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Citation for published version (APA):

Published in:
Earth Observation in a Changing World

Citing this paper
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Using SAR Intensity and Coherence to Detect a Moorland Wildfire Scar in the Peak District

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Summary
The aim of this paper is to assess the ability of SAR intensity and coherence to detect a moorland wildfire scar in the Peak District National Park (PDNP) in the UK. Spatially-robust data to monitor wildfire scar size and severity in UK moorlands is currently rare. Information on fire extent and rate of recovery of vegetation would be useful for conservation organisations. Knowing the size and location of fire scars would help the Fire and Rescue Service to plan future response to moorland fires. Fire scar boundaries can be mapped in the field using Global Positioning Systems (GPS), but this is labour intensive and not part of the Fire Service operational procedure. An alternative approach to monitoring fire scars in the landscape is required.

This paper presents SAR intensity and coherence results for the 18th April 2003 Bleaklow fire scar (7km²) in the PDNP. Time series of ERS-2 and ASAR (C-band) images for several months before and after the fire were pre-processed using SARscape 4.2 to produce geocoded greyscale images. The intensity and coherence values have been qualitatively related to precipitation and CORINE land cover classes. Four Interferometric (InSAR) pairs of ERS-2 data were processed to generate coherence images for the Bleaklow study site (one pair prior to the fire; one pair before and after the fire and two pairs post-fire). The InSAR pairs were used to investigate the temporal trend in coherence for CORINE land cover classes inside the fire scar and outside the fire scar.

1 Introduction
Optical remote sensing for fire scar detection is limited by cloud, especially in moorland environments (Legg, 1991 and Armitage et al., 2007) and thermal hotspot detection using MODIS (250m resolution) can miss UK moorland fires e.g. Wainstalls fire in West Yorkshire which occurred on 30th May 2011 was not detected by the European Forest Fire Information System (EFFIS) (EFFIS, 2011). Synthetic Aperture Radar (SAR) has been used successfully for fire scar detection in Mediterranean forest fires in central Portugal (Gimeno et al., 2004) and boreal fires in Alaska (Bourgeau-Chavez et al., 1997). The use of SAR data for fire scar detection in UK moorland environments could offer an alternative approach to GPS mapping of fire scar boundaries and can potentially provide additional useful information such as variations in burn severity of the fire scar and longer term vegetation recovery. Also monitoring of fire scars using SAR may offer the possibility of detecting and monitoring them at the landscape level rather than localised surveys and would build upon the few previous landscape level studies (Yallop et al., 2006; Chapman et al., 2010).
2 Aims and Objectives
The paper presents results of an ongoing pilot study to explore whether a fire scar signal can be detected using C-band SAR intensity and coherence within a degraded UK moorland environment. The work presented here forms part of a larger research project to evaluate SAR for monitoring fire scars in the PDNP and wider UK moorlands. The objectives of the pilot study are:

- To obtain and pre-process a time series of ERS-2 and ASAR images for the Bleaklow 2003 fire scar.
- Determine the ability of SAR intensity and InSAR coherence to detect the fire scar temporally in a moorland environment.
- Analyse qualitatively how scene variables such as precipitation and CORINE land cover classes affect the SAR intensity and coherence signal both inside and outside the fire scar.

3 Methodology
3.1 Study Area
The PDNP is an interesting study area as it would be very vulnerable to temperature increases predicted by UK Climate Impacts Programme (UKCIP) due to it being one of the most southern moorland landscapes in the UK (McEvoy et al., 2006). The PDNP is also one of the most visited national parks in the UK (Karooni, 2005). During the 18th April 2003 the Bleaklow area of the PDNP experienced an intense fire which burnt deep into the peat. Post fire the PDNP rangers mapped the perimeter of the fire scar using a Global Positioning System (GPS) (red outline Figure 1). Damage had occurred in the Bleaklow area by previous fires which have been logged by the PDNP rangers (See red dots and dates in Figure 1). The Bleaklow area is of high scientific importance with vegetation consisting of Heather (*Calluna vulgaris*), Cottongrass (*Eriophorum* spp.) and Mosses (*Sphagnum* spp.).

![Figure 1. Bleaklow study area, Peak District National Park, northwest England, showing: GPS outline of the 18 April 2003 fire scar; fire log point data 1976 to 2008 (MFF); CORINE land cover data; and intensity/coherence sampling points (black dots) (Millin-Chalabi et al., 2010).]
3.2 SAR data selection

The data was selected using the ESA Earth Observation Link (EOLi) data ordering client version 7.0.6. Seven SAR images consisting of ERS-2 and ASAR images at Product Level 1 (1P) were ordered. SAR images with a small incidence angle ranging from 22.76° - 23.23° were selected, as Huang and Siegert (2006) found that backscatter of fire scars decreases when the incidence angle increases. Table 1 provides details of the images selected for the SAR intensity analysis. Table 2 provides details of the InSAR ERS-2 pairs used for the SAR coherence analysis. The selection of the InSAR pairs was based on the baseline as it is advised that when using pairs of data the baseline should be no greater than 500m to avoid temporal decorrelation and going past the critical baseline (Sarmap, 2007).

Table 1. SAR images used for intensity analysis for Bleaklow pilot project. The fire occurred on 18th April 2003 (108 JD)

<table>
<thead>
<tr>
<th>SAR Data/Mode/Swath</th>
<th>Acquisition Date/Time (ddmmyyyy)</th>
<th>Time relative to fire (JD Julian day)</th>
<th>Incidence Angle (IA)</th>
<th>Az pixel spacing (m)</th>
<th>Rg pixel spacing (m)</th>
<th>Ground Range (GR) (m)</th>
<th>Pass Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>ERS-2</td>
<td>08/02/2003 11:01</td>
<td>-69 days (39 JD)</td>
<td>23.23°</td>
<td>3.97</td>
<td>7.90</td>
<td>20.26</td>
<td>Descending</td>
</tr>
<tr>
<td>ERS-2</td>
<td>15/03/2003 11:01</td>
<td>-34 days (74 JD)</td>
<td>23.23°</td>
<td>3.97</td>
<td>7.90</td>
<td>20.26</td>
<td>Descending</td>
</tr>
<tr>
<td>ASAR IM 12</td>
<td>22/03/2003 21:37</td>
<td>-27 days (81 JD)</td>
<td>22.82°</td>
<td>4.04</td>
<td>7.80</td>
<td>20.00</td>
<td>Ascending</td>
</tr>
<tr>
<td>ASAR AP 12 HHVV</td>
<td>03/04/2003 10:36</td>
<td>-15 days (93 JD)</td>
<td>22.76°</td>
<td>4.04</td>
<td>7.80</td>
<td>20.00</td>
<td>Descending</td>
</tr>
<tr>
<td>ERS-2</td>
<td>24/05/2003 11:01</td>
<td>+36 days (144 JD)</td>
<td>23.21°</td>
<td>3.97</td>
<td>7.90</td>
<td>20.26</td>
<td>Descending</td>
</tr>
<tr>
<td>ERS-2</td>
<td>28/06/2003 11:01</td>
<td>+71 days (179 JD)</td>
<td>23.28°</td>
<td>3.97</td>
<td>7.90</td>
<td>19.75</td>
<td>Descending</td>
</tr>
</tbody>
</table>

Table 2. InSAR pairs used for the coherence analysis for Bleaklow.

<table>
<thead>
<tr>
<th>ERS-2 InSAR Pairs</th>
<th>Orbit/Track</th>
<th>Baseline (m)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pair 1</td>
<td>08/02/2003 &amp; 15/03/2003</td>
<td>134</td>
<td>Pre-fire</td>
</tr>
<tr>
<td>Pair 2</td>
<td>15/03/2003 &amp; 19/04/2003</td>
<td>349</td>
<td>Pre &amp; immediately post-fire</td>
</tr>
<tr>
<td>Pair 3</td>
<td>19/04/2003 &amp; 24/05/2003</td>
<td>147</td>
<td>Post-fire</td>
</tr>
<tr>
<td>Pair 4</td>
<td>24/05/2003 &amp; 28/06/2003</td>
<td>654</td>
<td>Post-fire</td>
</tr>
</tbody>
</table>

3.3 SAR Pre-processing

SARscape 4.2 was used to pre-process all data ordered (Table 1 and Table 2). Focusing and multitasking was applied to all data to produce an intensity image. Frost (Figure 2 a/d), Lee (Figure 2 b/e) and Degrandi (Figure 2 c/f) filtering algorithms were tested with two ERS-2 images to assess differences in image results (Figure 2). The Degrandi filter (a multitemporal despeckling algorithm) smoothed speckle most effectively (requires amplitude coregistration prior to the multitemporal filtering algorithm being applied) (Figure 2 c/f). Geocoding and radiometric calibration was applied to produce geocoded...
greyscale images at 25m. ENVI band math was used to produce dB values and the images were degraded in ENVI to 100m resolution so that the radar pixels were comparable with the 100m CORINE land cover data. The sample points for CORINE land cover data are indicated by black points in Figure 1.

![Figure 2. (a-f) Comparison of filtering methods...](image)

InSAR pre-processing was applied to the data in Table 2 as detailed in Sarmap (2007) to obtain interferometric coherence. Coherence ranges between 0 - 1 and is:

*The function of systemic spatial de-correlation, the additive noise, and the scene de-correlation that takes place between the two acquisitions*, (Sarmap, 2007, p.144).

- 1 = High coherence (temporal correlation, no change on the ground)
- 0 = No coherence (no correlation, temporal decorrelation, significant change on the ground).

3.4 Land Cover and Precipitation

Intensity and coherence values were extracted in ArcGIS 10 for 15 points inside the fire scar for three CORINE land cover classes (peat bog, moors and heathland and natural grassland), and 15 points outside the fire scar for the same CORINE land cover classes. The five peat bog points inside the fire scar were bare peat (due to earlier fires), whereas those outside were mostly on intact, vegetated bog. The sampling scheme will be more detailed in future projects.

Precipitation data was monitored on an hourly basis at the Upper North Grain weather station in the PDNP, 4 km southwest of the fire scar. Total daily values were calculated for the pilot study to provide an indirect indicator of soil moisture conditions preceding the SAR image acquisitions (Figure 7).
4 SAR Results and Analysis

4.1 SAR Intensity Images

Figure 3. Time series of SAR intensity images for the Bleaklow 18 April 2003 wildfire. Top row pre-fire bottom row post-fire (adapted from Millin-Chalabi et al., 2010).

4.2 InSAR Coherence Images

Figure 4. InSAR coherence images for Bleaklow. Each produced from a pair of SAR images (Table 2).

4.3 SAR Intensity Analysis

Exposed peat bog inside the fire scar had the highest pre-fire intensity signal at 0.16 dB JD 39 which can be seen by the brightness towards the east side of the fire scar (Figure
3a) and is also reoccurring throughout all the ERS-2 and ASAR images (Figure 3b-f). Peat bog values stay high post-fire (0.78 dB JD 144 and -0.57 dB JD 179) as shown in Figure 5. The ERS-2 image acquired JD 74 and ASAR Image Mode image acquired JD 81 show a downward trend in backscatter intensity for all land cover classes except natural grassland and intact peat bog outside of the fire scar. Figure 7 shows that during JD 72 – JD 90 this was a very dry period with only one notable precipitation event (15.2mm) on JD 91, this could therefore explain the downward trend in backscatter intensity during this period and then a peak in backscatter intensity for the ASAR Alternating Polarisation image acquired on JD 93 (Figure 3d). Figure 7 shows that after the fire event on 18th April 2003 precipitation regularly occurred which would likely create wet conditions on the ground surface. Figure 3e-f exhibit strong backscatter intensity responses as shown by the brightness within the fire scar perimeter illustrating that backscatter intensity increases following precipitation events. This result agrees with Bourgeau-Chavez et al., (1997) findings.

Figure 5. Average intensity values (dB) inside and outside the Bleaklow fire scar for CORINE land cover classes, (Millin-Chalabi et al., 2010).

4.4 SAR Coherence Analysis
The coherence was produced for four InSAR pairs (Table 2). For the first InSAR pair there is low coherence ranging from 0.14 – 0.24 depending on the CORINE defined land cover class. The second pair shows a general slight increase of coherence for all land cover classes except natural grassland inside the fire scar which remains constant at 0.19 (Figure 6). The third InSAR pair was produced by two ERS-2 images acquired after the
fire (19/04/03 – 24/05/03). All three land cover classes inside the fire scar exhibit a noticeable increase in coherence which is illustrated in Figure 4c. The greatest increase in coherence is for the moors and heathlands class inside the fire scar with a value of 0.46 compared to the second InSAR pair at 0.29 (Figure 6). Visually this increase in coherence can be seen on the west side of the fire scar in Figure 4c where the moors and heathlands appear bright in the image compared to the same land cover class outside of the fire scar. Figure 6 shows that the coherence has actually decreased for the moors and heathland class outside of the fire scar from the second InSAR pair at 0.29 to the third InSAR pair at 0.23, this result is likely due to phenological change of the heathlands. The fourth InSAR pair shows an overall decrease in coherence for all classes (Figure 6). This is likely due to temporal decorrelation as the initial baseline for the pair is high at 654 (it is advised to not use InSAR pairs with a baseline greater than 500). It is also during this time that reseeding began on the east side of the fire scar which would also decrease the coherence value (Figure 4d).

Figure 6. Trend in average coherence of three CORINE land cover classes, inside and outside the Bleaklow fire scar. Fire date 18/04/03.

Figure 7. Total daily precipitation (mm) from 07/03/03 – 30/06/03 at Upper North Grain, 4km southwest of the fire scar, (Millin-Chalabi et al., 2010).

5 Conclusions
A large fire scar in a degraded moorland environment can be detected using SAR intensity and coherence. The occurrence of precipitation is a critical environmental
variable affecting the radar intensity signal. Within the fire scar, peat bog gave the highest intensity return probably due to its high sensitivity to soil moisture. Highest coherence values within the fire scar were obtained from InSAR Pair 3 (Figure 4c) for the two images acquired shortly after the fire. High coherence for Figure 4c could be due to a low baseline of 147 which also indicates low temporal decorrelation between 19/04/03 – 24/05/03. During the pre-processing it has been found that image results are sensitive to the filtering method applied with the degrandi algorithm used for this study. Further investigation is required for fire scars of different sizes, on different land cover types and with different preceding and post-fire precipitation conditions. The next step will be to analyse ALOS PALSAR data acquired for the 26th -29th May 2008 Kinder fire event to assess the affect of polarisation, frequency and fire size on fire scar detection in moorland environments.

6 Acknowledgements
The authors would like to thank: Landmap Service for ERS-2 and ASAR data supply under ESA Category 1 Project 2999; Moors for the Future for fire logs/scar data; PDNP Fire Operations Group for information on the fire; Martin Evans and Juan Yang, School of Environment and Development (SED) for Upper North Grain weather station data; Mimas and SED at the University of Manchester for funding.

7. References


