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Application of InSAR to the Analysis of Ground Deformation in ChangYun Area of Taiwan

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ABSTRACT

This paper provides an analysis of the ground movement observed over Changhua and Yunlin regions of Taiwan. The results are derived from an analysis of satellite Synthetic Aperture Radar (SAR) imagery using Differential Interferometric SAR (D-InSAR) processing methods. A total of 45 interferometric pairs were analyzed. Subtle atmospheric trends remain, however, the expected accuracy for the D-INSAR products is expected to be within the centimetre range. Within the gold corridor, observed deformation was within 1 cm. Combined with analysis of current agricultural and industrial activities in the end may be extremely useful in determining deformation stability and understanding risks to infrastructure (such as rail corridor) over longer periods of time.

KEY WORDS: InSAR, RADARSAT-2, Ground Deformation, Land Subsidence.

INTRODUCTION

Due to the rapid economic development in Taiwan's western plains, substantial increase in water demand, coupled with easy access to groundwater, making over-pumping of groundwater in this area widespread, cause the land subsidence problems, among them, the Changhua and Yunlin are most serious. Taiwan High Speed Rail right through the center of Changhua and Yunlin subsidence areas, it will therefore have an impact on land resources and structural safety of high-speed rail. How to quickly, efficiently, and accurately measure land subsidence, so as to identify the mechanism of land subsidence has become an important issue [Tainan Hydraulics Laboratory, 2015].

This study provides an overview of the surface movement observed within this region with SAR between October 1, 2015 and May 28, 2016. Ideally, longer term monitoring programs aim to provide information as to areas where ground motion patterns maybe: a) changing over time, b) remaining consistent over time c) appearing (i.e. previously unobserved motion). Such analysis enables understanding of current motion within the area of interest and may provide insight into future patterns of ground movement.

RESEARCH REGION AND DATA

Area of interest (AOI)

The AOI of ground deformation is shown in Fig. 1. Deformation analysis will be limited to area defined within red polygon. The AOI is located in southwestern region of Taiwan, centre coordinate E120.457°, N23.85°(using WGS84 coordinate system), south of Taichung City, Taiwan. The AOI is approximately 90 km by 50 km. Urban centres of Changhua and Yunlin are within this AOI. The area is a mix of urban, industrial and agriculture [Tainan Hydraulics Laboratory, 2016]. The climate of AOI is sub-tropical to tropical. During this observation period, strong atmospheric influences were observed during the months of January 2016 and April 2016, where rainfall amounts exceeded 100 mm per month.

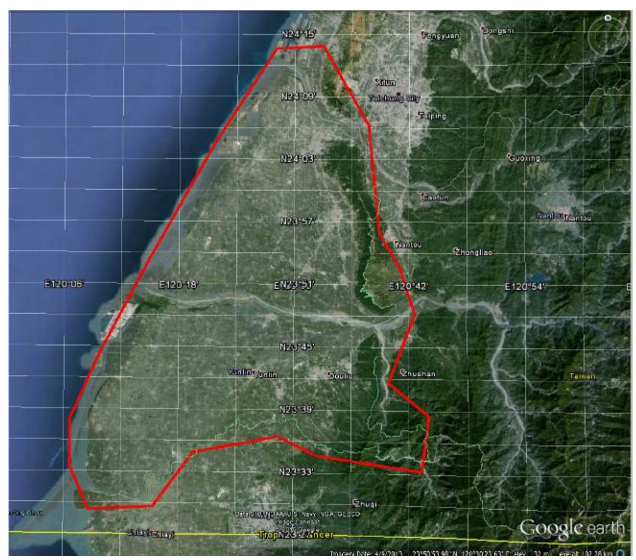

Fig. 1. Area of interest

Available Data

For this study, one track of RADARSAT-2 Extra-Fine data (a total of 10 RADARSAT-2 acquisitions) acquired from the descending pass of the satellite was obtained. The ground was imaged by the radar with approximately (5 m x 4 m) nominal resolution (slant range in near and far direction). The Extra-Fine beam mode selected has an incident angle of 40. Table 1 lists the RADARSAT-2 Extra-Fine data acquired between the months of October 2015 to May 2016 and used in the analysis for the current report. A total of 45 interferometric pairs were analyzed. Only those pairs with highest coherent information were analyzed for this study.

Table 1. RADARSAT-2 imagery acquired during monitoring period

No.	Date(YYYY/MM/DD) (UTC)
1	2015/10/01
2	2015/10/25
3	2015/11/18
4	2015/12/12
5	2016/01/05
6	2016/02/22
7	2016/03/17
8	2016/04/10
9	2016/05/04
10	2016/05/28

METHODS

InSAR [Fletcher, 2007; Rosen et al, 2000]

InSAR is a mature, well-validated set of methodologies for monitoring ground deformation precisely. The satellite radar sensor emits pulses of microwave energy which interact with surfaces or objects on the ground. A portion of the energy is reflected (backscattered) back to the sensor. This backscattered signal contains an amplitude or intensity component and a phase component. The amplitude component is useful for mapping and imaging, while the phase component is related to the distance traveled by the beam.

When a target shifts due to ground motion in the period between two satellite acquisitions, the distance between the sensor and the target changes, causing a small, precisely measurable phase difference in the backscatter signal. Two phase images from different dates can be combined to create an interferogram, which represents the phase difference between them.

The ground change, the cloud change, and the topography lead to the definition of the fundamental equation of InSAR:

$$\phi = \phi_d + \phi_a + \phi_t + \phi_n \qquad (1)$$

which describes the phase of the observed interference. The term ϕ_d is the ground deformation we are interested in observing and ϕ_a, ϕ_t, and ϕ_n are noise terms (atmosphere, topography, and system noise, respectively).

Precise ground deformation mapping removes the effects of the atmospheric and topographic noise terms. The system noise, for RADARSAT-2, is small (less than millimetres) and is not considered further. After orbital, atmospheric, and topographic effects are removed, the phase signal is directly related to the amount of deformation that occurred in that period.

Digitial Elevation Model (DEM)

DEM data is necessary to remove, as much as possible, phase noise that is introduced by local topography. The region surrounding AOI is covered by a 30m resolution Shuttle Radar Topography Mission (SRTM) DEM (http://earthexplorer.usgs.gov) (Fig. 2). The use of a high resolution local DEM, for localized and changing areas, is preferred to ensure the removal of local topographic phase noise is accurate.

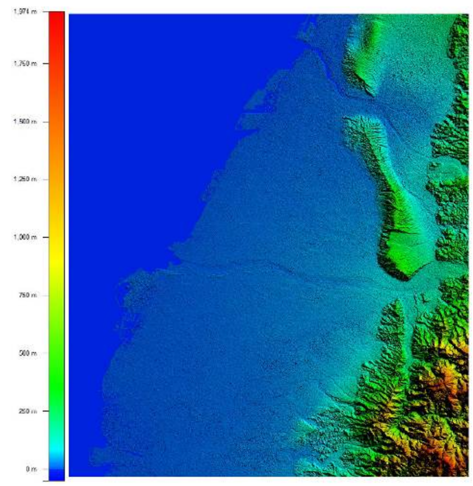

Fig. 2. SRTM 30m DEM

RESULTS AND DISCUSSIONS [McParland and Sato, 2016]

Maps showing cumulative vertical deformation and deformation rate are provided to illustrate movement within specific regions (Fig. 3), as observed from October 2015 to May 2016. Maps representing deformation over this period presents deformation between ±0.05 m in order to highlight areas of greater movement.

Fig. 4 provides the overall cumulative deformation observed. Deformation is scaled from +0.05 to -0.05 metres to highlight subtle areas of deformation. Areas of low coherence and water are masked. A localized area within Gold Corridor shows cumulative deformation within 0.5 cm to 1.5 cm range. Deformation within the spillway shows both uplift and subsidence within 5 cm range. This is an area that is under construction and measurements should be take with caution. The DEM used in this study may not be updated to represent the terrain in this area.

Maps showing deformation rate in select areas along Gold Corridor, high speed rail network and along industrial section near the coastal are provided in Figs. 5~9. Overall, no significant deformation patterns were observed in these areas. Figs. 5~7 provide the deformation detail of Gold Corridor area. In Area 1 and 2, the subsidence is about 1.5 to 2 cm/yr. In Area 3, the observed maximum subsidence is about 2.5 cm/yr. Figs. 8~9 provide an overview of deformation observed for a localized area near the coast (near industrial infrastructure). Deformation rate within this area is approximately 2 cm/year (subsidence). Within the spillway area, located in eastern section of the AOI, subsidence is within the 5 cm range. Deformation observed in this area could be indicative of on-going construction and or natural settlement of material due to construction activities. Further monitoring will be required to determine longer term deformation patterns.

The maximum cumulative deformation that is reported is approximately 5 to 6 cm in the vertical direction, confined to an area near the spillway. Other areas, such as within the gold corridor, observed deformation was within 1 cm. Due to a limited observation data set, temporal de-correlation was a factor in some regions within the AOI as such, no deformation measurements are reported. Radar interferometric deformation measurements of the natural terrain are limited by temporal decorrelation and other sources of noise. Incoherent changes can be result of increased surface moisture, changes in crop cycles, and surface excavation or construction (such as near the spillway).

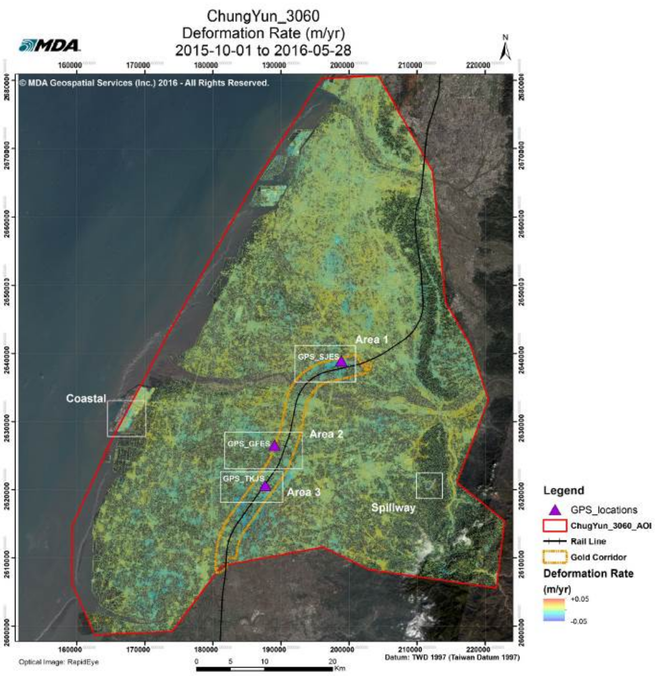

Fig. 3. Focus areas for additional D-InSAR analysis

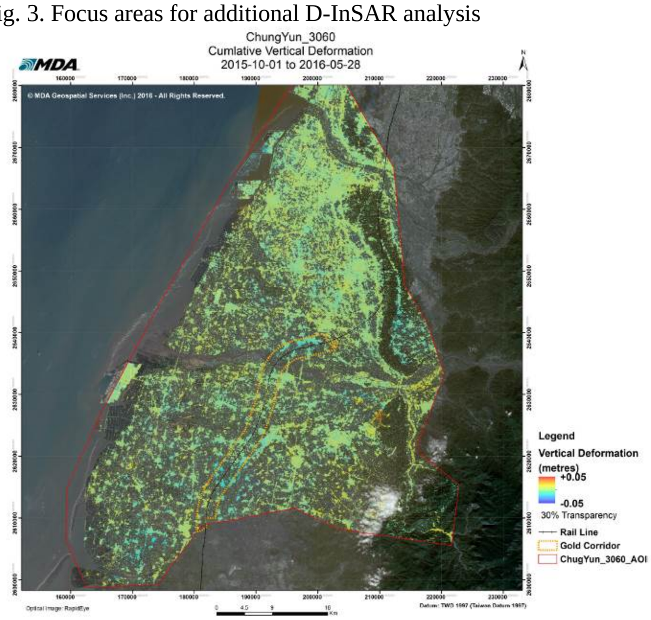

Fig. 4. Cumulative vertical deformation

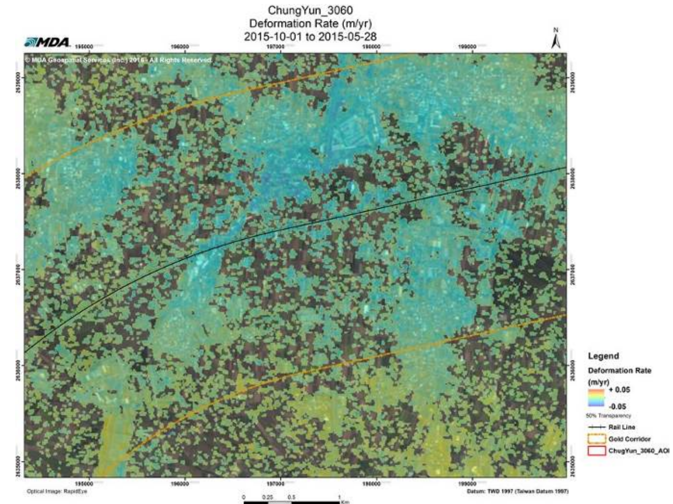

Fig. 5. Deformation rate map in Area 1

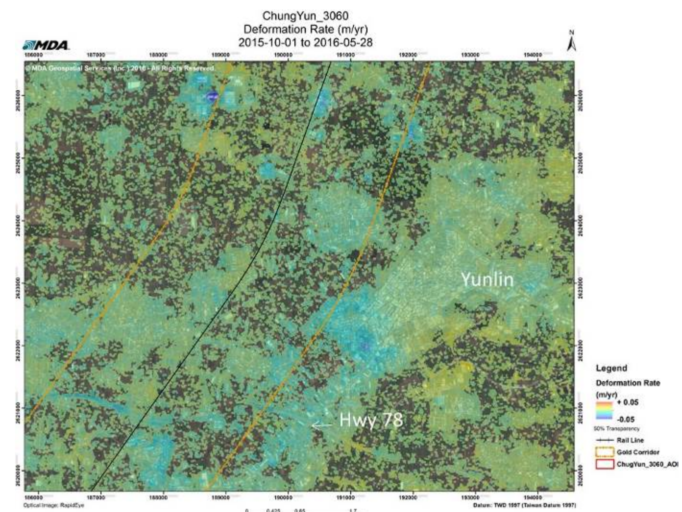

Fig. 6. Deformation rate map in Area 2

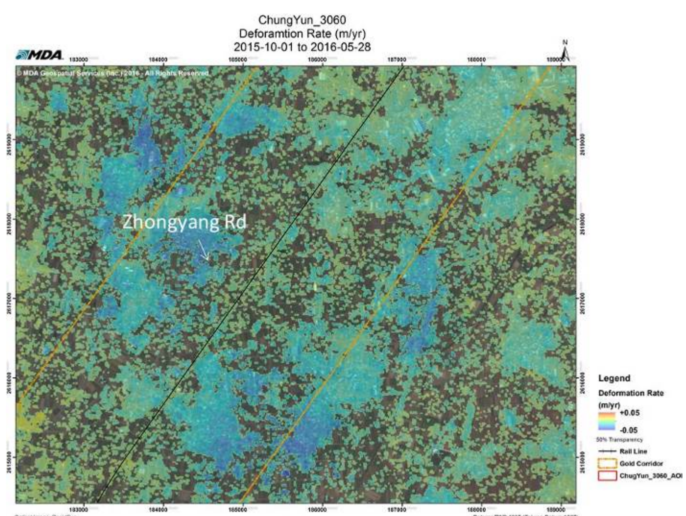

Fig. 7. Deformation rate map in Area 3

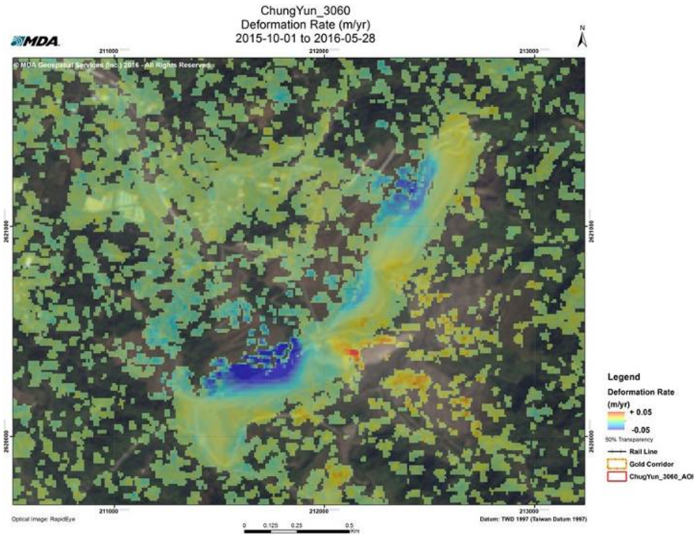

Fig. 8. Deformation rate map - spillway

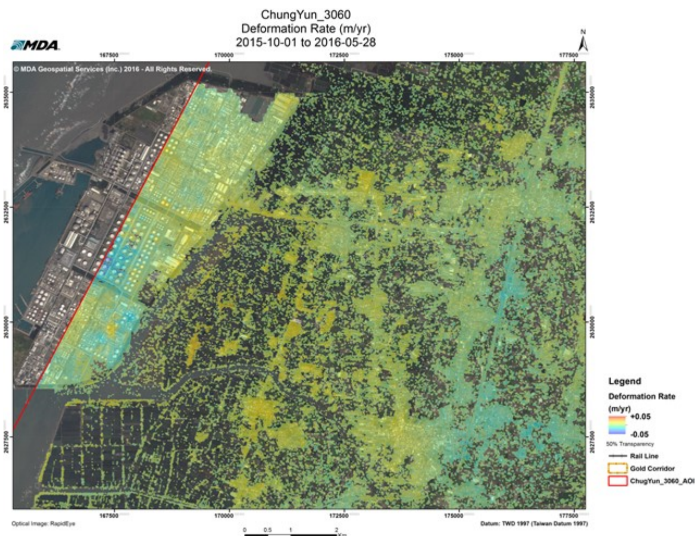

Fig. 9. Deformation rate map - coastal area

CONCLUSIONS

Overall, observations from RADARSAT-2 images showed medium to high coherence quality, specifically over hard target areas (urban centres, infrastructure, railway). A total of 45 interferometric pairs were analyzed. Subtle atmospheric trends remain, however, the expected accuracy for the D-INSAR products is expected to be within the centimetre range.

With continued collection of RADARSAT-2 images would provide a longer time series of information, where deformation patterns can be identified, as well as isolating atmospheric noises and seasonal displacements, along with advanced InSAR processing methodologies, (such as Homogeneous Distributed Scatterer (HDS) and or other Persistent Scatterer Interferometry (PSI) techniques) would provide a more thorough and detailed analysis of the deformation signal.

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