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Capitalizing on 1D RT models to interpret remote sensing data from 3D structurally heterogeneous vegetation systems

Bernard Pinty, **T. Lavergne**, N. Gobron,
J-L Widlowski, and M. M. Verstraete

EC-JRC Institute for Environment and Sustainability, Ispra, Italy

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ies Institute for Environment and Sustainability

Context

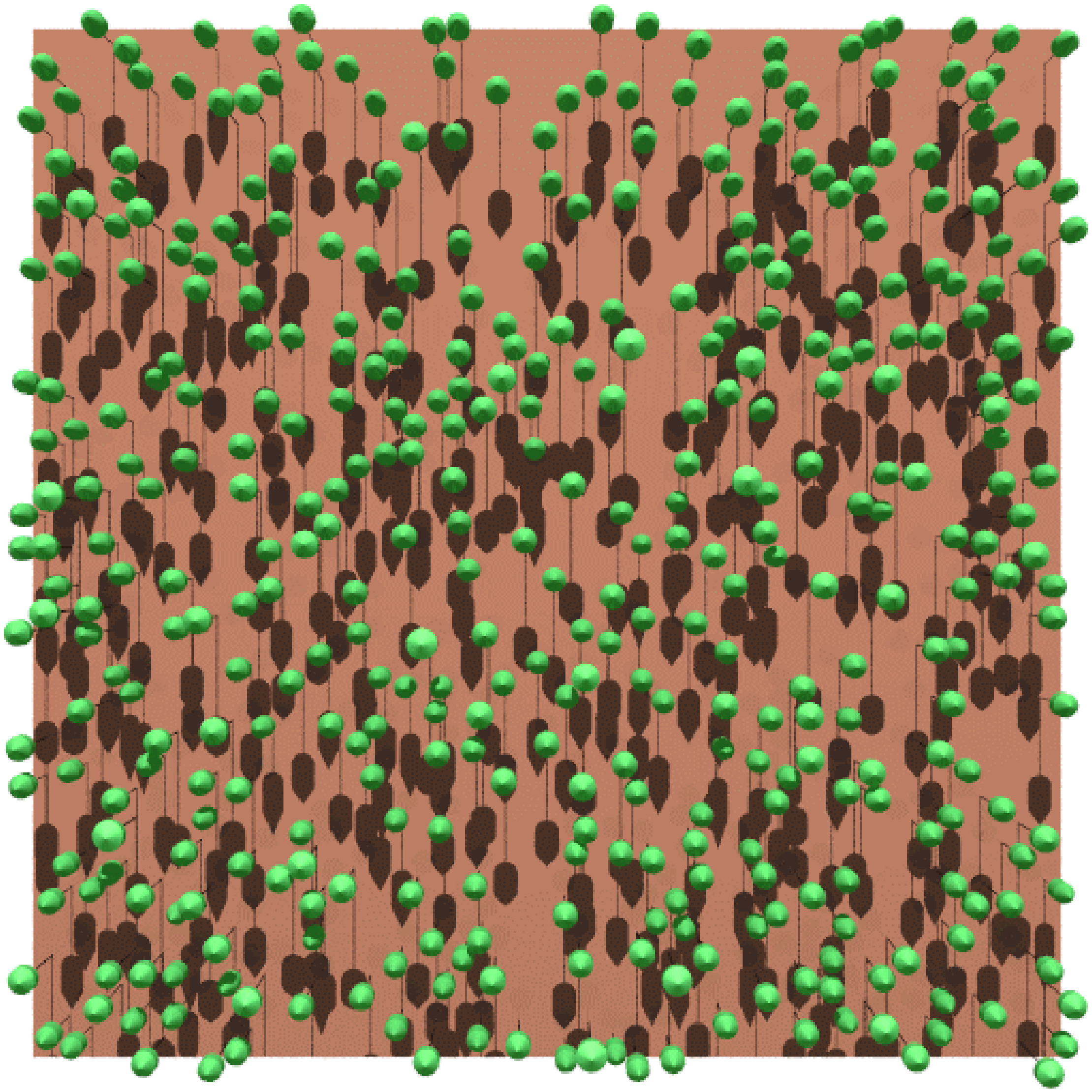
Interpret Remote Sensing data from medium resolution optical sensors to characterize (quantify) 3D heterogeneous vegetation (e.g. forests).

MISR (Terra) acquires multi-angular reflectances since 2000.

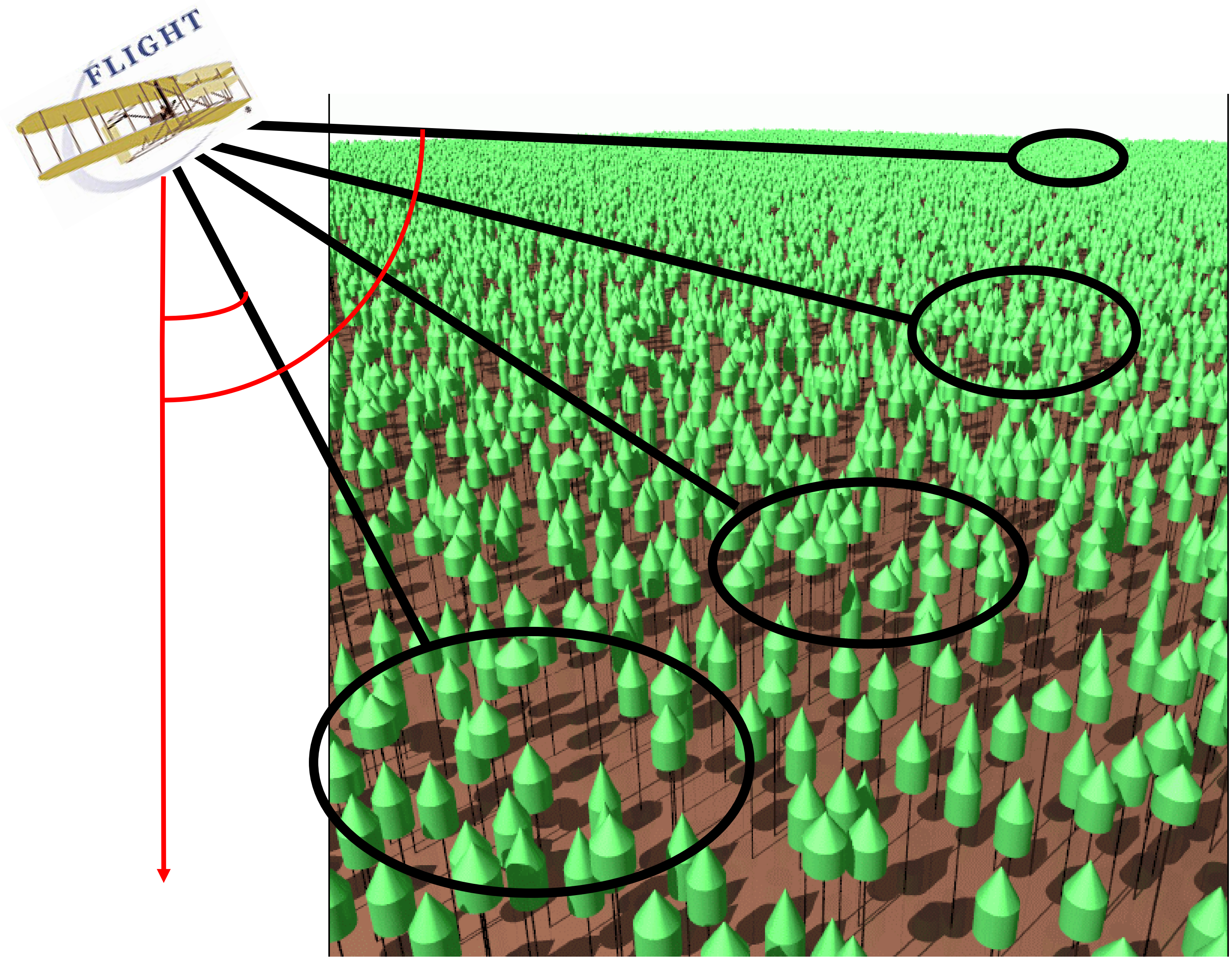
4 wavelengths, **9 view angles**

LandBRF (Level 2) are available at 1.1km resolution.

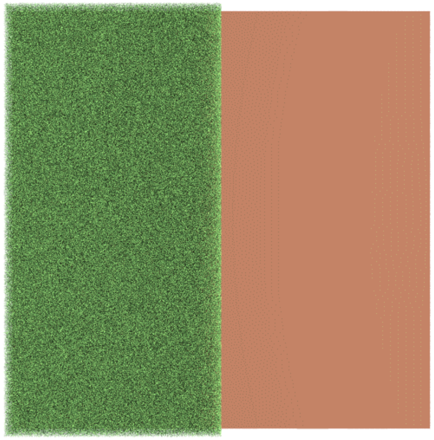
Multiangle views for surface structure

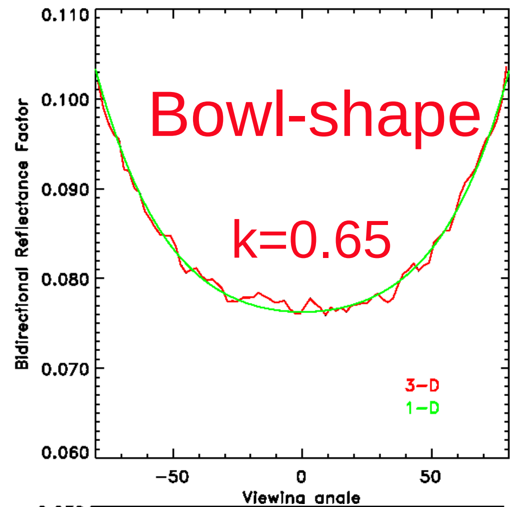


Multiangle views for surface structure

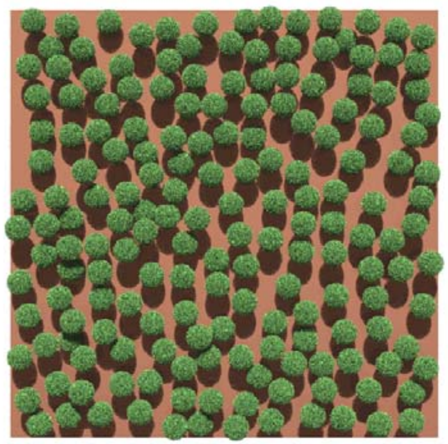


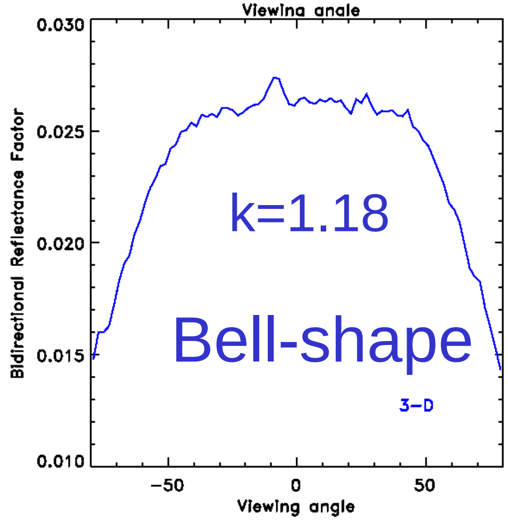
Angular signatures in the red band





1-D



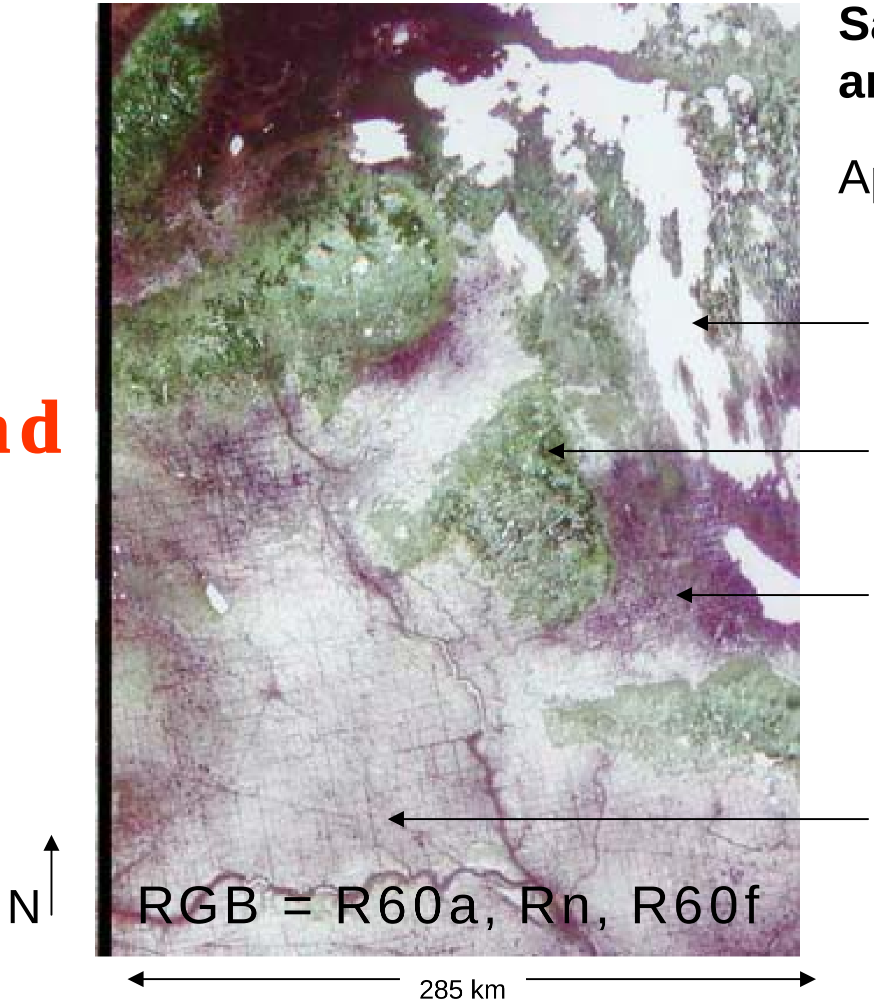


3-D

Ref: Pinty et al. (2002) IEEE TGRS

Surface structure from MISR/Terra

Red band



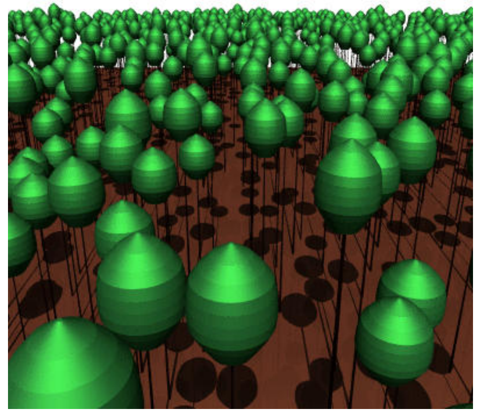
Saskatchewan and Manitoba

April 17, 2001

Ref: http://www-misr.jpl.nasa.gov/gallery/galhistory/2001_may_30.html

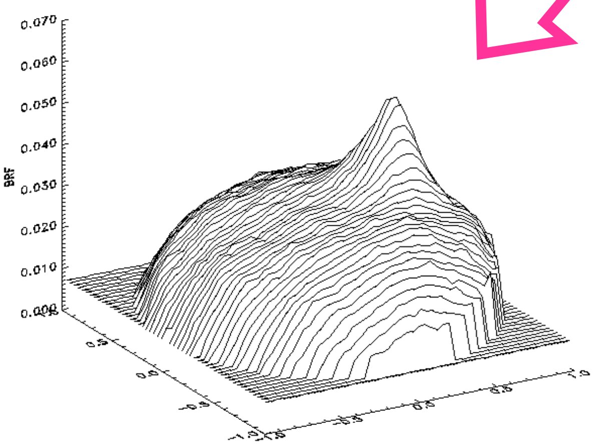
Inversion problem

Biome parameters

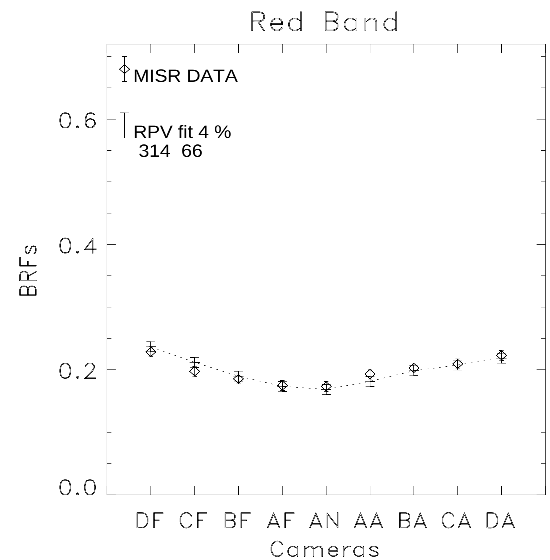


Retrieval

3-D radiative transfer model



Comparison



Simulated Bidirectional Reflectance Factor

Satellite BRF

Modelling Issues

3-D Monte-Carlo models are heavy to run.

Pre-calculate **Look Up Tables** (LUTs) over many biomes:

Forests: 1) tree density 3) greenness of leaves

2) LAI in crowns 4) *etc*

+ background (anisotropic) reflectance

BRF to be simulated in (at least) 2 wavelengths,

for several Sun angles and several view angles.

Solutions

1) Have a fast(er) 3D MC model;

The **Rayspread** model

2) Save as much effort as possible in constituting the LUTs:

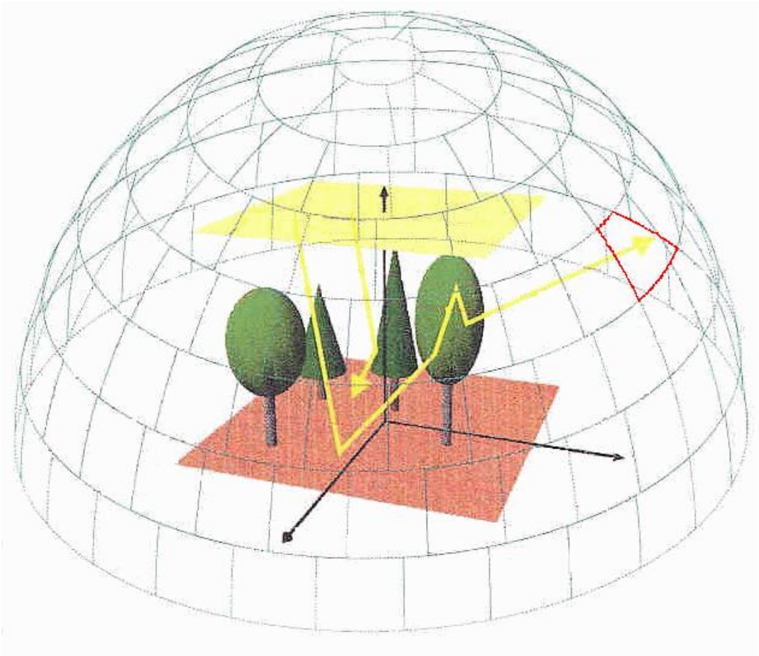
a) decoupling background / vegetation;

b) find spectrally invariant terms;

c) simplify least significant contributions.

The Rayspread model

Rayspread inherits from the **Raytran** model (3D Monte-Carlo raytracer)



Rayspread implements a variance-reduction technique: *local estimator* (*aka photon-spread*)

~ 100 times faster.

Rayspread results are non-discernible from **Raytran** (except for the Monte-Carlo noise). Both models participate to RAMI Phase 3.

Ref: Govaerts et al. (1998), Widlowski et al. (2006)

Solutions

1) Have a fast(er) 3D MC model;

Radiative components

2) Save as much effort as possible in constituting the LUTs:

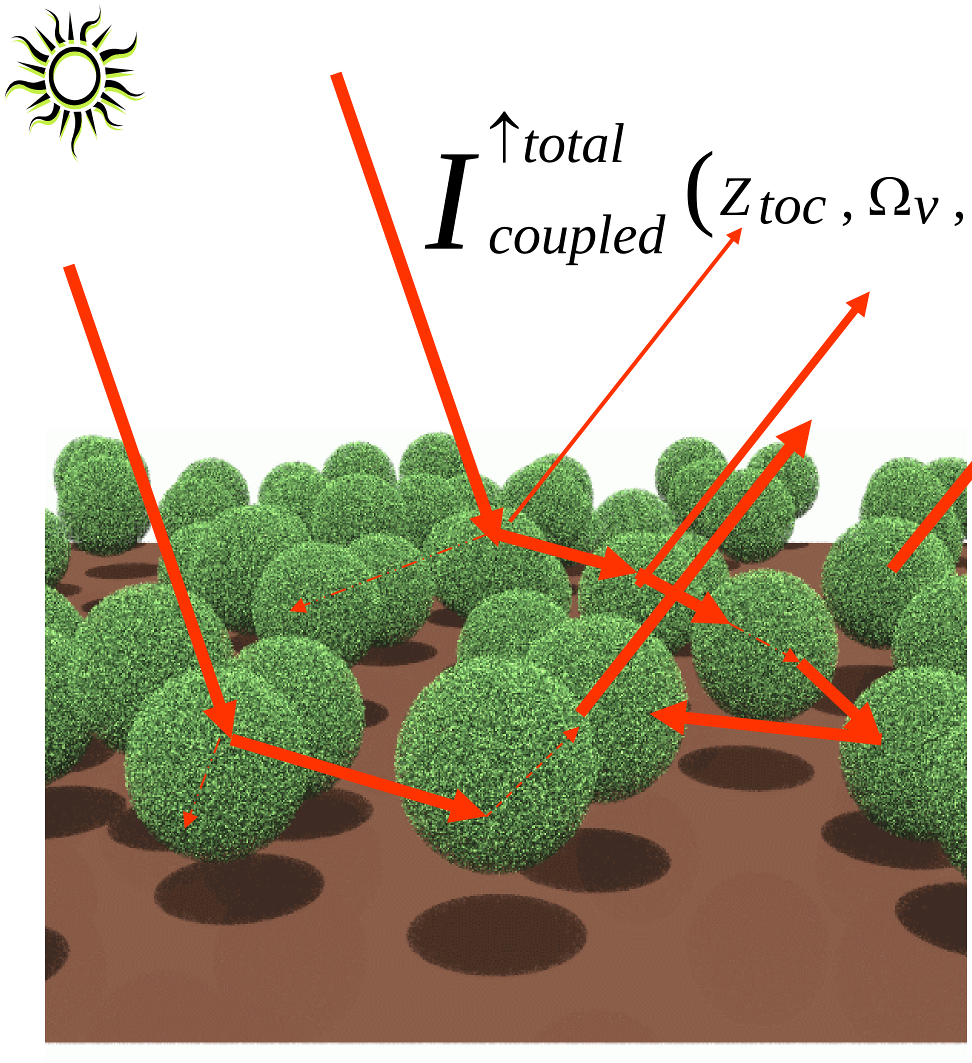
a) decoupling background / vegetation;

b) find spectrally invariant terms;

c) simplify least significant contributions.

Decompose the complex problem into simpler problems to solve

$$I^{\uparrow total}_{coupled}(z_{toc}, \Omega_v, \Omega_0) = I^{\uparrow Collided}_{vegetation}(z_{toc}, \Omega_v, \Omega_0)$$



Black Background contribution

1) It regulates the *absorption* processes associated to vegetation photosynthesis

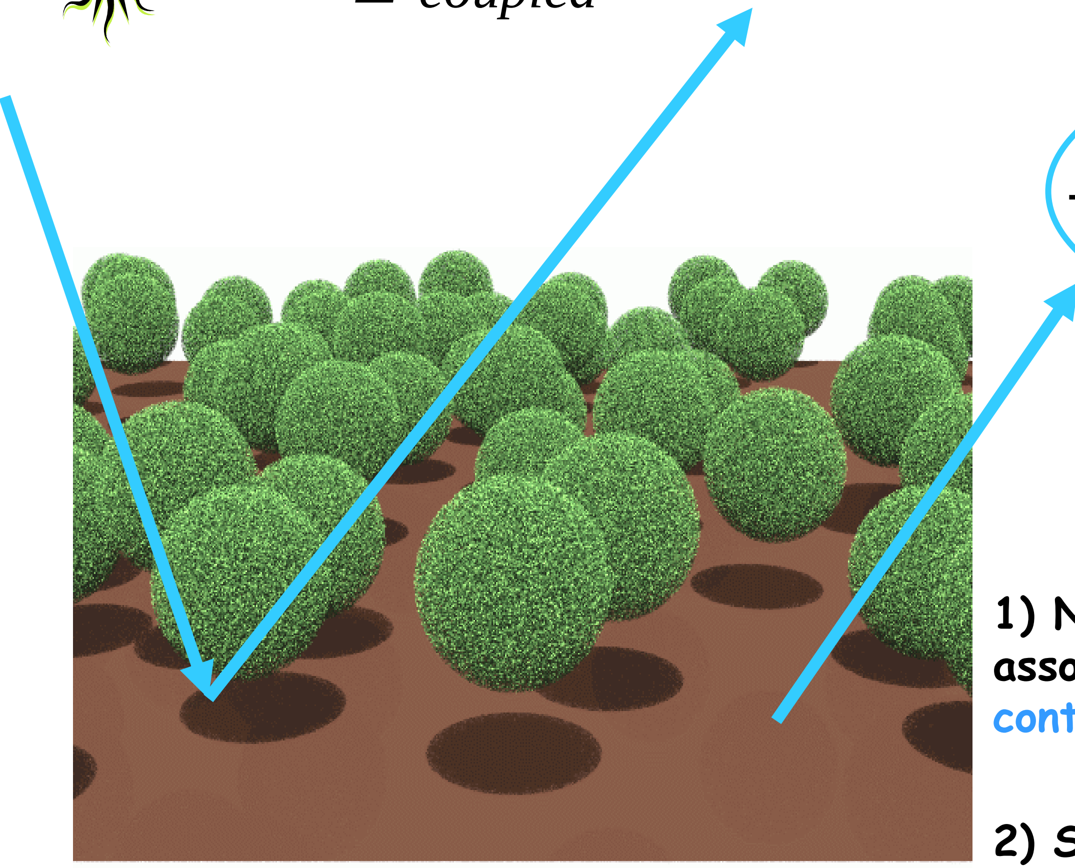
2) Strongly depending on the *density* of green vegetation

Ref: Pinty et al. (2004) Journal Geophysical Research, doi:10,1029/2004JD005214

Decompose the complex problem into simpler problems to solve

$$I^{\uparrow total}_{coupled}(z_{toc}, \Omega_v, \Omega_0) = I^{\uparrow Collided}_{vegetation}(z_{toc}, \Omega_v, \Omega_0)$$

$$+ I^{\uparrow Uncollided}_{background}(z_{toc}, \Omega_v, \Omega_0)$$



Black Canopy contribution

1) No absorption process by vegetation associated with this wavelength independent contribution

2) Strongly controlled by 3-D distribution of vegetation extinction coefficient

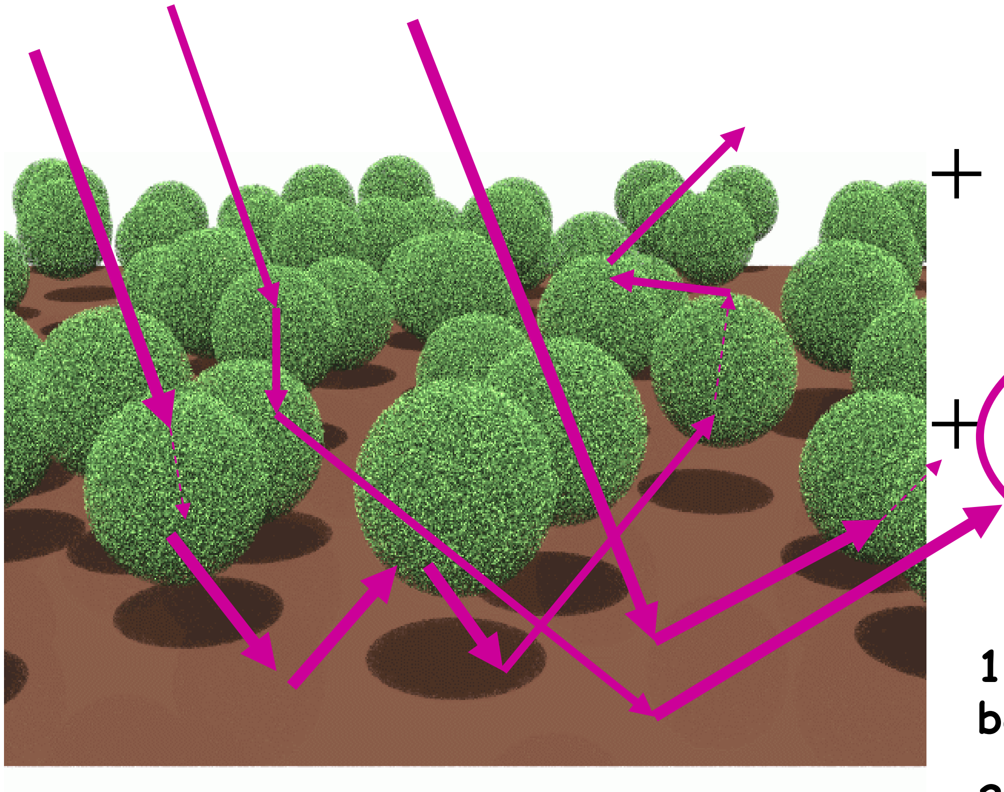
Ref: Pinty et al. (2004) Journal Geophysical Research, doi:10,1029/2004JD005214

Decompose the complex problem into simpler problems to solve

$$I^{\uparrow total}_{coupled}\left(z_{toc}, \Omega_v, \Omega_0\right) = I^{\uparrow Collided}_{vegetation}\left(z_{toc}, \Omega_v, \Omega_0\right)$$

$$+ I^{\uparrow Uncollided}_{background}\left(z_{toc}, \Omega_v, \Omega_0\right)$$

$$+ I^{\uparrow Multiplecollided}_{background}\left(z_{toc}, \Omega_v, \Omega_0\right)$$



1) Controlled by multiple scattering events between the background and the canopy

2) Mostly negligible in the visible domain of the solar spectrum

Ref: Pinty et al. (2004) Journal Geophysical Research, doi:10,1029/2004JD005214

Use a 1-D solution for the background-canopy multiple scattering contribution

3rd term = $$I^{\uparrow MultipleCollided}_{background}\left(z_{toc}, \mathbf{\Omega_v}, \mathbf{\Omega_0}\right)$$

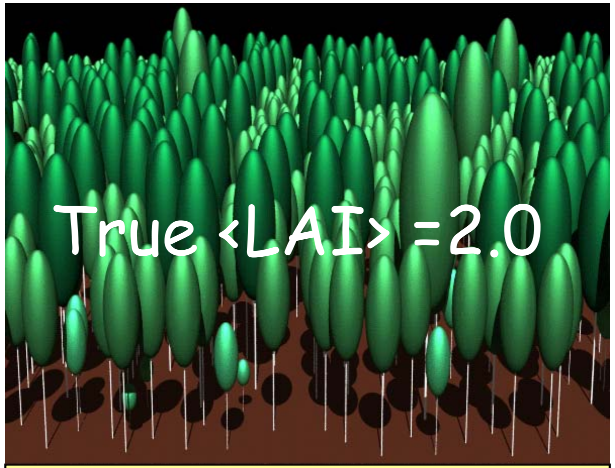
Developed analytical formulation of this intensity.

Assume a homogeneous plane-parallel, turbid medium representation (1-D solution).

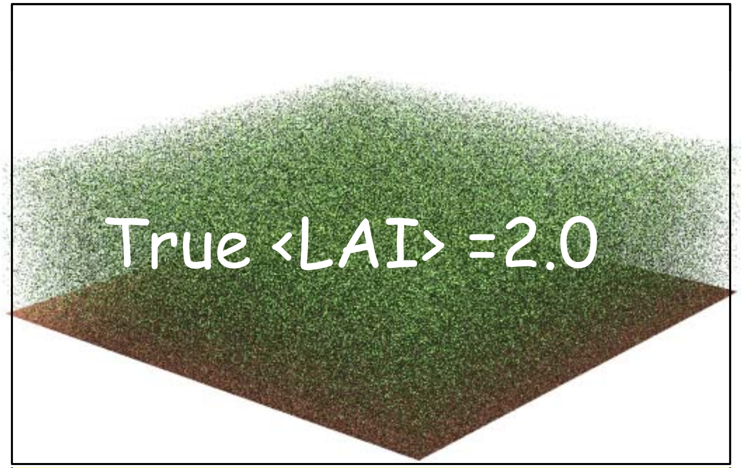
"Effective" state variable values are required for the 1-D model: $\widetilde{LAI}$, $\widetilde{r_l}$ and $\widetilde{t_l}$

Ref: Pinty et al. (2004) Journal Geophysical Research, doi:10,1029/2004JD005214

Effective state variable values ensure that 1-D fluxes are close to 3-D fluxes.



3-D heterogeneous system



1-D system representation

Direct transmission at 30 degrees Sun zenith angle,

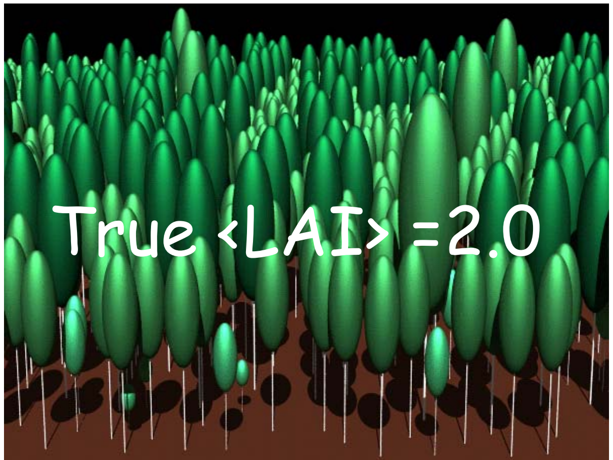
$$T_{3-D}^{direct}(<LAI>) = 0.596$$

Direct transmission at 30 degrees Sun zenith angle,

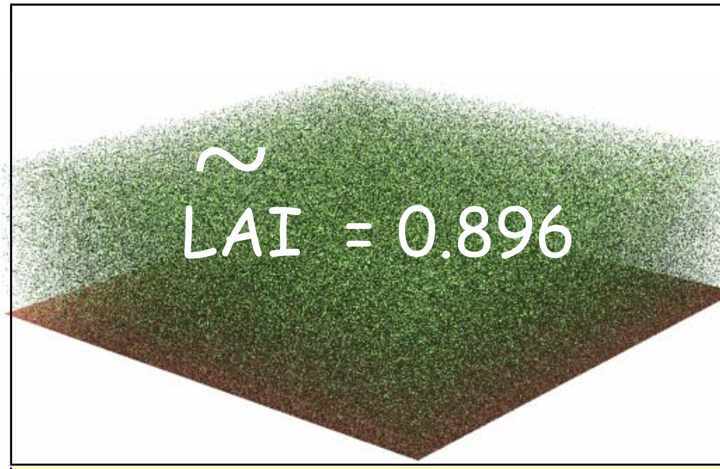
$$T_{1-D}^{direct}(<LAI>) = \exp\left(-\frac{<LAI>}{2\mu_0}\right) = 0.312$$

Ref: Pinty, B. (2006) Journal Geophysical Research

Effective state variable values ensure that 1-D fluxes are close to with 3-D fluxes.



3-D heterogeneous system



1-D system representation

$$\widetilde{LAI}(\mu_0) = \langle LAI \rangle \cdot \varsigma(\mu_0)$$

Estimates of the effective quantities

$\tilde{r}_l$ and $\tilde{t}_l$

are retrieved together from inversion of the R and Tdiff fluxes associated with the Black Background contribution from 3-D MC simulations.

$$\sum_{\mu_0} |\overline{R}_{veg}^{Coll}(z_{toc}, \mu_0; \mathbf{B}, \mathbf{O}, \mathbf{S}, LAI_{scene}) - \overline{R}_{veg}^{||Coll}(z_{toc}, \mu_0; \tilde{r}_l, \tilde{t}_l, \widetilde{LAI}(\mu_0)|$$

Reflected flux

$$\sum_{\mu_0} |\overline{T}_{bgd\mathbf{1}}^{Coll}(z_{bgd}, \mu_0; \mathbf{B}, \mathbf{O}, \mathbf{S}, LAI_{scene}) - \overline{T}_{bgd\mathbf{1}}^{||Coll}(z_{bgd}, \mu_0; \tilde{r}_l, \tilde{t}_l, \widetilde{LAI}(\mu_0)|$$

Transmitted flux

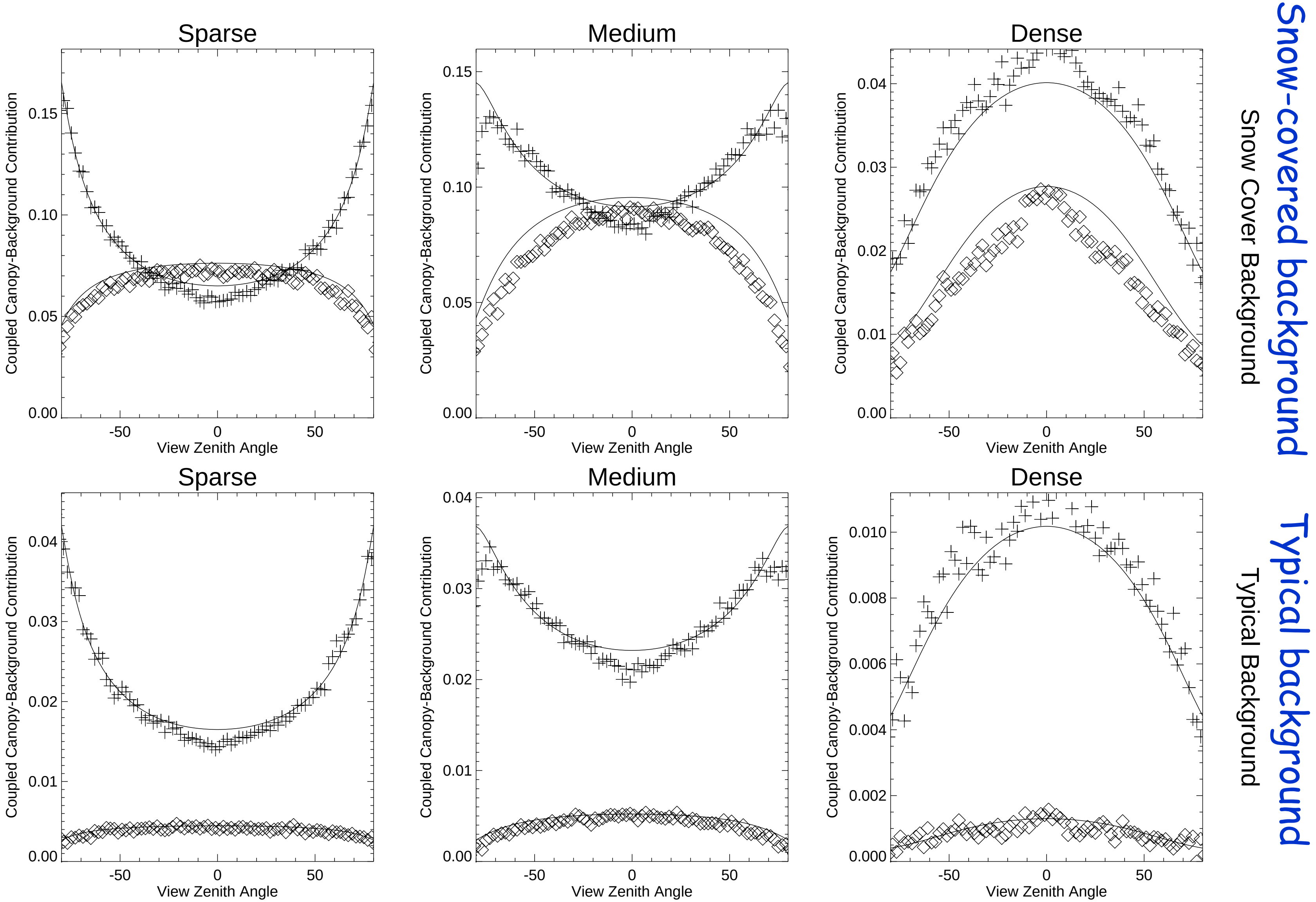
Ratio of effective (1-D)/true (3-D) values

Variable	Sparse	Medium	Dense
$\widetilde{LAI}$ (30°)	0.35	0.45	0.76
$\tilde{r}_l + \tilde{t}_l$ (NIR)	0.82	0.84	0.88
$\tilde{r}_l / \tilde{t}_l$ (NIR)	4.65	5.76	7.14

Effective variables are retrieved so that the 1-D model reproduces (at best) the 3-D MC fluxes.

Use the 1-D model for the estimation of directional intensities: **BRFs**

Performance of the analytical solution



Sun angle at 30 °

Final simplified expression for the radiance fields from any complex land surface

$$\rho^{total}_{coupled}(z_{toc}, \Omega, \Omega_0) \approx \rho^{Coll}_{veg}(z_{toc}, \Omega, \Omega_0; \mathbf{B}, \mathbf{O}, \mathbf{S}, LAI_{scene})$$
$$+\rho_0 [\breve{\rho}^{UnColl}_{bgd}(z_{toc}, \Omega, \Omega_0; \mathbf{B}, \mathbf{S}, LAI_{scene}, k, \Theta)$$
$$+\breve{\rho}^{||Coll}_{bgd}(z_{toc}, -\mu, \mu_0; \mathbf{B}, \tilde{\mathbf{O}}, \widetilde{LAI}_{scene}, k, \Theta, \rho_0)]$$

Monte Carlo solutions

Black Background

Black Canopy

Analytical 1-D solution

Multiply scattered with background

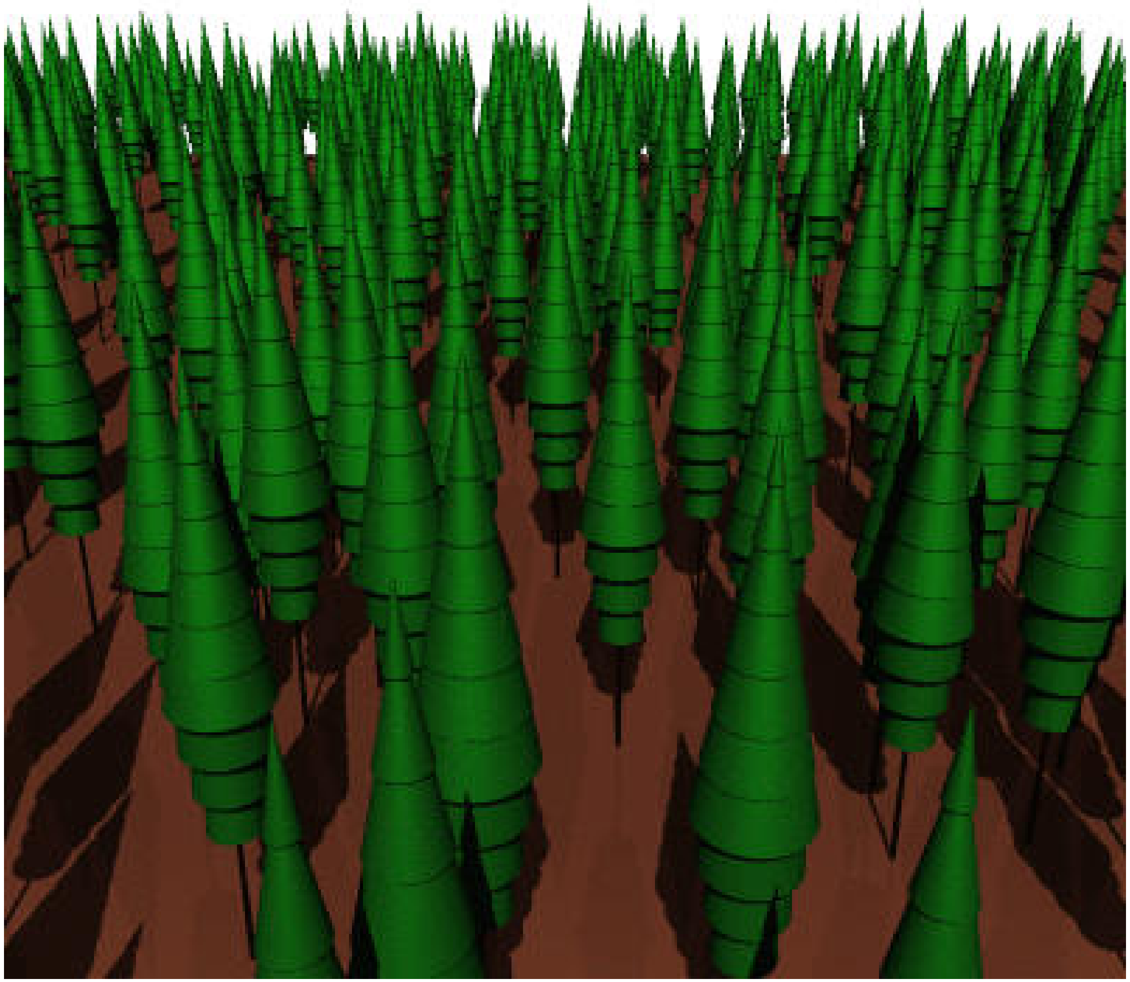
$$\breve{\rho}^{||Coll}_{bgd}(z_{toc}, -\mu, \mu_0; \mathbf{B}, \tilde{\mathbf{O}}, \mathbf{S}, \widetilde{LAI}_{scene}, k, \Theta, \rho_0) =$$
$$+\breve{\rho}^{||Coll}_{bgd\mathbf{1}}(z_{toc}, -\mu, \mu_0; \mathbf{B}, \tilde{\mathbf{O}}, \mathbf{S}, \widetilde{LAI}_{scene}, k, \Theta)$$
$$+\breve{\rho}^{||Coll}_{bgd\mathbf{n}}(z_{toc}, -\mu, \mu_0; \mathbf{B}, \tilde{\mathbf{O}}, \mathbf{S}, \widetilde{LAI}_{scene}, k, \Theta, \rho_0)$$

Ref: Pinty et al. (2004) Journal Geophysical Research, doi:10,1029/2004JD005214

Inversion strategy

- Use ecological knowledge, e.g., allometric equations to design a large set of canopy scenarios once for all (ref. Widlowski et al. (2003))

Examples of geophysical scenarios



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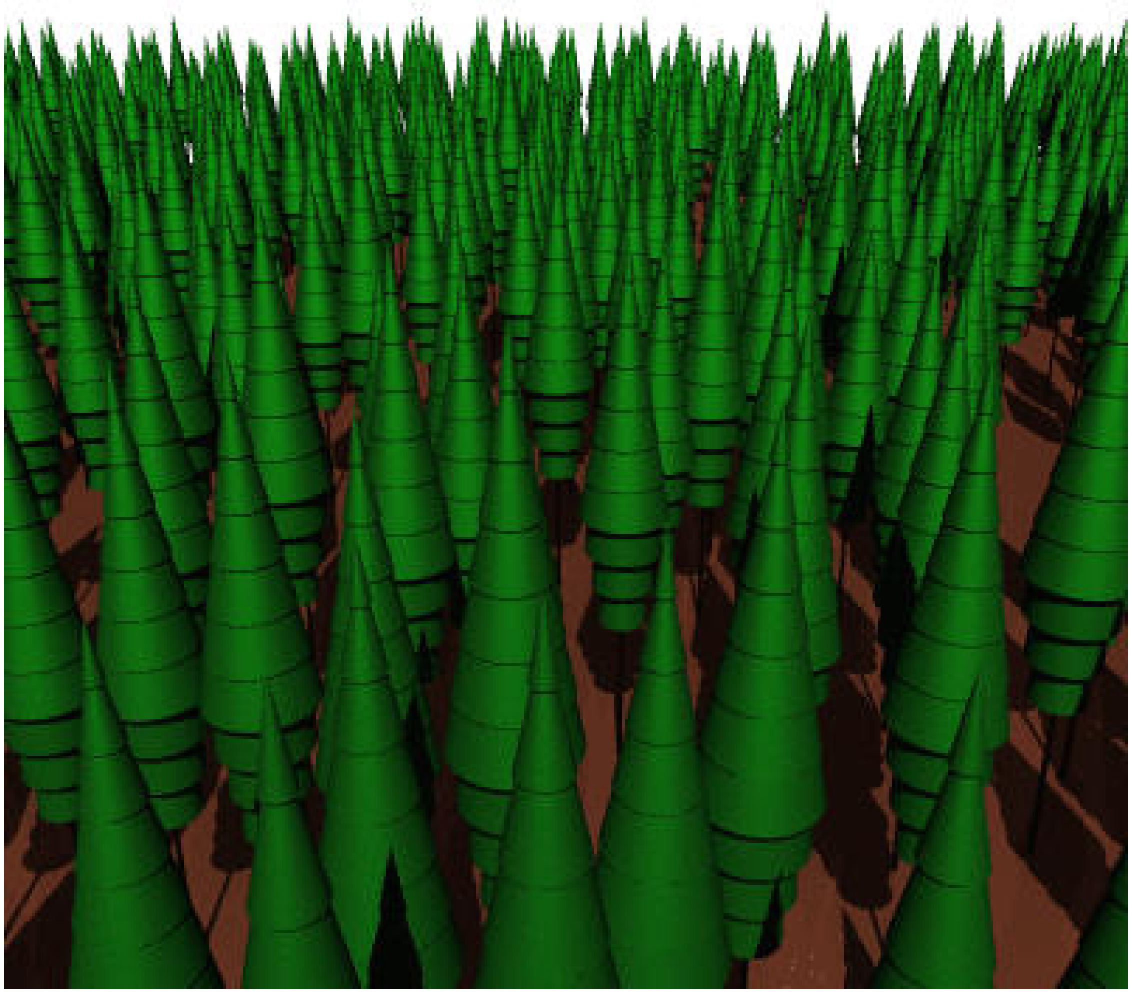

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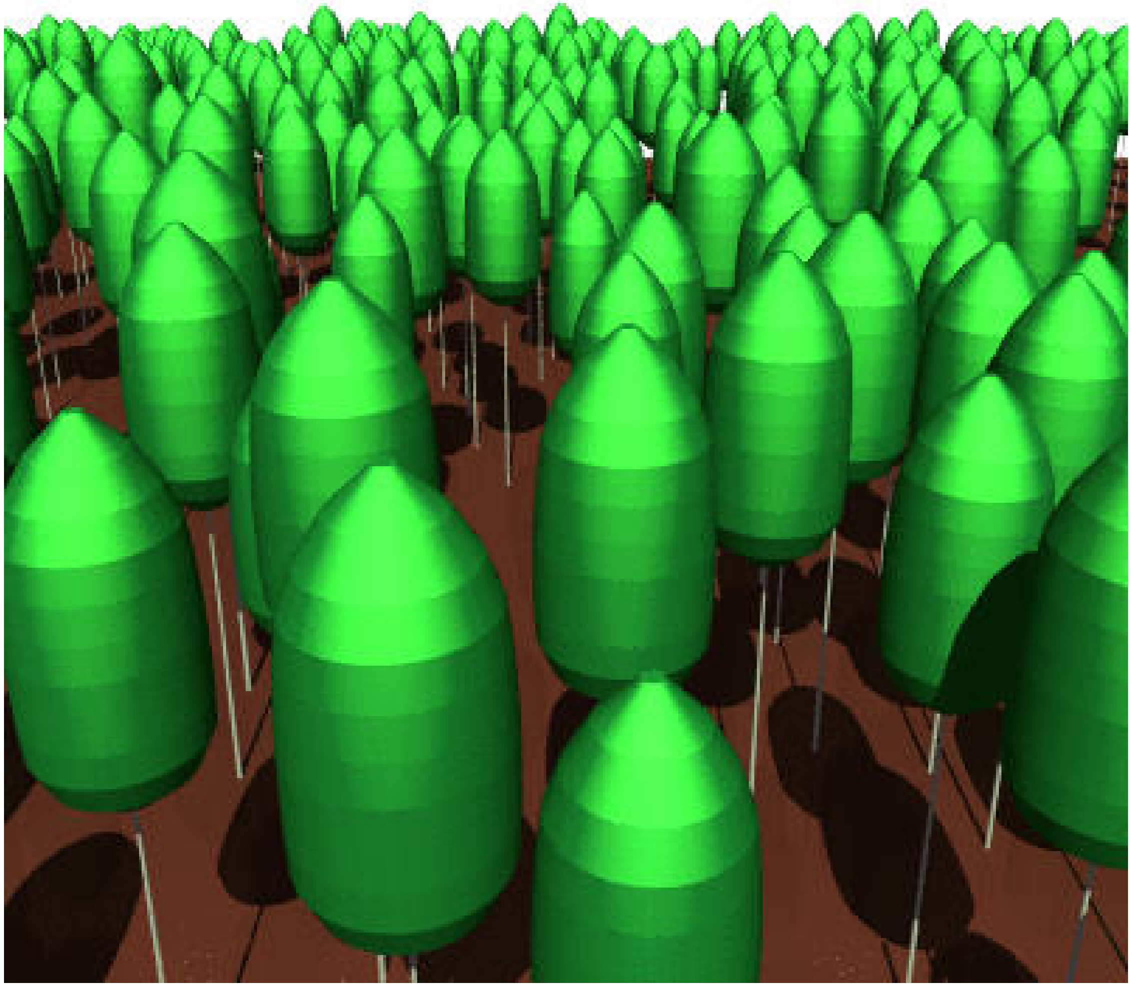

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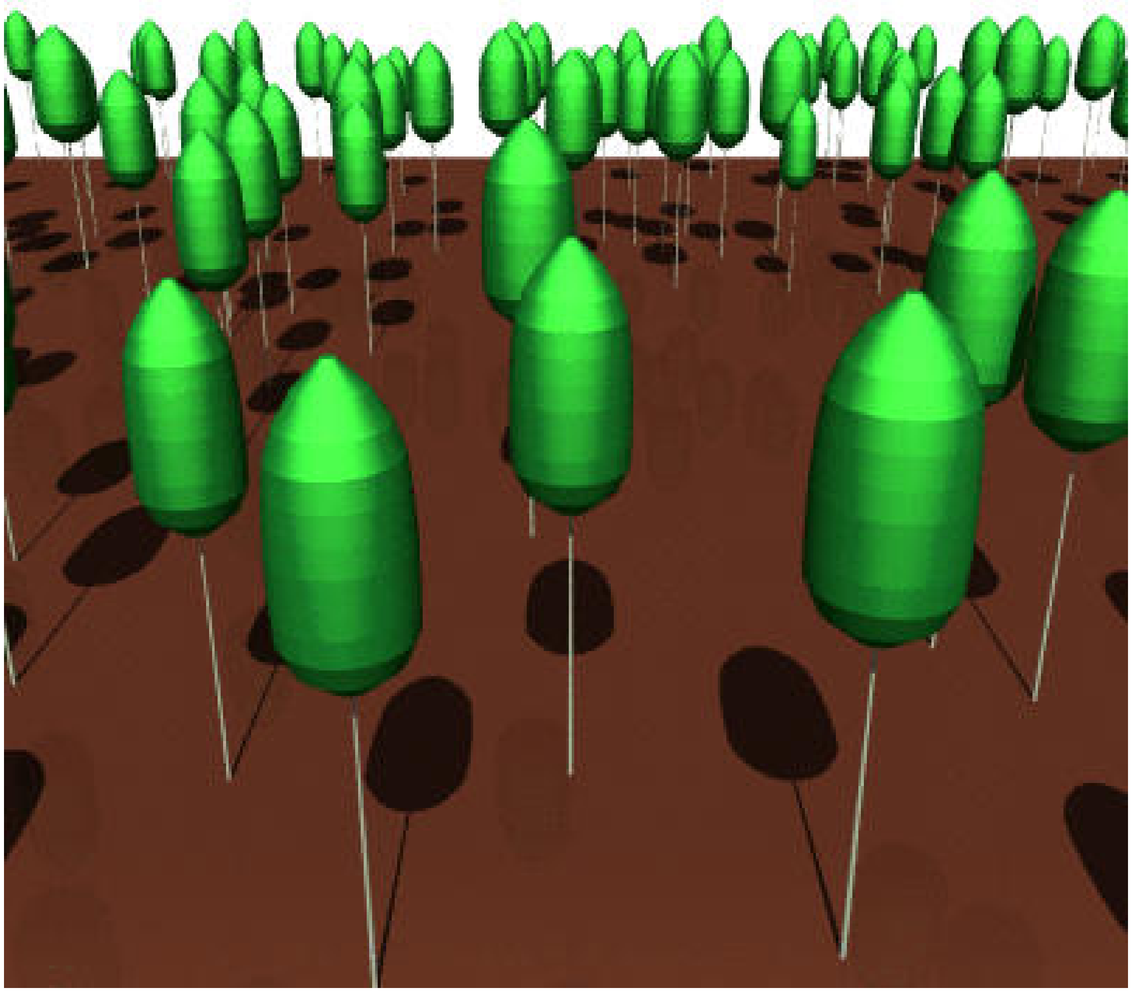

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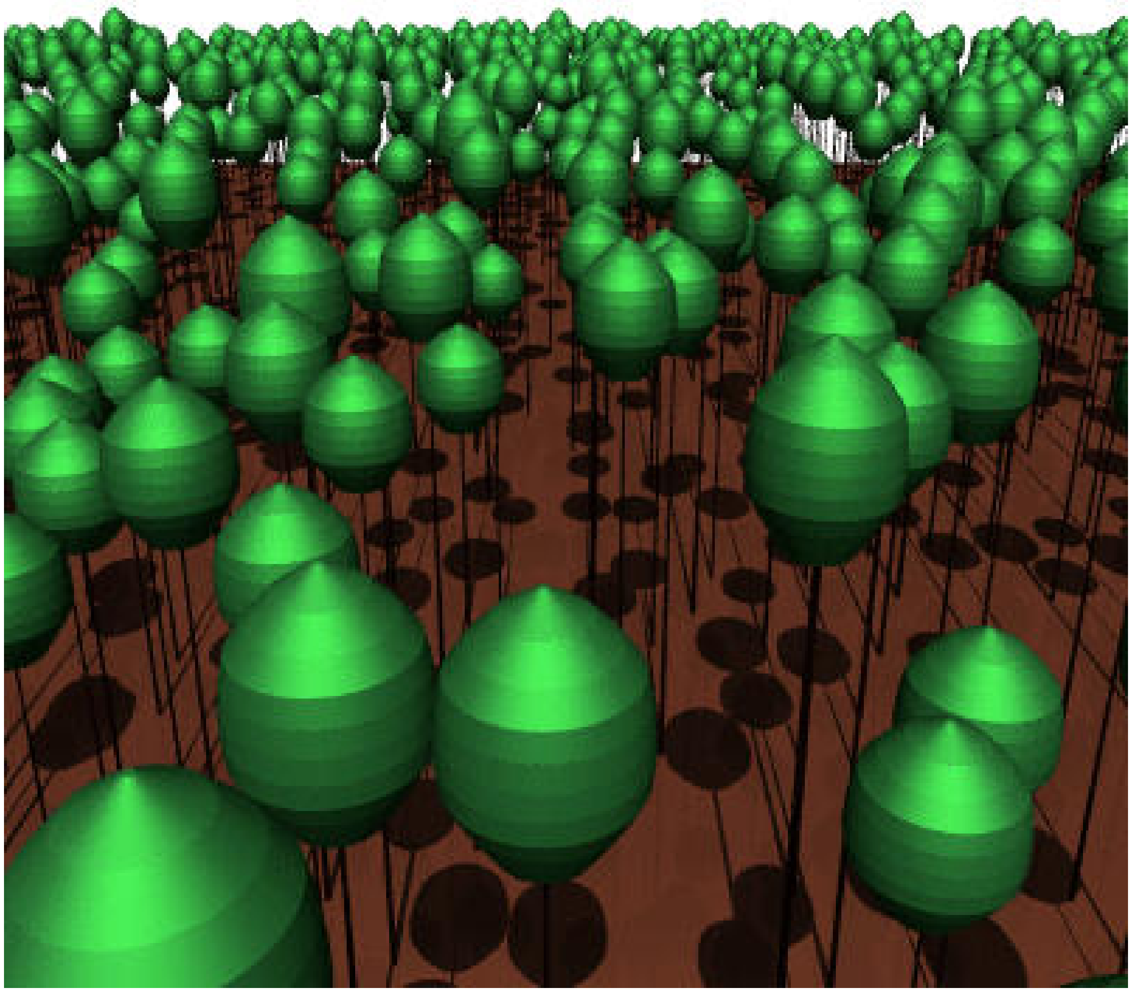

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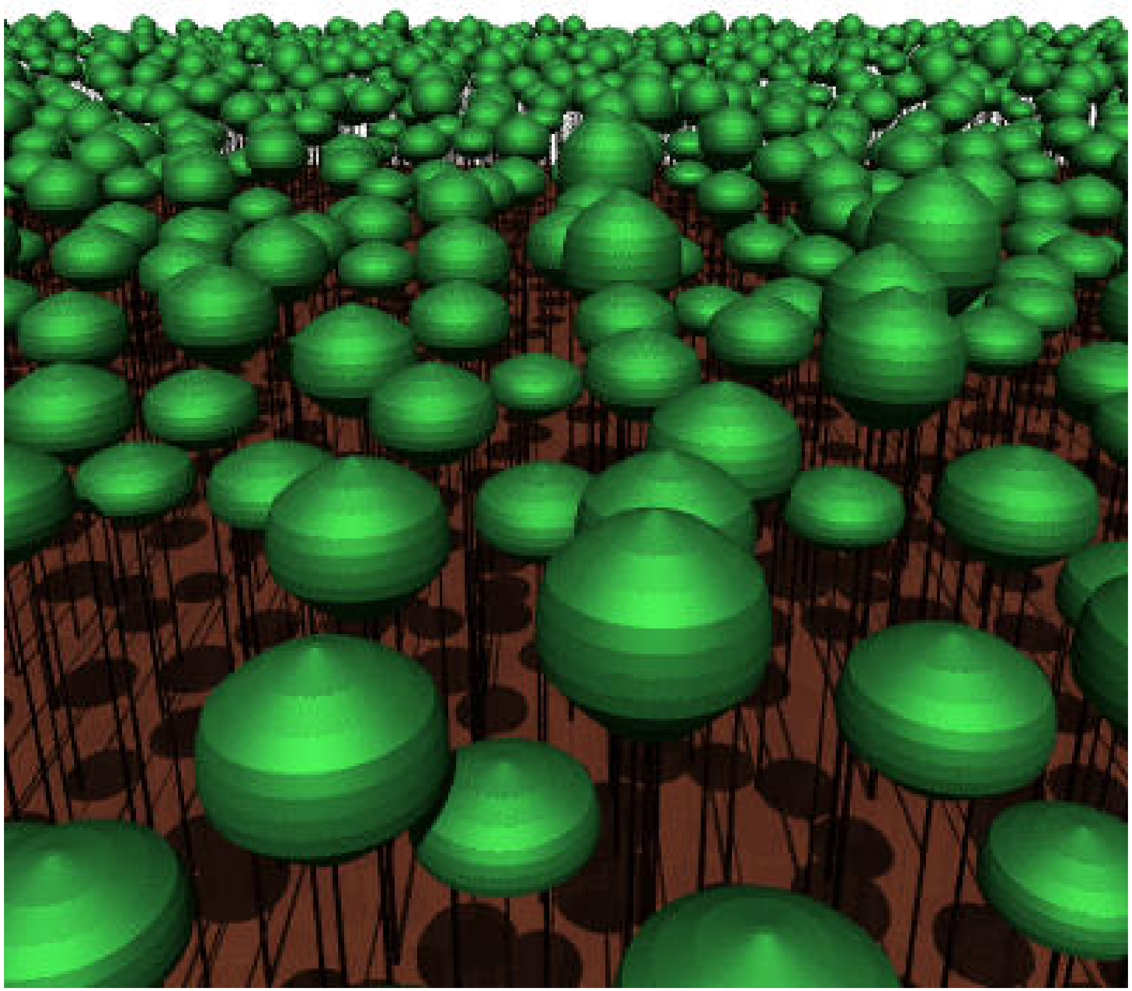

Inversion strategy

- Use ecological knowledge, e.g., allometric equations to design a large set of canopy scenarios once for all (ref. Widlowski et al. (2003))
- Estimate the Black Background and Black Canopy contributions associated with all scenarios: use 3-D MC simulations.
- Estimate the effective state variable values of the 1-D problem in order to simulate efficiently the vegetation-background coupled contribution (1-D model is faster).
- Adopt and inversion scheme minimizing the distance between measurements and simulations.

What did we gain?

- Inversion scheme based on limited MC simulations: Black Background and Black Canopy components only are requested.
- The background brightness value is solved as a continuous variable during the inversion.
- Allows detection of fast changes in the background conditions (e.g., snow and snow melting) and slow modifications in the canopy (e.g. LAI,…)

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Thank you... Questions?

bernard.pinty@jrc.it

http://www-gem.jrc.it/stars/