Remote Sensing Based Inversion of Gap Fraction for Determination of Leaf Area Index

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Introduction

The major physiological processes of vegetation including photosynthesis and evapotranspiration are determined by the vegetation biophysical parameters that describe the canopy structure. Leaf area index (LAI) is one of the principal biophysical parameters in climate, weather, and ecological studies, and has been routinely estimated from remote sensing measurements. LAI is defined as one half the total radiation intercepting leaf area per unit ground horizontal surface area (Gonsamo and Pellikka 2008). Several numerical models require a continuous field of high spatial and temporal resolution LAI measurements due to heterogeneity and size of vegetation or natural agricultural patches, and the large seasonal dynamics of vegetation. To fulfill these needs, the LAI retrieval methods including the processing of the remotely sensed data expected to be efficient and convenient for the end users. Generally speaking, the success of LAI estimation from remotely sensed data remains cumbersome and there is always a need to calibrate remotely retrieved parameters with ground based observation. This study is aimed at demonstrating the feasibility of the large scale LAI inversion algorithms using red and near-infrared reflectance obtained from high resolution satellite imagery. The algorithms are developed based on the principle commonly used for ground-based optical determination of LAI by applying Beer-Lambert's law and by assuming extinction coefficient for the gap fraction retrieved from spectral vegetation indices (SVIs).

Study Area and Data

The study site is located in the Great Lakes - St. Lawrence forest in Southern Quebec, Canada. It is part of the Gatineau Park (Figure 1), which is managed by the National Capital Commission (NCC) of Canada and centred at 45°30'N, 75°52'W. The park is about 10 km by 50 km and is mostly temperate hardwood forest. The ground *LAI* measurements were collected from 54 plots of 20 m by 20 m using hemispherical photography. All photographic procedures are described in Gonsamo et. al. (2009). Note: for simplicity, the effective LAI, which assumes random foliage distribution, was used in this study and is hereafter referred to as LAI. Plotwise LAI ranged from 2.6 to 5.7 with average value of 4 along the two sampling transects of Gatineau Park.

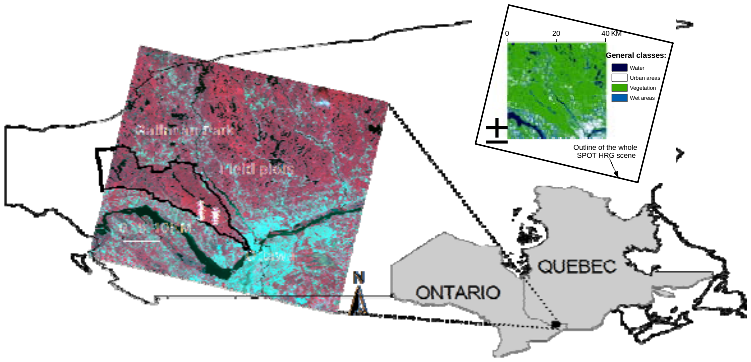

Figure 1. Study area showing the SPOT image scene and analysis extent

Radiances in digital counts in the green (500–590 nm), red (610–680 nm), near-infrared (780–890 nm) and shortwave-infrared (1580-1750 nm) wavelength regions were obtained in 10m resolution acquired on cloud free day of July 23, 2007, 10:49 local time by the SPOT 5 geometric imaging (HRG) instrument for 60 km × 60 km image swath. The SPOT 5 HRG image was orthorectified and atmospherically corrected using four DOS methods (Song et al. 2001), 6S radiative transfer code and Top Of the Atmosphere (TOA) reflectance.

The MODIS Collection 5 LAI product was acquired in a form of HDF subsets from the Warehouse Inventory Search Tool (WIST) client for searching and ordering earth science data from various NASA and affiliated centres (https://wist.echo.nasa.gov/). Only pixels retrieved with main algorithm without cloud contamination were used in further analysis.

The combined version 4 PROSPECT leaf model and the SAIL canopy model were used to simulate canopy reflectance data in order to test the robustness of the methodology developed in this study. For this analysis, the ranges of input were LAI (0.25 – 9 by increment of 0.25, and 12 as the largest LAI). Three standard soil backgrounds ranging from dark to bright were used. The other input parameters were kept constant to plausible values.

Methods

Gap fraction ($P_{(O)}$) is obtained from scaled difference of Normalized Difference Vegetation Index (NDVI; Gutman and Ignatov 1998), Scaled Difference Vegetation Index (SDVI) and Modified Soil-Adjusted Vegetation Index (MSAVI). The f_c cover estimated using the equations listed in Table 1 is a complement in unity of $P_{(O)}$, i.e., $f_c = 1-(P_{(O)})$.

Table 1. Fractional vegetation determination from vegetation indices

Name	*Formulation of f_c	Description
Gutman and Ignatov	$\frac{NDVI - NDVI_{back}}{NDVI_{\infty} - NDVI_{back}}$	Dense vegetation mosaic-pixel model
SDVI	$\frac{DVI - DVI_{back}}{DVI_{\infty} - DVI_{back}}$	Scaled difference vegetation index from DVI
MSAVI	$\frac{MSAVI}{MSAVI_{\infty}}$	Soil background invariant f_c determination from MSAVI

*SVI_{∞} and SVI_{back} were derived as maximum and minimum SVI, respectively, from the vegetated pixels (Figure 1). DVI = difference vegetation index.

Subsequently, LAI is estimated using Beer-Lambert law's (Gonsamo et. al. 2009) as:

$$LAI = -\frac{\ln(P_{(O)})}{k} = -\frac{\ln(1-f_C)}{k}$$

Where k is the extinction coefficient which is related to leaf spectral properties and leaf angles in the canopy and was assumed to be 0.5, which is a good approximation for a broadleaved forest considering the near nadir view. The same methodology was applied for independent dataset simulated using PROSPECT+SAIL model with three soil backgrounds. The sensitivity of the methodology was evaluated for different atmospheric correction methods, spatial resolution effects, effectiveness test with ground-based measurement and comparison with MODIS LAI product. The estimated LAI from SPOT image was corrected by the factor which was obtained by logarithmic averaging (Lang and Xiang 1986) of NDVI based gap fraction over the MODIS pixel and the corrected LAI result was further compared with MODIS product.

Results

All NDVI and MSAVI based methods are affected by atmospheric correction. The maximum LAI difference averaged all over the image was occurred among MSAVI based methods (21.45%), followed by approximately the same value for NDVI based method of Gutman and Ignatov (21.23%) and lastly SDVI based method (3.2%) (Figure 2). SDVI appeared to be invariant for varying atmospheric correction methods.

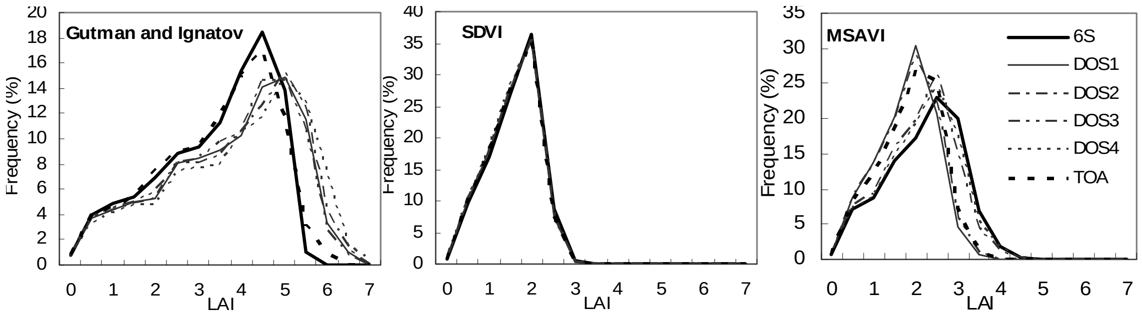

Figure 2. Histogram distributions of LAI estimations using varying gap fraction estimation techniques and atmospheric correction methods.

NDVI was found to be very sensitive for any scaling effect applied (Figure 3).The maximum LAI difference averaged all over the image was occurred among NDVI based method of Gutman and Ignatov (78.39%), followed by MSAVI based method (17.11%) and lastly SDVI based method (11.14%) (Figure 3). SDVI and MSAVI appeared to be less affected by varying averaging methods so that relatively insensitive to spatial resolution/scale differences.

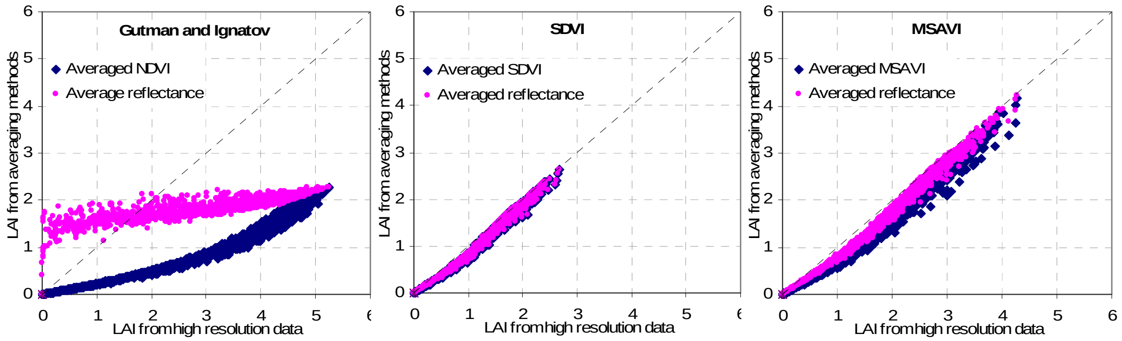

Figure 3. Comparison of estimated LAI values using 10m pixel size SVI values on X-axis averaged over 1km grids with: LAI inverted from averaged SVI and LAI inverted from averaged reflectance

MSAVI based retrieval resulted in the closest LAI estimate to ground-based measurements (Table 2). NDVI based method resulted in very narrow range of LAI. Nevertheless, except that of the CV, the other evaluation parameters (Table 2) may introduce bias for the comparison of SVIs based LAI with ground-based measurements due to the difference of the definitions assumed and practically could be achieved.

Table 2. Evaluation of different methods to derive LAI

Methods	Mean error (%)	RMSD (%)	CV* (%)	Bias (%)
Gutman and Ignatov	28	29.93	3.21	25.01
SDVI	36	40.24	12.45	-37.30
MSAVI	2	16.14	12	-4.23

*coefficient of variation (CV) of ground-based measurement = 16.39%

MODIS LAI product is overestimated compared to all methods (Figure 4). During the late summer, MODIS LAI products are known for great and progressive overestimation. The range of LAI measured as a coefficient of variation resulted in very good agreement indicating that both MODIS and SPOT LAI explained the variation similarly. We believe that the logarithmic gap averaging (~clumping index) factor has some physical meaning to explain the architecture of the vegetated canopy which remains to be discussed in detail if there is any need for such kind of parameter for ecosystem process modelling. The same gap averaging algorithm applied to very high resolution airborne data have been proven to substantially increase the agreement of ground-based and airborne LAI retrieval (not presented here).

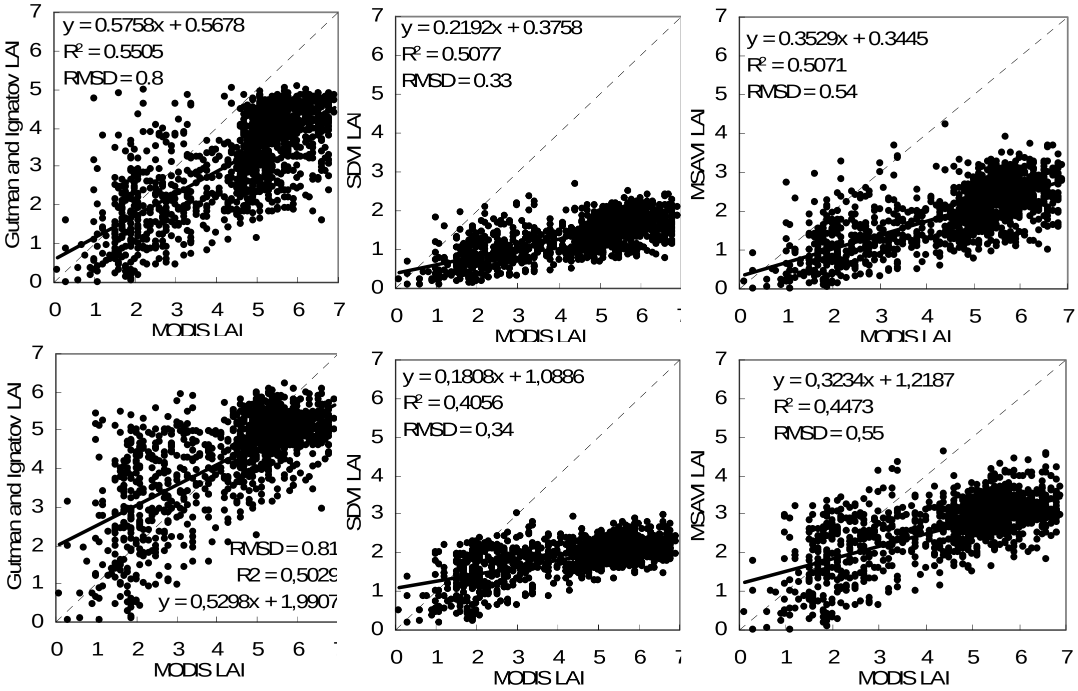

Figure 4. Comparison of MODIS LAI product with SPOT derived LAI based on NDVI, SDVI, and MSAVI methods. Above is not corrected and below is corrected with clumping index derived from logarithmic averaging of NDVI based gap fraction.

The, SDVI and MSAVI based methods was found out to be the most robust approaches (Figure 5). Soil background variation has minor effect for LAI retrieval. Over all, MSAVI is the best followed by SDVI and least being NDVI based method for LAI retrieval.

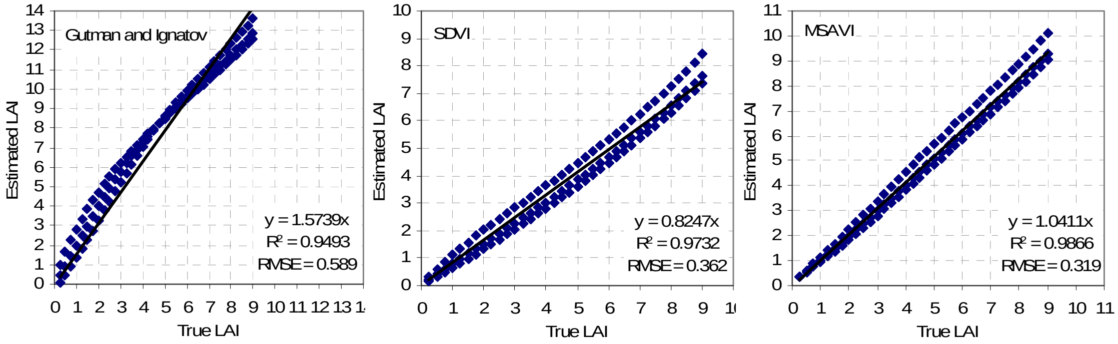

Figure 5. The performance evaluation of the three LAI retrieval methods as the simulated true LAI is plotted against retrieved LAI based on NDVI, SDVI and MSAVI methods. The SVIs are calculated from the reflectance simulated using three soil backgrounds and a range of LAI.

Conclusions

On the basis of simulated datasets, ground-based and satellite measurements, and the validity; the accuracy of the approach for LAI retrieval from the information solely contained on image scene was reasonably good. The varying definitions and assumptions used for LAI obtained from ground-based measurements, SPOT image retrieval and MODIS product, and the validity of using simple 1D radiative transfer model for robustness assessment make almost impossible any complete validation of the approaches. CI has potentials for correction of scale induced errors and further. SDVI was found out to be both scale and atmospheric correction invariant provided that the atmosphere all over the image scene is assumed to be constant. MSAVI was the best method followed by SDVI. Alternative LAI retrieval approach was presented in this study which may complement the classical methods.

Acknowledgements

The research was funded by the Academy of Finland through the TAITATOO-project and a personal grant (120190) to PP, and by Natural Sciences and Engineering Research Council of Canada funding to Douglas King. AG is financed partly by CIMO, Department of Geography of University of Helsinki, and the Finnish Graduate School of Geography. We are very grateful for financial grant provided for participation of IUFRO meeting from EuroDIVERSITY programme of EUROCORES funded by European Science Foundation (ESF).

References

Gonsamo, A., and P. Pellikka. 2008. Methodology comparison for slope correction in canopy leaf area index estimation using hemispherical photography. Forest Ecology and Management 256: 749–759.

Gonsamo, A., P. Pellikka. and D.J. King. 2009. Large scale leaf area index inversion algorithms from high resolution airborne imagery. International journal of remote sensing, submitted for publication.

Gutman, A., and G. Ignatov. 1998. The derivation of the green vegetation fraction from NOAA/ AVHRR data for use in numerical weather prediction models. International Journal of Remote Sensing 19: 1533-1543.

Lang, A.R.G., and Y. Xiang. 1986. Estimation of leaf area index from transmission of direct sunlight in discontinuous canopies. Agricultural and Forest Meteorology 35: 229–243.

Song, C., C.E. Woodcock, K.C. Seto, M.P. Lenney and S.A. Macomber. 2001. Classification and change detection using Landsat TM data: when and how to correct atmospheric effects? Remote Sensing of Environment 75: 230-244.