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Assessing integration of intensity, polarimetric scattering, interferometric coherence and spatial texture metrics in PALSAR-derived land cover classification

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ABSTRACT

Synthetic aperture radar (SAR) is an important alternative to optical remote sensing due to its ability to acquire data regardless of weather conditions and day/night cycle. The Phased Array type L-band SAR (PALSAR) onboard the Advanced Land Observing Satellite (ALOS) provided new opportunities for vegetation and land cover mapping. Most previous studies employing PALSAR investigated the use of one or two feature types (e.g. intensity, coherence); however, little effort has been devoted to assessing the simultaneous integration of multiple types of features. In this study, we bridged this gap by evaluating the potential of using numerous metrics expressing four feature types: intensity, polarimetric scattering, interferometric coherence and spatial texture. Our case study was conducted in Central New York State, USA using multitemporal PALSAR imagery from 2010. The land cover classification implemented an ensemble learning algorithm, namely random forest. Accuracies of each classified map produced from different combinations of features were assessed on a pixel-by-pixel basis using validation data obtained from a stratified random sample. Among the different combinations of feature types evaluated, intensity was the most indispensable because intensity was included in all of the highest accuracy scenarios. However, relative to using only intensity metrics, combining all four feature types increased overall accuracy by 7%. Producer's and user's accuracies of the four vegetation classes improved considerably for the best performing combination of features when compared to classifications using only a single feature type.

1. Introduction

Timely land cover information is essential for land resources management and conservation. Satellite remote sensing plays a key role in land cover monitoring due to its ability to obtain up-to-date information over large areas at relatively low cost. In the last few decades, optical satellite imagery has been extensively used to classify land cover (e.g. Hansen et al., 2000; Friedl et al., 2002; Homer et al., 2004, 2007). Nonetheless, the utility of optical data is highly restricted by solar illumination and atmospheric conditions, particularly in regions at high latitudes and/or prone to persistent cloud cover and heavy precipitation.

Synthetic aperture radar (SAR) is an important alternative to optical remote sensing. As an active microwave sensing system, SAR has an inherent advantage over optical sensors for its day-and-night and all-weather observation capability, which guarantees multiple image acquisitions over relatively short periods of time. Moreover, radar signals are sensitive to properties of soil (e.g. moisture and roughness) and vegetation (e.g. structure and biomass) (Fung, 1994; Ulaby et al., 1986), providing complementary characterization of land cover types relative to that achieved with optical imagery (Pohl and van Genderen, 1998).

The investigation of timely land cover information using radar remote sensing has become more practical since spaceborne SAR systems were developed and launched for regular data collection. Major past and current operational SAR sensors are COSMO-SkyMed (X-band), TerraSAR-X (X-band), TanDEM-X (X-band), ERS-1/2 (C-band), Radarsat-1/2 (C-band), Envisat/ASAR (C-band), Sentinel-1A (C-band), Seasat-1 (L-band), JERS-1 (L-band), ALOS/PALSAR (L-band), and ALOS-2/PALSAR-2 (L-band). The letter codes for the various bands correspond to different wavelength ranges, which determine the extent to which a radar signal is attenuated

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and/or dispersed by the atmosphere. Although radar signals are barely affected by clouds, the influence of heavy precipitation can be considerable at K- and X-band with operating wavelengths less than 4 cm (Danklmayer et al., 2009). In addition, radar wavelength is directly related to the depth of penetration into the canopy, and this depth determines the contribution of various scattering components to radar backscatter. Short wavelengths such as X-band (2.4–3.75 cm) and C-band (3.75–7.5 cm) mainly interact with the top leaves/needles, twigs and small branches, whereas long wavelengths such as L-band (15–30 cm) and P-band (30–100 cm) penetrate deeper into vegetation canopies and interact mostly with primary branches, tree trunks and also the underlying ground (Ulaby et al., 1986; Le Toan et al., 1992). The penetration depth of radar signals in other targets, such as snow and ice, also varies with the wavelength (Hoen and Zebker, 2000; Rignot et al., 2001).

In January 2006, the Japan Aerospace Exploration Agency (JAXA) successfully launched the Advanced Land Observing Satellite (ALOS). The Phased Array type L-band SAR (PALSAR) onboard the satellite operates in the L-band with 1270-MHz (23.6 cm) center frequency and 14- and 28-MHz bandwidths. It has five different observation modes: Fine Beam Single (FBS) polarization (HH or VV), Fine Beam Dual (FBD) polarization (HH/HV or VV/VH), Polarimetric (PLR) mode (HH/HV/VH/VV), ScanSAR mode, and Direct Transmission (DT) mode, where HH, HV, VH and VV represent the polarizations (horizontal or vertical) of transmitted (first letter) and received (second letter) radar signals. PALSAR data were consistently acquired on a repetitive basis of 46 days at off-nadir looking angles ranging from 9.7 to 50.8 degree, with ground resolutions from 10 to 100 m and swath widths from 30 to 360 km (Rosenqvist et al., 2007). These characteristics, especially the L-band frequency and multi-polarization modes, provide enhanced sensitivity to vegetation responses (Almeida-Filho et al., 2009). Accordingly, PALSAR imagery has been increasingly used in recent studies on vegetation information extraction, for example, crop classification (McNairn et al., 2009), forest cover monitoring (Thiel et al., 2009), forest growth stage investigation (Santoro et al., 2009), and forest species composition mapping (Wolter and Townsend, 2011; Miettinen and Liew, 2011).

Although PALSAR ceased functioning in May 2011 when the ALOS mission was terminated due to a power generation anomaly, it acquired thousands of L-band images during its five year operation, greatly contributing to the fields of cartography, regional land observation, disaster monitoring, and resource survey. Successful applications of PALSAR and its predecessor JERS-1 (the Japanese Earth Resources Satellite-1) (e.g. Simard et al., 2000; Rauste, 2005; Santoro et al., 2006) encourage the development of the follow-on mission ALOS-2 with PALSAR-2 onboard, which was designed to have enhanced performance on spatial resolution and observation frequency compared to ALOS/PALSAR. The ALOS-2 was launched on 24 May 2014, and it is currently under initial function verification. Images acquired by PALSAR-2 are planned to go public in November, 2014 (JAXA, 2014).

2. Background and research objective

Many features can be extracted from PALSAR imagery with the backscattering coefficient among the most commonly used. Expressing the strength (or intensity) of radar signals received by the sensor after scattering, the backscattering coefficient is a fundamental indicator of ground conditions, particularly of vegetation growth, due to its sensitivity to surface roughness with respect to polarization (e.g. Santoro et al., 2010; Dong et al., 2012). Polarimetric decomposition through eigen analysis on the complex data identifies characteristics that describe the type and contribution of scattering mechanisms, providing a meaningful and thorough exploitation of SAR polarimetry with the inclusion of the phase information that is discarded in studies using backscattering coefficient exclusively (e.g. McNairn et al., 2009). SAR interferometry, which is based on a combination of two complex images acquired at separate times over the target area, can be used to retrieve information complementary to that contained in individual images. Quantifying the degree of similarity, interferometric coherence is close or equal to one for two identical images and close or equal to zero for two completely different images (e.g. Meyer et al., 2011). Furthermore, textural information is considered an important data source for the description of spatial pattern and variation of surface features. Some previous studies have demonstrated the usefulness of texture measures as integrated with intensity data for land cover mapping (e.g. Walker et al., 2010; Longepe et al., 2011).

Table 1 provides a review of current studies using PALSAR-derived features gleaned from five major remote sensing journals: *Remote Sensing of Environment*, *ISPRS Journal of Photogrammetry and Remote Sensing*, *IEEE Transactions on Geoscience and Remote Sensing*, *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, and *International Journal of Remote Sensing*. These studies were chosen as they intended to use PALSAR data to monitor land cover resources such as forest and agriculture. Studies on lahar path detection (Joyce et al., 2009), estuarine shoreline delineation (Wang and Allen, 2008), and seismic surface displacement analysis (Zhang et al., 2010) were selectively included to showcase the diversity of PALSAR applications.

The use of different types of features in the sample articles is summarized in Table 1. Intensity was adopted in 22 of the 24 selected studies, where we define "intensity" to represent not only the backscattering coefficient, but also metrics computed based on the backscattering coefficient. For example, in Baghdadi et al. (2009), two polarization bands recording HH and HV backscatters and their difference (HH–HV) were compared with crop height and NDVI to investigate the correlations, respectively. Moreover, Almeida-Filho et al. (2009) defined a Normalized Difference Index (NDI) on HH and HV to enhance the detection of new deforestation areas. Several of these articles employed interferometric coherence when multitemporal PALSAR scenes were available, and the increase of information by the synergistic use of intensity and coherence was examined (e.g. Lonnqvist et al., 2010; Tanase et al., 2010, 2011). In contrast, polarimetric decomposition was employed in only two studies and texture feature extraction was used in three studies. The majority of studies (14 of 24) were based on a single feature type and only a single study examined a combination of three feature types. Consequently, there is limited knowledge regarding integration of multiple feature types for applications of PALSAR imagery.

Our objective is to fill this knowledge gap by assessing the potential of using various metrics of intensity, polarimetric scattering, interferometric coherence, and spatial texture extracted from multitemporal dual-polarized PALSAR data for land cover classification. Because different types of features represent different information content encapsulated in radar signals, we investigated the improvement in accuracy associated with the gain of information achieved by combining multiple feature types. Our goal is "utilitarian" in the sense that we seek to provide general guidance for practitioners related to how accuracy will be affected by combining two or more feature types. We do not delve into the mechanistic details of the classification (i.e. specific associations between features and land cover classes), but rather address the previously unanswered question of how much accuracy could potentially be improved by combining readily available multiple feature types with a commonly used classifier (random forest).