

POTENTIAL FOR DETERMINATION OF LEAF CHLOROPHYLL CONTENT USING AVIRIS

J. R. MILLER, J. R. FREEMANTLE, M. J. BELANGER, Earth Observations Laboratory, Institute for Space and Terrestrial Science, York University, Toronto, Canada, C. D. ELVIDGE, Desert Research Institute, University of Nevada, Reno, Nevada, USA and M. G. BOYER, Biology Dept., York University, Toronto, Ontario, Canada.

INTRODUCTION

It is widely known that pigments play the dominant role in determining leaf reflectance in the visible to near infrared spectral region. Specifically, the reflectance amplitude at 550nm and the spectral position of the red edge have been linked to leaf chlorophyll pigment content through field and laboratory studies. The potential to transfer such results to applications in forestry and agriculture through remote sensing presents the challenge to place interpretation algorithms on a quantitative basis and to develop measurement methodologies that are amenable for practical use with modern satellite/airborne sensors. Additional important questions being explored in current research include: (i) are such relationships species-dependent, (ii) do leaf-level conclusions translate to canopy-level relationships, and (iii) what sensor configurations, in terms of spectral/spatial resolutions, permit leaf chlorophyll content to be estimated?

This paper represents a preliminary evaluation of the potential of the AVIRIS sensor to provide quantitative estimates of canopy chlorophyll through the use of laboratory/field results in interpretation algorithms applied to AVIRIS imagery. Five AVIRIS images have been acquired over Stanford University's Jasper Ridge Biological Preserve during the period July 24, 1987 to September 20, 1989, providing imagery in April, June, July, August and September spanning the vegetation seasonal cycle, albeit from different years (see Table 1). Other papers have recently reported on the seasonal variation in the AVIRIS reflectance properties of the six dominant vegetation communities at the Jasper Ridge site (Elvidge and Portigal 1990, Miller *et al.* 1990a). This paper is focussed on the potential of AVIRIS to extract leaf chlorophyll estimates from the red edge reflectance spectral region.

METHODOLOGY

Leaf Chlorophyll and Red Edge Parameters

A two-year study of the relationship between leaf spectral reflectance properties and botanical parameters (chlorophyll *a* and *b*, total chlorophyll and water content) has been recently completed, consisting of weekly samples collected of leaves of ten trees located on the campus of York University, Toronto, Canada and subsequent laboratory analyses. Joint botanical and optical data were gathered from the deciduous species: aspen (*Populus tremuloides* Michx.), bur oak (*Quercus macrocarpa* Michx.), Manitoba maple (*Acer negundo* L.), sugar maple (*Acer saccharum* Marsh.) and Norway maple (*Acer platanoides* L. var 'Crimson King'). A detailed description of the experimental methodology is presented elsewhere (Belanger 1990; Belanger *et al.* 1990, Miller *et al.* 1990b).

The pigment data was obtained from 2 cm diameter leaf discs which were ground with a mortar and pestle in acid washed sand, extracted, centrifuged and assayed in 80 percent v/v acetone distilled water. The extracts measured with a Pye Unicam SP8-500 UV/VIS spectrophotometer were used to obtain estimates of pigment concentrations on an area

basis for chlorophylls *a* and *b* and a total using the specific absorption coefficients given by MacKinney (1941).

Spectral reflectance measurements (500nm to 900nm) were made of optically thick leaf stacks, relative to BaSO₄, using a Jobin-Yvon model H-20 V-IR monochromator (4 nm spectral resolution). The leaves were consistently measured at a mid-leaf point to the right side of the main leaf vein. This target area was lightly marked, with a felt pen, and the leaves were then stored in polyethylene bags and refrigerated discs were subsequently cut from the marked leaf area for the chlorophyll analyses.

The optical parameters which are normally used to define the red edge region (680-800 nm) include: R_s (the near IR shoulder reflectance), R_o (the red edge reflectance minimum), λ_o (the wavelength corresponding to R_o), λ_{pr} (the red edge inflection point wavelength, determined from the first derivative maximum). The Inverted Gaussian model (IGM) has been fitted to the red edge (Miller *et al.* 1985, 1990c) which is defined by four parameters: R_{sg} (the Gaussian shoulder reflectance), R_{og} (the Gaussian red edge reflectance minimum), λ_{og} (the wavelength corresponding to R_{og}) and λ_{pg} (the Gaussian inflection point). The IGM parameters are thought to represent a smoothed red edge reflectance curve so that the real and IGM parameters are very similar but show important differences (Miller *et al.* 1990c). In particular, it is important to note that the specification of the red edge position from simple derivative analysis of reflectance spectra is not independent of the instrument spectral resolution because the red edge normally manifests a distinct bi-modality, or at least an asymmetry, in the first derivative curve (Boochs *et al.* 1988; Horler *et al.* 1983, Miller *et al.* 1990b). The use of the IGM curve fitting approach has been found to extract red edge spectral information that is related to the dominant controlling parameter: chlorophyll content (Belanger *et al.* 1990), independent of variations in the bi-modality in the first derivative curve.

The results of the data analysis for leaf samples from spring flush (Julian day 135) through senescence (Julian day 288) are summarized in Figure 1. These data indicate that the relationship between total chlorophyll content per unit leaf area and red edge spectral position parameters λ_{pg} and λ_{og} , obtained by curve fitting with the IG model is species independent for the 4 deciduous species studied. Although it is premature to propose a universal algorithm to determine leaf chlorophyll content from red edge spectral parameters from remote sensing sensors it does provide a quantitative basis for inference of leaf chlorophyll content from AVIRIS in the absence of field botanical/optical data from the vegetation communities at the Jasper Ridge site.

AVIRIS Red Edge Reflectance Spectra

Each of the five AVIRIS images was "calibrated" to provide scene reflectance spectra through regression analyses between AVIRIS digital numbers (raw or radiometrically-corrected values) and spectral reflectances of pseudo-invariant targets in the scene that had been previously characterized via field spectral measurements (see Elvidge 1988 for details). Two of the five data sets had been spectrally-resampled by JPL to provide 210 spectral bands with a 9.8nm spectral interval (see Table 1). For the 224 band data a spectral mask was applied to remove spectral channels that generated erroneous data (Vane *et al.* 1988) and to choose between overlapping spectral channels.

Red edge reflectance spectra from AVIRIS image pixels viewing a 50-meter-square area located in a live oak (*Q. agrifolia*) vegetation community are shown in Figure 2. For each spectrum the AVIRIS data are shown as points and the solid line through the points represents the "best fit" IGM curve. This plot represents typical AVIRIS red edge reflectance data. Systematic changes are observed in the near IR shoulder reflectance through the season with maximum values in the June imagery and the reflectance minimum near 680nm is well-defined throughout the phenological period sampled. By contrast, for the grassland communities (not shown here, see Miller *et al.* 1990a; Elvidge

and Portugal 1990) the chlorophyll pigment influence on the reflectance at 680nm is prominent in the April image but is virtually non-existent from June to September.

RESULTS

Noise and spectral resolution limit the feasibility of first derivative analysis on AVIRIS red edge spectra, as in laboratory or field spectrometers data, to obtain red edge position information. A typical red edge spectrum is shown in Figure 3 along with the IG model fitted curve. The two spectral parameters of this model, λ_{pg} and λ_{og} , provide direct quantitative measures of the red edge spectral position and are readily computed on a pixel-by-pixel basis. Such analyses have been conducted to produce images of these and other reflectance/spectral parameters (Miller *et al.* 1990a). Given the developmental state of the AVIRIS sensor over the time span being investigated, the fact that the phenological cycle is being reconstructed from imagery from 3 different years and the absence of site botanical/optical data during this period a detailed evaluation of the results obtained is not warranted. Overall, the red edge spectral position parameters show similar seasonal behavior for all vegetation communities (Miller *et al.* 1990a), except for the grassland communities as mentioned above. Variations in red edge position between species were small compared to variations with time of year.

The red edge data interpreted in terms of seasonal variation in leaf chlorophyll content for live oak (*Q. agrifolia*) are presented in Figure 4 by using the relationships between red edge position parameters and chlorophyll from Figure 1. Chlorophyll seasonal profiles derived from both λ_{pg} and λ_{og} algorithms imply relatively constant leaf chlorophyll levels followed by chlorophyll degradation after July 24. These results are generally consistent with pigment phenological patterns previously observed in other species (Belanger *et al.* 1990). The April values are unexpectedly higher than June but given the constraints on the data set already mentioned no firm conclusions are warranted about the significance of such small variations. The offset in deduced chlorophyll values between inferences from λ_{pg} and λ_{og} may be generated by the degraded spectral resolution of AVIRIS (9.8nm) compared to that of the York University study (4 nm) or may imply inadequacy of the algorithm employed for this ecosystem.

CONCLUSIONS

This preliminary evaluation of the potential of AVIRIS to map canopy chlorophyll indicates that further detailed experiments are certainly warranted. The AVIRIS red edge spectra appear amenable to curve-fitting approaches for the extraction of red edge position information. Further, when red edge position to leaf chlorophyll algorithms are applied phenological patterns in pigment content are in general agreement with optical/botanical field studies of tree leaves.

The recent research results (Belanger *et al.* 1990) which suggest that a species-independent relationship exists between certain red edge spectral parameters and leaf chlorophyll content need to be explored under a wide range of species and climate regimes. If a universal relationship does in fact exist then red edge spectral parameters from remote sensing can be used to infer mean leaf chlorophyll content per unit area in each pixel viewed. Effects of spectral mixing due to differing species with different leaf chlorophyll concentrations and due to understory effects in thin canopies would not in this case invalidate inferences of pixel mean leaf pigment content per unit area. Further, non-vegetated substrate components with spectral reflectances that vary slowly with wavelength would not be expected in the extraction of chlorophyll information from the vegetation community being viewed. Comprehensive and coordinated field and airborne experiments currently under way should permit these issues to be addressed and resolved.

ACKNOWLEDGEMENTS

This work was made possible by financial support from the Natural Sciences and Engineering Research Council of Canada (Project CRD 0038987) and the Province of Ontario through the Institute for Space and Terrestrial Science.

REFERENCES

- Belanger, M. J. (1990), *A seasonal perspective of several leaf developmental characteristics as related to the red edge of plant leaf reflectance*. M.Sc. Thesis, York University, Toronto, Canada, 110 pp.
- Belanger, M. J., Miller, J. R., Boyer, M. G. (1990), The red edge of plant reflectance as influenced by leaf phenology, submitted to *Remote Sens. Environ.* July, 1990.
- Boochs, F., Dockter, K., Kupfer, G., Kuhbauch, W. (1988), Red edge shift as a vitality indicator for plants. Presented at the *Sixteenth International Congress of Photogrammetry and Remote Sensing*, Kyoto, Japan, 8 pp.
- Elvidge, C. D., (1988), Vegetation reflectance features in AVIRIS data, *Proceedings of the International Symposium on Remote Sensing, Sixth Thematic Conference on Remote Sensing for Exploration Geology*, pp. 169 - 178, held at Houston, Texas, May 16 - 19, 1988.
- Elvidge, C. D., Portigal, F. P. (1990), Phenologically induced changes in vegetation reflectance derived from 1989 AVIRIS data. Presented at the *23rd International Symposium on Remote Sensing of the Environment*, 16p, held in Bangkok, Thailand, April 18 - 25, 1990.
- Horler, D. N. H., Dockray, M., and Barber, J. (1983), The red edge of plant leaf reflectance. *Int. J. Remote Sens.* 4:273-288.
- Mackinney, G. (1941), Absorption of light by chlorophyll solutions. *Biol. Chem.* 140:315-322.
- Miller, J. R., Hare, E. W., Neville, R. A., Gauthier, R. P., McColl, W. D., and Till, S. M. (1985), Correlation of metal concentration with anomalies in narrow band multispectral imagery of the vegetation red reflectance edge. In *International Symposium on Remote Sensing of Environment, Fourth Thematic Conference, Remote Sensing for Exploration Geology*, San Francisco, pp. 143-153.
- Miller, J. R., Elvidge, C. D., Rock, B. N., Freemantle, J. R. (1990a), An airborne perspective on vegetation phenology from the analysis of AVIRIS data sets over the Jasper Ridge Biological Preserve, *Proceedings of the 10th International Geosciences and Remote Sensing Symposium*, held at the University of Maryland, Washington, D.C. May 20 - 24, 1990, pp. 565 -568.
- Miller, J. R., Wu, J., Boyer, M. G., Belanger, M. J., and Hare, E. W. (1990b), Seasonal patterns in leaf reflectance red edge characteristics. *Int. J. Remote Sens.* (in press).
- Miller, J. R., Hare, E. W., and Wu, J. (1990c), Quantitative characterization of the vegetation red edge reflectance. 1: An Inverted-Gaussian reflectance model. *Int. J. Remote Sens.* (in press).
- Vane, G., Chrien, T. G., Riemer, J. H., Green, R. O., Conel, J. E. (1988), Comparison of laboratory calibrations of the Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) at the beginning and end of the first flight season, *Proceedings of SPIE: Recent Advances in Sensors, Radiometry, and Data Processing for Remote Sensing*, Vol 924, pp. 168 - 178.

TABLE 1: AVIRIS Data Sets Over Jasper Ridge Biological Preserve

Date	Julian Day	Season	# Spectral Bands
April 13/89	103	spring	224
June 2/89	153	early summer	224
July 24/87	205	summer	210
Aug 31/88	244	late summer	210
Sept 20/89	263	early fall	224

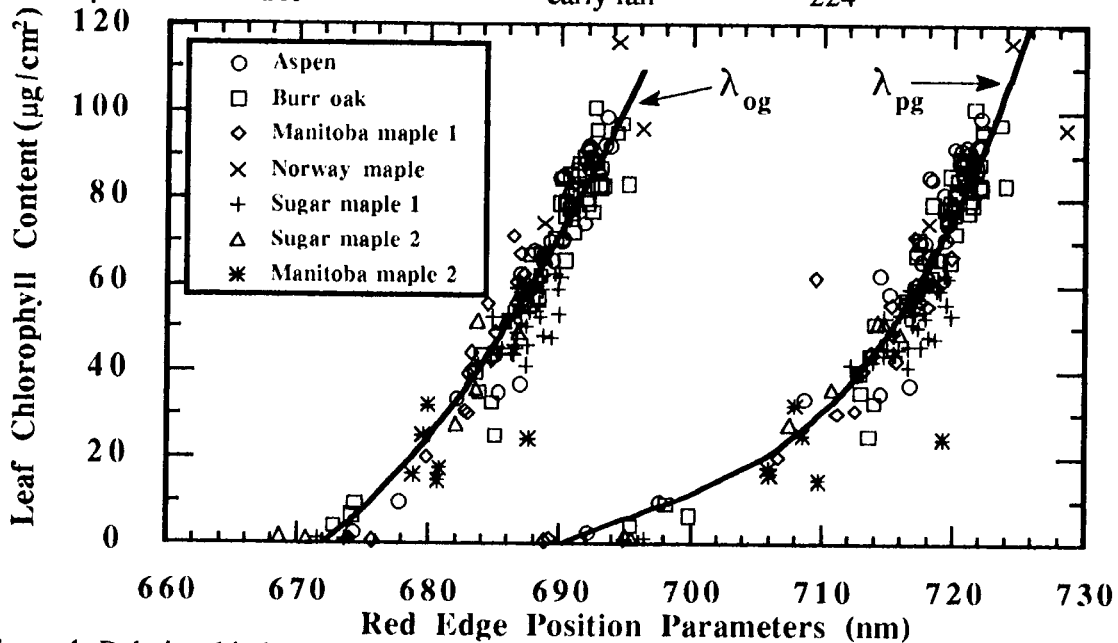


Figure 1. Relationship between the total leaf chlorophyll content per unit area and the Inverted Gaussian model red edge position parameters λ_{og} and λ_{pg} (see text) for leaves from 5 tree species sampled from spring flush through fall senescence.

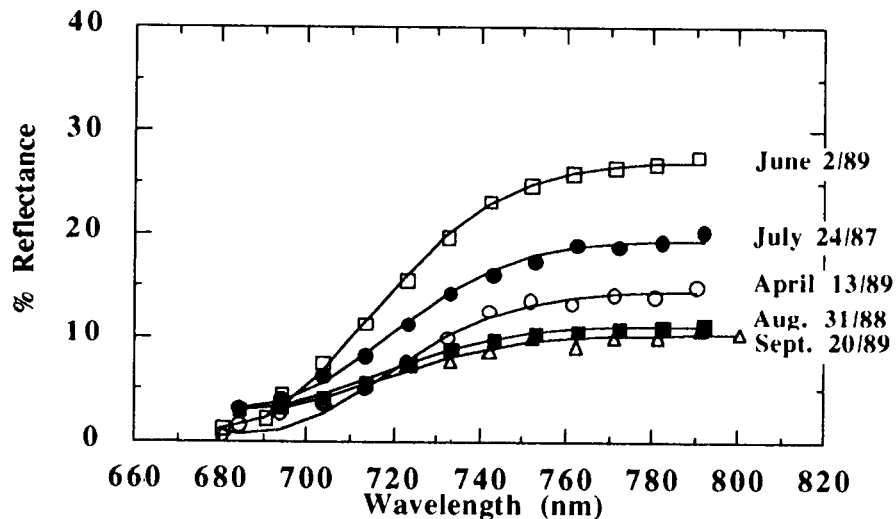


Figure 2. Seasonal variation in AVIRIS red edge spectra from live oak (*Q. agrifolia*) at the Jasper Ridge Biological Preserve. (Points - AVIRIS data; solid line - Inverted Gaussian curve fit).

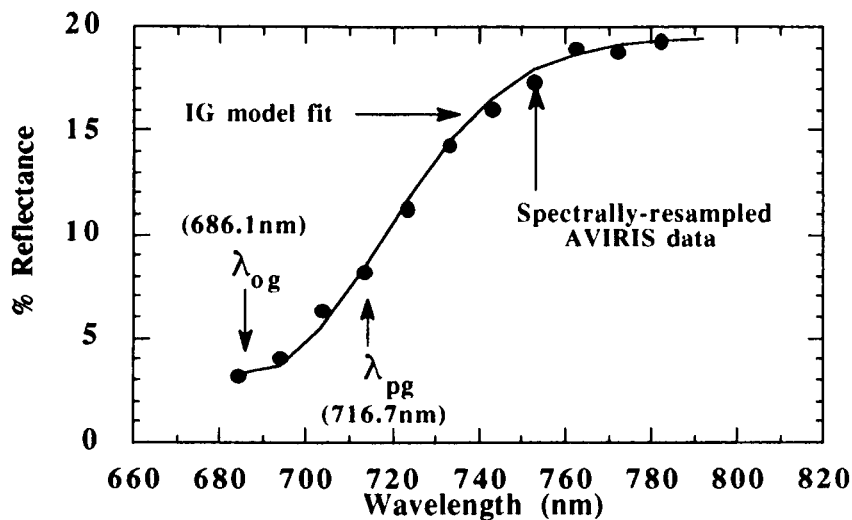


Figure 3. Detailed view of IGM curve fit for live oak (*Q. agrifolia*) red edge spectrum for July 24, 1987.

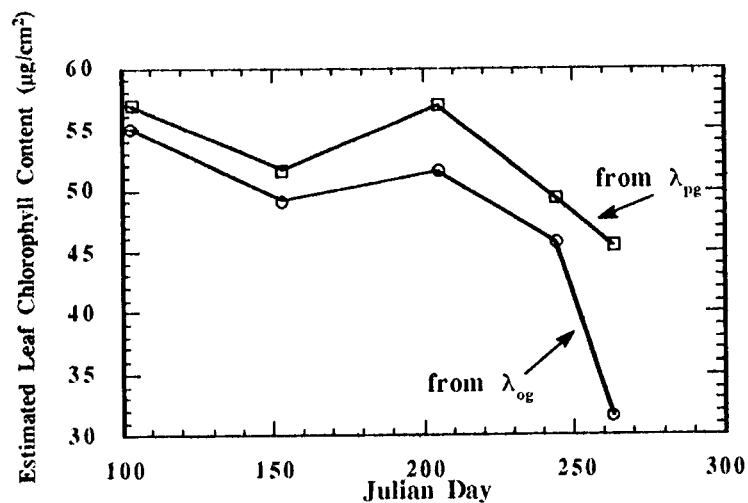


Figure 4. Estimated leaf chlorophyll concentration for live oak derived from AVIRIS red edge spectral curve fitting coupled with interpretation algorithms shown in Figure 1.