Derivation of Land Cover Continuous Fields over Canada from SPOT-VGT Imagery

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Abstract- **Recent comparisons of coarse (1 km) and fine (30m) resolution land cover maps across Canada indicate that single cover types rarely occupy more than 40% of a 1km pixel in forested areas. To address this aggregation problem we develop and apply a method for estimating continuous fields of vegetation structural characteristics using 1km resolution SPOT-VEGETATION (VGT) imagery. A sample of Landsat TM and ETM+ scenes stratified by ecozone is classified using a standard methodology to generate spatially distributed calibration centres. Neural networks. look-up-table labelling, and regression resulted in biases as large as 35% when vcalibrate dusing centers over 400km away. Only the linear least squares inversion approach produce a bias under 20%. A estimator based on a linear mixture model regularised by the *a priori* continuous field distribution over the calibration centres is developed. The regularisation parameter is defined by the spectral and spatial similarity of VGT reflectances between calibration centres and the regions being mapped. A strategy for mapping and validating Canada wide continuous fields using this method is described.**

I. INTRODUCTION

Land cover can be defined as the observed (bio)physical cover on the Earth's surface [1]. Coarse (~1km) resolution satellite imagery can provide key land cover information needed for scientific, resource management, and policy purposes at regional [2], continental [3], and global [4] extents,. Traditionally, land cover maps were produced using nominal thematic classes (e.g. [5]) resulting in 'hard classification' maps. However, validation studies reveal a significant inconsistency between coarse and fine resolution land cover products representing the same area resulting in only modest accuracies of coarse resolution products when assessed at pixel level [2,6]. Coarse and moderate resolution sensors are inherently limited for mapping land cover distributions in cases where there is substantial spatial variation in biophysical structure over length scales similar to or smaller than the sensor resolution. In these circumstances, sub-pixel land cover mixing precludes accurate results from a 'hard' classification over a large region. While this problem is exacerbated by overly detailed thematic legends [7], Cihlar et al. [2] showed that it is also present with the relatively simple 12 class IGBP land cover legend applied across Canada, especially within the boreal forest. Their comparison of a Canada-wide 1km land cover map derived from VGT imagery with a number of LANDSAT TM based 30m land cover maps suggests that, in general, the most frequent IGBP cover type occupies less than 35-40% of a 1km pixel. This implies that there are typically at least three different cover types within a coarse resolution pixel. This fundamentally limits the accuracy achievable using a discrete classification where each pixel is assigned one thematic label.

There are two common approaches to sub-pixel land cover mapping that potentially offer coarse scale land cover maps consistent with fine scale products while providing sufficient accuracy for users: continuous fields and fractional land cover mapping [8]. The 'continuous fields' approach assumes that there is no spatial co-variation between land cover attributes within the sensor footprint. The mapping task is then to identify the proportion of the pixel covered by each land cover attribute, e.g. percentage of woody overstory. The second approach, sub-pixel 'fractional cover' mapping, assumes that continuous fields are spatially correlated so that they can be described using a combination of nominal land cover categories. In the boreal forest for example, one category would correspond to 'evergreen needleaf treed overstory with a deciduous broadleaf shrub understory layer' and a second category would correspond to 'deciduous broadleaf treed overstory with a deciduous broadleaf shrub understory layer'. The resulting map would then consist of separate layers identifying the proportional cover of each category within each pixel. The advantage of this approach over continuous fields is that it constrains the possible number of land cover combinations prior to inverting of remote sensing measurements. However, fractional mapping may produce biases when the possible land cover categories are incorrectly specified.

Both existing (e.g. [2]) and planned Landsat TM based land cover maps across Canada offer an opportunity to test and validate sub-pixel land cover mapping algorithms using available moderate resolution imagery. The objective of this paper is to identify the most suitable approach to deriving sub-pixel land cover characteristics across Canada. The major component of our current study is a controlled experiment evaluating the performance of a number of popular algorithms for sub-pixel mapping. For brevity we focus on the continuous field mapping, although a fractional cover map will also be produced.

II. COMPARATIVE EVALUATION OF ALGORITHMS

A study was conducted to evaluate various techniques for mapping both sub-pixel fractions of land cover types and continuous fields of vegetation properties [8]. The approaches consisted of (1) a conventional "hard" per-pixel classification,

(2) an artificial neural network (ANN), (3) a clustering/look-up table approach (LUT), (4) multivariate regression (MR), and (5) linear least squares inversion (LLSI).

Two classified Landsat TM scenes within the BOREAS study region in central Canada were used to provide reference land cover (conifer forest, deciduous forest, shrub, bare, and water) and continuous fields (woody, bare, shrub, water) proportions. The fractions were summarized within overlapping 1.15 km pixels of SPOT-4 VEGETATION (VGT) imagery using a modeled point spread function. The sub-pixel classification algorithms were trained using peak of season VGT reflectances in the red, NIR, and SWIR channels, which were corrected for atmospheric effects and normalized to a common viewing geometry. A proximate treatment tested algorithm performance within a single TM scene, with one half used for training and the other used for testing. A distant treatment investigated the extendibility of the techniques by testing against a second, independent TM scene about 400 km away. Both accuracy (defined as the bias or difference in totals across and entire scene) and precision (define dto the root mean square, RMS, error on a pixel basis) were computed.

In the proximate treatment, the "hard" per-pixel classification performed poorly (RMS = 21%, Bias=35.6%). By comparison, the ANN, LUT, and MR resulted in RMS=6.9-8.0% and Bias=1-2.3% 6.9-8.0%. Fig. 1 shows a comparison of the spatial patterns of 1-km % woody continuous fields from Landsat TM and MR technique applied to VGT imagery. LLSI produces results with intermediate accuracy (Bias=5.2%) and precision (RMS=20.5%). In the distant treatment, all approaches had similar precision (RMS~20%) but the ANN, LUT, and MR approaches were substantially biased (30-40%). LLSI provided a substantially less biased estimate (Bias16%).

The results indicate that conventional "hard" classification offered the lowest performance for mapping sub-pixel cover. ANN, LUT, and MR approaches are able provide highly accurate sub-pixel mapping if they are applied to areas very similar in composition to the training data. Since these techniques calibrate to the *a priori* proportions in the training data, they may produce biased results when applied to areas with different land cover mixtures. LLSI was less accurate for local application, although it is not susceptible to bias when extended beyond the training region. We suggest that LLSI may provide the most robust approach for sub-pixel classification at continental scales using a minimal training set.

III. EXTENSION TO CANADA WIDE MAPPING

There are four major issues to consider in applying the LLSI approach on a Canada-wide basis: coarse scale features, calibration data, algorithm implementation, and validation strategy. A discussion of the derivation of coarse scale features is beyond the scope of this paper. The latter three items are discussed in terms of an ongoing effort to produce Canada wide maps.

A purposive sampling algorithm (PSA) [8] was applied to the 1km 'hard' classification to identify the 3 most representative Landsat scenes over each of the 15 Canadian ecozones. Some of the identified scenes were not available and temporarily replaced by an overlapping cloud-free scene. Note that the 1km 'hard classification' was produced by labelling clusters that are spectrally similar. A sampling ensures that all of the major spectral clusters in an ecozone will have some calibration data. Land cover maps were derived for each cloud-free scene (22 to date). Continuous fields maps will be derived by applying look up tables to the land cover maps [8].

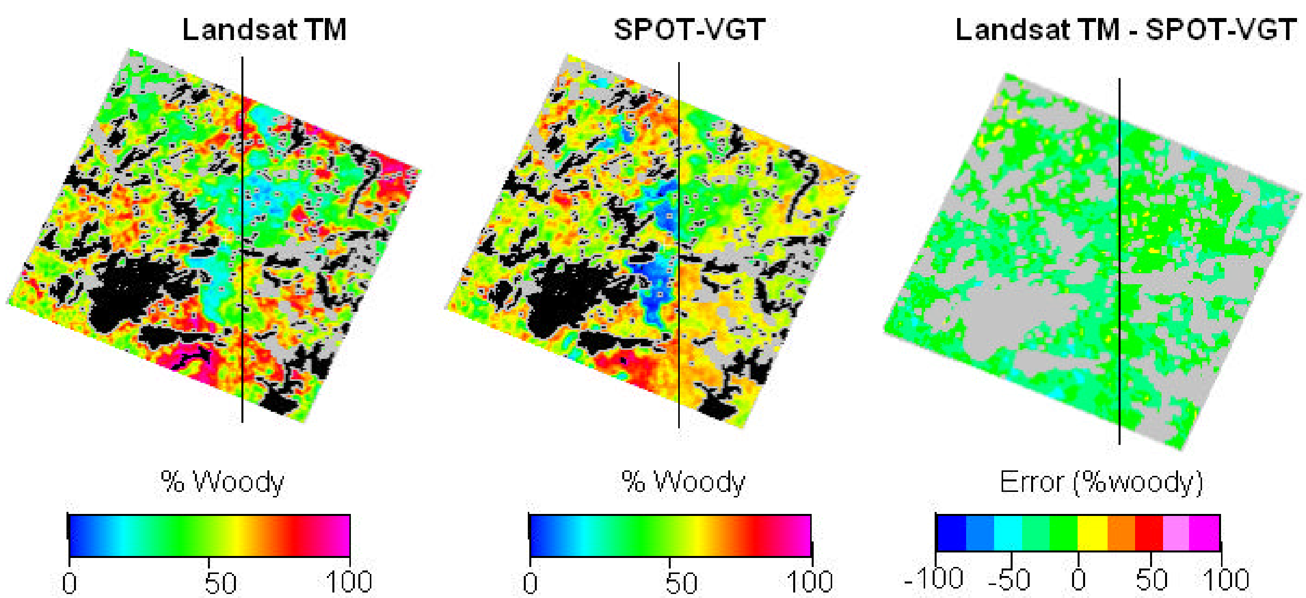

Fig. 1. Comparison of Landsat TM based estimates of woody cover and SPOT-VEGETATION based estimates of woody cover for the proximate treatment based on multivariate regression. A difference image is shown on the right.

A hybrid LLSI/MR approach was developed to maximize the use of a priori information when there is representative calibration data and minimize biases due to differences in *a priori* mixture composition. First, regions with current Landsat TM scenes are mapped using a direct aggregation of the fine scale land cover. Second, the fractional cover of water bodies is mapped for all 1-km pixels using rasterised 1:50,000 topographic maps. Finally, the standard LLSI algorithm was calibrated and applied on an ecozone basis after regularization using the *a priori* land cover fractions over the calibration areas as in [9]:

$$\min_{\boldsymbol{f}} \left(\boldsymbol{x}-\boldsymbol{M}\boldsymbol{f}\right)' \boldsymbol{N}^{-1}\left(\boldsymbol{x}-\boldsymbol{M}\boldsymbol{f}\right)+ l\left(\boldsymbol{f}-\boldsymbol{f}^{*}\right)' \boldsymbol{Q}^{-1}\left(\boldsymbol{f}-\boldsymbol{f}^{*}\right) \quad (1)$$

Where $\boldsymbol{x}$ is the observed coarse scale feature vector, $\boldsymbol{N}$ is a diagonal weighting matrix with elements proportional to the measurement uncertainty in each feature, $\boldsymbol{f}$ is the continuous field proportions, $\boldsymbol{f^*}$ is the mean proportions over the calibration data, $\boldsymbol{Q}$ is the covariance matrix between continuous fields over the training data, $\boldsymbol{M}$ is a matrix whose columns correspond to the calibrated features for each 'pure' endmember and l is a regularisation parameter. Equation 1 reduces to LLSI when l=0 and MR for l =1 suggesting l should be proportional to the similarity of the a priori mixtures between the calibration and target region. We propose to generate an initial estimate of the sub-pixel land cover using l =0 and to then produce a new estimate of l based on a similarity index (e.g. Kolmogorov Smirnov) between continuous field distributions over training and validation data. This approach will be implemented and evaluated in the next phase of the research program,

This validation protocol distinguishes between proximate and disparate calibration data while preserving the ecozone stratification. Essentially, three tests will be performed over areas corresponding to available Landsat land cover scenes:

1. Within scene, within ecozone: calibration regions will consist of contiguous rather than interlaced regions corresponding to quadrants of each Landsat scene in an ecozone. Accuracy will be assessed over areas of calibration scenes not included. This test provides an estimate of accuracy in areas close to calibration scenes but may be overly optimistic in other parts of an ecozone.
2. Between scene, within ecozone: Sub-pixel maps will be produced for each ecozone after withholding one calibration scene. The accuracy over the withheld scene will then be computed. This test may provide a representative accuracy assessment for most areas within an ecozone, which will normally not be in close proximity to a calibration scene.
3. Between ecozones: Sub-pixel maps will be produced using calibration scenes from spatially adjacent ecozones. Accuracy will be measured over the withheld calibration scenes of the ecozone being assessed. This test provides a worst-case estimate of accuracy.

IV. CONCLUSIONS

A sub-pixel approach is required to produce unbiased estimates of land cover over Canada from coarse scale (1km) satellite imagery. Both continuous fields and fractional cover maps may satisfy this requirement. A controlled evaluation of a number of common sub-pixel mapping algorithms found that only LLSI offered unbiased estimates when using calibration data disparate from the validation region. By contrast, the other algorithms were biased to the mean land cover proportions over the calibration data set. An ecozone stratified sampling of land cover from a sample of Landsat scenes is currently available for calibration and will be supplemented by additional scenes in the future. This calibration data will be processed using a hybrid sub-pixel mapping algorithm that defaults to MR in areas where land cover is similar to the corresponding calibration scenes and to LLSI in the opposite case. Three tests are proposed for evaluating the performance of this algorithm using available calibration scenes . The application and validation of the hybrid algorithm will be the subject of ongoing research, especially with respect to algorithm performance as a function of coarse scale features and ecozone.

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