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Random forest classification of salt marsh vegetation habitats using quad-polarimetric airborne SAR, elevation and optical RS data

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ABSTRACT

This research investigated the use of multi-source remote sensing data to map natural coastal salt marsh vegetation habitats. Coastal zones are very dynamic and provide a number of critical ecosystem services, particularly in relation to flood mitigation but they have been found to be difficult to monitor using remotely sensed data. This research analysed combinations of S-band and X-band quad-polarimetric airborne SAR, elevation data and optical remotely sensed imagery. In total 30 variables were analysed. The SAR inputs included backscatter intensity channels and Cloude-Pottier, Freeman-Durden and Van Zyl decomposition SAR descriptors. Classification was carried out using Random Forest classifiers at two thematic resolutions which generated a general mapping of salt marsh vegetation and a high-resolution mapping of thematically detailed salt marsh vegetation habitats. The results indicate that Random Forest models are able to handle multi-source datasets and generate high classification accuracies. Models based on either SAR or optical RS variables alone were found to be less accurate than models that combining variables from multiple sources. The results show that X-band SAR data provided the best information to map vegetation extent and analysis showed that S-band SAR data was better able to differentiate between different vegetation habitats. The methods and analyses suggested in this paper extend previous research into remote monitoring of costal zones and illustrate the opportunities for mapping natural coastal areas afforded through combinations of radar and optical remote sensing data.

1. Introduction

Coastal zones are areas where, put simply, the land meets the sea. Their morphology varies from cliffs, beaches and mangrove forests to low-lying coastal salt marshes (Bird, 2008). Due to the impact of wave activity, tidal currents and sediment supply, coastal zone morphology is constantly subject to change (Haslett, 2003). Coastal zones are some of the world's most densely populated areas; even though coastal zones with elevation of less than 10 meters cover only 2% of the global land mass, they host 10% of the world's population (McGranahan, Balk, & Anderson, 2007). They are predicted to experience the majority of the human population growth and economic development (Adam, 2002; Foresight, 2011). In Europe, for example, artificial surfaces increased 7.5% between 1990 and 2000 in coastal zones (Zisenis, 2010). Frequent morphological changes renders development of long-term and sustainable management plans a major challenge (European Commission, 2011).

Recently, there has been much attention on ecosystem-based coastal management policies (Zisenis, 2010) such as Integrated Coastal Zone Management (ICZM) first proposed in the 1990s (Garriga & Losada, 2010) and much research has sought to define the underpinning concepts associated with ICZM (McKenna, Cooper, & O'Hagan, 2008; Stejin et al., 2011). One aspect of ICZM is to utilise the ecosystem services associated with flood mitigation supported by well-functioning natural coastal habitats in order to provide more natural, resilient and cheaper forms of coastal protection (Zedler & Kercher, 2005). In the UK, for example the Environment Agency (EA) is carrying out a number of managed realignment projects that allow existing sea defences to be breached in order to re-establish natural coastal marshes (Turner, Burgess, Hadley, Coombes, & Jackson, 2007).

This paper explores the extent to which salt marsh vegetation habitats can be identified using data derived from a number of recent remote platforms and sensors including airborne polarimetric S-band and X-band Synthetic Aperture Radar, Digital Surface Model and optical Remote Sensing data. In particular, it uses polarimetric SAR decomposition descriptors and their analysis using Random Forest classification algorithms. The analysis examines the capacity of different

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data combinations to map salt marsh vegetation habitat extent and to differentiate between vegetation habitats.

1.1. Salt marsh habitats

In temperate climates, intertidal coastal zones provide specific conditions for halophytic plant communities, or salt marsh habitats (Adam, 1990). Salt marshes are at the fringe of many of the world's soft sedimentary coasts that are exposed to relatively low-energy wave action. They are characterized by herbaceous woody vascular plants, with an upper elevation limit of occurrence at approximately the highest astronomical tide (HAT) and a lower limit that is rarely below mean high water neap (MHWN) tide level (Adam, 2002). Salt marsh habitats are relatively species-poor and populated by distinct vegetation types, highly dependent upon soil salinity, flooding frequency and topography (Silvestri & Marani, 2004) due to the specific environmental niche that they occupy. The common zonations from sea to land are (Adam, 1990; JNCC, 2004): 1) Pioneer zone (dominant species *Spartina* spp., *Salicornia* spp., *Aster tripolium*), 2) Lower-Mid marsh (dominant species *Puccinellia maritima* and *Atriplex portulacoides*), 3) Middle-Upper marsh (dominant species *Limonium* spp. and/or *Plantago*) and 4) Upper marsh (dominant species *Festuca rubra*, *Juncus maritimus*). Fig. 1 provides a schematic overview profile of a general salt marsh vegetation succession. In the UK, the general extent of salt marsh vegetation is monitored by the EA at approximately decadal intervals (Environment Agency, 2011), based on interpretation of aerial photography.

1.2. Remote sensing opportunities

Remote sensing instruments, either airborne or on spaceborne platforms, have proven to be invaluable tools for the monitoring of the natural environment (Barrett, 2013), especially in difficult to access locations (Mumby, Green, Edwards, & Clark, 1999). The recent deployment of Synthetic Aperture Radar (SAR) remote sensing systems has resulted in a number of new applications (Hensley, Jones, & Lou, 2012; Koch, 2010; Schmullius & Evans, 1997). One of the critical advantages of SAR is that provides repeatable data acquisition because, unlike optical systems, it is relatively unaffected by atmospheric effects. Integrating both optical and SAR data provides opportunities for a more comprehensive understanding of land cover and change (Zhang, 2010). Optical remote sensing systems provide spectral information of the Earth's surface and SAR systems generate structural and electromagnetic information of surface targets. However, as yet relatively few studies have developed analyses that have fused these two general data types. In this context, the objective of this study was to determine the effectiveness of high-resolution airborne polarimetric S- and X-band SAR data for salt marsh vegetation habitat mapping.

Some recent research has evaluated the use of polarimetric SAR (Hensley et al., 2012; Lönnqvist et al., 2010). Airborne and remotely controlled platforms to deploy SAR systems have been found to provide better data quality data and more flexible operation (Ramsey, Rangoonwala, Suzuoki and Jones, 2011; Reigber et al., 2013). However, S-band SAR is a little-known and under-exploited microwave frequency band which attracted limited research (Hajnsek, Pottier, & Cloude, 2003; Natale et al., 2011) compared to X-, C- and L-band SAR systems. In order to be able to maximally benefit from future NovaSAR-S mission (Bird et al., 2013) further research into S-band performance and capabilities is needed.

In this research the Random Forest (RF) image classification algorithm (Breiman, 2001) is applied. Although there are numerous other supervised classification methods available, RF has been applied successfully in ecological land cover studies (Corcoran, Knight, & Gallant, 2013; Cutler et al., 2007). The RF algorithm has shown to improve classification accuracy considerably, as well as being largely insensitive to noisy data sets (Gislason, Benediktsson, & Sveinsson, 2006). Added to this, RF produces variable importance estimations, providing qualitative analysis of variable contribution.

In summary, whilst a number of papers have considered use of SAR for wetland mapping and monitoring (Clint Slatton, Crawford, & Chang, 2008; Dabrowska-Zielinska, Gruszczynska, Lewinski, Hoscilo, & Bojanowski, 2009; Dehouck, Lafon, Baghdadi, & Marieu, 2012; Henderson & Lewis, 2008; Ramsey, Zhong, Suzuoki, Rangoonwala and Werle, 2011), this paper provides new insights into the use of high resolution S-band SAR data for land cover mapping and evaluates the use of polarimetric SAR decomposition. Such capabilities have the potential to extend the remote sensing toolbox for mapping coastal vegetation habitats by adding SAR data which can be acquired independent of local weather and provides an information source complementary to optical RS systems.

2. Methods

This section describes the research area characteristics, the data, pre-processing and analysis methodologies used. The flow diagram in Fig. 2 outlines the processing and analysis steps.

2.1. Research area

The Llanrhidian salt marshes measure over 2000 ha in size and represents almost 5% of all British saltmarsh. They are located in the Loughor Estuary, on the northern shore of the Gower Peninsula, west of Swansea in South Wales (Boorman, 2003; Environment Agency, 2011; May, 2007) (Fig. 3). A number of ecological and geomorphological studies have been carried out over the past decades (Farleigh, 2010; Prosser & Wallace, 1999) and it has been found that generally the salt marsh is in 'favourable ecological condition', slowly increasing in size

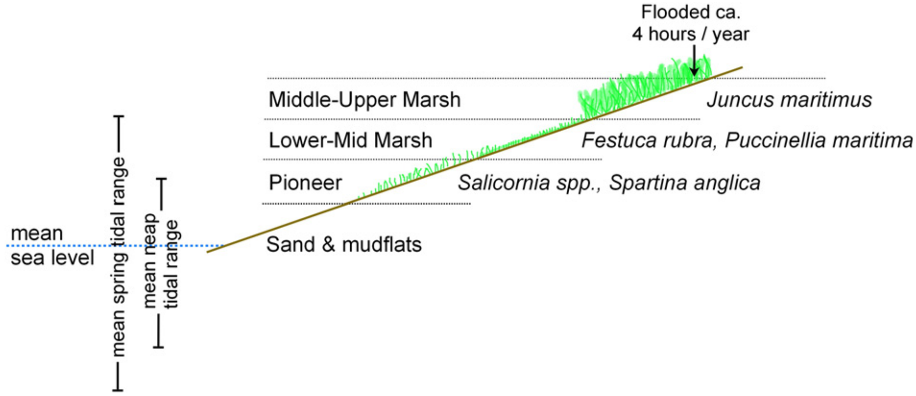

Fig. 1. Idealised cross profile through a Northwest European salt marsh from seaward side (left) to landward side (right), after (Boorman, 2003).