GROUND MOTION IN AREAS OF ABANDONED MINING: A CASE STUDY OF PSI APPLIED TO THE NORTHUMBERLAND REGION OF THE UK.

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ABSTRACT

An Abandoned Mines Advanced Terrain Motion Service was commissioned in the framework of the ESA GMES project Terrafirma to demonstrate the capabilities of Radar Interferometry areas of abondened mining. The Coal Measures form the bedrock for much of the study area in the north east of England. The coalfield has a working history dating back to Roman times with over twenty coal seams mined underground in more recent times. The working of deeper and deeper coal seams led to the need to pump mine water. All underground mining has now ceased, the majority of mines were closed by the 1980's. Over the past decade there has been a program to turn off the mine water pumps and allow groundwater levels to recover Two PSI datasets were created; one from 1995 to 2000 the other from 2002 to 2008.

PSI results from the 1990s show nine 'hotspots' of subsidence to the south and a larger area of uplift in the north. The subsidence areas show a strong spatial relationship with areas of past mining. However there is a discrepancy in the timing of PSI motions and that of expected subsidence given the type of workings. It is suspected that the motion relates to material extraction, water extraction and the accommodation of resulting motions along faults. Uplift, as seen in the data from the 2000s, this has been attributed to the recovery of groundwater levels as mine water pumping has ceased. The difference between the 1990s results and thoise form the 2000s is marked; areas which were undergoing subsidence between '95 and '00 are uplifting between '02 and '08. This drastic change is supported by minewater level data which shows that water levels have recovered within this time period, with the resulting increase in hydrostatic pressure accounting for the regional pattern of ground heave.

1. INTRODUCTION

Britain's coal reserves were a driving force behind the industrial revolution and have an exploitation history dating to Roman times in many areas. It has long been recognised that active mining has significant effects on ground stability. The Coal Authority, a government body established following the privatisation of the coal industry, is responsible for protecting the public in coal mining areas, and for administering coal mining subsidence damage claims. It also has a remit to protect the environment by treating mine water discharges and preventing problems associated with rising mine water.
The scope for radar based ground measurements to assist the Coal Authority with their understanding of ground motions offers an interesting possibility. This study investigates the use of Satellite InSAR for the Northumberland and Durham coalfield and forms part of the European Space Agency's Terrafirma project.

1.1. Geological Background

The productive Coal Measures form the bedrock for much of the Northumberland and Durham study area in the north east of England (***Figure 1***). The geological sequence of interest includes bedrock of Carboniferous strata, including the Westphalian Coal Measures, and Permian strata comprising the basal Permian Yellow Sands Formation and overlying Zechstein Group. The Carboniferous rocks dip gently eastwards and are overlain unconformably by the Permian rocks. The continuity of the outcrops of these units is interrupted by a number of normal faults. The coal-bearing strata dip gently to the east, part of the coalfield being concealed beneath the Permian strata to the south of the River Tyne and the coalfield extends beneath the sea [3].

Faulting in the area is mostly east-north-east trending, but there are a number that trend east-south-east, typical displacements are of the order of 25 m or less but some faults show displacements up to 200m. Quaternary deposits consist of Till, which can be up to 60 m thick and covers more than half of the area, glaciofluvial sands and gravels and glacial lake deposits. Borehole evidence suggests that the rockhead surface has an appreciably greater relief than the till plain that forms the present-day surface. Pre-existing, possibly pre-glacial, valleys coincident with or marginally offset from, the present-day valleys of the major rivers are largely infilled with glacial deposits.

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The coalfield has a working history dating back to Roman times. Over twenty coal seams have been mined underground and the coalfield has been one of the major sources of opencast (surface-mined) coal in Britain. The geological structure of the area determined the development of the coalfield with faults, in particular, serving to divide the area into zones of 'take'. The working of deeper and deeper coal seams, including those beneath the Permian, led to the need to pump mine water.

Figure 1. The Northumberland and Durham coalfield; depth of coal shown by colour; Grey <50m, orange>50m.

1.2. PSI Data and Results

PSI processing was carried out by NPA Satellite Mapping Ltd and the data were interpreted by BGS to add value in the form of a geological interpretation. The data and interpretation were then passed on to the Coal Authority as the end user to assess the usability for their needs.

Two SAR data stacks were processed for the study; one form the 1990s and one form the 2000s. These both view the area from the east, along a steeply-inclined line of sight, meaning the measurements are predominantly sensitive to vertical ground motion. Positive values (and blue colours in figures) denote uplift, and negative values (red colours) subsidence. 50 descending ERS scenes from 1995 to 2000 produced 115 555 PS points with an overall average annual motion of +0.407 mm/yr.

21 Envisat scenes from 2002 to 2008 produced 71899 PS points with an average annual motion of +2.47mm/yr. Ascending SAR datasets were not suitable for PSI processing but DiffSAR analysis was possible. The average standard deviation is lower than for the ERS data since fewer images were used in the processing.

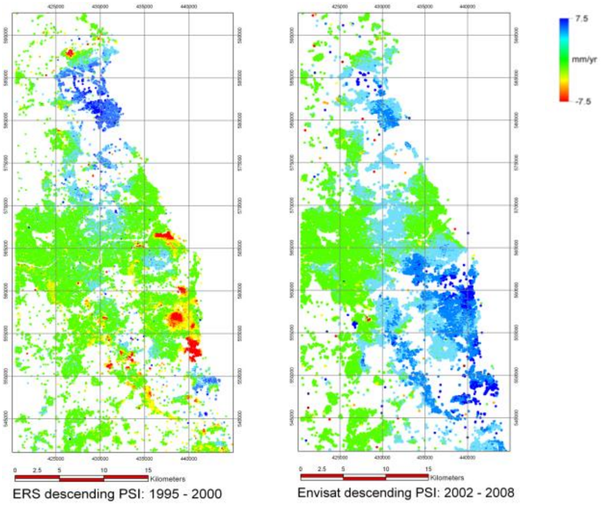


Figure 2. InSAR results, average annual velocities, for the Northumberland region, left shows deformation from 1995 to 2000 and right shows deformation from 2002 to 2008. Blue indicates surface uplift and red colours indicate surface subsidence. (InSAR data © NPA Satellite Mapping, a CGG Company; SAR data © ESA).

2. SURFACE DEFORMATION

2.1. Relationship to faulting

ERS results show some areas of motion are bounded by the pattern of faulting. The underlying reason for motion in several cases appears to be reactivation of faulting by factors such as ground water level change. Figure 3 shows the relationship between the regional motion and the regional pattern of faulting. Black circles outline areas where motion characteristics are seen to change over a fault at this scale. Figure 5 shows some of these relationships in more detail

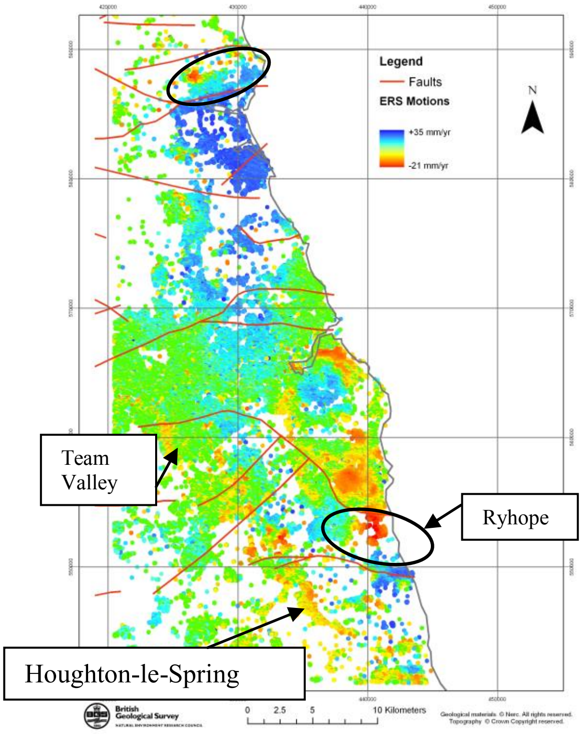
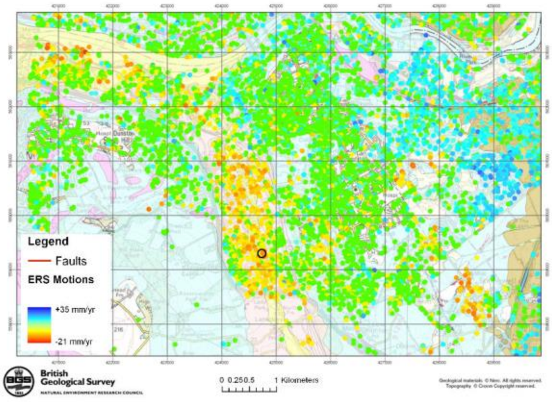


Figure 3: ERS (1995 to 2000) derived motion for the Northumberland region. Black circles on the image highlight motion phenomenon which appear to be bounded by the major faults in the region shown in red. Sites mentioned later are highlighted by text.

2.2. Compressible sediments in the Team Valley

The Team Valley area of Gateshead represents the pre-glacial channel of the River Wear which was eroded to below -46 meters OD. The channel is now infilled with alluvium which overlies a complex series of glacial clays, laminated-clays, silts and sands.

ERS results (Figure 4) show the centre of the valley to have subsided by up to 45 mm over the 1995 to 2000 period; this is attributed to compaction of the sediments through loading of the ground by buildings and to water abstraction.



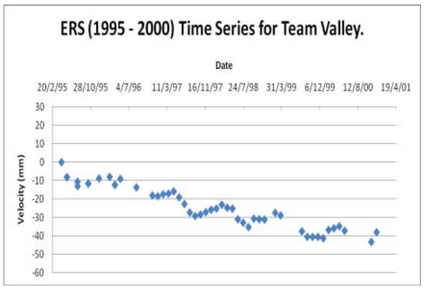
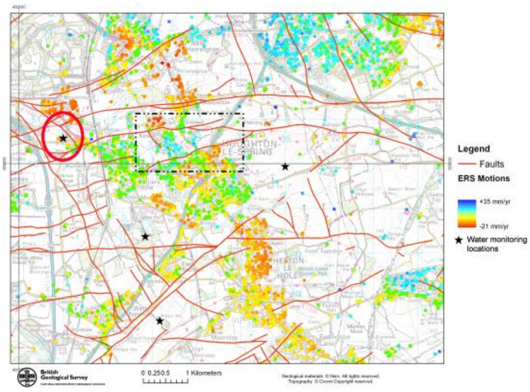


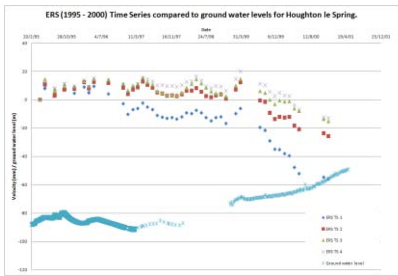
Figure 4: ERS 1995-2000 PSI data for the team valley nd Terrain motion time series for the cluster highlighted by black circle

2.3. Houghton-le-Spring

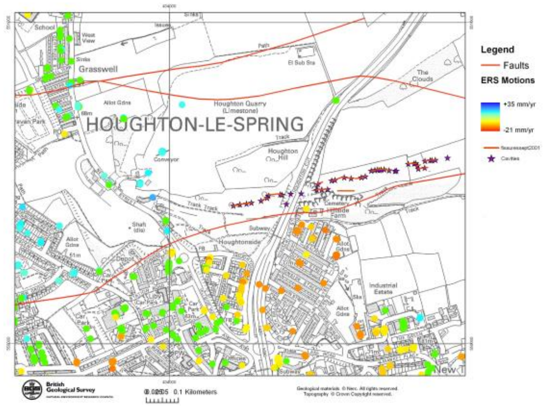
This area shows a complex spatial pattern of ground motion which appears to have arisen through the interplay of mining activities and ground water level changes due to pumping. Areas of motion appear to be bounded by the faulting in the area as shown on Figure 5. It is thought that changes in ground water levels, probably due to the cessation of mine water pumping, are causing differential motion of adjacent fault blocks; motion is accommodated by reactivation of existing faults as evidenced by fissures (Figure 5c). Ground water levels are seen to increase at the time that subsidence rates increase (Figure 5b).



a. *ERS motion in the Houghton area, red lines are faults and red circle highlights the area for which the Figure 3b graph is drawn. Black dashed rectangle highlights area shown in more detail in Figure 3c.*



b. *PSI motions (points) and ground water levels (blue crosses) in the area highlighted by the red circle*



c. ERS PSI shows differential motion across the fault (continuous red line). Subsidence has occurred to the south, which is the area that has been mined. To the north of the fault mild uplift is occurring. Field evidence supports motion in the area as evidenced by the cavities and fissures (stars and short red lines to the north of the fault). The area of coal mining is limited to the north by the fault. Coal was mined using the pillar and stall method.

Figure 5: ERS derived ground motion in the Houghton-le-Spring area for the period 1995 to 2000.

2.4. Areas of abandoned mining

Ryhope colliery was closed in 1966 (Figure 4), according to common opinion subsidence relating to the extraction of coal using the long wall technique would take place within 5-7 years of extraction. The ERS PSI data shows subsidence in this area occurring more rapidly but with an especially rapid motion from 1997 – 1998. It is not currently known if this subsidence is caused by coal extraction or if ground water levels have an effect.

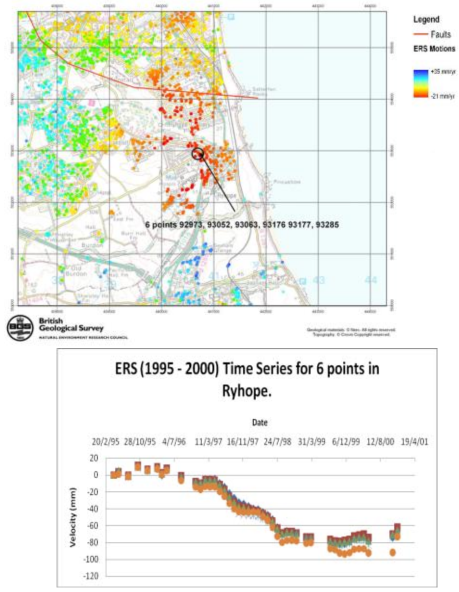


Figure 6: ERS PSI result for the Ryhope area

2.5. Differences between ERS and ENVISAT results

There are dramatic changes in the sense of ground motion between the 1995-2000 ERS result and the 2002-2008 Envisat result. This change appears to fit reasonably well with the recovery of minewater levels after pumping from the mines ceased, as shown by the PSI vs. minewater rise curves in Figure 7. The recovery of minewater levels following the cessation of takes place in 'minewater recovery blocks', water level recovers within a block until it reaches a tipping point at which point it will flow in to the adjacent block. Blocks are commonly defined by the faulting.

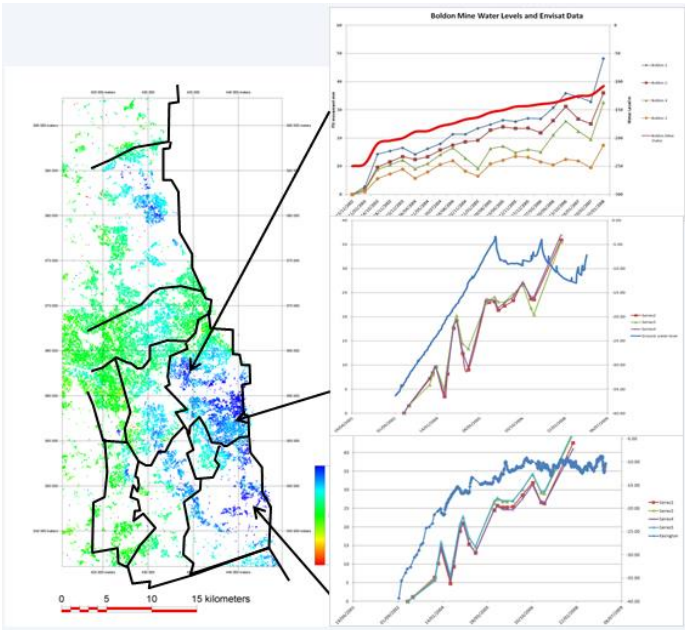


Figure 7: Minewater recovery curves (thick blue and red lines) compared with PSI derived ground motions for the monitoring stations highlighted by arrows.

3. USER PERSPECTIVE

Following receipt of the data the UK Coal Authority is impressed with the apparent ability to use PSI to identify areas where groundwater levels are rising. This is because PSI data has the potential to save money by reducing the need for unnecessary boreholes. Minewater monitoring boreholes can be cited in areas where PSI data has proven that minewater levels are rising via its ground motion signature, rather than employing an expensive ad hoc monitoring network of boreholes.

4. CONCLUSIONS

The use of InSAR data represents a very effective tool in the remote measurement of ground movements and has shown a strong correlation between the location of abandoned workings, water recovery and areas of surface uplift. Although its use for identifying new localised subsidence events attributable to coal mining is limited and inconclusive at this stage it is providing good information on where mine water is recovering and helping the Coal Authority prioritise sites where monitoring boreholes are required, providing potentially substantial savings.

Forthcoming InSAR data sources will improve consistency and frequency of data acquisition, which will further expand capabilities and improve overall results. In key areas (e.g. critical infrastructure) future InSAR monitoring could be optimised, for example by placement of artificial reflectors to increase measurement density.

5. REFERENCES

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6. ACKNOLEDGEMENTS

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