Detection and validation of forest disturbances using RADARSAT-2 data

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***Abstract**:* RADARSAT-2 SAR data was used to develop a monitoring program for Canadian forest lands with the aim to provide information on forest harvesting. A study site in British Columbia, Canada, characterized by coniferous forest, was selected. RADARSAT-2 MultiLook Fine mode, acquired from mid-June through mid-September, from 2011 to 2015 was analyzed with the aim to detect forest disturbances. Due to large data volumes and the need for efficiency, an automated end-to-end solution was implemented. The automated solution included image coregistration, temporal filtering, detection of forest disturbances, and delineation of the disturbances. To reduce the detection of false positives, a non-forest mask was developed that entailed a combination of CanVec data that delineated areas such as water bodies, roads, and urban/industrial areas and SAR-derived information such as layover and scattering from urban areas. To assess the performance of the change detection algorithm, the RADARSAT-2 changes were compared to tree-loss information from the Canadian Forest Service (CFS) and cut-block information from the BC Forest Service (BCFS). Since CFS and the BCFS information was representative of annual changes, but the RADARSAT-2 derived changes were representative of summer-only changes, there were discrepancies between the RADARSAT-2 data and the CFS/BCFS data. Notwithstanding these discrepancies, the detection performance was better than 80% for 2011/12 and 2012/13. For 2013/15, however, due to the two-year gap between data acquisition, the detection performance was 74%.

Keywords: RADARSAT-2, Forestry, Disturbance Mapping, SAR

1. Introduction

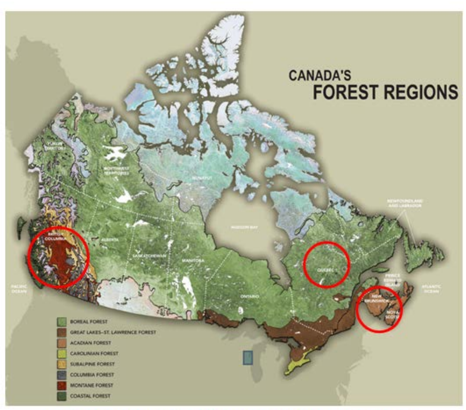
There is global interest in the state of the world's forests, particularly from a carbon tracking perspective. Canada has its own vast area of forests, and, as stated by the Canadian Forest Service (CFS), stores more carbon than the forests of almost any other nation. The vast forested areas led to the development of the National Forest Inventory (NFI) with the focus of monitoring Canada's commitment towards sustainable forest management and to satisfy requirements for national and international reporting. The purpose of the NFI was to assess and monitor the extent, state and sustainable development of Canada's forests in a timely and accurate manner.

The contribution of remote sensing technologies toward the NFI has been primarily based on optical sensors. Landsat data and other optical sensors at various resolutions have made a significant contribution to classification of forest areas, but some challenges exist. These challenges include cloud cover, as well as efficiency, consistency, and effectiveness of change detection methodologies for large areas. To address these challenges, the use of spaceborne radar was investigated. RADARSAT-2 data was used to develop a monitoring program for Canadian forest lands with the aim to provide information on forest cutblocks and to develop algorithms for the detection of forest disturbances. Due to large data volumes and the need for efficiency, an automated end-to-end solution was implemented. The automated solution included image coregistration, temporal filtering, detection of forest disturbances, and delineation of the disturbances.

The outline of this paper is as follows. The next section describes the study sites, followed by data processing. The data processing address the development of a forest, non-forest mask and outlines the change detection algorithm that was developed to detection changes to the forest canopy. The methodology is described in Section 4, followed by the results and the conclusion.

2. Study Sites and RADARSAT-2 Data

Three study sites were selected in Canada that were representative of different forest types and terrain. The study sites in New Brunswick and Quebec were characterized by primarily deciduous trees and the study site in British Columbia (BC) was characterized by coniferous forest. The focus of this paper is on the BC study site (Figure 1).



http://www.nrcan.gc.ca/forests/canada/classification

Figure 1. The three study sites (ref circles) were located in BC (left), Quebec (middle), and New Brunswick (right). The focus of this paper was on the BC study site.

The specific location of the study sites was selected based on the availably of historical RADARSAT-2 data (i.e. at least 2-3 years of data) acquired in the same imaging modes, thus allowing the application of automated canopy change detection algorithms. To augment the historical imagery, RADARSAT-2 data was acquired over the test sites during the summer of 2015 and 2016, but the 2016 data has not been processed, so it was not included in the analysis. RADARSAT-2 Multi-Look Fine (10 m nominal resolution), HH polarization, was the main acquisition mode for all the study sites (MDA, 2014).

For the BC test site, RADARSAT-2 data was acquired between early June and mid-September starting in 2011 and continuing through 2016. There was, however, no data acquired during the summer of 2014. The change detection algorithm (described in Section 3.2) required RADARSAT-2 data to be acquired in the same imaging mode, incidence angle, and the same imaging geometry, thus ensuring that within reason, the changes detected were due to forest-related changes and not due to variability of the image acquisition parameters. The RADARSAT-2 exact repeat period is 24 days, which means to acquire data in the same imaging geometry, imagery was collected every 24 days; therefore, during the mid-June to mid-September acquisition timeframe, three to four images were acquired.

3. Data Processing

3.1 Non-Forest Mask

To reduce the detection of false positives, a SAR-derived non-forest mask was developed. The initial input was the CanVec layers (http://ftp.geogratis.gc.ca/pub/nrcan_rncan/vector/canvec/) that included non-forested areas such as water bodies, roads, and urban/industrial areas. Based on analysis of the RADARSAT-2 imagery, areas of layover, strong backscatter (e.g. urban, industrial), and weak backscatter (e.g. water surfaces) were identified. The non-forest areas derived from the RADARSAT-2 imagery were merged with the CanVec layer to produce a final non-forest mask, and the change algorithm was applied to the forested areas (Figure 2).

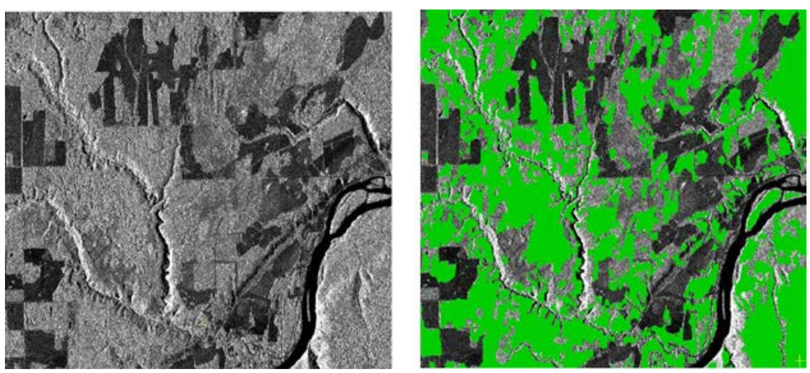


Figure 2. Example of forest mask (green) derived from CanVec data and RADARSAT-2 imagery. RADARSAT-2 subscene with no mask (left) and the same image with the forest mask applied (right)

3.2 Change Detection Algorithm

The change detection methodology was based on an algorithm that had been developed by MDA (van der Kooij, 2013). The methodology starts with either new acquisitions or the use of archived data. The data are processed to Single Look Complex and submitted for change detection processing. The change detection product is geocoded and archived. The final process is visualization of the change detection in a format that is commensurate with end user needs. The change detection processing starts with image co-registration. A series of products are created that include canopy disturbance, canopy texture, filtered images, and ratio images. The output products are, if needed, orthorectified and geocoded. The final products are either compressed to 8-bit raster images or a vector detection-product is generated. Once the

RADARSAT-2 data have been processed and ingested into change detection algorithm, the entire process, including generation of disturbance polygons, is fully automated.

The interface to the change detection processing is via a so-called Work Order that included three main user-defined inputs: (i) averaging, (ii) output spacing, and (iii) disturbance threshold.

(i) The averaging variable allows the selection of the averaging process for a given data set. A number of options were available, but the use of temporal averaging which reduces speckle, but preserves high frequency details, e.g. edges, was selected (Caves *et al.*, 2011);

(ii) The output spacing depended on the RADARSAT-2 beam mode that was used. The aim of the output spacing was to allow the generation of a consistent end product based on variable input resolution. For this study, the output spacing was set to 30 m;

(iii) The disturbance threshold was the ratio of the Before and After images. The ratio was calculated by first converting the RADARSAT-2 image to gamma-nought calibration and then taking the ratio of the Before and After image and the ratio was used to calculate a threshold that depended on the number of Before and After images. The highest threshold occurred when there was one image Before and one image After, and the lowest threshold occurred when the number of Before and After images increased and was the same, e.g. three images Before and three images After.

3.3 False Positives

Although a non-forest mask was used, detection of false positives was inevitable due to the use of an automated change detection process. To mitigate false positives, each region-of-change was assigned a True or False value based on the visual analysis and the use of optical data for reference. True indicated a forest disturbance detected by RADARSAT-2 that was related with forest harvesting, e.g. cutblocks, partial cutting. False indicated a forest disturbance detected by RADARSAT-2 that was attributed to activity in forest areas not related to harvesting, e.g. road construction, and activities adjacent to forest areas that had not been masked out, e.g. agriculture, water bodies, and industrial activity.

4.0 Methodology

The RADARSAT-2 data from the BC study site were processed using imagery acquired roughly between mid-June through mid-August for each year between 2011 and 2015, with the exception 2014. Typically three images were averaged to produce a single image that was considered characteristic of summer forest conditions. The procedure was to apply the change detection algorithm to the averaged summer images, e.g. the changes between the averaged 2012 images and the averaged 2013 images, and to visually remove false positives.

To assess the performance of the change detection algorithm, the RADARSAT-2 changes were compared to tree-loss information from the CFS and cut-block information from the BC Forest Service (BCFS). The CFS tree-loss information, estimated on an annual basis, was derived from Landsat data. The minimum identified tree-loss area was ~00.5 ha and was considered to have an accuracy of approximately 90% (L. Guidon, per. comm., May 2016). The CFS data encompasses tree-loss information due to anthropogenic sources (e.g. harvesting, road construction, conversion to non-forest use) and natural sources (e.g. fire, disease, wind blow-down).

Similar to the CFS tree-loss information, the BCFS cut-block information was derived from Landsat imagery, had a minimum area of ~00.5 ha, and represented cut-block areas on an annual basis (T. Salkeld, pers. comm., Oct 2015). In contrast to the CFS tree-loss information, the BCFS information encompasses actual and planned forest harvesting, meaning that tree-loss associated with non-forest harvesting was not in the BCFS data base.

Since CFS and the BCFS information was representative of annual changes, but the RADARSAT-2 derived changes were representative of summer-only changes, there were discrepancies between the RADARSAT-2 data and the CFS/BCFS data. Specifically, change that occurred after approximately September were not detected by RADARSAT-2 until the following year, e.g. an October change in 2012 was not detected by the 2011-2012 data, but was detected by the 2012-2013 data. The October 2012 change, however, was captured in both the 2012 CFS and BCFS information and subsequently flagged as a 2012 change. To solve this discrepancy, when a change was indicated by the CFS/BCFS data for a given year, the RADARSAT-2 data for that year and following year were processed. If the change detected by RADARSAT-2 was correlated with the CFS/BCFS changes, then change was deemed to have occurred in the current year.

4.0 Results

Figure 3a shows an example of typical changes detected, between 2011 and 2012 in this case, derived from a RADARSAT-2 MultiLook Fine image (8 m nominal resolution, 50 km x 50 km scene size, HH polarization). The incidence angle varied from 46.9° in the near range to 49.6° in the far range. A subscene (Figure 3b) shows areas-of-change related to forest harvesting (blue polygons) and changes attributed to false positives (red polygons), both based on visual analysis.

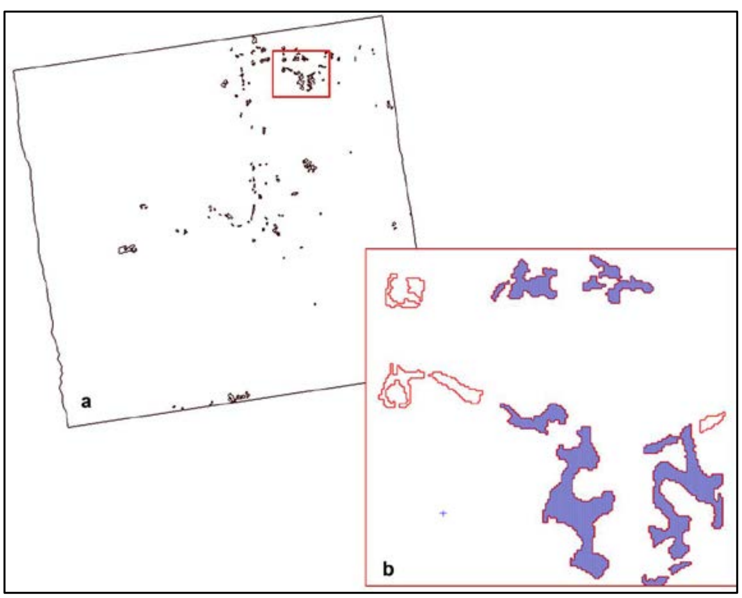


Figure 3. RADARSAT-2 detected changes between 2011-2012 for the entire image (a) (50 km x 50 km) and (b) a subscene (~ 10 km x 10 km). Based on visual analysis, the blue polygons were categorized as forest harvesting and the red polygons were categorized as false positives.

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Figure 4 shows the same area as Figure 3b. The RADARSAT-2 detected changes are indicated by blue polygons, and overlaid with BCFS cut blocks (orange polygons) and CFS tree loss (green polygons). Overall there was good agreement between the RADARSAT-2 changes and the BCFS cut blocks and CFS tree loss. Of note are the BCFS cut blocks that were not correlated with RADARSAT-2 changes or CFS tree loss. As aforementioned, the BCFS data contains both actual and planned harvesting, so in this case, the lack of agreement with CFS and RADARSAT-2 changes suggests that the cutblocks were planned for 2012, but did not happen in 2012. The black indicate CFS tree loss that was due to non-harvesting activity and as such was classified as false positives (see Figure 3). The lack of correlation with BCFS cut block data further supports the observation the tree loss was not related to harvesting.

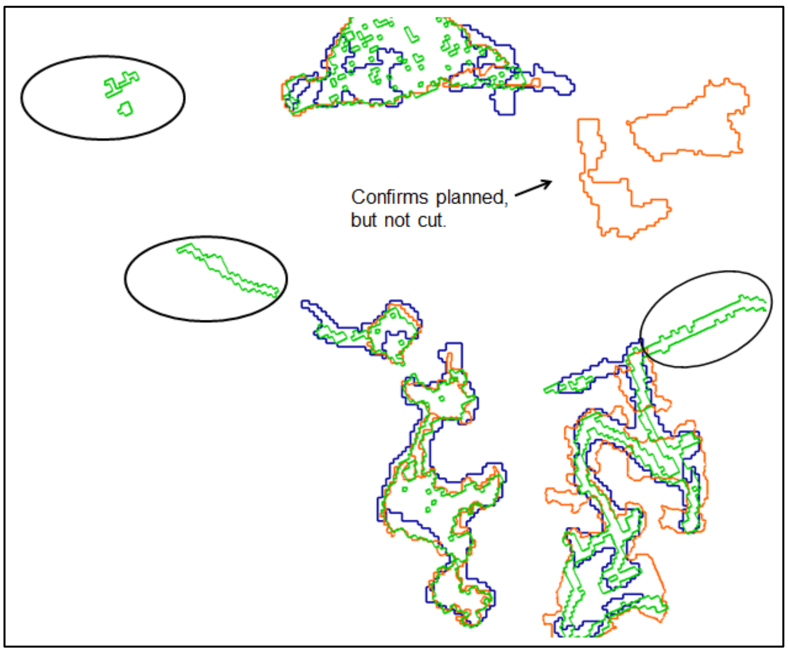

Figure 4. This is the same area as Figure 3b. The RADARSAT-2 detected changes are indicated by blue polygons, and overlaid with BCFS cut blocks (orange polygons) and CFS tree loss (green polygons). The BCFS cut blocks not correlated with CFS tree loss and RADARSAT-2 changes were planned for 2012, but did not occur in 2012. The areas under the black ovals were associated with tree loss, but not harvesting and were therefore categorized as false positives (see Figure 3).

The detection performance for 2011/12, 2012/13, and 2013/15 are listed in Table 1. The performance was based on the RADARSAT-2 detected changes for the entire image (with removal of false positives) that overlapped by at least 50% with the CFS and BCFS data. Note that no data was acquired in 2014, hence the gap between 2013 and 2015. The 50% overlap criteria was used to compensate for the timing differences in the summer-to-summer RADARSAT-2 changes versus the annual changes derive from the CFS and the BCFS data.

Further, the RADARSAT-2 detected changes were auto-delineated, so discrepancies between these changes and the CFS and BCFS change-delineation was expected. Overall the detection performance was better than 80%, with the exception of 2013/15 at 74%; the lower value was attributed to the two-year data gap.

Table 1. The detection performance for 2011/12, 2012/13, and 2013/15. The performance was based on the RADARSAT-2 detected changes for the entire image (with removal of false positives) overlapping by at least 50% with the CFS and BCFS data.

Year	Detection Performance
2011/12	84%
2012/13	89%
2013/15	74%

5.0 Summary and Conclusion

A study site in British Columbia, Canada, characterized by coniferous forest, was selected. RADARSAT-2 MultiLook Fine mode, acquired from mid-June through mid-September, from 2011 to 2015 was analyzed with the aim to detect forest disturbances.

To reduce the detection of false positives, a non-forest mask was developed that entailed a combination of CanVec data that delineated areas such as water bodies, roads, and urban/industrial areas and SAR-derived information such layover and scattering from urban areas. The non-forest areas derived from the RADARSAT-2 imagery were merged with the CanVec layer to produce a final non-forest mask.

The change detection methodology was based on an algorithm that had been previously developed by MDA. The methodology starts with either new acquisitions or the use of archived data. The data are processed to Single Look Complex and submitted for change detection processing. The change detection product is geocoded and archived. The final process is visualization of the change detection in a format that is commensurate with end user needs. Although a non-forest mask was used, detection of false positives was inevitable due to the use of an automated change detection process. To mitigate false positives, each region-of-change was assigned a True or False value, where True meant a forest change (e.g. harvesting, fires) and False meant a non-forest change (urban areas).

To assess the performance of the change detection algorithm, the RADARSAT-2 changes were compared to tree-loss information from the CFS and cut-block information from the BCFS. Since CFS and the BCFS information was representative of annual changes, but the RADARSAT-2 derived changes were representative of summer-only changes, there were discrepancies between the RADARSAT-2 data and the CFS/BCFS data. Notwithstanding these discrepancies, the detection performance was better than 80% for 2011/12 and 2012/13. For 2013/15, however, due to the two-year gap between data acquisition, the detection performance was 74%.

Further work is planned to complete the processing and analysis of the 2016 data, and to complete the analysis of the other two test sites. Of particular interest is the test site in New Brunswick. Unlike the British Columbia and the Quebec sites, where forest harvesting via cutblocks is common, the New Brunswick test is characterized by partial harvesting, where

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partial harvesting entails the removal of approximately 25% of the trees per unit area. Detection of partial harvesting is more challenging than detection of cutblocks, but refinements to the change detection algorithm and the use of high resolution RADARSAT-2 data (e.g. 5 m ExtraFine mode) should allow detection of subtle changes.

6.0 References

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