EUROPEAN COMMISSION
DIRECTORATE-GENERAL
Joint Research Centre

MITIGATING BRAIN DAMAGES ASSOCIATED WITH THE USE OF VEGETATION INDICES

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5th ESA EO Summer School on Earth System Monitoring and Modelling

August 2-13, 2010, ESRIN

Frascati, Italy

Joint Research Centre

Institute for Environment and Sustainability

Our road map

- Today (10.00- 11.00):

Context: **Science issues and caveats, challenges to face.**

- Today (12.30- 13.30):

Tools: **Doing the right thing!**

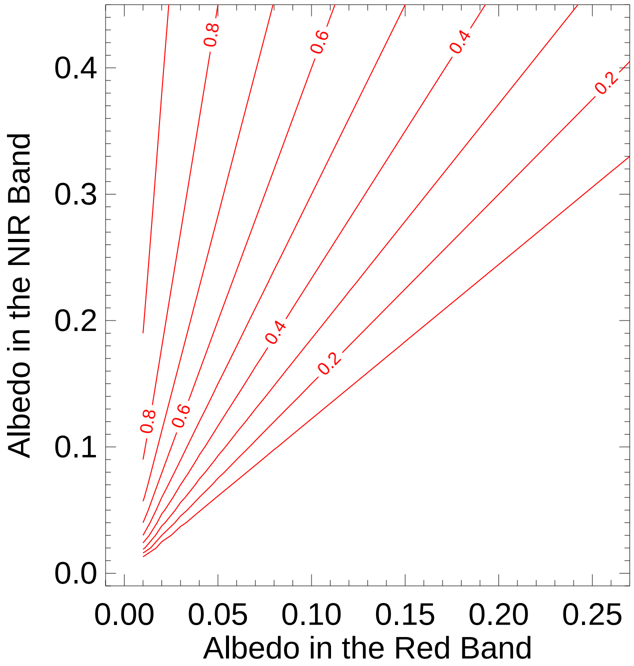
- Tomorrow (10.00- 11.00):

Applications: **Partitioning of Solar fluxes in Land Surface Canopies based on operational ESA and NASA products**

BASICS ABOUT NDVI

- NDVI is defined as

$$NDVI = \frac{R(\lambda_{NIR}) - R(\lambda_{RED})}{R(\lambda_{NIR}) + R(\lambda_{RED})}$$

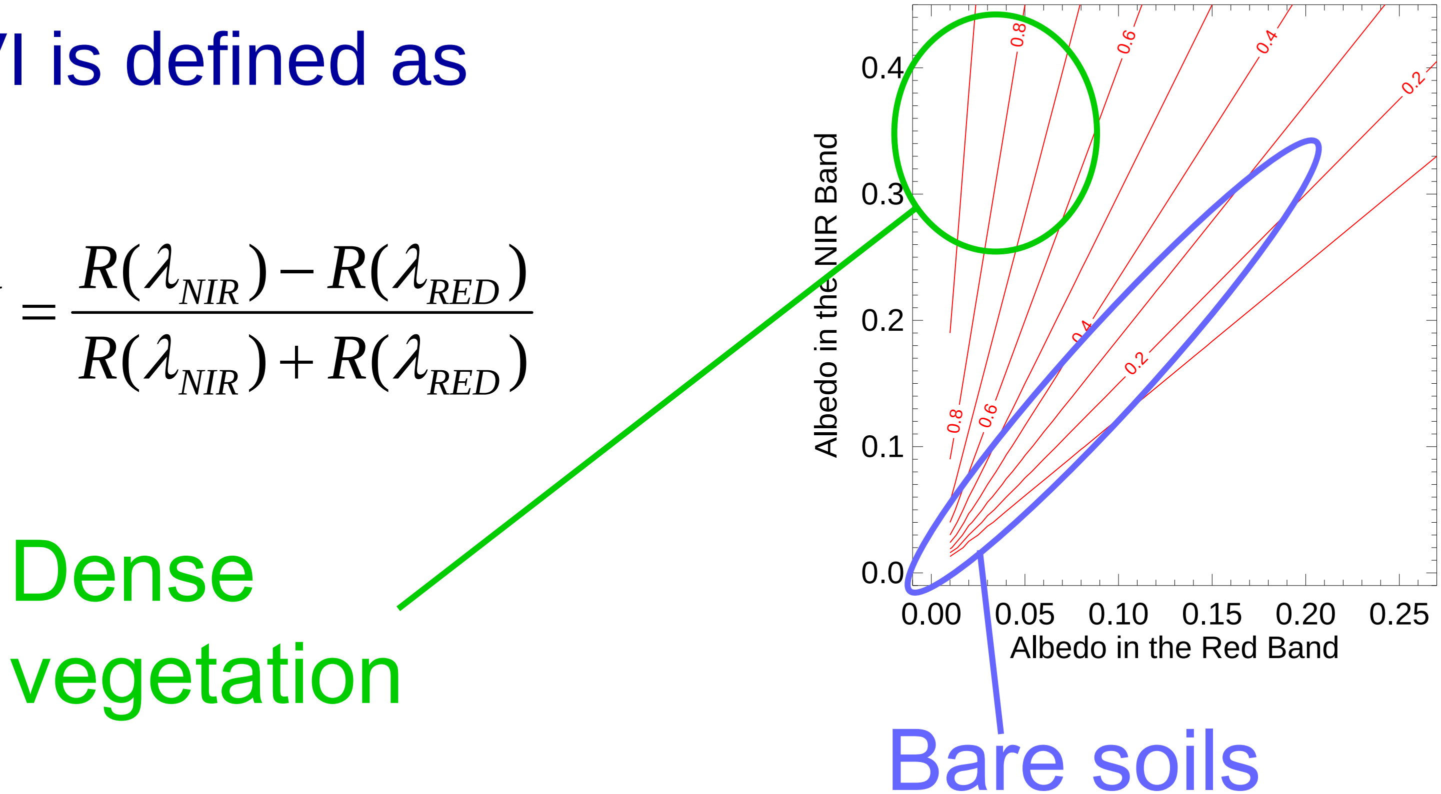


- Historically NDVI
  - was introduced to exploit early (2-bands) sensors such as ERTS and AVHRR
  - is neither a geophysical variable nor optimized for any particular purpose

BASICS ABOUT NDVI

- NDVI is defined as

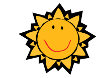
$$NDVI = \frac{R(\lambda_{NIR}) - R(\lambda_{RED})}{R(\lambda_{NIR}) + R(\lambda_{RED})}$$



- Proper interpretation:

  The higher the NDVI, the higher the probability that the target contains vegetation

Land-atmosphere coupling problem



$$I^{\uparrow}(z_{top},\Omega_0,\Omega;\tau_a,\vec{p}_a,\gamma_s,\vec{p}_s) \qquad I^{\downarrow}(z_{top},\Omega')=I_0\delta(\Omega'-\Omega_0)$$

z_{top}

Atmosphere

$$\begin{aligned}
I^{\downarrow tot}(z_0,\Omega_0,\Omega';\tau_a,\vec{p}_a,\gamma_s,\vec{p}_s) = {} & I^{\downarrow dir}(z_0,\Omega_0,\Omega';\tau_a,\vec{p}_a) \\
& + I_B^{\downarrow diff}(z_0,\Omega_0,\Omega';\tau_a,\vec{p}_a) \\
& + I_{ms}^{\downarrow diff}(z_0,\Omega_0,\Omega';\tau_a,\vec{p}_a,\gamma_s,\vec{p}_s)
\end{aligned}$$

z_0

$$I^{\uparrow}(z_0,\Omega_0,\Omega;\tau_a,\vec{p}_a,\gamma_s,\vec{p}_s) = \frac{1}{\Pi}\int_{2\Pi^-}\gamma_s(z_0,\Omega'\rightarrow\Omega;\vec{p}_s).I^{\downarrow tot}(z_0,\Omega_0,\Omega';\tau_a,\vec{p}_a,\gamma_s,\vec{p}_s)\,|\mu'|\,d\Omega'$$

All quantities are monochromatic

BASICS ABOUT NDVI

- NDVI is sensitive to various perturbing effects:
  -

- Numerous attempts to modify the formula:
  -

BASICS ABOUT NDVI

- Vegetation indices have been largely (ab)used by attempting to correlate them with LAI, FAPAR, biomass, precipitations, herbivore density, economical indicators, etc…

- When applied to data from different sensors, they formulae yield incompatible results because of differences in:
  -

- All these drawbacks have long been exhaustively described in the literature

Vegetation Indices: questions & issues

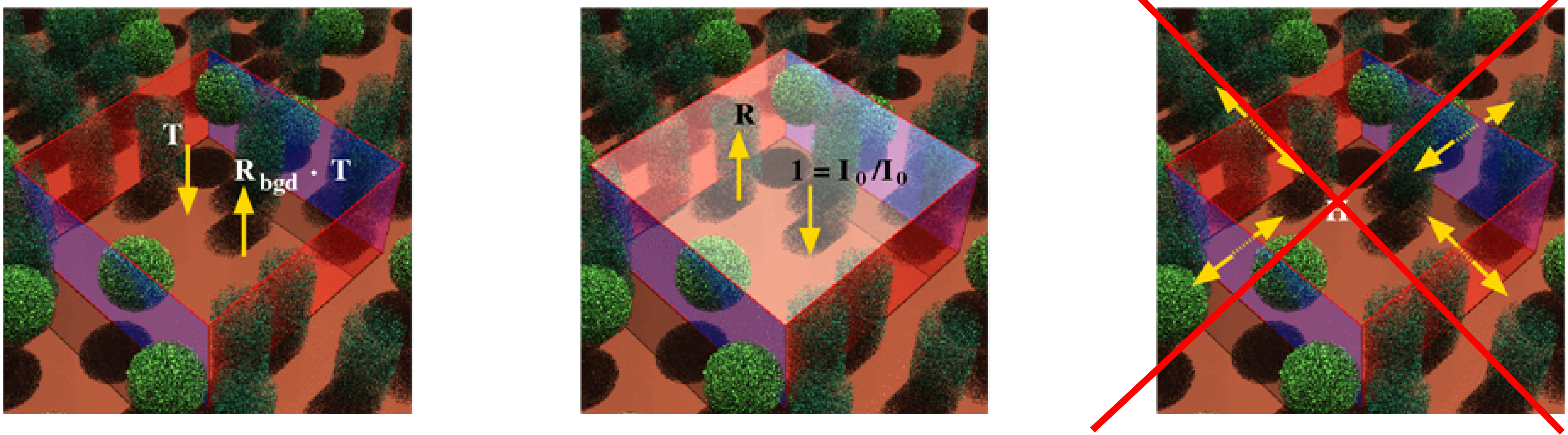
- Why do we need two bands and in particular the NIR band?

- VIs reduce two observations to one single value

  → increases number of unknowns and the inverse problem is more seriously ill-posed.

Scale analysis: energy conservation

fluxes at canopy/soil boundary — fluxes at canopy/atmosphere boundary — fluxes at lateral canopy boundaries



$$1 + R_{bgd}(\lambda) \times T(\mu_0, \lambda) = A(\mu_0, \lambda) + [R(\mu_0, \lambda) + T(\mu_0, \lambda)] + H(\mu_0, \lambda)$$

$[R(\mu_0, \lambda) + T(\mu_0, \lambda)]$ canopy albedo + total transmission

$R_{bgd}(\lambda)$ background albedo

$A(\mu_0, \lambda)$ canopy absorption

$H(\mu_0, \lambda)$ net horizontal flux

Two-stream model parameters

- 3 (effective) parameters of the canopy:

Leaf Area Index *amount of leaf material*

Canopy reflectance + transmittance

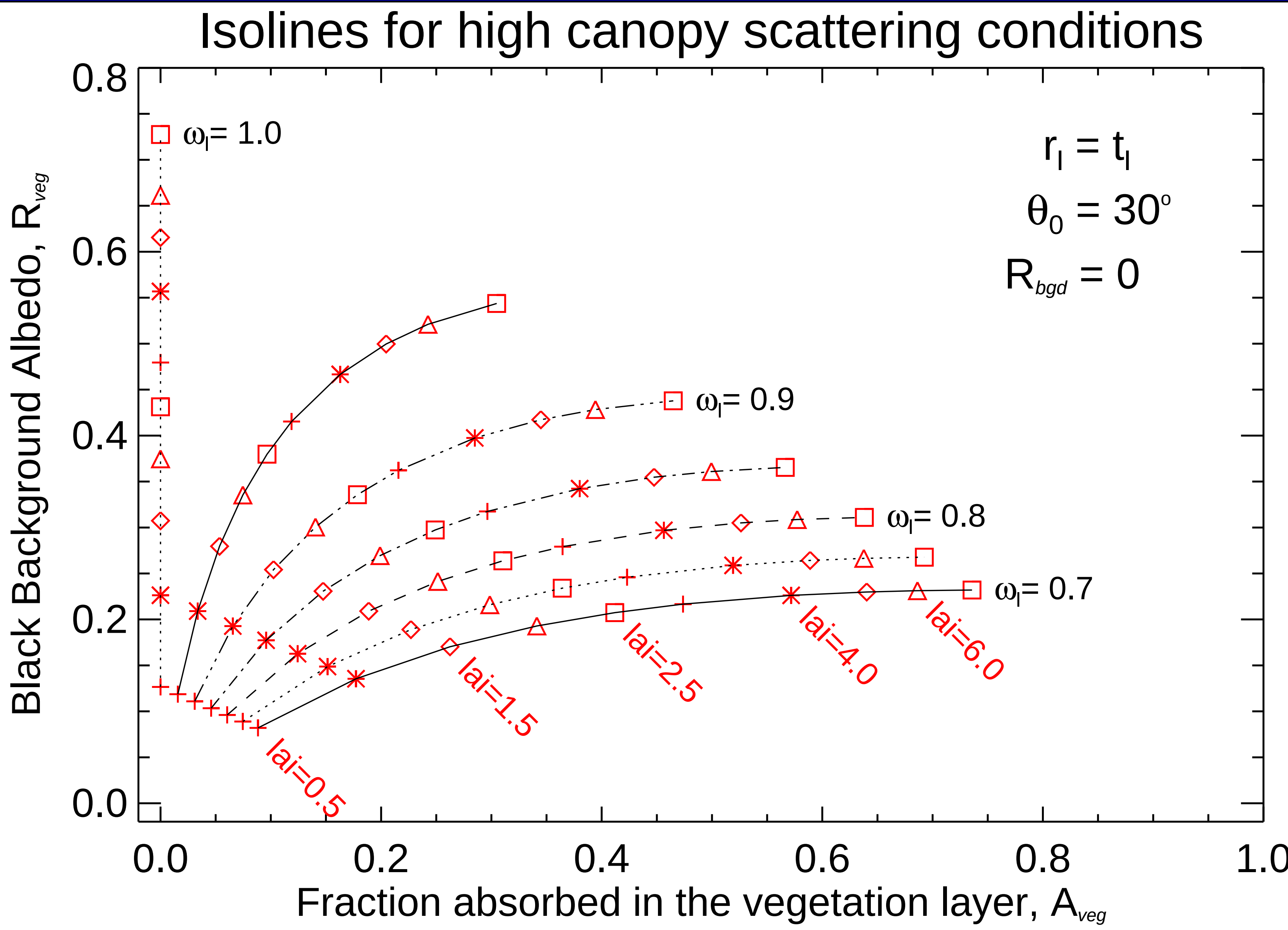
Canopy reflectance/transmittance } *canopy color*

- 1 (true) parameter of the background:

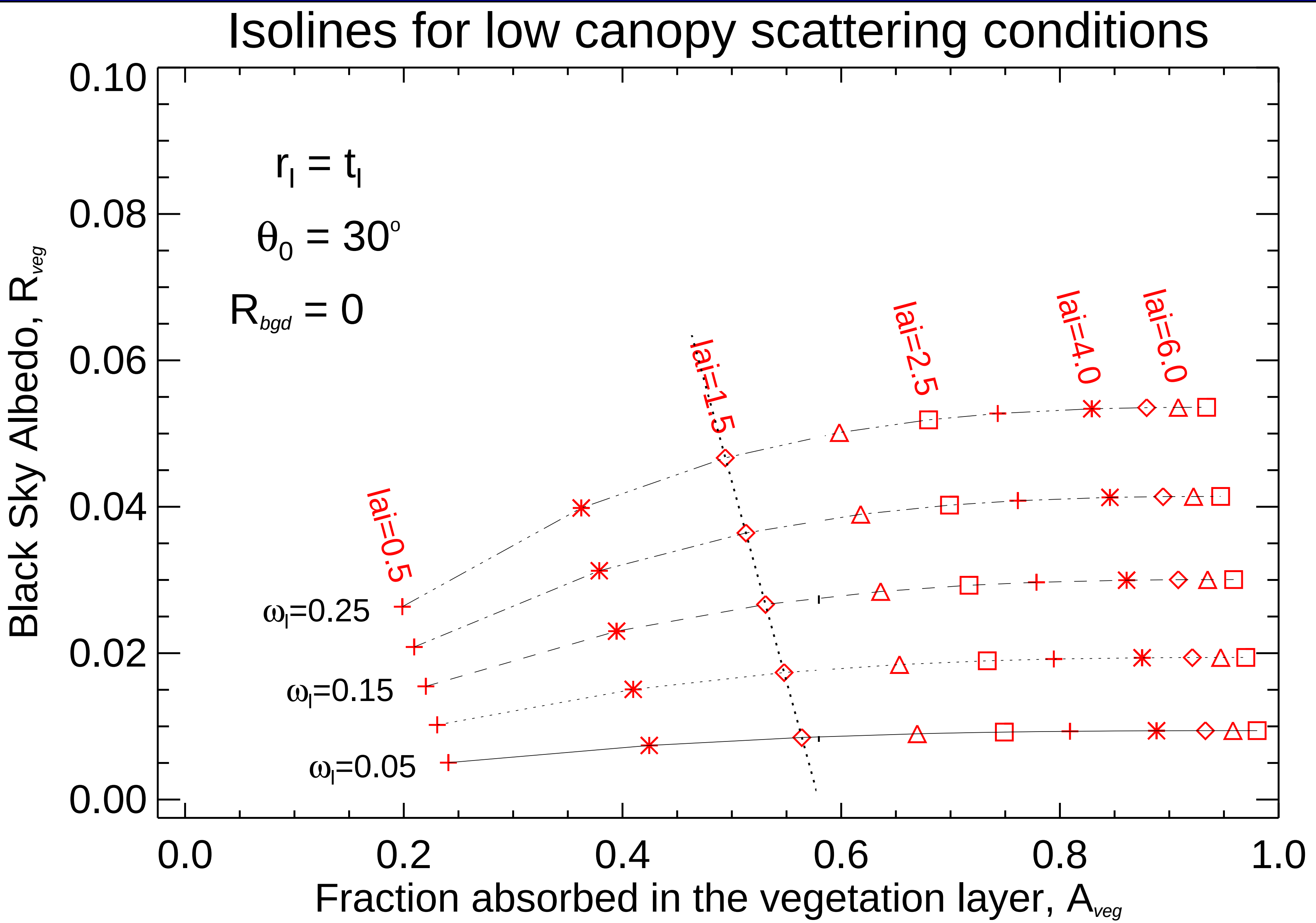
background Albedo *soil color*

Pinty etal., (2006): Journal of Geophysical Research, doi:10.1029/2005JD005952

Scattering in the NIR domain

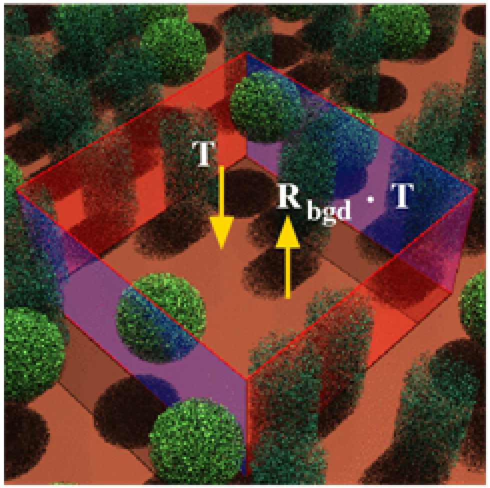


Scattering in the VIS domain

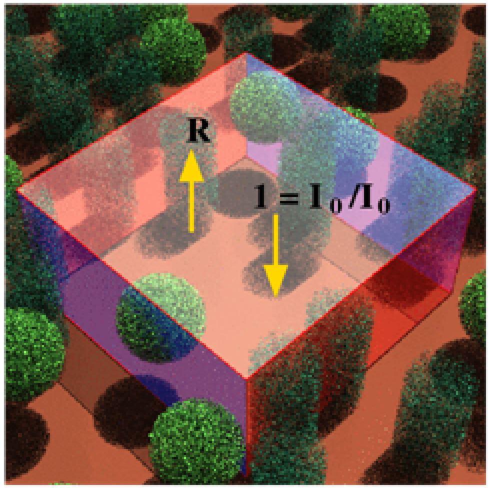


Scale analysis: Visible/PAR domain

fluxes at canopy/soil boundary



fluxes at canopy/atmosphere boundary



under single scattering dominated regime

$$1 + R_{bgd}(\lambda) \times T(\mu_0, \lambda) = A_{veg}(\mu_0, \lambda) + [R(\mu_0, \lambda) + T(\mu_0, \lambda)]$$

$\approx$

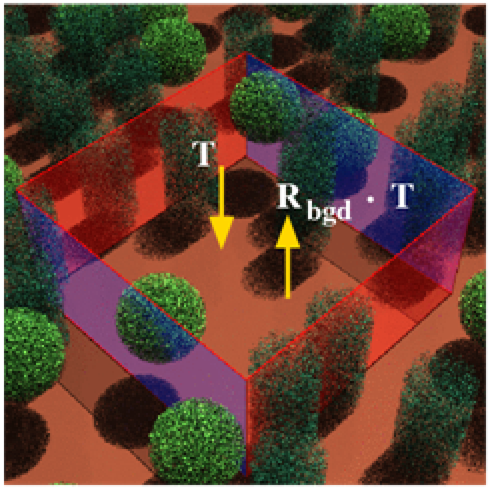
dense vegetation $T(\mu_0, \lambda) \rightarrow 0$ and $R(\mu_0, \lambda) \rightarrow R_{veg}^{Coll}(\mu_0, \lambda)$

sparse vegetation $T(\mu_0, \lambda) \rightarrow 1$ and $R(\mu_0, \lambda) \rightarrow R_{bgd}(\lambda)$

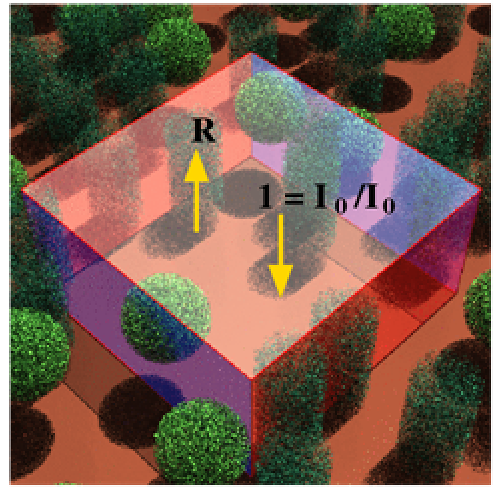
Pinty etal., (2009): Remote Sensing of Environment, doi:10.1016/j.rse.2008.08.017

Scale analysis: Visible/PAR domain

fluxes at canopy/soil boundary



fluxes at canopy/atmosphere boundary



under single scattering dominated regime

$$1 + R_{bgd}(\lambda) \times T(\mu_0, \lambda) = A_{veg}(\mu_0, \lambda) + [R(\mu_0, \lambda) + T(\mu_0, \lambda)]$$

$$\approx$$

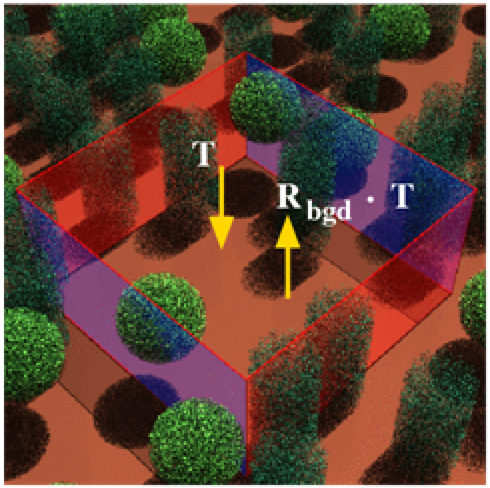
then $$1 \approx A_{veg}(\mu_0, \lambda) + T_{veg}(\mu_0, \lambda)$$

with $$T_{veg}(\mu_0, \lambda) = T_{veg}^{Uncoll}(\mu_0) + t_{veg}^{coll}(\mu_0, \lambda)$$

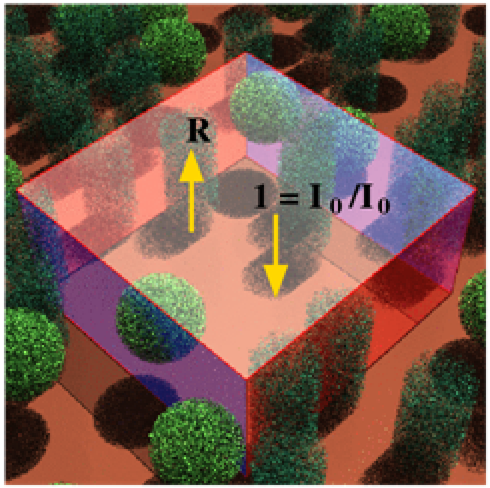
Pinty etal., (2009): Remote Sensing of Environment, doi:10.1016/j.rse.2008.08.017

Scale analysis: Visible/PAR domain

fluxes at canopy/soil boundary



fluxes at canopy/atmosphere boundary

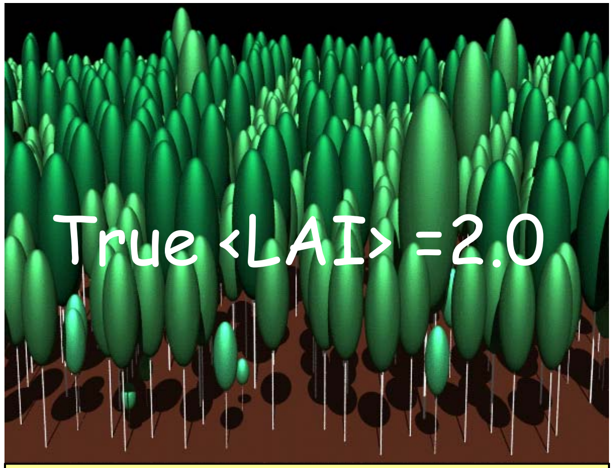


since $t_{veg}^{coll}(\mu_0, \lambda) << 0.05$

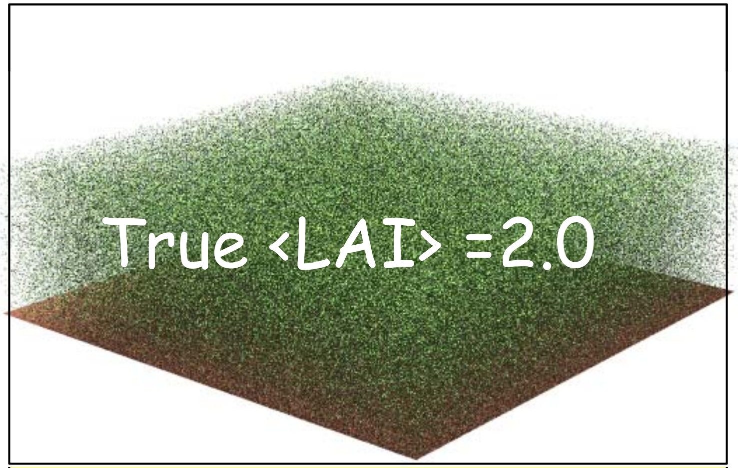
we have $A_{veg}(\mu_0, \lambda_{VIS}) \approx 1 - T_{veg}^{Uncoll}(\mu_0) \approx 1 - \exp\left(- \frac{\overleftrightarrow{LAI(\mu_0)}}{2 \times \mu_0} \right)$

canopy absorption (VIS) is well-approximated by spectrally invariant canopy interception

The concept of effective LAI



3-D heterogeneous system



1-D system representation

Direct transmission at 30 degrees Sun zenith angle,

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

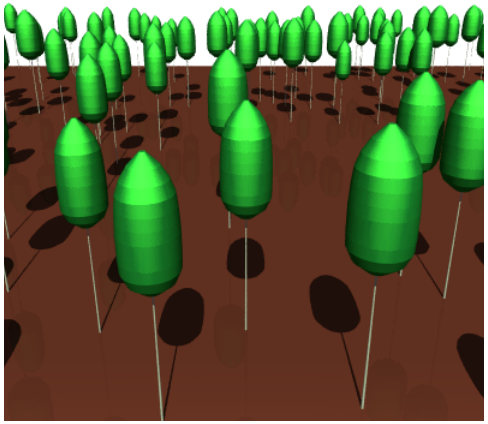
Direct transmission at 30 degrees Sun zenith angle,

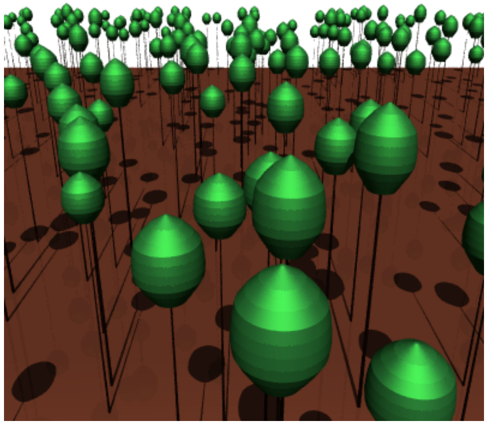
$$T_{1-D}^{direct}(<LAI>) = \exp\left(-\frac{<LAI>}{2\mu_0}\right) = 0.312$$

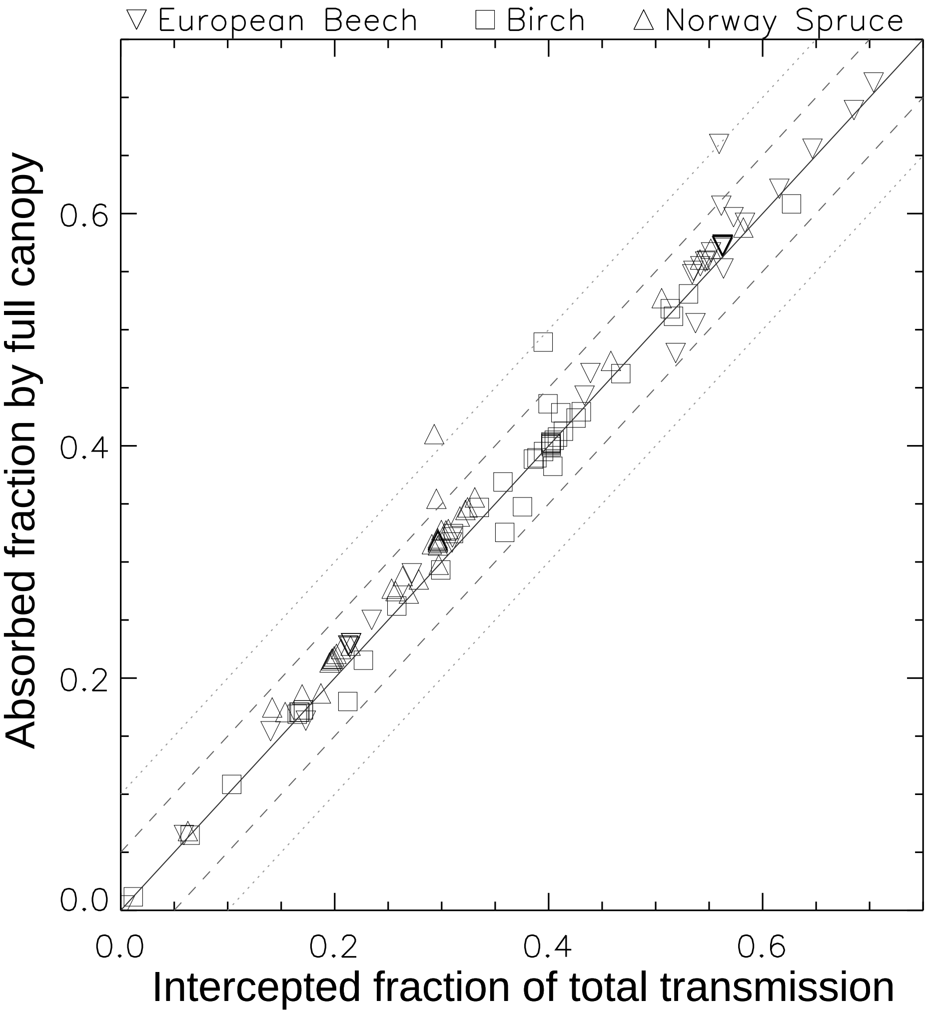
$$T_{1-D}^{direct}(LAI^{eff}) = \exp\left(-\frac{LAI^{eff}}{2\mu_0}\right) = \exp\left(-\frac{<LAI>\xi(\mu_0)}{2\mu_0}\right) = T_{3-D}^{direct}(<LAI>)$$

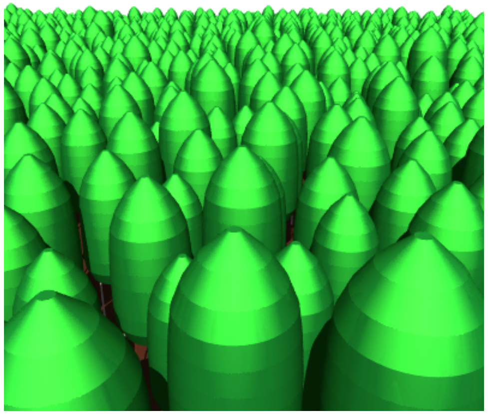
Structure factor

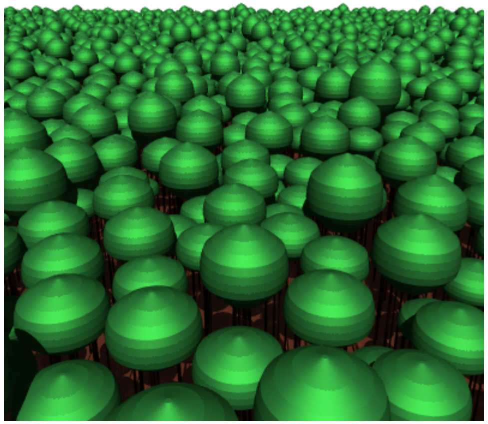
Absorption (VIS) versus Interception







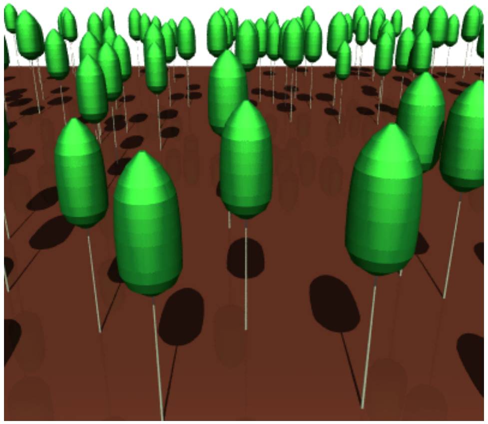


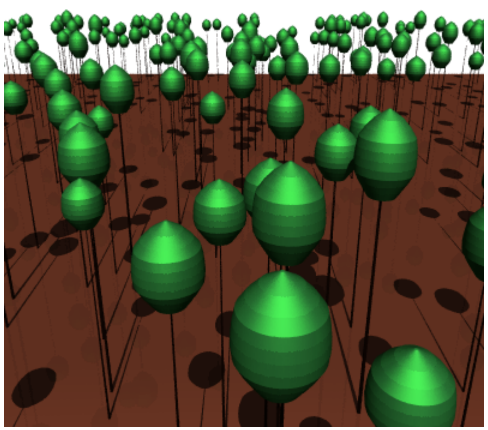


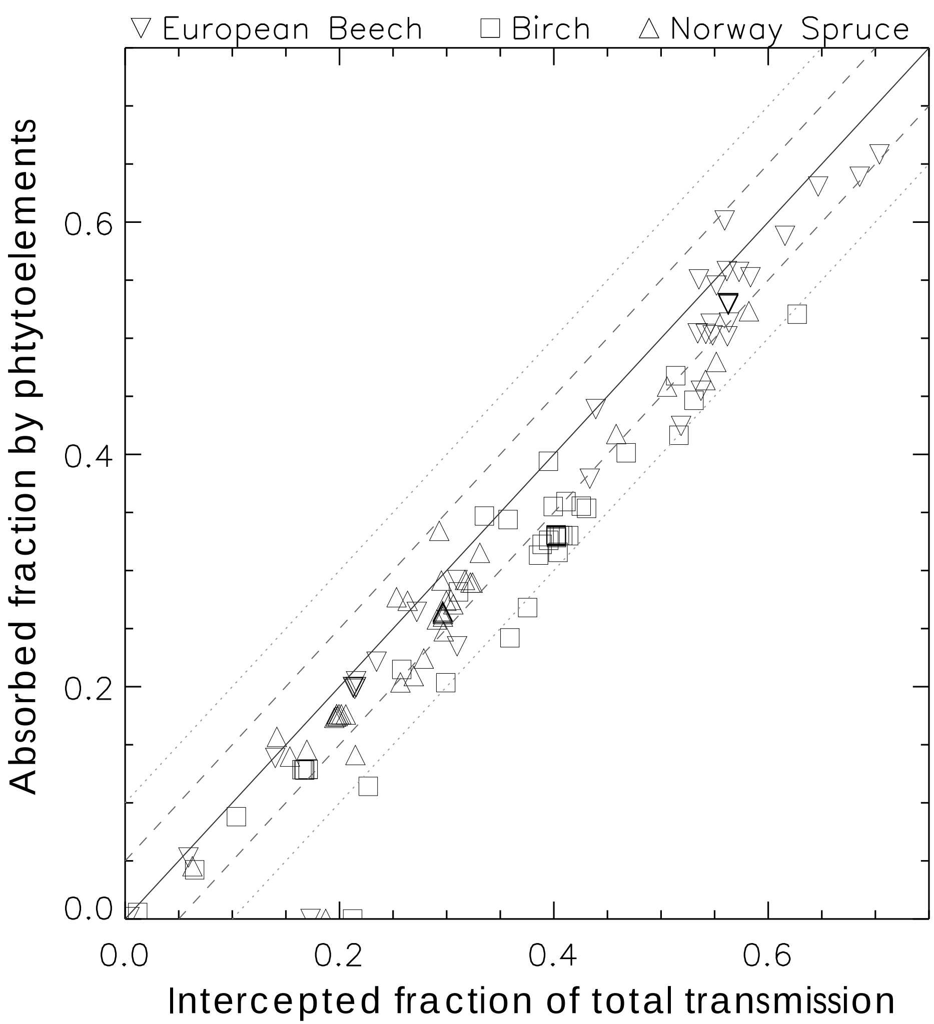
3D Monte Carlo model

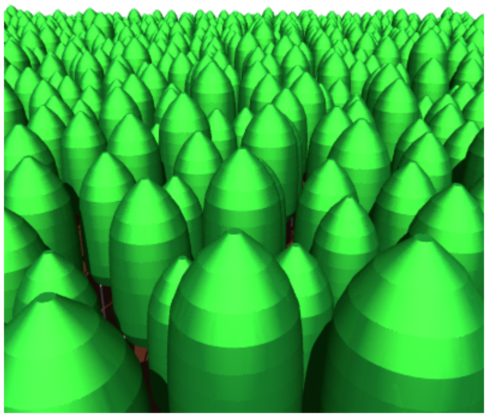
Pinty etal., (2009): Remote Sensing of Environment, doi:10.1016/j.rse.2008.08.017

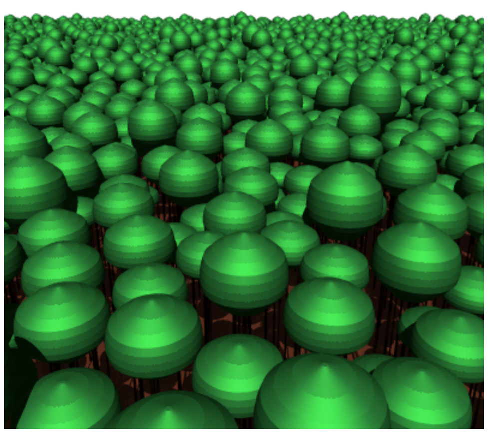
Absorption (VIS) versus Interception











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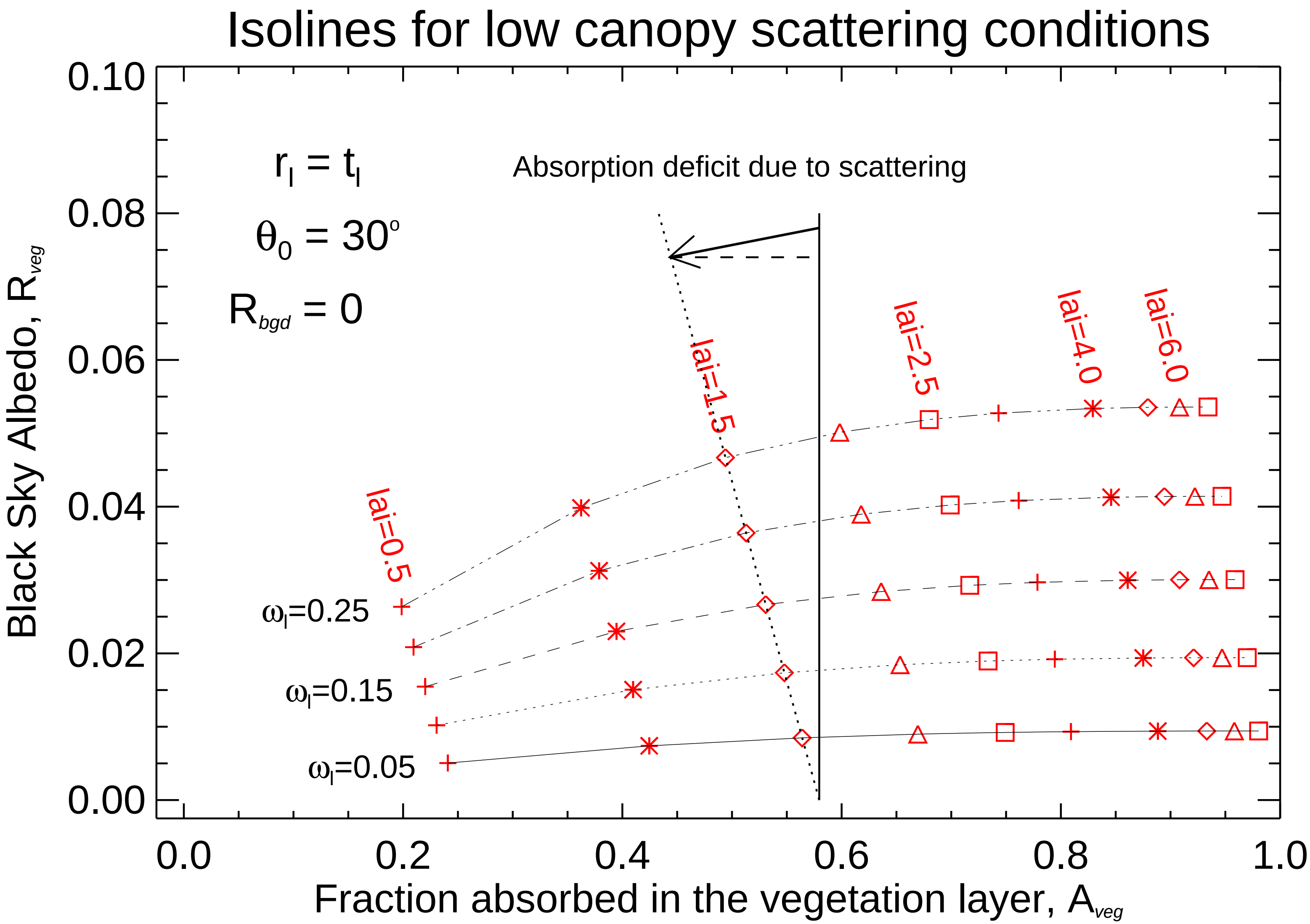
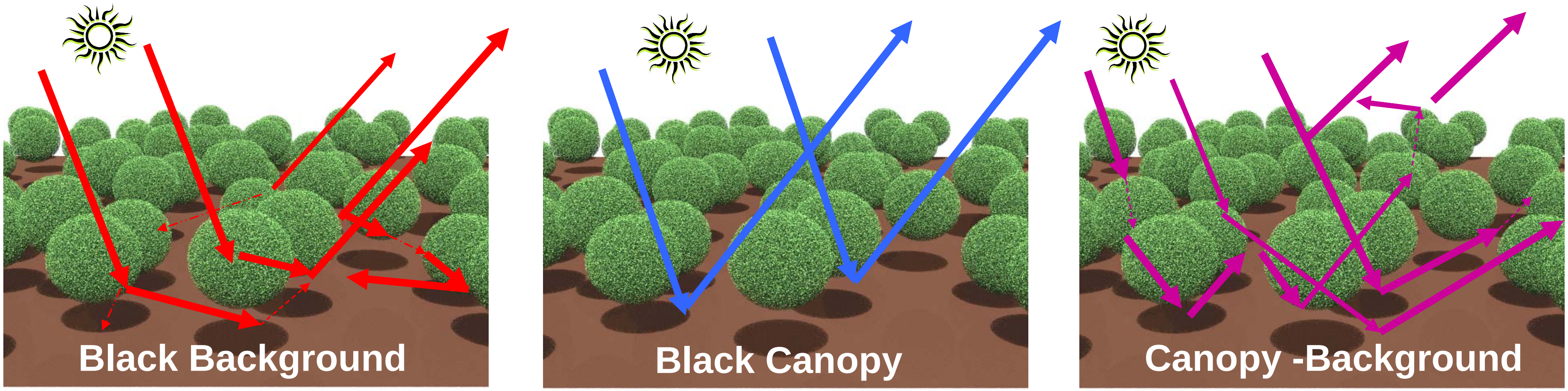
Absorption (VIS) versus Interception



Combining two spectral albedos

$$R(\mu_0,\lambda) = R_{veg}(\mu_0,\lambda) + R_{veg}^{Uncoll}(\mu_0,\lambda) + R_{bgd,veg}^{Coll}(\mu_0,\lambda)$$



- Regulates the ***absorption*** processes associated with vegetation photosynthesis
- Strongly depends on the **density** of green vegetation

- No absorption process by vegetation associated with this wavelength-independent contribution
- Strongly controlled by **3-D distribution of vegetation architecture**

- Controlled by multiple scattering events between the background and the canopy
- Mostly **negligible contribution in the visible** domain of the solar spectrum

Pinty etal., (2004): Journal of Geophysical Research, doi:10.1029/2004JD005214

Surface albedo model

Soil background through vegetation layer

$$R(\mu_0,\lambda) = R_{veg}^{Coll}(\mu_0,\lambda) + R_{veg}^{Uncoll}(\mu_0,\lambda) + R_{bgd,veg}^{Coll}(\mu_0,\lambda)$$

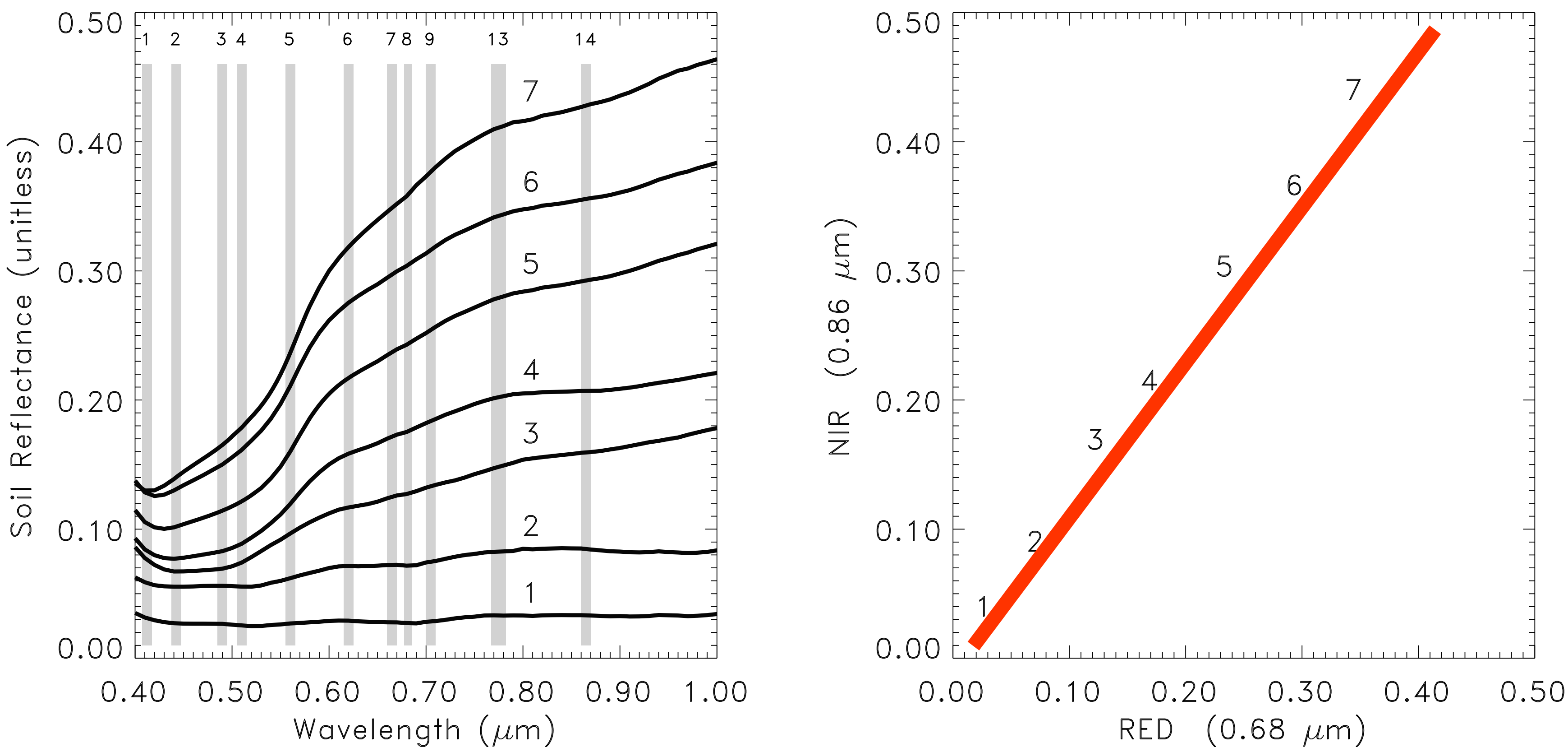
Vegetation only

Coupled vegetation

and background

Pinty etal., (2006): Journal of Geophysical Research, doi:10.1029/2005JD005952

Soil spectral correlation



$$R_{bgd}(\mu_0, \lambda_{NIR}) \approx a.R_{bgd}(\mu_0, \lambda_{VIS}) + b$$

$$a \rightarrow 1 \qquad b \rightarrow 0$$

Combining two spectral albedos

- Assumption 1 - a [VIS,NIR] soil line exists

- Assumption 2 - [interception - Absorption (VIS)] → 0

$$R(\mu_0,\lambda_{NIR}) - R(\mu_0,\lambda_{VIS}) \approx R_{veg}^{Coll}(\mu_0,\lambda_{NIR})$$

NO MORE CONTRIBUTION FROM THE SOIL BACKGROUND!!

Combining two spectral albedos

$$R(\mu_0, \lambda_{NIR}) - R(\mu_0, \lambda_{VIS}) \approx R_{veg}^{Coll}(\mu_0, \lambda_{NIR})$$

1st question: Why do we need two bands and in particular the NIR band?

1. to remove the soil contribution affecting both spectral bands

2. to ensure a large the dynamical range on the measured albedo

Combining two spectral albedos

- Assumption 1 - a [VIS,NIR] soil line exists
- Assumption 2 - [interception - Absorption (VIS)]→ 0

$$R(\mu_0, \lambda_{NIR}) - R(\mu_0, \lambda_{VIS}) \approx R_{veg}^{Coll}(\mu_0, \lambda_{NIR})$$

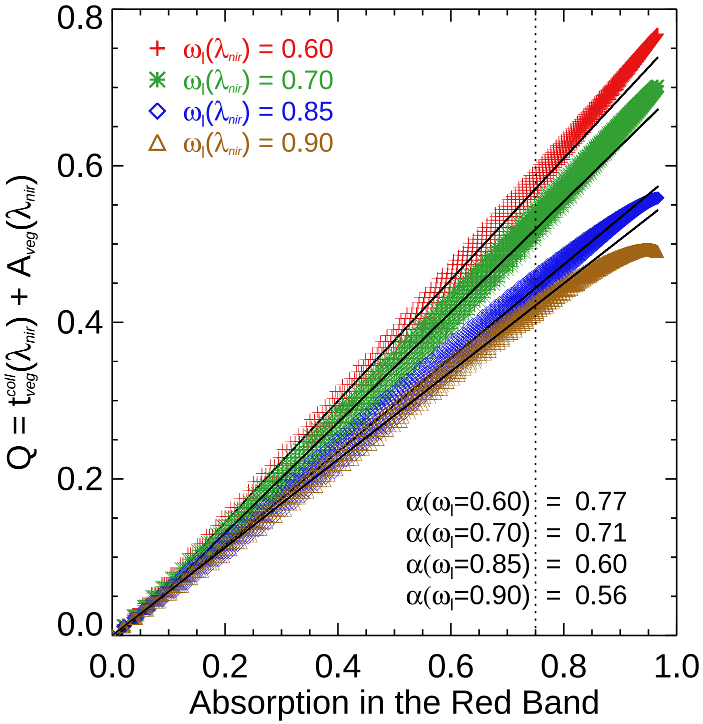
and

$$R(\mu_0, \lambda_{NIR}) - R(\mu_0, \lambda_{VIS}) \approx A_{veg}(\mu_0, \lambda_{VIS}) - Q(\mu_0, \lambda_{NIR})$$

where $Q(\mu_0, \lambda_{NIR}) = t_{veg}^{Coll}(\mu_0, \lambda_{NIR}) + A_{veg}(\mu_0, \lambda_{NIR})$

expresses the albedo deficit due to canopy absorption and diffuse transmission in the NIR

Scaling of $Q(\mu_0, \lambda_{NIR})$



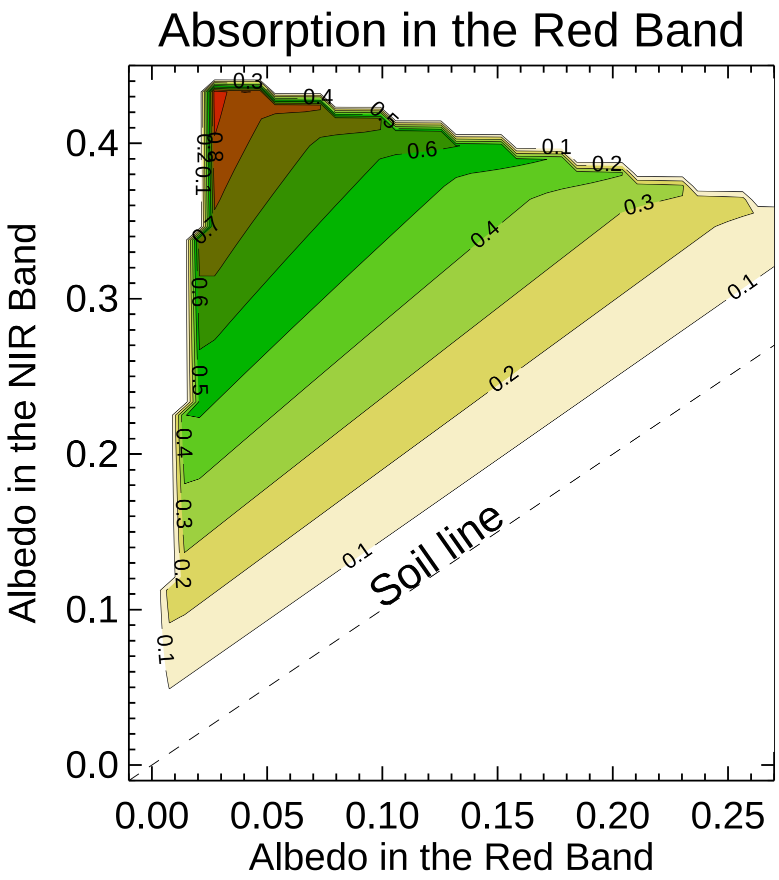
$Q(\mu_0, \lambda_{NIR})$ is controlled by multiple scattering processes:

$$Q(\mu_0, \lambda_{NIR}) \approx A_{veg}(\mu_0, \lambda_{VIS}) \times \alpha[\omega_l(NIR)]$$

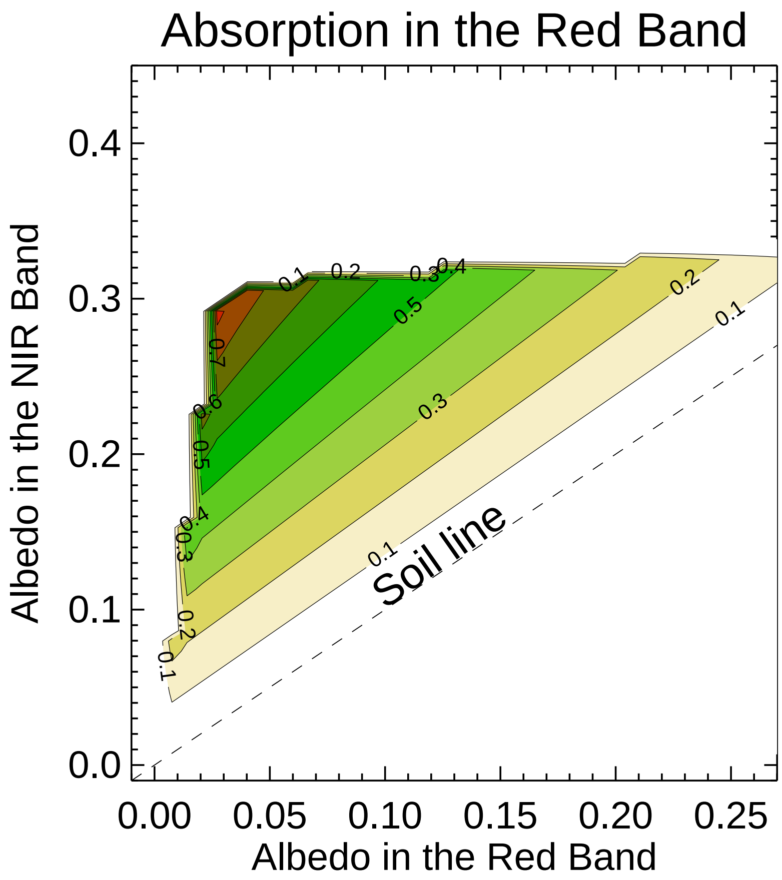
$$A_{veg}(\mu_o, \lambda_{VIS}) = \frac{R(\mu_o, \lambda_{NIR}) - R(\mu_o, \lambda_{VIS})}{1 - \alpha[\omega_l(NIR)]} \qquad 0.7 < \alpha[\omega_l(NIR)] < 0.5$$

dependency with respect to the ‘color’ of the canopy usually assumed to be ‘green”

Vegetation Indices: the $\omega_l(NIR)$ issue

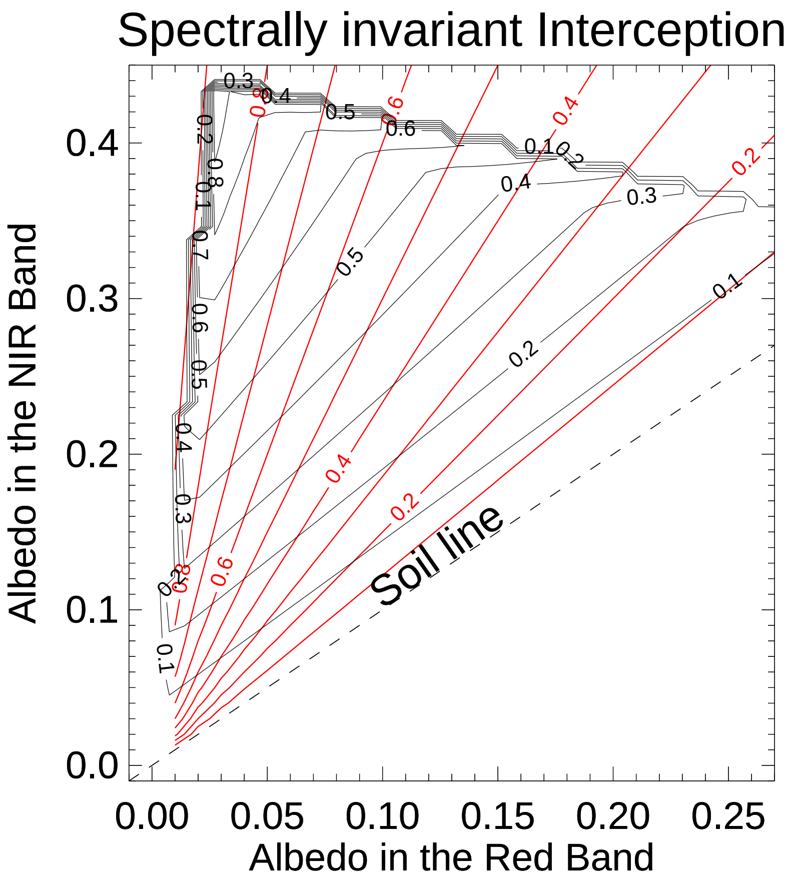


$$\omega_l(NIR) = 0.85$$

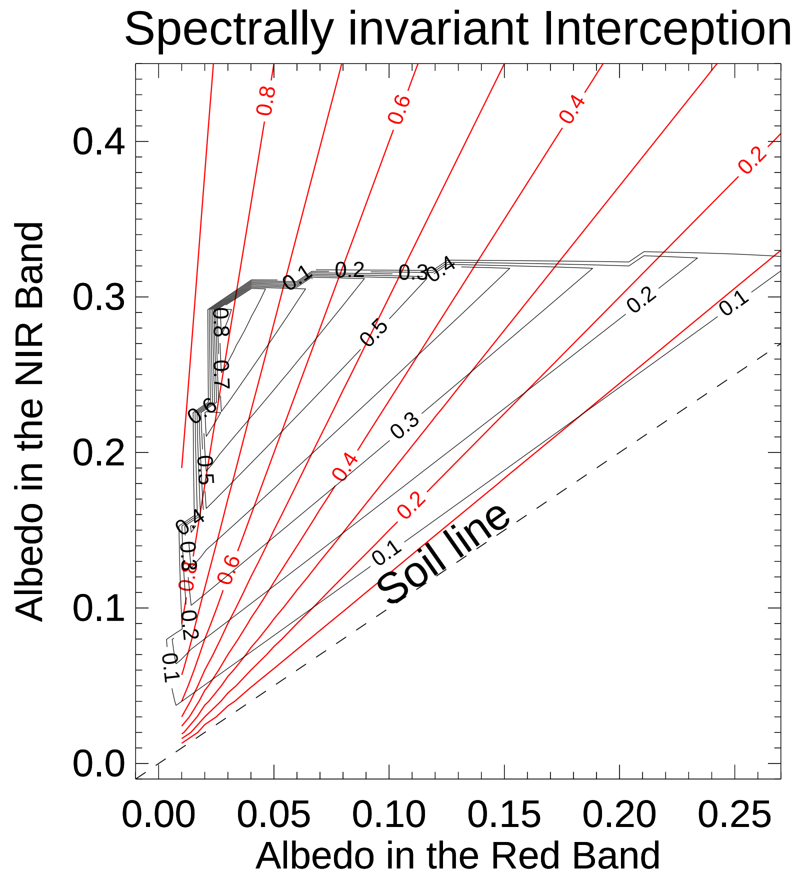


$$\omega_l(NIR) = 0.70$$

Vegetation Indices: the $\omega_l(NIR)$ issue

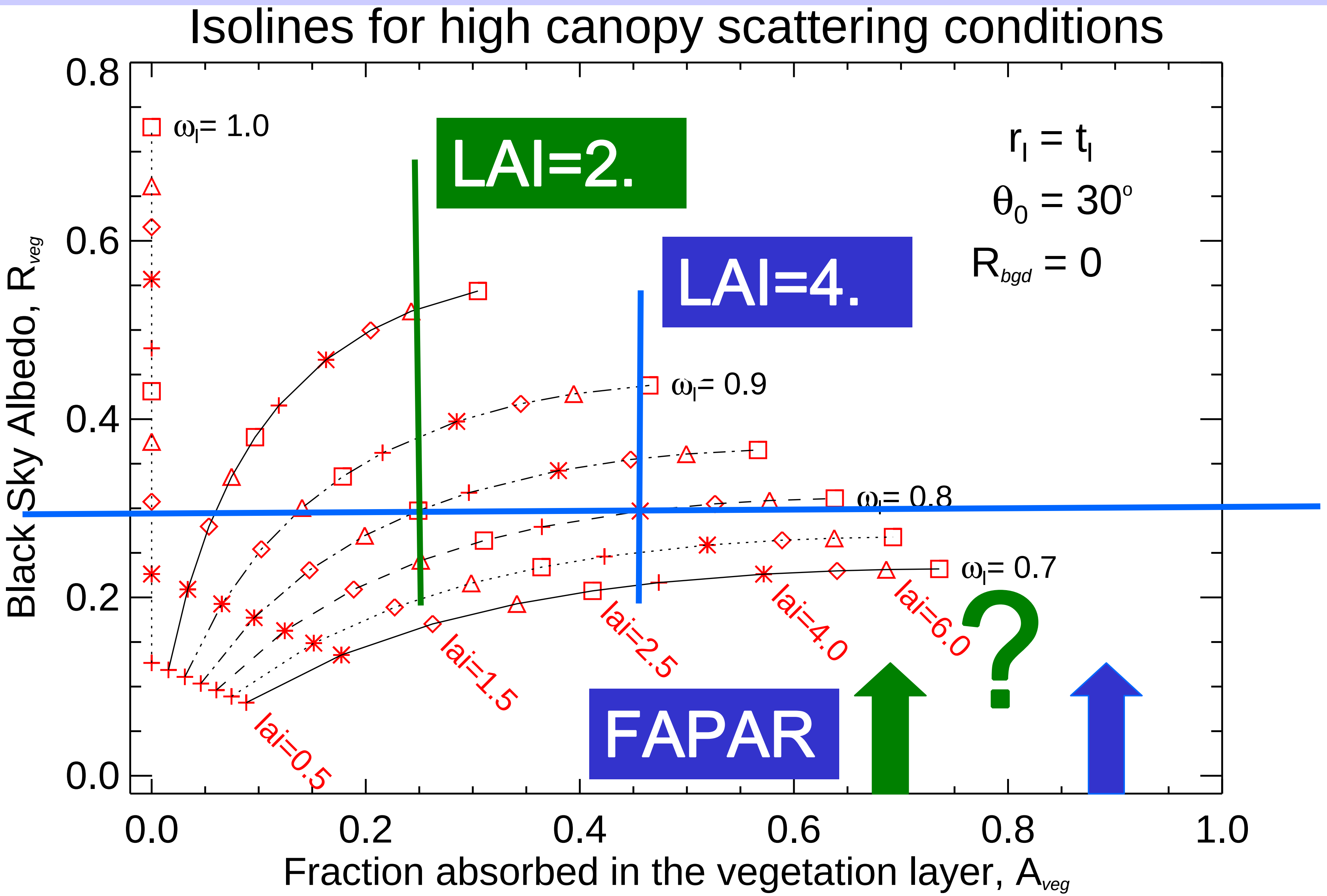


$$\omega_l(NIR) = 0.85$$



$$\omega_l(NIR) = 0.70$$

Vegetation Indices: the $\omega_l(NIR)$ issue



Pinty etal., (2009): Remote Sensing of Environment, doi:10.1016/j.rse.2008.08.017

Vegetation Indices: lessons learnt

- Canopy absorption in the VIS, i.e., FAPAR, is largely controlled by canopy interception
- Visible band is required to remove the background contribution to scattering, i.e., albedo, in the NIR domain.

Vegetation Indices: lessons learnt

- The color of the leaves do not really matter for estimating the absorption in VIS (FAPAR) since the process is driven by spectrally invariant interception
- The color of the leaves do matter a lot for estimating the absorption in VIS (FAPAR) from EO data due to the NIR contribution
- Any VIs including NDVI implicitly assume spectral correlations with respect to the soil and leave scattering properties

Vegetation Indices: issues

- Canopy scattering properties are unknown at pixel resolution and vary substantially with vegetation type
- NDVI almost 'works by chance' since the sum of the red and NIR channels remains numerically close to typical values related to canopy scattering albedo in the NIR.
- VIs have to be optimized with respect to the foreseen application e.g., the MERIS Global VI which is simply equivalent to FAPAR.

Vegetation Indices: issues

- Why do we need two bands and in particular the NIR band?

1. to remove the soil contribution affecting the visible band
2. to enlarge the dynamical range on the measured albedo

- VIs reduce two observations (at least) to one single value

  → increases number of unknowns and the inverse problem is seriously ill-posed.

VIs are based on hidden/non explicit spectral correlations between the canopy scattering properties and the background soil

Retrieval of land surface properties

Formulate the inverse problem **to optimize all available information** and statistically infer the state of the system

RT model relating observations to process parameters

Retrieval of land surface properties

Formulate the inverse problem **to optimize all available information** and statistically infer the state of the system

RT model relating observations to process parameters

Prior knowledge on model process parameters as PDF

Retrieval of land surface properties

Formulate the inverse problem **to optimize all available information** and statistically infer the state of the system

RT model relating observations to process parameters

Prior knowledge on model process parameters as PDF

Inversion package to retrieve model parameters to observations under controlled uncertainty propagations

Challenges for the EO Land community

- 4 identified ECVs namely Albedo, FAPAR, LAI and ultimately Land Cover are linked via radiation and phenological processes:

  They MUST be retrieved consistently and then specified in the same manner in host models

- Multiple datasets of these ECVs are available from different institutions:

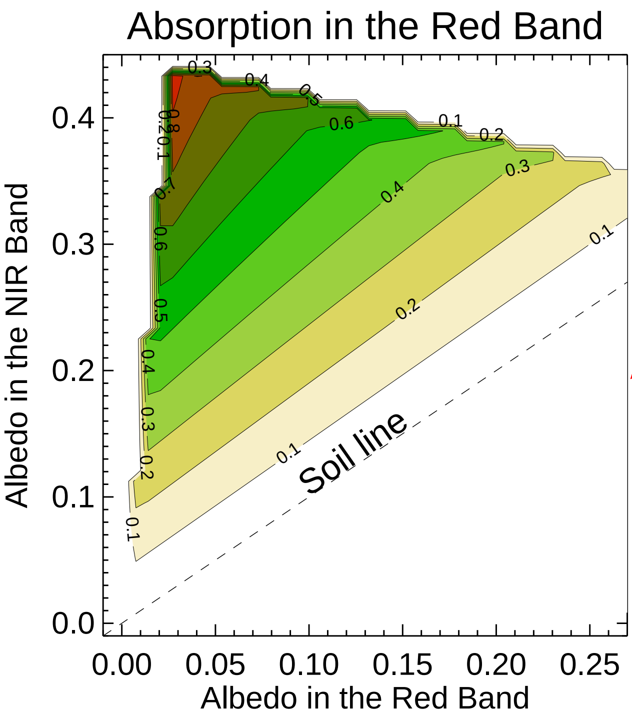
  They MUST be analyzed and exploited to establish a coherent set of information across platforms and institutions.

Vegetation Indices: basics

$$VI = f(Y) \quad \text{where} \quad Y = FAPAR \ \text{or} \ LAI$$

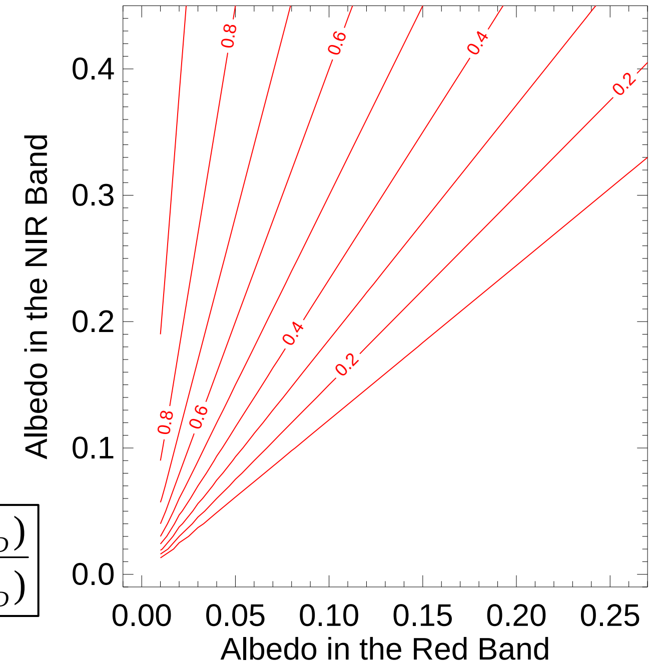
or any other vegetation attribute quantifying “greenness”

and $$VI = g[R(\lambda_{RED}), R(\lambda_{NIR})]$$



RT Model

$$VI = \frac{R(\mu_0, \lambda_{NIR}) - R(\mu_0, \lambda_{RED})}{R(\mu_0, \lambda_{NIR}) + R(\mu_0, \lambda_{RED})}$$

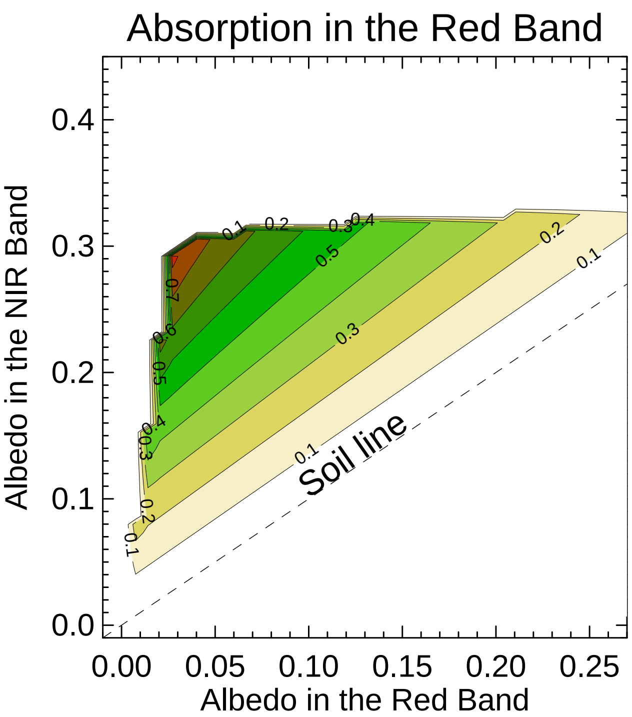


Vegetation Indices: basics

$VI = f(Y)$ where $Y = FAPAR$ or LAI

or any other vegetation attribute quantifying "greenness"

and $VI = g[R(\lambda_{RED}), R(\lambda_{NIR})]$



RT Model

$$VI = \frac{R(\mu_0, \lambda_{NIR}) - R(\mu_0, \lambda_{RED})}{R(\mu_0, \lambda_{NIR}) + R(\mu_0, \lambda_{RED})}$$