An Investigation of Two Date Unsupervised Classification in the Context of a National Program for Landsat Based Forest Change Mapping

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***Abstract*- A number of change mapping methods are being evaluated as part of a national program for monitoring Canada s forest cover, change and biomass (Earth Observation for Sustainable Development - EOSD). One approach being evaluated involves a simple two date multispectral unsupervised classification approach to map forest change at a national scale with Landsat data. Key factors are the types and consistency of change classes that emerge from the clustering algorithms and issues related to labelling these into desired change classes. The technique was investigated using two sites. Prince George in central British Columbia, Canada used 1990 and 1999 imagery. The second site of Petawawa in eastern Ontario, has fifteen images from a time period from 1984 to 2001 that were normalized and then analyzed in various image pairs.**

Utilizing the six visible and infrared Landsat bands from each of two dates in a K-means hyperclustering, classes of conifer, hardwood and mixedwood that had not changed were separated. Before any amalgamation, many clusters were associated with change, especially changes in vegetation on old cuts and open fields. Post-clearing ground vegetation density and type had a moderate influence on the clustering process. Pre-clearing forest type was only a factor in general terms, for example whether it was hardwood, softwood or mixedwood. Clearcuts often had several clusters associated with them, but were well detected when clusters were amalgamated. Partial cuts were only partly detected. The length of time after the cut was an important consideration in their detection. They were detectable for only 2 or 3 years after the cutting.

The above approach is expected to be one of several tools used in the EOSD initiative.

I. INTRODUCTION

Earth Observation for Sustainable Development (EOSD) is a collaborative project that has as its goal to map the forest cover of Canada periodically (5-10 years), monitor forest disturbance and change, produce biomass maps and estimates, and develop appropriate methods and systems for use of others [1, 2]. Moderate resolution satellite data such as Landsat imagery will form the core data source. The desired plan for the forest monitoring component of EOSD is to undertake full coverage mapping of major changes on the 5 to 10 year EOSD cycle, create a network of permanent satellite sample plots (PS^2Ps) to monitor major, more subtle and ephemeral changes annually, and use low resolution imagery such as MODIS to confirm and date specific changes. There are many change detection and classification techniques that can be brought to bear to accomplish these goals. These include post classification comparison, combined date unsupervised and supervised change classification, multitemporal principal component analysis, change vector analysis, and others [3, 4, 5, 6, 7]. Time trend analysis can be applied to the annual monitoring of the PS^2Ps. This paper explores some of the design issues related to using a two date unsupervised classification approach for detecting and classifying forest disturbance and other changes for the purpose of mapping major changes between a 5 to 10 year time interval. These major changes are clearcuts, burned areas, other forest clearing, and some regeneration and high mortality insect and disease damage.

Two date unsupervised classification for change detection is a standard approach and has been examined for forestry applications (e.g., [8]) and been applied operationally over large areas (e.g., [9]). In the EOSD context we need to know its appropriateness considering the forest terrain and typical changes of Canada and various operational constraints for EOSD. Important questions are:

1. what change classes will normally be clustered as separate entities in images with different types of forest terrain and change, and amount of change,
2. what are the best specific procedures and algorithms,
3. what accuracy can be expected, and
4. how well do non-change forest classes get determined?

Concentration in this study is on the first question.

Landsat imagery from two study areas was examined. The Petawawa site in Eastern Ontario exhibits a wide variety of change types and has a suite of 15 Landsat images, covering almost every year from 1984 to 2001. Various date pairs were used. The ability to detect different change types and the robustness and consistency of clustering techniques was investigated. In contrast, Prince George, B.C. the second site, has two images, 1990 and 1999. Forest cover is quite uniform and change mainly consists of numerous clearcuts. Therefore there are many replicates spatially to investigate the two date clustering process.

II. IMAGERY AND SITES

The Petawawa site is a 100 by 50 km area in eastern Ontario approximately 200 km northwest of Ottawa. It encompasses the Petawawa Research Forest, Canadian Forces Base-Petawawa, part of Algonquin Provincial Park and surrounding townships (centred at 77° 52 W; 46° 00 N).

It is in the Great Lakes-St. Lawrence Forest Region. The forest is a mix of boreal and temperate forest species (red pine, white pine, spruce, aspen, red oak, maple, and birch). Topography is generally flat or rolling but with some ridges. There are a variety of disturbances and changes due to the different land uses. These included clearcuts, partial cuts, burns, regeneration, soil disturbance and expanding industrial and infrastructure development on CFB Petawawa. It also contains several large open areas with a variety of ground vegetation density. There is little change in the research forest. Normal forestry activities and urban and rural expansion occur in the surrounding areas. The amount and type of change between image pairs depended on the dates being used. At various time periods clearcuts, burns, blowdown, partial cuts or no/little change were the dominant change features.

Both winter and summer Landsat imagery has been acquired over the last 30 years. For this study only summer Landsat TM imagery was examined. It was geometrically corrected to 25 m resolution commercially through the MOSAICS and GICS systems.

The Prince George site is in central British Columbia on the Interior Plateau (centred at 123° 20 W; 54° 15 N). The site covers approximately _ of a Landsat scene (135 by 105 km) and includes Prince George a city of 75,000 with some agriculture around it, but also has a large agricultural area with pasture and cropping in the southwest region of the site (Vanderhoof area). Agriculture accounts for approximately 1/10 of the site. The forest is predominantly conifer (lodgepole pine and spruce). Some mixedwood stands and pure hardwood, usually dominated by aspen, also occur. There is some expansion of agricultural fields, urban areas and rural residential dwellings. By far the most prevalent change is clearcutting of the conifer stands. Forestry is the main industry of the area and there is a patchwork of moderate sized regular shaped clearcuts. However, the agriculture area represented another large group of change pixels due to different cropping patterns and fallow conditions between the images. As well as the new clearcuts between 1990 and 1999, older cuts occur and are in various stages of ground vegetation cover and regeneration. There are a few old burn areas that are dominated by hardwoods, but there were no burns from 1990 to 1999. Topography varies, but is generally rolling with higher relief on the east side of the site. An important feature is a strong northeast-southwest geologic pattern of tight ridging caused by drumlinoid features.

Only two dates of imagery are used for the Prince George site, August 10, 1990 and September 12, 1999. Hardwoods on the September imagery were in partial senescence, but there was little leaf fall. Crops and pasture were in various stages of harvest and browning off. Conditions were clear for the 1990 imagery. The 1999 image had some haze and a streak of smoke extending northwest in a narrow band across the northeast part of the site.

III. METHODS

The sequence of imagery for Petawawa was normalized over all dates with an empirical approach. The differing image dates were matched for each band following the relative calibration methodology proposed by Joyce and Olsson [10]. Olsson [11] has shown that for forest mapping, stable forest may prove a better calibration feature than bright and dark targets such as lakes and soil. The procedure uses stable forest pixels to form a histogram, from which outliers are removed. A linear correction between image pairs is produced, which has an offset equivalent to the difference in the means of the stable forest mask and a gain equal to the ratio of their standard deviations. In a time series scenario each sequential pair is matched then systematically readjusted outward from a clear image reference. After calibration, a number of stable stands were selected and their band means plotted to ensure the effectiveness of the normalization. The 1990 Prince George image was normalized to the 1999 image in a similar fashion.

K-means unsupervised classification was conducted using the six optical bands from each image of the image date pairs. Minimum distance classification rules were used to conduct the classifications. The clustering was run with 241 classes requested, 12 iterations and a 20% sample. Clusters were labelled based on known conditions from inventory data, aerial photos, aerial observation and ground visits. The labelling was a description of the surface type or change, not predefined classes. The classification process and labelling takes into account both the time 1 and time 2 surface types. Table 1 lists the codes used to describe various cover types and changes examined in this study. A change from one cover type to another is indicated by a dash between time 1 and time 2 cover type descriptions (e.g., a label of CDM-lgv, means a conifer dense mature area has changed top open with low density ground vegetation; a label of CDM means it is a stable conifer stand for both dates). Clusters representing several different surface types or changes were reclustered. Clusters were then amalgamated into broader classes of stable surface types or changes. Areas of known surface type and condition were delineated and used as reference for quantifying what clusters represent and for determining accuracy.

Table 1. Cover type description codes.

Forest (type, closure, age)			Open	Other
C conifer	D dense	O old	bs bare soil, sparse ground vegetation	Burn
M mixed	O open	M mature	lgv low density ground vegetation	Urban
B broadleaf	S sparse	I immature	mgv medium density ground vegetation	Road
		Y young	dgv dense density ground vegetation	Wetland
		R regeneration	Agr agriculture crop, fallow and pasture	Water

IV. Results

For the Petawawa data set, a series of clusters were generated from examples of change types from various date pairs exhibiting these changes (not all change types were exhibited on any single pair of images). Clearcuts with different initial forest types (conifer, mixedwood and broadleaf) were classified as a forest clearing cluster regardless of pre- and post-clearing land cover (76% to 99% of pixels in test areas of different pre- and post-clearing cover types were identified as a forest clearing cluster). Exceptions were the mixedwood to bare and broadleaf to low density ground vegetation sites. They were sometimes confused with agriculture cropping classes. It appears that it is the extreme change from vegetated to sparse vegetation that dominates the clustering process rather than the fact that sites were crop or mixedwood and broadleaf. There was also some confusion of conifer clearcut with wetland areas that had dried between the two image pairs (1 to 18%, depending on post-clearing vegetation density). There was not good differentiation of pre-clearing forest type. A mixedwood to open cluster was not separated by the clustering process and most mixedwood clearcuts were occupied by the conifer to low or moderate ground vegetation clusters. Conifer burn sites were clustered as conifer burn clusters (46%) or conifer defoliated clusters (50%).

Detection of partial cuts was variable depending on the quantity of trees removed and time interval between the cutting and image acquisition. A series of classifications was conducted between a base date and images from successive years after partial cutting occurred. The cuts were identified as a series of dense conifer to open conifer clusters (CDM-COM), but over 35 to 45% of the pixels remained the pre-clearing forest cover class. In general, the cutting was detectable as a change for the year of the cut and one or maybe two years after (Table 2). A change in composition of the mixedwood partial cuts towards more broadleaf is also reflected in the time sequence of classifications.

Table 2a. Conifer partial cut class composition (%) for a five year sequence before and after the cut.

Time\Class	CDM	MDM	BDM	CDM-COM	CDM-BURN
Before cut	84.7	14.6	0.0	0.0	0.0
Year of cut	33.6	12.2	0.0	39.8	6.8
1 yr after	54.8	11.1	0.0	31.5	0.0
2 yr after	65.0	12.0	3.7	18.8	0.0
3 yr after	81.2	15.0	0.2	1.6	0.2

Table 2b. Mixedwood partial cut composition (%) for a five year sequence before and after the cut.

Time\Class	CDM	MDM	BDM	CDM-COM	CDM-BURN
Before cut	50.0	44.3	3.0	1.8	0.2
Year of cut	15.6	21.5	0.4	52.0	1.7
1 yr after	42.6	31.4	5.5	18.6	0.0
2 yr after	43.2	36.0	11.1	8.4	0.1
3 yr after	34.4	56.9	6.9	1.2	0.0

The nature of the clustering was examined using the 1986 and 1993 images, an image pair that encompassed a wide variety of change types. There were 182 clusters of which 132 were related to land cover (i.e., not water or cloud) and had more than 100 pixels within them for the whole site. The majority of these clusters were related to stable land cover types. Twenty one clusters (15%) were related to stable vegetated open ground. Twenty percent of the clusters were assigned to exposed soil or non-vegetated urban, industrial or road surface types. Stable forest types and conditions occupied an additional 40 clusters. Classification of broad classes of unchanging forest was accurate for the conifers, with 93% of pixels in the reference areas of conifer being classified as a conifer cluster. Mixedwoods and broadleaf were identified accurately as stable forest but were confused with each other. Most (33) of the remaining clusters were related to change. Ten percent of the clusters were taken up by either variation in vegetation density of open vegetation covered areas or changes in vegetation condition on open areas caused by vegetation changes over time or different growing conditions for a specific year. Only ten clusters were related to forest clearing, including three for burned conifer areas. An additional three represented partial cuts.

The stability of the clustering with different input images in terms of change types and amounts of changes needed to trigger a new cluster was tested empirically. The same clustering process was performed on a sequence of selected image pairs. A one to one correspondence of clusters can not be expected. For one matter, there are different clusters generated by different multispectral image structures at both low and high spectral values (e.g., from cloud, cloud shadow, lake sunglint and other factors). However, for the stable forest, cluster patterns were remarkably similar. Open fields generated quite different numbers and patterns of clusters, but these clusters represented similar characteristics (e.g., vegetation density and composition, albeit different specific densities and composition). Changes showed up well, usually in distinct classes, but these changed among image pairs. This is further evidenced by applying the clusters from one image pair (cluster means in the minimum distance classifier) to other image pairs. Again the overall forest type and detection of change was comparable.

For the Prince George site, stable dense conifer or dense conifer with some broadleaf (C/MD), the predominant forest types, only occupied 15 final clusters. Stable hardwoods occupied 11 clusters and only 4 were associated with mixedwoods. There were 171 final clusters in total related to land cover and with more than 100 pixels within them. Stable forest, stable ground vegetation, and stable urban, road, and exposed soil produced approximately half of these clusters, each accounting for 25 to 30 clusters. Of the 74 change clusters, 21 are related to clearcuts and 17 are associated with change in vegetation due to senescence. The majority (36), however, were related to changes in vegetation cover on the areas that were already open in 1990. These were generally related to increased vegetation cover (e.g., classes related to exposed soil changing to moderate ground vegetation density, low ground vegetation to dense, moderate density ground vegetation changing to dense, etc.). The older cuts with regrowing vegetation were much more common and complex on the Prince George site than for Petawawa. This likely accounts for the greater number of clusters generated for ground vegetation changes. Table 3 summarizes the proportion of each cluster present in reference sites of old clearcuts (prior to 1990) with changing ground vegetation density classes. In these revegetating and regenerating older clearcuts, the variation in time 1 and time 2 ground vegetation density dominated the clustering process. Quite subtle differences were captured reliably. Some clusters were related to disturbance of the old cuts and a decrease in vegetation density. Agricultural areas with different crop densities or pasture conditions were also occupied by these same clusters. There was, however, little confusion of agriculture areas with forest clearing classes.

A main interest is how well the classification captured new forest clearings. Within the Prince George site, such changes are simple, usually being dense conifer to low density ground vegetation in well defined, regular shaped cut blocks. Identification of these through the unsupervised classification approach was excellent. All the reference cut blocks representing new clearcut sites were predominantly classed as forest clearing clusters. Ninety five to 100% of the pixels within the test areas representing conifer clearcuts (conifer to bare through conifer to dense ground vegetation) were associated with a conifer clearing cluster and indeed most were a group of conifer/mixedwood clusters to bare clusters (Table 3). Recognition of mixedwood clearcuts did depend on post-clearing vegetation density. Mixedwood to light ground vegetation cover were well detected, while mixedwood cuts to moderate and dense ground vegetation were not identified well with 66% to 71% of the pixels being related to a forest to open cluster. These had a considerable number of stable forest classes or other vegetation change such as senescing ground vegetation or broadleafs associated with them (Table 3). Broadleaf clearcuts to light ground vegetation were confused with senescing ground vegetation and stable open broadleaf clusters (Table 3). It therefore appears that for mixedwood and for hardwood stands, once the ground vegetation becomes moderate or dense, some pixels are not recognized as changed or at least not a forest clearing change.

Pre-clearing forest types were only moderately differentiated by the clustering (Table 3). The change from forest to open seems to dominate the clustering process over the pre- or post-clearing surface type. The broadleaf cuts were generally identified correctly. The mixedwood cuts were classed mainly as the conifer/mixedwood to bare clusters. Conifer cuts were correctly identified as conifer to open. A factor is that the landscape did not have many cases of mixedwood and broadleaf forest clearings, so specific clusters may not have been separated. As well, the Prince George site is quite simple both in terms of forest type and post-clearing land cover and most cuts had low ground vegetation density. It is therefore expected that for fine forest type differentiation further reclustering of forest clearing areas or perhaps creative use of only the time 1 image may be needed.

Table 3. Proportion of reference sites occupied by clusters of different classes. Reference sites represent a suite of change types (different time1 and time2 landcover).

		Class Name																					
		CD stable	C/M stable	M stable	BD stable	BO stable	B senesced	CD - bs	C/MD - bs	C/MD - gv	M - bs	B - bs	bs stable	gv stable	gv senesced	bs - mgv	bs - m/d gv	lgv - dgv	l/mgv - dgv	mgv - dgv	dgv - vdgv	gv - bs	other
Test Area Cover Type	CD	47.0	52.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2
	MD	18.2	46.9	21.9	4.5	6.6	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	1.1	0.0	0.0
	BD	0.0	1.6	9.0	25.6	23.8	27.5	0.0	0.0	0.0	0.0	0.0	0.0	5.2	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.1	6.6
	CD - bare	0.0	0.0	0.0	0.0	0.0	0.0	45.0	55.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	CD - lgv	0.0	0.0	0.0	0.0	0.0	0.0	3.6	96.1	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	CD - mgv	0.0	0.0	0.0	0.0	0.0	0.0	0.0	99.4	0.0	0.0	0.1	0.2	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.2
	CD - dgv	0.0	0.0	0.0	0.0	0.3	0.0	0.0	98.3	0.3	0.2	0.0	0.0	0.0	0.1	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.2
	MD - bare	0.0	0.0	0.0	0.0	0.0	0.0	23.9	76.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	MD - lgv	0.0	0.0	0.0	0.0	0.0	0.0	4.5	27.7	1.3	10.5	51.9	1.3	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.9
	MD - mgv	0.0	0.3	0.3	0.1	8.3	13.6	0.0	50.9	9.8	5.5	0.0	0.0	0.0	6.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.4
	MD - dgv	1.7	5.8	8.2	0.0	6.6	0.2	0.8	69.3	1.1	0.0	0.0	0.0	0.0	0.0	1.9	0.2	0.9	0.2	0.8	0.0	0.0	2.6
	BDM - lgv	0.0	0.0	3.0	0.0	6.8	3.0	10.5	1.5	0.8	6.8	51.1	1.5	0.0	6.8	0.0	0.0	0.0	0.0	0.0	0.0	1.5	6.9
	BOY - lgv	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.6	90.6	1.4	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.6
	Lgv - m/lgv	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.1	0.0	0.0	0.0	11.6	2.5	5.2	48.9	14.8	16.5	0.2	0.0	0.0	0.0	0.0
	Mgv - dgv	0.0	0.1	0.9	4.2	2.1	10.7	0.0	0.0	0.0	0.0	0.0	4.0	0.1	4.1	27.1	1.2	7.1	7.0	29.2	1.7	0.0	0.5
	Dgv - vdgv	0.0	5.0	10.0	25.3	6.7	12.5	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.2	0.3	0.0	0.2	0.0	10.8	28.6	0.0	0.0
	Agriculture	0.0	0.0	0.0	0.0	0.3	0.4	0.0	2.7	0.1	0.2	2.8	21.8	12.7	15.4	31.5	0.1	0.2	1.1	0.1	0.0	8.5	2.0

The classes of new clearings that were clustered were not very strongly influenced by the post-clearing vegetation density. The clusters which were labelled conifer to bare soil/sparse ground vegetation (bs) captured almost all of the conifer forest clearing regardless of post-clearing ground vegetation density. The conifer to low-moderate density ground vegetation clusters (C/MD-gv) were not well populated or related to the cuts with more ground vegetation. However, those pixels within test areas that were in this cluster were generally related to areas of clearing with moderate or dense ground vegetation. In terms of forest change detection this means that a large number of clusters or complicated class structures are not required to create a good classification of forest clearing.

V. Summary And Conclusion

The characteristics of the clustering generated by a K means approach was examined for two sites with quite different forest conditions, change types and image date differences. If represented by sufficient pixels, quite fine changes in cover type can be detected. Change in land cover represented 25 to 45% of the land cover clusters. Changes in vegetation density on open areas can create a large number of clusters, although there were fewer such clusters for the Petawawa site. Disturbances such as clearcuts are represented by fewer clusters (approximately 10% of the clusters); the large spectral differences between dates dominating the clustering over subtle differences in the pre-clearing forest cover type or post-clearing ground vegetation density. In general there was some, but not consistent characterization of the specific type of change. For example, clearings for agriculture, forest harvest or industrial development were not necessarily clustered separately. Stable non-change forested classes were classified reasonably well. Clearcuts were detected with high accuracy. Subtler changes such as partial cuts were not well detected in separate clusters, but some partial cut sites were distinguished as a distinct cluster. Several years after the cutting, however, the partial cuts were rarely clustered as a change class. Therefore, in addition to the quantity and types of change prevalent in the landscape, effectiveness of the two date unsupervised classification approach is sensitive to the time interval between images.

Results of this study and work of others warrants inclusion of a two date unsupervised classification approach as one component of the EOSD change methodology.

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