Comparison of Methods for Estimation of Kyoto Protocol Products of Forests From Multitemporal Landsat

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Abstract- The Kyoto Protocol requires nations to report on their reforestation, afforestation, and deforestation (RAD). Using 1990 as a baseline, nations are also required to monitor changes in carbon stocks leading up to the reporting period 2008 to 2012. A study was conducted using three dates of summer Landsat 5 imagery to estimate above-ground carbon for a forested test site near Hinton, Alberta [1]. The carbon estimates were compared with those derived from Canada's national forest inventory. The remote sensing estimates for areas that had not changed were consistent year to year within 3%.

The experiment was repeated with the addition of leaf-on and leaf-off image pairs and Landsat-7 imagery. A comparison was made of the classification accuracies achieved for forest classes with single date and paired leaf-on and leaf-off image sets. Spatial properties were incorporated into the image analysis by first creating a multitemporal segmentation [2].

This paper reports on the classification methods used, compares the classification accuracies achieved, and gives recommendations for the creation of Kyoto Protocol products for temperate forests derived from remotely sensed imagery.

I. Introduction

The Kyoto Protocol requires nations to report on their reforestation, afforestation, and deforestation (RAD). Using 1990 as a baseline, nations are also required to monitor changes in carbon stocks leading up to the reporting period 2008 to 2012. Several European nations and the United States have announced that remote sensing is their primary tool for the monitoring of other nations to assess their compliance with international agreements, such as the Kyoto Protocol.

A study was conducted using three dates of summer Landsat 5 imagery to estimate above-ground carbon for a forested test site near Hinton, Alberta [1]. Provincial digital topographic data and paper forest cover maps were available to the project. We did not receive access to permanent sample plot data in the test area held by a forest company. Thus the project mimicked the likely situation for nations monitoring other nations. The carbon estimates derived from remote sensing were compared with those derived from Canada's national forest inventory (CanFI). The remote sensing estimates for areas that had not changed were consistent year to year within 3%. Above-ground carbon estimates resulting from each analysis were compared with those derived from the Canadian National Forest Inventory (CanFI). CanFI is based on provincial forest inventories and summarized into 10 km by 10 km cells. Remote sensing classifications indicated almost twice as much forest as in CanFI with half the biomass per hectare as in CanFI.

The experiment has been repeated in this paper with the addition of leaf-on and leaf-off image pairs and Landsat-7 imagery. A comparison was made of the classification accuracies achieved for forest classes with single date and paired leaf-on and leaf-off image sets and is described below.

Canada is a signatory to the Kyoto Protocol and must report on reforestation, afforestation and deforestation. Reporting commitments also include a baseline estimate of forest carbon stocks in 1990 and the monitoring of changes in carbon stocks leading up to the reporting period 2008 to 2012. This paper reports on the classification methods used, compares the classification accuracies achieved, and makes recommendations for the creation of Kyoto Protocol products for temperate forests derived from remotely sensed imagery.

II. Classification Methodology

The classification method used for this study uses both spectral and spatial properties of imagery by applying multitemporal segmentation [2]. The process was performed using our software called Robust Image Analysis System for Satellites and Aircraft (RIASSA), which is run in the PCI environment. A common set of segments is created based on six channels of each three leaf-on dates.

Comparisons between the three dates were made by classifying with input channels from only leaf-on imagery (6 channels) and classifying with inputs from both the leaf on and off imagery (leaf-all, 12 channels). A truth signature database was developed by clustering truth polygons of each desired class and selecting the appropriate unique signatures sets for both leaf-on and leaf-all image sets. This resulted in several unique signatures per class that were then used to classify the segments. Spectral variation within training segments caused by various illumination conditions could then be accounted for, and noise within an original truth polygon could be eliminated. Each segment was classified to

0-7803-7031-7/01/$17.00 (C) 2001 IEEE

one of the unique signatures, then the clusters were aggregated back to the original classes.

The following steps were performed to classify both the three date (leaf-on) image sets and the leaf-on leaf-off combinations (leaf-all):

1) Fused six dates of imagery using common GIS files and DEM;
2) Divided each image date into a common set of 1024 by 1024 overlapping tiles;
3) Segmented each tile into homogeneous objects using a 3 by 3 variance edge detection filter on three years of leaf-on bands 1-5, 7 (18 channels), and uniquely identified each segment (~24,000 segments per tile);
4) Identified cloud and shadow training segments on each date where appropriate;
5) Identified ~250 systematically sampled (on a regular grid) truth segments for each year as one of 16 classes (see Table), using polygons from Alberta Forest Service Phase 3 Inventory Maps (1993);
6) For each of the three dates, using leaf-on and leaf-all, and within each truth class, used K-Means clustering to divide the truth segments into 8 subclasses, and report the signatures of each encoded truth cluster;
7) Evaluated and recorded the state of each subclass where: erroneous truth clusters could be rejected from the training areas, similar (small Bhattacharrya distances) smaller clusters could be merged or eliminated, larger clusters remained.
8) Created a lookup table to convert truth encoded values to a maximum 64 unique state values;
9) Performed classification of imagery segments on each tile, based on signatures of unique states produced from whole study area.
10) Aggregated unique state classification to original truth classes using a lookup table.
11) Mosaicked the resulting classification tiles for the test site.
12) Performed accuracy assessment.

The results of this methodology are presented in the next section.

III. Classification Results

We classified LANDSAT-5 TM data using paired leaf-on and leaf-off imagery for the years 1985, 1990 and 1996. For each date, overall classification accuracies were computed using the weighted average of the individual classification results. Weighting was determined by the frequencies of occurrences of each class.

The overall accuracy of the classification for the six-channel paired segments for 1985, 1990 and 1996 increased substantially over the single image, leaf-on results (Table 1).

The paired leaf-on and leaf-off combination is an important tool for vegetation classification. The inclusion of the leaf-off data sharply delineates the signatures of the deciduous components in the imagery, resulting in increased overall classification accuracy. These accuracies compare very favorably with the reliability of information from traditional forest inventories.

Table 1: Overall classification accuracies for single leaf-on data and paired leaf–on/leaf-off images.

Year	Single date leaf-on overall classification accuracy	Paired leaf-on and leaf-off overall classification accuracy
1985	81.5%	94.45%
1990	90.3%	91.65%
1996	85.4%	94.45%

Fig. 1 shows a sub area (Tile D) from two paired Landsat images (1996) for the Hinton, Alberta test site rendered in RGB as (TM 5, TM 4, TM 3). The lower left corner of Tile D is a mixed wood area, which is mainly occupied by trembling aspen and jack pine. The crown density of the forests is between 31% and 70%. The height of dominant species is from 12 to 24 meters. We note that in the leaf-off image (October 1996), these areas appear bare. These bare areas in the leaf-off period may be due to several possibilities, such as (i) the regeneration is largely due to young hardwoods and mixed woods, or (ii) the regeneration is due to bushes. Fig. 2 shows the resulting classified image for the sub area shown in Fig. 1.

In expanding on previous work [1], we chose a Landsat-7 ETM+ image acquired in July 2000. This scene had cloudy portions. Tile D represents the clear sub area amounting to 65536 hectares for the results which follow. The earlier Landsat dates had been radiometrically corrected to the 1985 base year. The Landsat-7 data were also radiometrically adjusted to the 1985 base year.

Table 2 shows the results pertaining to the above-ground carbon determined from LANDSAT data spanning the years 1985, 1990, 1996 and 2000 for area of Tile D.

Table 2: Biomass and carbon attribute in the sub area of Tile D. All units are total values in an area of 65536 hectares.

Year	1985	1990 (Reg85)	1996	2000 (Reg85)
Clearcut (ha)	7336	2522	6772	10172
Biomass (Mm^3)	7.371	6.947	6.863	6.614
Carbon (Mt)	1.576	1.489	1.469	1.414
Total Tile Area (ha)	65536	65536	65536	65536
Carbon (Biomass*409 *0.5) in Mt	1.507	1.421	1.403	1.353
No change Carbon in Mt	1.397	1.340	1.382	1.414

We note a reduction of 3.5% in above-ground carbon in the year 2000 imagery compared with 1996. As noted earlier, the Landsat-7 data were put on the radiometric base of the 1985 data. Had this radiometric correction not been performed, the above-ground carbon estimate would be 1.173 Mt instead of 1.414 Mt, a difference of 17% and larger than the perceived reduction in above-ground carbon since 1985. This demonstrates an important requirement for multi-temporal analysis for carbon; namely, radiometric calibration with the removal of atmospheric effects and the reduction of imagery to reflectance.

IV. Carbon and RAD over time

For the estimation of reforestation, afforestation, and deforestation (RAD), we used Landsat data from 1985, 1990, and 1996 corresponding to 240,000 ha in the Hinton test site. In a cooperative environment, we would know the land use intent of the forest managers. Without this knowledge, it is necessary to infer land use intent from the remotely sensed data. The 1985 image was used as the base. A RAD image was created as follows.

The 16 classes for each of the three image dates were converted to one of three land-types: (1) Forest (F), (2) Non-Forest (N) and (3) Regeneration (R) in accordance with the matrix shown in Table 3. The forest cover consists of the three forest categories, Conifer, Mixed Wood and Deciduous. The regeneration class has been visually interpreted. In a RGB combination of TM bands 5,4,3, regenerating areas appear as bright green former clear cuts. All no-data classes, such as cloud and shadow, in any year were set to unclassified. All other classes were set to Non-Forest.

Table 3. Converting classes to three land types.

Class	Land Type
No Data	Unclassified
Conifer	Forest
Mixed Wood	Forest
Grassland	Non-Forest
Rock	Non-Forest
Cleared Land	Non-Forest
Scrub Conifer	Non-Forest
Scrub Deciduous	Non-Forest
Treed Muskeg	Non-Forest
Clear Cut	Non-Forest
Regeneration	Regeneration
Mine	Non-Forest
Water Dark	Non-Forest
Water Light	Non-Forest
Cloud	Unclassified
Shadow	Unclassified
Deciduous	Forest

We evaluated the twenty seven combinations and permutations of three dates and three land-types and assigned each to one of these RAD classes: Reforestation (R90, R96), Afforestation (A90, A96), Deforestation (D90, D96), Forest (F), Non-Forest (N) or No Data (ND). The results of these assignments are shown in Table 4.

Since the intent of the land use was not known, 1985 was set to be the base year. If an area was non-forest in 1985 and was changed to either forested land or regeneration, it is considered to be an example of afforestation. The year assigned to afforestation is when new forest or regeneration was detected.

Table 4. RAD classes selected from three land-types per three image dates, and resulting area of each combination of the 24 full tiles.

RAD	1985	1990	1996	Area
R90	F	R	F	0.39%
R90	F	R	R	0.51%
R96	F	F	R	0.62%
R96	F	N	F	4.15%
R96	F	N	R	1.11%
R96	R	N	F	0.62%
R96	R	N	R	0.25%
A90	N	F	F	6.35%
A90	N	F	R	0.39%
A90	N	R	F	0.08%
A90	N	R	R	1.31%
A96	N	N	F	9.85%
A96	N	N	R	1.21%
D90	F	N	N	1.40%
D90	R	N	N	0.59%
D96	F	F	N	2.83%
D96	F	R	N	0.32%
D96	R	F	N	0.02%
D96	R	R	N	0.36%
F	F	F	F	50.14%
F	R	F	F	0.03%
F	R	F	R	0.00%
F	R	R	F	0.13%
F	R	R	R	0.89%
N	N	F	N	2.82%
N	N	N	N	10.52%
N	N	R	N	0.70%
ND	ND	ND	ND	2.42%

Table 5. Reforestation, afforestation, and deforestation results for 1990 and 1996 for the Hinton, AB test site.

	1990	1996
Reforestation (ha)	2,052 (0.86%)*	15,356 (6.40%)*
Afforestation (ha)	18,492 (7.70%)*	25,161 (10.48%)*
Deforestation (ha)	4,517 (1.88%)*	8,023 (3.34%)*
Carbon (Mt)	5.70	5.15
No Change Forest Area (ha)	116,472 (51.2%)	116,472 (51.2%)

* Percent of whole township (240,000 ha)

Very little area (0.86%) was reforested between 1985 and 1990 (see Table 5). The deforestation label was attached to areas that had either forest or regeneration in 1985, but were non-forest in 1996. If an area has been deforested in 1990, and remained a non forest in 1996, it was labeled as deforested 1990 (D90). Half of the area (116,472 ha) was forest that didn't change over the 11 year time period. Fig. 3 shows the spatial distribution of the RAD and other classes.

V. Conclusions

This paper reports on experiments conducted with Landsat data over the Hinton test site in Alberta, Canada. Combinations of leaf-on leaf-off images were demonstrated to provide substantial improvements (8%) in classification accuracies for forest types. The classification procedures incorporated spatial segmentation and clustering and are described above.

Remote sensing was used to estimate the Kyoto quantities of reforestation, afforestation and deforestation and above-ground carbon for this managed forest site. In the absence of known land use intent, we used multitemporal remote sensing to infer intent with respect to a 1985 base year. Afforestation was found to be 18,402 ha in 1990 and 25, 161 ha in 1996. More than 51% (116,472 ha) of the forested area in the test site did not change from 1985 to 1996.

Acknowledgments

We acknowledge the cooperation of Dave Morgan of the Alberta Forest Service and thank him for providing digital topographic data and Phase 3 paper maps for the Hinton test site. We thank Mark Gillis for providing us access to the tables contained within the Canadian National Forest Inventory. DGG acknowledges support from the Natural Science and Engineering Research Council (NSERC) of Canada. We are most grateful for financial support from the Canadian Forest Service, Natural Resources Canada.

References

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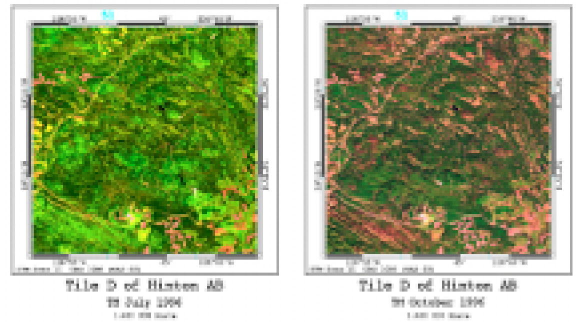
Fig. 1. Leaf-on (left) and leaf-off images acquired by Landsat-5 TM over the Hinton, Alberta test site in July 1996 and October 1996 respectively.



The relative differences in the vegetation cover are due to bushes and hardwoods being void of leaves in the fall.

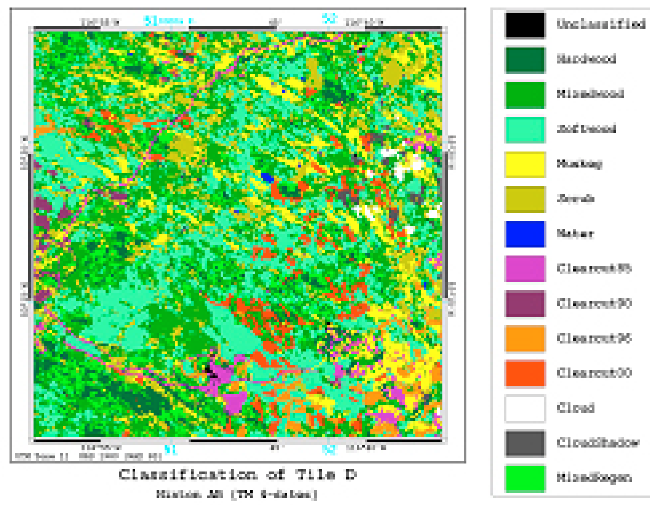


Fig. 2. This is the classified image for Tile D obtained from a Landsat-7 image (2000) which was orthorectified to a Landsat-5 TM image from 1985.

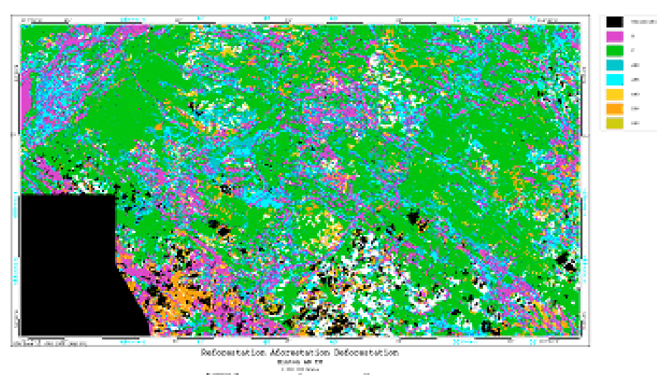


Fig. 3. This image of the entire test site shows the following RAD classes: reforestation (R90) in yellow green; afforestation as blue (A90) and turquoise (A96); deforestation as yellow (D90) and orange (D96). The other classes shown are forest (F) in green, non-forest (N) in pink, and unclassified in black.