Forest cover indicator based on multi-scale remote sensing information

S. G. Leblanc [a,*], W. Chen [b], and R. Fernandes [b]

[a] Canada Centre for Remote Sensing, Natural Resources Canada, Centre Spatial John H. Chapman, 6767, route de l'Aéroport, Saint-Hubert, Québec, Canada. J3Y 8Y9. Sylvain.Leblanc@CCRS.NRCan.gc.ca

[b] Canada Centre for Remote Sensing, Natural Resources Canada, 588 Booth Street, Ottawa, Ontario, Canada. K1A 0Y7. (Wenjun.Chen, Richard.Fernandes)@CCRS.NRCan.gc.ca

Abstract - Forests cover nearly half of Canada's landmass. While forested lands are often viewed as areas of wood production, forests also provide wildlife habitat and ecosystem mechanisms to clean air and water, and sequester carbon. Measuring the area of forested land in Canada on a regular basis provides an indicator of the availability of these important ecosystem services. This study examines the capability of coarse spatial resolution satellite data to quantify forest cover based on crown closure estimates. Field data, high and medium resolution remote sensing imageries, and a canopy radiative transfer model (Five-Scale) are used to assess the mapping potential of 1-km data, such as AVHRR, VGT and MODIS. The main challenge of the research is in the transition zone between boreal forest and the tundra, where few inventory data are available and the trees are found in clusters. The results will be used in a Canada-wide forest indicator that aimed at monitoring yearly changes in the forest extend due in part to forest fires, insect defoliation, regrowth and changes due to climate change. Different methodologies and initial results of this ongoing activity are presented.

Keywords: Forest cover, indicator, change detection.

1. INTRODUCTION

The exact extend and change of Canada forests are of great importance in climate change and sustainable development. The National Round Table on the Environment and the Economy (NRTEE) developed the Environment and Sustainable Development Indicators (ESDI) initiative to track the impact of current economic practices on the natural and human assets of Canada (NRTEE, 2003). Six indicators were proposed, and among them, a forest cover indicator to track changes in the extent of Canada's forests. Canada's landmass is approximately 920 millions hectares and its population is found mainly in the southern part of the country, near the US border, which makes remote sensing the perfect tool for monitoring Canada forest areas. However, as reported by the Canadian Forest Service, the annual change in forest extend from harvesting, fires, insects and diseases combined is in the order of only 1% of the total forested areas of Canada. This nevertheless represents about 4 million hectares a year. Moreover, the areas where forests are regenerating and treed northern areas that are susceptible to change into forests due to climate change are not well known. Forest cover is defined here as forest areas with crown closure (*CC*) greater or equal to 10% and the crown closure is defined as the vertical projection of the dominant canopy. Although high resolution images, aerial or space borne, will be used to facilitate the validation of the final crown closure maps in heterogeneous area, the smallest area used in the study is in the order of 90x90 m (3x3 LANDSAT TM/ETM pixels). Different methodologies are explored to retrieve crown closure from large swath sensors and an initial map is presented using available remote sensing products.

[*] Corresponding author

2. MODELLING AND PROCESSING

Many canopy structural parameters have strong relationships between each other for given species and conditions. Beer's law is an important relationship that relates foliage density to gap fraction as (Nilson, 1971):

$$P(\theta) = \exp[-G(\theta)L \cdot \Omega(\theta) / \cos(\theta)] \qquad (1)$$

where θ is the view zenith angle, $P(\theta)$ is the gap fraction, $G(\theta)$ is the unit leaf coefficient of projection in the θ direction, L is the leaf area index (LAI), and $\Omega(\theta)$ is the foliage clumping index. The product of LAI and clumping index is referred as the effective LAI (Chen, 1996). The crown closure is the complement of the gap fraction at θ =0, namely, $CC = 1 - P(0)$.

Large swath coarse resolution remote sensing data are generally limited in their available spectral bands with useful information for biophysical canopy properties. Only three broad bands are used in our study combined in the following vegetation indices (VI's):

1) SR, the simple ration (ρ_N/ρ_R).
2) ISR, the infrared simple ratio (ρ_N/ρ_S).

where ρ_N is the reflectance in the near infrared band, ρ_R the reflectance in the red band, and ρ_N is the reflectance in the short-wave infrared band. The simple ratio offers the possibility to go back to 1979 with AVHRR data while the ISR is only available with more recent sensors such as the new AVHRR on NOAA-16, VGT on SPOT 4 and 5 or MODIS on TERRA and AQUA. Relating theoretically canopy structures to remote sensing VI's can only be achieved with canopy models.

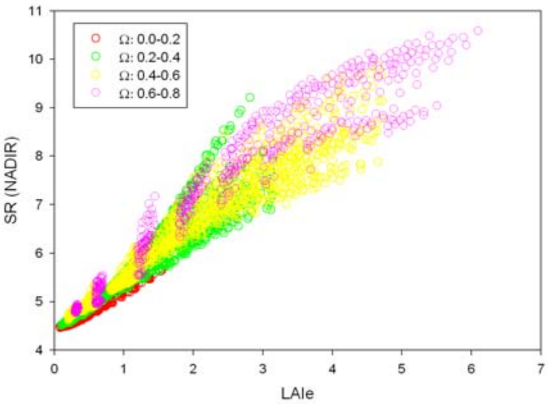

Figure 1. Five-Scale simulations of the simple ratio and effective LAI (LAIe) relationship. The clumping index used for calculating the effective LAI is from the solar zenith angle at 35°.

Based on the Five-Scale model (Leblanc and Chen, 2000), simulations in Fig. 1 show the best correlation between several Five-Scale input parameters and the simple ratio at nadir view: the effective LAI at the solar zenith angle is the canopy parameters that is the best related with the simple ratio. A similar relationship was found between the gap fraction at the solar zenith angle and SR (Leblanc et al., 2002). The crown closure was not well correlated to VI's, but it must be noted that the simulations used did not considered any covariation between the canopy structures. A wide range of conditions were simulated that may or may not exist in forests. These kinds of relationship are species dependent and require numerous field data for development and validation that are not available at this time.

Data from the 1998 Canadian LAI validation campaign (see Fernandes et al., 2003) are used as ground truth. The plots generally cover area near 90 by 90 m^2. The LICOR Plant Canopy Analyser LAI-2000 was used in all the plots in a cross-pattern of 10 points. A spreadsheet routine was developed to re-analyse the raw data from the LAI-2000. The data were originally analysed for leaf area index and foliage clumping. In this study the same data were reprocessed for effective Plant Area Index (PAIe) that considers all elements in the canopy, foliage and woody material, and for crown closure. The gap fraction readings from the upper ring (centred at view zenith angle of 7° corrected at 0°) of the LAI-2000 are used for the crown closure calculation:

$$CC_F = 1 - \exp\left[\ln\left[P(7°)\right]\cos(7°)\right] . \qquad (2)$$

Figs. 2, and 3 show relationships CC - SR and PAIe - SR for coniferous stands. SR is computed from LANDSAT-5 TM apparent surface reflectance. The CC showed low correlation to SR (R^2 of 0.48), while PAIe at 57° (where G(θ) is always near 0.5) was better correlated

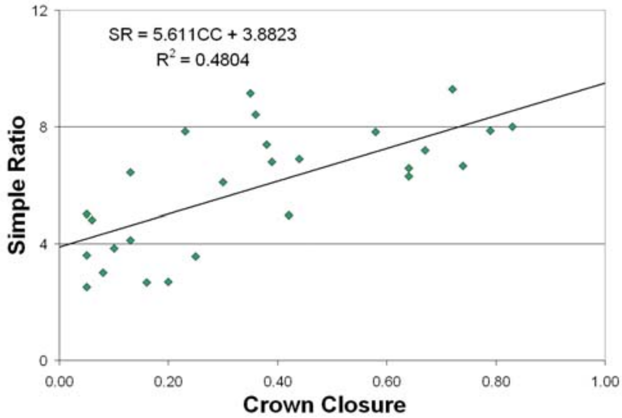

Figure 2. Relationship between ground measurements of crown closure and simple ration (SR) from LANDSAT TM.

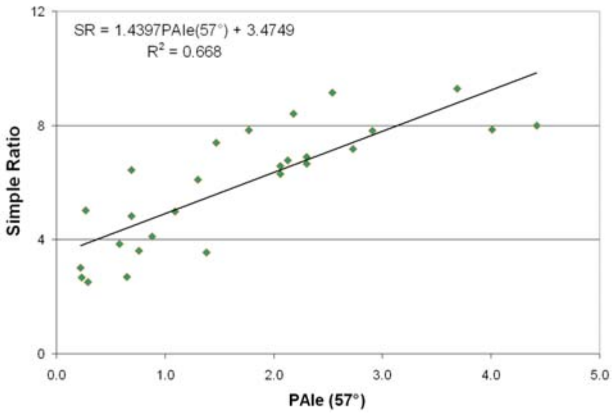

Figure 3. Relationship between ground measurements of PAIe and simple ration (SR) from LANDSAT TM.

(R^2 of 0.67). Only the SR relationships are shown here, but the ISR gave very similar results with R^2 of 0.32 and 0.61for ISR-CC and ISR-PAIe, respectively.

Based on relatively small sample available for the present analysis the SR seems as good as ISR for predicting *CC* or PAIe when proper atmospheric correction is applied to the data. This is of high importance for historical study of crown closure with AVHRR data that only have the near infrared and red bands. AVHRR does not have the exact same bands as LANDSAT but SR from both sensors are generally well correlated. Using field data from 1998 and 2000 field campaigns, the ISR was the best VI for LAI retrieval (Fernandes et al., 2003). Because of the limited field data available and poor relationships between VI's and crown closure, our first estimate of crown closure is done from available products as:

$$CC_{RS} = 1 - \exp\left[-0.5 \cdot L \cdot \Omega\right] \qquad (3)$$

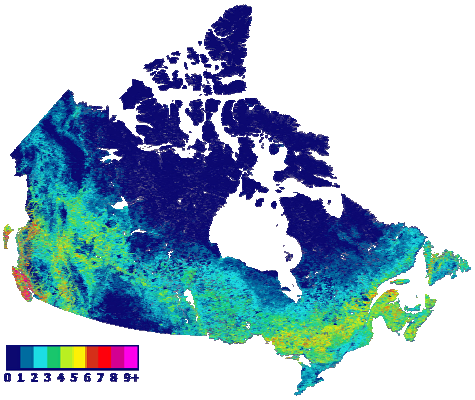

Figure 4. Mid-Growing Season Leaf Area Index map of Canada from 1998 SPOT-VGT data. The ISR was used to estimate the LAI for forested area while either the simple ratio of NDVI was used for shrubland and agriculture (Fernandes et al., 2003) based on a 1998 SPOT-VGT landcover map (Cihlar et al., 2002).

where the LAI and Ω are from available remote sensing products and the foliage orientation is assumed spherical, giving $G(\theta) = 0.5$ at all θ.

Robust structural regressions were developed between the VI's and ground LAI to account for errors in both satellite and ground measurements (Fernandes et al., 2003). The LAI map (Fig. 4), from 1998 SPOT-VGT data is based on a re-calibration of the LANDSAT algorithms (Fernandes et al., 2003). We used this available LAI map for which an error analysis was performed.

No information at 1km resolution exists for the clumping index, but a map at 7-km was produced from directional reflectance from the POLDER-1 sensor onboard the ADEOS-1 platform. Data from June 15 to June 30 1997, the period closest to the summer peak because of the platform failure, were used to produce anisotropy indices that were converted into clumping index at zenith angle of 35° based on a relationship developed with Five-Scale (Leblanc et al., 2002). Some areas of Canada did not have cloud free data during that 15-day period and the empty pixels were filled with the mean clumping index from the same cover type associated with that pixel. The cover types were assigned based on the dominant cover type in a 7x7 pixels window. Initial land cover information was derived from a landcover map of Canada 1998 (Cihlar et al., 2002). The resulting clumping index map can be seen in Fig. 5.

3. RESULTS and DISCUSSION

Using equation (3) with the LAI and clumping index maps, a crown closure map was produced (Fig. 6) for the whole Canada at 1-km resolution. This allowed the computation of the forested area of Canada. Table A shows the area of Canada with crown closure greater than 10% per ecozone. The total area is 392 million hectares. The majority of the forested areas of Canada are from the boreal shield ecozone with an estimate of 145 million hectares, based on the crown closure map.

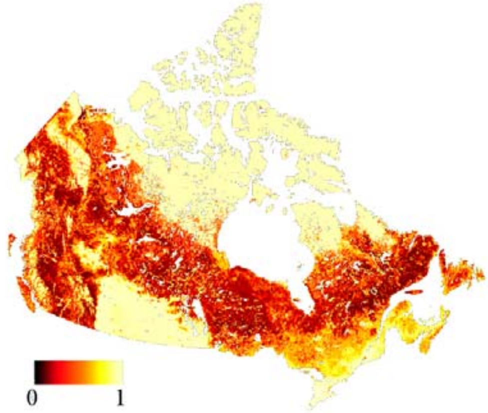

Figure 5. Foliage Clumping Index map from June 1997 ADEOS POLDER data (Leblanc et al., 2002).

A change in the 10% threshold used to separate forest from non-forest areas by one percent gave only a one percent relative change in the total number of forested area, but this is nevertheless equivalent to 2 to 3 million hectares in absolute number.

Since the relationship between VI's and effective PAI is very strong (R2 = 0.67), it may be possible to use the effective PAI directly in future version of the crown closure map. The scaling effect between LANDSAT level and 1-km VGT of effective PAI has not been tested, therefore, it was decided to use the LAI and clumping index for this initial study. Information about the zenithal variation of the clumping index may be necessary in that case since the effective PAI includes the clumping index at the zenith angle it is estimated. Moreover, in any *CC* retrieval using Beer's law, variation of zenithal of $G(\theta)$ also needs to be addressed to accurately estimate *CC*.

While these initial results demonstrate the capability of coarse remote sensing data to quantify forest cover based on crown closure estimates, several major challenges remain to be resolved before annually production of forest cover indicator can be carried out using remote sensing with coarse spatial resolution (1km). First, there is substantial degree of confusion between forested land and tundra. Our preliminary results indicated that over 80 million hectares over northern Canada have a crown closure >10% and have been classified as sparse woodland. Are they forested area or Tundra? Second, to delineate the small inter-annual changes in the forest cover indicator may be complicated by the relative large noise in remote sensing data when multiple-year trend is concerned. While large disturbances (fire, harvest, insects killing) give strong signals and are relatively easy to detect, small inter-annual increments due to re-growth are difficult to detect. Some alternative approaches may be needed: instead of looking at the difference between two adjacent years, we may look at 5-10 years change or trend. Forest stand age class, and other information (species, site quality) are essential to carry out such alternative (Pavlic et al., 2002; Fraser and Li, 2002; Zhang et al, 2003).

Finally, the crown closure map has not yet been validated and so extensive field calibration and validation is need. As part of the Fluxnet Canada project, the Canada Centre for Remote

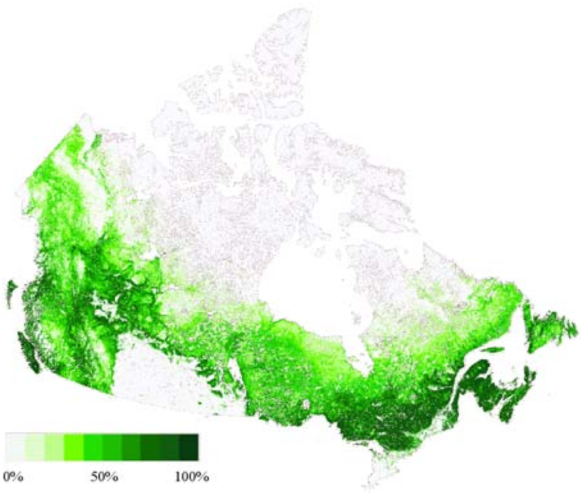

Figure 6. Canada wide Crown Closure based on LAI and clumping Index maps (Figs. 4 and 5, respectively).

Ecozone	Forested Area (million hectare)
1) Artic Cordillera	0
2) Northern Artic	0
3) Southern Artic	0
4) Taiga Plains	32
5) Taiga Shield	37
6) Boreal Shield	145
7) Atlantic Maritime	18
8) Mixed Wood Plains	3
9) Boreal Plains	49
10) Prairies	1
11) Taiga Cordillera	5
12) Boreal Cordillera	27
13) Pacific Maritime	13
14) Montane Cordillera	38
15) Hudson Plains	24
Total	**392**

Table A. Canadian forest areas by ecozone based on the crown closure greater than 10% from the map of Fig. 6.

Sensing bought several digital cameras with fish-eye lens that produce hemispherical photographs that will be used by different groups to measure canopy architecture, including crown closure, around Canada in the coming years, increasing dramatically the consistent ground truth data.

Other Government of Canada initiatives, such as the Earth Observation for Sustainable Development of Forests (EOSD) based on LANDSAT data and the National Forest Inventory (NFI) will provide snapshots of forest attributes useful in the calibration and validation of the crown closure maps.

3. CONCLUSIONS

A first Canada wide map of crown closure was produced. To be used in a national forest indicator, yearly maps are required. This implies that more field validation should be carried out every year to improve the retrieval of LAI and crown closure and to increase the number of validation points. Available products were used to calculate the crown closure, but other methods are being tested to improve the production of yearly crown closure map. AVHRR data from the last decades will be used to generate historical crown closure maps to assess the change in forested area in Canada. Although these maps are to be used in the forest cover indicator, they can also be used to follow temporal forest evolution.

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