VALIDATION OF CANADA-WIDE LAI/FPAR MAPS FROM SATELLITE IMAGERY*

J. M. Chen, L. Brown, J. Cihlar, S.G. Leblanc
Environmental Monitoring Section
Canada Centre for Remote Sensing,
588 Booth Street, 4th floor,
Ottawa, Ontario, Canada, K1A 0Y7
*Tel: (613)-947-1266 FAX: (613)-947-1406
E-mail: jing.chen@ccrs.nrcan.gc.ca

And
R. J. Hall, Canadian Forest Service, Edmonton
D. Peddle, University of Lethbridge
D. King, Carleton University
J. A. Trofymow, Canadian Forest Service, Victoria
E. Swift, Canadian Forest Service, Fredericton
J. Van der Sanden, Canada Centre for Remote Sensing
G. Pavlic, Intermap Technology Inc.

ABSTRACT

The leaf area index (LAI) and the fraction of photosynthetically active radiation absorbed by the canopy (FPAR) are two of the surface parameters which can be routinely derived from remote sensing measurements and have importance in climate, weather and ecological studies. Canada-wide LAI/FPAR maps are now being produced using cloud-free Advanced Very High Resolution Radiometer (AVHRR) imagery every 10 days at 1 km resolution. The archive of these products begins from 1993. To validate these products across Canada, a group of interested Canadian scientists was formed, and measurements of LAI and FPAR were made during the summer of 1998 in deciduous, conifer and mixed forests and in cropland. Common measurement standards using the commercial TRAC and LAI-2000 instruments were followed. Nine Landsat TM scenes at 30 m resolution were used to locate ground sites and to facilitate the scaling to 1 km pixels. In this presentation, we will discuss methodologies for mapping LAI and FPAR using fine-resolution data and for validating coarse-resolution maps in consideration of surface heterogeneity.

1.0 INTRODUCTION

Driven by the need of monitoring global vegetation under a changing climate, many space-borne observing systems have been and will soon be launched. The European

• Presented at the Fourth International Airborne Remote Sensing Conference and Exhibition/ 21st Canadian Symposium on Remote Sensing, Ottawa, Ontario, Canada, 21-24 June 1999

satellite sensor Vegetation on board of SPOT4 has been successfully acquiring high quality data since March 1998. As the first part of the US Earth Observing System (EOS), the Terra (AM-1) platform is scheduled for launch in summer 1999, carrying the MODerate-resolution Imaging Spectroradiometer (MODIS) and Multiple-angle Spectral Radiometer (MISR) sensors among others. With these new sensors, our capacity for quantifying the Earth's surface conditions will be dramatically increased (CEOS, 1997). Among many surface biogeochemical parameters which can be derived from remote sensing measurements, leaf area index (LAI) is a vegetation structural parameter of fundamental importance for quantitative analysis of many physical and biological processes related to vegetation dynamics and its effects on climate. FPAR is often used as an alternative to LAI. Many studies have shown broadband spectral measurements are useful for deriving LAI and FPAR (Spanner et al., 1994; Wulder et al., 1996), and global and regional LAI and FPAR maps have been produced. In the MODIS land product series, global coverage of LAI/FPAR will be produced frequently and regularly. At the Canada Centre for Remote Sensing, a new satellite data processing and image production system named GEOCOMP-N is currently being built in partnership with industry. This system will routinely produce Canada-wide LAI and FPAR maps every 10 days during the growing season (1 April to 30 November), among many other products. Accuracy assessment and validation of these moderate-resolution products are of concern to the potential users and have been important issues facing many space and remote sensing institutions world-wide. In this paper, we describe the procedures for the product validation and show preliminary results for LAI algorithms.

2.0 METHODOLOGY OF PRODUCT VALIDATION

2.1 VALIDATION PROCEDURES

Remotely derived parameters need to be compared with ground-based measurements of known accuracy to assess the quality of remote sensing products. The ground plots are generally on the order of tens of metres, and the surface heterogeneity (cover type and density changes within a large pixel) make it inadequate to compare a pixel of size larger than 250 m to a ground measurement. It is therefore mandatory to use fine-resolution images, in which ground plots can be located accurately, to validate lower resolution products. The procedures that we use for national scale LAI and FPAR map validation are as follows:

1. Selection of representative areas across Canadian diverse eco-climatic regions (Ecoregions Working Group, 1989) and identifying Landsat scenes covering these areas;
2. Collection of LAI and FPAR data in multiple (10-40) plots within each Landsat scene using the same measurement instruments and protocols;
3. Identification of the ground plots in the scenes and extraction of the remote sensing data for each of the plots;
4. Development of LAI/FPAR algorithms for each scene separately based on ground measurements within each scene. For scenes which do not have enough data points or

dynamic range to obtain significant relationships, algorithms developed using all other scenes will be used;

5. Production of LAI and FPAR maps from each Landsat scene using the scene-specific or overall algorithms;
6. Degradation of the Landsat LAI and FPAR maps into maps of lower resolution to compare and evaluate moderate-resolution maps, such as those derived from AVHRR, Vegetation and MODIS sensors.

We realise that both LAI and FPAR change during the growing season. In particular, deciduous forests experience large changes from leaf-on to leaf-off. Conifer forests also have annual variations in LAI (Chen, 1996a). Daily mean FPAR also changes with solar zenith angle at noon (Chen, 1996b). In this first step of our validation, we have just focused on LAI and FPAR distribution in Canada during mid-summer (late June- late August) that should coincide with the maximum photosynthetic capacity of the vegetation being observed. The next step will be to develop algorithms for describing the seasonal LAI and FPAR trajectory according to remote sensing and auxiliary data.

2.2 MEASUREMENT PROTOCOLS

Two commercial instruments were used: (1) TRAC (Tracing Radiation and Architecture of Canopies), which was developed at CCRS (Chen and Cihlar, 1995) and commercialised by the Third-Wave Engineering (mikek@3wce.com), and (2) LAI-2000 by Li-Cor Inc. (Welles and Norman, 1991). The TRAC measures FPAR directly and provides the actual LAI from sunfleck measurements, from which both canopy gap fraction and gap size distribution are obtained. A theory was developed to derive LAI and a foliage clumping index from the gap size distribution (Chen and Cihlar, 1995). The LAI-2000 measures the gap fraction and therefore only produces data for the effective LAI, which can be converted into LAI when the clumping index is known. However, the LAI-2000 has the advantage of hemispherical exposure, providing better angular coverage than TRAC. Since the LAI-2000 derives the gap fraction from diffuse radiation transmission, it is less restricted by the sky conditions. For reducing the effect of direct radiation on LAI-2000 measurements, it was only operated near dusk or dawn or under overcast conditions. TRAC can be operated under clear-sky conditions and large amount of data can be collected on a single clear day. It is therefore recommended to use both instruments in a field program (Chen, et al., 1997). In this project, TRAC was used for all the scenes and LAI-2000 was used for all but 2 scenes. All TRAC data were processed using a common processing software (TRAC.exe). All ground measurements were made in mid-summer 1998. For the mixed stands in Alberta and Ontario, a correction was made to the conifer shoot-level clumping based on measured basal areas of deciduous and conifer species. The location of each ground plot was determined using global positioning systems (GPS), which have an accuracy of about ±10 m. The accuracy is often less than manufacturer specifications because of the distortion of the signal within forest stands.

2.3 DISTRIBUTION OF SELECTED AREAS IN CANADA

Eight Landsat scenes were purchased from Radarsat International. They are distributed from the west to east coast (Fig. 1). No extensive ground measurements were made in 1998 in Saskatchewan and Manitoba, and therefore no new Landsat coverages in these two provinces were included in this study. However, extensive data sets from the BOREAS (BOREAS, 1997) Southern and Northern Study Areas (SSA, NSA) were collected in 1994 and 1996 (Chen et al., 1997). They were used to develop algorithms for mapping LAI of the BOREAS region and Canada using AVHRR images. New measurements in other provinces in 1998 provide an opportunity to determine if any regional differences in the LAI algorithm exist. Due to logistic constraints, no ground measurements were made in the northern territories. The location and characteristics of the each scene are given in Table 1.

2.4 IMAGE PROCESSING METHODOLOGY

The geo-referenced Landsat scenes were first registered using ground control points obtained from 1:50,000 maps. The registration was accurate to within ± one pixel. The registered images were subsequently corrected for atmospheric effects, and the digital numbers were converted to reflectance at the surface level. Only three channels were used in this study: 3 (red), 4 (near-infrared, or NIR), and 5 (mid-infrared, or MIR). From these three bands, two vegetation indices were formed: (1) simple ratio (SR), which is the ratio of NIR reflectance to Red reflectance; (2) reduced simple ratio (RSR), which is SR reduced by a factor related to MIR reflectance, i.e., RSR=SR[1-(MIR-MIRmin)/(MIRmax-MIRmin)], where MIRmin and MIRmax are the minimum and maximum MIR reflectance in a scene. They are scene specific, and are determined from the histogram of MIR reflectance. SR is often found to be more linearly related to LAI than NDVI, and it was therefore chosen for further analysis. SR is appropriate for use with AVHRR images, which have only red and NIR bands in the optical spectrum, but RSR would be useful for Vegetation and MODIS images. We found that RSR has two advantages over SR (Brown et al., 1999): (1) RSR reduces the differences between cover types, making the LAI algorithm less sensitive to the accuracy of landcover maps, and this is particularly useful for mixed cover types; (2) RSR suppresses the influence of the background (understory, moss and soil) on the LAI algorithm.

3.0 PRELIMINARY RESULTS

The validation procedures 1-5 (as outlined in section 2.1) are completed, but the procedure 6 has not yet been done because the corresponding 1998 AVHRR image processing is not yet finished. In our conference presentation, comparison of TM images will be made with 1994 AVHRR images as the first step. In this paper, a summary of the overall relationships between LAI and SR and between RSR and LAI is shown for the three main forest cover types: deciduous, conifer, and deciduous-conifer mixture (when the dominant cover type is less than 80% in the area). All data from forests are shown in Figures 2(a) and 2(b). Because of uncertainties caused by image registration and the location of ground plots obtained by GPS, an average of 3 by 3 TM pixels was used for each plot. Plots within 30 m of each other were therefore grouped into one and shown as a point in the figure. All available data are shown and the only filtering of data was for several plots which are obviously affected by roads and water bodies in the TM images. The results are very encouraging. Figure 2(a) shows an approximately linear relationship between SR and LAI for conifers in the full range of LAI. Although the overall SR-LAI relationship appears to be linear and statistically significant, the relationships within individual scenes are usually noisy. This is likely due to several factors including the small dynamic range in each scene and large uncertainties in the data due to errors in the LAI measurements, in the co-location of plots in the images, and in the variability of the background optical properties (understory, litter and soil). A similar relationship between RSR and LAI was also found for conifer (Figure 2(b)), indicating that only a small improvement can be obtained for conifer through the use of MIR data. Figures 2(c) and 2(d) show a large improvement for the deciduous type when RSR instead of SR is used. This is believed to be due to the ability of the RSR to suppress the influence of the understory which is more prevalent in deciduous stands than in conifer stands (Brown et al., 1999). The improvement for the mixed type after the use of RSR is also considerable, as shown in Figures 2(e) and 2(f). By comparing the plots arranged vertically in Figure 2, it can be seen that the differences in RSR among the cover types are substantially smaller than those in SR. This confirms the finding of Brown et al. (1999) that the use of MIR data can reduce the dependence on landcover information for LAI retrieval.

4.0 CONCLUDING REMARKS

It is encouraging to find that vegetation indices are highly correlated with LAI when LAI data are collected from a wide range of forest ecosystems. The significant relationships shown with the existing data provide some confidence in mapping regional LAI using moderate resolution satellite images. However, the large variability of the data points within each scene is still of concern. The heterogeneity of the background optical properties may be the main source of data variability, and will remain a problem until addressed by more detailed studies.

5.0 REFERENCES

BOREAS, 1997. Special Issue. *Journal of Geophysical Research,* 102:28,731-29,745.

Brown, L. J., J. M. Chen, and S. G. Leblanc, 1999. Short wave infrared correction to the simple ratio: an image and model analysis. *Remote Sensing of Environment,* (submitted).

Committee for Earth Observing Satellites (CEOS), 1997. 1997 CEOS Yearbook, European Space Agency.

Chen, J. M., P. M. Rich, T. S. Gower, J. M. Norman, S. Plummer, 1997. Leaf area index of boreal forests: theory, techniques and measurements. *Journal of Geophysical Research,* 102:29,429-29,444.

Chen, J. M., 1996a. Optically-based methods for measuring seasonal variation in leaf area index of boreal conifer forests. *Agricultural and Forest Meteorology,* 80:135-163.

Chen, J. M., 1996b. Canopy architecture and remote sensing of the fraction of photosynthetically active radiation in boreal conifer stands. *IEEE Transactions on Geoscience and Remote Sensing,* 34:1353-1368.

Chen, J. M. and J. Cihlar, 1995. Plant canopy gap size analysis theory for improving optical measurements of leaf area index. *Applied Optics*, 34:6211-6222.
Ecoregions Working Group, 1989. Ecoclimatic Regions of Canada, First Approximation. Ecological Land Classification Series No. 23. Environment Canada, Ottawa. 119p.
Spanner, M. A., L. Johnson, J. Miller, R. McCreight, J. Freemantle, J. Runyon, P. Gong, Remote Sensing of seasonal leaf area index across the Oregon transect. *Ecol. Appl.*, 4, 258-271, 1994.
Welles, J.M. and Norman, J.M. 1991. Instrument for indirect measurement of canopy architecture. *Agronomy Journal,* 83: 818-825.
Wulder, M. A., S. E. Franklin and M. B. Lavigne, High spatial resolution optical image texture for improved estimation of forest stand leaf area index. *Can. J. Rem. Sens.*, 22, 441-449, 1996.

Table 1. Location and characteristics of Landsat scenes as numbered in Figure 1.

Num	Location Name	Landsat TM scenes		Location		Description	No. of the sites
		Track	Frame	Lon Range	Lat Range		
1	Victoria	47	26	124d21'45"-122d39'37	48d04'35"-49d04'07"	Con	17
2	Whitecourt	44	22	117d31'48"-114d02'26"	53d05'28"-54d58'51"	Con, Dec, Mix	16
3	Kananaskas	42	24	115d42'46"-112d28'57"	50d06'33"-51d58'37"	Con, Dec	6
4	Radisson	19	23	79d18'50"-75d54'52"	52d08'55"-54d01'49"	Con	33
5	Fraserdale	20	25	82d09'58"-79d01'25"	48d56'28"-50d48'09"	Con, Mix	7
6	Ontario	19	27	81d40'48"-78d26'02'	46d27'32"-48d22'42"	Con, Dec, Mix	35
7	Ottawa	15	29	76d02'25"-74d36'15"	44d43'02"-45d39'13"	Agriculture	10
8	Acadia	10	28	66d54'50"-65d26'43"	45d26'17"-46d23'06"	Con, Dec	9

Figure 1. Landsat TM scenes selected for Canada-wide LAI image validation. The location and characteristics of each numbered scene are given in Table 1. The unnumbered rectangles (one large enclosing two small) indicate the BOREAS Region and study areas.

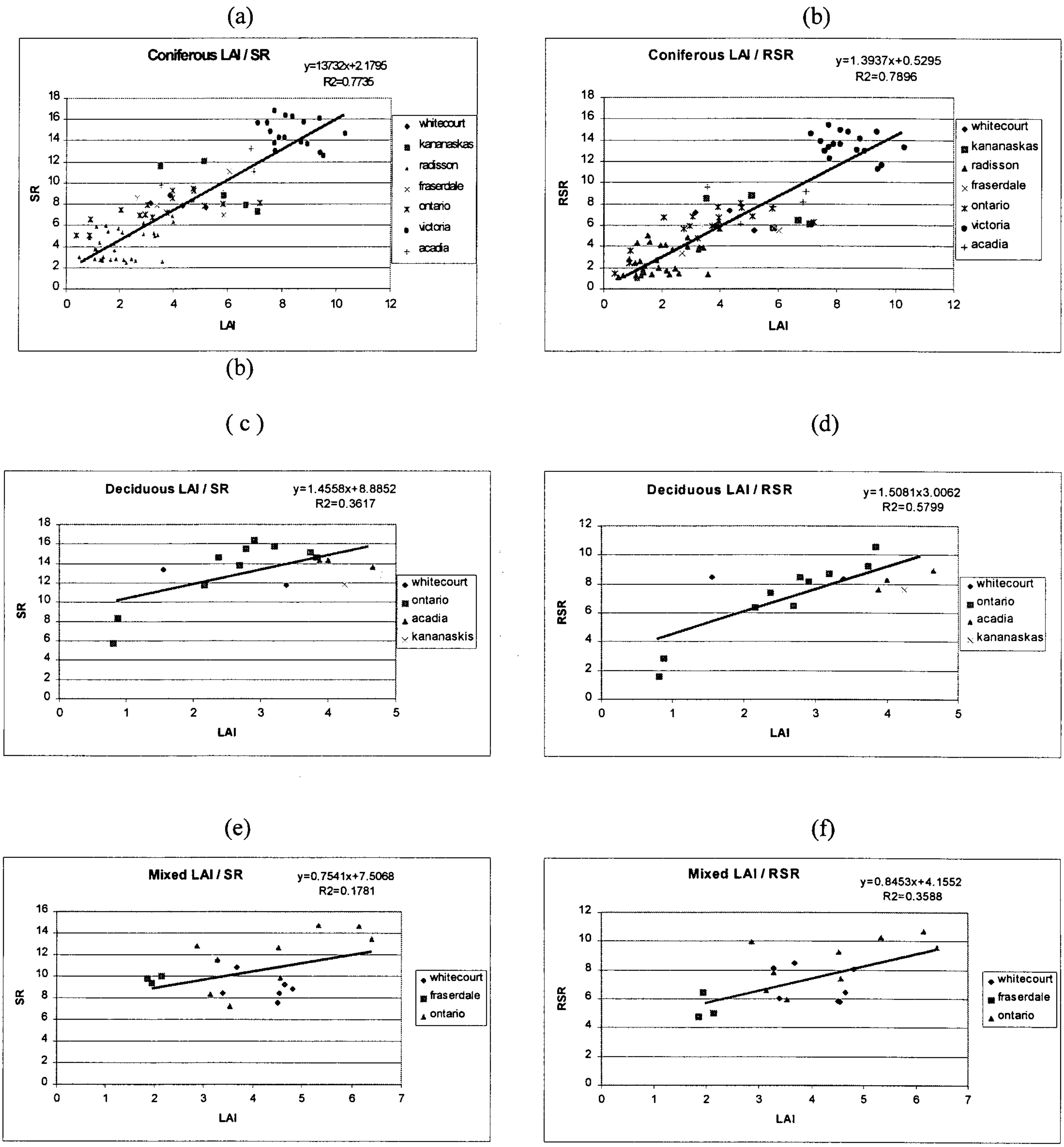

Figure 2. The response of simple ratio (SR) and reduced simple ratio (RSR) to the changes in leaf area index (LAI) for conifer, deciduous and mixed forest types for six selected areas across Canada. Both ground LAI and Landsat images were acquired in mid-summer 1998.

Proceedings of the Fourth

International Airborne Remote Sensing Conference and Exhibition/ 21st Canadian Symposium on Remote Sensing

Volume II

21-24 June 1999
Ottawa, Ontario, Canada

Published by
ERIM International, Inc.
P.O. Box 134008, Ann Arbor, MI 48113-4008, USA

The papers appearing in this two-volume set constitute the proceedings of the *Fourth International Airborne Remote Sensing Conference and Exhibition.* They reflect the authors' opinions and are published as received. Their inclusion in this publication does not necessarily constitute endorsement by ERIM International, Inc.

Copyright © 1999 ERIM International, Inc.

No liability is assumed with respect to the use of the information contained herein.

ISSN 1076-7924

Printed in the United States of America.