TECHNICAL NOTES

MEDIA KONSERVASI
SCIENTIFIC JOURNAL IN CONSERVATION, ENVIRONMENT & ECOTOURISM

Experimental Study on Tree Shape Identification and Interaction Among Trees

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Article Info:
Received 12 February 2024
Revised 20 November 2024
Accepted 25 November 2024

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Abstract

Forests play a crucial role in mitigating global warming and maintaining climate balance, necessitating a comprehensive understanding of forest dynamics. However, many optical characteristics related to forests remain poorly understood, particularly models for determining forest parameters such as tree species, shape, and inter-tree distances. Although several models exist for estimating leaf area index and photosynthetically active radiation, fewer models address structural forest parameters. This research aims to develop a model using visible and near-infrared radiometer data from Earth observation satellites to estimate forest parameters, including tree species, shape, height, and spacing. Results show that as the distance between trees increases, the impact of multiple reflections decreases significantly. Elliptical tree shapes exhibit approximately three times higher multiple reflection effects compared to conical shapes, indicating potential for distinguishing tree shapes through radiometric data. For canopy shapes, shorter, thicker trees experience more significant reflection effects than taller, thinner trees, suggesting the feasibility of estimating tree height. Overall, the impact of multiple reflections ranges from a few to 10% of TOA radiance, necessitating its consideration when calculating forest reflectance to ensure accurate forest parameter retrieval from satellite observations.

Keywords: canopy shape, TOA radiances, tree shape

1. Introduction

Forests have a significant impact on global warming, climate change, global balance, etc., so it is extremely important to understand forest dynamics. At present, optical characteristics etc. are not fully understood. In particular, a good model for determining forest parameters (tree species, tree shape, distance between trees, leaf area index, photosynthetically effective radiation, etc.) is desirable. Many forest models regarding leaf area index and photosynthetically active radiation have been proposed, but there are few proposals regarding models related to tree species, tree shape, and distance between trees. The purpose is to understand forest dynamics using visible and near-infrared radiometer data onboard Earth observation satellites. In particular, build a model to estimate forest parameters (tree species, tree shape, tree height, distance between trees, etc.). It is necessary to represent visible and near-infrared radiometer data on board an earth observation satellite using a radiative transfer model, and to describe the relationship between this and the forest model.

Adjacency effect of layered clouds estimated with Monte-Carlo simulation is proposed [1]. Non-linear mixture model of mixed pixels in remote sensing satellite images based on Monte Carlo simulation is also proposed [2]. Forest parameter estimation by means of Monte Carlo simulations with experimental considerations -Estimation of multiple reflections among trees depending on forest parameters is proposed [3] together with forest parameter estimation, by means of Monte-Carlo simulations with experimental consideration of estimation of multiple reflections among trees depending on forest parameters [4]. Monte Carlo Ray Tracing based method for investigation of multiple reflection among trees is conducted [5]. This paper deals with experimental approach for clarification of influences of the multiple reflection among trees on Top of the Atmosphere (TOA) radiance.

2. Experimental Method

There are two major models, Analysis model and Numerical simulation model. Former is a series of processes from sunlight incidence to the atmosphere, ground surface, atmosphere, and top-of-atmosphere radiance are described using Fredholm-type integral equations while later is a method that represents the incidence of sunlight by inputting photons generated by random numbers into a calculation cell, and stochastically estimates the brightness at the top of the atmosphere while tracking the behavior of the photons.

In the simulation study, tree shape model and forestry model are created. Namely, the following three conditions are considered:

Observation conditions (solar zenith angle/azimuth angle, sensor zenith angle/azimuth angle)

Atmospheric conditions (optical thickness of air molecules and aerosol)

Ground surface conditions (reflectance of trees and undergrowth, tree shape/size, distance between trees)

The following commercially available grass and four types of conifers are considered:

(1) Tree NO. 1: Rheingold; Tree shape: circular, horizontal diameter: 13 cm, vertical diameter: 12 cm

(2) Tree NO. 2: Goldcrest; Tree shape: conical, base diameter: 11 cm, height: 26 cm

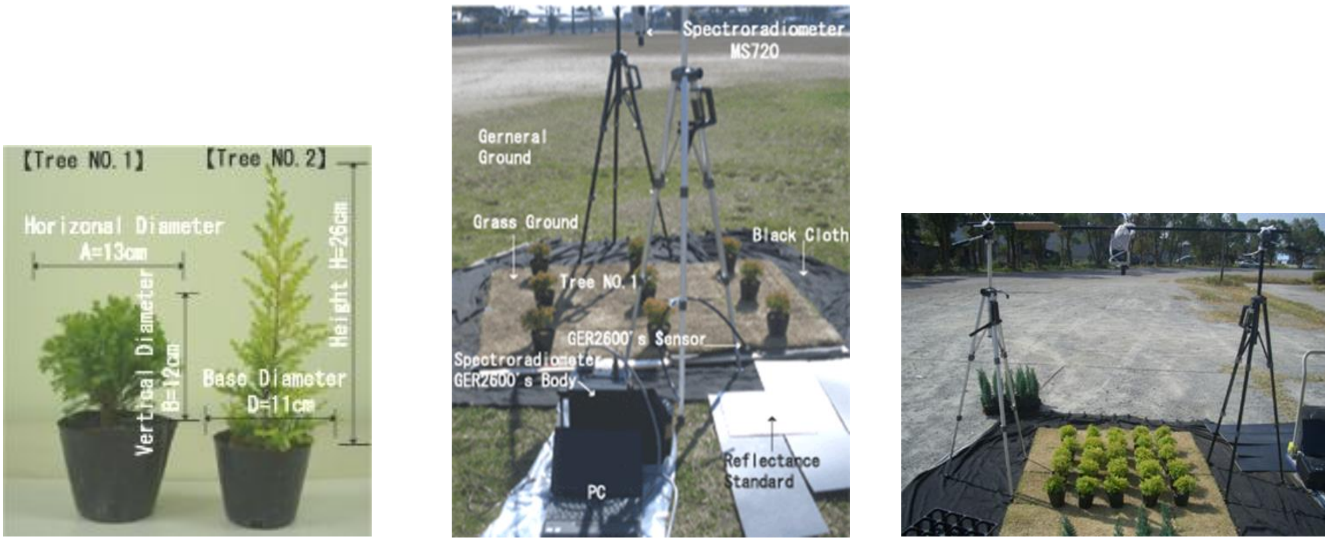
(3) Tree NO. 3: Rheingold; Tree shape: circular, horizontal diameter: 16 cm, vertical diameter: 14 cm

(4) Tree NO. 4: Eliwidy; Tree shape: conical, base diameter: 10 cm, height: 40 cm

Experiment outlook for measuring the radiance of a simulated forest is shown in Figure 1. In this experiment, the following radiometers are used:

(1) MS720 Transit height: 128 cm, Installation direction: Directly below

(2) GER2600 (monitors sunlight)



(a) Simulated trees (b) Experimental configurations (c) Simulated forest

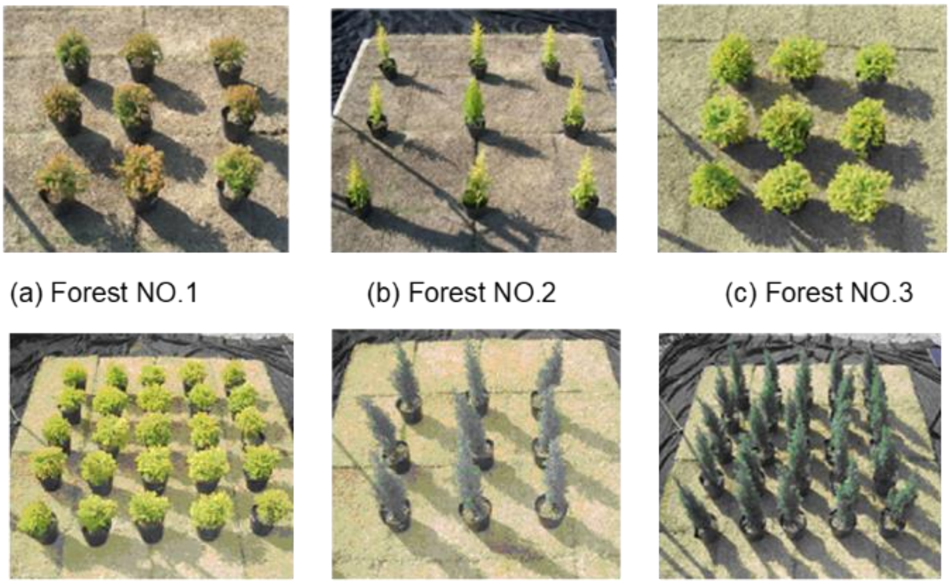
Figure 1. Experimental setup.

Experiment location: Saga University Athletic Grounds (33°14'N, 130°17'E) and Experiment time is as follows:

1st time: May 3, 2006 (sunny) Measurement time of data used: 11:29-15:24

2nd time: October 21, 2006 (sunny) Usage data measurement time: 12:25-13:41

Undergrowth: Rectangle 120 cm x 60 cm and Arrangement of trees: 2-dimensional arrangement using 9 or 25 trees as shown in Figure 2. There are six types of forest arrangements as shown in Table 1. In addition, to reduce reflections from bare ground around the experimental area, the surrounding area was covered with black cloth. The experiment focuses on visible light and near-infrared regions.



(a) Forest NO.1 (b) Forest NO.2 (c) Forest NO.3

(d) Forest NO.4 (e) Forest NO.5 (f) Forest NO.6

Figure 2. Six types of simulated forest arrangements.

Table 1. Parameters of the assumed six types of forest arrangements

No. of forest	Name of tree	No. of tree	Tree shape	Tree size (cm)	Tree num. (piece)
Forest No. 1	*Thuja occidentalis* "Rheingold"	Tree No.1	Ellipse	A13 x B12	9
Forest No. 2	*Cupressus macrocarpa* "Goldcrest"	Tree No.2	Cone	D11 x H26	9
Forest No. 3	*Thuja occidentalis* "Rheingold"	Tree No.3	Ellipse	A16 x B14	9
Forest No. 4	*Thuja occidentalis* "Rheingold"	Tree No.3	Ellipse	A16 x B14	25
Forest No. 5	*Chamaecyparis lawsoniana* "ellwoodii"	Tree No.4	Cone	D10 x H40	9
Forest No. 6	*Chamaecyparis lawsoniana* "ellwoodii"	Tree No.4	Cone	D10 x H40	25

Remarks: A is horizontal diameter and B is vertical diameter for ellipse-shape tree; D is base diameter and H is height for cone-shape tree.

3. Experimental Results

Spectral reflection characteristics of trees and Change characteristics of radiance due to distance between trees are shown in Figure 3 and Figure 4.

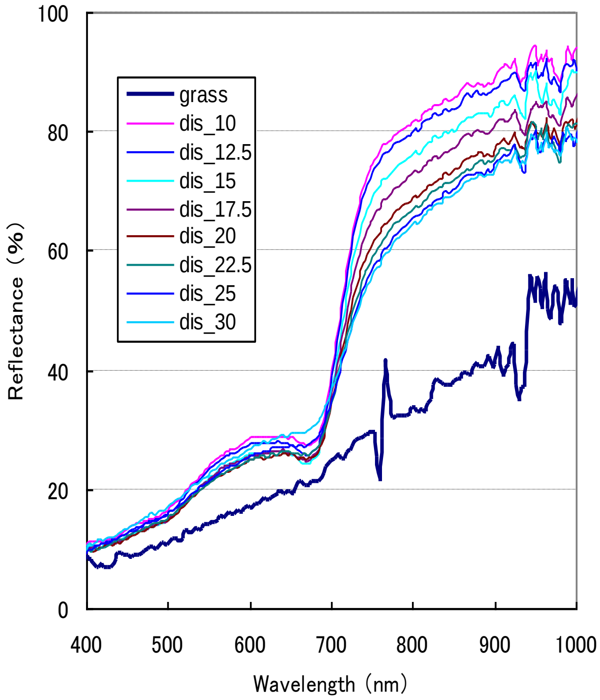


Figure 3. Spectral characteristics of the six types of simulated forest.

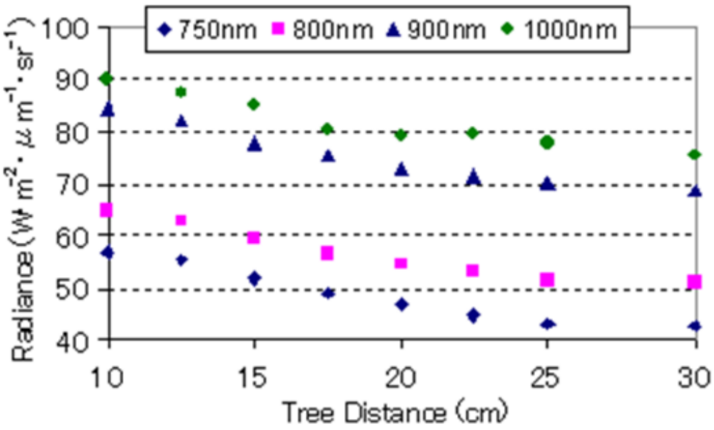


Figure 4. Relation between tree distance and radiance.

From these experimental data, it is found that the followings:

Visible light range (400-700 nm): Low reflectance.

Near-infrared region (750-1000 nm): High reflectance

Spectral reflectance characteristics of typical vegetation

As the distance between trees increases, the reflectance decreases.

The decrease is relatively large when the distance between trees reaches 25 cm, but is gradual beyond that. Therefore, it seems that multiple reflections between trees are at work.

Next, dependency of tree shapes on multiple reflection among tree is investigated. The results are shown in Figure 5 and Figure 6.

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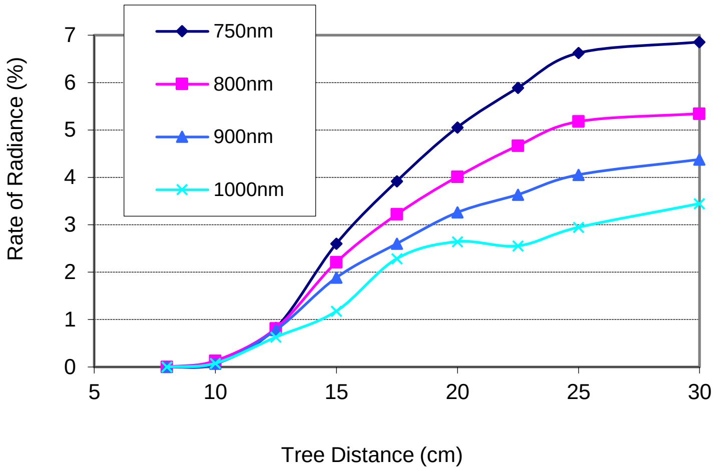

Figure 5. Forest No.1 (Tree shape: oval).

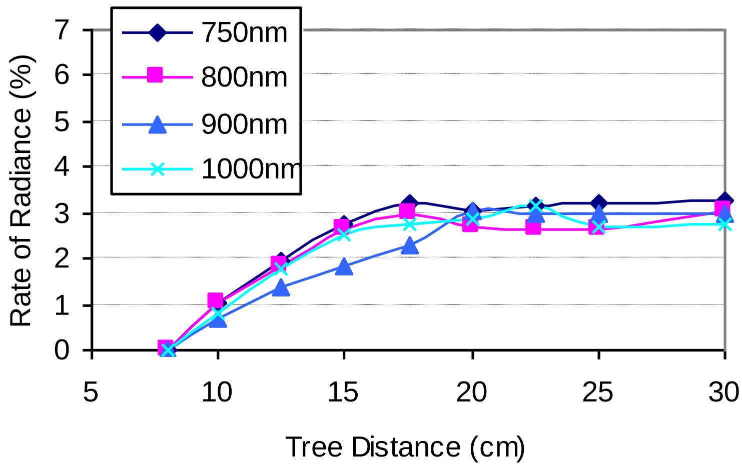

Figure 6. Forest No.2 (Tree shape: conical).

The maximum rate of change at four wavelengths (per unit area unit reflectance) are the followings:

Oval: 6.76%, 5.29%, 4.32%, 3.40%, Conical: 3.28%, 3.04%, 3.00%, 2.77%

The multiple reflections between the elliptical trees are larger than the conical ones. It is suggested that a factor in determining forest tree shape. Table 2 and Table 3 show the input parameters for the simulation. It is found that the simulation results from Monte Carlo simulation are matched to the experimental data.

Table 2. Input parameters for imitated forest No.1

Parameters	750 nm	800 nm	900 nm	1000 nm
Reflectance				
Grass reflectance	29 %	33 %	42 %	53 %
Tree reflectance	75 %	82 %	89 %	93 %
Optical thickness				
Air molecule	0.03	0.02	0.01	0.01
Aerosol	0.06	0.06	0.07	0.05
Sun-Sensor Geometry				
Solar zenith angle		41º		
Solar azimuth angle		15º		
View zenith angle		0º		
Canopy Properties				
Horizontal diameter (A)		13 cm		
Vertical diameter (B)		12 cm		

Table 3. Input parameters for imitated forest No.2

Parameters	750 nm	800 nm	900 nm	1000 nm
Reflectance				
Grass reflectance	29 %	33 %	42 %	53 %
Tree reflectance	65 %	75 %	84 %	92 %
Optical thickness				
Air molecule	0.03	0.02	0.01	0.01
Aerosol	0.06	0.06	0.07	0.05
Sun-Sensor Geometry				
Solar zenith angle		43º		
Solar azimuth angle		29º		
View zenith angle		0º		
Canopy Properties				
Base diameter (D)		11 cm		
Height (H)		26 cm		

4. Conclusions

The influence of multiple reflections between trees on top of the atmosphere (TOA) radiance depends on changes in forest parameters such as inter-tree distance, tree shape (ellipse/cone), and canopy shape (aspect ratio). As the distance between trees increases, the influence of multiple reflections between trees gradually decreases. The effect of multiple reflections in an elliptical shape is larger than in a conical shape (about 3 times). Therefore, it suggests the possibility of distinguishing forest tree shapes. Regarding tree crown shape, the influence of multiple reflections on thick and short trees is greater than on tall, thin trees. Therefore, it suggests the possibility of determining tree height in forests. Most importantly, the effect of multiple reflections between trees on TOA radiance is on the order of a few to 10%, and this effect must be taken into account when calculating the reflectance of a forest from the measured TOA radiance.

Conflicts of interest

There are no conflicts to declare.

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