COASTAL ZONE DEFORMATION OVER EASTERN INNER GULF OF THAILAND USING MULTI-TEMPORAL INSAR METHOD

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ABSTRACT: For the last few decades, the area of eastern coast of the inner Gulf of Thailand i.e. Chon Buri, Sriracha, Laem Chabang and Pattaya City, has been under constant transformation due mainly to infrastructure development. While deformation is evident visually, the availability of ground measurements for the detection of coastal deformation are extremely limited and remotely sensed data, particularly radar imageries can properly serve as alternative data source. The aim of this study is to map coastal zone deformation between 2005 and 2011 by exploiting the coherent points, in radar image whose scattering elements are likely to be anthropogenic object such as bridges, dikes, buildings or elevated roads. A multi-temporal InSAR method incorporating both persistent scatterer and small baseline approaches is one of the space-geodetic techniques capable to detect surface deformation up to millimeter accuracy. This technique has overcome the limitations of classic InSAR which suffers from atmospheric influence and temporal decorrelation. The processing chains of StaMPS-MTI are applied with Radarsat-1 data shows that approximate 30,000 pixels are successfully detected as monitoring points with around 50 PS/km^2 average pixel density. We interpret the detected deformation as the subsidence of ground surface whose rates are between 0 to -23.6 mm/year with a standard deviation between 0.4 and 7.8 mm/year. In particular, large scale subsidence is detected around large development area, particularly at Mueang Chon buri, Laem Chabang deep-sea port, Pattaya city and Cape Sa-Mae-Saan. The study demonstrate a strong potential of Multi-temporal InSAR as a monitoring tool and the results will lead to better understanding of the causes of coastal zone land subsidence.

1. INTRODUCTION

There are 4 causes of coastal erosion in the Gulf of Thailand (Nutalaya, 1996) such as sea level rise, increase of eroding energy, depletion of sediment influx, and land subsidence. Thus, the coastal deformation in this paper will focus mainly on land subsidence or the surface expression of different natural phenomena in vertical direction. While, the major causes of land subsidence generally related to ground water pumping, or even the construction and weight of manmade structures along the coast line of eastern inner gulf of Thailand which become the urban areas.

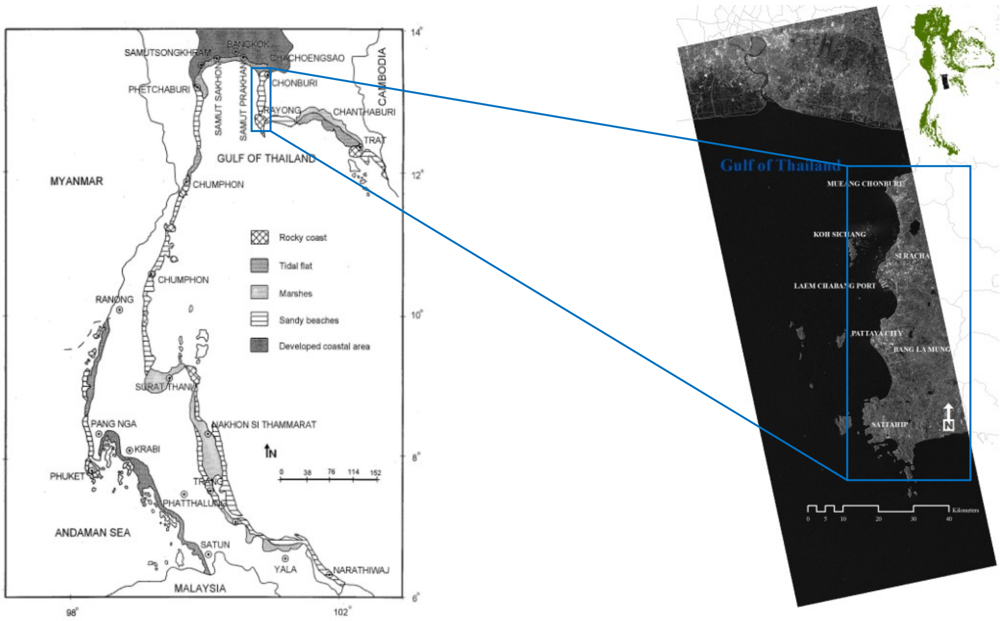
SAR Interferometry (InSAR) is basically a very attractive technique to map elevation model based on the use of phase information that is obtained by Synthetic Aperture Radar (SAR). The more advance technique called Differential InSAR (DInSAR) can be applied to the fast deformations such as earthquake, landslide, etc. However, this method is limited by several parameters such as low correlation due to large baselines, coherence loss due to long temporal baselines, unwrapping error, atmospheric error, etc.

Therefore, to overcome the limitations above, there are many recent developments which examine Interferometric phase from permanent structures to an area that is normally characterized by low coherence. Besides, the displacement along the line of sight (LOS) directions can be possible detected in sub-millimeter accuracy allowing the measurement of slow terrain motion (Ferretti et al., 2001) for example land subsidence, etc. The Persistent Scatterers Interferometry (PSI) is such the techniques that used to calculate the small motions of individual ground and structures points over wide areas.

Finally, the aim of this paper is to detect ground deformation in the area of eastern inner gulf of Thailand by applying Multi-Temporal InSAR method which combined PSI and Small Baseline techniques using a dataset of 10 Radarsat-1 imageries. The application in the area is very interesting due to the fact that there are no levelling network covering. Thus, the necessity to monitor the area arises in the frame of concerning the historic deformation taken place between 2005 until 2011, respectively.

2. EASTERN INNER GULF OF THAILAND

The total coastal length of Thailand is about 2,815 km. (937 km. for Andaman Sea coast and 1,878 km. Gulf of Thailand coast) (DMR, 2011). The Gulf of Thailand coast usually classified into 5 types ('see figure 1a') such as rocky coast, tidal flat, marshes, sandy beaches, and developed coastal area based on their geographic location. From the study area, we can identify the coastal types which are beach sand at Chon buri, Sriracha, Pattaya and rocky coast at Sattahip as shown in figure 1b.



(a) Coastal types in Thailand

(b) Location map ©Radarsat-1 Image Copyright 2011 CSA.

Figure 1: (a) The coastal types of Thailand from (DMR, 2011), (b) Location map of the study area.

The eastern coast of the inner Gulf of Thailand i.e. Chon Buri, Sriracha, Leam Chabang and Pattaya City are main sites for development in several aspects such as industries, aquaculture, infrastructure, recreation and tourism where groundwater over pumping is considered cause of land subsidence. Thus, the most remarkable case among the coastal problems in this area is the land-use on particularly during the property boom in the early 1990. The tall hotel, condominium buildings and road constructions along the coastline are constructed close to the beach, so the weights of those structures are considered as another problem of land subsidence accelerating of erosion, and also flooding. The land uses in rocky coast at Sattahip usually are roads, resorts construction, naval base, etc. Thus, the permanent structure build to protect coastal erosion such as sea dike can be monitored using the techniques that we will explain afterward.

3. MULTI-TEMPORAL (TIME SERIES) INSAR

Multi-temporal (Time Series) InSAR techniques are extensions of conventional InSAR to deal with the limitations of differential InSAR such as phase delay and coherence loss by analyzing the Interferometric phase time series whose coherent targets remains high coherence in time. It allows us for the correction of uncorrelated phase noise terms and reduces errors associated with the deformation estimates. Currently, there are two main complementary methodologies namely persistent scatterer Interferometry (PSI) and small baseline (SB) techniques. The difference on each method is depended on scattering mechanism ('see figure 2'). PSI (Ferretti et al., 2001) methods apply statistical techniques to identify pixels with a single dominant scatterer, and use the associated Interferometric phase to infer a deformation time-series. In contrast, if the return signals rely on the distribution of scattering centers, the SB methods (Sandwell and Price, 1998), (Berardino et al., 2002) will be formed to determine an average velocity model by averaging numerous interferograms with small baselines to reduce the atmospheric effects. As a result, it is possible to detect and measure sub-millimeter variations over time.

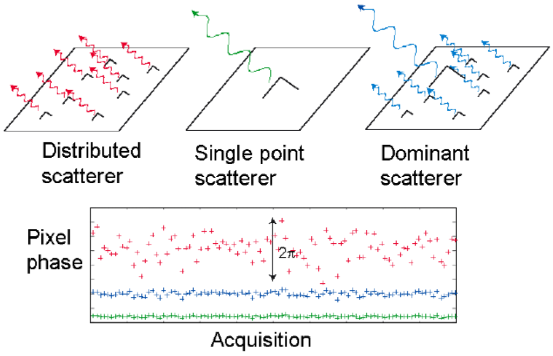


Figure 2: Scattering mechanism - distributed scatterers (red), ideal single point scatterer (green) and persistent scatterer (blue). The persistently scattering pixel exhibits smaller phase variation than the distributed scattering pixel (Piyush, 2010).

4. STANFORD METHOD FOR PERSISTENT SCATTERERS AND MULTI-TEMPORAL INSAR

The original development of StaMPS was undertaken at Stanford University, but subsequent development has taken place at Delft University of Technology called Stanford method for persistent scatterers and multi-temporal InSAR (StaMPS-MTI) that also includes SB method and combined multi-temporal InSAR method. For PSI analysis, a set of N single master interferograms, where the master scene has been chosen to minimize the decorrelation effects (Hooper et al., 2007), is analyzed at the highest possible resolution. We can simplify equation (1) to

$$\phi_{\text{int},x,i} = \phi_{def,x,i} + \phi_{top,x,i} + \phi_{atm,x,i} + \phi_{orb,x,i} + \phi_{n,x,i} \tag{1}$$

Where $\phi_{def,x,i}$ is the phase change of the movement in the satellite line-of-sight (LOS) direction, $\phi_{top,x,i}$ is the residual phase caused by uncertainty in the DEM, $\phi_{atm,x,i}$ is the phase deference in atmospheric delay of two passes, $\phi_{orb,x,i}$ is the residual phase due to orbit inaccuracies, and $\phi_{n,x,i}$ is the noise term due to variability in scattering from the pixel, thermal noise and coregistration errors. The pixels we seek are those for which $\phi_{n,x,i}$ is small enough that it does not completely obscure the signal.

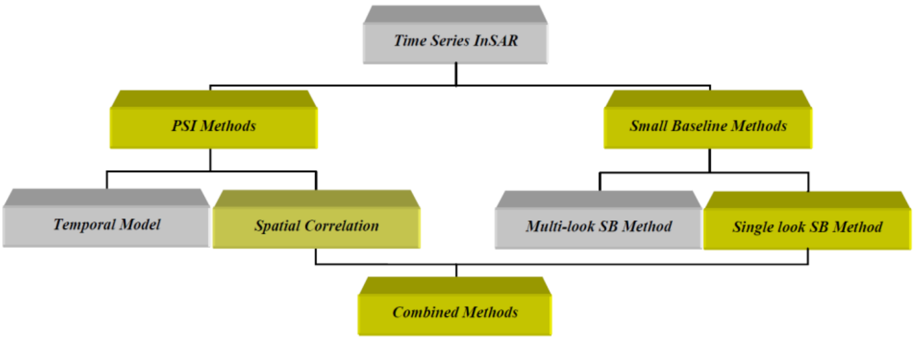


Figure 3: Main Categories of InSAR Time Series Algorithms. StaMPS-MTI relying on correlation in space: (Hooper et al. 2004), and single look SB method which are combined before phase unwrapping.

The StaMPS is a collection of spatial and temporal filtering routines that allow us to estimate each of these phase components. The first four terms in equation (1) dominate the scatterer term and need to be reliably estimated for identification of PS pixels. All the observed Interferometric phases are wrapped values and hence, the low pass components are estimated using a combination of a low pass filter and an adaptive phase filter (Hooper et al., 2007) that preserves the Interferometric fringes.

As explained in (Hooper et al. 2008), a minimum of five acquisitions are required to process large regions, and possible to success for the processing approach. The main categories of algorithms are shown in figure 3. The PS analysis of StaMPS-MTI uses primarily spatial correlation of the phase to identify phase-stable pixels, and does not require any approximate model of displacements (such as linear or periodic). The SB analysis of StaMPS-MTI uses amplitude difference dispersion values and then performs phase analysis in space and time to identify coherent pixels. Lastly, StaMPS-MTI uses a 3D unwrapping algorithm, which is advantageous over 2D algorithms because insufficient spatial density of persistent or coherent pixels can be compensated by unwrapping in time.

5. RESULTS

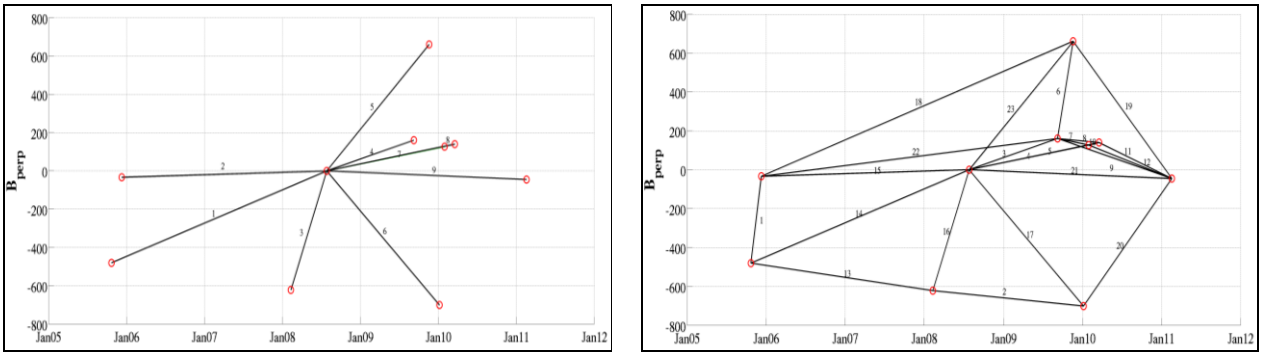
In this study, we used Radarsat-1 images acquired between October 2005 and February 2011. Table 1 shows the time series of the data set with temporal and perpendicular baseline using 27-July-2008 as a master image. All of these images are used to identify persistent and coherent pixels to estimate land subsidence in coastal zone study area.

Table 1: Radarsat-1 time series data set.

DATE	TEMP. BASELINE (DAYS)	PERP. BASELINE (M.)
23-Oct-2005	-1008	-480
10-Dec-2005	-960	-34
10-Feb-2008	-168	-621
27-July-2008	0	0
08-Sep-2009	408	160
19-Nov-2009	480	660
06-Jan-2010	528	-700
30-Jan-2010	552	127
19-Mar-2010	600	140
18-Feb-2011	936	-45

5.1 Interferograms formation

In our case, we start with SLC images from Radarsat-1 generated at GISTDA's facility using product generation system from MacDonald, Dettwiler and Associates Ltd. (MDA-Canada). Therefore, the focusing step is skipped and the images are imported directly into Doris software for reading and cropping specifies area.



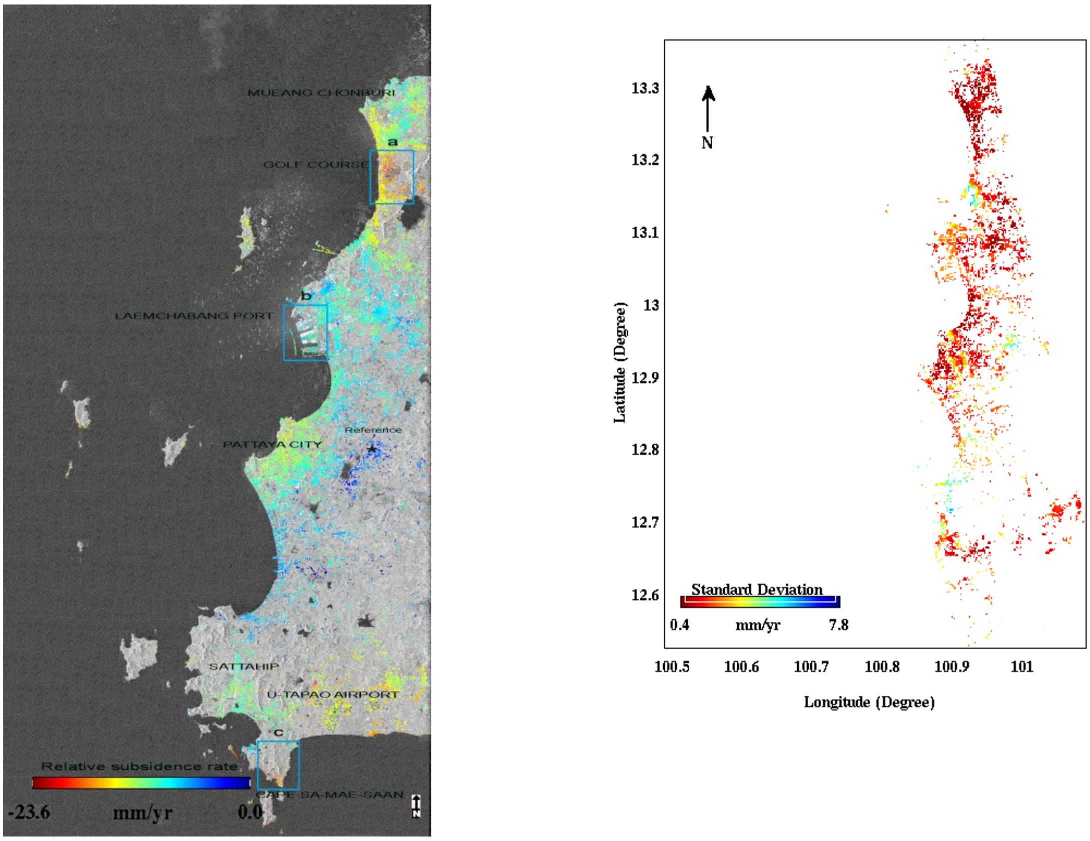
(a) (b)

Figure 4: (a) PSI, perpendicular and temporal baseline plot with respect to the master image used in the PS processing. (b) SB, perpendicular and temporal baselines are with respect to the master image used in the PS processing. Circles represent images and lines represent the PSI and SB interferograms formed.

Then, the interferograms will be formed using Doris steps which are extracts orbit info, coarse coregisters, coregisters the slave-master and/or slave-slave coregistration, resamples the slave image, simulated dem interferograms and creates the final interferograms. We formed 9 interferograms using 10 images acquired with respect to single master for PS and 23 interferograms for SB analyses, respectively. Figure 4a and 4b show the interferograms formation using baseline plot from 2 approaches prepared for the next step multi-temporal InSAR processing using StaMPS-MTI.

5.2 Multi-temporal InSAR Processing

Preliminary applications of PS and SB methods identified sufficient coherent pixels (25,489 for PS and 9,576 for SB) to enable further processing. The combined processing called "PS and SB merge" has been done with 33,030 PS pixel selected. The range of average velocities is between -10.4 to +8.1 mm/year. Since there is no benchmark in the study area to fix the detected velocities into ground reference frame, a point with small rate at 12.93E and 100.96N (Black star) was treated as stable and a reference to all other points. Assuming that there is no horizontal motions, we then mapped InSAR-detected velocities which is in radar line-of-sight direction into vertical direction, using incidence angle 37.96 degrees at image center. It is revealed that subsidence rates fall between 0 to -23.6 mm/year. Distribution of subsidence rates is shown in figure 5a.



(a) (b)

Figure 5: (a) StaMPS-MTI result of PS+SB analysis, Radarsat-1 time series dataset between October 2005 –2011 (zoom in location a, b, and c can be found in figure 6), (b) Standard deviations of mean LOS velocity (0.4-7.8 mm/year) plotted in latitude and longitude (degree).

We calculated standard deviations of the mean LOS velocity by using percentile bootstrap method (Efron and Tshibirani, 1986) which recalculates the velocity many times from different samples in time ('see figure 5b'). Most of the estimated velocities have standard deviations less than 1 mm/year, but there are areas where the standard deviations are up to 7 mm/year. This may be caused either by unwrapping errors or real deviations of the subsidence in these areas from linear behaviour. Thus, in order to detect coastal deformations, InSAR can be a measurement in the area with acceptable accuracy.

6. CONCLUSION AND DISCUSSION

The multi-temporal InSAR processing technique has proved to be useful as there is no ground measurement data. The application of the technique on 10 Radarsat-1 satellite images covering the eastern coast of the inner Gulf of Thailand reveal fast subsidence in many areas, particularly at Golf course, Mueang Chon buri, Laem Chabang deep-sea port and Cape Sa-Mae-Saan. The maximum subsidence rate is -23.6 mm/year at golf course, Mueang Chon buri can be seen in figure 6a. Besides, many coherent pixels on the permanent structure can be found on Laem Chabang deep-sea port (location of which shown in figure 6b) with the average subsidence rate of -10 mm/year. The last area that we consider is the Sattahip area through the cape ('see figure 6c'), we found the subsidence rate up to -20 mm/year on a fishing village of the Cape Sa-Mae-Saan.

The study demonstrates that coastal zone deformation over eastern inner gulf of Thailand can be monitored with high accuracy by multi-temporal InSAR. As the study area is still under intense development, more severe subsidence is expected to occur and InSAR will prove to be an indispensable measurement technique to monitor the progression and evolution of coastal subsidence.

(a): Golf course, Mueang Chon buri	(b): Laem Chabang deep-sea port	(c): Cape Sa-Mae-Saan

Figure 6: Multi spectral THEOS imagery of selected area (a) Golf course, Mueang Chon buri, (b) Laem Chabang deep-sea port, and (c) Cape Sa-Mae-Saan to present land use, land cover explaining the land subsidence in coastal area.

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