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A monitoring protocol for vegetation change on Irish peatland and heath

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ABSTRACT

Amendments to Articles 3.3 and 3.4 of the Kyoto Protocol have meant that detection of vegetation change may now form an interracial part of national soil carbon stocks. In this study multispectral multi-platform satellite data was processed to detect change to the surface vegetation of four peatland sites and one heath in Ireland. Spectral and spatial thresholds were used on difference images between master and slave data in the extraction of temporally invariant targets for multi-platform cross calibration. The Kolmogorov–Smirnov test was used to evaluate any difference in the cumulative probability distributions of the master, slave and calibrated slave data as expressed by the *D* statistic, with values reduced by an average of 89.7% due to the cross calibration procedure. A change detection model was created which incorporated a spatial threshold of 9 pixels and a standard deviation (SD) spectral threshold. Kappa accuracy values for the five sites ranged from 80 to 97%, showing that 1.5 SD was the optimum spectral threshold for detecting vegetation change. Change detection results showed mean percentage change ranging from 2.11 to 3.28% of total area and cumulative change over the observed time period of between 15.24 and 49.27% of total area.

Introduction

Peatlands play a vital role in the global carbon cycle, containing one third of terrestrial soil carbon on 4–6% of the land surface (Yu et al., 2010). Maintenance of peatland Carbon (C) stock has taken on a renewed importance with Articles 3.3 and 3.4 of the Kyoto Protocol/Marrakech.

Accords recognising soil organic carbon (SOC) as a biosphere sink (IPCC, 2006). Its preservation has therefore implications for national CO_2 budgets in terms of financial and biodiversity value, carbon credits and compliance (EPA, 2011). The lack of globally consistent, temporally frequent peatland maps results in uncertainty when assessing the role of peatlands in the global carbon and water cycles (Krankina et al., 2008).

Many countries have significant peatland resources. Ireland, which is the demonstration area for the multispectral, multi-platform change detection process presented in this paper, has about 20% peatland area (Connolly and Holden, 2009) accounting for 53% (1071.13 Mt C) to 62% (1503 Mt C) of national soil carbon stock (Eaton et al., 2008; Tomlinson, 2005). It is estimated that 74% (based on 301 sites) (Connolly et al., 2007) to 82% (IPCC, 1996) of blanket bogs and 93% (Crushell et al., 2008) of raised bogs are disturbed (Connolly and Holden, 2011a). The definition of disturbance in habitats and ecosystems has been discussed in various studies (Connolly and Holden, 2011a; White and Jentsch, 2001; Hammond, 1979; Pickett, 1985; Hofgaard et al., 2010). A precise definition for all natural/semi-natural habitats is unachievable (Turetsky et al., 2002); however a general definition which can be applied to peatlands and heaths is "events that cause physical and measurable changes which occur outside the natural range of dynamics for an ecosystem" (White and Jentsch, 2001). The full implications for C balance (Tallis, 1998; Bragg and Tallis, 2001) are difficult to quantify (Renou-Wilson et al., 2011) because of the remote nature of these habitats. On Irish peatlands, anthropogenic disturbance is due primarily to land reclamation, afforestation, machine and hand harvesting for fuel, vegetation burning for grazing, and more recently the erection of wind turbines (Tallis, 1998; Farrell and Doyle, 2003; Cooper and McCann, 1995; Connolly and Holden, 2011b). The time scale of some of these disturbance events such as fire is rapid, requiring temporally frequent observations in order to quantify their extent. Peatlands are spatially extensive

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therefore satellite based multispectral data are ideal for monitoring vegetation change due to potential for high spatial and temporal resolution data acquisition (McGovern et al., 2000; Achard et al., 2008).

Change detection is the process of identifying differences in the state of an object or phenomenon by observing it at different times (Singh, 1989), and has now become one of the main applications in environmental remote sensing (Mas, 1999; Lillesand et al., 2004). Approaches range in complexity from image differencing (Coppin and Bauer, 1994) and image ratios (Gupta, 1998) which are easy to apply, to more complex procedures such as vector analysis (Lambin and Strahler, 1994) that can provide more detailed results (Lu et al., 2003). It is however generally accepted that no one process is suitable for all change detection scenarios (Coppin et al., 2004). To date, remote sensing based change detection of peatlands has been limited to a few studies (Ozesmi and Bauer, 2002; Mehner et al., 2004; Kleinod et al., 2005; Connolly et al., 2011). For national scale monitoring vegetation indices (VI) offer the advantage of robustness because of the strong correlation between upwelling radiance and vegetation cover (Coppin et al., 2004) as well as compressing multispectral data to a single image (O'Connell et al., 2013). Furthermore, a VI can reduce spectral, radiometric and atmospheric inconsistency across platforms by increasing the signal-to-noise ratio for improved cross calibration (Steven et al., 2003; Martinez-Beltran et al., 2009; Thenkabail, 2004). Enhanced Vegetation Index 2 (EVI2):

$$EVI2 = 2.5\left(NIR - \frac{R}{NIR + 2.4(R) + 1}\right) \quad (1)$$

where NIR is the Near InfraRed band and R is the Red band, has been found to accurately depict vegetation communities on Irish peatlands (O'Connell et al., 2013) and overcomes soil background contamination by having additional weighting on red reflectance data (Rocha and Shaver, 2009).

Variables such as atmospheric conditions, surface moisture, solar elevation, sensor inconsistencies and vegetation phenology can all contribute to uncertainty in change detection when using a single platform data source. In temperate maritime climates such as Ireland extensive cloud cover means that over 78% of all optical based satellite imagery of the land surface taken throughout the year is completely obscured (Palle and Butler, 2001). Change detection studies often require high temporal resolution, therefore to overcome the issue of cloud cover there is a need to source data from multiple platforms. A multi-platform methodology therefore introduces further uncertainties over a single platform study due to variations in field of view as well as spatial, spectral and radiometric inconsistencies (Richards and Jia, 2006). Although mean band widths for the various medium and high resolution platforms range on average between ±2 nm in the visible and infrared, spectral response functions can differ by up to 25% in the red, and 6% in the NIR (Teillet et al., 2007). Also satellite data acquired from various data distribution sources can have different levels of geometric correction applied to compensate for rotation and curvature of the Earth, as well as variation in the scan width, Field of View (FOV), altitude and velocity of the platform in question (Richards and Jia, 2006). Randomised distortions of varying magnitudes can still occur after geo-referencing; therefore the use of Ground Control Points (GCPs) in geometric registration of multi-temporal imagery is essential in achieving sub-pixel (0.25 pixels) level spatial correlation (Lu et al., 2003). This means effective image pre-processing is a critical stage for change detection studies (Mas, 1999; Lillesand et al., 2004; Lu et al., 2003; Coppin et al., 2004).

Cross calibration aims to develop linear or non-linear relationships to facilitate the comparison of reflectance data from one sensor with another (Steven et al., 2003; Teillet et al., 2007; Wulder et al., 2008). One of the most widely used crosscalibration procedures is linear regression of temporally invariant targets (Steven et al., 2003; Martinez-Beltran et al., 2009; Thenkabail, 2004; Teillet et al., 2007; Gallo et al., 2005). This procedure utilises the concept of a linear spectral response in temporally invariant ground targets (e.g. water bodies and urban environments) across platforms of a similar spatial resolution (Teillet et al., 2007). The selection of temporally stable ground targets is essential for achieving a reliable regression equation between master and slave image data. Furthermore, objects from elsewhere in the spectral range (e.g. water bodies or boreal forests) can help fix the regression line by extending the range of data in the scatter-plot (Martinez-Beltran et al., 2009). Many studies have shown the effectiveness of linear regression with results reporting less than 4% variability in spectral response of VI's after cross calibration (Steven et al., 2003; Martinez-Beltran et al., 2009; Thenkabail, 2004; Miura et al., 2006). Statistical measures, such as the Kolmogorov–Smirnov (KS) test, can be used to assess the similarity between datasets before and after cross calibration (Eghbali, 1979; LeDrew et al., 2004).

The objective of this study was to develop and validate a method to detect changes in peatland and heath vegetation that might be indicative of disturbance when multispectral and multi-platform images were used.

Methods

Study sites

The multi-platform cross-calibration and change detection procedure was tested using data from four peatland areas and one heath in the Republic of Ireland (Fig. 1). Each site was chosen for accessibility, geographical distribution, proximity of disturbed and undisturbed vegetation and the availability of auxiliary data via; 1 m Aerial photography (Ordnance Survey Ireland); Commonage Framework Plans (NPWS, 2011); habitat maps/surveys (NPWS, 2007); disturbance records (personal communication, NPWS rangers) and high resolution (1–5 m) satellite data. Ground based GPS data delineating a large burn event in Clara (site C) in May 2008 was also available and used in the calibration process. For each site the habitats were classified according to Fossitt (2000) with habitat codes indicated in the text in square brackets.

Kerryhead (A)

The Kerryhead peninsula, Co. Kerry, southwest Ireland (52.4120°N, 9.9002°W) is upland heath with a mosaic of dry siliceous heath [HH1], dry-humid acid grassland [GS3] and wet heath [HH3] (Fossitt, 2000) dominated by gorse (*Ulex*), bracken (*Pteridium aquilinum*), moor-grass (*Molinia caerulea*) and peat moss (*Sphagnum*). The site extends 624 ha, from 85 m to 195 m amsl (above mean sea level) and average annual precipitation of 1100 mm (MetÉireann, 2011).

Moanveanagh (B)

Moanveanagh, Co. Kerry, southwest Ireland (52.4539°N, 9.4130°W) is a raised bog consisting of high bog [PB1] and cutover areas [PB4] and is dominated by *Sphagnum* lawns, pools and flushes, common heather (*Calluna vulgaris*) and moor-grass (*M. caerulea*). This site extends 215 ha, from 29 m to 41 m amsl and average annual precipitation of 1300 mm (MetÉireann, 2011). Moanveanagh is a candidate for Special Area of Conservation (SAC) under the EU Habitats Directive (NPWS, 2010a). Although peat extraction had theoretically ceased, the effect of this anthropogenic disturbance are still present.

Clara (C)

Clara, Co. Offaly, midlands of Ireland (53.3211°N, 7.6272°W), is a raised bog [PB1] dominated by *Sphaghnum* under waterlogged