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

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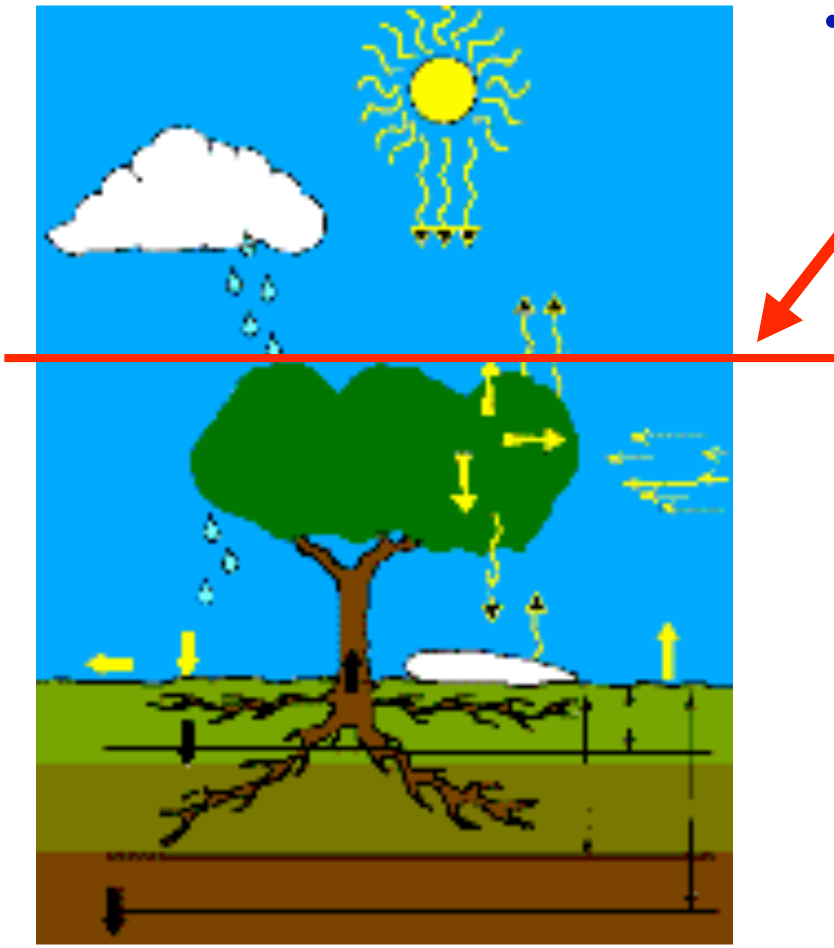
Institute for Environment and Sustainability

How does radiation redistribute energy between the atmosphere and the biosphere?

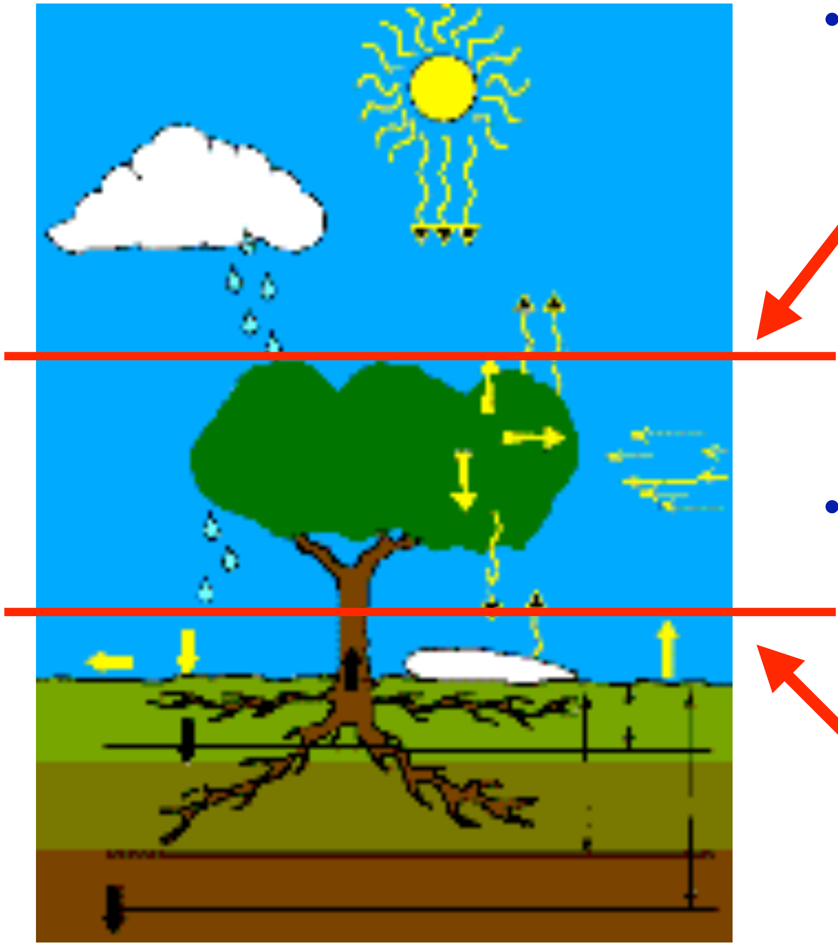


Ref: Bonan, G. B. (2002) Cambridge Univ. Press

- The “surface” corresponds to the boundary condition of RT atmospheric problem

Need to understand and represent the albedo of that “surface”

How does radiation redistribute energy between the atmosphere and the biosphere?



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- The "surface" corresponds to the boundary condition of RT atmospheric problem

Need to understand and represent the albedo of that "surface"

- The "surface" corresponds to the upper boundary condition of the vegetation plus soil RT and other problems

Need to understand and represent the RT processes yielding the distribution of energy below that "surface", e.g., transmitted fluxes

3-D structural effects and short term climate: the snow case with ECMWF/NCEP

e a r t h   o b s e r v a t o r y

FEATURES

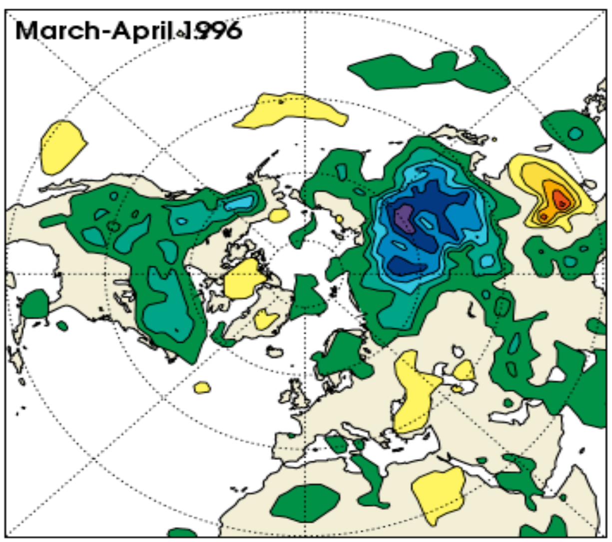
glossary on ◉ off ○

Ref: Viterbo and Betts, 1999, JGR

1 ◀ ▶ 3

Everyone Complains About the Weather...

Betts and his BOREAS colleagues observed that, in the spring, daily weather forecasts significantly underestimated air temperatures over the boreal forest, sometimes by as much as 10—15°C (18—27°F) (Viterbo and Betts, 1999). Additionally, the BOREAS team found that predictions of cloud cover over the boreal region were often far off the mark. Everyone complains about the weather, but how could the forecasts be so wrong so often?



This map shows the average errors in the European Centre for Medium-Range Weather Forecasts at 850mb (roughly equivalent to an altitude of 1500m) for March and April of 1996. The predictions, made five days in advance, were compared to actual measurements. The 1996 model did not include the adjustments to forest albedo.

(Figure from Viterbo, P. and A.K. Betts, 1999: The impact on ECMWF forecasts of changes to the albedo of the boreal forests in the presence of snow. J. Geophys. Res. (In press, BOREAS special issue). Courtesy A.K. Betts)

Forecast Errors (°C)

-7 -5 -3 +1 +3 +5

The scientists noticed a pattern that confirmed their earlier suspicions: the temperature forecasts were farthest off in late spring when snow was on the ground and grew more accurate after the snow melted. From summer through fall, the weather models matched actual measurements more

"...weather forecasts significantly underestimated air temperatures over boreal, sometimes by as much as 10-15 C..."

Ref: http://eobglossary.gsfc.nasa.gov/

3-D structural effects and short term climate: the snow case with ECMWF/NCEP

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glossary on ◉ off ○

FEATURES

Everyone Complains About the Weather...

1 ◀ ▶ 3

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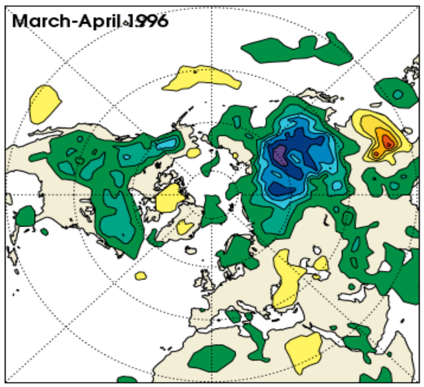

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"...—the BOREAS team found that the models were overestimating **albedo** (the amount of **light** reflected by the surface). ..."

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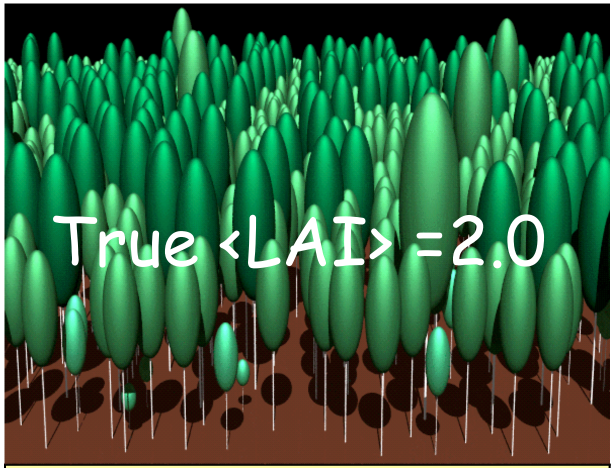
Using "true", i.e., domain-averaged, optical depth and other true radiation transfer (RT) state variables (<X>) in a 1D RT scheme can only yield seriously erroneous radiant flux estimates



3-D heterogeneous system

Direct transmission at 30 degrees Sun zenith angle,

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

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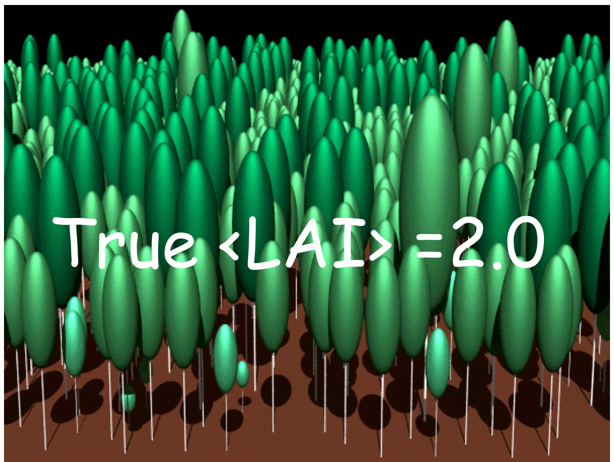


3-D heterogeneous system

Absorption in the visible (PAR) domain

1-D 2-stream model

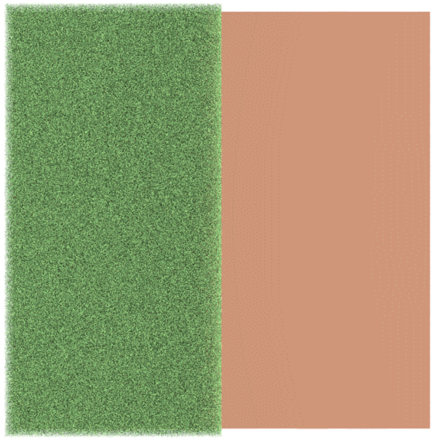
3-D MC model

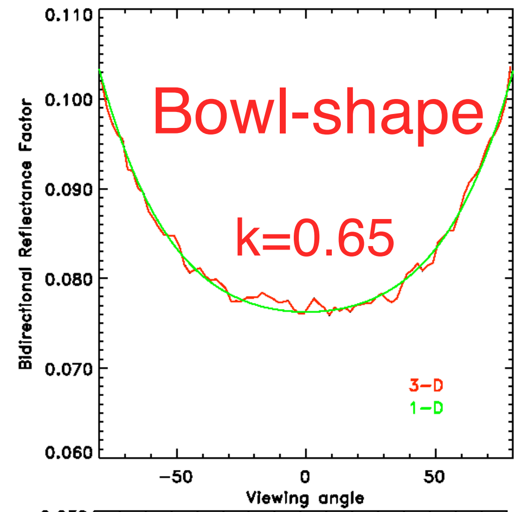
Albedo (DHR) in the near-infrared domain

1-D / 2-stream model

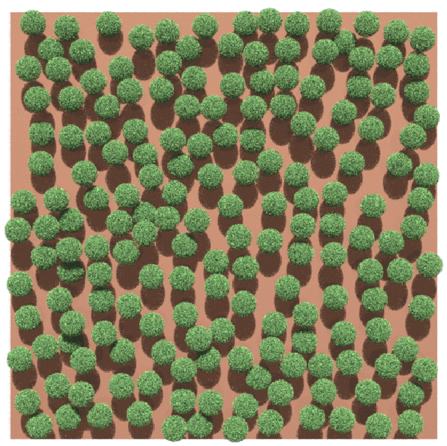
3-D MC model

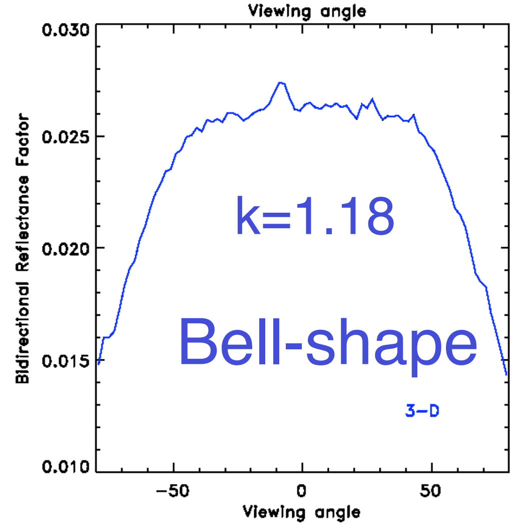
Angular signatures in the red region





1-D

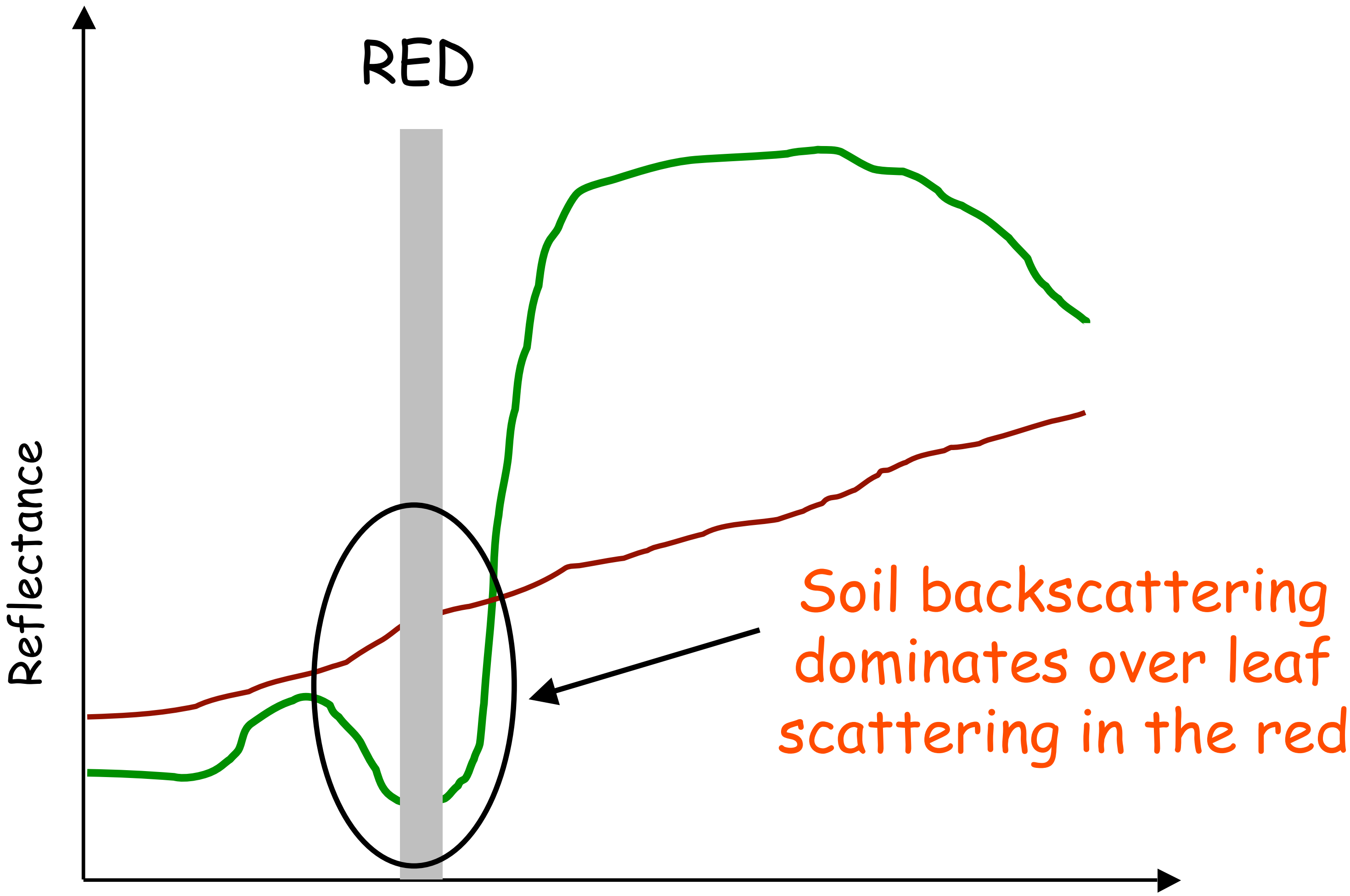




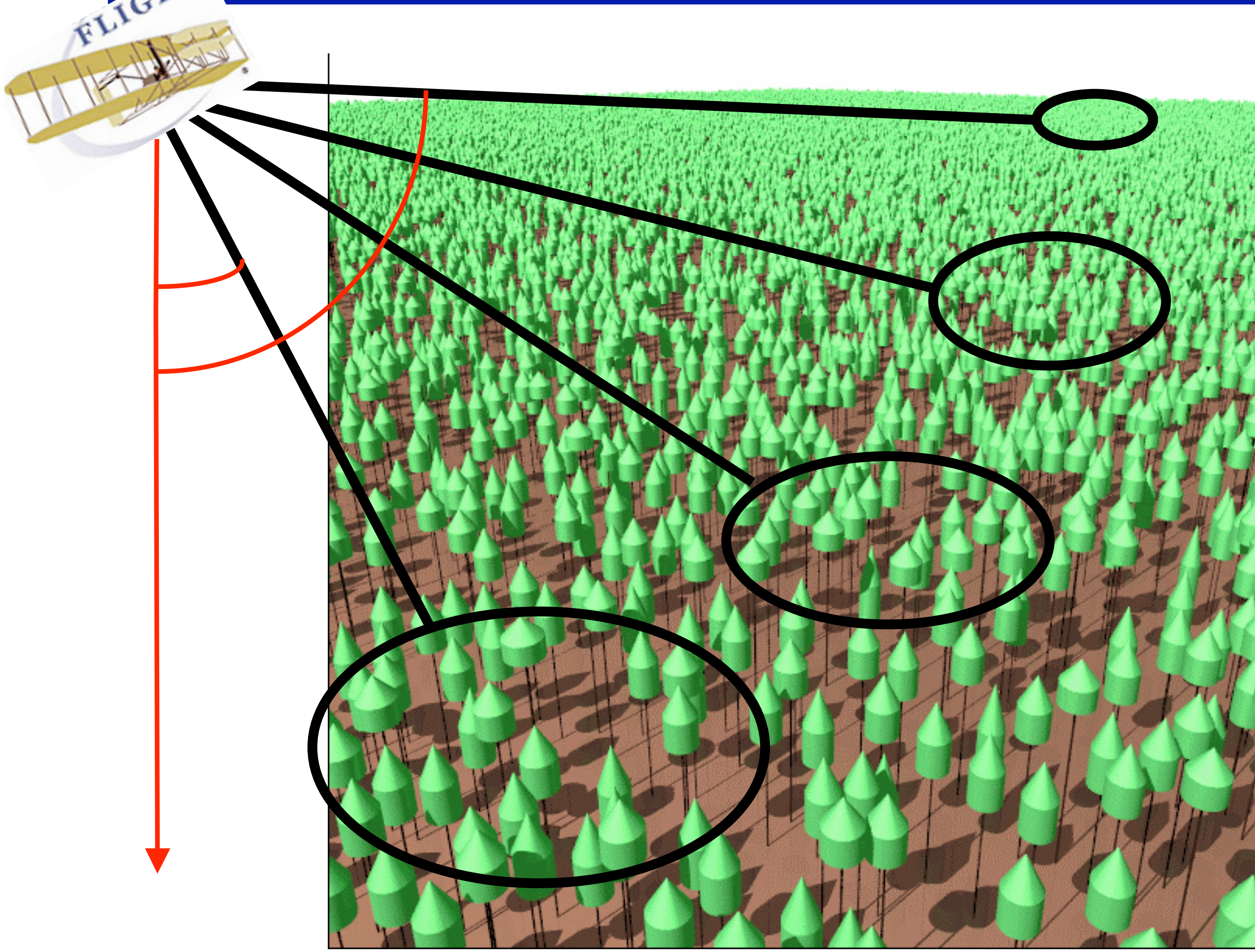
3-D

Ref: Pinty et al. (2002) IEEE TGRS

Spectral contrast between the vegetation canopy and the background



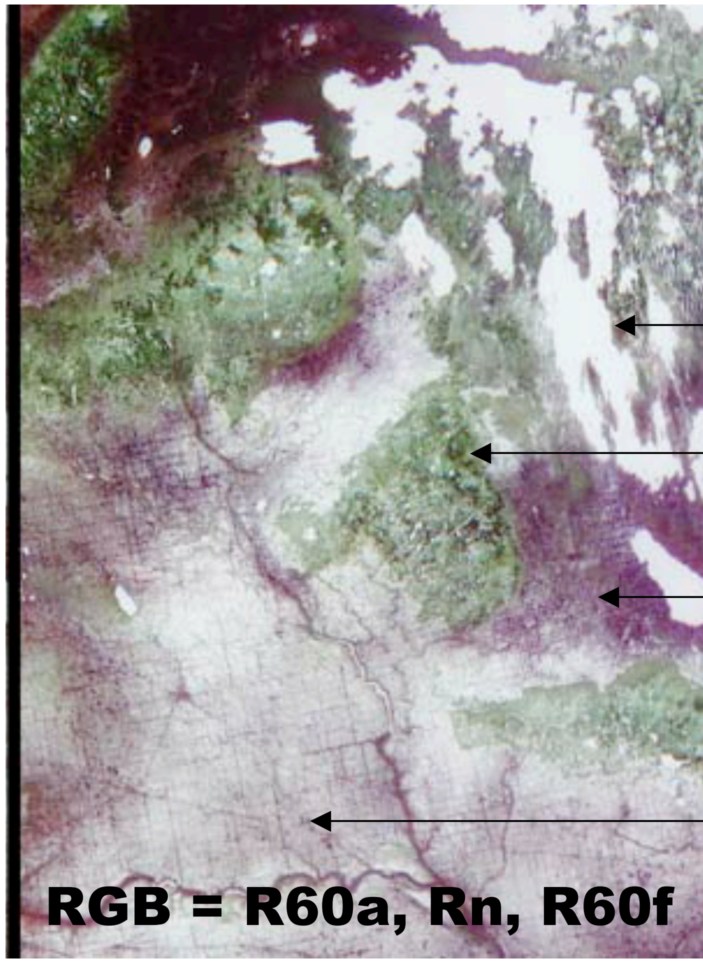
Multiangle views for surface structure



Surface structure from MISR/Terra

Saskatchewan and Manitoba

April 17, 2001



Snow

Forests

Agriculture

Roads

N

285 km

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

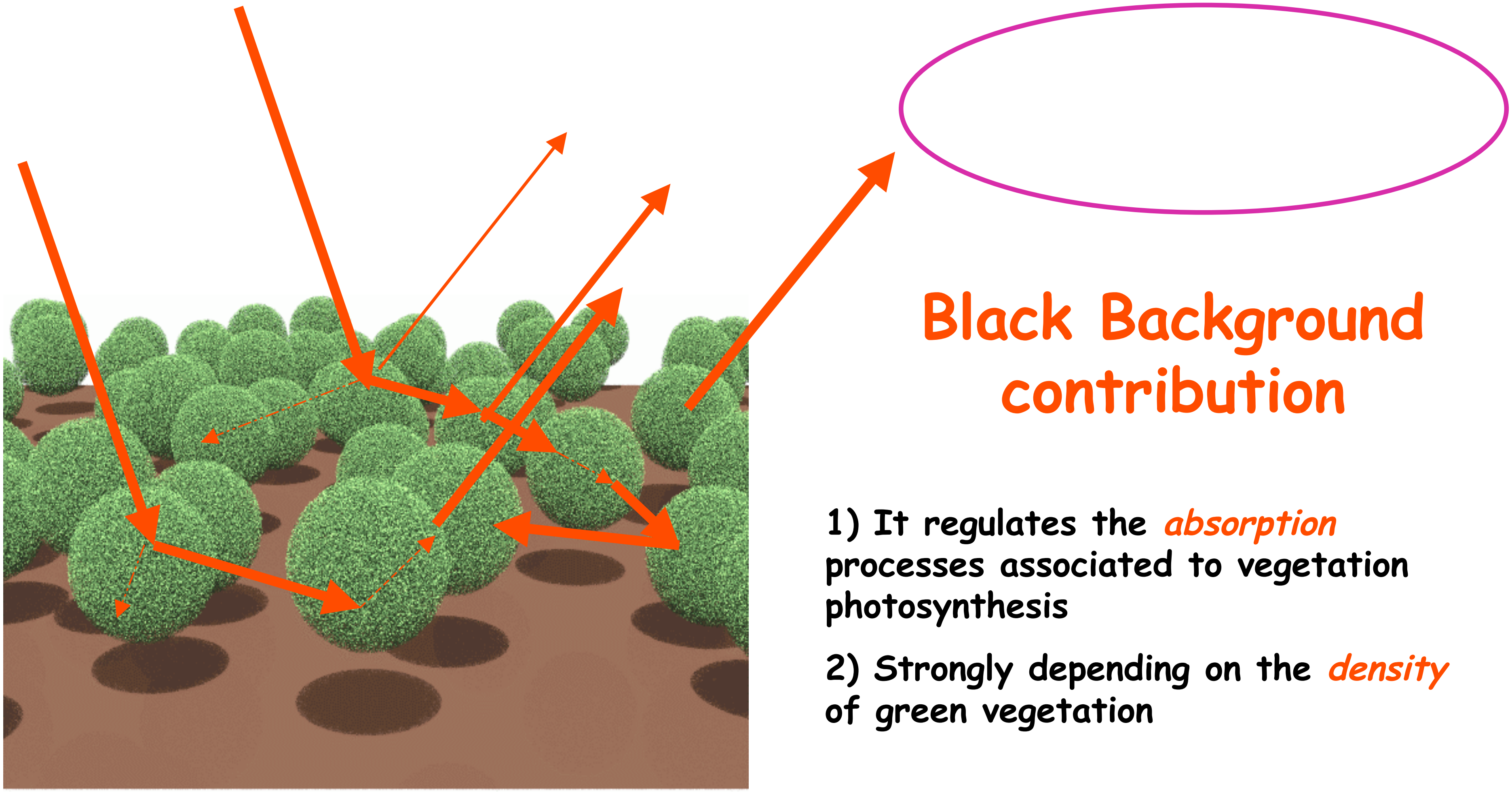
Main objective

- Retrieve information on state variables from 3-D vegetation systems such as forests while preserving the integrity of the structural effects.

Approach

- Optimize the use of 3-D MC simulations for the most significant structure-induced effects
- Couple with 1-D equivalent RT solutions for the less contributing factors

Decompose the complex problem into simpler problems to solve

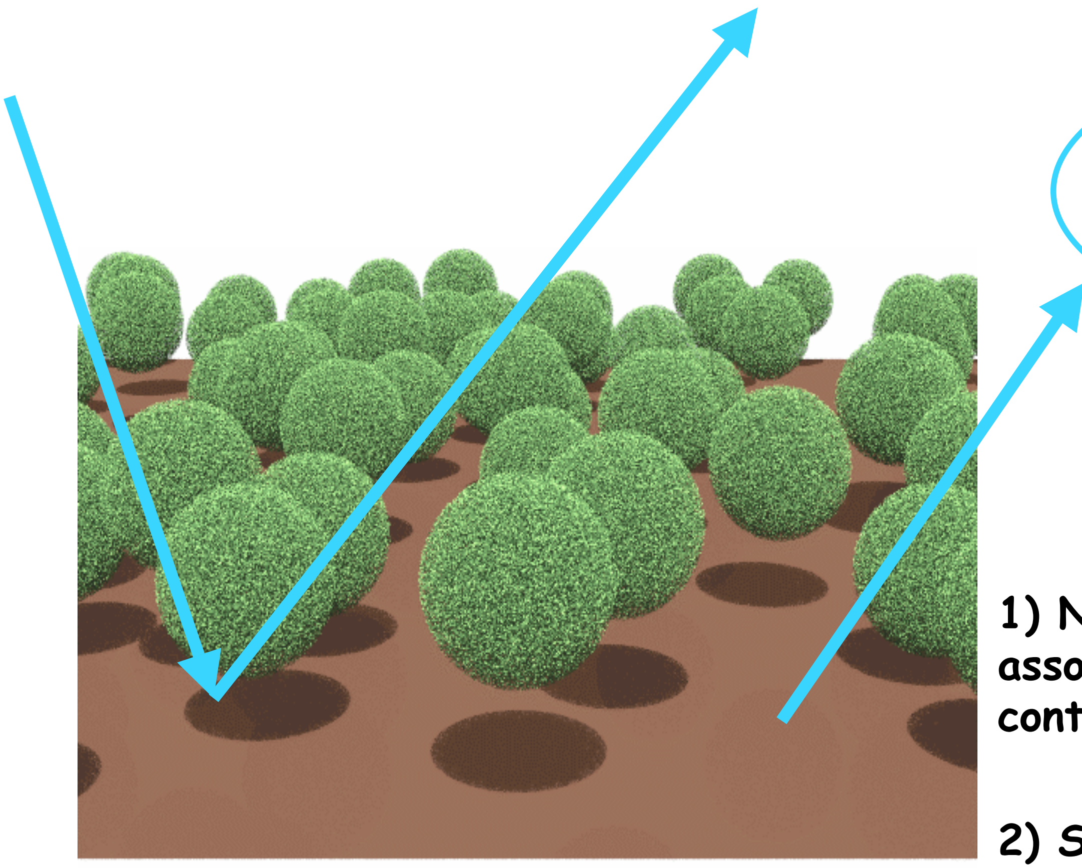


Black Background contribution

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

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

Decompose the complex problem into simpler problems to solve

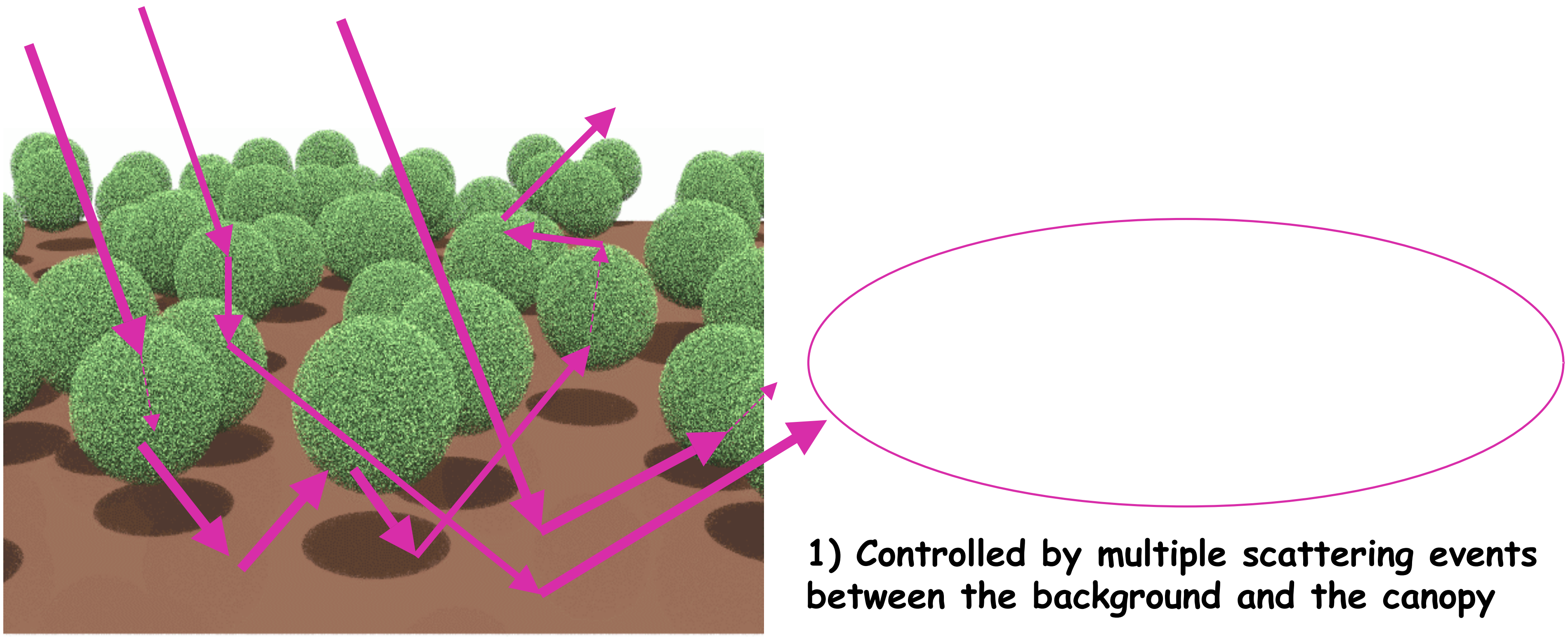


Black Canopy contribution

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

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

Decompose the complex problem into simpler problems to solve



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

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

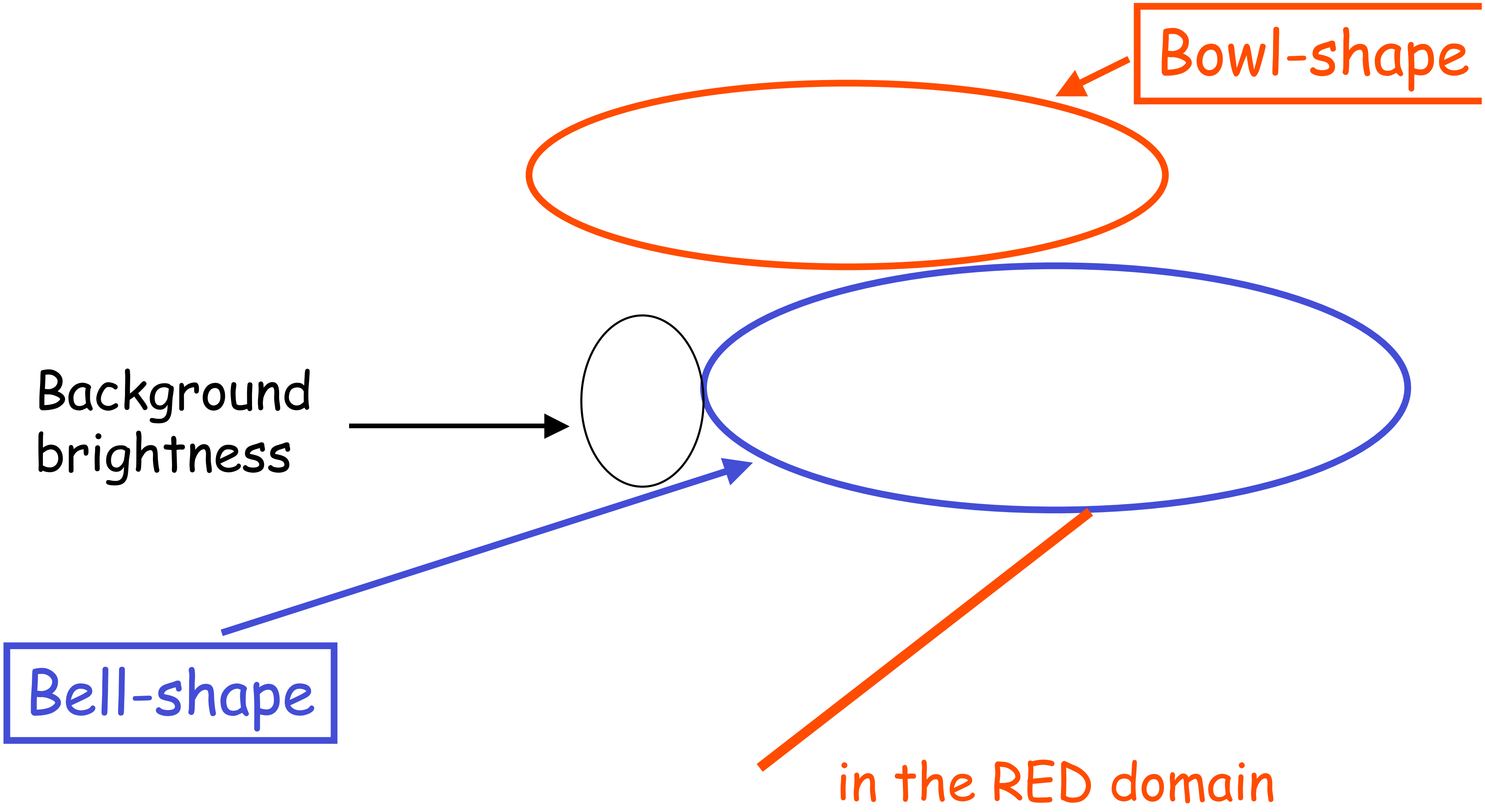
Snow cover **Near-Infrared** **Red**

Black Background contribution

Black Canopy contribution

Multiple Collided contribution with backgound

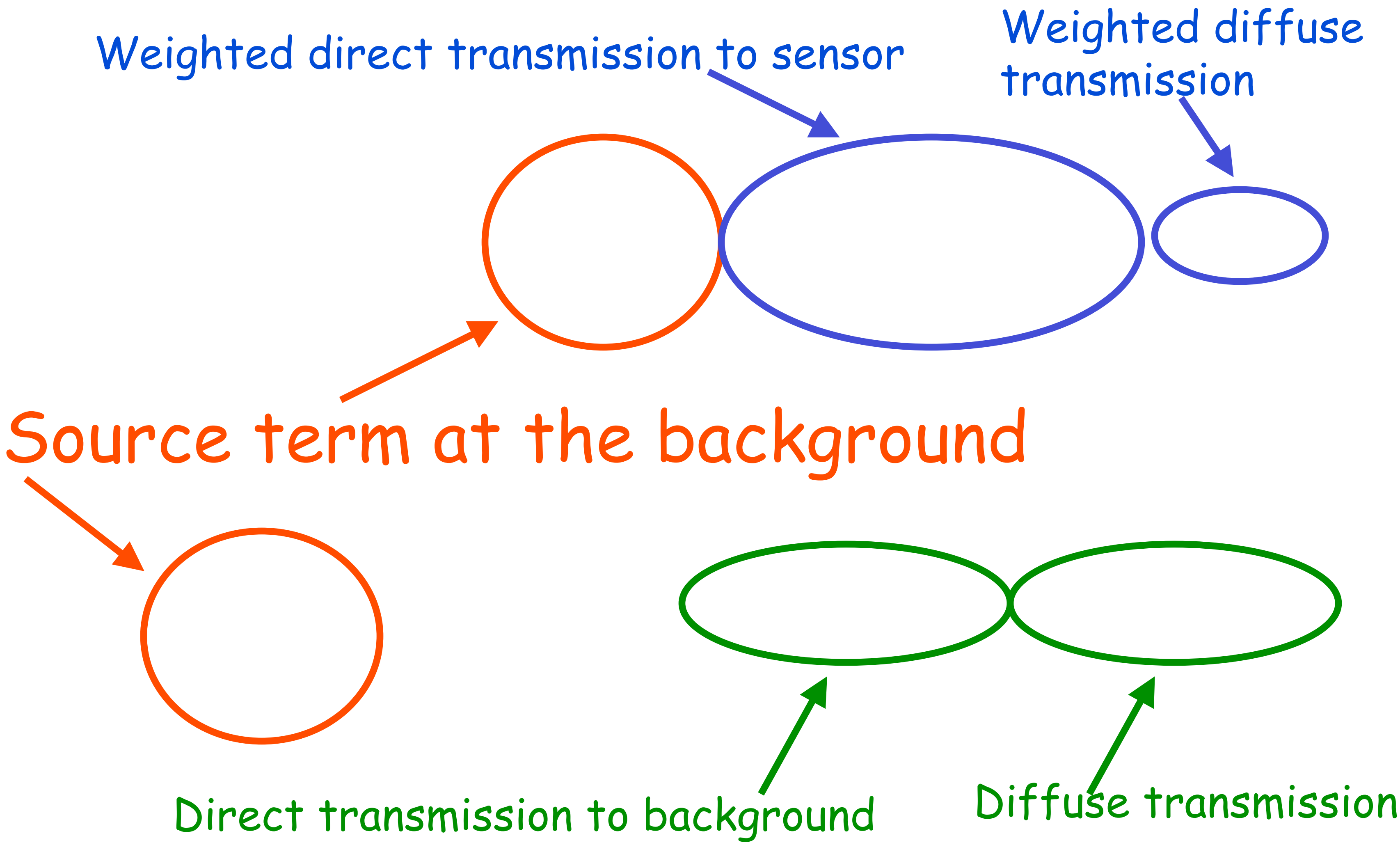
Decompose the complex problem into simpler problems to solve



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

1. Use azimuthal average of the diffuse radiance fields scattered by the background
2. Assume a homogeneous plane-parallel turbid medium based representation

Parameterization of the equivalent turbid medium layer: All scattering orders >1 with the background



Parameterization of the equivalent turbid medium layer: First order of scattering with the background

$$\breve{\rho}^{||Coll}_{bgd\mathbf{1}}(z_{toc}, -\mu, \mu_0) \approx \exp(-\widetilde{LAI}/2\,|\mu|)\, f_0(-\mu, \mu_0)$$
$$+ \exp(-\widetilde{LAI}/2\,\mu_0)\, g_0(-\mu, \mu_0)$$
$$+ h_0(-\mu, \mu_0)$$

Direct transmissions with effective LAI value

Azimuthal average of diffuse transmission

Azimuthal average of background BRF shape

Requirements from a 1-D turbid medium

- 3 (effective) state variables:

1. *Optical depth: LAI*
2. *single scattering albedo :*
   Leaf reflectance+ Leaf transmittance
3. *asymmetry of the phase function*
   Leaf reflectance/transmittance

- 2 boundary conditions:

1. *Top: Downward flux from the atmosphere*
2. *Bottom : Upward flux from the background*

Estimates of the effective radiative quantities

$\widetilde{LAI}$

is retrieved from inversion of the exponential attenuation law against Black Canopy (wavelength -independent) contribution from 3-D simulations

$\widetilde{LAI}$

$\widetilde{LAI}$ is lower than the true domain-averaged

Estimates of the effective radiative quantities

$\sim$ and $\sim$

are retrieved from inversion of the R and Tdiff fluxes associated with the Black Background contribution from 3-D simulations and given $\widetilde{LAI}$

Reflected flux

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

Diffuse flux

Ratio of effective/true domain-averaged values

Variable	Sparse	Medium	Dense
$\widetilde{LAI}$	0.35	0.45	0.76
$\sim$ + $\sim$ (NIR)	0.82	0.84	0.88
$\sim$ / $\sim$ (NIR)	4.65	5.76	7.14

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 solution

Multiply scattered with background

Performance of the analytical solution

Snow-covered background

Typical background

Sun angle at 30 °

Performance of the analytical solution

Snow-covered background

Typical background

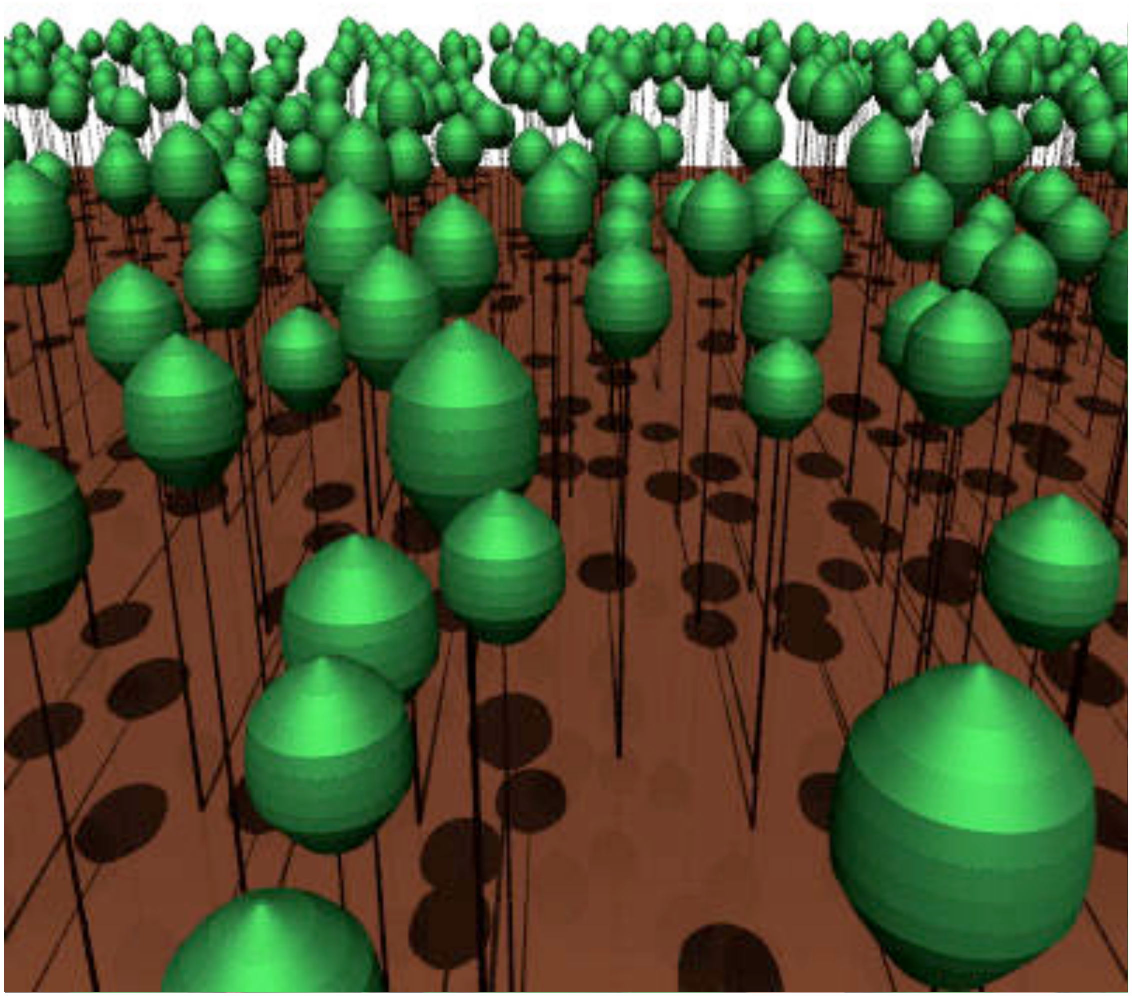
Sun angle at 60 °

Performance of the analytical solution

Inversion strategy

- Use ecological knowledge, e.g., allometric equations to design a large set of canopy scenarios once for all: take advantage of RAMI results

Examples of geophysical scenarios



Inversion strategy

- Use ecological knowledge, e.g., allometric equations to design a large set of canopy scenarios once for all: take advantage of RAMI results
- 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 : LAI from the Black Background and rl and tl from the Black Canopy contributions
- Adopt and inversion scheme minimizing the distance between measurements and simulations: Adjoint model of the 1-D representation

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 us adding constraints on the Black Canopy contribution as a function of time

- Allows detection of fast changes in the background conditions, e.g., snow and snow melting