The Potential of Persistent Scatterer Interferometry for Complementing GPS Installations at Tide Gauges: Experiences from the United Kingdom

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Abstract

Persistent Scatterer Interferometry (PSI) is a powerful technique for measurement and monitoring of vertical land movements (VLM) by the analysis of the time series of especially selected pixels in satellite imaging radar data. Contrary to other geodetic techniques, such as precise levelling and/or continuous GPS, which are used at tide gauge (TG) sites to monitor their stability, PSI is capable of providing estimates from a local to regional spatial extent. Over the past years, PSI has been successfully applied to the monitoring of urban and rural areas, as well as volcanoes and land slides, providing millimetre-level accuracy. However, the application of PSI to coastal areas and to monitoring TG sites has not been well investigated.
In this study the suitability of the PSI technique using ERS1/2 and Envisat imaging radar data is investigated for the application to coastal areas and to monitor the stability of benchmarks and GPS installations at four TGs in the United Kingdom. We present results on scatterer identification under varying levels of urbanization and/or vegetation at TG sites and on ocean tide loading in PSI processing. The latter is routinely modelled in GPS analyses, but largely ignored in PSI.

Introduction

The National Tidal and Sea Level Facility (NTSLF) at the National Oceanography Centre (NOC) operates the UK tide gauge network, which consists of 44 operational installations (Figure 1). Between 1997 and 2005 continuous GPS (cGPS) stations were established at 10 of these and related results have been published in the literature (e.g. Teferle et al., 2009).
Based on the availability of synthetic aperture radar (SAR) data (ERS1/2 and ENVISAT) four of the ten tide gauge sites with cGPS stations were selected for this study. Table 1 gives an overview of the number of SAR scenes and the time period over which these are available for each sites. Figure 2 shows details of the tide gauge and cGPS installations at the four sites in Liverpool, Newlyn, North Shields and Sheerness. It should be noted that NOC also carried out absolute gravity measurements near Newlyn at annual frequency from 1996 to 2010 (Williams et al., 2001).

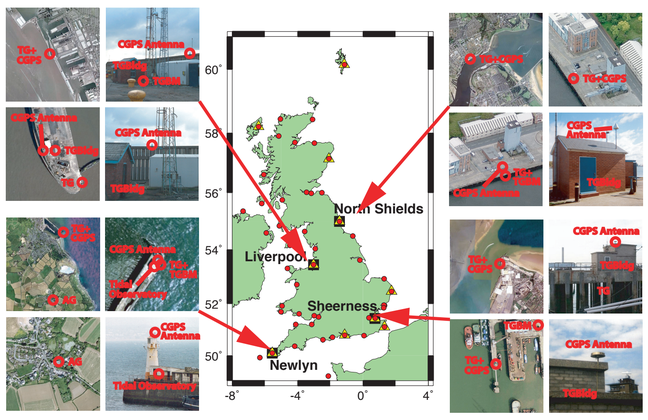

Figure 1: UK tide gauge network (red dots), tide gauges with co-located cGPS (yellow triangles) and the four tide gauge sites selected for this PSI study at Liverpool, Newlyn, Sheerness and North Shields (black squares).

Site	ERS	ENVISAT
Sheerness	Number:31 03/01/95-24/12/97	Number:40 13/12/02-03/03/09
North Shields	Number: 32 24/05/95-30/12/99	Number:19 11/02/03-07/10/08
Liverpool	Number:37 03/04/95-14/12/99	
Newlyn	Number: 34 06/04/95-11/12/99	

Table 1: SAR data availability for Liverpool, Newlyn, Sheernes and North Shields

Persistent Scatterer Interferometry (PSI) has been successfully applied to the monitoring of urban and rural areas, as well as volcanoes and land slides, providing millimetre-level accuracy. The advantage of this technique lies in the fact that it can provide the spatial extent of any vertical land movements. Loval surveys, cGPS and absolute gravity (AG) can only provide this information at specific points (Brooks et al., 2007; Zerbini et al., 2007).
Here the PSI processing was carried out at the University of Nottingham and at the British Geological Survey. Stacks of ERS and ENVISAT (SAR) data were gathered for the four sites and were processed using the Gamma Interferometric Point Target Analysis (IPTA) software (Wegmueller et al., 2004) and also the University of Nottingham Punnet software. As the results between the two packages were equivalent only Gamma IPTA results are presented.

The two questions addressed here are:
1) Does ocean tide loading affect PSI analyses?
2) Can PSI be used to complement local surveys to monitor differential movements between the various geodetic sensors and their benchmarks?

Ocean Tide Loading

Ocean tide loading (OTL) is the Earth's elastic response due to redistribution of water mass from ocean tides. In Cornwall, UK, the vertical land motion due to OTL can be as high as 14 cm in a single 6 hours interval, placing Cornwall amongst the places with the highest OTL amplitudes in the world. Although OTL is corrected for in other geodetic techniques, this is not the case for PSI. Only DiCaprio and Simons (2008) suggested that OTL effects could propagate into PSI results.
In order to correct for OTL in the Gamma IPTA processing, the OTL displacements for each PS point location for each image date have been calculated using the SPOTL software (Agnew, 1996). TPX7.0 model has been used and solid body tides were not considered here.

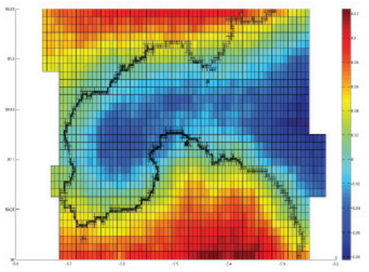

Figure 2: Ocean tide loading model for Newlyn from SPOTL.

The grid over which the OTL is calculated has been modified to be more suitable for coastal processing, i.e. it is better to use 'qtree' rather than 'uniform' grid cells. The qtree grid cells get smaller at the coast to get more accurate information of the OTL at the coast (Figure 2). Then the output OTL displacement in east, north and up components were converted into the radar line-of-sight (LOS). These were then converted into phase and imported into the Gamma IPTA software where the phase information was converted into a software compatible point list. The software was then used to wrap the OTL phases and it was re-run until the point interferograms were generated, at which point the OTL wrapped phases were differenced from the interferograms. Although the differential OTL effect reached levels of 1mm over the area of interest, the results presented in Figure 3 suggest that it is negligible in PSI analyses over small regions even with large OTL signals.

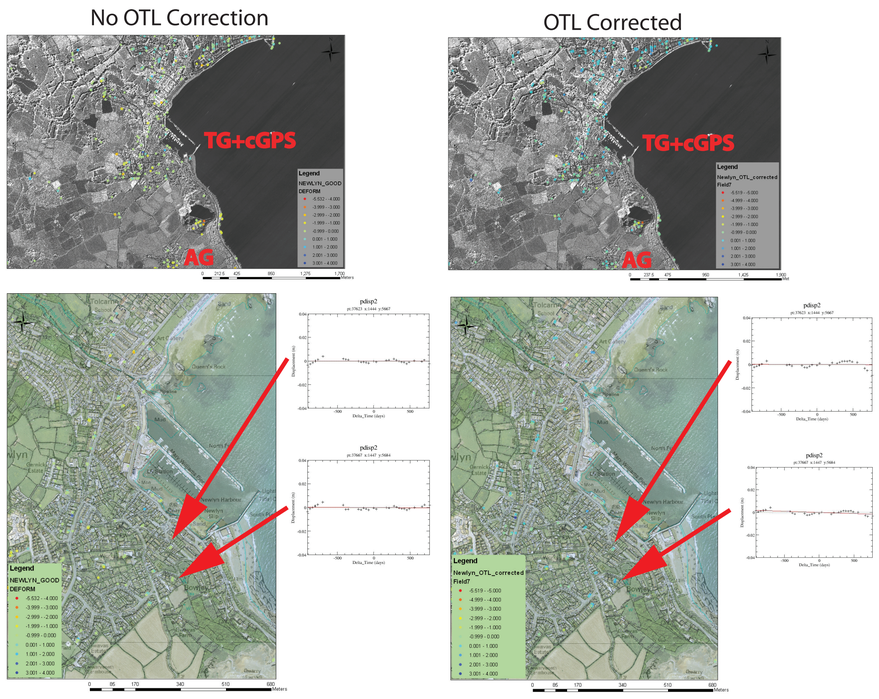

Figure 3: PSI results for Newlyn without (left) and with (right) OTL corrections applied during GAMMA IPTA processing. Top figures show the regional pattern while the lower figures show the detail in the town of Newlyn and the harbour. Time series of PS point (37623 and 37667) displacements are shown and indicated negligible OTL effects. The locations of the tide gauge and cGPS stations (TG+cGPS) as well as of the absolute gravity stations (AG) are also indicated.

Regional and Tide Gauge Site Results

Here the Gamma IPTA processing results for Newlyn, North Shields, Sheerness and Liverpool are presented. The four tide gauge sites and their surrounding regions are characterized by different levels of urbanization and vegetation; North Shields and Liverpool being highly urban, Newlyn and Sheerness being in rural settings, surrounded by farmland and salt marshes (in the case of Sheerness).
The identification of PSI points is highly dependent on the number of scatterers, which remain stable over time. In urbanized areas it is possible to identify 100s of thousands of PS points, resulting in clear patterns of local to regional uplift or subsidence (Liverpool and North Shields). It is difficult to identify PS points in densly vegetated areas such as woodland, farmland and coastal salt marshes (Newlyn and Sheerness).
An number of different algorithms to identify PS points have been investigated as part of this work. Shown here are the best results obtained for each region and tide gauge site.
As the PSI vertical land movement results are relative, i.e. with respect to a reference PS point, the PSI results were "calibrated" using the vertical velocity estimate of the cGPS station and nearby PS points. Various possible calibration methods were investigated with little difference to the overall results.

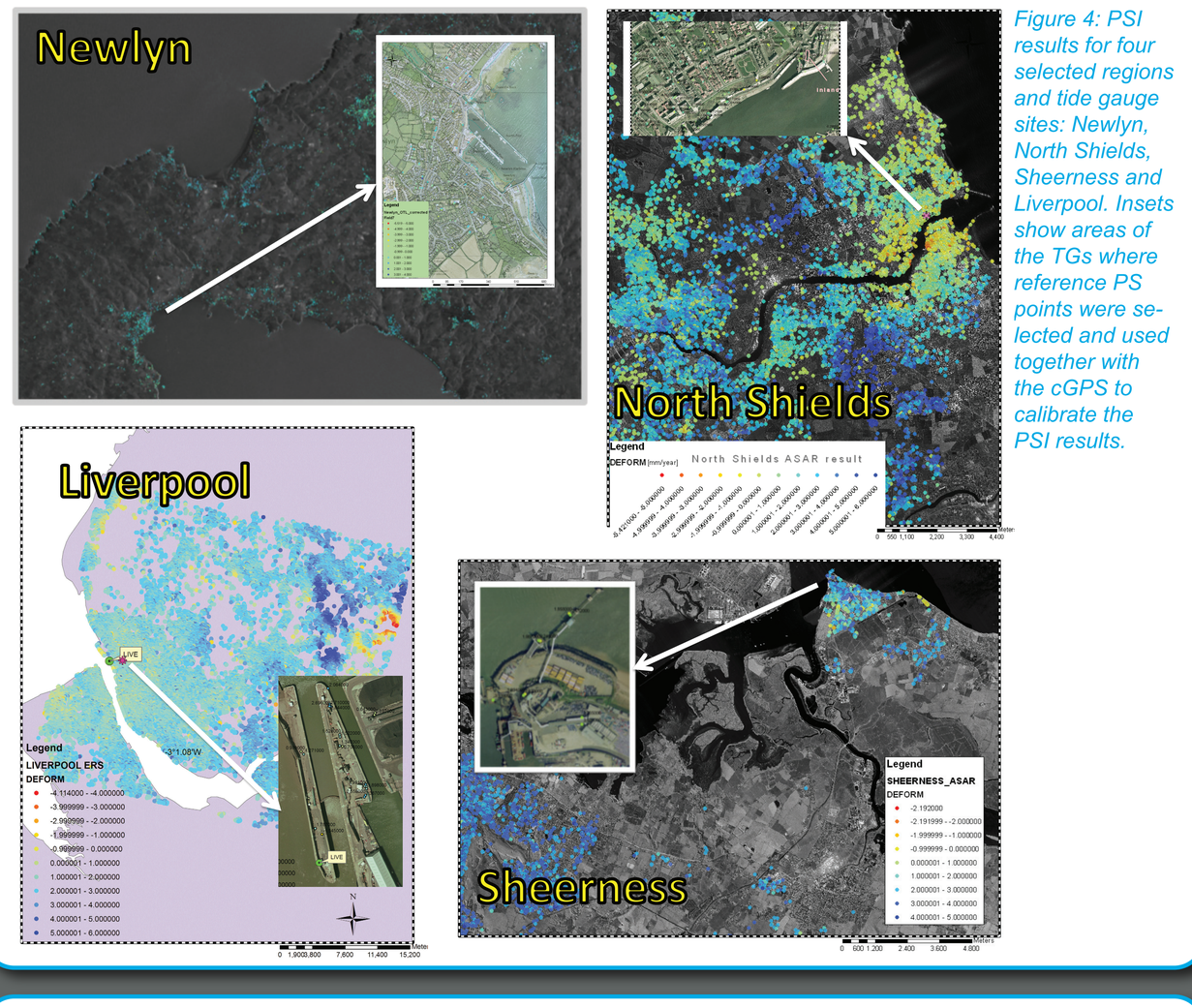

Figure 4: PSI results for four selected regions and tide gauge sites: Newlyn, North Shields, Sheerness and Liverpool. Insets show areas of the TGs where reference PS points were selected and used together with the cGPS to calibrate the PSI results.

North Shields Tide Gauge Site Results

For the tide gauge site in North Shields it is possible to investigate if PSI can be used to supplement local survey and cGPS measurements for monitoring local site stability. Figure 5 shows the area of the tide gauge and of the nearby Lighthouse, which is assumed to be on stable bedrock and where the primary tide gauge benchmark is located. It can be seen that overall there is little to no differential vertical land motion indicated by the PS points, confirming results from local surveys.
As demonstrated above the urban area including North Shields lies in a region that has been intensively mined for coal over the last 200 years. The PSI results show that there are many areas of significant uplift and subsidence in the neighbourhood of the TG. According to Bateson et al. (2012), ground motion appears to be linked to a recovery in groundwater levels following mine closure, the effects of which are still not properly understood. Although the PSI results confirmed the TG site was stable, the extent of instability in the region could have threatened the site's integrity. Therefore, PSI could be an invaluable new tool in appraising new TG sites and in monitoring the stability of existing monuments.

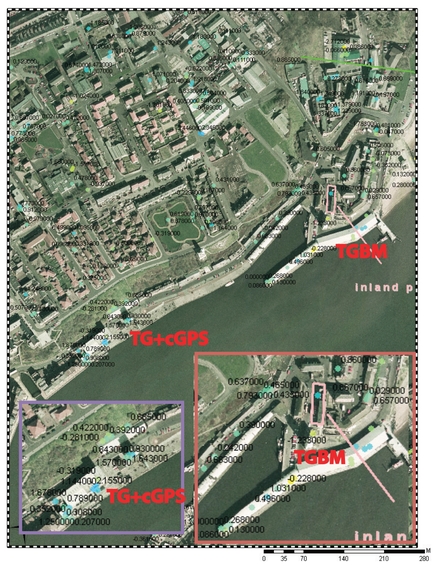

Figure 5: PSI results for North Shields tide gauge (TG+cGPS) and tide gauge benchmark site near the lighthouse (TGBM).

Conclusions

This study investigated the use of Persistent Scatterer Interferometry (PSI) as a complementary technique to cGPS (and absolute gravity) to monitoring the vertical land movements at tide gauges (TGs).
The assessment if differential displacements due to ocean tide loading (OTL) need to be modelled in PSI processing showed that this effect is negligible over small areas, even for locations with large OTL signals.
PSI processing was then carried out for four selected TG sites (with cGPS installations) in the United Kingdom, which are characterized by varying levels of urbanisation and vegetation. The PS point distribution was variable between the sites, being very good for North Shields and relatively poor for Newlyn.
Using a PSI reference point close to the cGPS seemed adequate to calibrate the PSI results. Once calibrated, the PSI results were in context with the cGPS measurements. For TG sites with plentiful PS points (North Shields), PSI is certainly a useful supplement to other geodetic techniques used at TG sites, with applications for both stability monitoring of existing and for appraising new TG installations.
However, the project experienced a poor PS point density from ENVISAT and ERS SAR data. It is expected that high-resolution SAR sensors (TerraSAR-X, Cosmo-Skymed, Radarsat-2) would significantly improve this in the future.

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