UNIVERSITY OF TWENTE.

# RETRIEVAL OF LEAF AREA INDEX FROM REMOTE SENSING DATA

## PART IV: (PHYSICAL APPROACH- USE OF RADIATIVE TRANSFER MODELS)

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# INTRODUCTION- SPECTRAL SIGNATURES

- Spectral signatures of vegetation covers are used to study vegetation type, species type, health, growth, different stress, productivity and many other characteristics.

- At leaf level → leaf traits

- At canopy level → plant traits, undesired effects, ( e.g. soil reflectance, sun and view geometry) and combined interaction effects

# PHYSICAL APPROACH

- Link between plant traits, external factors and the combined interactions effects → physical/deductive models
- Estimating vegetation parameters involves using radiative transfer models (RTM).
- RTMs offer an explicit connection between a number of plant traits and the spectral reflectance.
- At canopy level RTMs explain the transfer and interaction of radiation inside the canopy based on physical laws. The spectral variation described as a function of canopy, leaf and soil background characteristics.

# RT MODELLING

- Support the interpretation of RS data
  - ✓ Compute the RS signal as the function of important biochemical and biophysical variables
  - ✓ Provide understanding of the signal sensitivity to environmental parameters
- Assist in feasibility studies
  - ✓ Compensate for data gaps
  - ✓ Assist in experimental studies
- Robust parameter retrieval through inversion e.g. LAI

# RADIATIVE TRANSFER MODEL (RTM) FOR VEGEGTATION

- Leaf level → leaf biochemical and structural properties

- Canopy level → leaf, canopy, soil, sun and sensor geometry (canopy architecture, leaf scattering, soil scattering)

- 1D radiative transfer models → vegetation canopy is presumed to be a turbid medium with randomly distributed canopy elements
- 3D RTMs → applicable to horizontally heterogeneous or discontinuous canopies

# RADIATIVE TRANSFER MODEL

- Depending on ecosystem and parameter of interest, models from different levels are combined (leaf optical model with canopy reflectance model)

- Computationally demanding and need knowledge of a number of leaf and canopy variables.

# RT CANOPY MODEL

- Require descriptions of:
  - canopy architecture
  - (Vertical leaf area density (LAI), the leaf normal orientation distribution,  leaf dimensions (infinitesimal scatters) affects canopy scattering in retroreflection direction, leaf thickness effects on reflectance /transmittance
  - Leaf scattering properties
  - (Leaf surface, internal structure, leaf biochemistry; leaf size increase leaf area for constant number of leaves result in increasing LAI, leaf thickness: decrease transmittance (increase reflectance)
  - soil scattering: moisture content, type/texture, surface roughness.
  - Observation Geometry

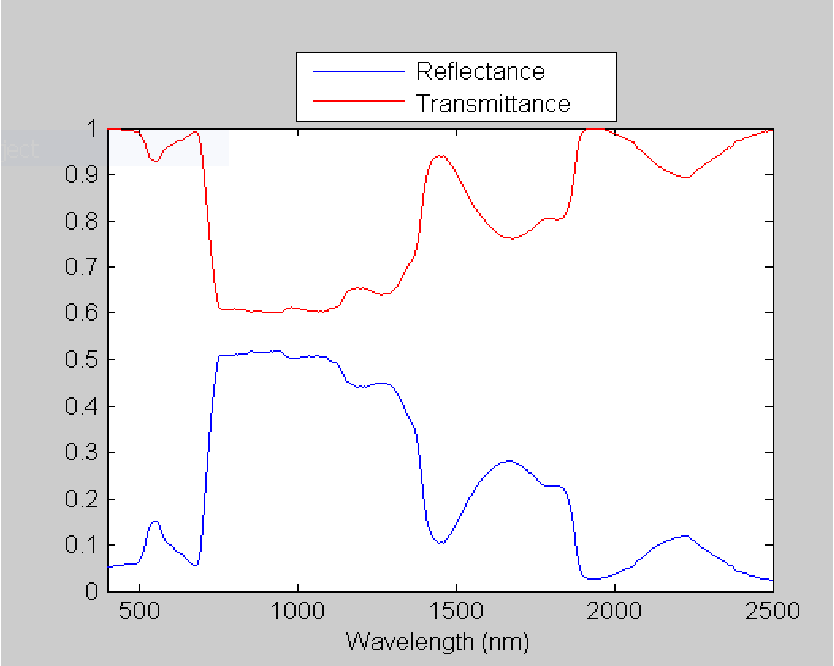
# EXAMPLES OF LEAF AND CANOPY MODELS

- **Leaf models e.g.**
  - PROSPECT (*Leaf Optical Properties Spectra*), Jacquemoud and Baret (1990)
  - LIBERTY (*Leaf Incorporating Biochemistry Exhibiting Reflectance and Transmittance Yields*), Dawson et al. (1998)
- **Canopy models e.g.**
- SAIL (Scattering by Arbitrary Inclined Leaves) Verhoef (1984)
- INFORM
- DART

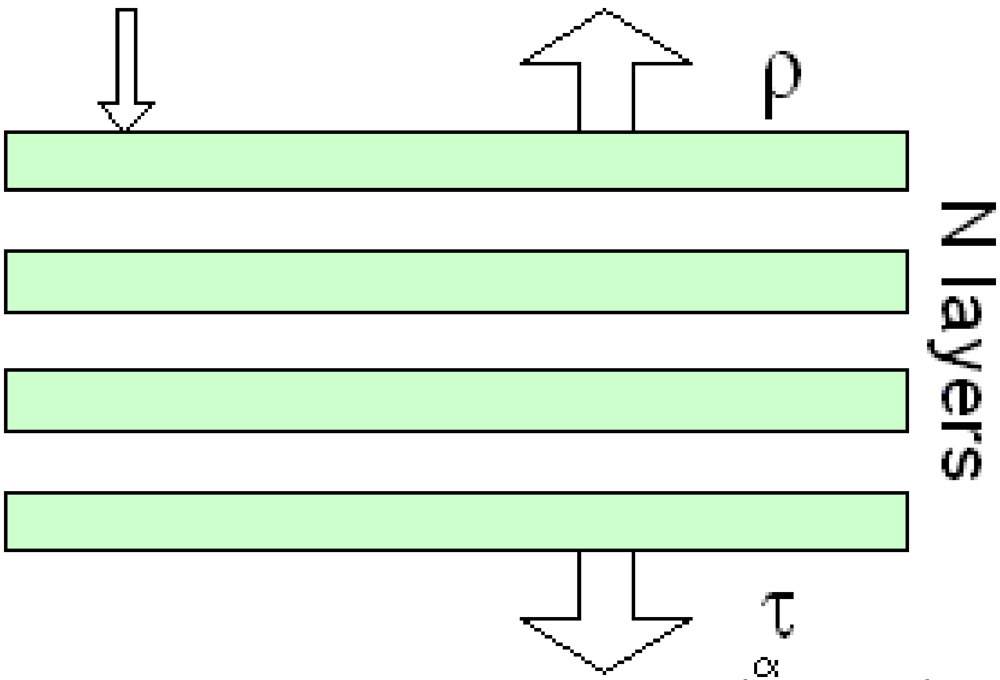
# PROSPECT MODEL

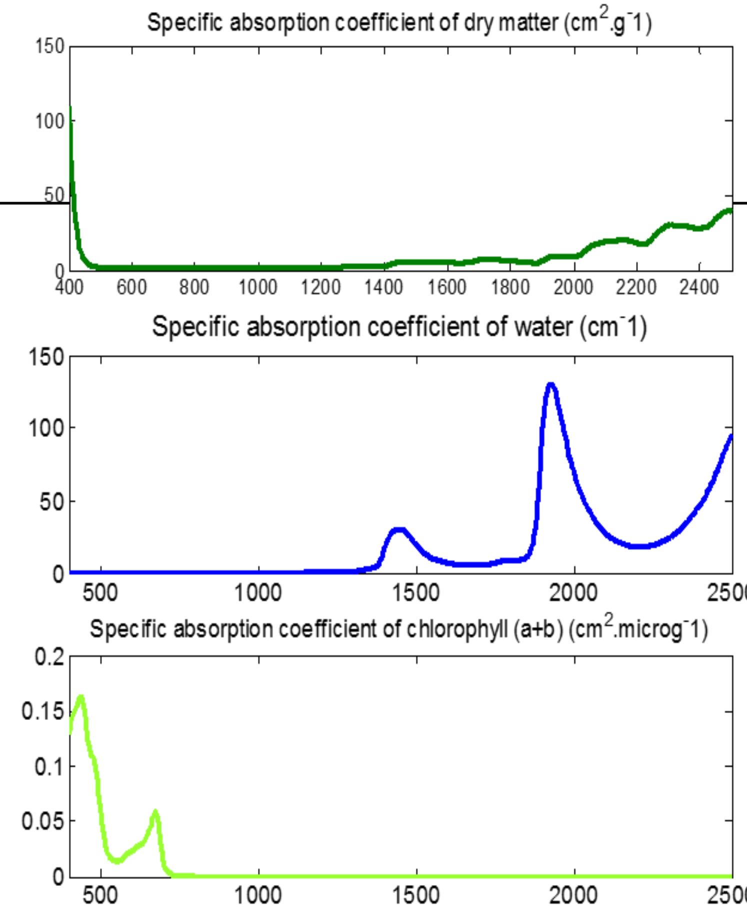
PROSPECT (Jacquemoud & Baret 1990) simulates the reflectance and transmittance of a single leaf based on (the following) **input parameters** and thier **absorption coefficients**

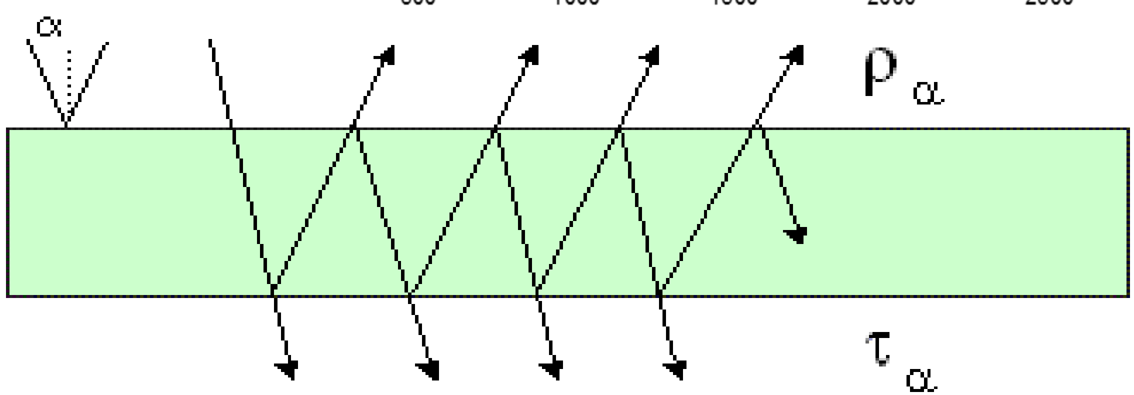
- Leaf Chlorophyll a+b concentration
- Leaf water concentration
- Leaf dry matter concentration
- Leaf structure parameter



# PROSPECT MODEL




n = index of refraction
k = coefficient of absorption

# PROSPECT model

$[R_{mod}(\lambda), T_{mod}(\lambda)]$ = PROSPECT ($N$, $k(\lambda)$, $n(\lambda)$)   (1)

leaf structure parameter N

Absorption coefficient of one elementary layer $k(\lambda)$.

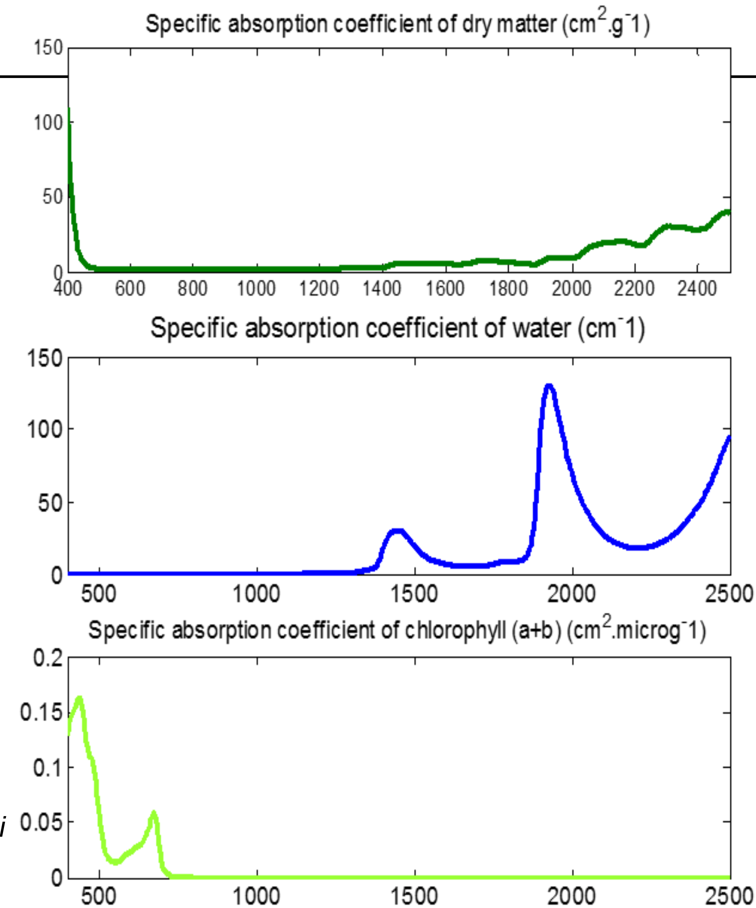
Refractive index n(λ).

Hemispherical reflectance $R_{mod}(\lambda)$ and transmittance $T_{mod}(\lambda)$

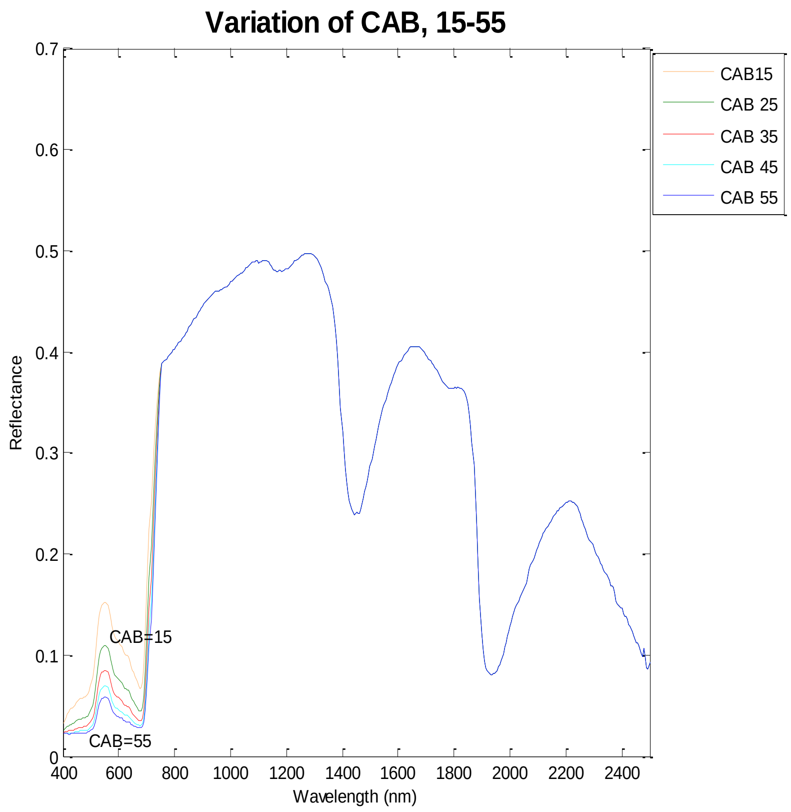
$$k(\lambda) = \sum_i k_i(\lambda) \times \frac{C_i}{N} \quad (2)$$

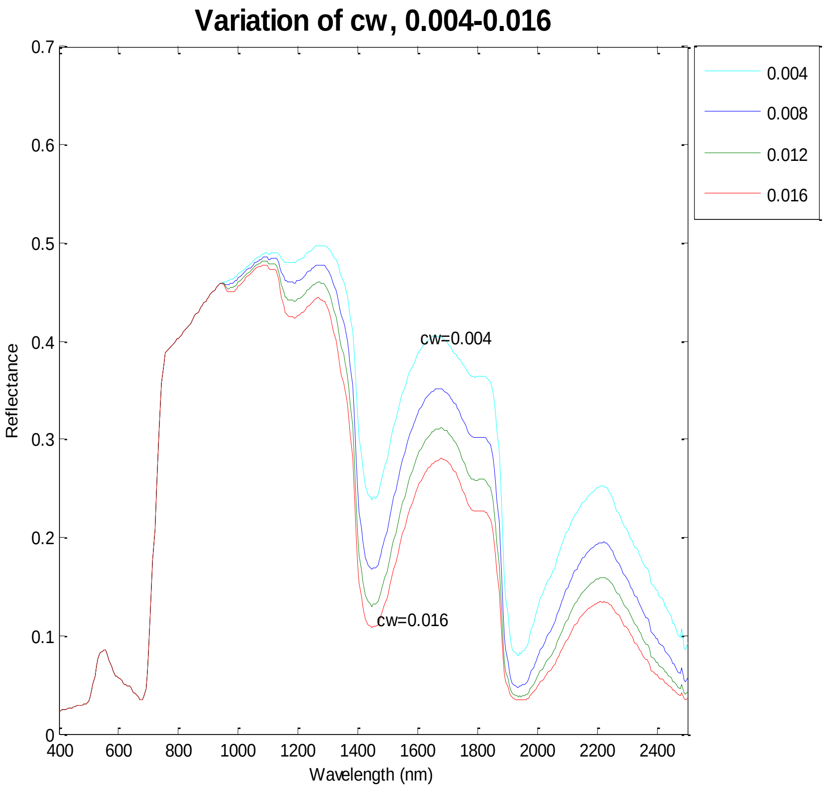
**linearly mixed by the** concentration of leaf absorbers $C_i$ and their corresponding specific absorption coefficients $k_i(\lambda)$

$[R_{mod}(\lambda), T_{mod}(\lambda)]$ = PROSPECT ($N$, Chl, LMA, EW)   (3)



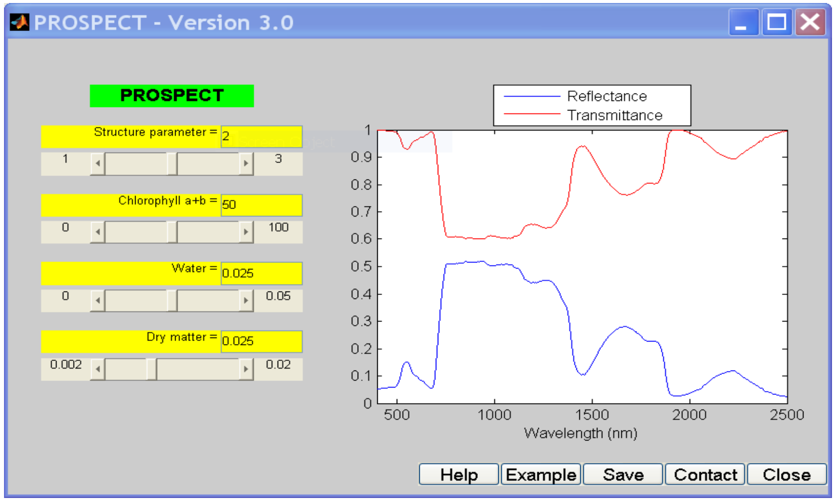
# SENSITIVITY ANALYSIS OF PROSPECT



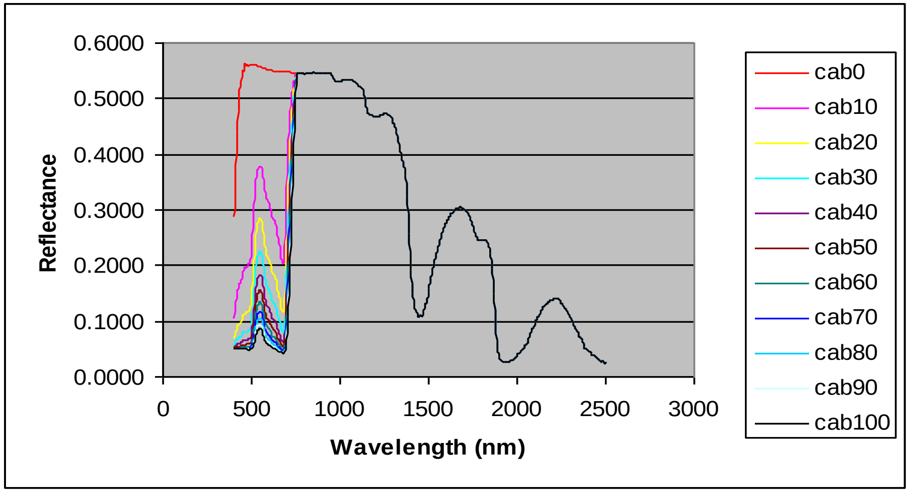



# PROSPECT model in Forward mode

PROSPECT GUI in Matlab




Modeling results



# SAIL MODEL

- Scattering by arbitrary inclined leaves (Verhoef 1984, 1985)
- Models energy-canopy interaction in 3 streams (downward direct flux, downward and upward diffuse flux)
- 1-D turbid medium model
- Canopy represented by small absorbing and scattering elements
  - distributed randomly
  - with known angular distribution
  - with known optical properties
  - Canopy structural parameters, diffuse skylight, sun and sensor zenith and azimuth angles, soil reflectance
  - Canopy is non lambertain surface, therefore canopy reflectance depend on  the angle which is illuminated and viewed.

# SAIL MODEL

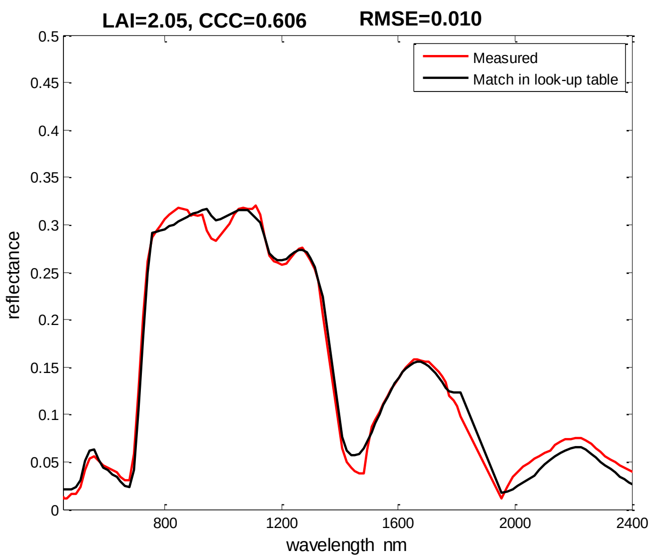
| Parameter | Abbreviation in model | Unit |
|---|---|---|
| Leaf area index | LAI | $m^2\ m^{-2}$ |
| Mean leaf inclination angle | ALA | Deg |
| Sun zenith angle | ts | Deg |
| Sensor viewing angle | to | Deg |
| Azimuth angle | phi | Deg |
| Fraction of diffuse incoming solar radiation | skyl | No dimension |
| Hot spot size parameter | hot | $m\ m^{-1}$ |
| Soil brightness parameter | scale | No dimension |

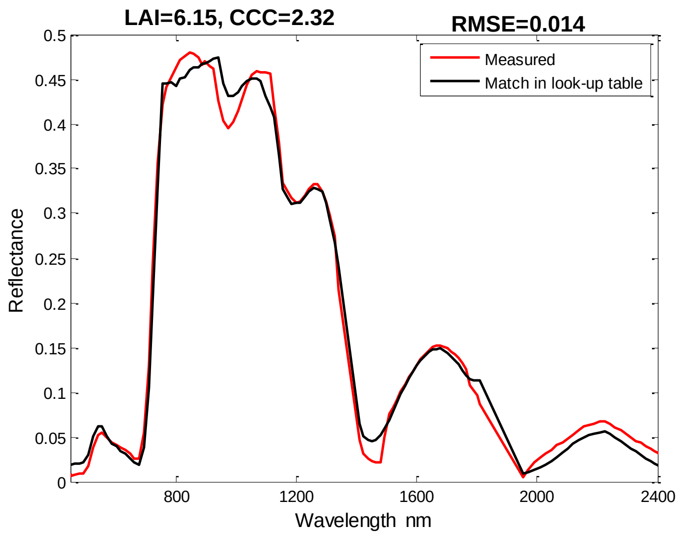
# PROSAIL

- Combination of :
  - SAILH canopy reflectance model (Verhoef, 1984; Verhoef, 1985; Kuusk, 1991)
  - PROSPECT leaf optical properties model (Jacquemoud and Baret, 1990)

- Relatively simple and need only a limited number of input parameters
- Reasonable computation time

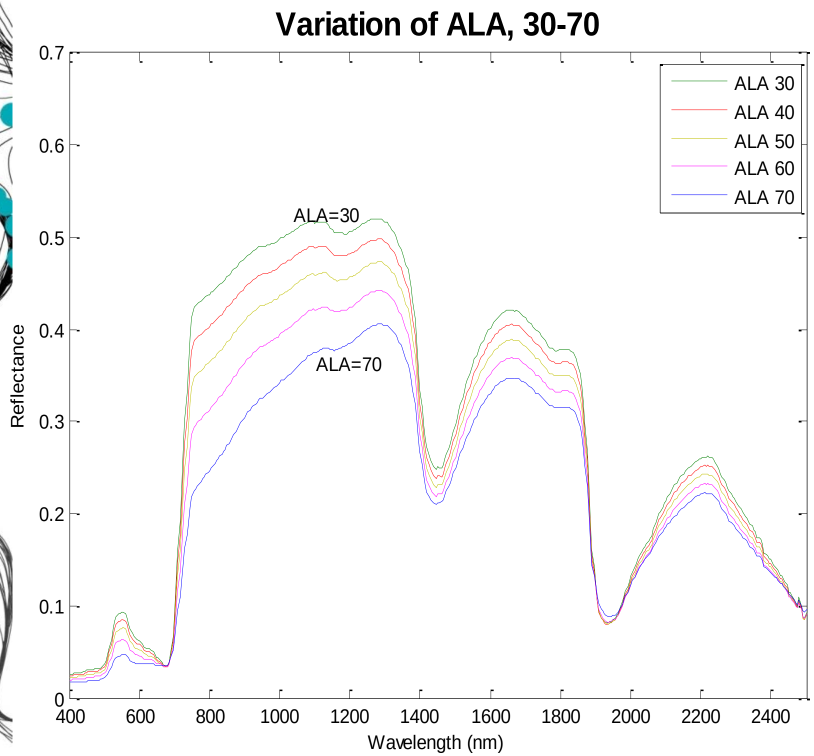
# MEASURED & BEST MODELLED SPECTRUM

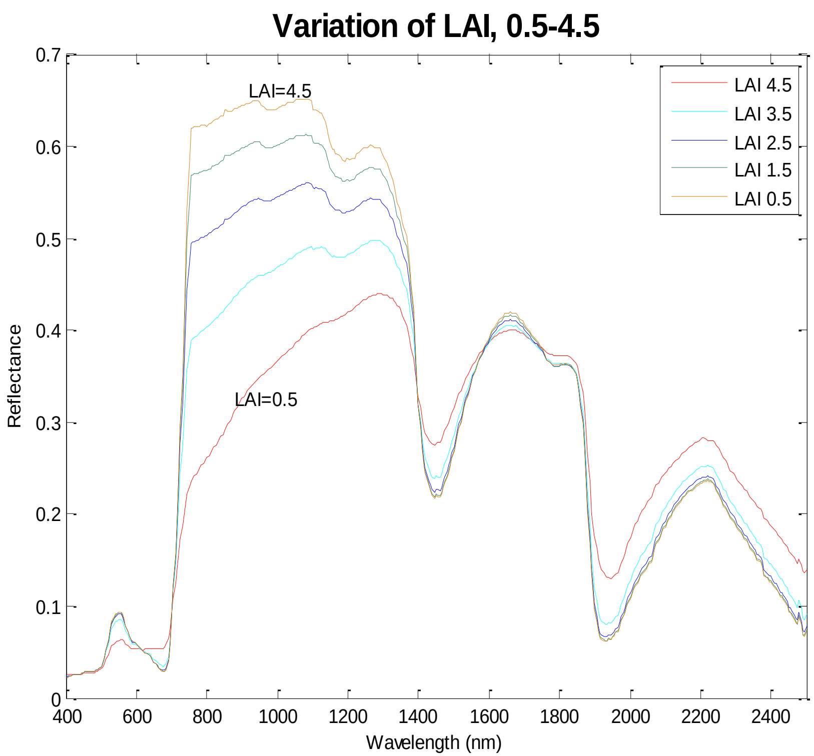



(Darvishzadeh, et al. 2011, ISPRS)

# SENSITIVITY ANALYSIS OF PROSAIL

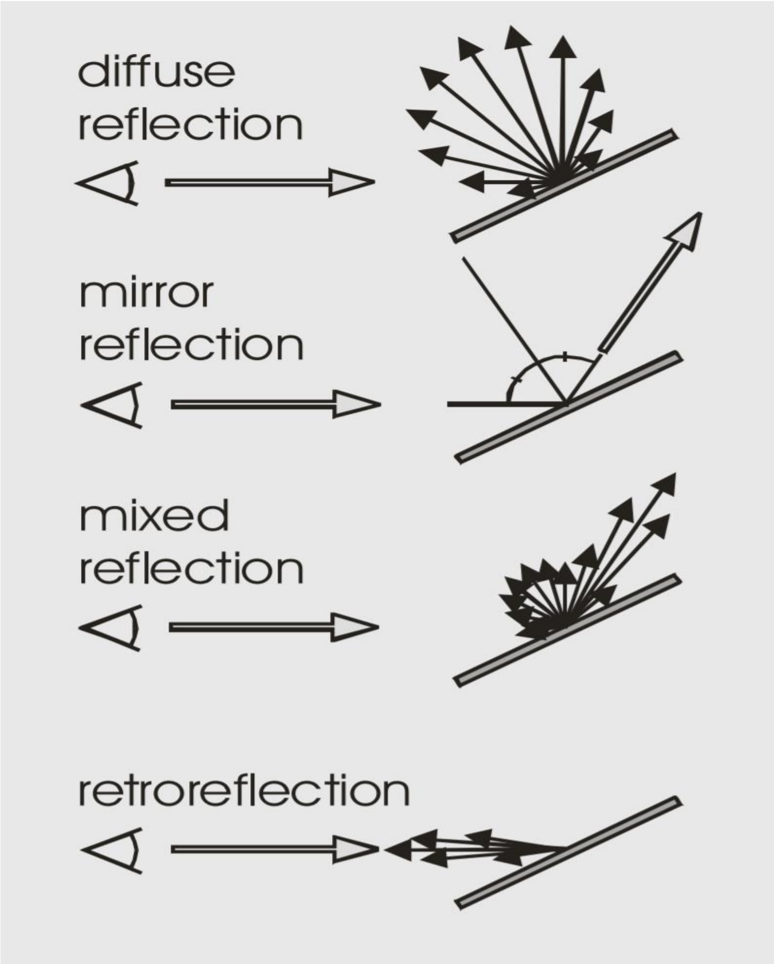


# SUMMARY

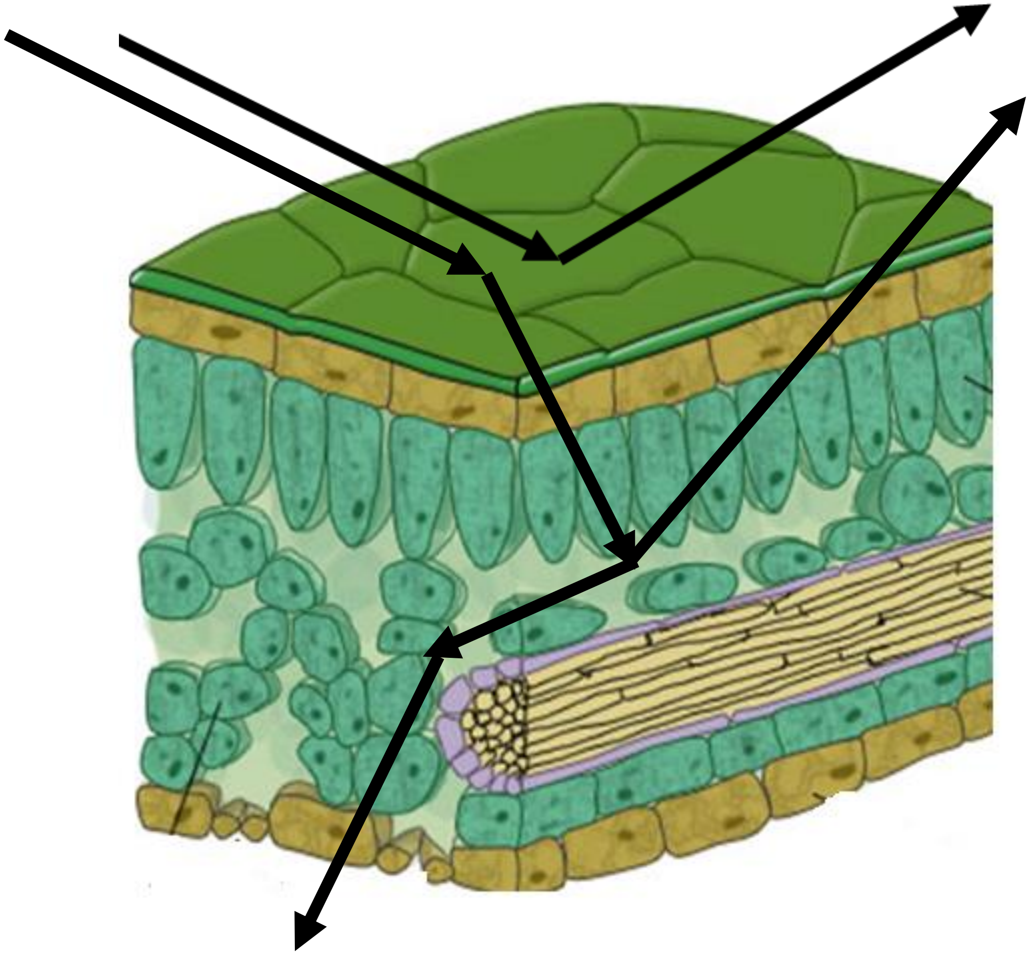
- RTMs explain the transfer and interaction of radiation inside leaf/canopy based on physical laws.
- The RTMs are sometimes combined to model a complex situation
- Complex models are more realistic, but they have many input variables and are therefore hard to be utilized
- Simple models may be less realistic but easier to use due to limited number of input parameters
- To use these models to estimate vegetation variables they need to be inverted.

# TYPES OF REFLECTIONS



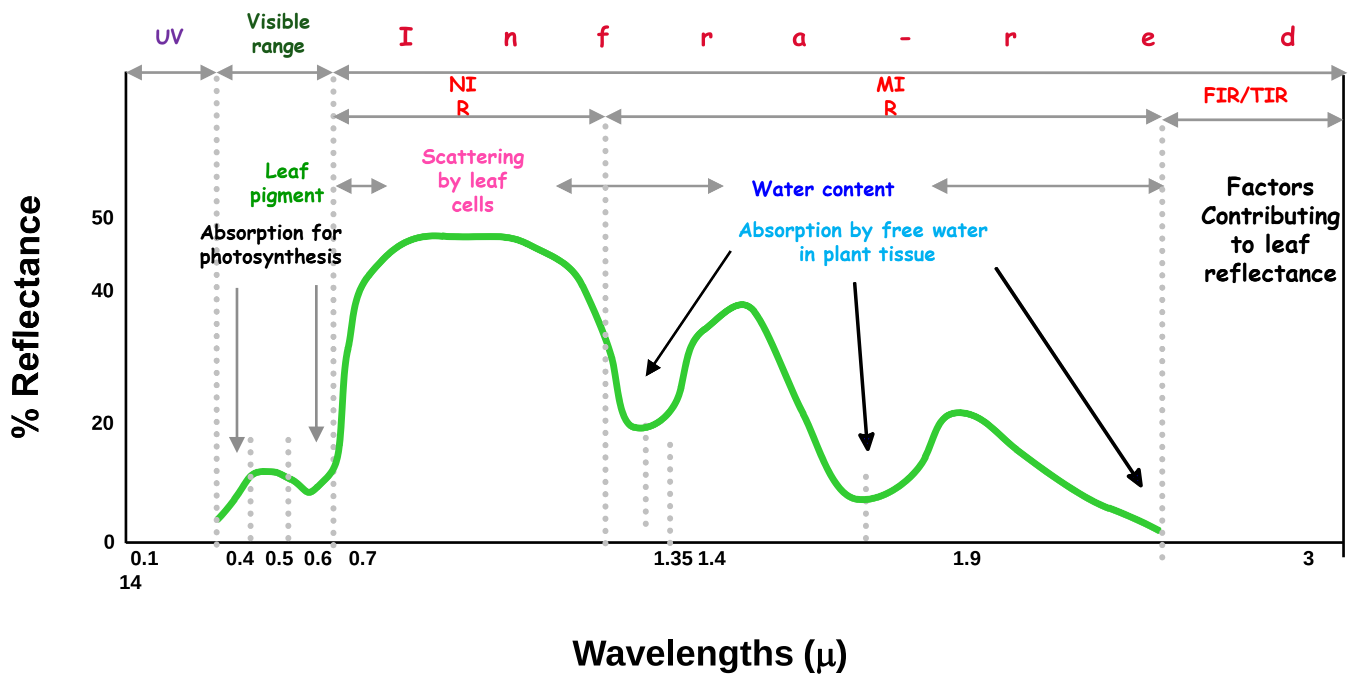
# SCATTERING PROPERTIES OF LEAVES

- Specular from surface smooth (waxy) surface: strong peak
  - ➢ hairs, spines: more diffused
- Variation of refractive index: 1.5@400 nm; 1.3@2500nm
- Complex structure (thickness)
  - ➢ more scattering
  - ➢ lower transmittance
  - ➢ more diffuse



Diffused from scattering at internal air-cell wall interfaces

# Spectral reflectance of healthy, green vegetation



# Refractive index/ Index of refraction

- Measure of bending of a ray of light when passing from one medium to another one.

- Refractive index (n) is described as ratio of the sine of the angle of incidence to the sine of the angle of refraction.

$$n = \sin i / \sin r$$

- Is also equal to the velocity of light (c) at a wavelength in empty space (vacuum) divided by its velocity (v) in a substance

$$n = c/v$$