Mining Subsidence Land Surveying by SAR Interferometry

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Abstract

The overall philosophy of this collaborative project, between Doncaster College, RJB Mining (UK), GEC Marconi Research Centre and Matra Marconi Space (UK), is to in subsidence prediction models implemented in the mining industry. These models are used to help mine management, in terms of productivity, conformity with regulat minimised environmental and economical impacts. However, models produce actual to predicted subsidence results in the range 43%-773%, corrected from local exp aims to provide accurate data on elevation change due to mining activity, via the application of radar interferometry with ERS synthetic aperture radar (SAR) data. Th data can then be fed into subsidence models to improve predictions about further subsidence. Initial interferometry results are presented showing evidence of subsid underway and preliminary interpretations are offered and discussed.

Keywords:SAR, Radar, Interferometry, Differential Interferometry, Mining Subsidence, Downwarp.

Introduction

The overall philosophy of this collaborative project, between Doncaster College, RJB Mining(UK), GEC Marconi Research Centre and Matra Marconi Space, is to improve the accuracy of subsiden in the mining industry. These models are used to help mine management, in terms of productivity, conformity with regulatory consent, and minimised environmental and economical impacts. H predicted subsidence results in the range 43%-773%, corrected from local experience. The project aims to provide comprehensive data on elevation change due to mining activity, via the appli (SAR) interferometric techniques and ERS SAR data. These elevation change data can then be fed into subsidence models to improve predictions about further subsidence. Initial interferometry evidence of subsidence. Validation is underway and preliminary interpretations are offered and discussed.This work forms part of the BNSC Earth Observation Link Programme and is sponsored Space (UK) Ltd.and RJB Mining (UK) Ltd.

In the UK, mining subsidence is typically limited to 1 metre by planning consent. The dynamics of subsidence involve vertical movement, spreading beyond the worked panel at around 37^{o} and thickness. Variation in subsidence rate occurs due to inconsistency of geological formations, rock mechanical properties and the overall uniqueness of the situation. The dynamics of mining subs industry standard [Ref. 2] is applied largely by use of generalised graphs, which are usually empirically derived from observation, with the results adjusted by local experience. Computer model parameters of seam thickness, depth of mining, and amount and direction of seam gradient. The reliability of this modelling is extremely variable, with reported actual to predicted subsidence r 3]. Part of this can be accounted for by the empirical nature of the models which makes them highly sensitive to the accuracy and extent of survey data available.

Currently, mineral surveyors conduct line surveys of subsidence along roads and canal banks, which represent a very small proportion of the area of influence of the mine working, and this sma wide variation in modelling results. Remote sensing data has the potential to improve modelling subsidence accuracy by significantly increasing the quantity of feedback data compared to that a methods.

ERS SAR data, used in conjunction with SAR interferometry techniques (in particular differential interferometry) may be able to provide such information to the mining industry with a potential order of 1cm and horizontal resolution of about 20m. However, the technique is not yet proven, and the project aims to investigate whether SAR data can provide elevation change information a by the mining industry. Once this has been established, it is intended that subsidence maps be produced that can be linked into appropriate subsidence models, the results of which can be com based solely on line survey data.

2. Differential Interferometry

The use of differential interferometry is aimed at the detection and measurement of small scale surface movements. The technique commonly involves the generation of two interferograms fror interferogram spanning some surface change, the other a 'reference'. The former is expected to contain fringes due to the terrain and the surface movement, whereas the latter contains terrair two interferograms, the terrain effects can be removed from the "surface" change measurement, leaving only the effects of the surface movement. It is also possible to use a single interferogra change, and a reference digital elevation model (DEM) from some other source to remove the terrain effects from the data [Ref. 5]. In addition, it is likely that where topography and baseline a will not be necessary, and therefore a single interferogram will suffice for "differential" interferometry.

3. Testsite and Ground Data

The project intends to study two sites, the Selby Coalfield in the UK, where subsidence is limited to 1m, and the Silesian coalfield in the Czech Republic, where up to 40m subsidence has been e working of coal seams. Work is currently concentrated on the Selby site in order to demonstrate the capability of ERS data to detect and measure mining subsidence. The site occupies a predon majority of terrain under 10m, and is covered in arable farm land. The Selby site is preferred to establish a capability, as detailed ground data exist, which have been made available by RJB Min mined areas, dates of mining activity, subsidence measurements acquired along survey lines, and subsidence predictions. In an area of concern, lines surveys are typically acquired every 6 mor to millimetric accuracy. Once a subsidence monitoring capability has been established, it will be applied to the Silesian site.

4. Image Data

Both 35 day repeat and tandem ERS single-look complex (SLC) data are available to the project for interferogram generation. In selecting the initial data for interferogram generation, the follov optimise interferogram coherence.

Interferometric baseline under 200m.
Temporal separation 35 days or less.
Acquisitions between September and March.
No rainfall during or immediately before acquisition.

The SLC data is processed using the interferometric processor developed at MRC [Ref. 6]. This processor facilitates the rapid production of large area interferograms and performs complex imag generation and formation of associated interferogram products, such as DEMs, differential DEMs and coherence maps. Developed under the Application Visualisation System (AVS) environment that it can be rapidly reconfigured to include enhanced processing steps such as the addition of new phase unwrapping algorithms, but it is also easy to use, with a range of "standard" networks

5. Interferometry Results

To date, two tandem pairs and one 35 day repeat pair of ERS SLC data have been processed at MRC. Initially, effort has been concentrated solely on interferogram generation and analysis for tl determine if subsidence can be detected and measured. Due to the baselines selected and the low relief of the terrain at the Selby site, it has not been necessary, so far, to remove terrain effec interferogram using a reference data source.

The 35 day repeat interferogram was generated using data from February and March, 1993, with a baseline of -161m. A small section of the interferogram is shown in Figure 1. The data has be statistics and is represented in approximately ground range with 50m horizontal resolution. Although the data has been acquired outside the growing season, coherence is relatively low due to the two images, but provides coherent coverage of more than 50% of the site.

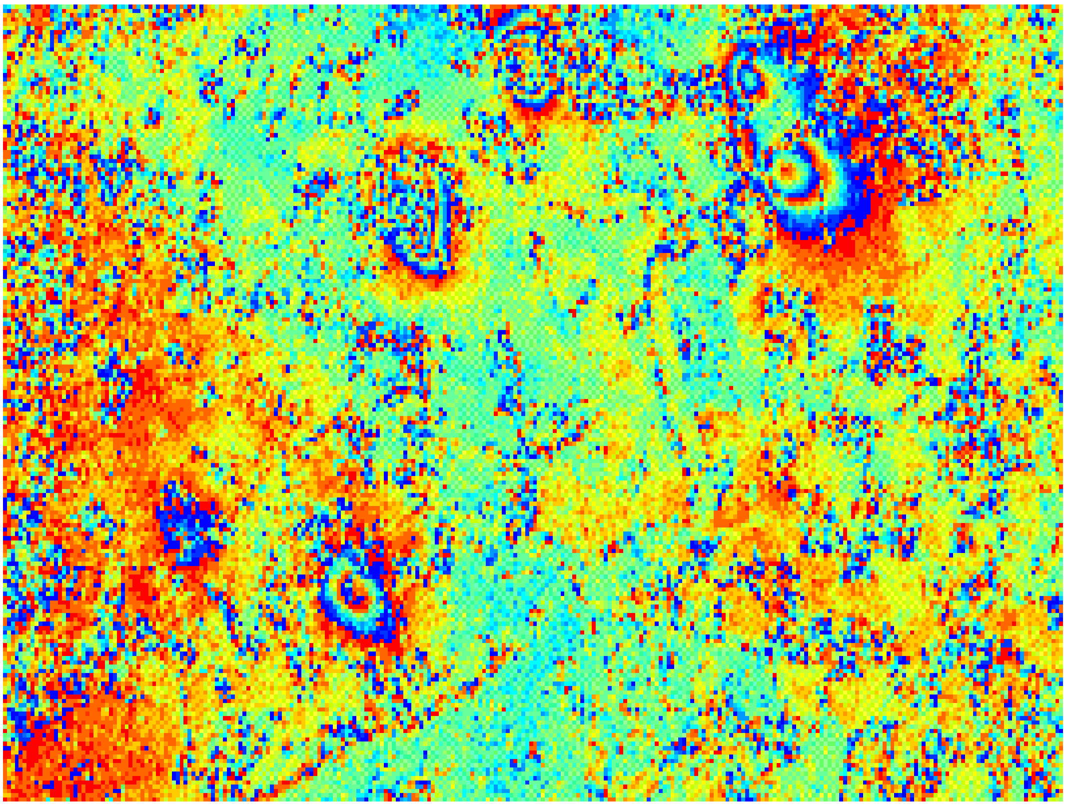

Figure 1 Zoomed phase image of interferometric fringes corresponding to mining subsidence, Selby, Yorkshire, UK. 12/2/93 to 19/3/93.

Interest here is focused on the circular, concentric fringe features. By comparison with ground data, it has been established that these do not correspond to terrain features. A colour cycle in thi elevation change of about 50m, implying that we would have to be seeing a terrain feature several hundred metres in height, when the highest elevation in the image is only about 20m. The fe localised (about 500m in horizontal scale) and regular in shape and would therefore appear not to be due to atmospheric effects or any residual geoid effects that might be visible. The circular f compared with areas of known mining activity and the locations compare well, suggesting that they are probably due to ground subsidence.

Each fringe in a subsidence feature represents a surface movement of 28mm in the radar look diction. Some of the features have evidence of three or more fringes, suggesting a surface change Features with at least one fringe are clearly visible in the image, provided that they occur in relatively coherent regions, indicating that the vertical measurement accuracy is at least of the orde favourable coherence conditions, or better given ideal conditions.

Two pairs of tandem data have also been processed and analysed; although the interferogram coherence is far superior to the 35 day repeat data, no obvious subsidence features can be seen. subsidence occurring in a 24 hour period at the Selby site is too small to be detected by this technique (we might expect 2.3mm of subsidence in 24 hours, based on 8cm in 35 days).

6. Validation Results

The interferometric phase image (Figure 1) shows a number of distinctive concentric fringe features, which after geocoding to mine working drawings and Ordnance Survey 1:25000 maps have with areas of mining activity up to and including the acquisition dates. These phase data can be converted to elevation changes by phase unwrapping.

The close up phase image of the largest subsidence feature (Figure 2), geocoded to a 1:10560 Ordnance Survey map and overlaid with a mine workings plan (without surface detail), shows two activity between two satellite passes.

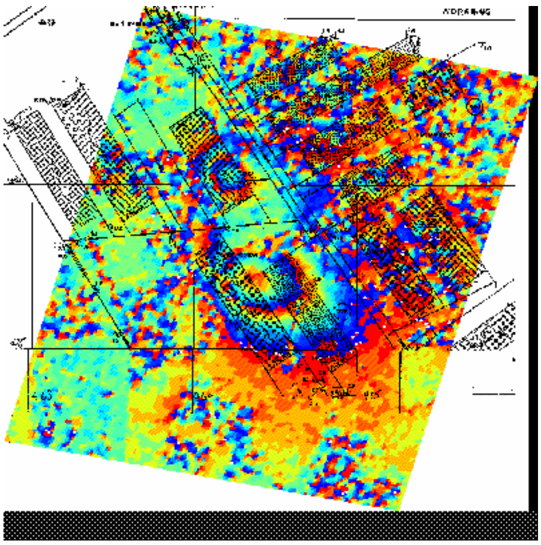

Figure 2. Geocoded interferometric fringe features overlaid with mine workings drawing showing mine panels and roadways. Selby, Yorkshire, UK. 21/2/93 to 19/3

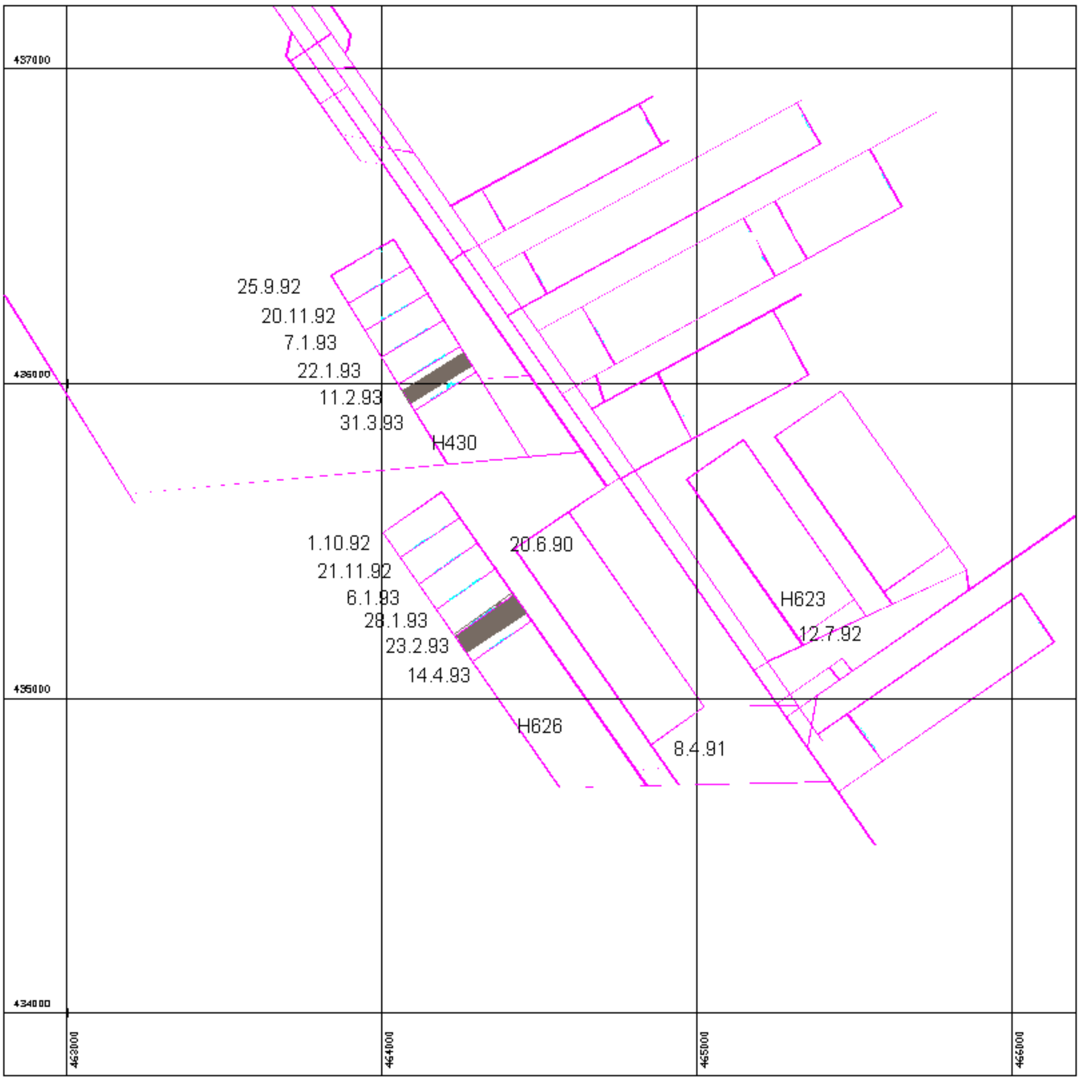

Figure 3. Mine workings drawing showing panel numbers and progress dates of coal faces.

Active seams (H430 and H626) during the period of image coverage are illustrated in Figure 3, with dates and locations of the working face also marked. In particular, the records of progress in
and H626 show a close correlation to the fringe position. That is to say that the fringe centres occur at the location of the working face of the panel. For instance, in seam H430 the working face
panel (these panels were worked north-west to south-east), reflected in the location of the fringe centre, whereas in seam H626 the working face had not passed the half way stage, which is ag

The east-west asymmetry of the outer fringes is explained by residual subsidence from panels visible to the east, especially panel H623, which was completed at its southern end in July 1992, 1
passes. Residual subsidence typically continues for a year (sometimes longer) after mining has ceased.

A north westward vector in the fringes is caused by residual subsidence behind the working face on the productive panels. The displacement of the fringe centres from the panel centre line is ge
subsidence displacement of around 50m in the direction (75°) of the strata dip in this area. However, there is unexplained variance in the degree of subsidence above the two active panels; sub
panel H626 compared to panel H430 (approximately 2.25 fringe cycles and 2 cycles, corresponding to 63mm and 56mm, respectively). This difference may be explained by variance in producti
panels of the two active areas or by the proximity of previously worked seams.

Unfortunately, for this image pair there is no surface survey data available close to the acquisition dates and so quantitative validation of the amount of subsidence is not possible.

7. Conclusions and Future Directions

Initial results suggest that mining subsidence can be detected using 35 day repeat SAR data and SAR interferometry techniques, and that this subsidence can be measured at the very least to a
However, there would appear to be a central dilemma in applying this technique. A balance needs to be found between a useable temporal separation between images (in terms of interferogram
suitable length of time to lapse for a measurable amount of subsidence to occur.

From the results so far, it is also clear that it is unlikely that the tandem data can be used to *directly* measure surface change in the UK. However, it may be the case that at the Silesia site, tand
effects due to the greater amount of subsidence occurring. In addition, tandem data has an important role to play in providing reference terrain information when terrain effects have to be rem
data.

We are pleasantly surprised at such positive results in the 35 day repeat data, given the reduced levels of coherence (for this site) which result from such a long repeat interval. This gives enco
appropriate repeat interval might be an effective tool for detailed routine monitoring of ground subsidence.

Work will continue on producing and validating surface change measurements for the Selby site. The issues of all year coverage, extended temporal measurements (i.e. covering a 6 month peri
separation for accurate and reliable subsidence measurements will be addressed. Once a capability has been firmly established, it will be applied to the Silesian coalfield site.

In order to carry out a quantitative evaluation of subsidence measurements using this technique, ground surveys, at Selby, of currently productive mine areas have recently been carried out by
with ERS data acquisition.

8. Acknowledgements

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