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BOREAS TE-18 GeoSail Canopy Reflectance Model

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BOREAS TE-18 GeoSail Canopy Reflectance Model

K. Fred Huemmrich

Summary

The SAIL (Scattering from Arbitrarily Inclined Leaves) model was combined with the Jasinski geometric model to simulate canopy spectral reflectance and absorption of photosynthetically active radiation for discontinuous canopies. This model is called the GeoSail model. Tree shapes are described by cylinders or cones distributed over a plane. Spectral reflectance and transmittance of trees are calculated from the SAIL model to determine the reflectance of the three components used in the geometric model: illuminated canopy, illuminated background, shadowed canopy, and shadowed background. The model code is Fortran, sample input and output data are provided in ASCII text files.

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1. Model Overview

1.1 Model Identification
BOREAS TE-18 GeoSail Canopy Reflectance Model

1.2 Model Introduction
The GeoSail model is made up of two parts: the SAIL that calculates within crown radiative transfer, and the Geo part that determines amount of shadowing in a scene. The program consists of a driver that reads and writes the model input and output and calls subroutines that make up the model. This code has been compiled on Vax and Macintosh computers without problems.

1.3 Objective/Purpose
The purpose of the GeoSail model was to develop a relatively simple model that would be able to describe the reflectance characteristics of boreal forests based on ground-based measurements of the canopy characteristics.

1.4 Summary of Parameters

Model inputs include:

- Canopy components
  - Quantity of each component
  - Inclination angle distribution
  - Spectral reflectance and transmission for each wave band
  - Leaf area index (LAI) within the tree crown
- Spectral reflectance of the background for each wave band
- solar zenith angle
- shape of the crowns (either cylinder or cone)
- height to width ratio of the crown
- crown coverage

Model outputs include:

- Nadir view reflectance of the scene for each waveband
- Total scene LAI
- Fraction of photosynthetically active radiation (PAR) absorbed by the canopy (Fpar).

Two sample input and output data files are provided. Both calculate visible and near infrared reflectance and Fpar, one is for aspen stands and the other is for spruce stands.

1.5 Discussion

GeoSail uses the SAIL model to calculate canopy spectral reflectance and transmittance. Shadowed background reflectance is the product of the background reflectance and the transmission from SAIL. The component reflectances: illuminated canopy, illuminated background, shadowed canopy, and shadowed background are then used as inputs into a geometric model. The geometric model determines the fraction of each of the components in a scene, given a crown shape, the canopy coverage, and the sun angle. In this model all tree crowns are assumed to be identical and do not overshadow each other.

1.6 Related Models

The SAIL model was developed by Verhoef (1984), the code is a modified version of the code written by Alexander (1983). The SAIL model is in subroutine sail, the sail subroutine calls a second subroutine mmult (a matrix multiplication subroutine). The geometric part of the model is based on Jasinski's geometric model (Jasinski 1990, Jasinski and Eagleson 1989 and 1990). A complete description of GeoSail is in Huemmrich (1995). There are two GeoSail subroutines: geocyli and geocone, to describe tree crowns that are shaped like cylinders or cones. These subroutines use crown reflectance and transmittance values passed from the sail subroutine.

2. Investigator

2.1 Investigator Name and Title

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2.2 Title of Investigation

BOREAS Staff Science

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3. Model Theory

The GeoSail model combines a geometric model, which calculates the amount of shadowed and illuminated components in a scene, with the SAIL model, which calculates the reflectance and transmittance of the tree crowns. Scene reflectance is determined in the model by calculating an area-weighted average of three landscape components: illuminated canopy, illuminated background, and shadowed background. The simplicity of this model is a result of the assumption that single values for the reflectance and transmittance of light by canopy clumps are enough to provide a reasonable overall description of scene reflectance and absorption. The geometric part of GeoSail uses the model developed by Jasinski for the limiting case where the shadows cast by clumps of vegetation are very small relative to the size of the area observed (Jasinski and Eagleson 1989; Jasinski 1990; Jasinski and Eagleson 1990). The Jasinski model consists of a scene made up of geometric solids scattered over a plane with a Possion distribution. The solids are identical in size and shape and cast shadows on the background plane, but do not overshadow each other. The fraction of a scene that is shadowed is determined by

$$S = 1 - C - (1 - C)^{(n+1)} \quad (1)$$

where S is the fraction of shadowed background and C is the fraction covered by the solids, i.e. the canopy coverage. The parameter n is the ratio of canopy cover to shadow area for a single geometric solid. Thus the shadowed fraction will vary with differences in the geometry of the canopy components and the solar zenith angle.

Trees display a wide variety of shapes. In general, tree shape can be described with three parameters: size, ratio of height to width, and shape. The height to width ratio should adjust with conditions, as the tree increases in height to reach the canopy and in width to occupy space in the canopy and to intercept light. The balance between growth in height and width depends on the growth strategies of the tree and the surrounding trees, the environment where the tree is growing, and that per unit length horizontal branches are more expensive than vertical growth. The shape of a tree determines the total amount of light it can intercept and defines limits to leaf placement. Many shapes can be used to describe the tree forms, for example spheres, cones, and ellipsoids have all been used in past modeling work. In Jasinski's model the n term makes it easy to describe different tree shapes. For cylindrical solids n is calculated using the height to width ratio of the cylinder, R, and the solar zenith angle, Ø:

$$n = R \tan(\varnothing) \quad (2a)$$

n can also be calculated for cones as:

$$n = (\tan(\beta) - \beta)/\pi \quad (2b)$$

Where ß is determined from the aspect angle of the cone, Ψ, and the solar zenith angle as

$$ß = \mathrm{Arccos}(\tan(\Psi)/\tan(\varnothing)) \qquad (3)$$

The fraction of the area that is illuminated background, B, can then be calculated by

$$B = 1 - C - S \qquad (4)$$

To calculate the scene reflectance the reflectance of each component in the scene is weighted by its fractional area and summed:

$$r_t = C\, r_c + S\, r_s + B\, r_b \qquad (5)$$

Where p_t is the total scene reflectance and r_c, r_s, and r_b are, respectively, canopy, shadow, and background reflectances in a specific waveband. Equation 5 assumes that there is no interaction between the components, such as mutual shading. The canopy and shadow reflectances are obtained from SAIL model results. Canopy reflectance, r_c, is the SAIL model reflectance with LAI set at the value for the LAI for a single tree. The illuminated background reflectance, r_b, is the same background reflectance used in the SAIL model. Shadows are areas of lower illumination due to light absorption by the canopy, so the shadow reflectance, r_s is the product of the transmittance through the canopy, calculated by the SAIL model, and the background reflectance. This formulation of scene reflectance allows for multiple scattering within tree canopies but assumes no multiple scattering between trees.

If the trees are described as cones and the aspect angle of the cone is less than the solar zenith angle, then a portion of the cone is shadowed. From a nadir view the fraction of shadowed canopy (C_s) is

$$C_s = ß/\pi \qquad (6)$$

The shadowed canopy is assigned its own reflectance value, adding another term to equation 5.

GeoSail calculates the fraction of absorbed photosynthetically active radiation (Fapar) differently from the SAIL model. In the SAIL calculations of Fapar the PAR fluxes into and out of the canopy are determined and the absorbed photosynthetically active radiation (APAR) is calculated as the difference between the PAR into and out of the canopy (Goward and Huemmrich 1992). In GeoSail the method used to calculate Fapar follows the approach of Bègué (1991). The fraction of absorbed PAR is calculated by,

$$\mathrm{Fapar} = (1-t_c)\{(C+S) + (B\, r_b\, I_D) + (S\, r_s\, I_D)\} + \{C\,(r_s - r_{HC})\} \qquad (7)$$

where t_c is the transmittance of PAR through the canopy and r_{HC} is the hemispheric reflectance from the top of the canopy. Values from both of these variables come from the SAIL model. I_D is the diffuse interception, that is the fraction of non-directional light which is absorbed by the canopy clumps. This is calculated by integrating the interception of light by the canopy for all possible solar zenith angles. Diffuse interception is given by,

$$ID = \int_{\varnothing=0}^{\pi/2} (C + S)\, d\varnothing \qquad (8)$$

It is the amount of light intercepted by the canopy clumps as the solar zenith angle goes from 0 to 90 degrees.

The components of equation 7 can be explained as follows: the term C+S is the fraction of the incoming light that intercepts a canopy clump; the term B r_b I_D is the radiation which directly hits the background and is reflected back into the canopy, assuming the background is a Lambertian reflector; S r_s I_D is the light reflected from the shadowed background that is reflected back into the canopy; and C (r_s - r_{HC}) is the light reflected from the background under the vegetation clump into the canopy minus the light reflected from the top of the vegetation clumps.

4. Equipment

Not Applicable.

5. Data Acquisition Methods

Leaf and twig spectral reflectance and transmittance values come from the BOREAS Terrestrial Ecology (TE)-12 group: Radiation and Gas Exchange of Canopy Elements in a Boreal Forest. Background reflectance values were collected by the BOREAS Remote Sensing Science (RSS)-19 group: Variation in Radiometric Properties of the Boreal Forest Landscape as a Function of the Ecosystem Dynamics. The high spectral resolution data were averaged to broad bands. Crown LAI values came from TE-6: Measurement and Scaling of Carbon Budgets for Contrasting Boreal Forest Sites. Estimates of canopy cover came from tables in the 1994 BOREAS Experiment Plan (EXPLAN94).

6. Observations

6.1 Data Notes

None.

7. Data Description

7.1 Spatial Characteristics

7.1.1 Spatial Coverage

The GeoSail model does not have a specific spatial scale. The model assumptions, however, are based on viewing a scene where the size of the shadows cast by the trees are small relative to the size of the pixel.

7.1.2 Spatial Coverage Map

Not Applicable.

7.1.3 Spatial Resolution

Not Applicable.

7.1.4 Projection

Not Applicable

7.1.5 Grid Description

Not Applicable.

7.2 Temporal Characteristics

7.2.1 Temporal Coverage

Not Applicable.

7.2.2 Temporal Coverage Map

Not Applicable.

7.2.3 Temporal Resolution

Not Applicable.

7.3 Data Characteristics

7.3.1 Input Parameter/Variable

The GeoSail program asks for the input file name, the input file should be a text file structured as shown below. The following sample input file is in the file Aspen_In.DAT:

```
Aspen_Out.DAT
2  1  2
ASPEN WITH 2% TWIGS, 98% GREEN
5. 15. 25. 35. 45. 55. 65. 75. 85.
 .015211  .04517  .07376  .10010  .12341  .14297  .15818  .16858  .17387
0.2205   0.2073  0.1825  0.1491  0.1111  0.0731  0.0397  0.0149  0.0017
 0.070  0.505
 0.032  0.407
 0.245  0.677
 0.000  0.000
 0.132  0.225
42.27
4.90    0.1
CYLI
3.5
10
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
```

The first line is the name of the output file, which can contain up to 25 characters.

The second line gives input values for the model, there should be three integers separated by spaces. These input values are as follows: 1. number of different wavelength bands to calculate (up to 10) 2. number of canopy layers (up to 15) 3. number of different types of components in the canopy (up to 15) (this example shows 2 wavelength bands, 1 canopy layer, and 2 canopy components)

The third line a comment line to describe the run, up to 50 characters

The fourth line is the midpoint angles for the nine leaf inclination angle bins. These should be floating point numbers separated by spaces

The next lines are the fraction of the leaves that fall into each leaf angle bin; there will be one line for each canopy component. (In this example the first line are the values for a spherical leaf angle distribution, and the second line is a planophile distribution.)

The next two lines are the reflectances and transmittances of the first canopy component. The first line has the reflectances of the canopy component for each of the wavelengths. The second line has the transmittances.

As there is more than one component in the canopy being modeled there is other pair of lines following the first pair describing the spectral reflectance and transmittance of the second component. This pattern would repeat for each additional canopy component. (In this example the first line is aspen leaf reflectance in red and near infrared bands, the second line is the leaf transmittance in the same two wavelength bands, the third line is aspen branch reflectance, and the fourth is the branch transmittance [set to zero])

After the component reflectance and transmittance lines is the background reflectance values for each wavelength band. (In this example the background is leaf litter)

The next line is the solar zenith angle for the simulation.

The following line has the LAI of each of the components. These are the LAI values to describe an individual tree crown. If there were multiple layers specified, the LAI for the first component of the first layer is the first number. This is followed by the LAI for the first component of the second layer, continuing through all the layers, then repeating the pattern for the second component through all the layers, and so on. All of the values would be separated by spaces in the same line. (In this example the leaves have an LAI of 4.9 and the branches have an LAI of 0.1, for a crown plant area index [PAI] of 5)

All of the inputs up to this point go into the SAIL model, which then calculates the crown spectral reflectance and transmittance.

The next line is a four-letter code to describe the crown shapes as cylinders (CYLI) or cones (CONE).

The next line is the height to width ratio of the crowns. (In this case the trees are described as cylinders, the height of which is 3.5 times the diameter.)

The next line gives the number of different canopy coverages to calculate reflectances.

The next lines (the number of them is given above) each have a different value for the fraction of canopy cover, that is the fraction of the scene covered by the cones or cylinders. (In this case there are 10 different coverages to be calculated, starting with 0.1 through 1.0)

To the output file, the program writes out all of the input values. From the SAIL model the nadir viewed reflectance, the transmittance, and the hemispheric reflectance for each wavelength band are also written to the output file. From the GeoSail model the total LAI, that is the product of the crown PAI and the fraction canopy cover, the nadir view reflectance, and the instantaneous fraction of radiation absorbed for each band are output. In the case where the input parameters are for the PAR wavelengths, the fraction of radiation absorbed is Fapar.

The file SPRUCE_IN.DAT is a sample GeoSail input file for calculating red and near infrared reflectance for spruce trees. The file ASPEN_IN.DAT is a sample GeoSail input file for calculating red and near infrared reflectance for aspen trees.

7.3.2 Variable Description/Definition

See Section 7.3.1

7.3.3 Unit of Measurement

The measurement units for the variables contained in the input data files are:

Variable Description	Units
Output file name	[none]
Number of different wavelength bands to calculate	[count]
Number of canopy layers	[count]
Number of different types of components in the canopy	[count]
Comments	[none]
Midpoint of leaf inclination angle bins	[degrees]
Fraction of the leaves which fall into each leaf angle bin	[unitless]
Canopy component spectral reflectance	[unitless]
Canopy component spectral transmittance	[unitless]
Background spectral reflectance	[unitless]
Solar zenith angle	[degrees]
LAI of canopy component	[unitless]
Code for crown shape	[none]

Crown height to width ratio	[unitless]
Number of different canopy cover values	[count]
Canopy cover	[unitless]

7.3.4 Data Source

The source for the variables contained in the input data files are:

Variable Description	Data Source
Output file name	[investigator]
Number of different wavelength bands to calculate	[investigator]
Number of canopy layers	[investigator]
Number of different types of components in the canopy	[investigator]
Comments	[investigator]
Midpoint of leaf inclination angle bins	[investigator]
Fraction of the leaves which fall into each leaf angle bin	[investigator]
Canopy component spectral reflectance	[TE-12]
Canopy component spectral transmittance	[TE-12]
Background spectral reflectance	[RSS-19]
Solar zenith angle	[investigator]
LAI of canopy component	[TE-06]
Code for crown shape	[investigator]
Crown height to width ratio	[investigator]
Number of different canopy cover values	[investigator]
Canopy cover	[EXPLAN94]

7.3.5 Data Range

The range of values for the variables contained in the input data files are:

Variable Description	Minimum Data Value	Maximum Data Value
Output file name	N/A	N/A
Number of different wavelength bands to calculate	1	10
Number of canopy layers	1	15
Number of different types of components in the canopy	1	15
Comments	N/A	N/A
Midpoint of leaf inclination angle bins	1	89
Fraction of the leaves which fall into each leaf angle bin	0	1
Canopy component spectral reflectance	0	1
Canopy component spectral transmittance	0	1
Background spectral reflectance	0	1
Solar zenith angle	0	89
LAI of canopy component	0	999
Code for crown shape	CONE	CYLI
Crown height to width ratio	0	999
Number of different canopy cover values	1	999
Canopy cover	0	1

Note: the value 999 means the maximum size is arbitrary.

7.4.1 Output Parameter/Variable

The output file produced by GeoSail from the sample input file Aspen_In.Dat (Section 7.3.1) is shown below and is stored in the file Aspen_Out.Dat.

```
OUTPUT FROM: ASPEN_IN.DAT

ASPEN WITH 2% TWIGS, 98% GREEN

LEAF INCLINATION ANGLES
    5.0    15.0    25.0    35.0    45.0    55.0    65.0    75.0    85.0
 0.0152 0.0452 0.0738 0.1001 0.1234 0.1430 0.1582 0.1686 0.1739
 0.2205 0.2073 0.1825 0.1491 0.1111 0.0731 0.0397 0.0149 0.0017

COMPONENT          OPTICAL PROPS
COMPONENT     BAND      REFL      TRANS
    1          1        0.0700    0.0320
    1          2        0.5050    0.4070
    2          1        0.2450    0.0000
    2          2        0.6770    0.0000

SOIL REFLECTANCE
BAND     SOIL REFL
   1       0.1320
   2       0.2250

SOLAR ZENITH ANGLE:      42.27

SAIL MODEL OUTPUT
TOTAL CROWN LAI=   5.000
BAND      REFL     TRANS      HEMI REFL
  1      0.0253   0.0360     0.0275
  2      0.4175   0.2313     0.4739

GEOSAIL OUTPUT
CYLINDRICAL CROWNS    HEIGHT/WIDTH=   3.500

CANOPY COVER   TOTAL LAI   BAND      REFL         FRAC ABS
   0.100         0.500       1       0.0887       0.3793
   0.100         0.500       2       0.1999       0.2875
   0.200         1.000       1       0.0589       0.6132
   0.200         1.000       2       0.1932       0.4355
   0.300         1.500       1       0.0396       0.7632
   0.300         1.500       2       0.2006       0.5123
   0.400         2.000       1       0.0280       0.8551
   0.400         2.000       2       0.2186       0.5417
   0.500         2.500       1       0.0220       0.9074
   0.500         2.500       2       0.2443       0.5393
   0.600         3.000       1       0.0198       0.9335
   0.600         3.000       2       0.2750       0.5162
   0.700         3.500       1       0.0200       0.9438
   0.700         3.500       2       0.3090       0.4806
   0.800         4.000       1       0.0214       0.9457
   0.800         4.000       2       0.3446       0.4382
```

0.900	4.500	1	0.0233	0.9439
0.900	4.500	2	0.3809	0.3930
1.000	5.000	1	0.0253	0.9412
1.000	5.000	2	0.4175	0.3469

Output file description is as follows. The first line is the comments line from the input file.

Under the heading "LEAF INCLINATION ANGLES", the first line is the midpoint of each of the leaf inclination angle bins. The next lines are the fraction of the leaves which fall into each leaf angle bin, there will be one line for each canopy component.

Under the heading "COMPONENT OPTICAL PROPS", are the input values of the component spectral reflectance and transmittance for each wavelength band. The columns are the component number, the wavelength band number, the spectral reflectance, and the spectral transmittance.

Under the heading "SOIL REFLECTANCE", are the input values of the background spectral reflectance for each wavelength band. The columns are the wavelength band number and the spectral reflectance for that band.

Next the input solar zenith angle is given.

The output of the SAIL model is listed under the heading "SAIL MODEL OUTPUT." The total crown LAI is the sum of the input LAI values for all of the different components. From the SAIL model the nadir viewed reflectance, the transmittance, and the hemispheric reflectance for each wavelength band are listed.

The GeoSail output is listed under the heading "GEOSAIL OUTPUT." The type of canopy crown shapes used in the calculation is listed along with the input height to width ratio. The following table lists the total LAI, that is the product of the total crown LAI and the fraction canopy cover, the wavelength band number, the nadir view reflectance, and the instantaneous fraction of radiation absorbed for that wavelength band. In the case where the wavelength band is for the PAR wavelengths, the fraction of radiation absorbed is Fapar.

The file SPRUCE_OUT.DAT is a sample GeoSail output file, the result of running the input file SPRUCE_IN.DAT. SPRUCE_OUT.DAT contains calculated red and near infrared reflectance for spruce trees. The file ASPEN_OUT.DAT is a sample GeoSail output file, the result of running the input file ASPEN_IN.DAT. ASPEN_OUT.DAT contains calculated red and near infrared reflectance for aspen trees.

7.4.2 Variable Description/Definition

See section 7.4.1.

7.4.3 Unit of Measurement

The measurement units for the variables contained in the output data files are:

Variable Description	Units
Input file information	[none]
Comments	[none]
Midpoint of leaf inclination angle bins	[degrees]
Fraction of the leaves which fall into each leaf angle bin	[unitless]
Wavelength band number	[count]
Canopy component number	[count]
Canopy component spectral reflectance	[unitless]
Canopy component spectral transmittance	[unitless]
Background spectral reflectance	[unitless]
Solar zenith angle	[degrees]
Total crown LAI	[unitless]
SAIL canopy nadir reflectance	[unitless]
SAIL canopy transmittance	[unitless]
SAIL canopy hemispherical reflectance	[unitless]

Crown shape	[none]
Crown height to width ratio	[unitless]
Canopy cover	[unitless]
Total LAI	[unitless]
GeoSail nadir reflectance	[unitless]
GeoSail instantaneous absorption	[unitless]

7.4.4 Data Source

The data source for the variables contained in the output data files are:

Variable Description	Data Source
Input file information	[input file]
Comments	[input file]
Midpoint of leaf inclination angle bins	[input file]
Fraction of the leaves which fall into each leaf angle bin	[input file]
Wavelength band number	[input file]
Canopy component number	[input file]
Canopy component spectral reflectance	[input file]
Canopy component spectral transmittance	[input file]
Background spectral reflectance	[input file]
Solar zenith angle	[input file]
Total crown LAI	[calculated]
SAIL canopy nadir reflectance	[SAIL model]
SAIL canopy transmittance	[SAIL model]
SAIL canopy hemispherical reflectance	[SAIL model]
Crown shape	[input file]
Crown height to width ratio	[input file]
Canopy cover	[input file]
Total LAI	[calculated]
GeoSail nadir reflectance	[GeoSail]
GeoSail instantaneous absorption	[GeoSail]

7.4.5 Data Range

The range of values for the variables contained in the output data files are:

Variable Description	Minimum Data Value	Maximum Data Value
Input file information	N/A	N/A
Comments	N/A	N/A
Midpoint of leaf inclination angle bins	1	89
Fraction of the leaves in each leaf angle bin	0	1
Wavelength band number	1	10
Canopy component number	1	15
Canopy component spectral reflectance	0	1
Canopy component spectral transmittance	0	1
Background spectral reflectance	0	1
Solar zenith angle	0	89
Total crown LAI	0	999
SAIL canopy nadir reflectance	0	1
SAIL canopy transmittance	0	1
SAIL canopy hemispherical reflectance	0	1
Crown shape	CONE	CYLINDER

Crown height to width ratio	0	999
Canopy cover	0	1
Total LAI	0	999
GeoSail nadir reflectance	0	1
GeoSail instantaneous absorption	0	1

Note: the value 999 means the maximum size is arbitrary.

7.5 Sample Data Records

See sections 7.3.1 and 7.4.1

8. Data Organization

8.1 Data Granularity

The smallest unit of model information tracked by the BOREAS Information System (BORIS) includes model code, sample input, and output files.

8.2 Data Format

Model source code is written in Fortran and available as American Standard Code for Information Interchange (ASCII) text file. Sample input and output data are also stored in ASCII text files.

9. Data Manipulations

9.1 Formulae

9.1.1 Derivation Techniques and Algorithms

See section 3 for key model equations.

9.2 Data Processing Sequence

9.2.1 Processing Steps

First input variables for SAIL model are read in, using these inputs the SAIL subroutine is called to calculate crown reflectance and transmittance, SAIL model results are output. The geometric model inputs are read in, based on input code one of two geometric model subroutines is called. The geometric subroutine calculates scene reflectance and radiation absorptance and outputs those values.

9.2.2 Processing Changes

None.

9.3 Calculations

9.3.1 Special Corrections/Adjustments

When using cone-shaped crowns, if the solar zenith angle is less than the cone aspect angle, there are no shadows in the scene. This will cause the model to fail.

9.3.2 Calculated Variables

Crown nadir reflectance, crown transmittance, crown hemispherical reflectance, total crown LAI, total scene LAI, scene nadir reflectance, and fraction of absorbed radiation.

9.4 Graphs and Plots

None.

10. Errors

10.1 Sources of Error

GeoSail is a simple model, it assumes all trees in the scene are identical and have identical reflectance and transmittance characteristics. The model also assumes that tree shadows are uniform, and are very small relative to the size of the pixel. In the model trees do not cast shadows on other trees. GeoSail accounts for multiple scattering within tree crowns, but not between crowns.

10.2 Quality Assessment

10.2.1 Model Validation by Source

GeoSail has been able to model the observed patterns of red and near infrared reflectance for aspen and spruce stands over the BOREAS sites, as well as sites in the Superior National Forest in Minnesota.

10.2.2 Confidence Level/Accuracy Judgment

For the open woodlands of the boreal forest, GeoSail can provide estimates of canopy reflectance within approximately 15 percent. It tends to overestimate Fapar.

10.2.3 Measurement Error for Parameters

None.

10.2.4 Additional Quality Assessments

None.

10.2.5 Data Verification by Data Center

None.

11. Notes

11.1 Limitations of the Model

GeoSail only simulates nadir views, and assumes all trees in the scene are identical.

11.2 Known Problems with the Model

None.

11.3 Usage Guidance

Be careful not to allow the solar zenith angle to be less that the cone aspect angle when using cone-shaped crowns. This will cause the model to fail.

11.4 Other Relevant Information

None.

12. Application of the Model

The GeoSail model is a useful, yet relatively simple, model that can describe canopy reflectance for forests and open woodlands. It can be used for the examination of estimation of biophysical variables from optical remote sensing data.

13. Future Modifications and Plans

There may be a hyperspectral version of GeoSail in the future.

14. Software

14.1 Software Description

The GeoSail model is made up of two parts: the SAIL model that calculates within crown radiative transfer, and the Geo (geometric model) part that determines amount of shadowing in a scene. The program consists of a driver that reads and writes the model input and output and calls subroutines that make up the model. This code has been compiled on Vax and Macintosh computers without problems.

The SAIL model code is a modified version of the code written by Alexander (1983). The SAIL model is in subroutine sail, the sail subroutine calls a second subroutine mmult (a matrix multiplication subroutine). The geometric part of the model is based on Jasinski's geometric model (Jasinski 1990, Jasinski and Eagleson 1989 and 1990). A full description of GeoSail is in Huemmrich (1995). There are two GeoSail subroutines: geocyli and geocone, to describe tree crowns that are shaped like cylinders or cones, respectively. These subroutines use crown reflectance and transmittance values passed from the sail subroutine.

14.2 Software Access

The GeoSail code is freely available, the code should be found with this documentation.

14.3 Platform Limitations

The model is a fairly straightforward Fortran code, so it should be able to be compiled with most Fortran compilers.

15. Data Access

The model and associated data files are available from the Earth Observing System Data and Information System (EOSDIS) Oak Ridge National Laboratory (ORNL) Distributed Active Archive Center (DAAC).

15.1 Contact Information

For BOREAS data and documentation please contact:

ORNL DAAC User Services
Oak Ridge National Laboratory
P.O. Box 2008 MS-6407
Oak Ridge, TN 37831-6407
Phone: (423) 241-3952
Fax: (423) 574-4665
E-mail: ornldaac@ornl.gov or ornl@eos.nasa.gov

15.2 Data Center Identification

Earth Observing System Data and Information System (EOSDIS) Oak Ridge National Laboratory (ORNL) Distributed Active Archive Center (DAAC) for Biogeochemical Dynamics http://www-eosdis.ornl.gov/.

15.3 Procedures for Obtaining Data

Users may obtain data directly through the ORNL DAAC online search and order system [http://www-eosdis.ornl.gov/] and the anonymous FTP site [ftp://www-eosdis.ornl.gov/data/] or by contacting User Services by electronic mail, telephone, fax, letter, or personal visit using the contact information in Section 15.1.

15.4 Data Center Status/Plans

The ORNL DAAC is the primary source for BOREAS field measurement, image, GIS, and hardcopy data products. The BOREAS CD-ROM and data referenced or listed in inventories on the CD-ROM are available from the ORNL DAAC.

16. Output Products and Availability

16.1 Tape Products

None.

16.2 Film Products

None.

16.3 Other Products

None.

17. References

17.1 Model Documentation

None.

17.2 Journal Articles and Study Reports

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Sellers, P., F. Hall, H. Margolis, B. Kelly, D. Baldocchi, G. den Hartog, J. Cihlar, M.G. Ryan, B. Goodison, P. Crill, K.J. Ranson, D. Lettenmaier, and D.E. Wickland. 1995. The boreal ecosystem-atmosphere study (BOREAS): an overview and early results from the 1994 field year. Bulletin of the American Meteorological Society. 76(9):1549-1577.

Sellers, P.J., F.G. Hall, R.D. Kelly, A. Black, D. Baldocchi, J. Berry, M. Ryan, K.J. Ranson, P.M. Crill, D.P. Lettenmaier, H. Margolis, J. Cihlar, J. Newcomer, D. Fitzjarrald, P.G. Jarvis, S.T. Gower, D. Halliwell, D. Williams, B. Goodison, D.E. Wickland, and F.E. Guertin. 1997. BOREAS in 1997: Experiment overview, scientific results, and future directions. Journal of Geophysical Research 102(D24):28,731-28,769.

Verhoef, W. 1984. Light scattering by leaf layers with application to canopy reflectance modeling: the SAIL model. Remote Sens. Environ. 16:125-141.

17.3 Archive/DBMS Usage Documentation

None.

18. Glossary of Terms

None.

19. List of Acronyms

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ASCII   - American Standard Code for Information Interchange
BOREAS  - BOReal Ecosystem-Atmosphere Study
BORIS   - BOREAS Information System
DAAC    - Distributed Active Archive Center
EOS     - Earth Observing System
EOSDIS  - EOS Data and Information System
Fapar   - Fraction of Absorbed Photosynthetically Active Radiation
GSFC    - Goddard Space Flight Center
LAI     - Leaf Area Index
NASA    - National Aeronautics and Space Administration
ORNL    - Oak Ridge National Laboratory
PAR     - Photosynthetically Active Radiation
RSS     - Remote Sensing Science
SAIL    - Scattering from Arbitrarily Inclined Leaves
TE      - Terrestrial Ecology
URL     - Uniform Resource Locator
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13. ABSTRACT *(Maximum 200 words)*
The SAIL (Scattering from Arbitrarily Inclined Leaves) model was combined with the Jasinski geometric model to simulate canopy spectral reflectance and absorption of photosynthetically active radiation for discontinuous canopies. This model is called the GeoSail model. Tree shapes are described by cylinders or cones distributed over a plane. Spectral reflectance and transmittance of trees are calculated from the SAIL model to determine the reflectance of the three components used in the geometric model: illuminated canopy, illuminated background, shadowed canopy, and shadowed background. The model code is Fortran, sample input and output data are provided in ASCII text files.

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