A Windows Graphic User Interface (GUI) for the Five-Scale model for fast BRDF simulations.

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ABSTRACT

In recent years, the computational power of personal computers (PC) has increased to the point that computationally-demanding research can now be achieved on low cost PC machines. Furthermore, portable laptops allow heavy computational science to be carried out anywhere, even during field measurements. The radiative-transfer models Four-Scale (Chen and Leblanc, 1997; Leblanc et al., 1999; Chen and Leblanc, 2000) and LIBERTY (Dawson et al., 1998), which were both originally coded in C, has been combined to form a five scales model. This new Five-Scale model was adapted to the Windows environment with a Graphic User Interface (GUI) to facilitate its usage. The software allows the Bidirectional Reflectance Distribution Functions (BRDF) to be computed and plotted in real-time in four different ways: (1) customised planes (e.g., principal plane) of different spectral reflectances and components such as the probabilities of seeing sunlit and shaded foliage and background; (2) a hemispherical mode to view reflectance at all angles at once; (3) a hyperspectral mode that uses reflectivity spectra of foliage and background to compute the canopy reflectance under a specific view-target-sun geometry; and (4) a user-defined mode that allows the user to specify changes in any parameters such as Leaf Area Index (LAI) for studying vegetation indices and other canopy properties. The simulations can be saved in ASCII format for importing to other software. This interface is a good tool for studying radiative transfer in vegetation for various remote sensing applications. The usefulness of the model as a learning tool and advantages of the model for the study of multiangular measurements are presented.

KEYWORDS: BRDF, LIBERTY, FIVE-SCALE, RADIATIVE TRANSFER MODEL.

INTRODUCTION

The anisotropic behaviour of reflected solar radiation from vegetation, which is often referred to as BRDF, is a practical problem in remote sensing applications. Because of the complexity of this topic, remote sensing textbooks, so far, only barely mention the BRDF, e.g., Campbell (1996) added only one page from his previous edition about non-Lambertian behaviour of surfaces. Fruitful research in this topic has so far been mostly limited to the production of models for making angular correction and normalisation to remote sensing images (e.g. Roujean et al., 1992, Walthall et al., 1985, Wanner et al., 1995), i.e., the BRDF has been considered as noise to remove rather than information sources. An accurate, flexible BRDF model with the capability of immediate display of simulated results is not only critical for deriving useful information from BRDF measurements but is also a useful tool for educational purposes. Such a tool can now be produced because of the computer technology advancements of the last two decades. Today low cost computers are faster than the workstations of only a few years ago, and the price of high-end PCs is steady, which means that for the same investment, more powerful PC can be acquired every year. For the scientific community, it means that programs developed for workstations can now be implemented on personal computers and thus can be used anywhere on laptops, even during field campaigns. Moreover, with Microsoft Windows being the most commonly used operating system around the world, compiled versions for this platform are easy to share compared to UNIX workstations, where the code has to be recompiled on each system due to a lack of standard. Ready-to-use programs are perfect for beginners, or for users with low computer programming skills. Complex models are often used as black boxes by beginners because of the amount of parameters required and the complex theory behind them. In an effort to make Five-Scale easy to use, the program has been upgraded from the "command line mode" to a GUI for Windows. The GUI allows users of different technical background to simulate and study directional reflectance of plant canopies in real–time allowing less data manipulation and potential for errors.

FOUR-SCALE

The geometric-optical radiative transfer model Four-Scale was developed with emphasis on the structural

composition of forest canopies (Chen and Leblanc, 1997). Four-Scale can simulate the reflectance of a forest canopy at any sun-target-view geometry. It employs the following methodologies: 1) The model simulates tree crowns as discrete geometrical objects: cone and cylinder for conifers, and spheroid for deciduous species. The non-random spatial distribution of trees is simulated using the Neyman type A distribution (Neyman, 1939) to simulate patchiness of forest stands. The size of the crowns decreases when the trees are found in large clusters and the trees can also be subject to a repulsion effect (i.e., no vertical overlaps occur) to better represent the competition for light. 2) Inside the crown, a branch architecture, defined by a single inclination angle (Leblanc et al, 1999), is included. A branch is in turn composed of foliage elements (individual leaves in deciduous and shoots or group of shoots in conifer canopies) with a given angular distribution. 3) The hotspot is computed both on the ground and on the foliage with gap size distributions between and inside the crowns, respectively. 4) The tree surface created by the crown volume (cone and cylinder, or spheroid) is treated as a complex medium so that shadowed foliage can be observed on the sunlit side and sunlit foliage on the shaded side. 5) A geometrical multiple scattering scheme using view factors is used to compute the reflectivities (Chen and Leblanc, 2000). Four-Scale has shown good agreements with measured boreal forest BRDF taken with PARABOLA and POLDER. Figure 1 shows the principal solar plane of a mature jack pine (*Pinus banksiana*) stand measured with PARABOLA, and the airborne POLDER in Saskatchewan, Canada, along with simulations made with Four-Scale. The input parameters are from field measurements (see Leblanc et al., 1999). The model is able to reproduce the distinct BRDF of both bands: a pronounced hotspot can be seen in the red band with the reflectance decreasing almost linearly at large zenith angles which contrasts with the near-infrared band in which the reflectance exhibits a curved shape at large zenith angles.

LIBERTY: A 5th SCALE

Prior to the inclusion of a multiple scattering scheme in Four-Scale, the reflectivity of shaded scene components had to be known to model canopy reflectance. Shaded reflectivity measurements for different stands are not always available and thus had to be estimated using previously known sites information. By adding the multiple scattering scheme (Chen and Leblanc, 2000), Four-Scale is able to model the reflectivity of the shaded components without using band-specific multiple scattering factors based on known reflectance spectra for the foliage and the background. This becomes critical for the simulation of hyperspectral reflectance. Since the availability of full optical range spectra is limited, the
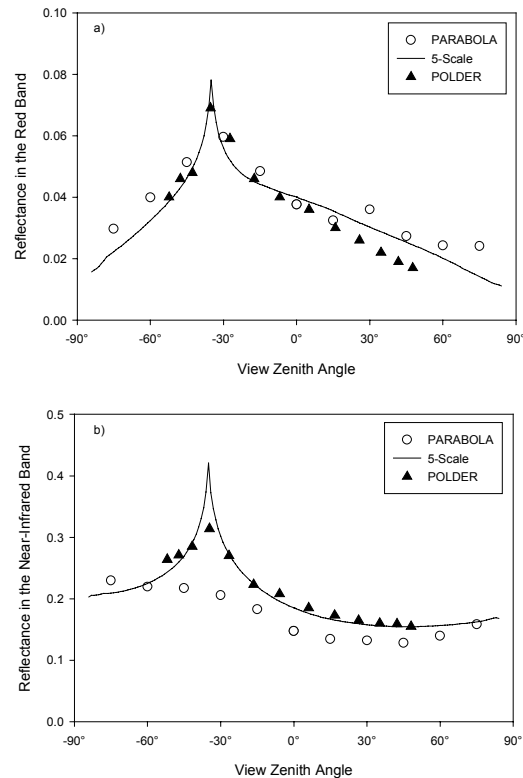

Figure 1: 4-Scale simulations of POLDER and PARABOLA data of the BOREAS Old Jack Pine site for a) the red and b) the near infrared band, respectively.

LIBERTY model (Leaf Incorporating Biochemistry Exhibiting Reflectance and Transmittance Yields) (Dawson et al., 1998) was added to Four-Scale. LIBERTY represents a fifth scale at which the interaction of light is considered. LIBERTY is a general-purpose radiative transfer model that simulates the reflectance and transmittance spectra of a leaf, or stack of leaves, in the visible and near infrared wavelengths (400 - 2500 nm). It is similar to PROSPECT (Jacquemoud et al, 1996), but it considers the finite dimension of leaves in the cross-light directions so it is suitable for conifer needles. The foliage (leaves or needles) is treated as an aggregation of cells, with multiple scattering between the cells. The output spectrum is a function of three structural parameters (cell diameter, intercellular space, and leaf thickness) and the combined absorption coefficient of leaf biochemical parameters (e.g., chlorophyll and water). LIBERTY simulations have shown less than 3% root mean square error compared with laboratory measurements of pine needle reflectivity (Dawson et al., 1998). LIBERTY can be inverted to obtain biochemical parameters from foliage hyperspectral measurements. It can be used within Five-Scale or separately by compiling the code, or using a separate Windows GUI. Figure 2 shows an application of the LIBERTY and Four-Scale combination.
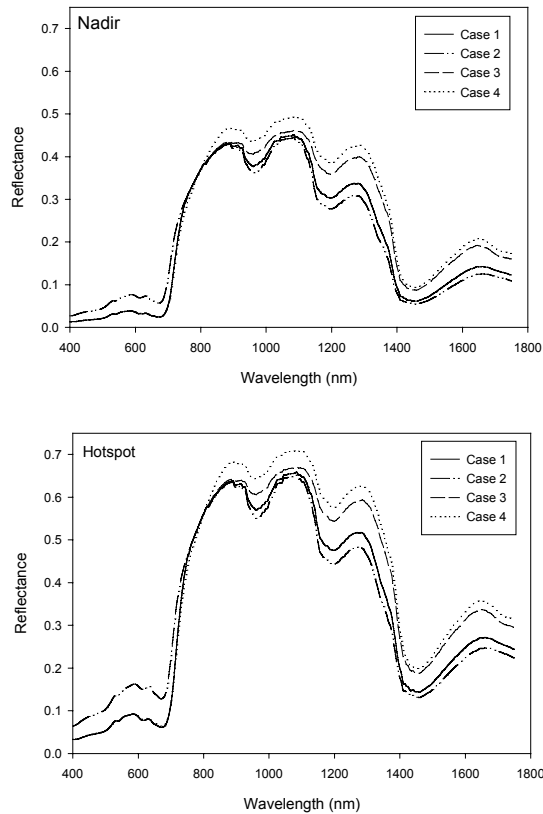
Figure 2: 5-Scale simulation of hyperspectral data with different foliage properties. Table 1 has the LIBERTY input parameters.
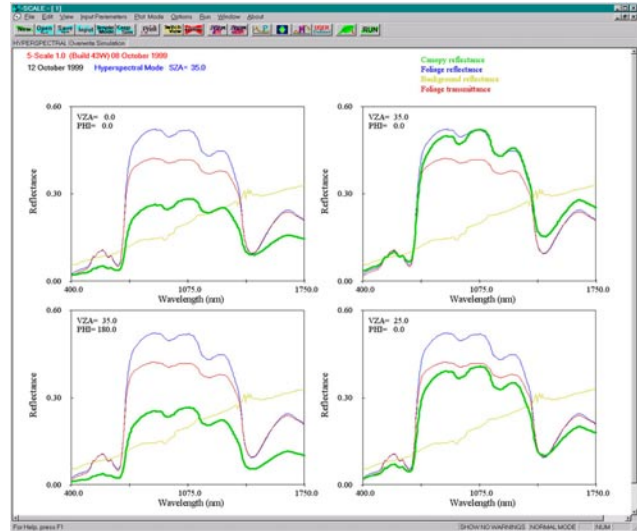

Figure 3: Snapshot of 5-Scale with an example of the hyperspectral mode output. The foliage optical properties were simulated with LIBERTY while the background is from soil measurements.

By varying the biochemical composition of jack pine needles, Five-Scale is able to model the change in reflectance that a sensor would measure at different view and sun geometries. The example of Figure 2 indicates that the reflectance changes due to changes in foliage biochemical properties may be similar at different view angles. This could mean that a complete spectrum combined with a few selected view angles of multi-spectral reflectance could be sufficient to characterise the BRDF-hyperspectral properties of a canopy. The GUI can compute and display four canopy reflectance spectra at four view angles simultaneously (see Figure 3).

THE INTERFACE

The Windows interface for Five-Scale is written with Microsoft Visual C++ (the latest version of Five-Scale is compiled with MS VC++ 6). The "Four-Scale" and "LIBERTY" parts of the model are in ANSI C, while the interface itself is in C++. Other computer languages and compilers can be used to create GUI, but a generic compiler such as the Visual C++, although having a longer learning curve, has more flexibility. The main advantages of Five-Scale's interface are user-friendliness:

only relevant parameters, specific to a mode or option, can be modified by the user (see Figure 4).The results appear in real time in the display window (see Figure 3). The program can be used to produced publishable quality hardcopies (see Figures 5 and 6). The model in execution gives warnings to the user to consider changing some parameters that may not be physically realistic, such as tree mutual repulsion effects when the number of crowns per unit area is very large. Four predefined plotting modes are available:

The plane mode is used to plot planes such as the principal solar plane at angle increment of 1° or more. The default setting shows the reflectance at 670 nm (red), 875 nm (near infrared), and 1600 nm (short-wave infrared), with three vegetation indices: the normalised difference vegetation index (NDVI), the simple ratio of near infrared and red reflectance (SR), and the reduced simple ratio (RSR) from Brown et al. (2000). The RSR was developed using an early prototype of the GUI. Proportions of sunlit and shaded foliage and background computed by Five-Scale are also shown along with other properties such as the hotspot functions and gap fraction. Shadow proportions have some applications in forest parameter retrieval as demonstrated by Hall et al. (1995). Figure 5 shows some of the output from a simulation for a black spruce forest (*Picea mariana)*. Multiple simulations can be plotted on the same graph to study the directional behaviour of reflectance based on different parameters. The two lines represents two different solar zenith angles (35° and 60°). The amount of shaded foliage seen clearly increases in the higher solar zenith angle case of 60° compared to the other case at 35° for all view angle far
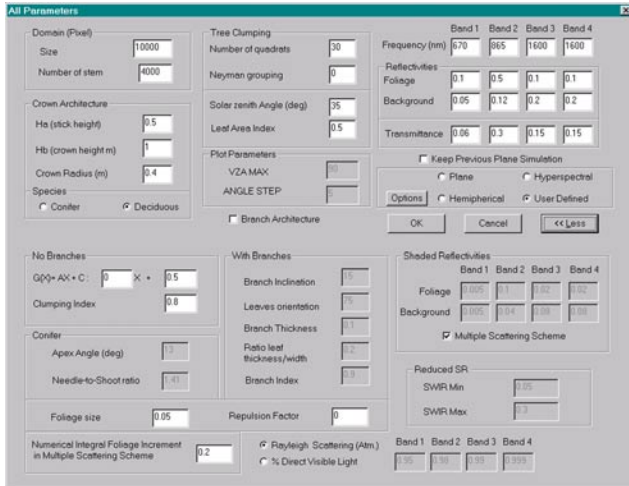
Figure 4: Dialog box used to enter the input parameters. Gray edit boxes are for parameters that cannot be changed because they are not used in the specified mode.
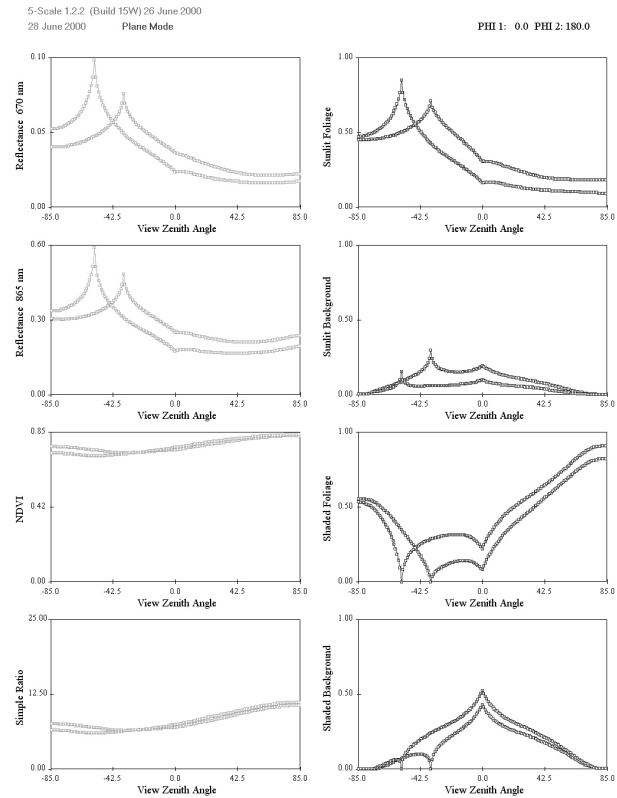

Figure 5: Printout example of the plane mode for a principal plane of a black spruce forest. The simulation are at solar zenith angles of 35° and 55°.

from the hotspot. Both the NDVI and the SR are larger on the forward scattering side than the backscattering side with a minimum at the hotspot. The directionality of NDVI has been studied using airborne POLDER data and Four-Scale by Leblanc et al., (1997).

2) The hemispherical mode is used to plot the full angular distribution of canopy reflectance using colour-coded squares, each representing a specific view geometry. When used at its maximum resolution (1°), it gives a contour plot-like graph (see Figure 6). The model displays the red and near-infrared reflectance by default, with the NDVI and SR, but it can be changed to show reflectances of four bands at once. Figure 6 shows that the reflectance of a similar black spruce forest as Figure 5. The reflectance pattern in the near-infrared (865 nm) differs from the red reflectance (670 nm) mainly in the backscattering, at view angle larger than the hotspot. The reflectance does not decrease once it reaches 0.35 (green) as it does in the red band plot.

3) The hyperspectral mode has four plot areas with reflectance at nadir, the hotspot, the anti-hotspot (same view and solar zenith as the hotspot, but on the forward scattering side), and a user-defined angle (see Figure 3). In the present version, LIBERTY can be used only in the hyperspectral mode, although the values of foliage reflectivity and transmittance calculated with it can be manually inserted into the other modes. This mode is the only mode that uses the five scales of the model. It allows the users to test the links between foliage biochemical content and the reflectance measured by remote sensors.

4) For more general purposes, Five-Scale has a fourth mode, the user-defined mode that allows more flexibility. Most intermediate biophysical parameters computed by

the model can be shown against each other, e.g., crown size versus crown closure.

Figure 3 has the simulation of a jack pine stand with a soil background. Since the soil reflectance increases almost linearly with the wavelength, the simulated canopy reflectance follows the foliage reflectance but with a slight increase with the wavelength. The hotpot spectra simulation showed here is almost identical to the foliage reflectivity.

Within that mode, a hotspot-darkspot mode has been added to study the relationship of the difference between the hotspot, where sun and view geometry coincide, and the darkspot, where the lowest reflectance is found, to the clumping index or other structural parameters as shown by Chen et al., (1999). The input parameters for the user-defined mode can be generated within Five-Scale (linear variation only) or imported from an ASCII file. This mode should accommodate most researches. For more complex research, the Five-Scale code for a command line version is also available. This User Defined mode is perfect for testing variation of vegetation indices such as NDVI and SR to canopy parameters such as LAI, crown size and crown distribution, etc.

Case	Chlorophyll Content (mg/m^2)	Water Content (g/m^2)	Intercellular air Space determinant	Albino visible absorption
1	200	100	0.045	2
2	50	130	0.045	2
3	200	50	0.045	2
4	200	50	0.050	3

Table 1. List of parameters that are changed from the defaults (case 1) for Figure 2.

The time required to simulate one reflectance value is proportional to the number of trees in the scene and the number sub-scene elements (quadrats). The current version can do a principal plane simulation (-85° to 85° at an angle step of 1° = 171 simulated reflectances; see figure 5) of a black spruce forest of 4000 trees in an hectare domain in approximately 60 seconds on a Pentium II at 400 MHz. The GUI allows the datapoints to be displayed with or without symbols and lines. The printout format is either Letter or A4. Simulations can be viewed numerically by pressing the "Switch View" button. All simulation values can be saved in an ASCII file for importation into other software to produce more customisable graphs. For cases where many parameters are unknown, a simple mode with fewer input parameters can be used. In that case, many parameters are assumed by the model for more general cases. The values used for those fixed parameters are found in the manual.
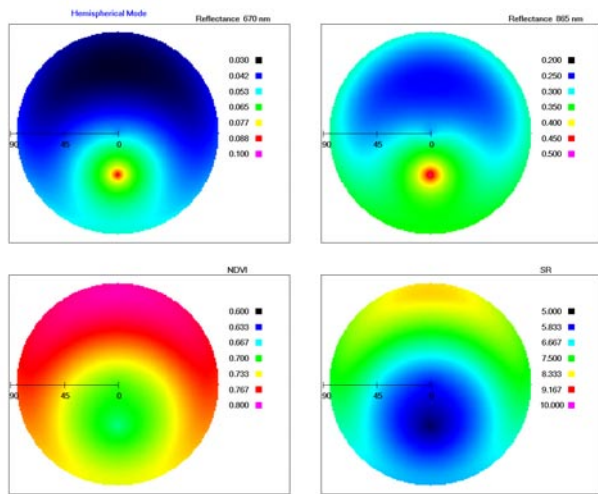

Figure 6: Example of the hemispherical mode output showing the red and near infrared reflectance with the NDVI and SR computed with the two bands for a black spruce forest.

MANUAL

Since 5-Scale is also available as a command line program by compiling the ANSI C code, the manual is written in the independent platform format html, readable with any web browsers. The manual has the latest updates made to the model, the general theory behind it, and some of the papers related to the model are also included in html format. The parameters are explained in the manual and typical values are given for several types of forest. Examples of the format of input and output ASCII files are shown. The manual complements the published papers; it contains changes that were too small to be included in new papers and some typographic errors found in the published text are described.

DISCUSSION/CONCLUSION

For the purposes of simulating multiple angle remote sensing signals and developing algorithms for biophysical and biochemical parameter retrieval, we developed the 5-Scale model. We have also made an additional effort to improve the friendliness of the model in terms of model implementation, results display and output modes and formats. This model is therefore not only useful for general research purposes but also be used as an educational tool. People with no programming skills can use to interface to quickly learn how different biophysical parameters in plant canopy affect the directional reflectance measured by sensors. Even advance programmers can save time by being able to view results as they are computed. With projectors capabale of displaying computer monitor output, Five-Scale can be used to simulate BRDF in front of a live audience in a conference or a classroom. The GUI is a perfect tool in remote sensing courses where it can be used by students to better understand what can be measure by sensors and the influence of several parameters on the BRDF shape and magnitude.

We made a move from UNIX workstations to the PCs for easiness of model installation and execution. The Four-Scale and LIBERTY models were combined to make it a 5-Scale model. The Graphics User Interface can be useful for many research applications, especially the user-defined mode that can be used to visualise the interdependency between the various parameters. The GUI should have enough flexibility for most users, but the capability of the interface is expected to grow as new features are added with time. For example, a better hyperspectral mode is expected that would allow more view angles to be displayed simultaneously and the User Defined mode will be improved for more general research purposes. We have used the GUI technology for producing other interfaces, such as a POLDER extraction program used to extract the BRDF of a given set of pixels from the level 2 spaceborne POLDER data and an airborne image correction program (used by Pellikka et al., 2000).

Five-Scale and LIBERTY Windows executable programs are available freely on request by contacting the authors. For users who may need the code to compile on their system, source code of a command line version can also be provided.

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