Feasibility of InSAR technologies for nationwide monitoring of geohazards in Great Britain

Cigna, F., Bateson, L., Jordan, C. and Dashwood, C.

British Geological Survey, Nicker Hill, Keyworth, NG12 5GG Nottingham, United Kingdom
Contact details: 0044 115 9363551; fcigna@bgs.ac.uk

Abstract

The objective of this study is to map the feasibility of InSAR technologies to monitor ground motion over the entire landmass of Great Britain by combining the effects of local topography and landuse. We employ medium to high resolution DEMs and account for different sensor acquisition modes and orbital characteristics (e.g., those of the European satellites ERS1/2 and ENVISAT) to evaluate the visibility of the terrain to the different acquisition geometries, identify areas affected by geometrical distortions (e.g. layover and shadow), and facilitate selection of the best modes to be employed to monitor the different areas of the landmass with InSAR. Combination of topographic visibility with land cover information then allows assessment of the probability of the targets on the ground to behave as good radar reflectors, and facilitates the estimation of the expected density of Persistent Scatterers identifiable over the different urban and rural areas of GB. The results will act as milestones for future InSAR applications to a wide range of geohazards in GB, and will show the potential of future nationwide monitoring.

Keywords: *InSAR feasibility*, *radar imagery*, *topographic distortions*, *Persistent Scatterers*, *geohazard*

1. Introduction

The British Geological Survey (BGS) is the national geoscience centre, and is the UK's premier provider of objective and authoritative geoscientific data, information and knowledge for wealth creation, sustainable use of natural resources, reducing risk and living with the impacts of environmental change. Alongside the full range of geohazard information, the BGS maintains the National Landslide Database and the Earth & Planetary Observation & Monitoring Team is constantly assessing and developing new technologies for geohazard mapping.

Building upon successful achievements of recent applications of InSAR (Synthetic Aperture Radar Interferometry) and PSI (Persistent Scatterer Interferometry) technologies in other EU countries such as Italy, Switzerland and The Netherlands, our study aims to evaluate and map the potential of these techniques to monitor ground motion over the entire landmass of Great Britain (GB). InSAR and PSI are readily and increasingly applied in urban and sub-urban areas within many national and international initiatives (e.g. ESA-Terrafirma, EU-FP7-PanGeo and SubCoast and other GMES programs), and have demonstrated their potential for monitoring of geohazards from space, by using a wide range of spatial scales (regional to local), temporal samplings (yearly to weekly) and significantly high precisions (up to a few millimetres).

Combination of local topography and satellite Line Of Sight (LOS) orientation may cause geometrical distortions within the radar scenes (foreshortening, layover and shadowing effects), induce significant underestimation of land motions, or even hamper the identification of reflective targets over the observed areas (e.g., Colesanti and Wasowski 2006; Cigna *et al.* in press). The geometrical visibility of a slope thereby depends on its orientation with respect to the sensor acquisition geometry (i.e. the LOS), and can also vary within different portions of the same scene. Use of appropriate geometry for the investigated area is therefore fundamental for each InSAR- and PSI-based analysis, to both guarantee the potential visibility of the area under investigation, and make sure that the motions affecting the area can be determined using the selected satellite acquisition geometry. Land use and cover also play a fundamental role for any InSAR and PSI monitoring, and usually control the spatial coverage of their output products. Buildings, infrastructure, man-made structures, exposed rocks and debris act as good radar reflectors, while forests and densely vegetated areas cause temporal decorrelation and prevent the identification of stable scatterers (e.g., Colesanti and Wasowski 2006).

2. Methodology and data

Some approaches to model topographic visibility and land use suitability of InSAR and PSI technologies were developed in the last decade to model and better understand these limitations. For instance, Colesanti and Wasowski (2006) analyze the visibility conditions of unstable slopes with different orientations and identify the ranges of aspect and slope which determine radar layover, foreshortening and shadow. Similarly, Cascini *et al.* (2010) discuss and implement the approach of *a priori* InSAR landslide visibility mapping in Campania Region (Italy). Colombo *et al.* (2006) cross-combine the effects of topography and land use in Piedmont (Italy), map the likelihood of identifying radar targets over the different classes of land use, and mask out layover and shadow regions by means of the approach of Kropatsch and Strobl (1990) using a 20m resolution elevation model. Notti *et al.* (2010, 2011) synthesize the effects of local topography and land cover into the R-, LU- and RC-indexes, and test them over the Upper Tena Valley (Spain) and in NW Piedmont (Italy). Barboux *et al.* (2011), Notti *et al.* (2011) and Cigna *et al.* (in press) calculate the percentage of maximum slope-oriented motions measurable by using the satellite acquisition geometry. Although the calculation of the latter is based on geometrical considerations analogous to those behind the R-index ones, the current approach employed to calculate this percentage do not allow the identification of active layover regions as efficiently as the R-index does, and its validity is limited to hilly and mountain areas, while application over flat areas or very gentle slopes is of low significance.

To assess the nationwide feasibility of InSAR and PSI for monitoring of ground motions in GB, we employ medium to high resolution DEMs and detailed information on land cover over the entire national territory. Exploited DEMs include the 90m resolution SRTM (Shuttle Radar Topography Mission) by NASA and USGS, the 30m resolution ASTER GDEM (Global DEM) by NASA and METI, the airborne InSAR-derived Intermap NextMap DEM at 5m resolution, and photogrammetrically-generated 2m DSM and 5m DTMs from the PGA. Different land cover maps available over GB are being used, including the EEA CORINE Land Cover map and the GMES Land Theme's Urban Atlas, and possibly also the Land Cover Maps of GB 1990, 2000 and 2007 released by CEH-NERC.

3. Results and discussion

The initial test we performed focuses on the topographic visibility of the radar acquisition geometry and exploits the SRTM DEM V4 at 90m resolution (http://srtm.csi.cgiar.org/) as a first approximation-screening for higher resolution studies. We applied the R-index model developed by Notti *et al.* (2010, 2011) to assess the visibility of the national territory at the medium resolution, and considered the acquisition parameters and geometries of the European satellites ERS1/2 and ENVISAT (operational in 1991-2011 and 2002-2012 respectively) for interferometric purposes. An average look angle θ of 23° and an orbit inclination γ of 14° were initially assumed for both ascending and descending modes over the entire territory. The calculated index ranges between -1 and 1, and synthesizes the ratio between an area on the ground and its respective slant range pixel in the radar geometry. Positive values from 0.3 to 1 generally indicate regions of good to very good visibility (i.e. slopes facing away from the SAR sensor), while 0 to 0.3 indicate foreshortening effects (i.e. back scattering from these areas is compressed in a few image pixels; affect slopes facing the sensor and with steepness lower than θ), and negative values are indicative of active layover (slopes facing the sensor and steeper than θ, hence producing layover onto other areas).

Nationwide maps of R-index for both the ascending and descending acquisition modes show that topography is not the major limitation over most of GB (Figure 1). Most of the territory is dominated by gentle topography and steepness of the slopes in the hilly and mountain regions do not exceed 40°-50°, hence no significant effects of active layover are observed. Exceptions are some hilly regions for example in Scotland, in the Lake District and Wales, where the visibility of the slopes is highly influenced by the satellite acquisition mode (ascending or descending). The result allows a better identification of areas not visible from the satellite sensors, and thereby facilitates the selection of the most appropriate acquisition mode when undertaking InSAR monitoring in these areas. As expected, E-, NE- and SE-facing slopes are characterized by better visibility using the ascending geometry, while W-, SW- and NW-facing slopes have better visibility with the descending acquisition mode.

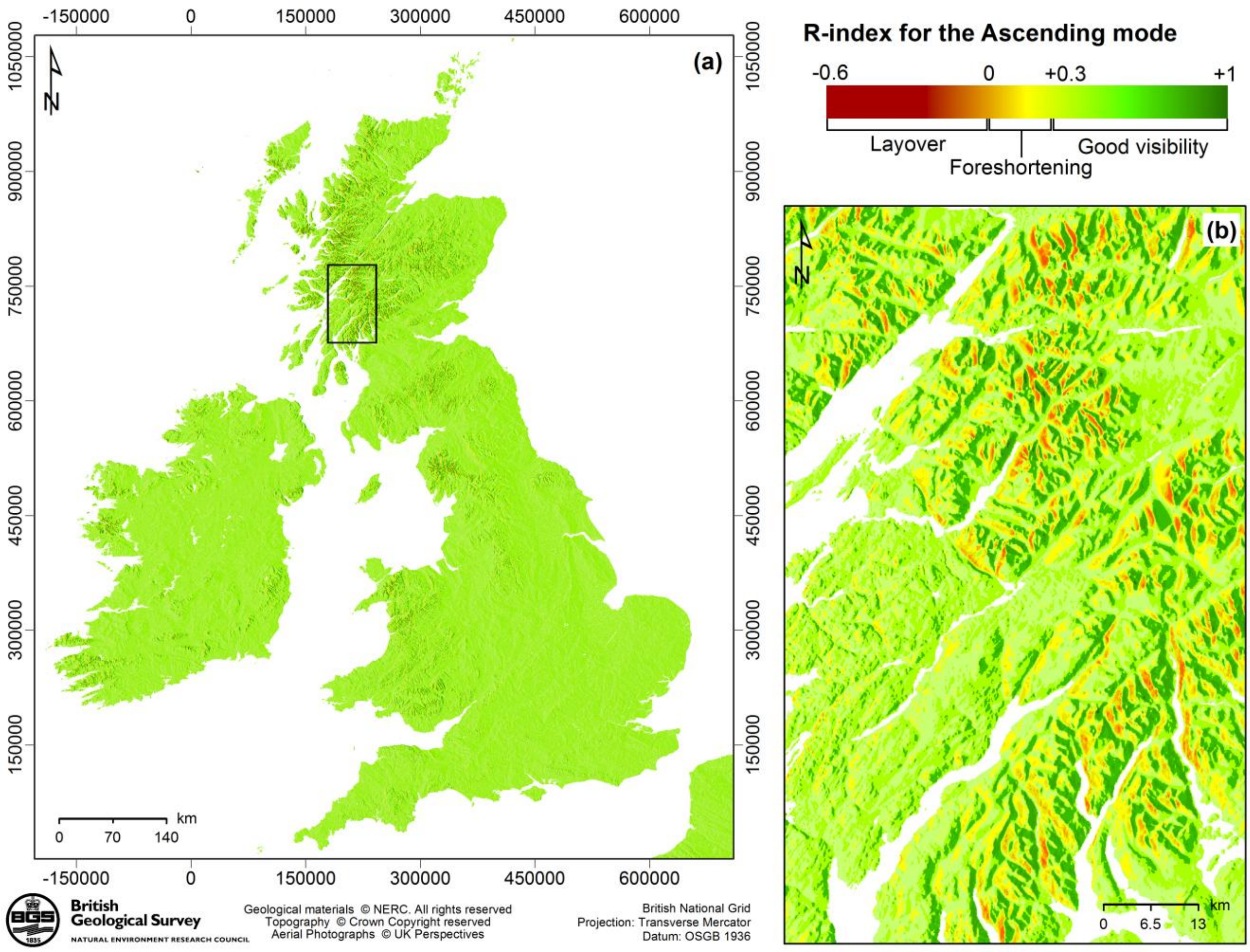

Figure 1: *(a) Nationwide map of topographic index R-index for the ERS1/2 and ENVISAT ascending mode with θ of 23°. (b) Inset, Western Scotland.*

An improved modelling of the topographic visibility is achieved through the generation of the shadow and layover masks by means of a simplified version of the Kropatsch and Strobl approach (1990), which allows the identification of not only the areas of radar shadow (slopes facing away from the sensor and steeper than 90°-θ, hence 67°), but also both active and passive layover regions (Figure 2). Indeed, the R-index approach only accounts for the effects of active layover, while it does not identify the areas of passive layover (on which the active ones lay over). The results of the layover and shadow maps show that, in most cases, layover effects observed for the descending geometry over slopes facing E, can be avoided by employing the ascending one (and vice versa for W-facing slopes). No shadow areas have been identified throughout the UK, due to the absence – at least in the SRTM DEM – of slopes steeper than 60°-70°.

The same approach will be implemented by exploiting other higher resolution DEMs, and by analyzing the impacts and advantages brought to the visibility map by more detailed topographic data. With reference to landslide processes, we will also assess the sensitivity of the satellite LOS to slope-oriented motions nationwide, and quantify the percentage of the actual motions that can be captured by InSAR and PSI technologies using the approaches described by Barboux *et al.* (2011), Notti *et al.* (2011) and Cigna *et al.* (in press). Combination of topographic visibility with land cover information will allow assessment of the probability of the different targets on the ground to behave as good radar reflectors, and facilitate the estimation of the expected density of radar reflectors identifiable over the different urban and rural areas of the landmass.

4. Conclusions

The preliminary results presented here suggest that InSAR should be a suitable technology for geohazard monitoring in the UK. The results of our forthcoming higher resolution study will act as milestones for future InSAR and PSI applications to a wide range of geohazards in GB, ranging from landslide processes to natural and human-induced land subsidence, ground collapses and shrink-swell of clay deposits. They will also show the potential of a future wide-area InSAR study of GB, as a follow up to the recent and successful examples of the Extraordinary Plan for Environmental Remote Sensing of Italy, and the nationwide mapping of land subsidence over The Netherlands.

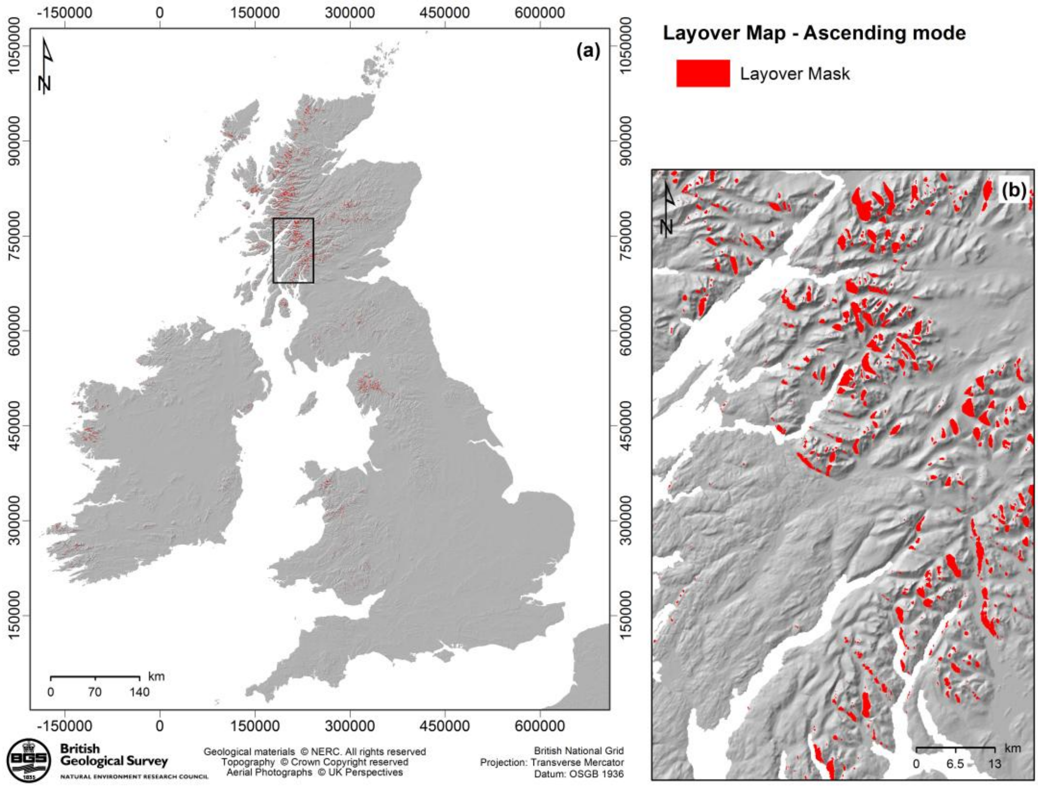

Figure 2: *(a) Nationwide map of SAR layover in the ERS1/2 and ENVISAT ascending mode with θ of 23°, overlapped onto the SRTM shaded relief. (b) Inset, Western Scotland.*

5. References

BARBOUX, C., DELALOYE, R., STROZZI, T., COLLET, C. and RAETZO H., 2011, TSX assessment for slope instabilities monitoring in Alpine periglacial environment (Western Swiss Alps, Switzerland). In *Fringe 2011 Workshop*, 19-23 September 2011, Frascati, Italy (ESA SP-697, January 2012).

CASCINI, L., FORNARO, G. and PEDUTO, D., 2010, Advanced low- and full-resolution DInSAR map generation for slow-moving landslide analysis at different scales. *Engineering Geology*, **112**, 29–42.

CIGNA, F., BIANCHINI, S. and CASAGLI, N., in press, How to assess landslide activity and intensity with Persistent Scatterer Interferometry (PSI): the PSI-based matrix approach. *Landslides*, 1-17. doi: 10.1007/s10346-012-0335-7.

COLESANTI, C. and WASOWSKI, J., 2006, Investigating landslides with space-borne synthetic aperture radar (SAR) interferometry. *Engineering Geology*, **88**, 173–199.

COLOMBO, A., MALLEN, L., PISPICO, R., GIANNICO, C., BIANCHI, M. and SAVIO, G., 2006, Mappatura regionale delle aree monitorabili mediante l'uso della tecnica PS. In *10th National Conference ASITA*, 14-17 November 2006, Bolzano, Italy.

KROPATSCH, W. and STROBL, D., 1990, The Generation of SAR Layover and Shadow Maps From Digital Elevation Models. *IEEE Transactions on Geoscience and Remote Sensing*, **28**, 98–106.

NOTTI, D., DAVALILLO, J.C., HERRERA, G. and MORA, O., 2010, Assessment of the performance of X-band satellite radar data for landslide mapping and monitoring: Upper Tena Valley case study. *Natural Hazards and Earth System Sciences*, **10**, 1865–1875.

NOTTI, D., MEISINA, C., ZUCCA, F. and COLOMBO, A., 2011, Models to predict Persistent Scatterers data distribution and their capacity to register movement along the slope. In *Fringe 2011 Workshop*, 19-23 September 2011, Frascati, Italy (ESA SP-697, January 2012).