High resolution mapping of Antarctic vegetation communities using airborne hyperspectral data

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Summary

The Antarctic Peninsula (AP) is one of the most rapidly changing environments on the planet; mean annual air temperatures have increased by ~3 ºC in the last 50 years. This climatic change has led to longer summers and higher summer-growing season temperatures and, coupled with local glacial retreat, new bare-ground is exposed for colonisation by pioneering vegetation communities. Due to the exceptional rates of environmental change the AP has been considered globally important in identifying the biological consequences of climate change. To monitor and assess changes of AP vegetation, a robust, quantitative assessment of vegetation is required. Previous studies have applied standard techniques, such as the Normalised Difference Vegetation Index (NDVI) to satellite data from the AP. Because the reflectance spectra of lichens, the dominant and most diverse component of the AP flora, differs from vascular plants in both the visible and near infra-red portion of the spectrum, any work using NDVI for the detection of vegetation might overlook the presence of lichens. This study presents a new spectral filtering technique which was applied to an airborne hyperspectral dataset to produce a high resolution map of vegetated areas from a test site on the AP.

1 Introduction

The Antarctic Peninsula (AP) has seen an increase in mean annual air temperature of ~3ºC in the last 50 years (Vaughan *et al*., 2003), making it one of the most rapidly changing areas on the planet. The changing climate as a result of rising temperatures, has led to higher summer-growing season temperatures (Convey and Smith, 2006) and as a result of local glacial retreat (Pritchard and Vaughan, 2007) new rock outcrops and areas of scree and soil are exposed for colonisation by terrestrial biota (Walther *et* al., 2002; Convey and Smith, 2006). Due to these exceptional rates of change the AP has been highlighted as a globally important barometer for identifying the biological consequences of climate change (Convey, 2003). To monitor and assess changes of AP vegetation, a robust, quantitative assessment of vegetation is required (Fretwell *et al.*, 2011). Field based techniques in the Antarctic incur significant logistical challenges as a result of the climate and topography in addition to the limited spatial coverage and invasive nature of the work. A non-invasive, remote sensing approach provides many advantages over field based techniques. Previous work using satellite remote sensing has shown that traditional approaches such as the Normalised Difference Vegetation Index (NDVI; Rouse *et al*., 1974) are difficult to apply in the Antarctic (Fretwell *et al*., 2011). It has already been recognized that any work using NDVI for the detection of vegetation might overlook the presence of lichens even if their land cover is extensive (Petzold and Goward, 1988). The reflectance spectra of lichens and vascular plants are different in both, the visible near infrared (VNIR; 0.4 - 1 µm) and shortwave infrared (SWIR; 1 - 2.5µm) portion of the solar spectrum; in particular the depth of the visible – near-infrared step is characteristically smaller in lichens (Petzold and Goward, 1988; Haselwimmer and Fretwell, 2009). In the AP, where lichen contribution to vegetation diversity and extent increases in importance, NDVI would show decreasing spectral vegetation values, and areas completely covered with lichens could be erroneously classified as having sparse cover of vascular plants (Petzold and Goward, 1988).

High resolution airborne hyperspectral imagery has been widely used for a variety of applications, including vegetation monitoring, but has not yet been assessed in the Antarctic. The British Antarctic Survey and partners collected the first known airborne hyperspectral dataset over the Antarctic in February 2011. The simultaneous deployment of commercially available VNIR and SWIR spectrometers generated a dataset covering the 0.35 to 2.5 µm spectral range at a spectral resolution of 9.6-14 nm. This study presents results from high resolution mapping of Antarctic vegetation communities using this unique airborne hyperspectral dataset from a study area on the AP. Results from a new lichen matched filter technique are compared to the traditional NDVI approach.

2 Study Area

Lagoon and Kirsty Island (67º 35' S, 68º 16' W; Figure 1), in the Ryder Bay area of Antarctica, were surveyed in February 2011 acquiring hyperspectral imagery from multiple imaging spectrometers supplied by ITRES Research Ltd. (ITRES Research Ltd., 110, 3553-31st Street NW, Calgary, AB, T2L 2K7, Canada)

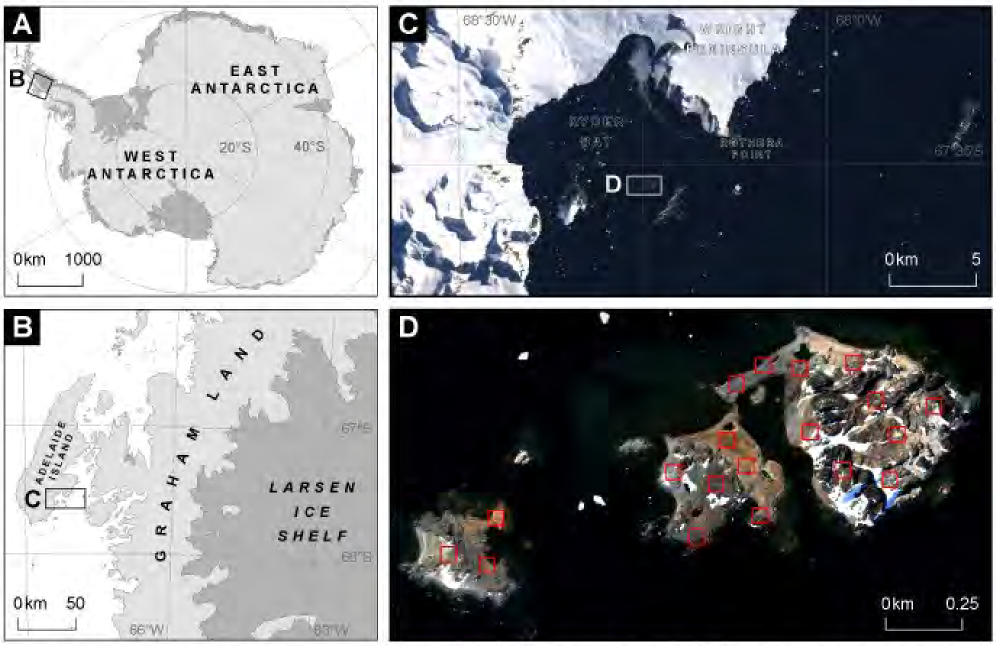

Figure 1. (A) the context of Adelaide Island within Antarctica; (B) The context of the Ryder Bay area within the Antarctic Peninsula; (C) the Ryder Bay area (with a Landsat colour image) showing extent of the hyperspectral area (Box labelled D); (D) hyperspectral colour composite image of Kirsty Island (Left) and Lagoon Island (Right) with areas visited during the field campaign shown in red squares.

3 Methodology

3.1 Data

Airborne hyperspectral data were collected from the ITRES Research Ltd. CASI-1500 and SASI-600 imaging spectrometers, with a total of 172 bands imaging from 0.4 to 2.5 µm. The imagery was geometrically and radiometrically corrected, followed by atmospheric correction using a radiative transfer modelling approach (see Black *et al*., 2014 for full details). The imagery was masked to removed surface and sea water along with snow/ice areas following the steps outlined by Harris and Rogge (2005).

The collection of lichen spectra from Lagoon and Kirsty Island was carried out using an Analytical Spectral Devices (ASD) FieldSpec Pro 3® spectrometer during a field campaign in January 2014. The ASD spectrometer records continuous spectra across the 0.3 to 2.5 µm spectral range. A total of 19 field stations were sampled (Figure 1), with spectral measurements derived from a 10 m^2 region. The presence of vegetation was confirmed at 17 of the 19 field stations.

3.2 Image Processing

Normalised Difference Vegetation Index (NDVI) was calculated using equation (1) (after Rouse *et al*., 1974)

$$NDVI = \frac{(NIR - VIS)}{(NIR + VIS)} \qquad (1)$$

where *NIR* and *VIS* represent the spectral reflectance measurements acquired in the visible (~0.6 µm) and near-infrared (~0.8 µm) regions, respectively. The narrow spectral bands from the hyperspectral CASI imagery at 0.67 µm (*VIS*) and 0.8 µm (*NIR*) were used to calculate the NDVI (Haboudane *et al.*, 2004).

We performed matched filtering (c.f. Harris and Rogge, 2005) using the lichen spectra of *Buellia* sp. collected in the field. It has been shown that a single lichen endmember can account for lichen contribution if normalisation is applied (Zhang *et al.*, 2005). As ground truthing, we used 17 of the 19 sites (10 x 10 m each) for which the presence of lichens was confirmed in the field (Figure 2). We compared the areas where the lichen filter showed presence of lichens and areas where NDVI values were greater than 0.2 (indicating that the presence of vegetation is almost certain; Fretwell *et al*., 2011).

4 Results

The matched filter successfully detected the presence of lichens at 95% of the field sites (16 of 17), whereas the NDVI only detected vegetation at 53% (9 of 17) of the sites.

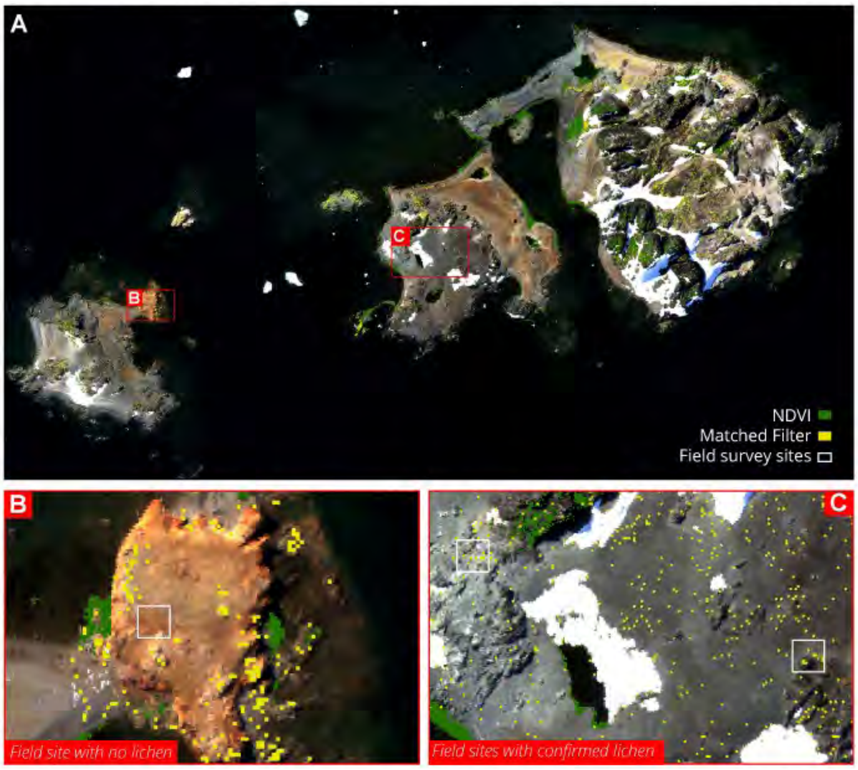

Figure 3. (A) Lagoon and Kirsty Island image with results from the matched filter (yellow) and NDVI (green) overlain; (B) inset showing a close up of Kirsty Island, where the white box indicates a field site without lichen presence; (C) inset showing a close up of western Lagoon island with field sites with confirmed lichen presence shown in white squares.

5 Discussion and Conclusions

Our data confirm that the use of a matched filtering technique allows for the detection of lichen flora in the Antarctic Peninsula, showing a considerable improvement over NDVI for the mapping of flora in this area. Our results highlight the importance of using techniques other than NDVI thresholds for the detection and mapping of vegetation in areas where lichens (and likely other non-vascular plants) are the main component of the communities; as is typical in high latitudes and high altitude environments. It has been proposed that NDVI thresholds are not the best technique for mapping distribution of lichens from remote sensing imagery (Petzold and Goward 1988, Haselwimmer and Fretwell 2009). However, this is the first study to compare NDVI threshold detection with an alternative technique for lichens in the Antarctic, and proposes a new methodology for mapping lichen distribution in the AP.

The results presented here suggest that studies based on the spectrum of only one species of lichen might be sufficient for the accurate mapping of lichen habitats in this environment, consistent with Petzold and Goward's (1988) study. The same technique proposed here could be applied in the future to intermediate spectral and spatial resolution imagery. Images of intermediate spectral and spatial resolution will be available in the future from planned satellite launches (e.g. WorldView-3, HyspIRI, Sentinel-2, EnMAP), and they will be of great importance in the study of vegetation in Polar Regions.

6 Acknowledgements

Hyperspectral Data used were collected during an airborne survey funded by the UK Foreign and Commonwealth Office and conducted by the British Antarctic Survey, ITRES Research Ltd. (http://www.itres.com) and Defence Research & Development Suffield, Canada (http://www.drdc-rddc.gc.ca) in February 2011. M Black is funded by a Natural Environment Research Council (NERC) PhD studentship in conjunction with the British Antarctic Survey and the University of Hull (NERC Grant: NE/K50094X/1). Fieldwork was supported by an Antarctic Funding Initiative CGS grant (CGS-086) and a spectrometer loan from the NERC Field Spectroscopy Facility (FSF Loan No.: 675.0613). P Casanovas was supported by the SCAR fellowship scheme 2013-14.

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