# InSAR Estimates of Clay Dynamics Related to Soil Moisture

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## InSAR Time Series Analysis Using Small Baseline Subset (SBAS) Technique for Monitoring Land Subsidence

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Subsidence is the downward movement of the Earth's surface relative to a datum. Many factors including underground mining, drainage of organic soils, natural compaction of soft soil, sinkholes, permafrost thawing and aquifer-system compaction occasion land subsidence and elevation changes of the ground surface in various regions. These variations can detect and estimate by different techniques such as GPS survey, leveling, and observations from disparate satellite sensors. Compared to conventional approaches, InSAR technique causes a revolutionary change in assessing displacement fields derived from seismic faults, landslides, subsidence, volcanoes, mining activities and other land deformation phenomena, since it can monitor broad areas with low cost, the short period of time, high precision and extraordinary spatial density of measurement points. In this research, 34 differential interferograms acquired from ENVISAT ASAR sensor over Mashhad plain in northeast Iran (from Sep. 2003 to Oct. 2008, in descending orbit and with normal baseline less than 300 m) have been processed. After DInSAR processing, to estimate land subsidence in the studied region, time series analysis using small baseline subset (SBAS) algorithm on the interferograms has been implemented. The results of the time series analysis are greatly compliant with continuous GPS observations in stations of the region and indicate that the maximum value of the cumulative subsidence equals ~98 cm during the studied period.

## InSAR Estimates of Clay Dynamics Related to Soil Moisture

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The ability to perform time series analysis of distributed scatterers in SAR stacks opens up possibilities for the development or improvement of novel applications of InSAR. Recently, interest for InSAR applications to near-surface hydrological processes related to soil moisture is growing. Here we investigate clay soil swelling and shrinkage induced by soil moisture variations for hydrological and geotechnical purposes. Two main mechanisms of how soil moisture affects interferometric phase have been described: (i) clay swelling and shrinkage, causing actual deformations as a result of soil moisture content variations, and (ii) changes in the soil dielectric constant, influencing the propagation of the electromagnetic wave related to soil moisture content.

Disentangling the contributions of each of the aforementioned mechanisms in interferometric phases is challenging, as both mechanisms, combined with other phase contributions, may occur simultaneously over clay soils. To fully explore the potential of radar interferometry to measure clay swelling and shrinkage, improved understanding of all soil moisture related phase governing mechanisms is needed. Mechanisms that are not fully understood, and are therefore not incorporated in InSAR models, will affect the phase estimation, potentially limiting new applications or giving rise to misinterpretation.

Here, we study the interferometric phase over an agricultural area with clay soils in the Netherlands. The goal is to estimate vertical deformation as a result of clay shrinkage, and thereby apply corrections (i.e. phase reduction) of unwanted signals and develop methodology to improve phase unwrapping. We show that the phase contribution from clay shrinkage can be much more significant than the soil moisture induced dielectric phase, and that time series can be corrected for using a simple soil moisture phase model. Subsequently, a simple clay shrinkage model, based on widely available contextual data, can be used to improve phase unwrapping. Methodology and models are developed and validated with in-situ measurements of deformation. The results show that clay shrinkage can have a big impact on deformation estimates from distributed scatterers and can be exploited for hydrological studies or corrected for in

other deformation studies. This study is relevant for hydrological monitoring as elevation change observations from clay soils might serve as a proxy for soil water storage change, especially on larger scales.

## Assessment of Deep-Seated Landslide Susceptibility Using TCP-InSAR Techniques in Dense Forest Area, Taiwan

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Deep-seated landslide, also known as deep-seated gravitational slope deformation (DSGSD), is generally linked to high relief mountain environments. Deep-seated landslides are normally slow and continuous movements of a large volume of soil and rock, and are sometimes the cause of catastrophic failures. Due to geodynamic context caused by active mountain building and sub-tropical climate setting dominated by high precipitations, deep-seated landslides are commonly observed in mountainous region in Taiwan. In Taiwan, over thousand landslides, including some fast catastrophic failure of deep-seated landslides, occur every year. Therefore, how to locate deep-seated landslides and monitor their activity has become an urgent task for the island to mitigate landslide hazards. This study illustrates the superiority of using the temporarily coherent point InSAR (TCP-InSAR) technique to monitoring the activity of deep-seated landslides in mountainous densely vegetated areas of Taiwan. In order to overcome the great topographic relief and heavy vegetation of mountain environment, the LiDAR derived 1 m resolution DEM is used to recognize deep-seated landslides with their landslide morphologic features. After that, L-band ALOS/PALSAR satellite radar images are selected for TCP-InSAR analysis due to their longer wavelength, which can better penetrate vegetation to determine the displacement of deformed slope. The study area is located in the Central Mountain Range of Central Taiwan. The selected study area is extremely susceptible to landslides during heavy rainfall because of its great topographic relief, high-slope gradients, and presence of highly foliated and weathered slate and thick poorly consolidated soils. The elevation of the study area decreases from 2,200 m in the northern mountain ridge to 855 m. The distributions of slope gradient in the study area, which calculated from the LiDAR derived 1 m resolution DEM via spatial analyst tool of ArcGIS, fall mainly in ranges of from 20 degrees to 40 degrees. The area with a slope gradient between 30 degrees and 40 degrees is 32% of the study area, while the area with a gradient between 20 degrees and 30 degrees accounts for 34. 22% of the study area has a slope of less than 20 degrees and only 1 % has a slope greater than 50 degrees. In addition, in order to reduce long wavelength error and localize atmospheric error, only 100 km2 is selected as the study area for TCP-InSAR analysis. Within the study area, an averaged density over 1300 TCPs/km2, which is significantly higher than the result of traditional PS InSAR analysis, is obtained. Within the study area, over ten DSGSDs with an area over 10 ha have been recognized in LiDAR derived 1 resolution DEM. Three specific deep-seated landslides are selected to illustrate the results of TCP InSAR analysis that one located at Chingin area (site D057) and two located at Lushan area (Site D066 and D067) are selected for detailed discussions. The average annual down moving displacement rate within the period of 2006-2011 is -15.1 mm/yr, -14.4 mm/yr, and -12.6 mm/yr. The standard deviation of TCP measurement in Lushan area is estimated about 7-8 mm by comparison the TCP data with GPS data. In addition, significant seasonal variations, which indicate higher and lower moving rates during rainfall and the dry season respectively, are also observed.