Radiative transfer in a forest

A. Kuusk, Vienna, February 2006

VI *vs* physical model

Forest structure

Forest radiative transfer models - RAMI, Phase 2, Phase 3

Monte-Carlo ray tracing models

Radiosity models

Hybrid models

Radiative transfer model FRT

Comparison of models

Problems

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THEORY

APPLICATION

DEFINITION OF MODEL PARAMETERS (INPUT)
SCALE - TEMPORAL

DATA SOURCES

DATA PREPROCESSING

CLASSIFICATION.

BIO CHANGE EST

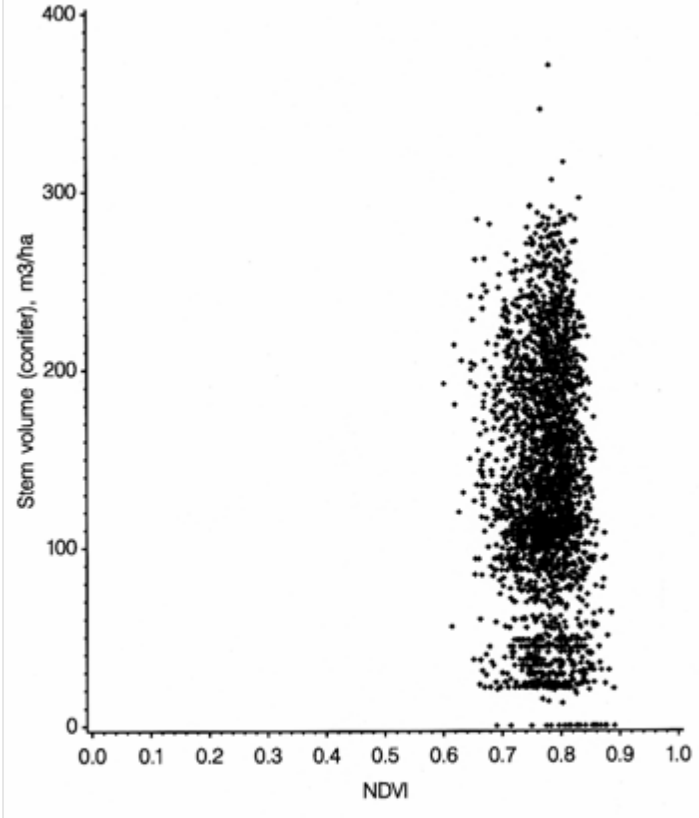
- VI
- MODEL INVERSION

WHAT IS WRONG WITH THIS PICTURE?

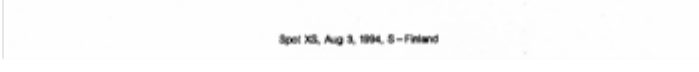
F. Hall, GSFC, 1995

VI

- simple
- 2 (3, 4) spectral channels
- empirical relations
  – site and time specific
  – calibration needed

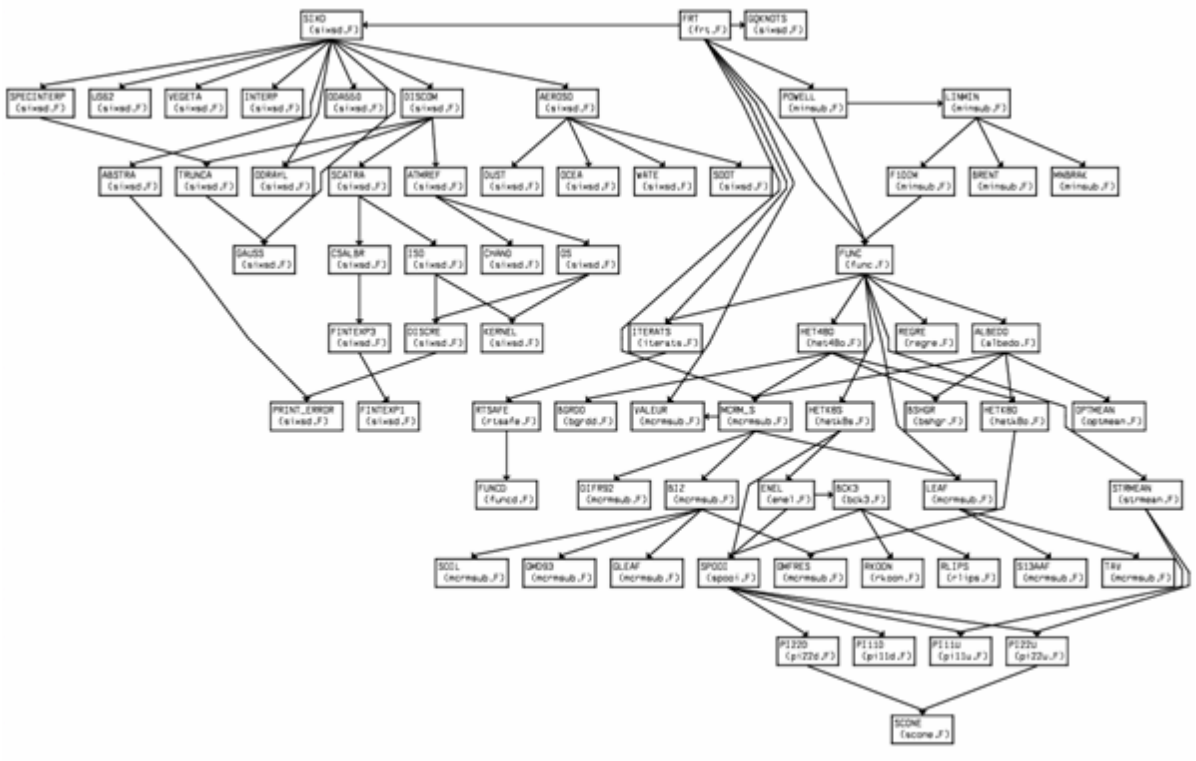


(T. Häme, Suonenjoki workshop, 1997)

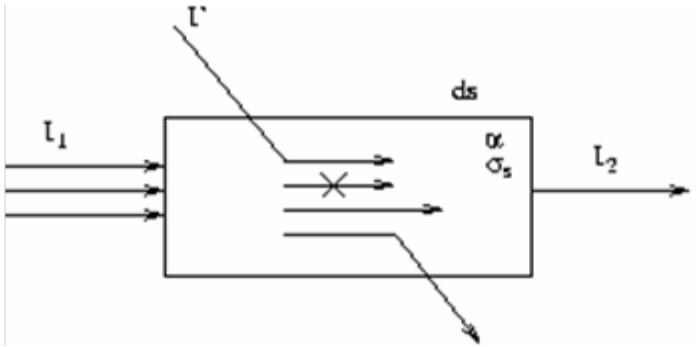


physical model

- complex & computer-intensive
- works at any wavelength
- based on numerous assumptions
- large number of input parameters
- difficult to validate



RT equation



$$\mu \frac{dI}{dz} = -\alpha I + \int_{4\pi} \sigma_s I' d\Omega' \ \ (+ S)$$

$$I = I(z,\Omega)$$

$$\alpha = \alpha(z,\Omega)$$

$$\sigma_s = \sigma_s(z,\Omega,\Omega')$$

$$\mu = \cos(\theta), \quad \Omega = (\theta,\varphi)$$

$$ds = dz / d\mu$$

elementary volume ?

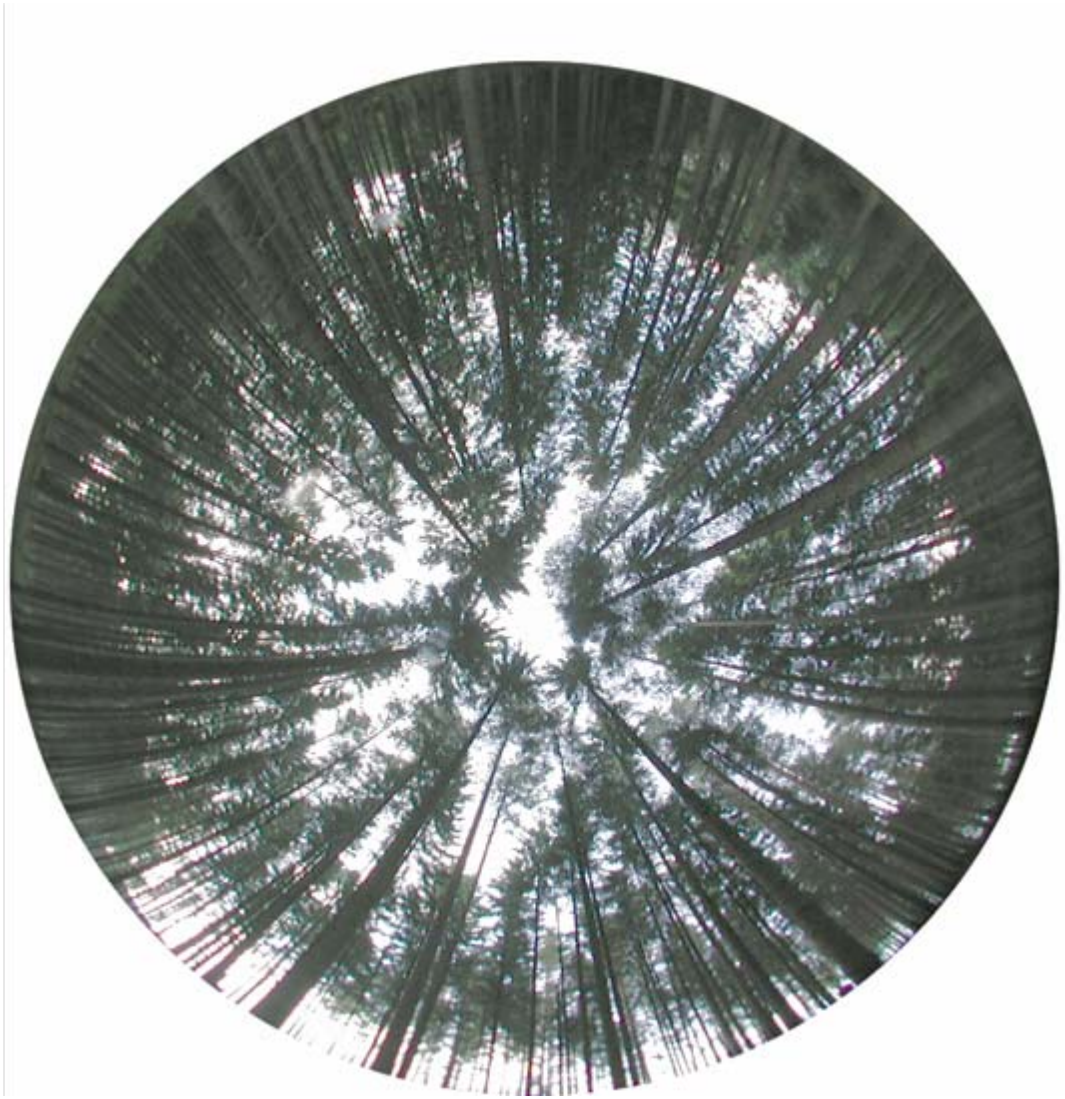
Forest structure

2.

Forest structure

3.

Forest structure



4.

RAMI = RAdiation transfer Model Intercomparison, JRC, Ispra

http://rami-benchmark.jrc.it/

Forest radiative transfer models

RAMI, Phase 2, (2002)	RAMI, Phase 3, (2005)
Monte-Carlo ray tracing models	
• Flight, North, 1996	• Flight, P. North, Univ. Swansea, UK
• Raytran, Govaerts and Verstraete, 1998	• Raytran, T. Lavergne, JRC, Italy
• Sprint-2, Thompson and Goel, 1998	• Rayspread, T. Lavergne, JRC, Italy
• Drat, Lewis, 1999 and Saich et al., 2001	• Sprint3, R. Thompson, Cox, USA
	• Drat, M. Disney, P. Lewis, UCL, UK
	• Frat, P. Lewis, M. Disney, UCL, UK
Radiosity models	
• RGM, Qin and Gerstl, 2000	• RGM, D. Xie, W. Qin, Beijing N. Univ., China
	• Hyemalis, R. Ruiloba, NOVELTIS, France
Hybrid models	
• GORT, Li et al., 1995	• DART, J.P. Gastellu, E.Martin, CESBIO, France
• SGORT, Ni et al., 1999	• FRT, M. Mõttus, A. Kuusk, T. Nilson, Tartu Observatory, Estonia
• LIM, Su, Unpublished	
• DART, Gastellu-Etchegorry et al., 1996	• 5scale, N. Rochdie, R. Fernandes, CCRS, Canada
• FRT, Kuusk and Nilson, 2000	

(Thanks to Dr. Widlowsky)

Monte-Carlo ray tracing models

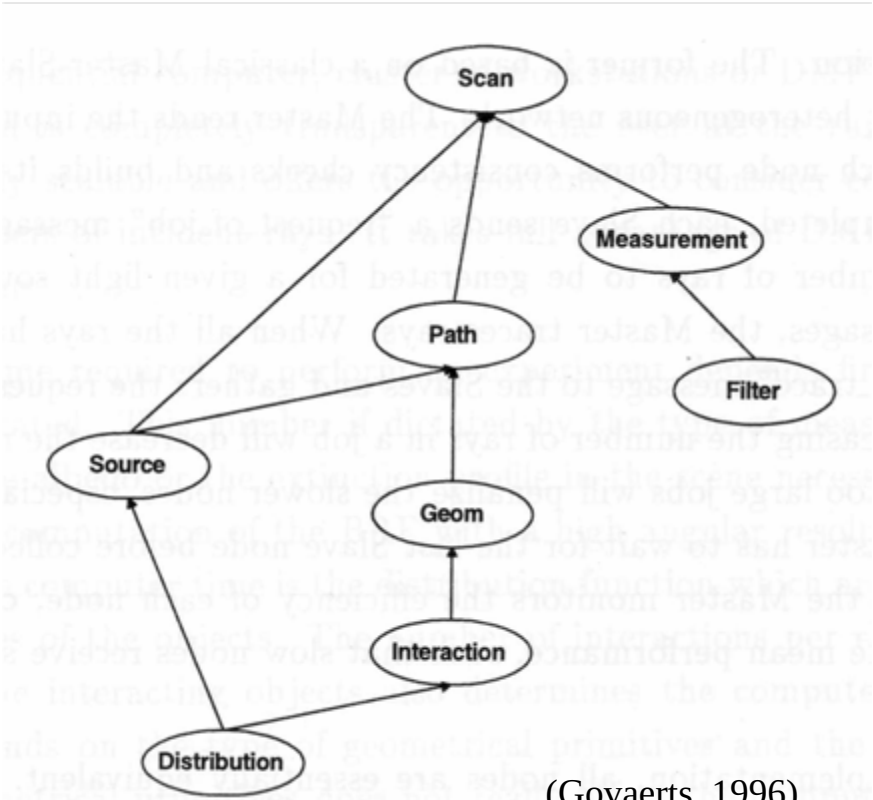
Flight. P.R.J. North, 1996. University of Wales, Dept. Geography. Swansea.

- large scale structures by geometric primitives (cones in a sample run)
- foliage within crowns described by volume-averaged parameters
- the sky radiance field is anisotropic
- 3D photon trajectories are simulated, accounting for the probabilities of free path, absorption and scattering -

  the forward mode

Raytran. Y.M. Govaerts, 1996**;** Y.M**.** Govaerts and M.M. Verstraete, 1998. JRC, Ispra.

MC - forward mode



(Govaerts, 1996)

Distribution	- scattering distribution functions
Interaction	- ray-matter interaction model
Geom	- geometrical primitives
Path	- propagation of a ray
Source	- energy sources
Filter	- filter of ray path
Measurement	- extract information from the paths
Scan	- control the propagation model

Drat -the aDvanced Radiometric Ray Tracer.

P. Lewis, 1999; Saich et al., 2001. University College, Dept. Geography, London

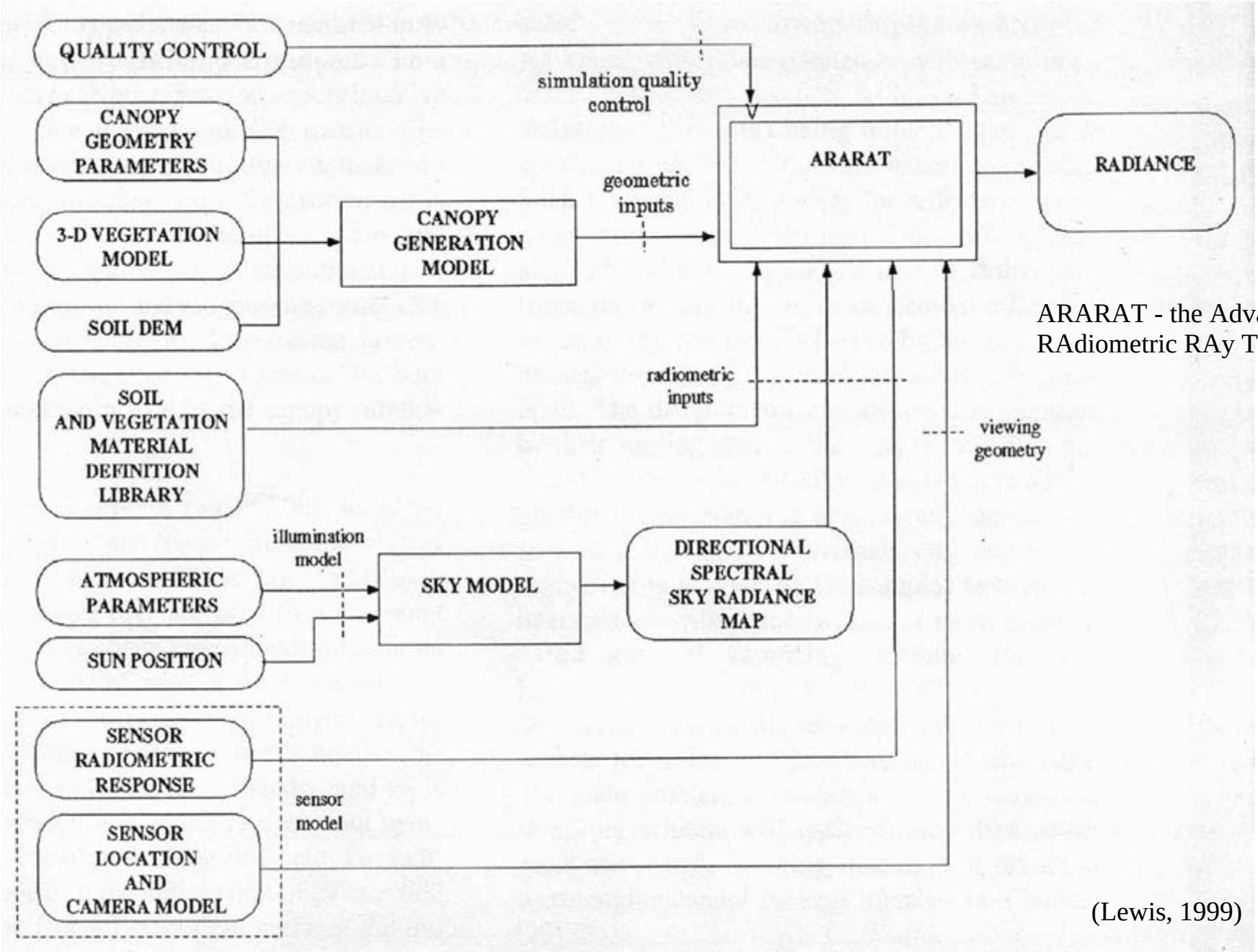
Vegetation is built using The Botanical Plant Modelling System (BPMS)
BPMS is a form of L-systems - the branches of a tree as geometric primitives

ARARAT - the advanced radiometric ray tracer,
reverce ray tracing,
a variety of camera models implemented

(Dürer, 1525)

(http://www.geog.ucl.ac.uk/~plewis/)

Drat , P. Lewis, 1999; Saich et al., 2001. University College, Dept. Geography, London



ARARAT - the Advanced RAdiometric RAy Tracer

(Lewis, 1999)

Radiosity model RGM

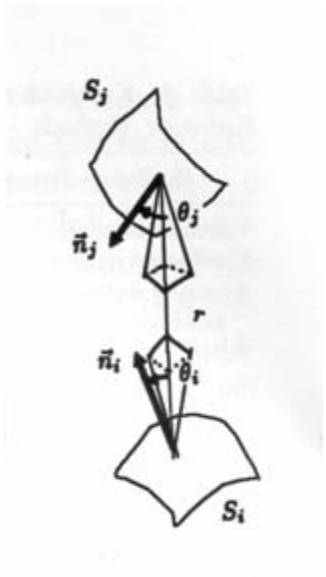
W. Qin, S. Gerstl, GSFC NASA, LANL

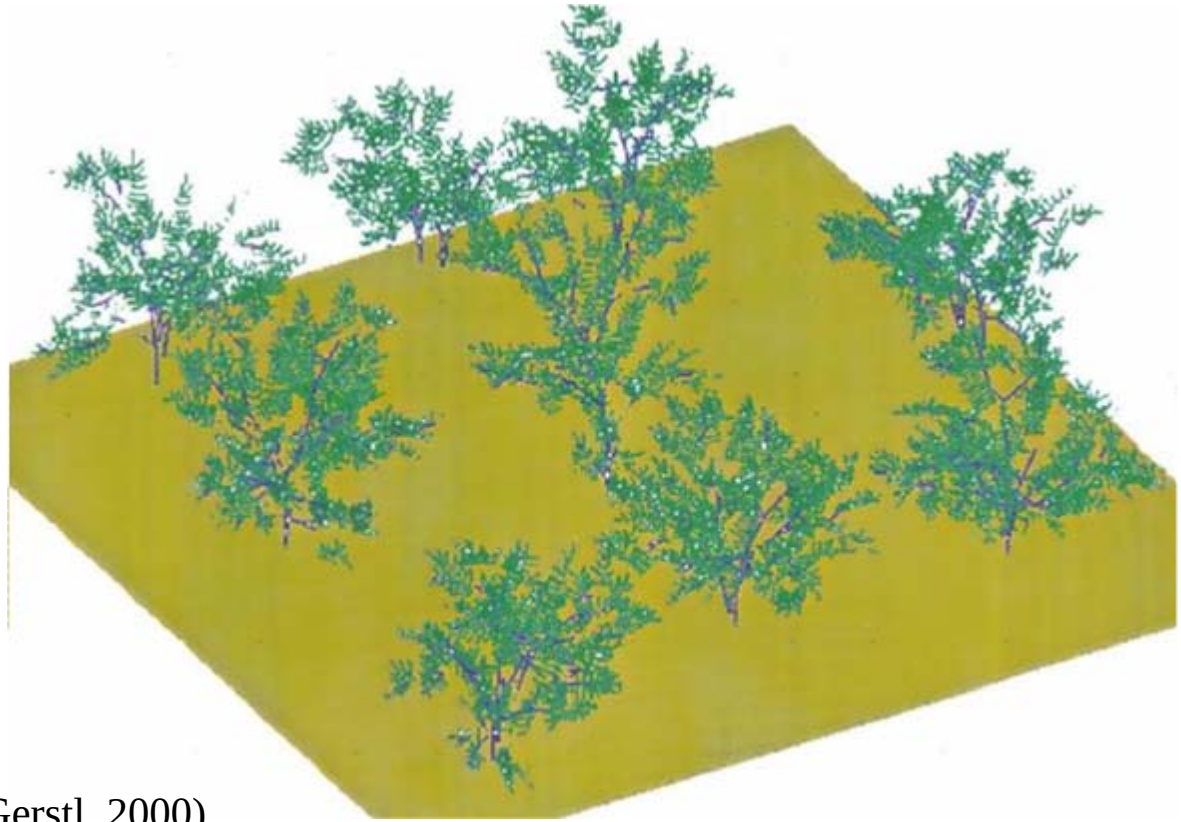
MELS - modified extended L-systems module

RGM - radiosity-graphics combined module

radiosity - the radiation flux density,
leaving a surface element

3D assemblies of scatterers
(leaves, branches)
and view factors are the key terms





(Qin and Gerstl, 2000)

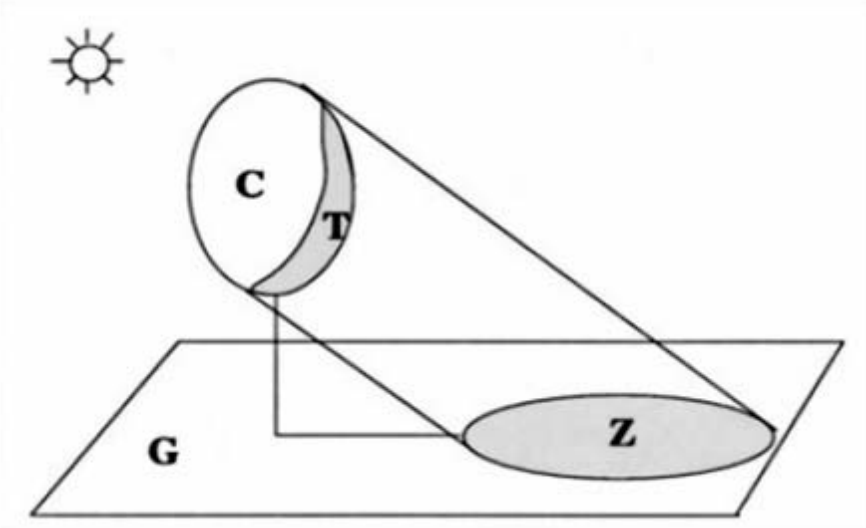
Hybrid models

GORT

X. Li, W. Ni, A. Strahler, Boston University

SGORT

- single scattering from geometrical optics
- effects of higher orders of scattering from RT theory
- geometric optical model is used to estimate
  aerial proportions of the components C, T, G, Z



(Ni and Li, 2000)

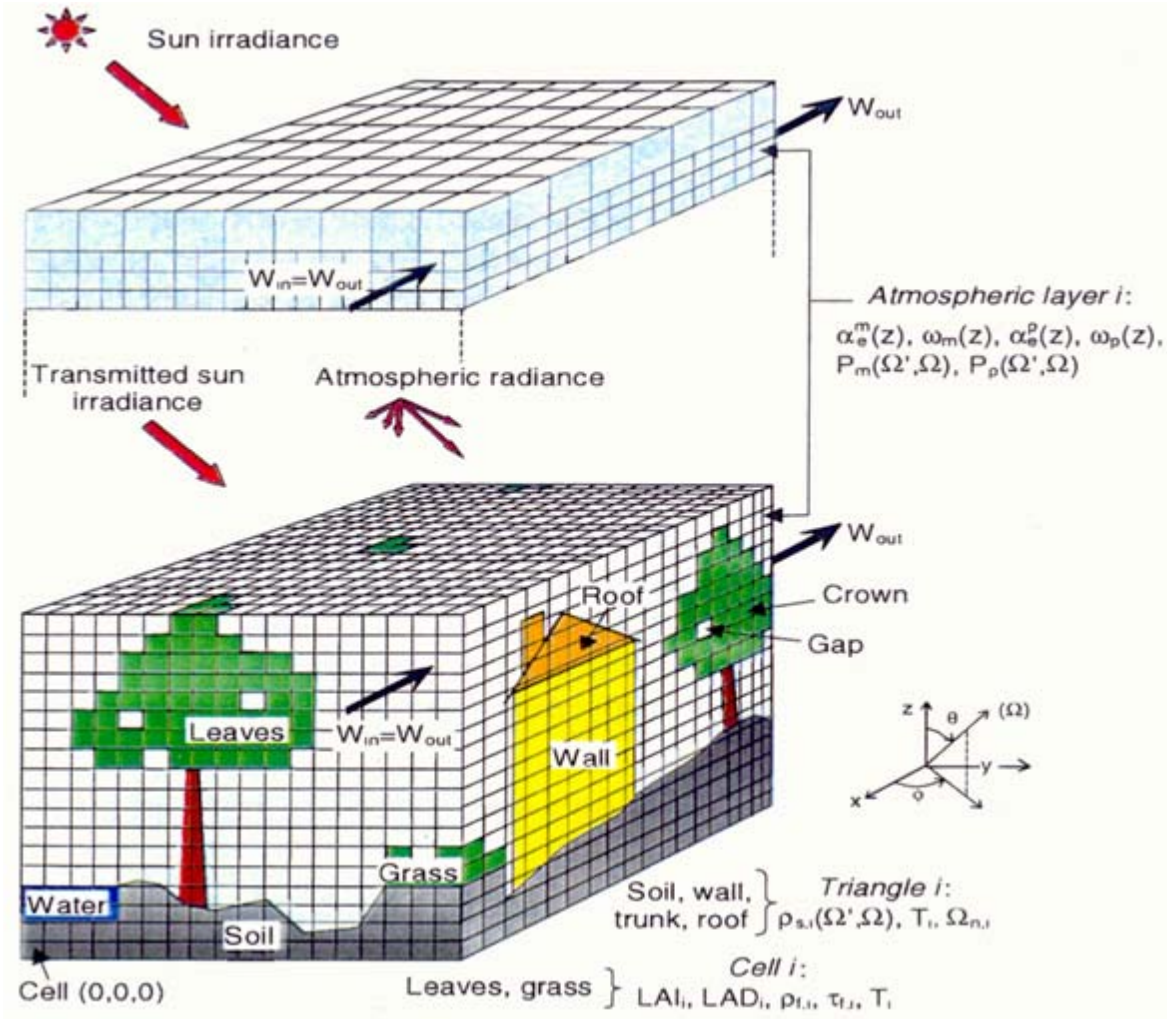
DART - Discret Anisotropic Radiative Transfer model

J.P. Gastellu-Etchegorry et al., CESBIO, Toulouse

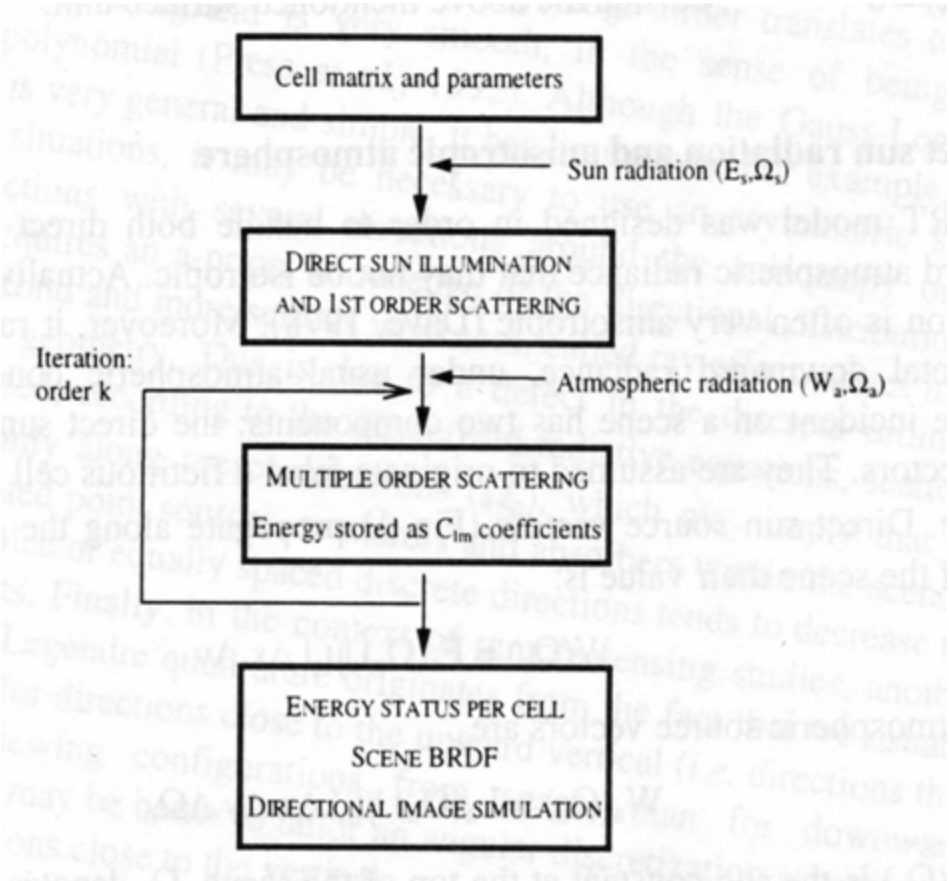
RT in a cell matrix, based on the discrete ordinate method and on an iterative approach
- the cells may be of different size
- cells are simulated as turbid media, or solid media with surface

The model is statistical within individual cells, deterministic when dealing with the shape and spatial distribution of the objects that make up the scene.

(Gastellu-Etchegorry et al., 2001)



DART

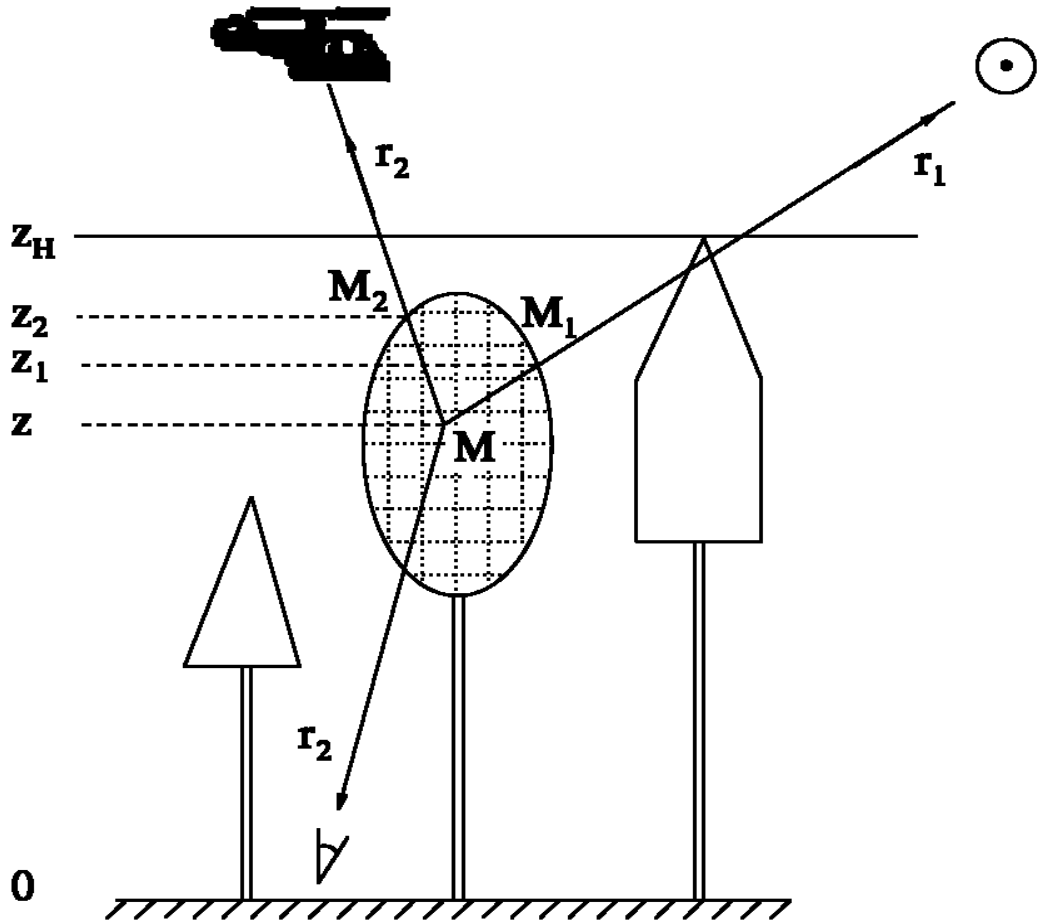


(Gastellu-Etchegorry et al., 1996)

Radiative transfer model FRT (Kuusk & Nilson, 2000)

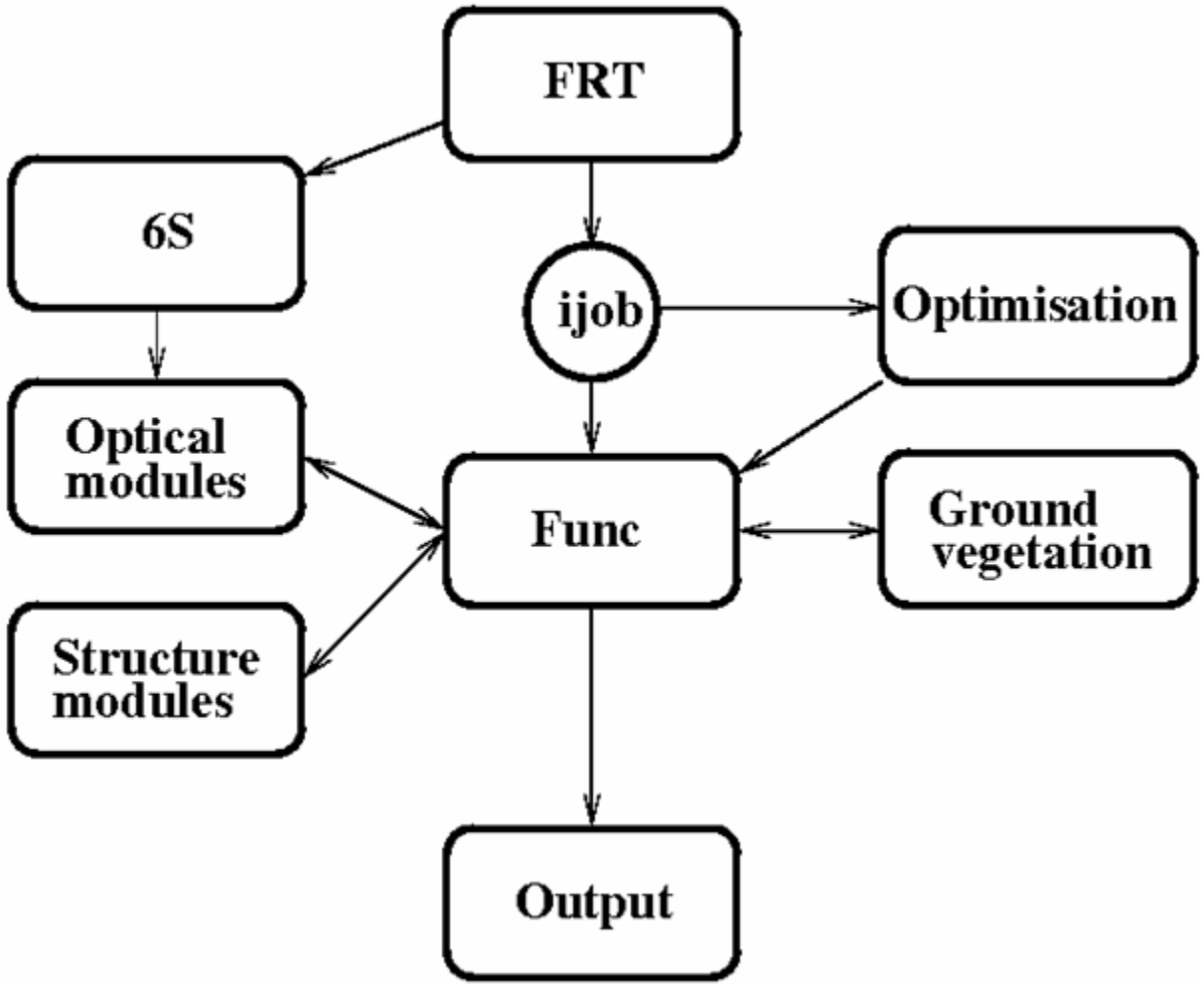
A probabilistic hybrid radiative transfer and geometric-optical model

- several tree classes
- spectral range 400-2400 nm, resolution 1 nm
- direct and inverse modes



Separately calculated

- single scattering in crowns
- single scattering on stems
- single scattering on ground vegetation
- diffuse fluxes of sky radiation and multiple scattering

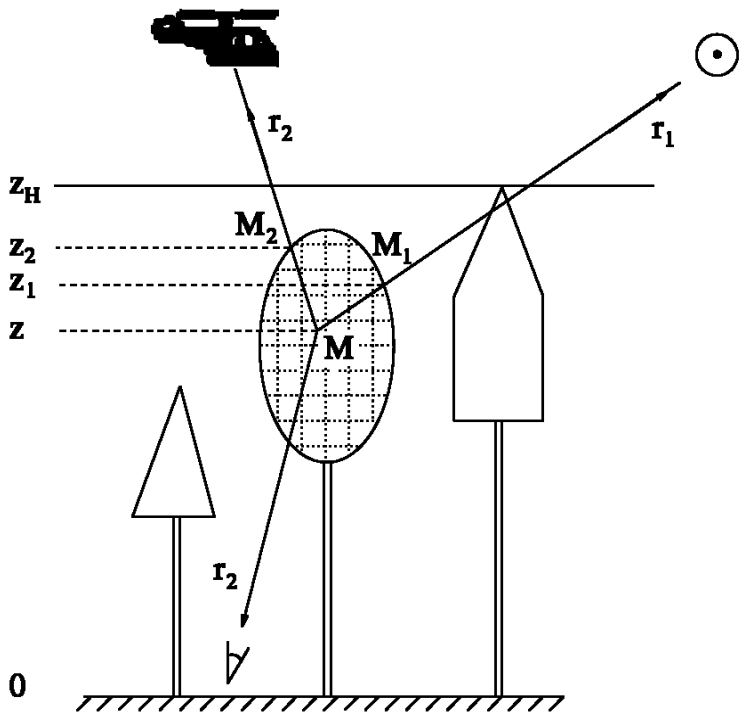

FRT
6S
ijob
Optimisation
Optical modules
Func
Ground vegetation
Structure modules
Output

Single scattering in crowns

- spherical LAD
- “hot spot”
- leaf models PROSPECT and LIBERTY: r_{leaf}, t_{leaf}
- specular reflection on leaves
- clumping of leaves into shoots
- uniform displacement of shoots
- neighbour trees, tree pattern

Single scattering on ground vegetation

- two-layer horizontally homogeneous CR model (Kuusk, 2001)
- leaf models PROSPECT and LIBERTY: r_{leaf}, t_{leaf}
- specular reflection on leaves
- 2-parameter (elliptical) LAD
- “hot spot”
- non-Lambertian soil
- Price' vectors for soil reflectance spectrum



Leaf model(s)

PROSPECT, Jacquemoud and Baret, 1990
LIBERTY, Dawson et al., 1998

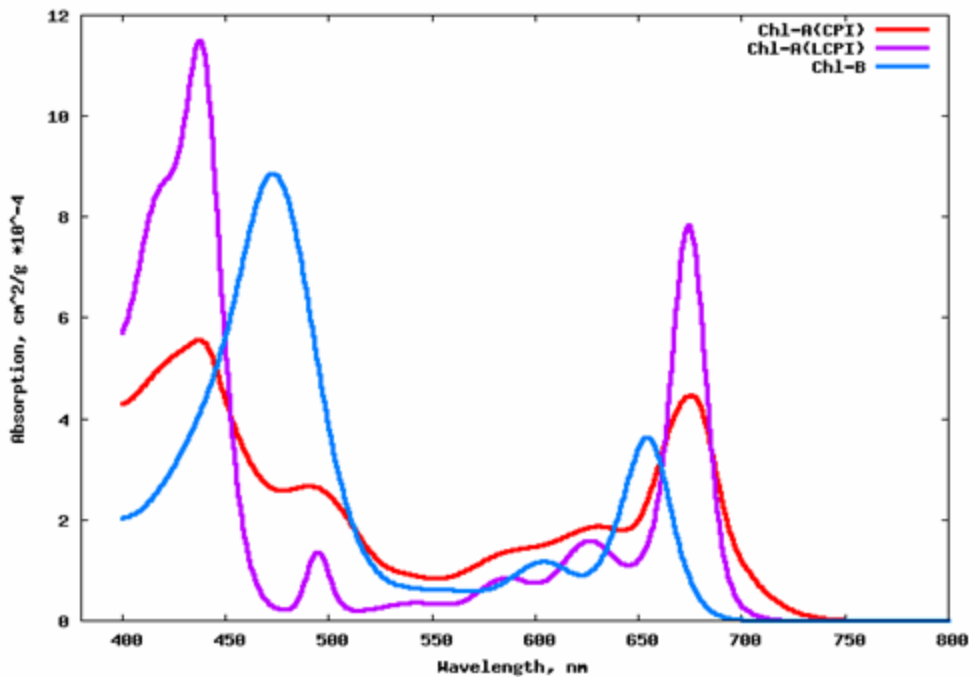
Absorption coefficient

$$k_0(\lambda) = k_e(\lambda) + \sum_i \frac{C_i K_i(\lambda)}{N}$$

Leaf components
- water
- lignin
- protein
- hemicellulose
- cellulose
- starch
- sugar
- chlorophyll-A (LHCP)
- chlorophyll-B
- chlorophyll-A (CPI)

Absorption spectra of leaf components

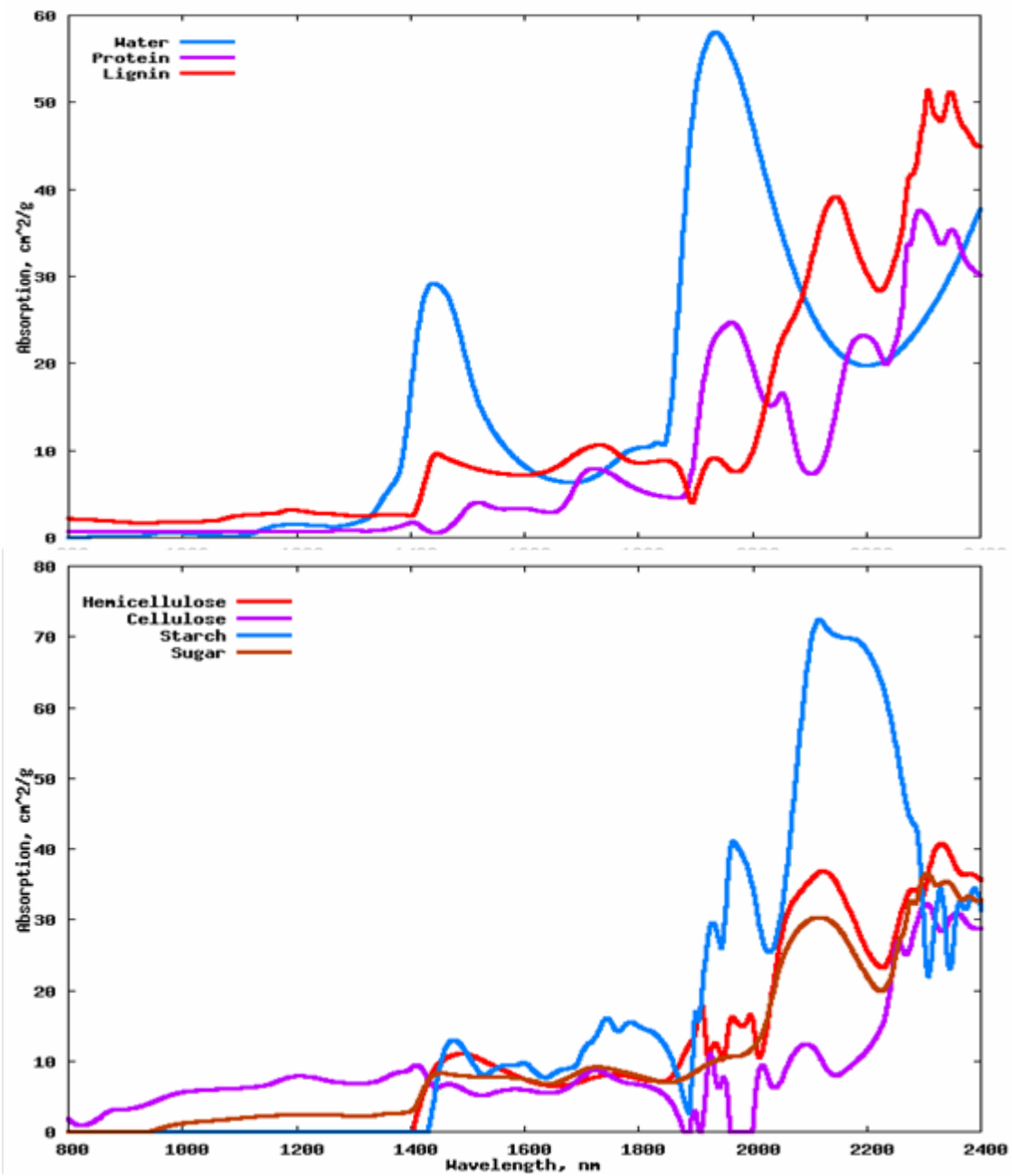
Visible



(Maier, 2000)

Absorption spectra
of leaf components

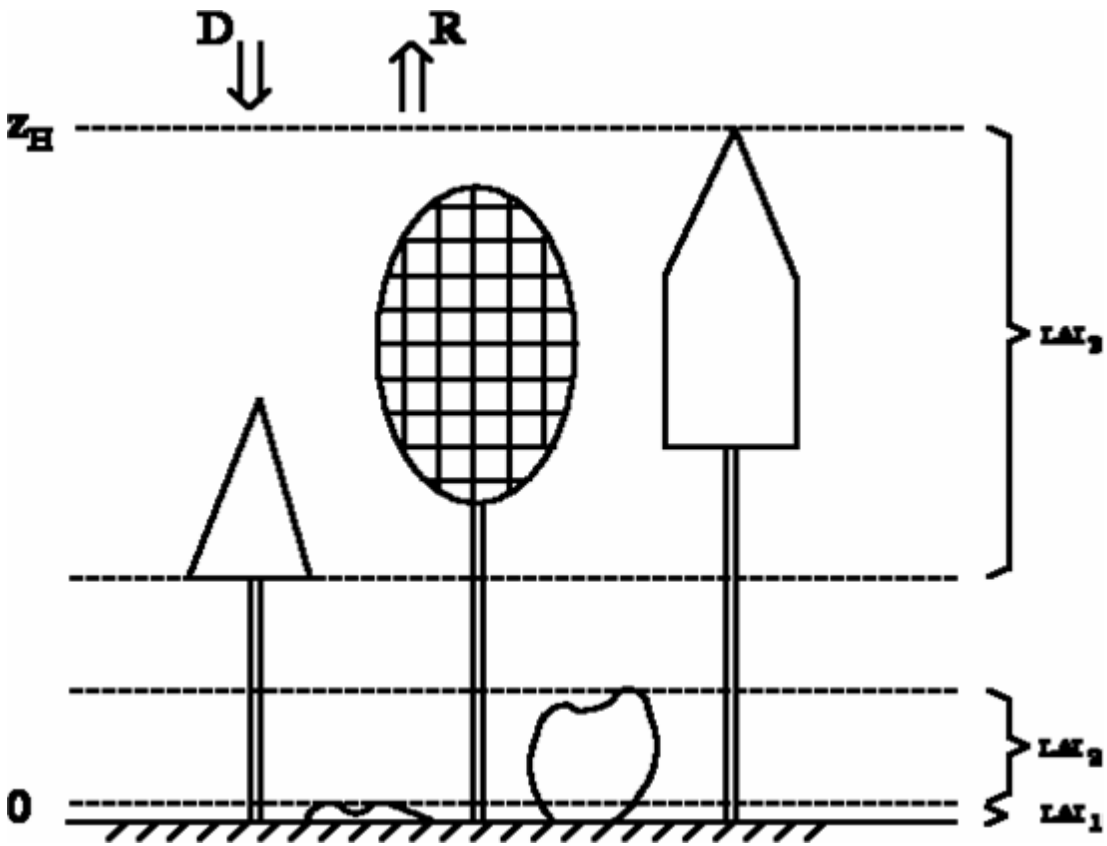
NIR



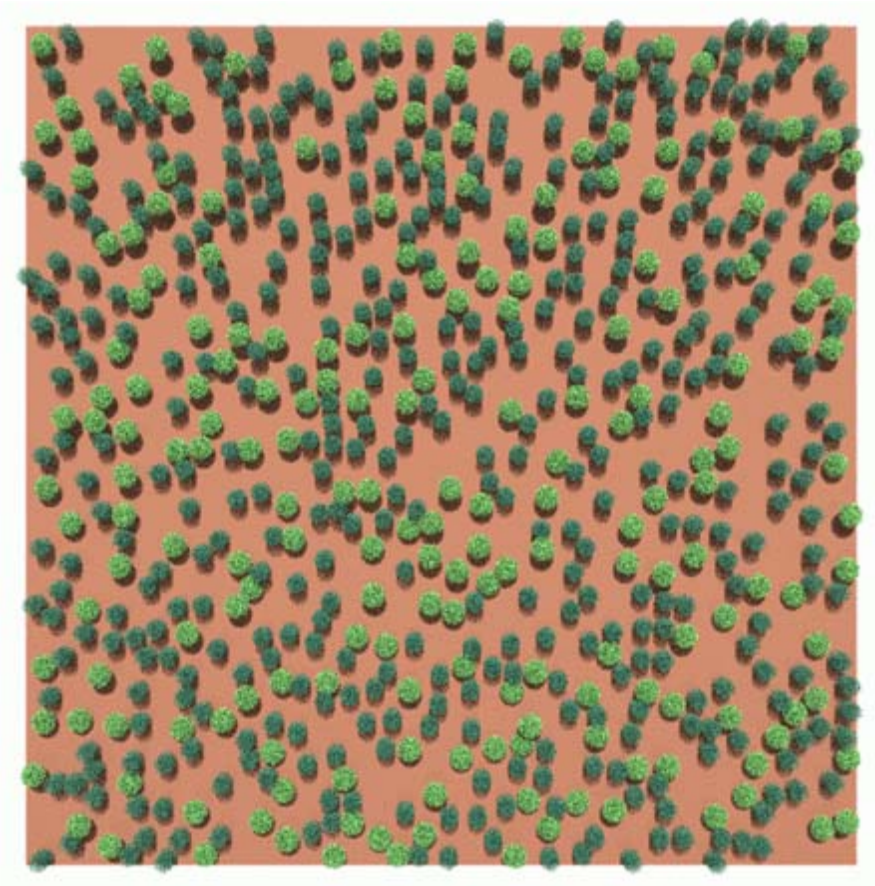
(Fourty et al., 1996;
Bach, 1995)

Diffuse fluxes

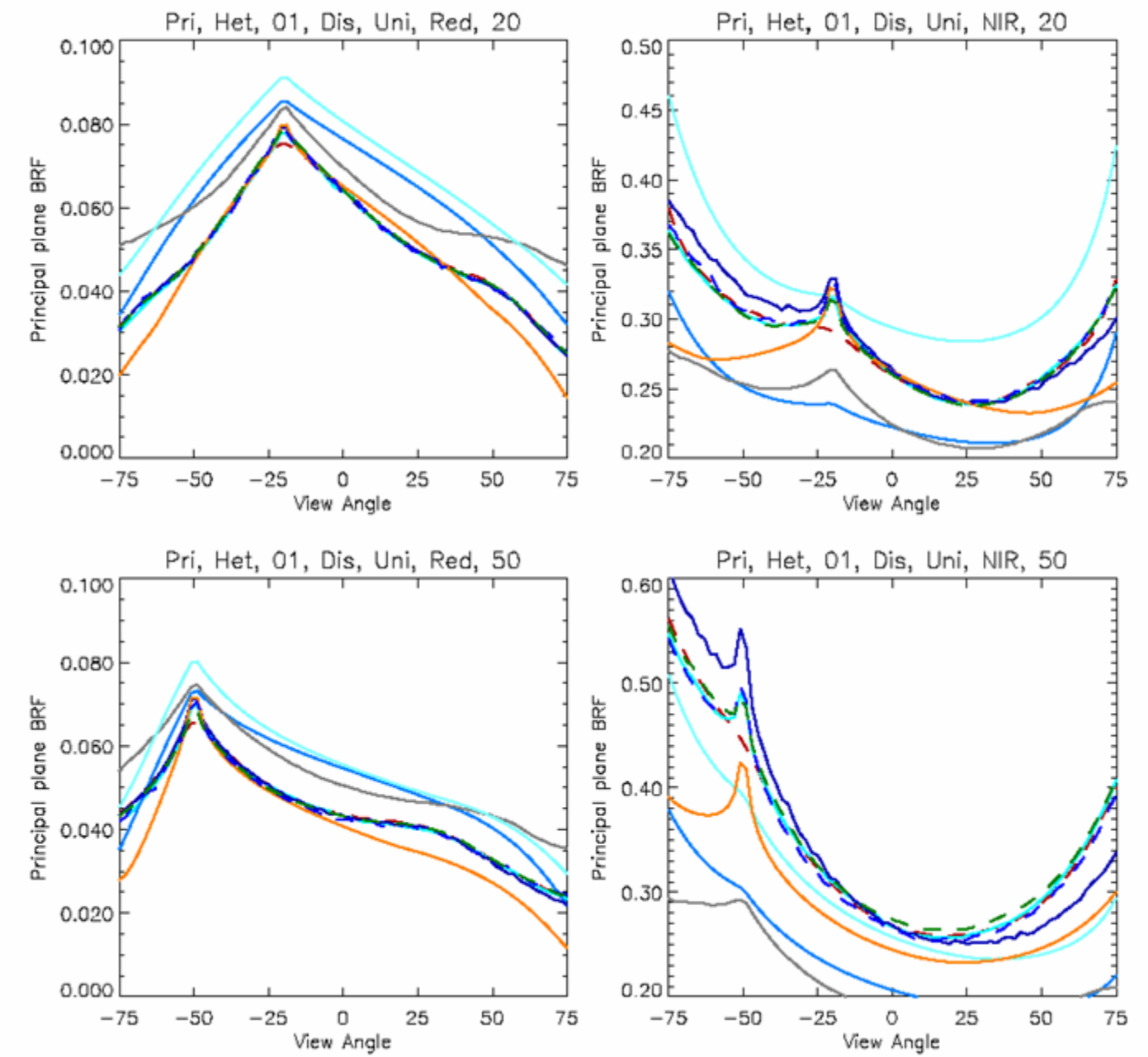
- 4-flux approximation (similar to the SAIL model) for a single layer
- the adding method for multiple layers
- “effective” LAI depends on view angle, crown form and tree pattern



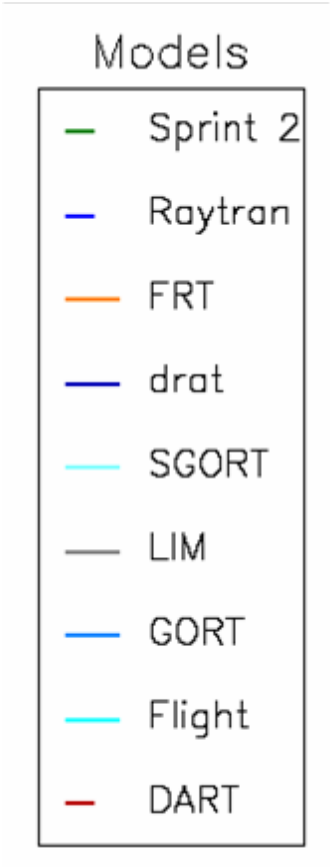
Comparison of models,
Pinty et al, RAMI, Phase 2
http://rami-benchmark.jrc.it/

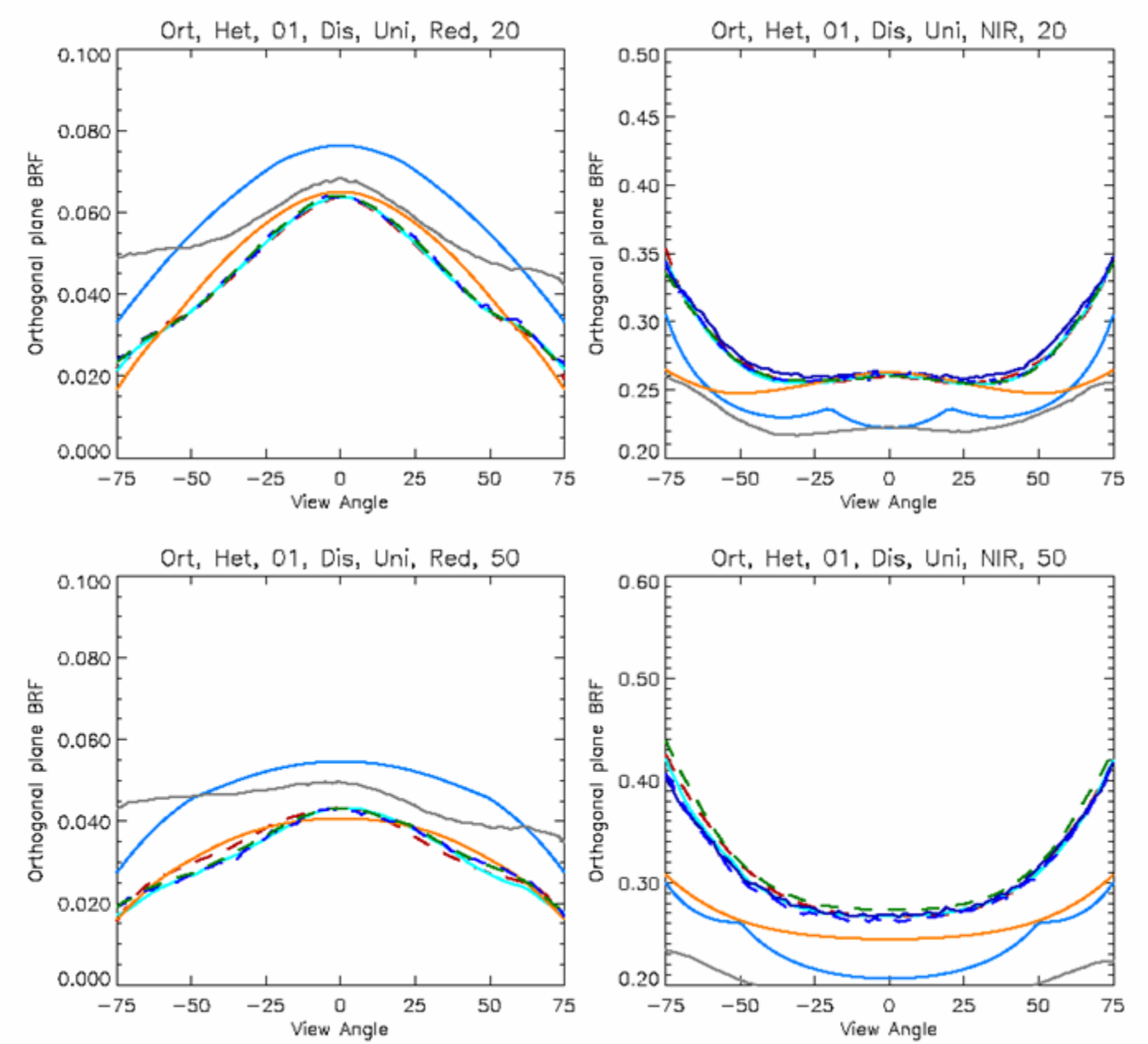


Comparison of models, Pinty et al, RAMI, Phase 2, principal plane



Comparison of models, Pinty et al, RAMI, Phase 2, perpendicular plane





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Forest radiative transfer models

RAMI, Phase 2

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- DART, Gastellu-Etchegorry et al., 1996
- FRT, Kuusk and Nilson, 2000

RAMI, Phase 3

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- Raytran, T. Lavergne, JRC, Italy
- Rayspread, T. Lavergne, JRC, Italy
- Sprint3, R. Thompson, Cox, USA
- Drat, M. Disney, P. Lewis, UCL, UK
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- 5scale, N. Rochdie, R. Fernandes, CCRS, Canada

(Thanks to Dr. Widlowsky)

Problems

- structure
  - displacement of branches, shoots, leaves/needles
  - levels of clumping, **side effects**
  - the shape of stems
  - ground vegetation
- multiple scattering
- biochemistry
- validation

Gap probability

$$a_s(\theta) = \exp\left(-\frac{G_L(\theta)L}{\mu}\right)$$

$\mu = \cos(\theta)$, L - leaf area index (LAI)

Two possibilities for changing the

cap probability in a canopy of fixed LAI:

- changing orientation:

  $G_L^{(1)} \rightarrow G_L^{(2)}$

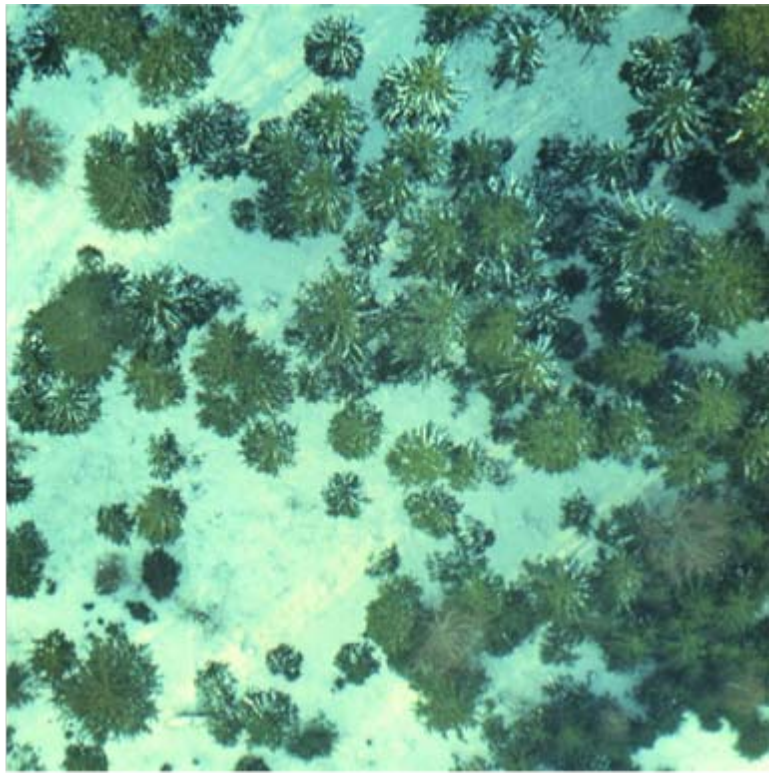
- changing foliage pattern:

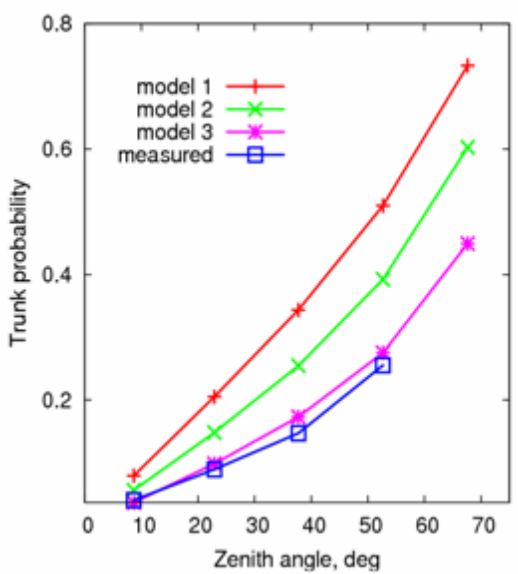
  $L \rightarrow L_{eff} = cL,$ then $\rho_L \rightarrow \rho_{L,eff}$, $\tau_L \rightarrow \tau_{L,eff}$

Photon recollision in a shoot

(Smolander & Stenberg, 2003)

Multiple scattering at stand level





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