Int J Appl Earth Obs Geoinformation 73 (2018) 450–462

Contents lists available at ScienceDirect

Int J Appl Earth Obs Geoinformation

journal homepage: www.elsevier.com/locate/jag

An efficient feature optimization for wetland mapping by synergistic use of SAR intensity, interferometry, and polarimetry data

Fariba Mohammadimanesh[a,*], Bahram Salehi[a], Masoud Mahdianpari[a], Mahdi Motagh[b,c], Brian Brisco[d]

[a] C-CORE and Department of Electrical Engineering, Memorial University of Newfoundland, St. John's, Newfoundland, A1B 3X5, Canada
[b] Department of Geodesy, Section of Remote Sensing, GFZ German Research Centre for Geosciences, Potsdam, 144173, Germany
[c] Institute of Photogrammetry and GeoInformation, Leibniz Universität Hannover, Hannover, 30167, Germany
[d] The Canada Centre for Mapping and Earth Observation, Ottawa, Ontario, K1S 5K2, Canada

ARTICLE INFO

Keywords:
Wetland
Interferometric coherence
Random Forest
Support vector machine
Feature optimization

ABSTRACT

Wetlands are home to a great variety of flora and fauna species and provide several unique environmental services. Knowledge of wetland species distribution is critical for sustainable management and resource assessment. In this study, multi-temporal single- and full-polarized RADARSAT-2 and single-polarized TerraSAR-X data were applied to characterize the wetland extent of a test site located in the north east of Newfoundland and Labrador, Canada. The accuracy and information content of wetland maps using remote sensing data depend on several factors, such as the type of data, input features, classification algorithms, and ecological characteristics of wetland classes. Most previous wetland studies examined the efficiency of one or two feature types, including intensity and polarimetry. Fewer investigations have examined the potential of interferometric coherence for wetland mapping. Thus, we evaluated the efficiency of using multiple feature types, including intensity, interferometric coherence, and polarimetric scattering for wetland mapping in multiple classification scenarios. An ensemble classifier, namely Random Forest (RF), and a kernel-based Support Vector Machine (SVM) were also used to determine the effect of the classifier. In all classification scenarios, SVM outperformed RF by 1.5–5%. The classification results demonstrated that the intensity features had a higher accuracy relative to coherence and polarimetric features. However, an inclusion of all feature types improved the classification accuracy for both RF and SVM classifiers. We also optimized the type and number of input features using an integration of RF variable importance and Spearman's rank-order correlation. The results of this analysis found that, of 81 input features, 22 were the most important uncorrelated features for classification. An overall classification accuracy of 85.4% was achieved by incorporating these 22 important uncorrelated features based on the proposed classification framework.

1. Introduction

Wetlands are areas with either temporarily or permanently saturated soils that affect plant establishment, animal life, and soil development. Controlling floods, improving water-quality, supporting wildlife habitat for several unique species of flora and fauna, and shoreline stabilization are some of the advantages of wetlands (Mahdianpari et al., 2017a). Satellite remote sensing data have significantly contributed to wetland mapping given the remoteness, vastness, and ever-changing nature of these ecosystems. Importantly, Synthetic Aperture Radar (SAR) sensors are advantageous for wetland studies due to their capability to operate independently of solar radiation and day/night conditions. Furthermore, the SAR signal penetrates through vegetation canopies and soil, making it an ideal tool to monitor the flooding status of vegetation (de Almeida Furtado et al., 2016).

For several years, per-pixel image analysis has been used for land cover classification due to the coarse resolution of pixels in satellite imagery relative to the size of the ground object. However, because of continuous development of satellite remote sensing tools and the availability of high spatial resolution imagery, the Object-Based Image Analysis (OBIA) technique has become popular for land cover classification (Blaschke, 2010). Incorporating different features, such as object size and shape, combining multiple sources of data with different spectral and spatial resolution, and utilizing spatial and hierarchical relations of neighbouring pixels are the main advantages of the object-based approach (de Almeida Furtado et al., 2016). Moreover, an

* Corresponding author at: C-CORE, Captain Robert A. Bartlett Building, 1 Morrissey Road, St. John's, NL, A1B3X5, Canada.
E-mail address: f.mohammadimanesh@mun.ca (F. Mohammadimanesh).

https://doi.org/10.1016/j.jag.2018.06.005
Received 15 December 2017; Received in revised form 11 June 2018; Accepted 12 June 2018
0303-2434/

integration of advanced machine learning tools, such as Support Vector Machine (SVM) and Random Forest (RF), with the object-based approach has further improved accuracy of land cover classification in recent years (Ghosh and Joshi, 2014).

When classifying complex land cover, accuracy is not only influenced by classifier robustness but other factors, such as input features and their discrimination power affect the classification results. Although several studies have examined the capacity of SAR intensity and polarimetric decomposition methods for wetland classification (e.g., de Almeida Furtado et al., 2016; Mahdianpari et al., 2017a), the potential of interferometric coherence has not been thoroughly investigated. Nevertheless, the efficiency of interferometric coherence for classification of different land cover types has been noted (Mohammadimanesh et al., 2018). In particular, Ramsey et al. (2006) investigated the capability of SAR intensity, phase, and interferometric coherence for coastal land cover classification. They reported that the SAR intensity was less responsive to land covers and had high temporal variations. Conversely, the interferometric coherence of the different classes was highly varied and provided a superior capacity for discrimination. In Central Siberia, Thiel et al. (2009) used ALOS PALSAR summer-intensity and winter-coherence to discriminate forest and non-forest areas. Jin et al. (2014) also investigated the discrimination power gained by synergistic use of intensity, polarimetric, interferometric coherence, and textural features obtained from multi-temporal ALOS PALSAR data for land cover mapping in Central New York State, USA. They reported the inclusion of four feature types improved classification accuracy of about 7% relative to exclusive use of intensity. Zhang et al. (2015) used interferometric coherence obtained from ALOS data for classification of wet and dry marshes in the Liaoh River Delta, China. Also in China, Jiang et al. (2017) examined the capacity of HH-polarized TerraSAR-X intensity and coherence for land cover mapping in the city of Zhuhai, Pearl River Delta. Most recently, Wang et al. (2018) used multi-temporal TerraSAR-X backscatter intensity and coherence to map permafrost landscapes in a complex sub-arctic environment.

Despite the high capacity of state-of-the-art machine learning algorithms, such as RF and SVM, to handle a large number of input features, the classification accuracy can be considerably improved upon the inclusion of important uncorrelated features into the classification scheme (Millard and Richardson, 2015; Mahdianpari et al., 2017b). This highlights the significance of employing an efficient feature selection method to remove redundant information within input data, thus alleviating computational complexity. Moreover, such a feature selection method deepens the knowledge of which input features are most suitable for specific classification tasks (Chan and Paelinckx, 2008). Thus, identifying the best combinations of features that have more separable land cover information is highly desirable. Accordingly, several feature selection methods have been proposed and can be found in the literature (e.g., Melgani and Bruzzone, 2004). Some of these studies noted that RF variable importance can be used as an efficient feature selection method for dimensional reduction of remote sensing data (Chan and Paelinckx, 2008; Millard and Richardson, 2015). The RF variable importance indicates the influence of each feature on the classification accuracy for a set of input data through the out-of-bag estimates and, accordingly, has been successfully employed as a feature selection method (Chan and Paelinckx, 2008; Millard and Richardson, 2015).

The goal of this study was to investigate the potential of interferometric coherence for wetland mapping and the synergistic use of coherence with intensity and polarimetry. Each feature has specific characteristics, which may improve the capacity to discriminate between different land cover classes. For example, SAR intensity is primarily an indicator of ground conditions due to its sensitivity to surface roughness and dielectric constant, polarimetric features characterize the type of the ground target scattering mechanism, and interferometric coherence indicates the mechanical stability of the ground targets during satellite acquisition time intervals (Jin et al., 2014). Thus, the objectives of this research were to: (1) determine the contribution of varying input features, including intensity, interferometric coherence, and polarimetric decompositions, obtained from multi-temporal X- and C-band SAR data to the classification results; (2) identify the improved discrimination capacity obtained from the synergistic use of different input features; (3) quantify the redundancy within a large number of input features and its influence on the classification accuracy; (4) optimize both the type and number of input features by integrating RF variable importance and Spearman's rank-order correlation analysis; and (5) compare the performance of a kernel-based classifier, SVM, and an ensemble classifier, RF, using an object-based classification approach. To the best of our knowledge, this study is the first to investigate the synergistic use of such input features for wetland classification. The proposed classification scheme serves as a framework, progressing towards an operational methodology for mapping wetland complexes in Canada, as well as other wetlands worldwide with similar ecological characteristics.

2. Study area and data

The 700 square kilometer study area is located in the north eastern part of the Avalon Peninsula, in Newfoundland and Labrador, Canada (Fig. 1). Land cover within the Avalon pilot site is highly diverse and includes extensive heathland, balsam fir forest, as well as urban and agricultural areas. Notably, all wetland classes characterized by the Canadian Wetland Classification System, including bog, fen, marsh, swamp, and shallow-water are found within this region.

In this study, field data were acquired for 257 ground sites in the ice-off seasons of 2015-2017. For reference data preparation, reference polygons were sorted by size and alternatingly assigned to training and testing groups. An alternative assignment of reference data ensured that both the training and testing had an equal assignment of small and large wetland polygons to allow for similar pixel counts and to account for the high variation of intra-wetland size. Fig. 2 illustrates the distribution of the training and the testing polygons for each land cover type across the study area.

HH polarized X-band images from TerraSAR-X in StripMap mode were acquired between August and November 2016, coinciding with the ice-off season. RADARSAT-2 C-band imagery in either single (HH) or quad polarization was acquired in the interval between April and August 2016 (see Table 1). Due to the small swath of FQ mode, more than one image was needed to cover the whole study area (FQ22; see Fig. 1).

3. Methods

Fig. 3 illustrates the proposed methodology for this study. After SAR data pre-processing, different features were extracted and grouped into three major feature types, including intensity, interferometric coherence, and polarimetric features. Next, different combinations of features were applied to an object-based image analysis framework. The classification results were then evaluated using the testing polygons, which were held back for the validation and accuracy assessment. However, a number of these input features had redundant information and were not useful, meaning that incorporating highly correlated features did not significantly improve classification accuracy. They also increased the computational complexity of the classification. Thus, we applied an efficient method to optimize both the type and number of input features. In particular, we used a combination of RF variable importance and Spearman's rank-order correlation in a pair-wise correlation framework. Based on these analyses, the most important uncorrelated features were extracted and applied to the final classification scheme.