Using SAR to Detect Moorland Fire Scars in the Peak District

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Abstract
Severe moorland fires can burn into peat releasing CO$_2$ into the atmosphere, destroy moorland habitats and cause gully erosion, but spatially-robust data on moorland fires is lacking for the UK. Precise fire scar boundaries have only recently begun to be recorded by GPS in a few areas such as the Peak District National Park (PDNP). A landscape-scale method of monitoring moorland fire size and frequency, and the rate of vegetation recovery would improve the evidence base; assist carbon budget calculations and restoration programmes. Optical active fire and burned area databases are limited by cloud cover, but Synthetic Aperture Radar (SAR) potentially offers a UK-wide method of monitoring fire scars.

The overall aim of the project is to investigate the extent to which SAR can be used to detect moorland fire scars and monitor the rate of vegetation recovery, as has been achieved in boreal (Bourgeau-Chavez et al, 1997) and tropical environments (Huang and Siegert, 2006). The paper presents results of an initial pilot project to test the capability of ERS-2 and ASAR data to detect the 7 km$^2$ 18th April 2003 Bleaklow fire scar in the PDNP against GPS, mapped just after the fire event. Archival time-series SAR imagery was supplied by the Landmap Service, originally sourced from the European Space Agency (ESA). C-band ASAR and ERS-2 data were pre-processed in SARscape 4.2 to produce geocoded greyscale images. The data shows that backscatter values are affected by rainfall occurrence to a greater degree after the fire event. Peat exposed by the fire and pre-existing bare peat areas are the most sensitive to soil moisture variation. Future research will test this finding for other fires. It will also assess sensitivity to environmental variables such as land cover and soil temperature, and to radar sensor variables such as radar frequency and polarisation.

1 Introduction
Fire logs collected by the Fire and Rescue Service and the PDNP rangers have been used to assess the extent of fires and their location (CCVE, 2005). However, the georeference recorded in the fire log can vary from the ignition point, the centre of the fire scar or a visual estimation of the centre of the fire ground. Remotely sensed data offers an alternative approach which has the ability to spatially record moorland fire scars at the landscape scale. Remote sensing can provide not only a more accurate fire location, but potentially also information on fire size (area inside the fire scar boundary), variation in burn severity within the fire scar (immediate post-fire effects) and rate of vegetation recovery (longer term ecological response).

SAR data specifically has the advantage of not being affected by cloud cover so a time series of images can be used. Cloud cover in the Northwest region of the UK and for the UK as a whole is problematic for temporal studies requiring optical remote
sensing (Legg, 1991 and Armitage et al., 2007). SAR has been successfully used for fire scar detection in boreal (Bourgeau-Chavez et al., 1997), tropical (Huang and Siegert, 2006), Mediterranean (Gimeno et al., 2004) and savannah (Menges et al., 2004) environments. This study will test the applicability of the technique in a UK moorland environment.

2 Aims and Objectives
The paper presents the initial results of a pilot study to explore whether a fire scar signal can be detected using SAR within a degraded UK moorland environment. The work presented here forms part of a larger research project to evaluate SAR for monitoring fire scars and post fire vegetation recovery in the PDNP and wider UK moorlands. The objectives of the pilot study are:

- To identify a time series of different SAR images available for monitoring the Bleaklow 2003 fire scar.
- Determine the ability of SAR to detect the fire scar over time in a moorland environment.
- Understand how scene variables such as rainfall and vegetation affect the SAR fire scar signal.

3 Methodology
3.1 Study Area
The Bleaklow study area was selected because it experienced one of the largest fires in the PDNP, and the fire scar boundary was mapped using a Global Positioning System (GPS) by the Park rangers (Figure 1). The Bleaklow area is of high scientific importance. It is a carbon rich, but degraded peatland environment. Much damage has already been caused by past wildfire (McMorrow et al., 2009).
Fires negatively impact on the carbon budget by releasing carbon dioxide to the atmosphere during the fire, and leading to loss of carbon in dissolved and particulate form in streamflow (Worrall and Evans, 2009). Bleaklow has multiple statutory designations to protect its habitat and wildlife; for instance birdlife such as Golden Plover (*Pluvialis apricaria*) and Dunlin (*Calidris alpine*); vegetation such as Heather (*Calluna vulgaris*), Cottongrass (*Eriophorum* spp.) and Mosses (*Sphagnum* spp.).

3.2 SAR data selection and pre-processing

The data (Table 1) was selected using the ESA Earth Observation Link (EOLi) data ordering client version 7.0.6. Eight SAR images consisting of ERS-2 and ASAR images at Product Level 1 (1P) were used, including two ASAR modes; Image Mode (IM) and Alternating Polarisation (AP). The three ASAR images were the only scenes available for this location from the ESA data archive. The ERS-2 data provided more choice, with two or three scenes per month. One scene per month was selected, starting ten weeks before the fire to assess the change in the SAR signal before and after the fire. SAR images with a small incidence angle ranging from 22.76º - 23.23 º were selected, as Huang and Siegert (2006) found that backscatter of fire scars decreases by 0.1 dB for each degree of incidence angle.

Table 1. SAR image ordered from ESA 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 (dmmmyyyy)</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>23.23º</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>23.23º</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>22.82º</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>22.76º</td>
<td>4.04</td>
<td>7.80</td>
<td>20.00</td>
<td>Descending</td>
</tr>
<tr>
<td>ERS-2</td>
<td>19/04/2003 11:01</td>
<td>+1 day (109 JD)</td>
<td>23.05º</td>
<td>3.97</td>
<td>7.90</td>
<td>20.26</td>
<td>Descending</td>
</tr>
<tr>
<td>ERS-2</td>
<td>24/05/2003 11:01</td>
<td>+36 days (144 JD)</td>
<td>23.21º</td>
<td>3.97</td>
<td>7.90</td>
<td>20.26</td>
<td>Descending</td>
</tr>
<tr>
<td>ASAR IM 12</td>
<td>19/06/2003 21:39</td>
<td>+62 days (170 JD)</td>
<td>22.83º</td>
<td>4.04</td>
<td>7.80</td>
<td>20.00</td>
<td>Ascending</td>
</tr>
<tr>
<td>ERS-2</td>
<td>28/06/2003 11:01</td>
<td>+71 days (179 JD)</td>
<td>23.28º</td>
<td>3.97</td>
<td>7.90</td>
<td>19.75</td>
<td>Descending</td>
</tr>
</tbody>
</table>

The SAR data was pre-processed using SARscape 4.2 to produce 100m geocoded images using the pre-processing steps illustrated in Figure 2. The CORINE land cover map and fire scar boundary were used to select 15 points inside the fire scar on three land cover classes (peat bog, moors and heathland and natural grassland), and 15 points outside it. 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 refined to make points more comparable for future work.
3.2 Precipitation Data
Rainfall data was monitored on an hourly basis at the Upper North Grain weather...
station in the PDNP, 4 km southwest of the fire scar. A total daily value was calculated for this study to provide an indirect indicator of soil moisture conditions preceding the SAR image acquisitions (Figure 3).

4 Results and Discussion

Backscatter was extracted for the three CORINE land cover classes sampling points inside and outside the fire scar. SAR images in Figure 4e and 4g were excluded from the analysis due to issues of misregistration, which will be resolved in future work. The class with the highest pre-fire backscatter was exposed peat bog inside the fire scar at -0.16 dB JD 39 (Figure 4a), created by earlier fires. It remains consistently high post-fire (0.78 dB JD 144 and -0.57 dB JD 179). SAR images acquired during the dry period JD 72 – 90 (Figure 3), show an overall downward trend of backscatter for all land cover classes except natural grassland and largely intact peat bog outside the fire scar. A peak in backscatter occurs on 03/04/03 (JD 93) following 15.2mm of rainfall on JD 91. Gimeno and San-Miguel-Ayaz (2004) found that dry-season scenes images had lower backscatter values, similar to the 22/03/03 result (Figure 5).

The post-fire period was wet. For the 14 days preceding the 24/05/03 (Julian day 144) image, there had been rainfall, with a peak of 20.6mm three days before the 24/05/03 image was acquired (Figure 3). A similar pattern of rainfall also occurred for the 28/06/03 image where 13.8mm of rain occurred on JD 177. No rain events occurred on the actual day of image acquisition for the May and June image. Average backscatter values for the last two images in the time series increased significantly from the 22/03/03, acquired during very dry conditions. This result agrees with the findings of Bourgeau-Chavez et al. (1997), that backscatter increased after rain events just prior to image acquisition. Amount and timing of rainfall is thus an important variable affecting the detectability of the fire scar in this environment.

![Figure 3. Total Daily Rainfall (mm) from 07/03/03 – 30/06/03 at Upper North Grain, 4 km south-west of the fire scar](image-url)
Figure 4. SAR time series of Bleaklow, fire occurred on 18th April 2003, (108 JD), where JD = Julian Day
The post-fire increase in backscatter (Figure 5) suggests either a rougher surface texture or dielectric properties normally associated with greater surface wetness. The former is unlikely after a fire of the severity reported by rangers and fire crew. In June 2003, MFF started a reseeding programme covering parts of the eastern area of the fire scar, an area already eroded prior to the fire and further damaged after the 2003 fire event. However, the nurse grass crop would not have germinated sufficiently to increase roughness and backscatter by the time the post-fire SAR images were acquired. It is more likely that the dielectric properties of the charred area, which included much existing and peat newly-exposed by the fire, were more responsive to wetting from post-fire rainfall than the previous vegetation, resulting in a stronger backscatter signal. Charred or dried peat is known to be hydrophobic, but the gross change from a vegetated to unvegetated surface seems to have been more important. Studies on recent fires and controlled burns will allow these factors to be investigated.

![Figure 5. Average Backscatter values (dB) inside and outside the Bleaklow fire scar for CORINE land cover classes](image)

5 Conclusions
This pilot study has shown that a large fire scar in a degraded moorland environment can be detected using SAR imagery, and that rainfall is a critical factor. It suggests that SAR backscatter in this environment is sensitive to pre-fire moisture, and warrants further investigation as a method of assessing fire risk. Relationship of backscatter to the Met Office Fire Severity Index will be explored.

Outside the fire scar, natural grassland generally gave the lowest backscatter return and heathland the highest, and relates well to their relative surface roughness. Within the fire scar, the peat bog CORINE land cover class gave the highest backscatter return, probably because it is relatively more sensitive to surface soil moisture variation. Further investigation is required for fire scars of different sizes, on different land cover types, and critically, with different preceding and post-fire conditions.
rainfall patterns. Sensitivity to other scene variables and polarisation and frequency will also be investigated.

6 Acknowledgements
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7. References


