorrelation in conventional InSAR studies by identifying resolution elements whose echo is dominated by a single scatterer in a series of interferograms.

The working principle of conventional InSAR is as shown in Figure 3. At time1, the synthetic aperture radar emits microwave and hits a ground target. Phase of the back-scattered energy, as well as amplitude information, is recorded. At time2, it receives another radar signal which records topographical change due to land uplift. Phase difference in these two images, or passes, can generate an interferogram, which is a contour of change in slant range direction. The phase difference is related to the slant-range difference and can be processed to derive height information, i.e. Digital Elevation Model (DEM).

The surface area on the ground represented by a pixel in a SAR image, in general, contains hundreds of ground targets (Massonnet and Feigl, 1998). A new method for identifying PS pixels in a series of interferograms, which based primarily on phase characteristics and finds low-amplitude pixels with phase stability, has been developed (Hooper et al., 2004). Their approach is to form interferogram and remove most of the topographic phase signature using a DEM. The residual phase, $\Phi x,i$, residual phase of the xth pixel in the ith topographically corrected interferogram is the summation of the following five terms:

1. $\Phi def,x,i$ = phase change due to movement of the pixel in the satellite line-of-sight (LOS) direction;
2. $\Phi \alpha,x,i$ = phase equivalent of the difference in atmospheric retardation between passes;
3. $\Phi orb,x,i$ = phase due to orbit inaccuracies;
4. $\Phi \varepsilon,x,i$ = residual topographic phase due to error in the DEM;
5. $nx,i$ = noise term due to variability in scattering from the pixel, thermal noise and coregistration errors.

**3.2 Data**

Twenty interferograms have been generated using twenty-one Envisat satellite images (Track 461 and Frame 3105, Fig. 4) of European Space Agency (ESA). Parameters of these images are shown in Table 1 and Figure 5. Perpendicular baseline ($B\perp$) is a crucial parameter in forming an interferogram. Spatial decorrelation increases as the baseline increases and a non-zero baseline will give a difference in look angle (Fig. 3). The resolution or coherence of an interferogram, in general, becomes better and better as perpendicular baseline gets smaller and smaller.

**4 PSI Result**

**4.1 PSI mean velocity**

Figure 6 is the result of PSI mean velocity stacking from twenty interferograms that are generated by Envisat data (Table 1 and Fig. 5). The overall relative slant range displacement is 13.8 mm/yr spanning from November 2003 to December 2007 with the lowest and highest pixel values, -6.0 and 7.8 mm/yr respectively (Fig. 6). Warm colour codes indicate uplift while cold colour codes and negative sign imply subsidence. The distribution of the highest pixel values concentrates on the area next to the YAME GPS station, or in the other word, on east side of the Hukou fault. Another obvious uplift is clearly shown in and around the Shuanglienpo lineament. The former is the location of Pingchen Industrial Park while the latter is a mixture of residential, industrial, and academic region. National Central University is situated at Shuanglienpo of the Pingchen Tableland (exactly at the location of SA04 GPS station). Manifestation of any tectonic activity in these densely populated regions is vital to seismic hazard assessment.

4.2 Interpretations of PSI Result

Pixels of resulting PSI mean velocity are projected using GMT command (Wessel and Smith, 1998) along the profile (XX') that has been plotted and analyzed the subsurface structures by Wang (2003) (Fig. 7). Only those pixels whose coordinates are within 0.1 km beside the profile are projected. The upper diagram (a) shows the locations of the profile, continuous GPS stations, and four structures, namely Shuanglienpo syncline, Pingchen anticline, Hukou fault and Hukou anticline on 40-metre DEM. The middle diagram (b) indicates the projected PSI pixels along the profile, XX'. It is a relative slant range displacement with respect to distance in kilometre. Matching the projected PSI pixels to the subsurface cross-section done by Wang (2003) in the lower diagram (c), interesting features immediately revealed:

a) Active structure observed in seemingly tectonic inactive area: High PSI values, indicating uplift, are pointing to area near Shuanglienpo syncline. The rate of relative slant range displacement is higher in Shuanglienpo syncline than in Pingchen anticline. This is an interesting observation. The question of what the mechanism that contributes to the uplifting in a synclinal but not in an anticlinal area arises. The growth of blind faults which lie beneath the Shuanglienpo syncline can reasonably explain the observed uplift on the ground surface.

b) Ramp beneath the south limb of Hukou anticline is apparently locked: No sign of any uplifting in Hukou anticline revealed but even slightly subsides. Nonetheless, the south limb of it comparatively shows uplifting. This may indicate that a portion of a ramp beneath the south limb of Hukou anticline is locked. This information is important to the regional seismic hazard assessment. This implies that strain is slowly accumulating.

c) Rate of slant range displacement should be higher in the south limb of Hukou anticline than it shows in the cross-section: The reason is that fewer PSI points (few pixels in Hukou anticline!) are found in the southern part of the profile when compared to its northern part (Fig. 6). When projecting PSI pixels along the whole profile (XX'), the cross-sectional view in and round Houkou anticline does not give a comprehensive detail (Fig. 7).

## 5 Discussion

### 5.1 Local GPS velocity field and strain rate

Measurements from seven Taiwan continuous GPS stations during the period 2006-2009, in the Taoyuan-Hsinchu area, are plotted (Fig. 8). According to the measurements, the relative vertical displacement among these stations is 12.1 mm/yr (Fig. 8). The largest vertical displacement is 9.8 mm/yr in TWTF station (see Table 2), where it is located in between Shuanglienpo syncline and Pingchen anticline (see Figs. 6, 7 and 8). The general picture of topographic change as shown in PSI measurement (see section 4.1) agrees with the general trend in vertical displacement of GPS measurements.

Spatial manifestation of velocity field changes with various reference frames. In Taiwan, S01R (Paisha station), located at Penghu, representing the relative stable Eurasian continental plate, is conventionally used as reference station to measure the plate convergence. As indicated in Figure 8, spatial distribution of GPS vectors is different from the conventional one since the reference frame used is ITRF2005. Strain rate, nevertheless, reflects change in velocity gradient among GPS stations. It is independent of any reference frame; and, because of that, it makes discussions on regional strain accumulation and seismic hazard possible (Ward, 1994). Using the published campaign-mode GPS data (CGS, 2006), Figure 9 shows the horizontal principal axes of strain rates. It reveals that contraction occurs at the eastern side of Hukou Fault. It matches one of major characteristics from PSI findings (Fig. 6, see also section 4.1). Regarding GPS data processing, readers are referred to Lin et al. (2010).

### 5.2 Regional deformation and tectonic relationship

It is exciting to see the seemingly tectonic inactive region such as our study area, Taoyuan-Hsinchu, shows signs of surface deformation. With the advancement in remote sensing technique such as radar interferometry, the latest InSAR persistent scatterers can detect minute change in ground surface. In this study, the area of interest is specifically chosen as a direct consequence of the previous study (Ng et al., 2009; Ng, 2010). Besides the Taoyuan-Hsinchu area, Miaoli should also be included. Unfortunately, the problem of acquisition of Envisat satellite images arises and Miaoli area cannot be covered.

There are several main structures that are conventionally considered as inactive, for instance, Shuanglienpo syncline, Pingchen anticline, Hukou fault and Hukou anticline. Once, the Central Geological Survey (CGS) has considered the existence of Shuanglienpo fault (or precisely, lineament). It is even removed from the list of 1:25,000 geologic map in 2010 since there is no sign of tectonic activity. Nonetheless, an independent study from DInSAR (Chang, 2008) and this study using InSAR persistent scatterers have revealed uplifting in the area. Taking advantages from the previous study (Wang, 2003), a striking finding is that the uplift region is right beneath the Shuanglienpo syncline and the growth of a blind fault system beneath Shuanglienpo syncline can fairly explain the uplift on the surface.

Another important finding is the surface deformation on the eastern side of Hukou fault. In PSI mean velocity (Fig. 6), the highest PSI pixel values concentrate on the eastern side of the fault. It is further validated by GPS strain rate (Fig. 9). These are vital and now the area can no longer be considered inactive or pose no possible hazard.

Among those four structures in the region, Hukou fault is comparatively dangerous. It is slowly accumulating strain at its eastern side. This active fault of second category, Hukou fault, can do large damage in the area around it. The situation will be bad since it is located at the densely populated cities such as Jhongli and Hsinchu. The movement of Hukou fault may even trigger the neighboring fault systems such as Hsinchu fault and Hsincheng fault.

## 6 Conclusions

Crustal observations from InSAR persistent scatterers (PSI) and GPS in this study reveal an interesting story behind the apparent quietness or tectonic inactive in the Taoyuan-Hsinchu area. As an integrated work based on analyses from previous studies (Suppe, 1983; Wang, 2003; Shyu et al., 2005) and from latest crustal observations from radar interferometry and GPS, we are able to demostrate, in a dual opposing folds-and-blind faults system (Wang, 2003), an ongoing growth of blind fault(s) and a possible locking of a fold ramp.

As a summary, we are able to demonstrate activeness in a seemingly tectonic inactive or quiet region, Taoyuan-Hsinchu area. With the increasingly analytical method, InSAR persistent scatterers can detect minute surface deformation. In this study, the extraordinary findings are that the blind fault system beneath the Shuanglienpo syncline is keeping growing while the Hukou fault is slowly accumulating strain as shown by GPS strain rate.

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