Finding the tree line: quantitative derivation of forest cover estimates

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Abstract- Human activities and climate change are affecting the current position of our ecosystem boundaries and it is expected that the boreal northern tree line will shift to the north due to milder climate at high latitude. This change in extent of the boreal forest will affect greatly the carbon cycle and sustainable development of the north. To be able to assess these changes, field measurements using digital hemispherical photography were acquired to quantitatively estimate vegetation characteristics such as leaf area index (LAI) and canopy crown closure in the Yukon and Northwest Territories of Canada during the summer of 2004. Crown closure is used in this study as a quantitative measure to assess forest presence/absence based on a given forest definition. Empirical relationships are derived using LANDSAT ETM+ images that were normalized with coarse resolution SPOT-VGT data. The best results are found when linear combination of bands for the broadleaf species and linear combination of exponential relationships for the coniferous species are used. The crown closure maps from LANDSAT images are then used to calibrate low-resolution forest cover maps from NOAA-AVHRR and SPOT-VGT data.

1. INTRODUCTION

Forests are one of Canada's most important natural resources covering more than 400 million hectares. Changes in the boundary of this large ecosystem are important. These changes can be estimated by the migration of the tree line separating the open boreal forests and the tundra. Temperature rise in the north due to climate change has already been measured and its effect on vegetation is a topic that is being actively investigated. Although the tree line itself is important, various forest definitions can shift its location by hundreds of kilometers. Therefore, to accommodate different forest definitions, crown closure is used as a quantitative forest measure in this study. Previous efforts (Leblanc et al, 2003; Chen et al., 2005a) have shown the potential of remote sensing in extracting the crown closure as a forest indicator (NRTEE, 2003). The present study uses crown closure to improve the forest cover indicator that uses a crown closure of 10% or more to define the forested area. Furthermore, the tree line delimitating forest from tundra vegetation is being used in a carbon sequestration project (Chen et al., 2005b). This paper aims at finding crown closure and forested area in northern Canada at LANDSAT TM/ETM+ scale (30m) to improve coarse resolution forest area mapping by calibrating products at 1km resolution with 30m data.

2. MATERIALS AND METHOD

2.1 Field measurements

In July 2004, a group of scientists form Canada Centre for Remote Sensing traveled along the Dempster highway from Dawson City in the Yukon, to Inuvik in the NWT, collecting vegetation information and samples. Crown closure measurements were acquired using a Nikon 995 digital camera with a fish-eye lens at about 1.4 m from the ground at multiple sites. The crown closure estimates based on using view angles from 10 to 80 degrees and using only view angles near the zenith (10 to 25 deg) were averaged to obtain an estimate of the crown closure. This method was used because not enough photographs were taken in some plots, thus an under sampling of the vertical view had to be compensated by using view angles further from the zenith. The northern end of Dempster highway is in the McKenzie delta where numerous small lakes can be found and this constitutes a challenge when using coarse resolution remote sensing data to assess forest cover.

2.2 Remote sensing data

Cloud-free and atmospherically corrected composites (Latifovic et al., 2003) of SPOT VEGETATION red (610–680 nm), near-infrared (780–890) nm), and shortwave infrared (1580–1750 nm) from the 2000 growing season are used in this study. Moreover, four LANDSAT ETM+ scenes, covering the Dempster highway, from 2000 were normalized to remove atmospheric effects by using the SPOT data (Olthof et al., 2005). These images were mosaic and classified to 43 classes, (Chen et al., 2005b) but only information about water and conifer content along with the normalized reflectance are used here.

2.3 Analysis

Although the forested areas in the Northern Canadian territories are mainly composed of needleleaf species, broadleaf species such as aspen and birch can be found in the Mackenzie delta in the Northwest Territories. Because of the difference in optical properties of broadleaf and needleaf species, they are studied separately. However, The number of plots from the Dempster fieldwork with deciduous species was scarce. Data from 44 sites are used in the needleleaf species analysis. Since there were not many field measurements in deciduous sites, data from previous field campaigns in Quebec and Ontario are used (Chen et al., 2002) with Atmospherically corrected LANDSAT TM data.

3.0 RESULTS and DISCUSSION

In-situ data were compared with different vegetation indices (e.g. NDVI, SR, ISR) and individual bands. For low crown closure values, good results were found using individual bands with exponential behavior. Figure 1 shows the curves found for the crown closure measurements at a function of the individual bands 3 (red), 4 (NIR), and 5 (SWIR) of LANDSAT 7 ETM+ normalized data.

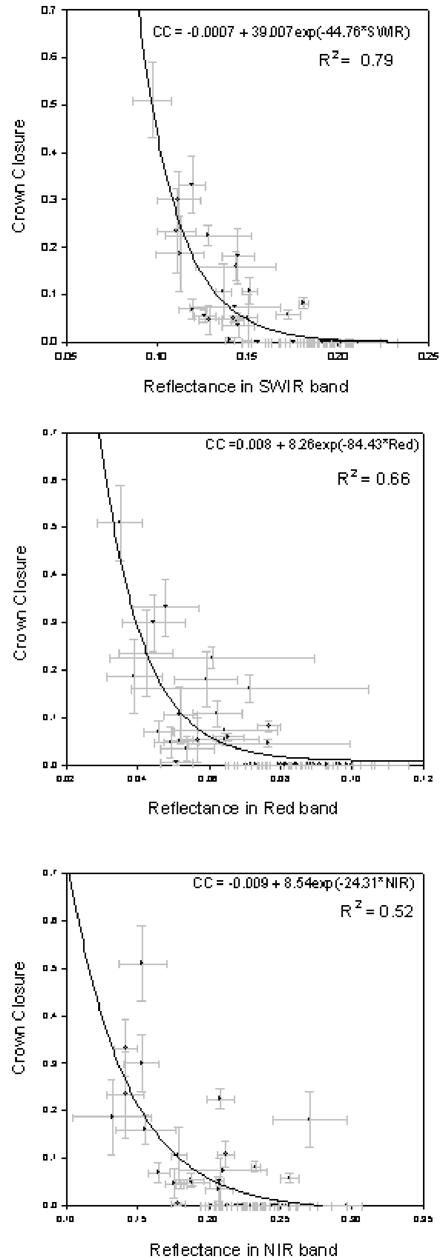

Figure 1. Field measurements of crown closure in 0.5-1ha plots versus averaged reflectance in 3x3 LANDSAT ETM+ pixels.

From these relationships, a combined linear mixture of these bands is used and gave:

$$CC(\text{Needleleaf}) = 0.0023 + 1.39^* CC(\text{SWIR}) - 0.52^*CC(\text{Red}) + 0.097^* CC(\text{NIR}) \quad (1)$$

with a R^2 of 0.80. This relationship has a larger weight on the SWIR band. For deciduous species, a relationship found from field data acquired in Ontario and Quebec in 1998 and compared with LANDSAT TM data (Chen et al., 2002) is used:

$$CC(\text{Broadleaf}) = 1.39 - 2.24^*\text{SWIR} - 13.32^*\text{Red}. \quad (2)$$

These two relationships, along with estimation of conifer presence in the 30m pixels based on a classification, are applied to the mosaic. Figure 2 shows the average crown closure at 990m obtained by averaging ETM+ pixels to approximate 1km data. This figure can be seen as ground truth for that area when compared with data from coarser resolution sensors such as AVHRR, MODIS, or VEGETATION. A preliminary crown closure map was produced using SPOT-VGT and ADEOS-POLDER (Leblanc et al., 2003; Chen et al., 2005a). This map was not validated and some areas, such as the Mackenzie delta, seemed to overestimate crown closure. Figure 3 can be used to explain how coarse resolution data can overestimate CC.

Figure 2. Crown closure estimates of the Dempster highway mosaic at 990m obtained from averaging 30m resolution crown closure products.

The insert in Figure 3 shows what was previously found using VEGETATION and POLDER data. In Figure 3, the algorithm from Eqs. 1 and 2 are applied to the simulated SPOT-VEGETATION data. It is very clear that the CC estimates from mean reflectance at 990m are generally much larger than the true case when the CC at 30m was averaged to 990m. Figure 4 shows that the Mackenzie area is filled with small lakes, pounds and wetlands. Since the water bodies have low reflectances values, they will tend to increase the crown closure estimates as the larger the crown closure, the lower the CC estimates (see Fig. 1). To solve this problem, the ETM+ data can be used to calibrate the coarse resolution data. This is done here with a different product than the crown closure itself.

The forest cover indicator is aimed at finding forested areas, defined as an area of at least 1ha with crown closure larger than 10%. In the preliminary map (Leblanc et al., 2003), 1km pixels were either completely forested of non-forested. By using the ETM+ data, the percentage of forest area in a 90x90m area (3x3 pixels), which is very close to 1ha when footprint considerations are included, is estimated. Figure 5 shows the percentage of 90x90m-forested area within a 990x990m pixel.

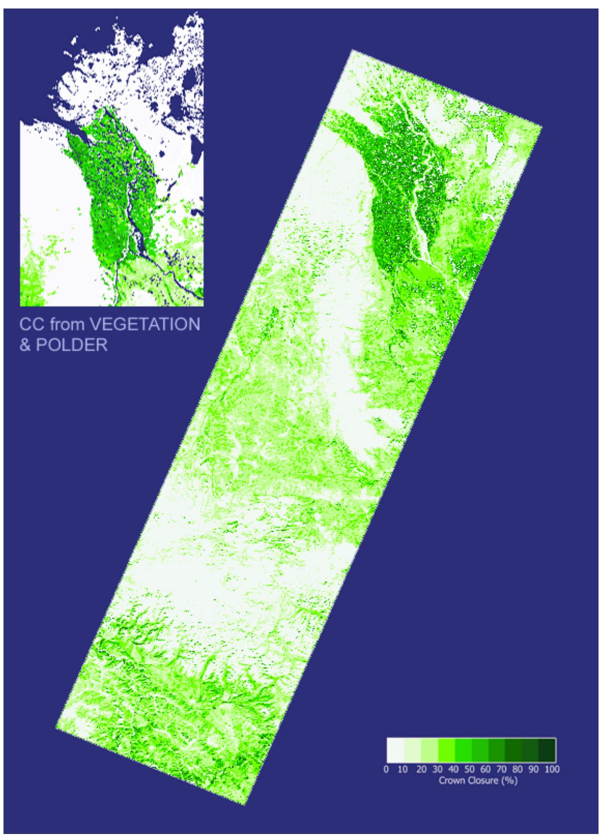

Figure 3. Crown closure estimates of the Dempster highway mosaic with algorithm applied on the 990m averaged reflectances. The top left insert is from the derived crown closure obtained with SPOT VEGETATION and ADEOS-1 POLDER data (Leblanc et al., 2003; Chen et al., 2005a).

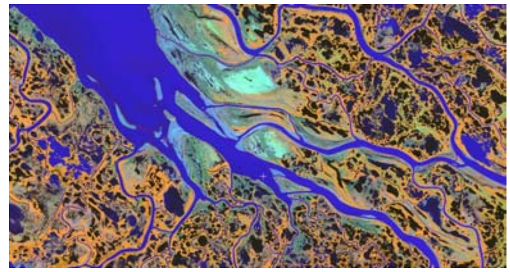

Figure 4. This portion of the Dempster mosaic at full resolution with Band 4,5,3 in RGB (electronic version only), shows the large number of water bodies and wetlands that exists in the McKenzie delta.

A comparison of reflectance values at 990m and percentage of forest area is found in Figure 6 (only SWIR is shown). For the Dempster mosaic, clear relationships are found and can be applied to coarse resolution data. It seemed that the sub-pixel water in that mosaic gives a completely different relationship.

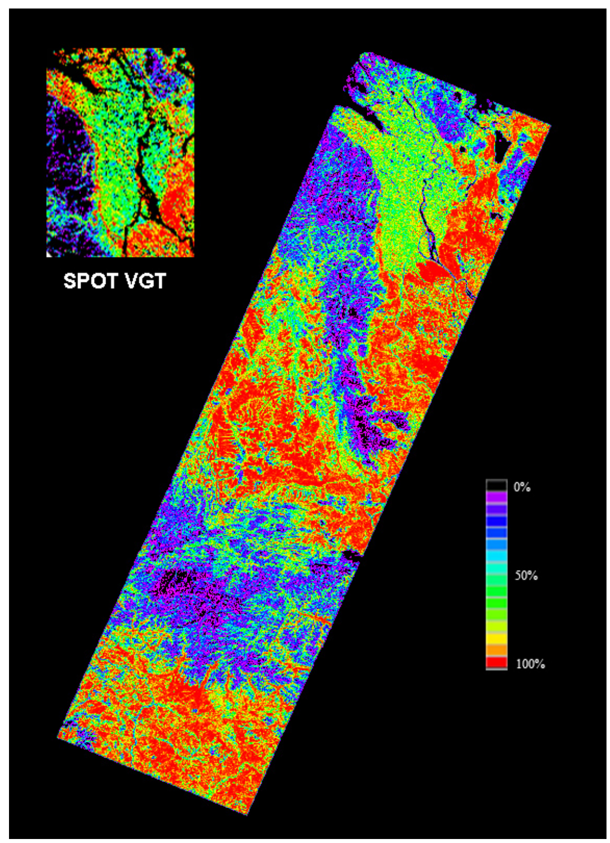

Figure 5. Scaled forest information at 990m where the intensity represents the percentage of 90x90 m^2 areas where CC was greater than 10%, i.e. where forest was found. 100% means that all 121 90x90 m^2 areas were forested areas. The insert shows the results from a slightly modified relationship applied to SPOT VTT data.

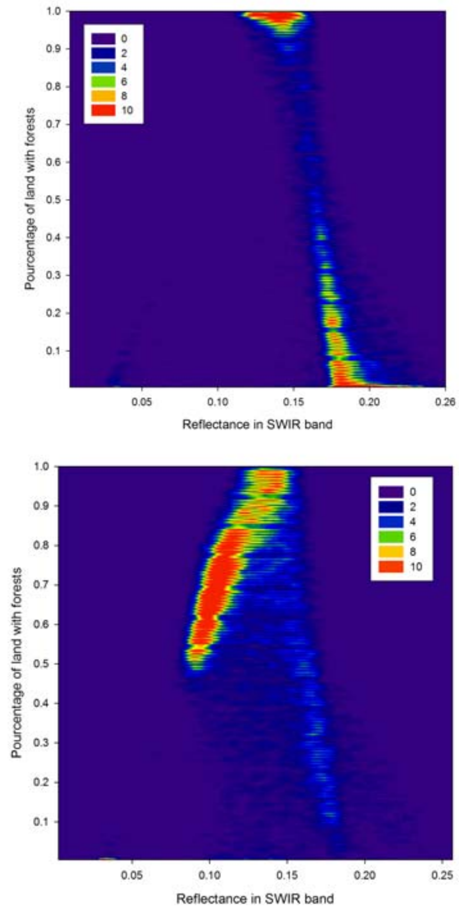

Figure 6 a) Percentage of forest contained in a 990m pixel based on LANDSAT ETM+ 90x90m area in function of the SWIR band reflectance at 990m for a) area with no water, and b) areas with water. Other bands gave similar results.

The case without water is very clear and near linear. However, when water is present, some pixels seem to be on the same line as the non-water relationship. Overall, using these two relationships for the SWIR band: one for the reflectance higher than about 0.4 and one below that threshold is a great improvement over what was done before. The insert in Figure 5 shows such an application to SPOT-VGT data. A calibration between the SPOT-VGT data and the actual percentage from the ETM+ data will be done to improve this mapping. It is not clear if this methodology can be applied to other regions of Canada. Other products are already available that could improve this. A Canada wide map of water fraction within 1km pixels has been produced (Pavlic et al., 2002). It can be used to insured that pixel with reflectance lower than the thresholds contains water bodies.

4. CONCLUSIONS

The Mackenzie area in Northern Canada is one of the most difficult areas to estimate vegetation parameters such as crown closure based on coarse resolution data due to the vast amount of small lakes, pounds and wetlands. Nevertheless, coarse resolution data, when used with proper scaling techniques, can be a useful tool for estimating the forested area. The percentage of 1ha forest areas in a given 1km pixel area can be estimated once regional scaling is found. More fieldwork is planned in the summer of 2005 to improve the 30-90 m crown closure estimate, especially for broadleaf species. Other northern region will be visited in the future to assess validity of the relation found in other parts of Canada.

5. REFERENCES

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