# Mapping Forest Biomass on Several Pilot Regions in Canada with Landsat TM and Forest Inventory Data

Luc Guindon[1], Richard A.Fournier[2], André Beaudoin[1], Joan E. Luther[3], Ron J. Hall[4], Douglas E. Piercey[3], Éric Arsenault[4], Marie-Claude Lambert[1] and Brad Case[4]

[1]Canadian Forest Service, Laurentian Forestry Centre, Ste-Foy, QC
[2]CARTEL, Université de Sherbrooke, Sherbrooke, QC
[3]Canadian Forest Service, Atlantic Forestry Centre, Corner Brook, NF
[4]Canadian Forest Service, Northern Forestry Centre, Edmonton, AB

***Abstract* - A method has been developed to map forest biomass with Landsat TM and ETM imagery coupled with forest inventory data. The method involves applying an unsupervised classification to a Landsat TM/ETM scene. The unsupervised clusters are labelled according to cover types and forest structure (crown closure and height) using random samples extracted from inventory datasets as training pixels. Biomass values are assigned to the clusters according to the dominant forest type and structure contained within the clusters. The method was tested on five pilot regions throughout Canada with an objective of evaluating its application in several ecological regions with different species composition and stand structure. This paper concerns (1) the implementation of this method and (2) the comparison of those results between regions. The overall results for classifying forest cover types range from 50 to 60% for the five regions. Correlations between remotely sensed and inventory biomass estimates are variable for different species and pilot regions. However, results show that the method provides a complement to existing inventory-based methods for mapping biomass in managed areas and may constitute an alternative approach for northern areas with weak forest inventory databases.**

## I. INTRODUCTION

The spatially-explicit estimation of biomass is important to support carbon budget and global change modeling, as well as national reporting needs on criteria and indicators of sustainable forest management. In previous work [1], stand level forest inventories have been used to derive spatially-explicit forest biomass by applying biomass look-up tables to forest cover type and structure information contained in forest inventories. However, such an approach has several limitations among which are the incomplete coverage and the long time frame over which such inventories are updated (usually 10-15 years). Satellite remote sensing is a tool that is well adapted to complement existing inventory programs for biomass estimation with the availability of low-cost Landsat imagery between inventory cycles and the apparent consistency in multi-temporal image products allowing for efficient up-dating and national synthesis.

Several approaches have been explored for the estimation of biomass from satellite remote sensing imagery including direct estimation with empirical models which relate biomass to satellite spectral reflectance [2]. As an alternative, the approach reported in this paper, links spectral clusters from remote sensing to operational forest inventory maps as a means of deriving stand attributes that feed into look-up tables for estimating biomass.

This paper documents one component of an overall strategy for national implementation of biomass mapping methods using inventory and Landsat TM data [3]. It describes the regional expansion of a baseline method for mapping forest biomass as part of the Earth Observation for Sustainable Development of Forests (EOSD) project [4]. More specifically, it reports on the implementation of a method, previously tested in Newfoundland [1], and includes the compilation, comparison and preliminary validation of results over several pilot regions in Canada. A companion paper [5] reports specific biomass mapping results obtained in Alberta using a slightly modified version of the biomass mapping method described in this study.

## II. STUDY AREAS

Five pilot regions within the boreal shield and boreal plain ecozones were used for regional implementation of the method (Table 1 and Fig. 2 in [3]) to capture, as much as possible, the large diversity across Canada in terms of forest ecosystems as well as inventories among three provinces. A more detailed description of those regions can be found in [1] for Newfoundland, [5] for Alberta and at the web site www.cfl.forestry.ca/ECOLEAP/pilotregions.html.

Table 1: Pilot regions and Landsat TM data.

| Pilot region | Area ($km^2$) | dominant species groups | Landsat data, date |
|---|---|---|---|
| Labrador, NF | 33,000 | Black Spruce | TM, 08/21/1999 |
| Western NF | 6,000 | Balsam Fir and Black Spruce | TM, 08/04/1995 |
| Foothills, AB | 2,500 | Lodgepole Pine and White Spruce | TM, 09/08/1999 |
| Abitibi, QC | 8,000 | Black Spruce and Trembling Aspen | ETM, 8/17/2000 |
| Quebec, QC | 8,500 | Sugar Maple and Balsam Fir | TM, 08/08/1996 |

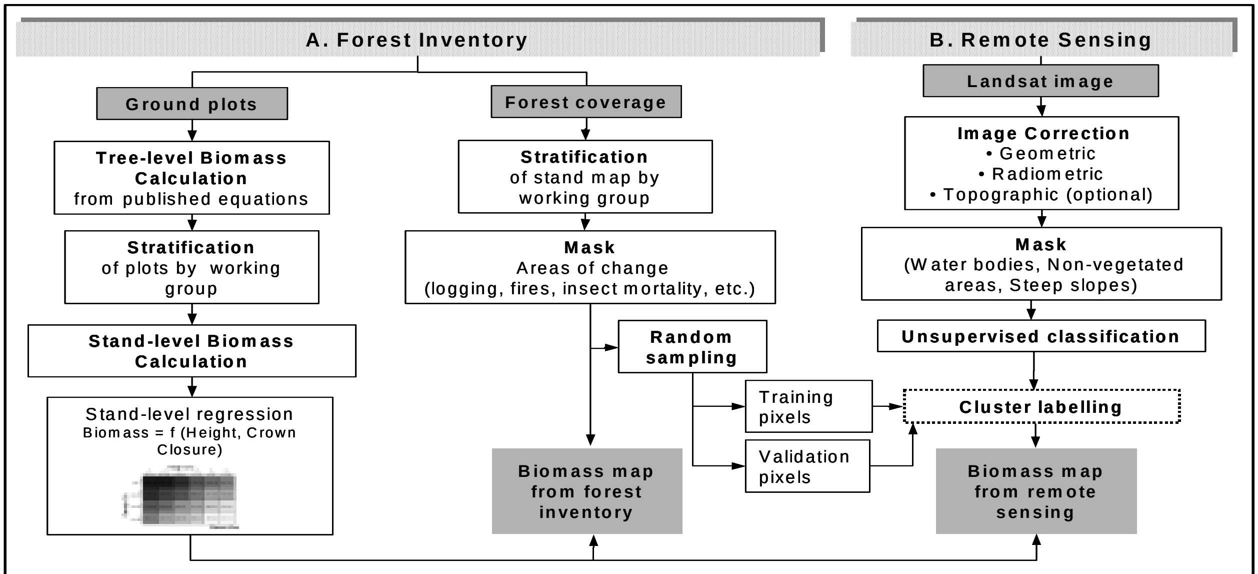



Fig. 1 Method for estimating biomass from Landsat TM and forest inventory data

## III. MATERIALS & METHODS

The method applied throughout the five pilot regions is illustrated in Fig. 1 and described in more detail in [1]. The method uses several sources of geospatial information layers integrated in a regional GIS database including sampling plot databases, forest inventory coverages (stand maps), and Landsat TM or ETM imagery.

### *A. Biomass from inventory ground plots*

Biomass estimates are determined from the inventory ground plot datasets in order to provide biomass look-up tables that can subsequently be used to assign biomass values to the remote sensing image classifications.

Tree-level allometric equations, either published or derived using statistical models, were used for each region to estimate biomass for each inventory ground plot. Biomass was summed for each inventory plot. Then the inventory plots were stratified by regional working groups (WG) for the purpose of determining stand-level biomass equations. Stand-level biomass estimates were regressed against height and crown closure classes, hence providing biomass equations for predicting biomass for each WG. Applying the regression equations to all possible combinations of crown closure and height classes resulted in look-up tables that provide biomass values for all combinations of height and crown closure classes within each WG.

### *B. Biomass from remote sensing*

Biomass was estimated from remote sensing as a function of land cover type and structure (height and crown closure) extracted from Landsat TM or ETM imagery. The classification of the Landsat image followed standard unsupervised classification routines which included geometric, radiometric and topographic pre-processing and masking of areas that were not considered for biomass estimation prior to clustering.

K-means unsupervised classification was applied on the remaining vegetated areas using 255 spectral clusters. The K-means clusters were then labeled using training pixels randomly sampled from the forest inventory stand maps. An equal number of samples were selected by regional WG with a maximum of one pixel per forest inventory stand. Buffers between stands were removed from the sampling areas to avoid selection of mixed pixels for training purposes. Each cluster was then labeled according to 1) the majority of pixels from each WG and 2) the proportion of pixels from each crown closure and height class. The average biomass was then determined for each cluster according to the dominant WG and the crown closure and height proportions applied to the biomass lookup tables. An independent random sample of pixels from the forest inventory coverage was used to assess the classification accuracy of the forest types as well as the biomass estimates derived from the remote sensing image.

## IV. RESULTS AND DISCUSSION

Table 2 presents the overall classification accuracy of forest types for each pilot region. Similar overall classification accuracies (51-63%) were obtained over the five pilot regions. Using a validation sample, predicted biomass values from remote sensing were correlated with biomass values derived from inventory maps. Correlation results, reported in Table 3, were usually highest for coniferous species and lowest for deciduous species. The highest correlations were observed in Labrador, which may be explained by the relative simplicity and low diversity of cover types compared to other regions. Similar correlations were also obtained in Alberta that can be explained, in part, by the use of continuous stand height in the inventory and the largest range of biomass compared to all regions. The poorest results were obtained for the two Quebec regions. For Abitibi, intensive logging activities made the accurate updating of the forest coverage to the Landsat image date difficult. For Quebec, topographic effects were not removed and this likely contributed to the poorer results.

Overall results can be explained by various error sources and limiting factors. Many error sources (sampling, biomass equations) propagate through the scaling-up linking process from tree to plot and stand levels. On the remote sensing side, the number of spectral clusters has an impact, as shown in [5], and further work is required to determine an optimal number. The selected number of random samples within each forest strata also has an impact on the statistical representativeness of WGs within the area. In addition, the spectral cluster labeling performs an average of look-up table biomass averages that smoothes out predicted biomass values. Finally, spectral limiting factors include 1) spectral confusion between various combinations of WG and biomass and 2) decreased sensitivity to biomass for low biomass cover types where understory contributes to the signal, and for high biomass covers where signal saturation results in underestimated biomass.

## V. CONCLUSIONS

A method for biomass mapping coupling forest inventory and Landsat data was implemented over five Canadian pilot regions towards its validation for future national implementation. The correlation results are highly variable between the five pilot regions, and an in-depth validation is on-going using validation sets as well as ground biomass from georeferenced sample plots.

## ACKNOWLEDGEMENTS

This project is a component of the Earth Observation for Sustainable Development (EOSD) project supported financially by the Canadian Space Agency. It was made possible with the generous collaboration of Provincial Ministries of Natural Resources and industrial data sets. The technical assistance of Carl Marks is appreciated.

Table 2. Cover type classification accuracy (%) for each pilot region by forest type (C: coniferous; D: deciduous; M: mixed).

| Region | C | D | M | Overall |
|---|---|---|---|---|
| Labrador, NF | 75 | 37 | 39 | 63 |
| Western NF | 76 | 27 | 23 | 59 |
| Foothills, AB | 79 | 15 | 22 | 60 |
| Abitibi, QC | 65 | 32 | 39 | 53 |
| Quebec, QC | 74 | 68 | 26 | 51 |

Table 3. Correlation between biomass values determined from inventory and remote sensing databases.

| Region | Forest Type | N | r | Sig. |
|---|---|---|---|---|
| Labrador, NF | C | 75 | 0.70 | 0.000 |
| | D | 13 | 0.89 | 0.000 |
| | M | 39 | 0.56 | 0.000 |
| Western NF | C | 83 | 0.60 | 0.000 |
| | D | 27 | 0.35 | 0.074 |
| | M | 39 | 0.57 | 0.000 |
| Foothills, AB | C | 357 | 0.58 | 0.000 |
| | D | 62 | 0.55 | 0.000 |
| | M | 39 | 0.63 | 0.000 |
| Abitibi, QC | C | 414 | 0.42 | 0.000 |
| | D | 81 | 0.25 | 0.029 |
| | M | 72 | 0.14 | 0.179 |
| Quebec, QC | C | 455 | 0.26 | 0.000 |
| | D | 300 | 0.09 | 0.120 |
| | M | 62 | 0.25 | 0.052 |

## REFERENCES

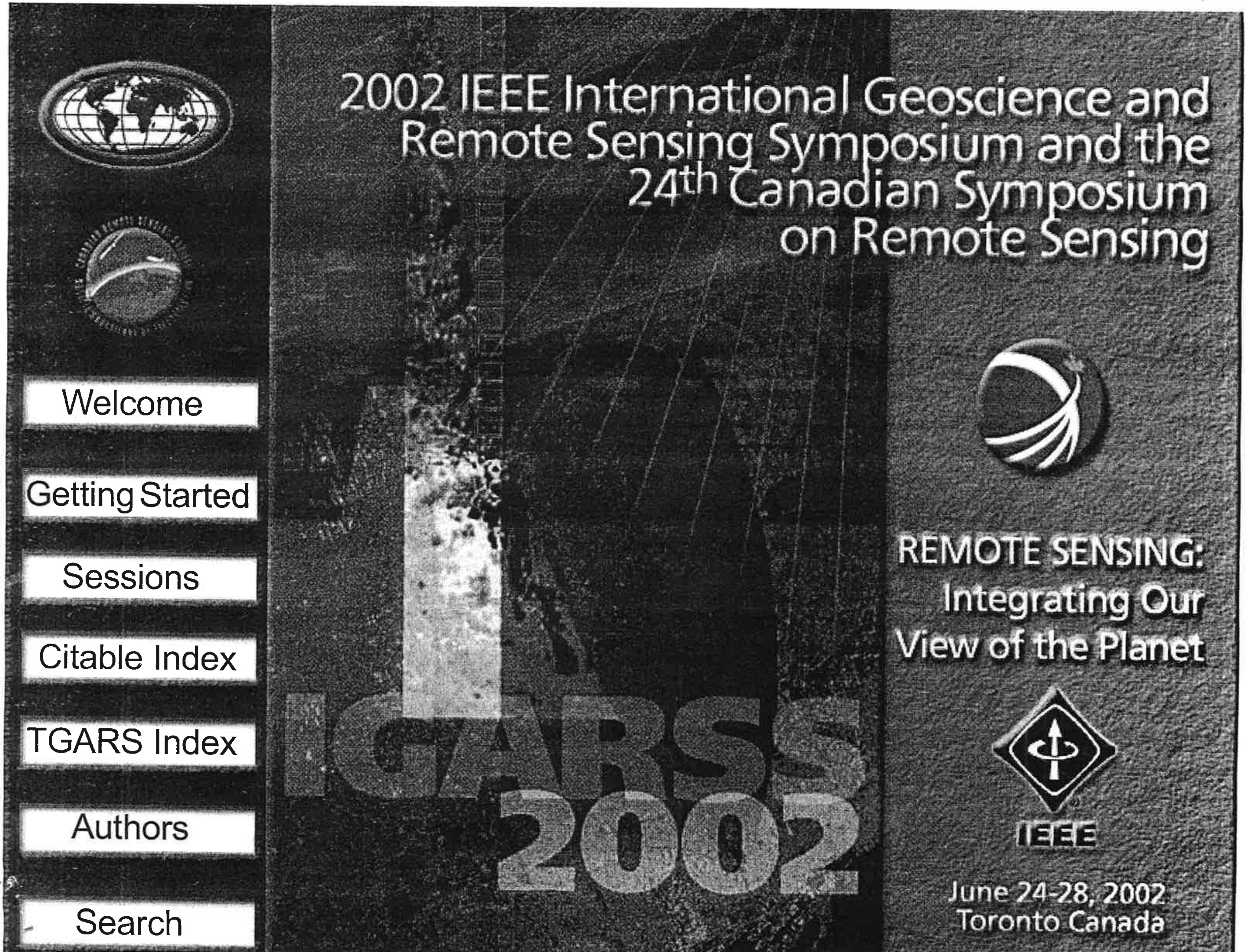
[1] Guindon, L., Luther, J. E., Fournier, R., Lambert, M.-C., and Piercey, D., "Mapping forest biomass using Landsat TM and forest inventory data: test case in Newfoundland," P*roceedings, 23rd Canadian Symposium on Remote Sensing*, Sainte-Foy, Quebec, 2001.

[2] Ravan, S. A., and Roy, P. S. 1997. Satellite remote sensing for ecological analysis of forested landscape. *Plant Ecology* 131:129-141

[3] Luther, J.E., Fournier, R.A., Hall, R.J., Ung, C.H., Guindon, L., Piercey, D.E., Lambert, M.-C. and Beaudoin, A., "A Strategy for Mapping Canada’s Forest Biomass with Landsat TM Imagery", *Proceedings, Int. Geoscience and Remote Sensing Symposium / 24th Canadian Remote Sensing Symposium*, Toronto, Canada, 2002.

[4] Wood, J. E., Gillis, M., Goodenough, D., Hall, R., Leckie, D., Luther, J. E., and Wulder, M., "Earth Observation for Sustainable Development of Forests: Project Overview," *Proceedings, Int. Geoscience and Remote Sensing Symposium / 24th Canadian Remote Sensing Symposium*, Toronto, Canada, 2002.

[5] Hall, R.J., Case, B.S., Arsenault, E., Price, D.T., Luther, J. E., Piercey, D.E., Guindon, L. and Fournier, R., "Modeling and Mapping Forest Biomass using Forest Inventory and Landsat TM Data: Results from the Foothills Model Forest, Alberta", *Proceedings, Int Geoscience and Remote Sensing Symposium / 24th Canadian Remote Sensing Symposium*, Toronto, Canada, 2002.


2002 IEEE International Geoscience and Remote Sensing Symposium and the 24th Canadian Symposium on Remote Sensing
Welcome
Getting Started
Sessions
Citable Index
TGARS Index
Authors
Search
IGARSS 2002
REMOTE SENSING: Integrating Our View of the Planet
IEEE
June 24-28, 2002
Toronto Canada