Landsat ETM+ Classification of Fluxnet Canada Flux Stations

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***Abstract*— Changes in land use and cover and natural disturbance are thought to be major controls of the dynamic sink/source balance for the immense boreal terrestrial carbon stock. Fluxnet-Canada is a national research network developed to study the influence of climate and disturbance on terrestrial carbon cycling along an east-west transect of Canadian forest and peatlands. The purpose of the present work was to create large-area land cover classifications from satellite imagery to support Fluxnet scaling and modeling studies. The methodology presented in [9] was implemented on seven Fluxnet monitoring sites across Canada. A Landsat ETM+ image covering each site was clustered to 150 classes using unsupervised K-Means classification prior to 50-cluster merging through classification by generalization (CPG). The resulting clusters were merged to 16-class landcover maps through interactive labeling using cluster bitmaps to create spatial context for the 50 clusters. The bitmaps aided the analyst when ground data was scarce or nonexistent. The products were sent to Fluxnet-Canada site managers for ground validation and the classifications were refined according to the feedback provided. The final landcover maps were used in the calculation of leaf area index (LAI) for the Landsat ETM+ scenes, thus allowing for upscaling of carbon flux measurements based on the correlation of LAI to carbon flux.**

Keywords-Landsat; classification; Fluxnet; LAI

I. Introduction

Human enterprise has had a significant impact on the global carbon cycle, while evidence is growing that these changes are affecting Earth's climate. Changes in land use/cover and natural disturbance are major controls of the dynamic sink/source balance of the immense terrestrial carbon stock. Fluxnet-Canada is a national research network developed to study the influence of climate and disturbance on terrestrial carbon cycling along an east west transect of Canadian forest and peatlands. As the scale of the Fluxnet-Canada network is Canada wide and the instrumentation is site specific, medium resolution imagery, such as that from Landsat ETM+, is a logical tool for scaling site-specific measurements of carbon flux to larger areas within Canada.

The methodology presented in [9] was implemented on seven Fluxnet monitoring sites across Canada. As explained in [9] the key features of this approach are an increase in the ratio of computer to human analysis and automation for high data volume or large area processing. This method is thus an ideal candidate for producing a consistent set of Fluxnet classifications. As field validation was not feasible for this work, the completed classification maps were delivered to the Fluxnet-Canada site managers for accuracy assessment and the maps were adjusted accordingly. The final landcover products were then used for producing higher-level products.

Leaf area index (LAI) is a valuable parameter for upscaling site-specific measurements to larger areas. LAI was therefore calculated for all land cover maps using published Canada Centre for Remote Sensing (CCRS) algorithms. The final land cover and LAI maps were delivered to the Fluxnet site managers. All validation is to be completed by members of the Fluxnet-Canada teams.

II. Objective

A. Purpose

The purpose of this set of remote sensing based land cover maps is to meet the needs of scientists and others interested in land cover distribution surrounding the Fluxnet-Canada study sites across Canada.

B. Carbon

Canada's boreal forests are composed of forest and peatland ecosystems. Although both are important carbon stores, forests contain the majority of carbon in living biomass, while peatlands hold more than 99% of their carbon in dead biomass [11]. Although Fluxnet-Canada monitors both forests and peatlands, LAI is useful only in scaling procedures involving forests, as the leaf area is representative of the amount of carbon held and produced within a forest.

At the Fluxnet-Canada monitoring sites, the Eddy Covariance technique is used to measure the exchange of CO2 H2O sensible heat and radiant energy for various ecosystems

[11]. Each station has at least two tower sites within 50 km of each other, with one site located in a mature forest stand or peatland and one site located in a disturbed forest stand or alternate peatland type [11]. The variation in site location allows for studying the controls of C flux from individual ecosystem components.

C. Landsat

Seven Landsat ETM+ scenes were selected to cover the Fluxnet study sites across Canada. All scenes were processed to at-sensor radiance units prior to projection and correction using header-file specific gains and biases. The Landsat scenes were received from the data provider in the Level 1-G (systematically corrected) Hierarchical Data Format.

Scenes acquisition dates ranged from 1999 to 2001, with all collections falling between June and August with no more than 10% cloud cover.

TABLE I. LANDSAT ETM+ SCENES USED IN THE FLUXNET SITE CLASSIFICATION

Fluxnet Study Site	Date	Path	Row
New Brunswick	2001/06/28	10	28
Eastern Peatland	2000/07/05	16	29
Quebec	2001/08/25	16	25/26
NorthernOntario	2001/08/21	20	26
Saskatchewan (BERMS)	2001/08/12	37	22/23
Western Peatland	2001/08/15	42	22
British Columbia	1999/08/27	49	25

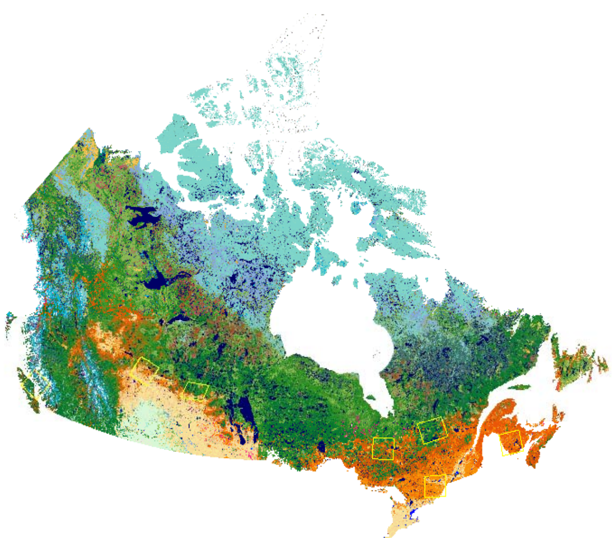

Figure 1. Fluxnet sites across Canada. Background from [19].

D. Water and Wetland products

To aid in the classification of areas with little corresponding ground data, water and wetland products were created to cover the full Landsat scenes. The vector coverages were acquired by CCRS for the production of a 1-km resolution water fraction map of Canada [18]. The quality of the vector layers was variable and therefore had to be inspected thoroughly before use. The layers were originally obtained from the National Topographic Database (NTDB) and divided by NTS Map sheet number [1]. Therefore, multiple sheets had to be collected, merged, subset, and reprojected to match each Landsat image.

In all but one scene, water was accurately extracted based on verification with existing imagery. The exception was the Northern Ontario scene, where water bodies and wetlands were too spectrally variable to extract accurately. A water mask was therefore created based on histogram segmentation [6]. As in all histogram operations, a histogram is derived for the spectral bands under investigation (Landsat band 4 in this case). The land and water mean digital numbers (scaled at-sensor radiance) were then differentiated from a bimodal histogram and the pixel values were assigned to the closest mean. In this case, mean and standard deviations were calculated from the digital numbers contained in the distribution of water pixels and pixels that fell within 2 standard deviations of the mean were classified as water.

Because interpretation of wetlands from aerial photography is difficult and the 'wetland' category can vary spectrally, the vector wetland layers could only be used for reference for cluster labelling and not as an exact label. The wetland vectors were also useful for extrapolating the understory of the forested classes as well as the makeup of the broadleaf vegetation classes.

E. LAI products

Leaf area index (LAI) is defined as half the all-sided green leaf area per unit ground surface area projected on the horizontal datum [20] and is a quantitative measure of foliage density [10]. LAI is also an important indicator of vegetation status for modeling water fluxes [17] and energy [3]. The current study used validated nation-wide LAI algorithms developed in previous studies [7] [10] to measure LAI over the Fluxnet-Canada study areas. To model LAI from ETM+ surface reflectance measurements, each Landsat scene was initially processed using the Infrared Simple Ratio (ISR=TM4 / TM5) LAI algorithm introduced in [10], stratified by the land cover classification. The LAI for pixels classified as needle-leaf forest was modeled using regression equation (1) while those pixels classified as broadleaf forest used (2).

$$LAI = (0.9000 + 0.6900 \ln ISR)^4 \quad (1)$$

$$LAI = (-0.3500 + 1.1200\ ISR\ 0.5)^4 \quad (2)$$

The regions defined as agriculture in the land cover map were modeled based on crop type from the land use map using either the Simple Ratio (SR) vegetation index or the NDVI due to the lack of field data to calibrate ISR based regressions.

III. CLASSIFICATION METHODOLOGY

The principal characteristics of the classification methodology are threefold. First, it retains as much information about land cover in the region as possible, especially regarding forest types and conditions, such that when the classified image is visually compared to the original data (contrast-stretched using a formalized set of steps), the observer finds minimal (and justified) difference between the two. Second, the method standardizes and automates as many of the steps as possible, thereby improving compatibility among classifications. Three, it is applicable to imagery from both Landsat TM and ETM+ (i.e., all the necessary information to differentiate between the classes should be available in a single-date image)[9].

A combined classification approach was employed that uses features of three procedures: K-Means clustering to derived a large number of initial clusters; Classification by Progressive Generalization (CPGcs) [9] to automatically merge these to ~50 cluster without a significant loss of land cover information; and Enhancement – Classification Methodology (ECM) [2] for checking the quality of these two steps, further analyst-controlled merging, and the assignment of clusters to specific land cover classes (labeling). Reference [9] provides a more detailed discussion of the combined procedure, and details may be found in the above references.

The legend corresponds to that of the NVCS/FGDC nomenclature [12]. In the example of the legend below, the image code for individual cover types are shown as /xx/. They are inserted in the appropriate sections of the NVCS/FGDC nomenclature [12][9]. Categories for coarse resolution satellite data were not used in producing land cover maps from Landsat data but are included in the study for completeness and to show the relationship to maps produced using SPOT4/VEGETATION and similar data [8].

A.Mixed evergreen-deciduous open tree canopy (25-75% evergreen or deciduous)

3. Mixed needle-leaved evergreen - cold-deciduous open tree canopy

Mixed coniferous (50-75% coniferous trees)

/13/ Medium to low density

This class often occurs as regenerating cover after disturbances.

Mixed deciduous (25-50% coniferous trees)

/14/ Medium to low density

Figure 2. Example of NVCS/FGDC nomenclature used in class identification

A. Pre-processing

The data were available from the provider at level 1G, which includes radiometric and systematic correction. Details of the data format are available in [16].

Atmospheric correction was performed on all scenes using 6S to produce top of atmosphere (TOA) reflectance for the extracted bands [5]. Each scene was converted to the Universal Transverse Mercator (UTM) projection and NAD 83 datum with the respective zones corresponding to each image. Finally, Bands 4, 5, and 3 were extracted from the image, loaded into the Red Green and Blue color guns respectively, and linear enhancements were performed to minimize the water features and maximize the contrast within vegetation features.

B. Classification

After each image was preprocessed, an unsupervised K-Means classifier was applied to create an image containing 150 clusters for input to CPG. CPG was used to reduce the number of clusters to ~50 through spectral distance merging tables. Finally, the image was reduced to ~16 classes through interactive labeling using available ground data and bitmaps representing each of the ~50 clusters. The bitmaps could be viewed alone or in conjunction with other bitmaps to represent the spatial distribution of the clusters to aid in the merging of clusters. The classes within the final ~16-class images were assigned to 1 of 46 classes (see Figure 2 for an example). These products were sent to the Fluxnet Canada site mangers for ground validation.

C. Validation

The individual Fluxnet-Canada site teams conducted the validation and accuracy assessment of the maps as the teams are the most knowledgeable concerning the sites involved in the study. Validation varied by site and was the sole responsibility of the Fluxnet-Canada teams.

D. LAI

In order to apply LAI algorithms to ETM+ imagery, digital numbers must be converted to surface reflectance. It is well documented that aerosol optical depth (AOD) is one of the most influential parameters in the atmospheric correction procedure for ETM+ visible and infrared bands over land targets [14]. In this study, AOD was estimated using the dense dark vegetation (DDV) approach similar to [15] with modifications made for application in Canadian forests [4]. In future work, the LAI values will be tested against in situ measurements at the Fluxnet tower sites as suggested in [10].

IV. RESULTS

The resultant classifications and LAI maps appeared reasonably accurate when compared to images created for the SILC database in proximity to the Fluxnet stations. When used in previous studies, the methodology has proven reliable and created classifications with accuracies approaching 85% [2]. The main limitation was knowledge of site-specific ground vegetation details when merging spectral clusters in the final stage of classification. To offset the problem, the site managers were also sent the ~50 cluster images for remerging of unrepresentative classes. The final product therefore consisted of an image containing atmospherically corrected bands of Landsat ETM+ imagery, raw uncorrected bands, a ~50 cluster image based on the spectral properties of the imagery, a ~16 class landcover map, and a map of LAI.

V. LIMITATIONS

The major limitation of the present study was the lack of available ground truth information for labeling and product validation of data. Classification errors corrected after the initial classification could have been avoided all together with the addition of a larger validation dataset. The classifications were completed based mainly on the spectral properties of images and comparisons of the resultant maps to mapped regions outside the study areas. Knowledge of the spectral properties of the imagery, though useful, will never replace knowledge of the site in question.

VI. CONCLUSION

As the scale of the Fluxnet-Canada network is Canada wide and the instrumentation is site specific, medium resolution imagery, such as that from Landsat ETM+, is a logical tool for scaling site-specific measurements of carbon flux to larger areas within Canada. As well, the methodology of [9] is an acceptable method for creating accurate classifications for use in higher-level products. In the present research, landcover classifications were created for use in scaling and modeling projects within the Fluxnet research network. Although the validation and accuracy assessment of the classifications is left to the site managers (due to their extensive knowledge of the areas in question) the products created are based on the spectral properties of the imagery, thereby delivering a robust product that is useful for a range of scaling and modeling purposes.

VII. ACKNOWLEDGEMENTS

The authors would like to thank Ian Olthof and Richard Fernandes for their assistance and suggestions in the completion of the project as well as the Fluxnet-Canada site managers and supporting teams for the ground data collected and field validation of the imagery.

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