MAPPING FIRE SCARS FROM SPACE USING RADARSAT-2 POLARIMETRIC SAR

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Abstract

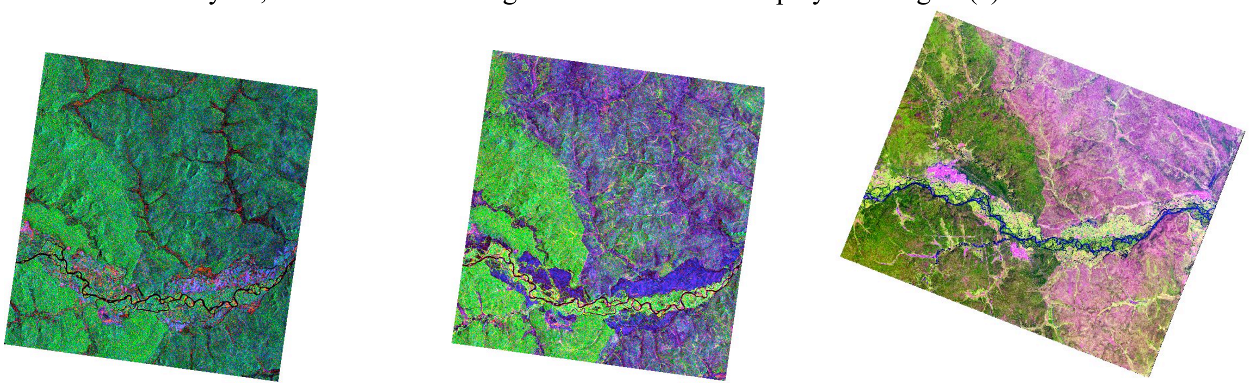
Through our joint work between the Pacific Forestry Centre (PFC) of the Canadian Forest Service (CFS), Natural Resources Canada (NRCan), in BC and the National Key Lab of Microwave Imaging Technology (NKLMIT) of the Institute of Electronics at the Chinese Academy of Sciences (IECAS), new methods for analyzing Canada's Radarsat-2 C-band fine quad-pol data for forest applications have been developed. The use of polarimetric information in the quad-pol data has revealed the possibility of mapping historical fire scars in forested areas. In this paper, two Radarsat-2 FQ19 data sets were acquired during 2009 over our study area in Ta-He, Northeast of China, where forest fire occurred in September 2001. The data sets were corrected for any Faraday rotation, azimuth polarization orientation shifts, and SNR in HV channels to generate reflection symmetry in the coherency matrix of the polarimetric SAR data for further analysis. Combining polarimetric decompositions and classifications, the fire scars in the study area for polarimetric SAR were detected and the results between the two Radarsat-2 images were compared. A classification approach of Jong-Sen Lee's, based on the Freeman/Durden decomposition, was implemented and applied.

Introduction

Accounting of carbon emissions is an important activity, which requires the mapping of fire scars in forested areas. Most historic fire data have been acquired by sketch mapping from small planes, GPS mapping from helicopters, and photo-interpretation. Due to the limitations of mapping technology, in general, the older the data, the less reliable it is. Moreover, fire perimeters derived from these traditional methods often include unburned "islands" and may overestimate burned areas by as much as 20%. Observed climate change in the boreal forest is prolonging the fire season with longer and drier summers, causing increased fire frequency and size of wild fire events. The distribution of these remote fire events and environmental conditions make them a challenge to accurately monitor and map. Therefore, fire scar information products derived from remote sensing data, using a consistent methodology, are required. In recent years, advanced space-borne SAR systems have become available, such as ALOS PALSAR, TerraSAR-X, and Radarsat-2. Over previous sensors these offer better spatial resolution, shorter revisiting times, cross polarization, more polarimetric parameters, and all-weather data acquisition capability. In this paper, we first describe the preparation of Radarsat-2 Fine Quad-pol (FQ) data, then the assessment of decomposition parameters reliant only upon polarization ratios and phase, and finally the classification methodologies for the mapping of fire scars in the study area.

Study Sites and Data Sets

The study site is located in Ta-He, Heilongjiang Province, China, which is near the border between China and Russia. The centre geo-coordinates are registered at 52°26'N, 125°32'E. The study area is about 400 km^2 and is relatively flat with an average elevation range of 420 m above sea level and an average slope less than 15°. The forest stands in this region are dominated by Larch and White Birch. A wild forest fire occurred in September, 2001, burning and damaging more than half of the study area. Two Radarsat-2 FQ19 images were collected over the site on July 14 and October 18, 2009, with a look angle of 39°. Fig. 1 (a) and (b) show the two Freeman-Durden decomposition [1] images for the July and October Radarsat-2 images respectively. Forest has strong volume scattering (green). Burned areas, on the other hand, show relatively strong surface scattering (blue) especially for the October image. A SPOT5 Level 1A image was also acquired for ground truth reference with 10m spatial resolution multi-spectral channels and a 2.5m resolution panchromatic channel. This SPOT5 image was collected on July 27, 2006. An RGB image of this data set is displayed in Fig. 1 (c).



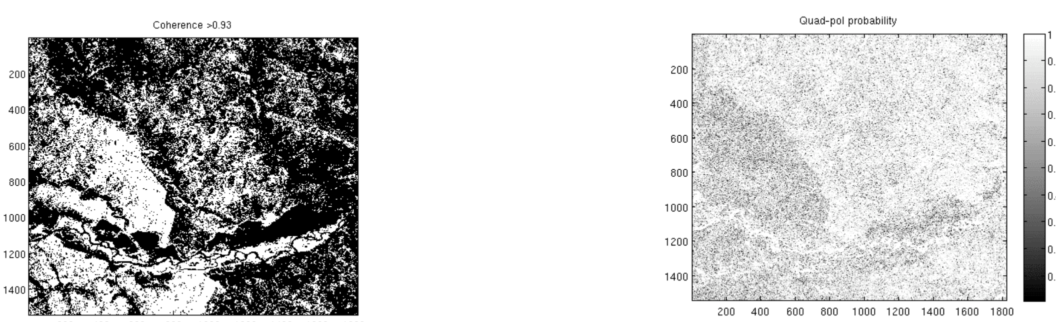
(a) Radarsat-2 Jul. 14, 2009 Double(R), Volume(G), Surface(B)

(b) Radarsat-2 Oct. 18, 2009 Double(R), Volume(G), Surface(B)

(c) SPOT5 10m Jul. 27, 2006 R: Band4 G: Band1 B: Band2

Figure 1 Radasart-2 and SPOT 5 data used for this study

The data processing employed for forestry applications of the Fine Quad-pol Radarsat-2 data required estimation of the coherency matrix [T] for a pixel. However, the two Radarsat-2 data sets provided were in a SLC (single look complex) format. We employed multi-looking on the Radarsat-2 FQ19 data by 4×2 (azimuth × range), yielding an intermediary product with around 3 or 4 equivalent looks, allowing the use of square windows for speckle filtering. We applied a box car filter with window size 5x5 before an assessment of the overall quality of the data, which we performed by estimating the HV/VH coherency [1]. We expected and did see a diversity of polarimetric response across different land cover types. The importance of using the quad-pol mode other than the simpler dual-pol polarimetric mode was assessed with a new test statistic: the quad-pol probability parameter [2].



(a) HV/VH coherence

(b) Quad-pol probability

Figure 2 Polarimetric parameters estimated from Radarsat-2 Oct. 18, 2009 (in radar domain)

Figure 2 (a) shows the HV/VH coherence image over the study site in the non-geocoded radar domain for the October image; Figure 2 (b) is the quad-pol probability image of the same data. We see very good diversity for the Ta-He site, with the burned region having the low HV/VH coherence and high quad-pol probability, clearly contrasted with the forest stands. For the July image, much higher entropy was observed over the burned areas; due to the Radarsat-2 sensitivity to random volume scattering at C-band, we saw less diversity across the image. The quad-pol probability image also showed only a marginal advantage of quad-pol over dual-pol for the July data set.

Wishart Clustering Based Unsupervised Classification

The polarization information contained in quad-pol data sets shows great potential for measuring forest scattering characteristics and producing separation between different forest areas for forest type discrimination, clear-cut and fire scar delineation. Forests have strong volume scattering; burned areas show relatively strong surface scattering with mixed volume and double bounce scattering; clear cuts and farmer's lands all have strong surface scattering. Our study is focused on exploring effective classification methods (based on the scattering characteristics) for the identification of forest areas, fire scars, and other non-forested areas in the study region. The Wishart classification scheme with different approaches has been investigated and studied, especially with the Freeman-Durden three-component decomposition initialization [3,4]. The initialization for the Wishart classification using the Freeman-Durden decomposition separates the polarimetric SAR data into three categories of pixels that are each dominated by the following scattering mechanisms: single bounce, double bounce, and volume scattering, respectively. Throughout the algorithm, the data remains separated in this way. Next, the pixels are divided according to their power into a large number of small seed classes, each containing an equal number of pixels; the small seed classes are merged together (within each of the scattering categories) based on the between-class Wishart distance [4]. Since the pixels in the three categories are kept separate from one another, this unsupervised terrain classification produces the classes that contain pixels with the same type of a scattering mechanism.

Reflection Asymmetry Effect Compensation

The reflection symmetry condition $\left\langle S_{HH}S_{HV}^{*}\right\rangle = \left\langle S_{HV}S_{VV}^{*}\right\rangle = 0$ as a basic assumption of the Freeman-Durden's three-component decomposition must be satisfied. Commonly, the reflection asymmetry effect of longer wave SAR data is induced by non-flat surface structures, such as topography, branches and leaves. For Radarsat-2 C-band SAR, the shorter wavelength return is more sensitive to the vegetation canopy than rough surfaces beneath the canopy. To perform compensation, a polarization orientation angle (POA) shift is estimated according to Equation (1) and (2) [5]:

$$\eta = \frac{1}{4}\left[\tan^{-1}\left(\frac{-4\,\mathrm{Re}(<(\tilde{S}_{HH}-\tilde{S}_{VV})\tilde{S}_{HV}^{*}>)}{-<|\tilde{S}_{HH}-\tilde{S}_{VV}|^{2}>+4<|\tilde{S}_{HV}|^{2}>}\right)+\pi\right], \tag{1}$$

$$\theta = \begin{cases} \eta, & if \quad \eta \le \pi/4 \\ \eta-\pi/2, & if \quad \eta > \pi/4 \end{cases}, \tag{2}$$

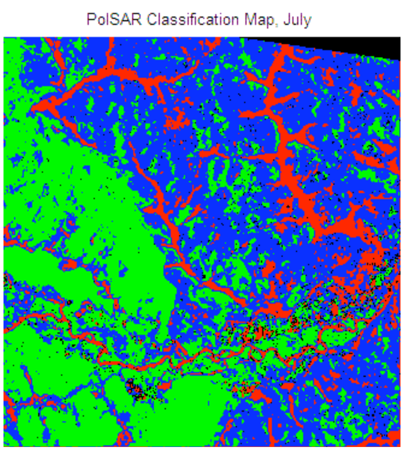
where θ is the POA shift, and $\tilde{S}_{XY}$ is the polarimetric SAR scattering matrix term. Next, the reflection asymmetry effect is compensated by removing the effect of the POA shift from the coherency matrix T as in Equation (3) [6].

$$T^{new} = UTU^{T}, U = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos 2\theta & \sin 2\theta \\ 0 & -\sin 2\theta & \cos 2\theta \end{bmatrix} \tag{3}$$

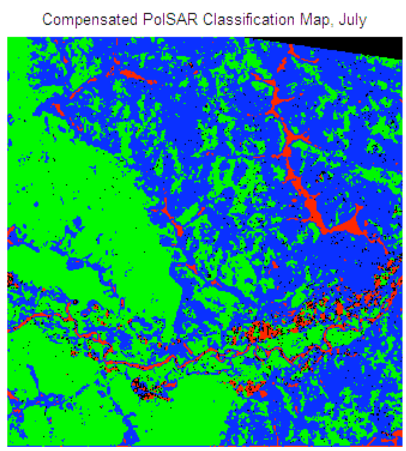
An advantage of this compensation algorithm is that it depends only upon the coherency matrix T but not any other data sources.

Experiment Results

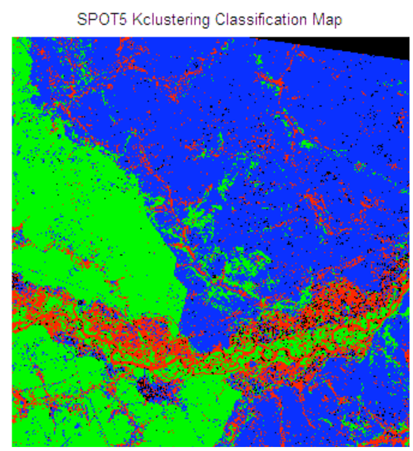
The Wishart classifications with the Freeman-Durden decomposition initialization were performed on both Radarsat-2 data sets. For the classification comparison, a classification result of SPOT5 imagery using the K-means approach is shown in Fig. 3(e). Three classes are identified that are: Forest (Green), Fire Scar (Blue), and Mixed class (Red). Fig. 3(a) and (c) are the classification maps from the non-compensated Radarsat-2 data, in July and October respectively. Based on these results, we conclude that the reflection asymmetry effect compensation have to be performed before the speckle filtering of the Radarsat-2 quad-pol data. Different filtering window sizes were tested and here we recommend that a window size of 9×9 be used for the box car filter and 5×5 for the Freeman-Durden decomposition. The initial number of 'seed' clusters in each category of the Wishart classification is set to 90. The termination criteria are set to 1) the number of pixels switching classes is no more than 1% of the total pixel number of image and 2) the number of iterations is not greater than 12. To compare the radar classification results with the SPOT5 classification, we merged 15 clusters from the output of the Wishart classification with Freeman-Durden initialization into three main classes.



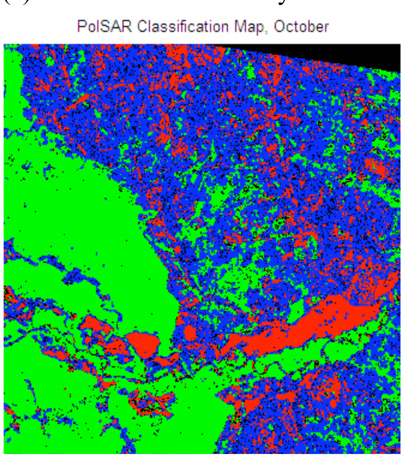
(a) RS-2 classification July



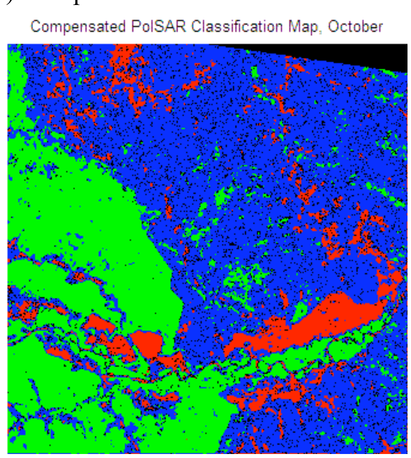
(b) Compensated RS-2 classification July



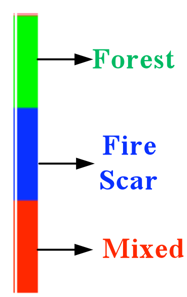
(e) SPOT 5 classification



(c) RS-2 classification October



(d) Compensated RS-2 classification October



(f) Legend

Figure 3 Radarsat-2 Wishart classifications with the Freeman-Durden decomposition initialization

Fig. 3(b) and (d) are the classification maps after the reflection asymmetry effect compensation was performed on the Radarsat-2 July data and October data respectively. Our visualization suggests that the classification results from the Radarsat-2 October image are better than the July results due to the leaf off condition in the fall. Moreover, the compensated classification results in (c) and (d) are more cleaner and closer to (e) than the results in (a) and (b) respectively. The differences of the decomposition results in October - before and after the compensation - are larger than the results in July. Mostly, this phenomenon happened in the fire scar area, because ground vegetation gives away during the fall allowing the signal from the Radarsat-2 sensor to reach the ground surface. If there is no reflection symmetry compensation, some of these areas in radar image are still being grouped into the volume category, changing both the cluster merging and classification results and exaggerating the proportion of the volume scattering component. The accuracy assessment of fire scars mapping on this study site is being performed by comparing with the SPOT5 K-clustering classification result. For the compensated Radarsat-2 classification from July, 85% of the forested areas and 68% of the fire scar areas agree with the classification results of the SPOT5 data. For the Radarsat-2 fall image from October, 80% of the forested areas and 85% of the fire scar areas agree with the SPOT5 classification image.

Conclusions

This paper focuses on utilizing the phase information contained in Radarsat-2 polarimetric SAR data to increase the sensitivity of SAR measurement for fire scar detection and forest area classification. Two Radarsat-2 FQ data were acquired and the reflection asymmetry effect compensation was performed. The unsupervised Wishart classification based on the Freeman-Durden decomposition was implemented and applied on the Radarsat-2 FQ data. Different options for the speckle filtering and the initial number of 'seed' clusters in each category of the Wishart classification were considered. The classification results were analyzed and found to agree, in general, with the reference SPOT5 data. Our study results indicate that Radarsat-2 C-band FQ data is useful for forest applications, especially for fire scar and forested areas estimation and identification. The Freeman-Durden Wishart classification method is an effective classification tool because it preserves the dominant scattering mechanism during the classification process. We also showed that the reflection asymmetry compensation processing is important and improves the classification results.

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