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Hyperspectral remote sensing of a moorland wildfire scar: the May 2008 Grindsbrook-Kinder fire

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Abstract

Wildfires are vegetation fires started maliciously or accidentally by people, or land management fires which burn out of control. The Peak District has experienced over 360 wildfires since 1976, mainly in drought years such as 2003 and 2006. Regeneration is rapid from fires passing quickly through the dwarf shrub canopy, leaving the moss and litter layer intact, but damaging when fires burn into the peat. A method of estimating variability in burn severity at the landscape scale is required. Metrics such as the differenced normalised burn ratio (dNBR) have been used with varying success as proxies for fire intensity and ecosystem response in forests, but have not been tested for degraded peat moorland vegetation.

The remote sensing component of this multidisciplinary project aimed to: (i) test the dNBR for estimating variations in burn severity of dwarf shrub vegetation in degraded UK peatland; (ii) investigate the presence of a suspected charring signal in peat soil. Work was conducted at four scales: microscale laboratory radiometry on dried and ground char samples; wet and dry laboratory radiometry on 60 mm cubed peat blocks from burnt plots; field radiometry of 0.25m\textsuperscript{2} quadrats; and hyperspectral airborne images.

A wildfire on 26 May 2008 created and 11 ha wildfire scar on the Kinder plateau, near Edale, Peak District National Park. Percent cover of charred stems (‘stick’), loose char, peat, litter and vegetation was recorded for 42 burnt and 23 unburnt 0.25m\textsuperscript{2} quadrats three weeks after the fire. Eagle and Hawk images and aerial photography were acquired by NERC-ARSF five weeks later on 1 July 2008. Pre-fire vegetation maps allowed paired burnt and unburnt sites to be identified for calculation of dNBR from the single-date image. However, atmospheric correction and mosaicking of the airborne images has so far not been sufficiently good to undertake dNBR or other qualitative analysis. The paper therefore reports on radiometry analysis to date. Char-only microscale samples show the charring signal as flattening of the spectra. It was successfully related to temperature and duration for peat samples burnt in a muffle furnace and used to estimate variations in fire conditions across the scar. An equivalent char signal was not detected in field samples at larger scales, because it was masked by water, roots, stick and surface texture. Recommendations are made for future data collection and analysis.
1 Overview

Fire has historically been used to manage moorland habitats by encouraging growth of new heather for grouse. Wildfires, however, are unwanted vegetation fires, including fires lighted deliberately or accidentally by people, and land management fires which burn out of control. The Peak District has experienced over 360 wildfires since 1976, mainly in drought years such as 2003 and 2006 (McMorrow et al., 2009). Severe peatland wildfires threaten ecosystem services from biodiversity, carbon storage and water quality, and cause loss of livelihood and social disruption. The most damaging fires are those which burn into the peat as smouldering combustion. They create long-lived fire scars and trigger erosion, which then requires costly restoration. In contrast, regeneration is rapid after flaming combustion, i.e. fire passing quickly through the dwarf shrub canopy, leaving the moss and litter layer intact. Damage in terms of ecosystem response is therefore not the same for all wildfires. It depends on fire behaviour factors such as fire intensity and duration and the pre-fire condition of the peatland, including previous fire regime and degree of erosion. A method of estimating variability in fire severity at the landscape scale is required.

Burn or fire severity is a contested term, depending on time elapsed since the fire and the end-user’s interest, whether soil, vegetation or societal damage. Keeley (2009) identifies different terms for each stage of the fire sequence: fire intensity, the physical energy output from an active fire (duration is also important); burn or fire severity, immediate effects in terms of loss of soil and near-soil organic matter and/or above ground biomass; and longer term ecosystem responses or societal impacts. Thermal sensing of active fires and optical remote sensing of burn scars address the first two, respectively. The normalised burn ratio (NBR), based on near infrared (NIR), to shortwave infrared (SWIR), Landsat TM/ETM bands 4 and 7, has been used successfully as a proxy for burn severity in forests (e.g. van Wagtendonk et al. 2004). Burned Area Emergency Response (BARC) mapping uses pre- and post-fire NBR differenced (dNBR) for post-fire operational estimation of the severity at medium spatial resolutions (Robichaud et al., 2007).

The dNBR index relies on the reduction in NIR and an increase in SWIR caused when burning replaces green with non-photosynthetically active vegetation or charred soil. It has not been tested for more challenging degraded moorland environments with already exposed peat surfaces. The high spatial and spectral resolution of airborne hyperspectral imagery should be more appropriate for this task and has been used in classification or spectral mixture analysis approaches to map the mosaic of charred, scorched, green vegetation within fire scars (Lewis et al., 2007; Miller, and Thode, 2007; De Santis and Chuvieco, 2007). Previous work with airborne hyperspectral data on degraded moorland found flattened spectra for burnt peat (McMorrow et al., 2004), and proposed the existence of a hyperspectral charring signal; that is, reduced depth of NIR and SWIR absorption features as lignin and cellulose are combusted and the masking effect at water absorptions is reduced. Clay and Worrall (2009) have showed promising relationships between this charring signal and the intensity and duration of burn for dried, ground laboratory samples of char.

We report here on progress towards testing standard burn severity metrics for dwarf shrub vegetation and exposed peat in a degraded UK peatland, and to investigate the extent to which the hyperspectral charring signal can be detected in field conditions and upscaled from laboratory to field and airborne image scales.
2 Study Area
A wildfire on 26 May 2008 created an 11 ha fire scar at Grindsbrook Clough on the Kinder plateau, near Edale in the Peak District National Park, northwest England (figure 1). It is thought to have started near the path at the eastern end (grid reference 410500, 387300). The stand-replacing canopy fire moved quickly through the heather, bilberry and cotton grass, driven by a strong easterly wind. It left a charred surface of short standing heather stems (‘stick’), charred moss clumps an a blackened crust on pre-existing peat surfaces (created by a wildfire in 2006). Hotspots burned into the peat for three days, mainly in back burn areas, i.e. where the fire was slow-moving against the wind and downslope over the southern plateau edge. Five fire crews, National Park rangers and a helicopter were used to extinguish the fire, helped by rain on the second day. Park rangers recorded the fire scar boundary shortly afterwards with GPS.

![Figure 1: NERC ARSF aerial photography of Kinder-Grindsbrook 26 May wildfire scar, Peak District National Park, north-west England. Image acquired 1st July 2008.](image)

3 Data and method
Remote sensing data was collected opportunistically to complement field quadrat data and char radiometry for a pre-existing carbon budget study of the fire scar (Clay et al., 2009). Methods of data collection are presented in chronological order.

Quadrat data: Percent cover of charred stems (‘stick’), char (loose fragments of black carbon), exposed peat, litter and residual photosynthetically-active vegetation had already been recorded in 42 burnt and 23 unburnt 0.25 m² quadrats on 16-18 June, three weeks after the fire. Biomass loss per plot was also estimated. Methods are described in Clay et al. (2009)

Char-only laboratory radiometry: Surface samples of char were collected concurrently from within burnt quadrats. They were dried, ground and used to obtain full-wavelength reflectance spectra with a Varian NIRS spectroradiometer (Clay and Worrall, 2009).
**SPECIM airborne image and quadrat-scale field radiometry:** Eagle and Hawk images and aerial photography (figure 1) were acquired opportunistically by NERC ARSF on 1 July 2008, five weeks after the fire. Cotton grass shoots up to 200 mm tall had resprouted in places but comprised less than 5% of all but one burnt quadrat. Due to equipment availability, ASD Field Spec3 field radiometry had to be carried out the day after the flight. Spectra for seven unburned calibration targets and 15 burnt quadrats were recorded, where possible at quadrat locations.

**Selection of paired burnt and unburnt sites:** A pre-fire vegetation map (Chapman et al., 2009) and the 23 unburnt quadrats were used to identify unburnt sites of equivalent land cover on the image for as many as possible of the 15 burnt field radiometry quadrats. Nine were excluded due to cloud or cloud shadow, or because they did not fall on the reference swath (due to different Eagle and Hawk swath widths and problems in mosaicing). Unfortunately, accurate atmospheric correction has not been possible so far. Image spectra will be extracted to calculate dNBR from the paired sites if atmospheric correction can be improved.

**Block-scale laboratory radiometry:** Peat blocks of 60mm cubed were sampled from within the 15 burned field radiometry quadrats. Five ASD contact probe spectra were averaged for the top (burnt) surface of each block. To normalise for peat humification and species composition, five were also recorded for the (unburnt) basal surface. Blocks were oven-dried overnight and the top and basal spectra were recorded again to investigate the effect of moisture on the char signal.

In all, hyperspectral data were obtained at four scales: (i) micro-scale laboratory radiometry of char (ii) four peat block laboratory radiometry datasets – wet burned top, wet unburned base, dry burned top, dry unburned base; (iii) quadrat-scale field radiometry; (iv) pixel-scale airborne images. We report here on aspects of the radiometry results. Width, slope of shoulders and depth of the absorption feature were extracted from the radiometry spectra. NBR was calculated as in equation 1, where \(R_{1300}\) and \(R_{2200}\) are reflectance at 1300 and 2200 nm, respectively:

\[
\text{NBR} = \frac{R_{1300} - R_{2200}}{R_{1300} + R_{2200}}
\]

### 4 Results and discussion

#### 4.1 Microscale char-only radiometry

Promising regression relationships have been established between depth of the water absorption feature at 1900 nm in burnt peat and simulated wildfire temperature. The simulation involved a series of muffle furnace experiments using various combinations of temperatures and durations (figure 2) (Clay and Worrall, 2009). These relationships have been used with the Grindsbrook char samples to estimate fire temperature over the scar, assuming a two minute burn (figure 3). They will later be compared to image dNBR.

Relationships with temperature potentially exist at other water and ligno-cellulose absorption features, e.g. 1440 and 2100 nm. These could be explained by more complete combustion of residual plant material at higher temperatures. However, the duration of the fire is also important.
Figure 2: Example spectra from peat burning experiments, showing flattening of spectra at higher temperatures (Clay and Worrall, 2009)

Figure 3: Preliminary estimated temperatures over the Grindsbrook fire scar, established using a muffle furnace experiment to simulate wildfire by burning peat at different temperatures and durations (Clay and Worrall, 2009).

4.2 Block-scale laboratory radiometry

Spectra for burnt (top surface) of dried blocks have lower albedo and are flatter (shower absorption features) relative to their unburnt basal side and an unburnt peat sample from one of the calibration sites (08) (figure 4). All have similar spectral shape. Spectra for burnt, but previously exposed peat (Q16) are flatter, similar to severely burnt vegetated surfaces (Q4 and Q6). Unburnt peat redeposited in pools (Q17) is intermediate between burnt peat and burnt vegetation, and would be confused with them. The degree of flattening does not relate to quadrat-scale measures of burn severity, such as percent cover of stick and char. The blocks sampled only stick, char and peat soil components, whereas quadrats included other components. We have yet to calibrate the dry top spectra against muffle furnace results, or compare against char-only and field scale results.
Comparison of wet and dry blocks spectra shows the masking effect of water on the charring signal. As would be expected, dried samples have a higher albedo and shallower water absorption features than their wet counterparts. Differences between the top (burned) and basal (unburned) surface are clearer in the dry state, but not consistent enough to detect a convincing charring signal. The proportion of stick, char and roots was surprisingly variable even in a 60 x 60 mm surface. Non-contact radiometry of a larger area is preferable to provide a larger field of view. Larger samples would be better, but impracticable as destructive sampling on the scale required is environmentally damaging. Field radiometry is the better option, despite weather issues.

4.3 Quadrat–scale radiometry
Quadrat-scale spectra have so far shown disappointing relationships to the percent char and stick data quadrat data. Completely burnt and unburnt quadrats were used, whereas to establish quantitative relationships between proportions of field of view components and NBR or other spectral indices, partially burnt quadrats would also need to be included. Scorched vegetation should also be recorded. Relationship to biomass loss will be investigated.

4 Conclusions
Depth of water and ligno-cellulose absorption features in dried and ground pure char samples measured in laboratory conditions are related to burn temperature. So far, no consistent equivalent char signal can be detected in field conditions. We attribute this first, to the masking effect of water, and second, to the presence of non-char components. Unlike the char-only scale, quadrat and block samples are structurally and spectrally variable; for instance, the stick component creates shadow, and roots affect the basal block spectra. Block and field radiometry scales relate to proportion of
components other than char within the field of view, notably residual green vegetation, non-photosynthetically active vegetation, soil and ash. The need to dry, grind and pack samples for the NIRS technique means that volume scattering is minimised, unlike field and contact mode radiometry.

The 1900 nm feature would not be usable in field conditions or with airborne data because of water absorption by the atmosphere, soil and vegetation. However, other absorption features show promise and are being investigated further. The ash-char ratio has been used as a field indicator of completeness of combustion. Rangers reported an ash layer, but it had been lost by the time of the remote sensing and sampling. Experience gained from experimental burns in Northumberland (Tsitsopoulos et al., 2010) shows that the ash was washed away by overnight rain. Operationally, it is unlikely that airborne remotely sensed data could be acquired rapidly enough after a fire to record the ash layer. However, timing of remotely sensed data collection should be as soon as possible after the fire if the objective is recording burn severity before vegetation recovery begins, and repeated at intervals for several years afterwards to record ecological response to the fire (Keeley, 2009).

A better atmospheric correction of the image is required before quantitative analysis such as dNBR and extraction of a hyperspectral char signal can be undertaken. The unavoidable one-day delay in collecting calibration target spectra produced an unacceptable atmospheric correction. We are investigating using a concurrent relationship established the same day at Burbage Moor. The problem of mosaicing swaths with cloud shadow also needs to be addressed. If these problems can be overcome, spectral mixture modelling could be used to map variations in burn severity within the fire scar, where burn severity is regarded as a function of the proportion of photosynthetically active to non-photosynthetic active components.

Percentage cover estimates of char stick and green vegetation components were not adequate to characterise burn severity. It is recommended that the maximum charred stick diameter is measured, as it has been shown to be strongly correlated to burn severity (Keeley, 2009). Qualitative BAER classes (Parsons 2003) could be adapted for dwarf shrub vegetation. Experience from experimental burns in Northumberland suggests that scorching of the moss layer strongly affects reflectance (Tsitsopoulos et al., 2010), and is also an important indicator of long-term ecological response to fire. Future experimental burns will allow fire behaviour to be measured directly and compared to field measures and remotely sensed measures of burn severity.

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7 References
A case study: A report for the National Trust (Edale: Moors for the Future Partnership)

CLAY, G.D and WORRALL, F., 2009. Using near-infrared reflectance spectroscopy to investigate the effects of a moorland wildfire in the uplands of the UK. European Geophysical Union conference, Vienna.


