SAIL-thermique, a model to simulate land surface emissivity (LSE) spectra

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INRA SCIENCE & IMPACT

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Introduction

- ❑ **Land Surface Emissivity (LSE) is required for deriving Land Surface Temperature (LST)**

- ❑ **Emissivity spectra are required for:**
  - **→ interpreting atmospheric sounding from hyperspectral TIR sensors (AIRS, IASI)**
  - **→ analyzing relation with surface and vegetation moisture, plant chemistry (?)**
  - **→ species identification (?) -> specific spectral features**

- ❑ **There is very few available information on LSE and spectral LSE**

  except from multispectral TIR sensors as ASTER and few leaf samples in spectral libraries

  (measurements are complex and up to recently only geologists were interested)

- ❑ **Few models of LSE accounting for vegetation canopy characteristics exist**

  (eg. Anton and Ross 1990, Olioso 1992, Snyder and Wan, 1998, 4SAIL Verhoef et al. 2007…)

- ❑ **None (?) of them was evaluated against data**

Recent progress

- Hyperspectral and multispectral sensors
  - → ASTER, MODIS,…
  - → IASI, AIRS…
    - ⇒ Spectral LSE maps, better than older climatologies (?)
  - → future missions : HysPIRI, ECOSTRESS, IASI-2, TRISHNA… => better accuracy is expected

- Spectral libraries
  - → ASTER and MODIS spectral libraries provided first information
    - ⇒ almost all LSE and LST extraction algorithms
  - → new information on
    - ⇒ spectra for leaf of various plant species
    - ⇒ emissivity spectra changes with moisture level (leaf and soil)
    - ⇒ leaf spectra model in 0.4 - 5.7 µm range (PROSPECT-VISIR, Gerber et al. 2012)

- LSE models
  - → coherent results between different LSE models

But still no evaluation against data and not used for extracting LSE or build LSE maps

Hypothesis

- ❑ It is possible to use "standard" Radiative Transfer models for simulating land surface emissivity in presence of vegetation canopy

But

- ❑ Previous model evaluation were only done by comparison to other models

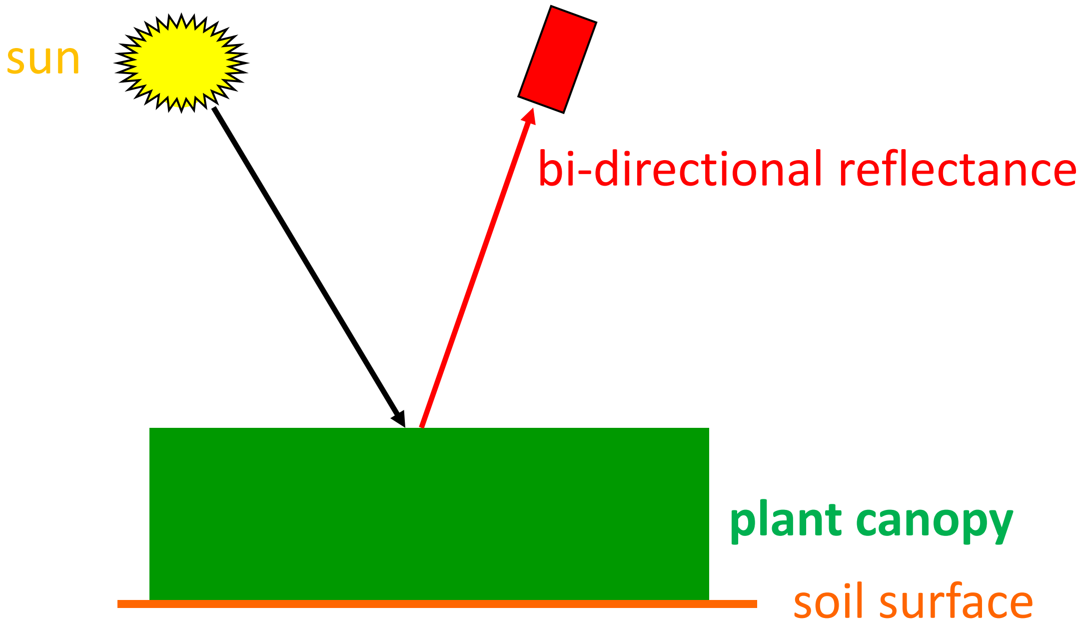
  (ex: François et al., 1997, Guillevic et al., 2003, Sobrino et al., 2005, Ren et al. 2015…)

- ❑ We have to evaluate modeled land surface emissivity against in-situ measurements

In this talk:

- → Presentation of the SAIL-Thermique land surface emissivity model
- → Test of the model against ground data
- → One example of application of the model for the (re-)evaluation of the Temperature-Emissivity-Separation algorithm (TES)

SAIL model (Verhoef 1984-1985)



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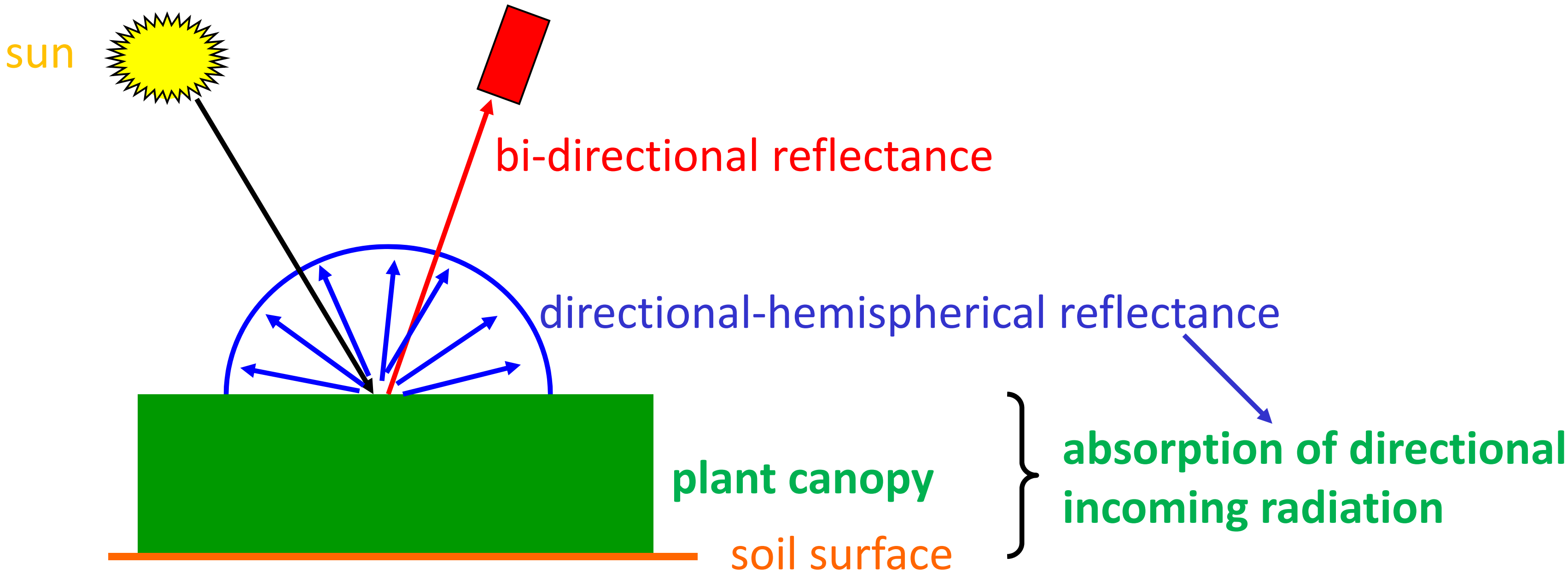

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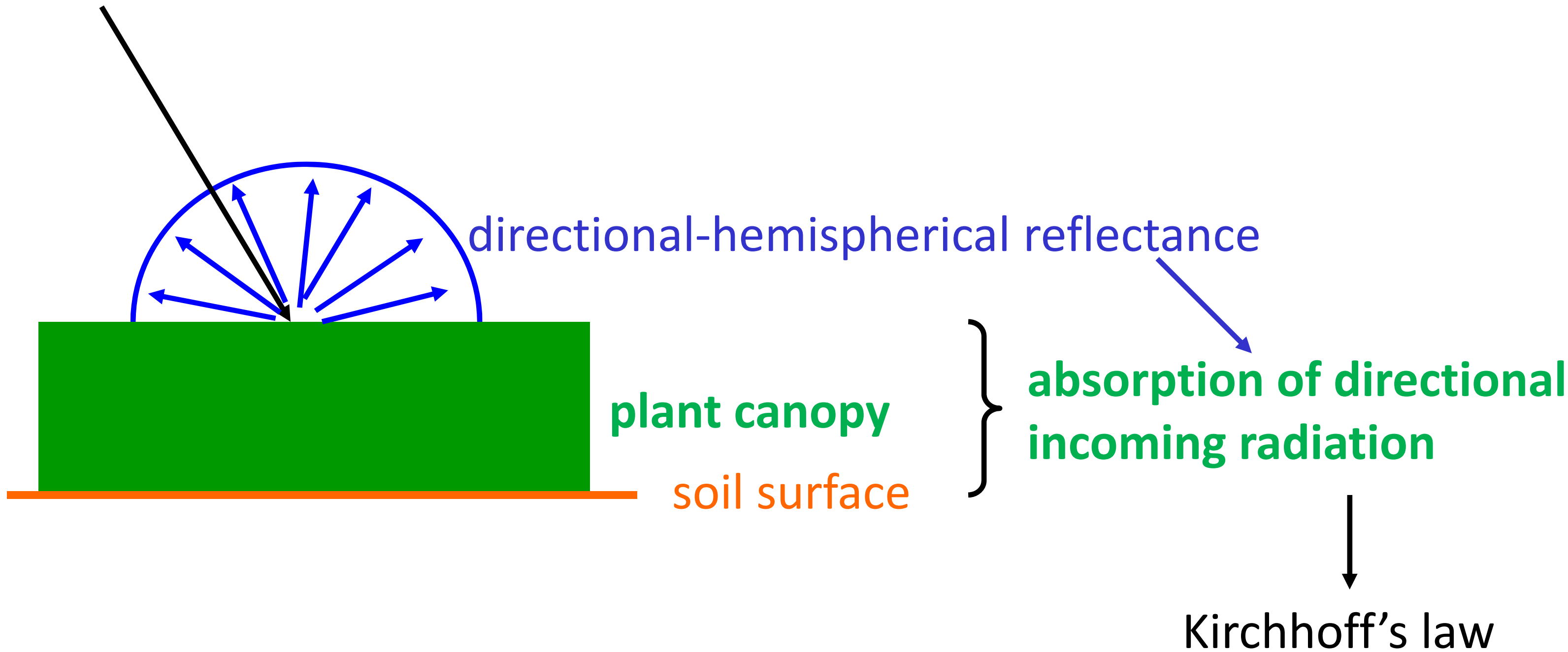

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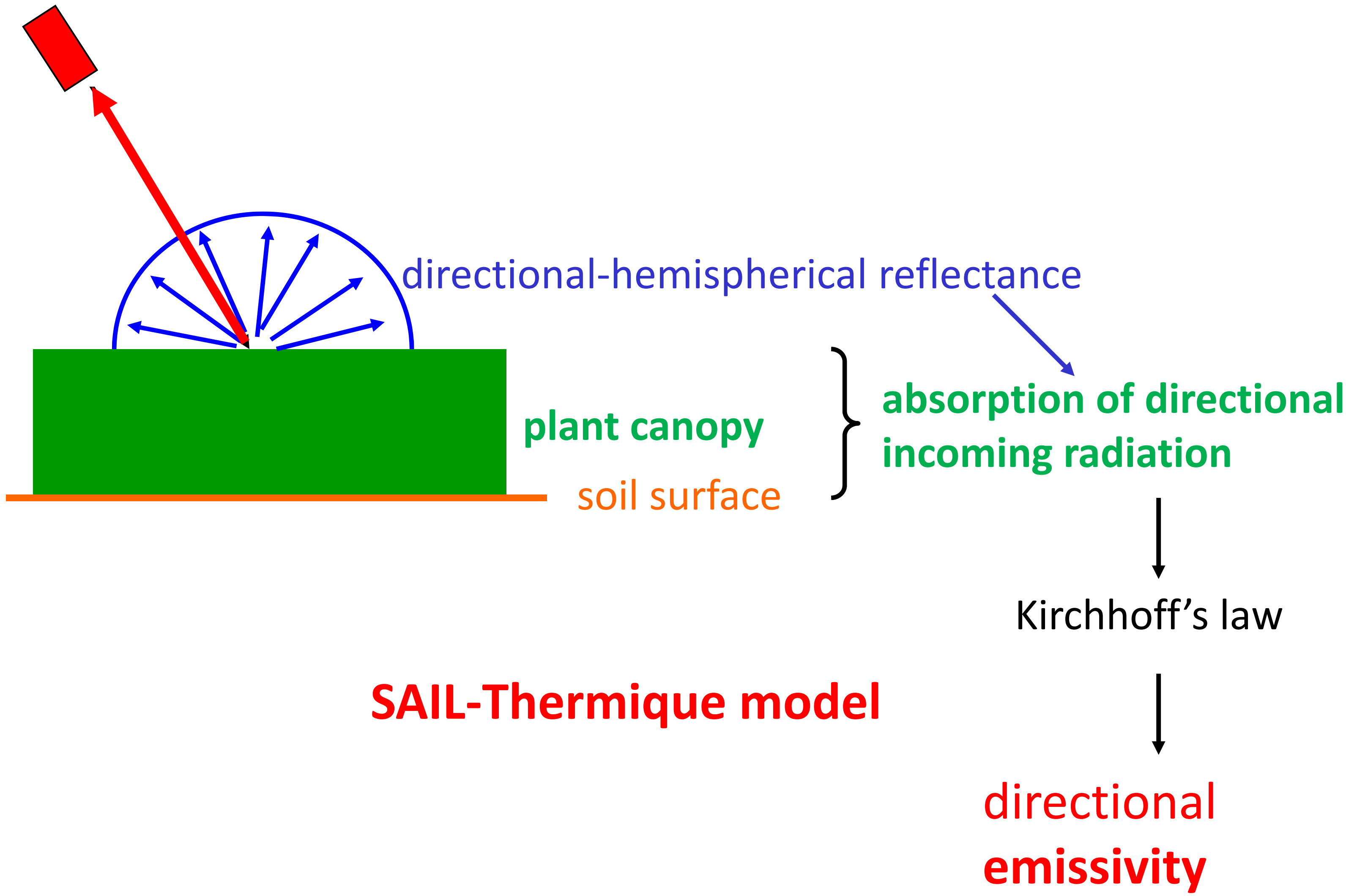


Inputs and outputs of the SAIL and the SAIL-Thermique models

	SAIL	SAIL-Thermique
Inputs	• LAI • mean leaf angle • leaf/stem reflectances • leaf transmittance • soil reflectance • geometry of observation • Sun position	• LAI • mean leaf angle • leaf/stem reflectances • leaf transmittance • soil reflectance • geometry of observation
Outputs	•spectral reflectances •NDVI •absorption of solar radiation (and albedo)	•land surface emissivity • absorption of thermal radiation by vegetation and soil

One (strong) hypothesis: horizontaly homogeneous canopy

but {
→ several superposed horizontal layers
→ several vegetation elements can be mixed

Test of the model: datasets -> LSE data

- **Bibliographic data:**
  van de Griend and Owe (1993), Valor and Caselles (1996), Sugita et al. (1996)

- **Available database including ground measurements of land surface emissivity :**
  DAISEX, Alpilles-ReSEDA, WATERMED

- **Original data in Avignon and Camargue (HyEurope 2007)**

- **Most measurements done using the box method (few by using 'TES')**
  - → **8-14 or 8-13 µm**
  - → **1, 4 or 6 bands**

-> overall: ~100 individual data points !!

- **Comparison to LES simulated using 4SAIL (Verhoef et al. 2007)**

Test of the model: datasets

❑ LAI (measured or 'approximated' by NDVI)

In most cases:

❑ no leaf angle

❑ no leaf optical properties

=> stochastic simulations

→ direction of observation = nadir

→ LAI: uniform distribution [0 – 6]

→ mean leaf angle : uniform distribution [45° - 70°]

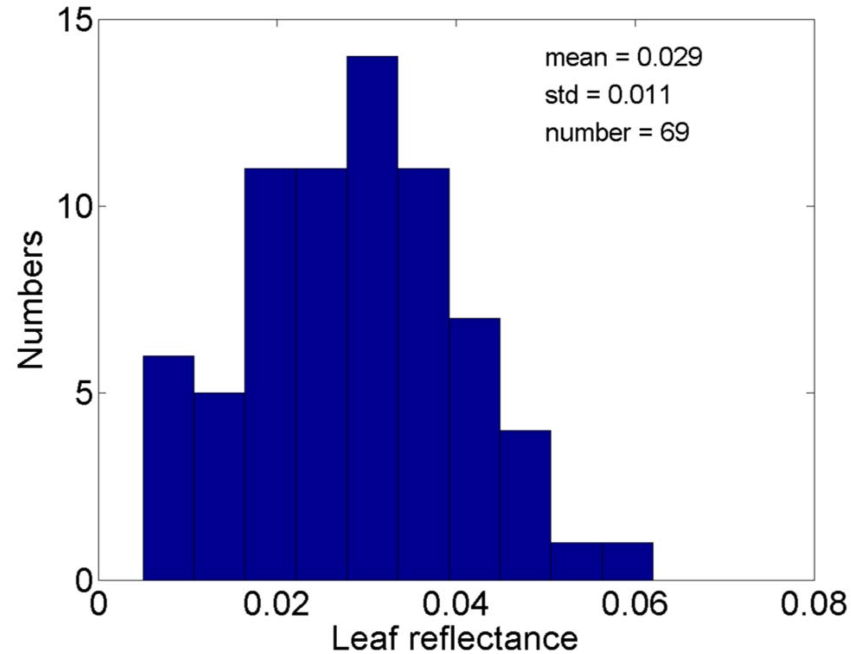
→ leaf properties: - normal distribution of reflectances with [mean 0.029 and std 0.011]

- transmittance set to 0

Test of the model: datasets

→ leaf reflectance : normal distribution with [mean 0.029 and std 0.011]

leaf optical property data:
- ASTER spectral library
- MODIS spectral library
- Fuchs and Tanner 1966
- Idso et al. 1969
- Wang et al. 1994
- Coll et al. 2001



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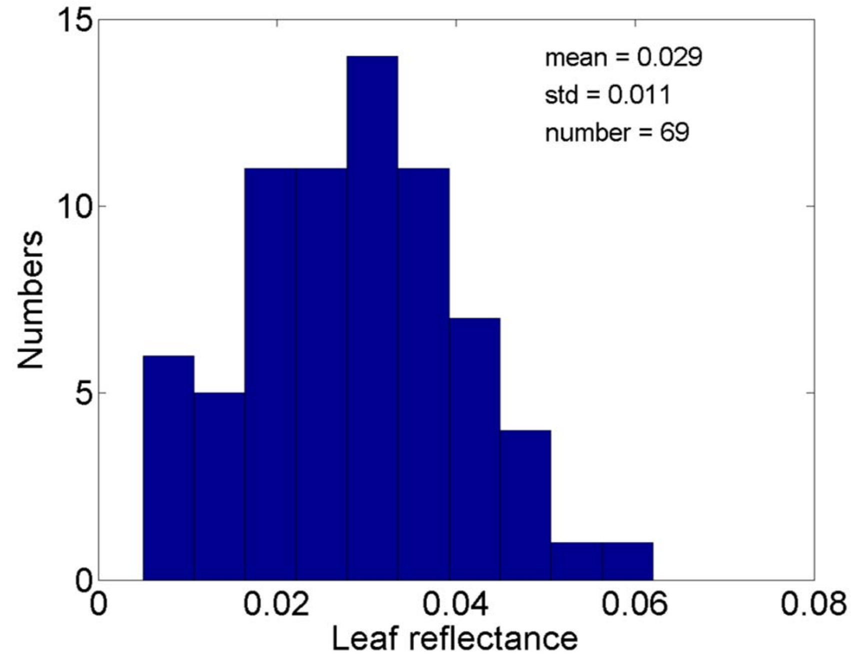

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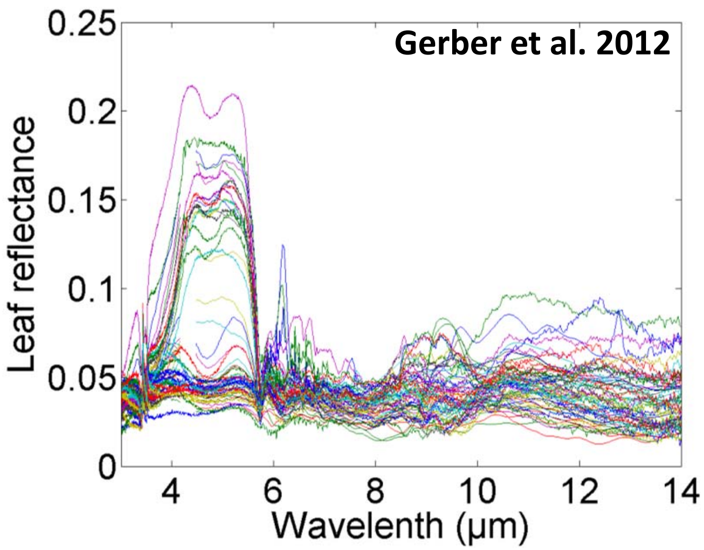
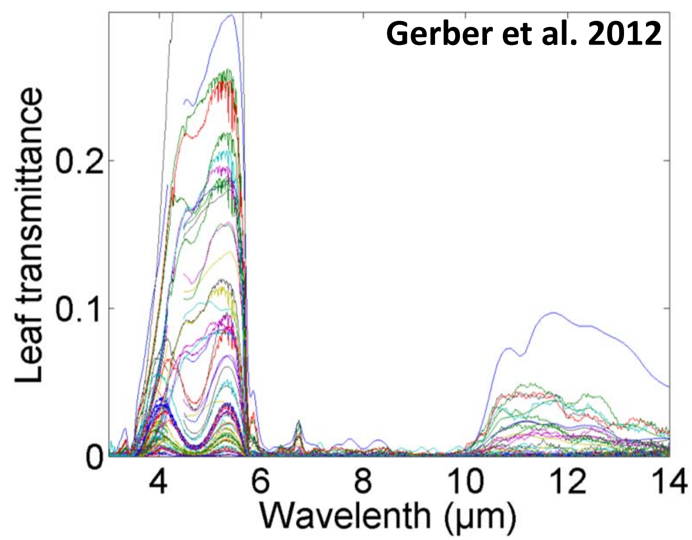
new leaf optical property data:
- Gerber et al. 2012
- Fabre et al. 2012





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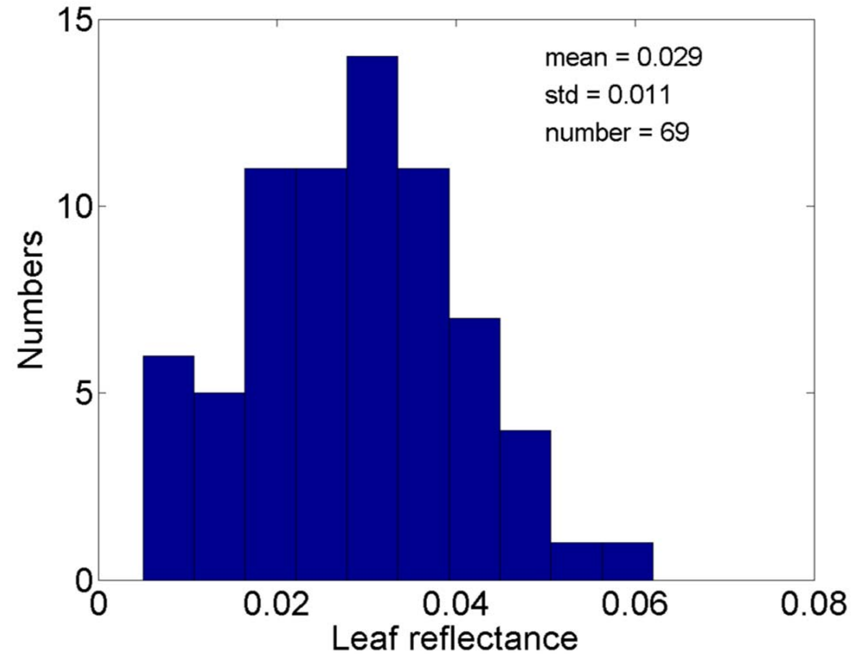

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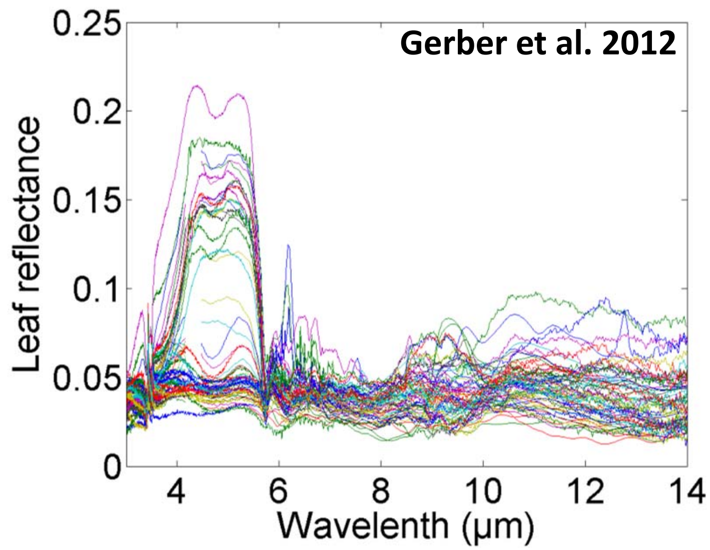

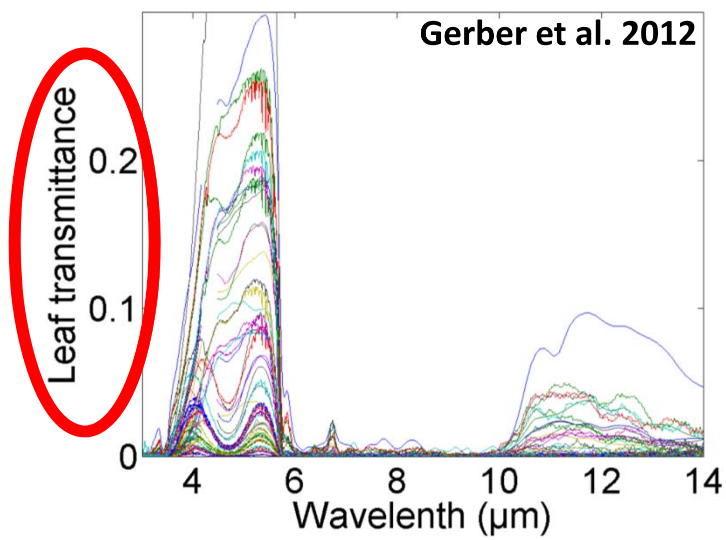

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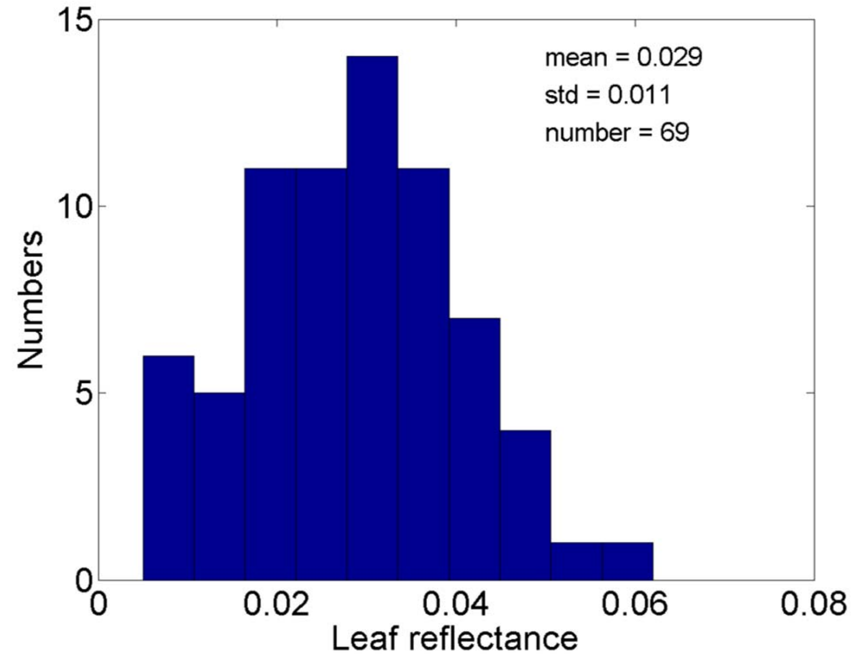

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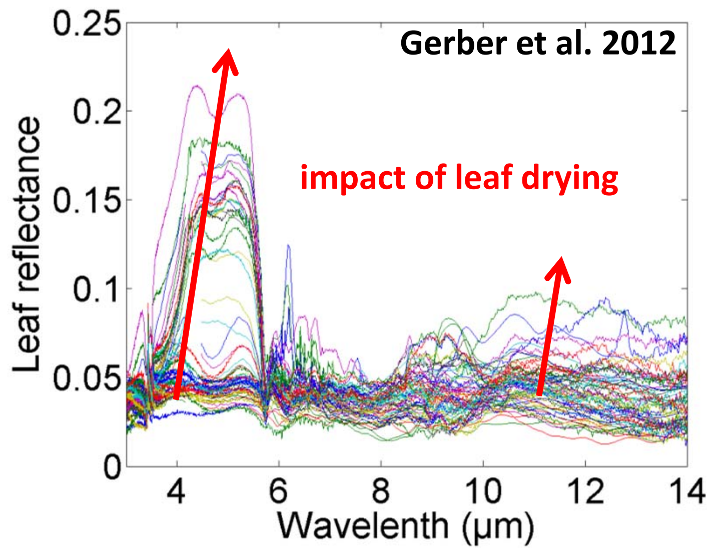
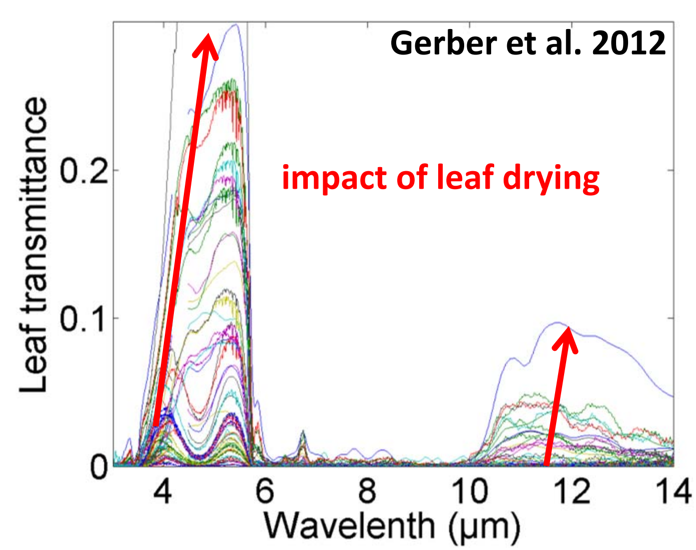
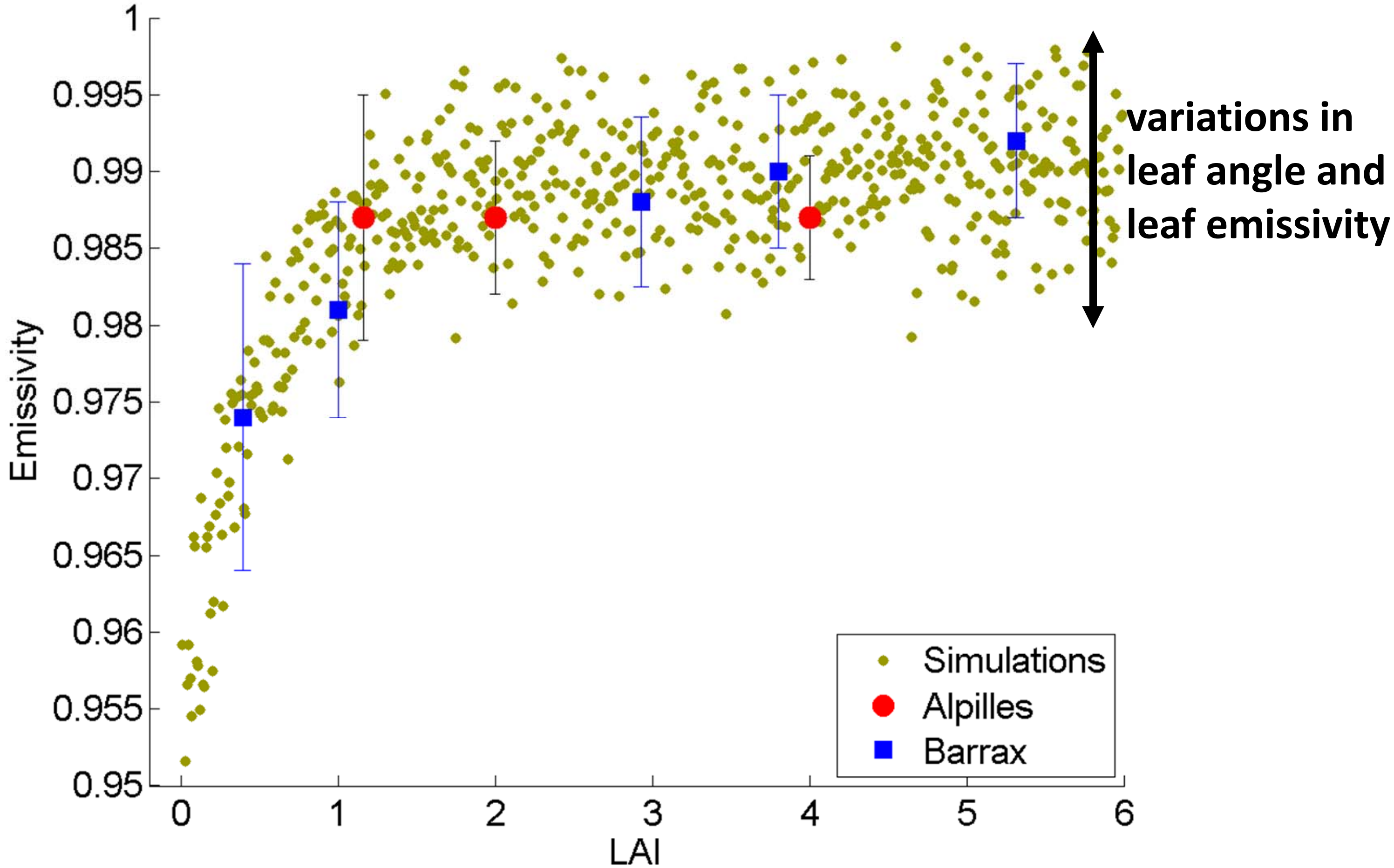


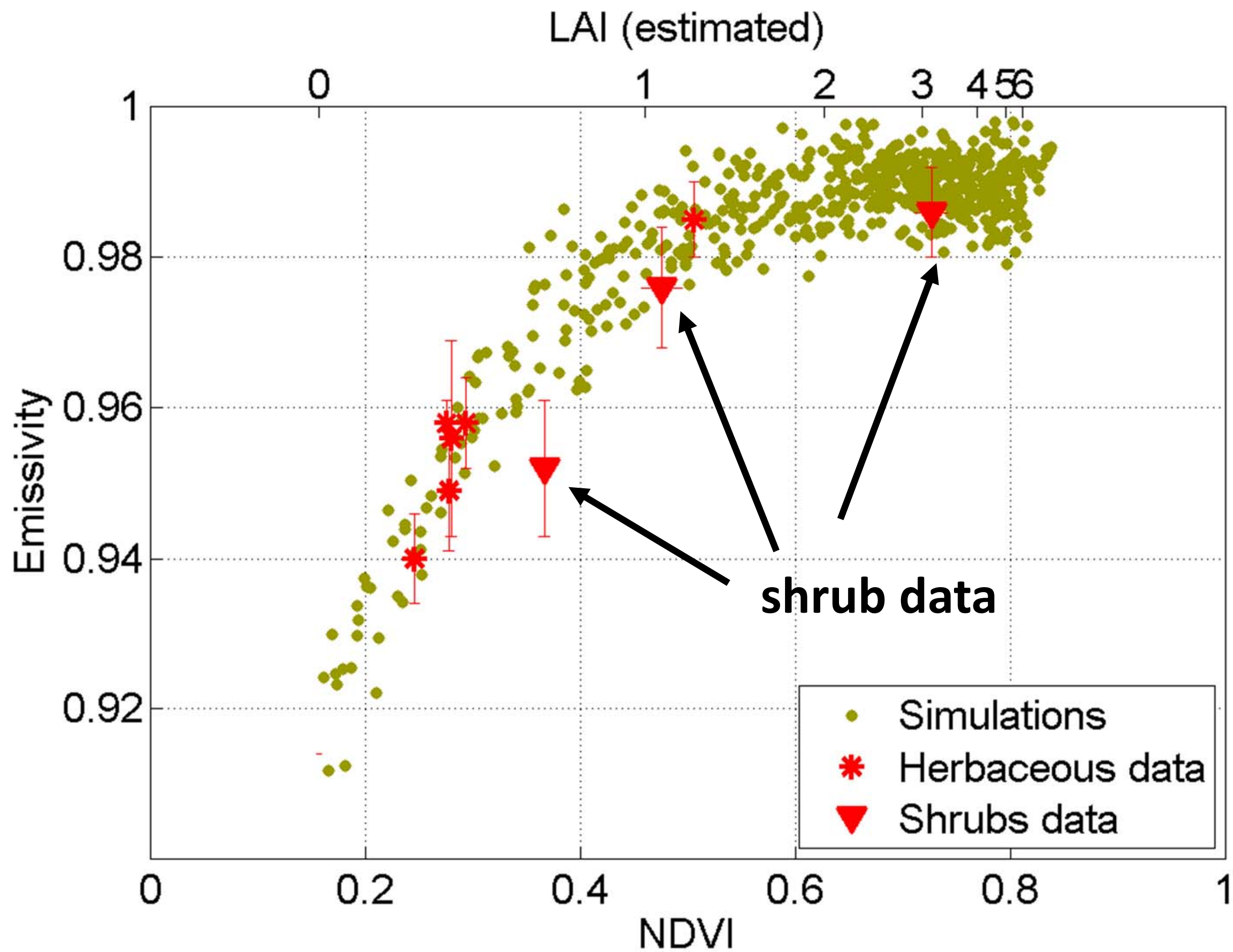


Evaluation of SAIL-Thermique: Alpilles + Barrax (8-14 µm) [crops]



Evaluation of SAIL-Thermique: **van de Griend and Owe 1993 (8-14 µm)**

[herbaceous, shrubs]



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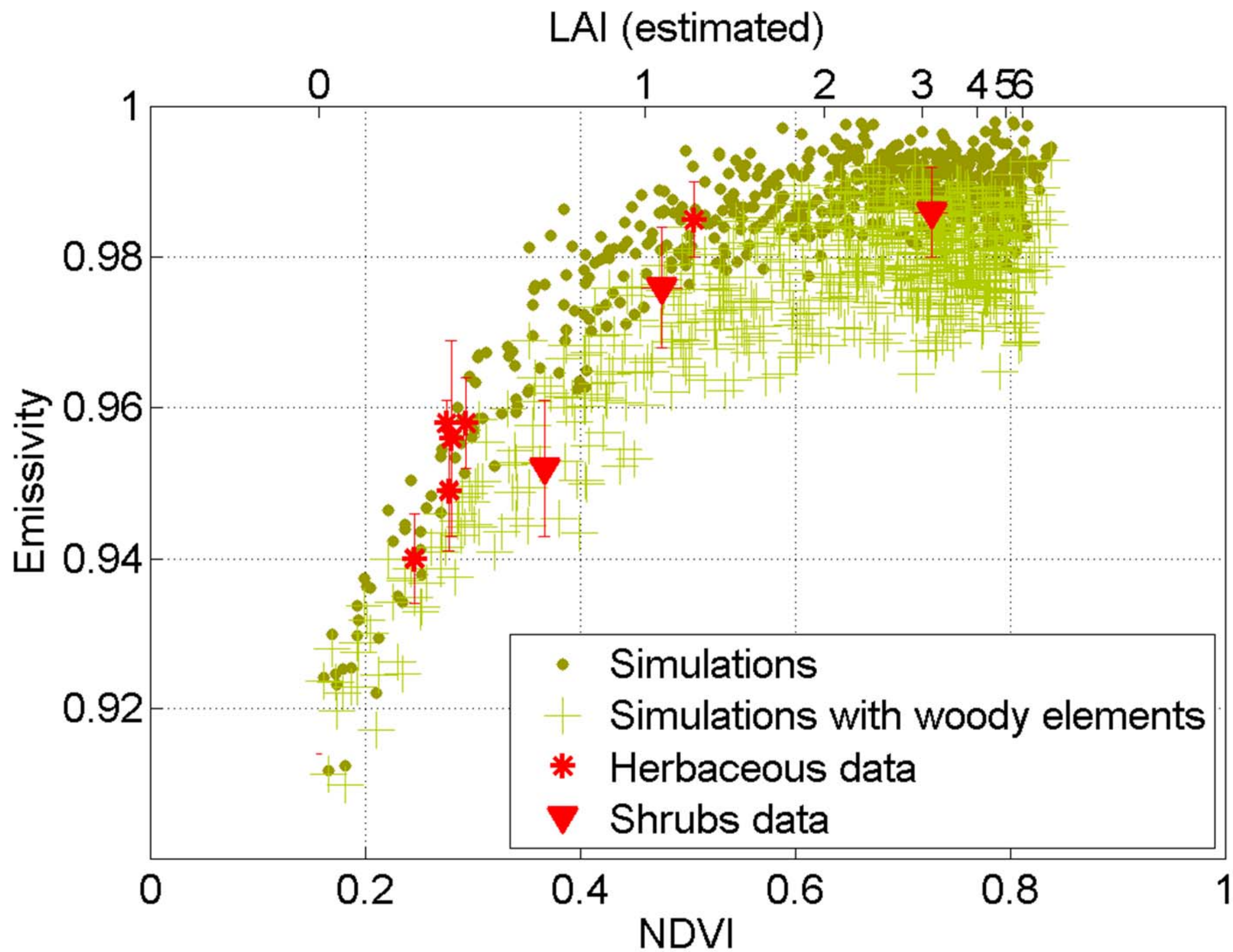
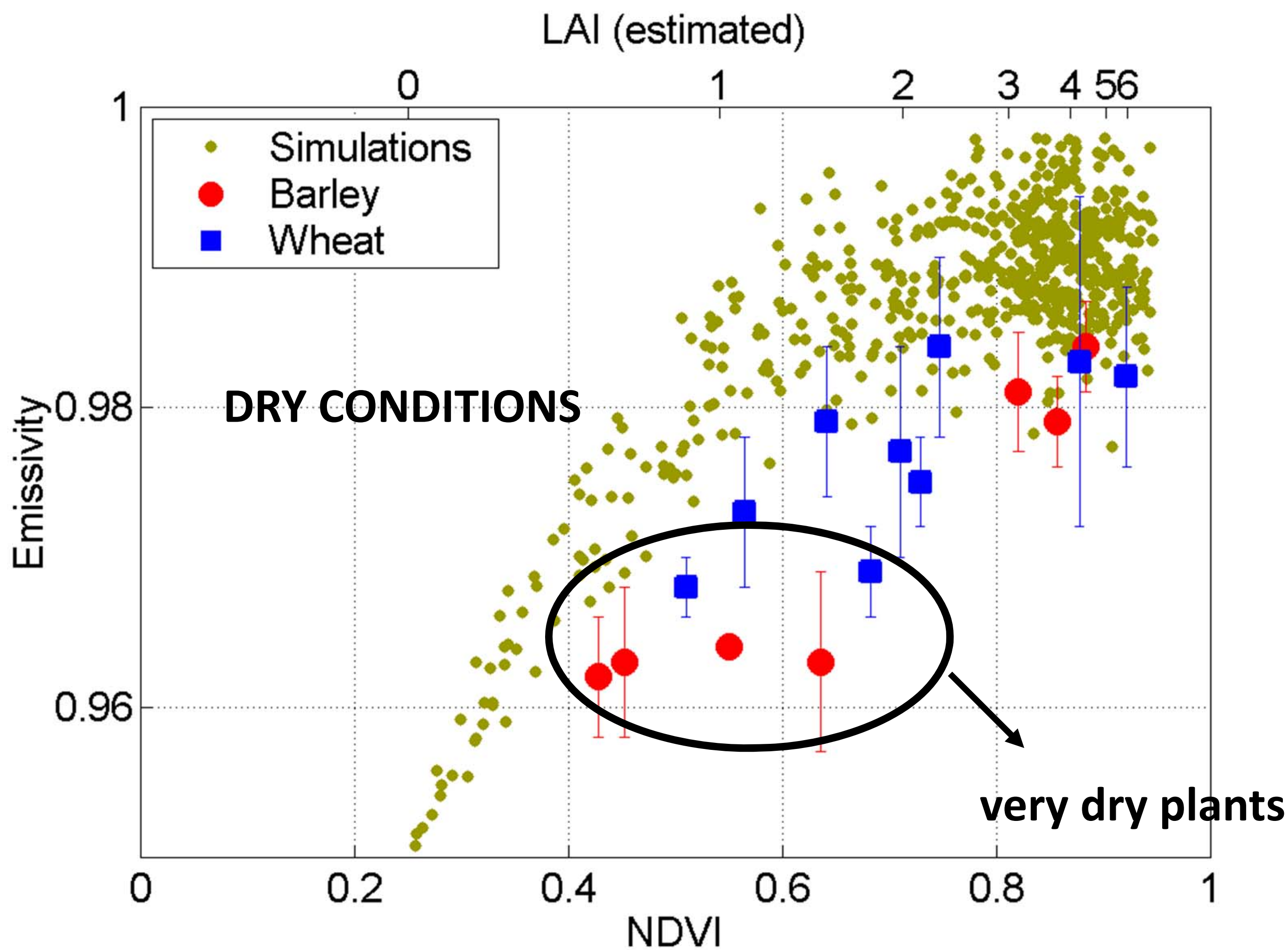
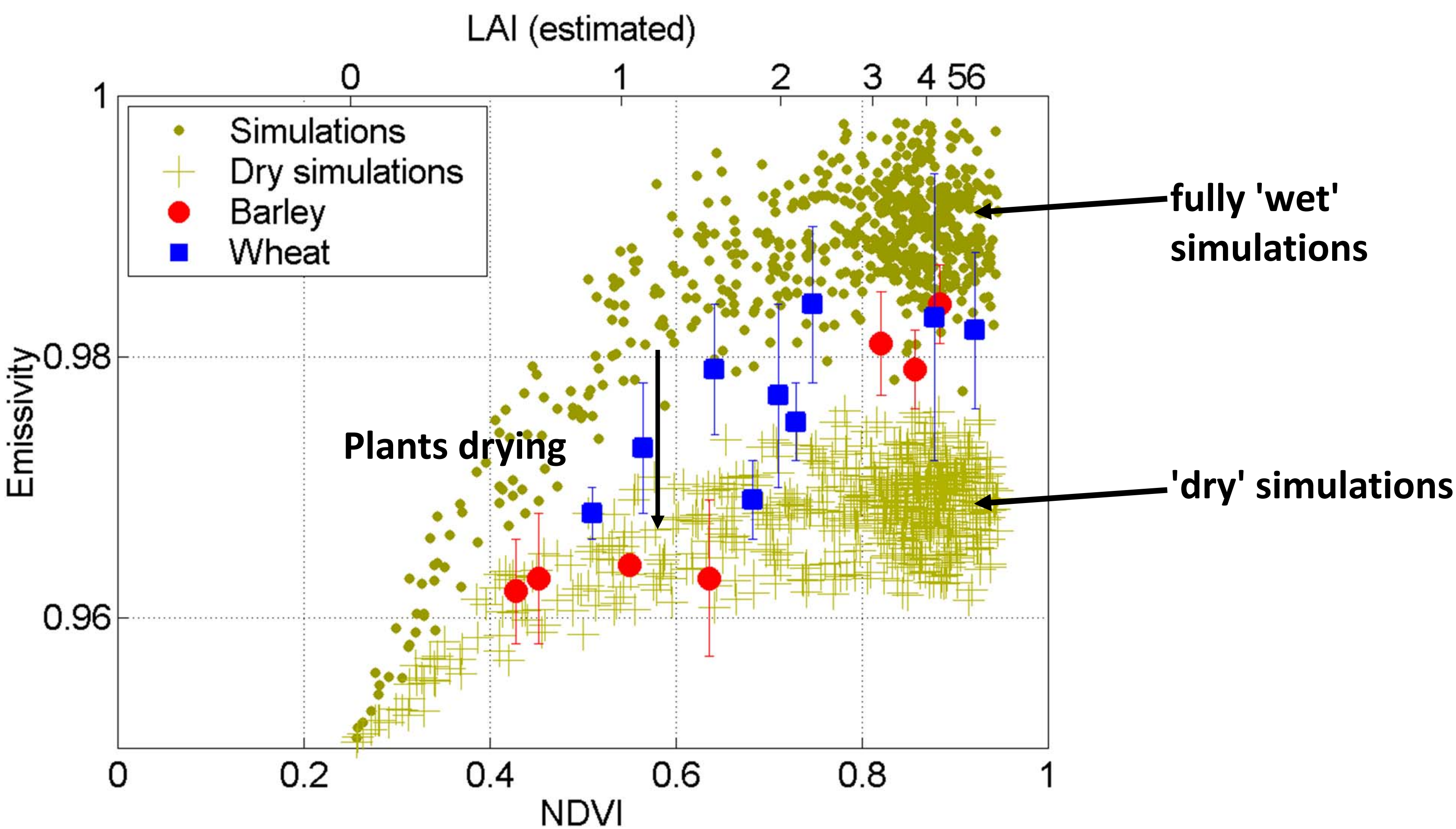


Evaluation of SAIL-Thermique: **Marrakech 2003 (8-13 µm)** **[dry cereals]**



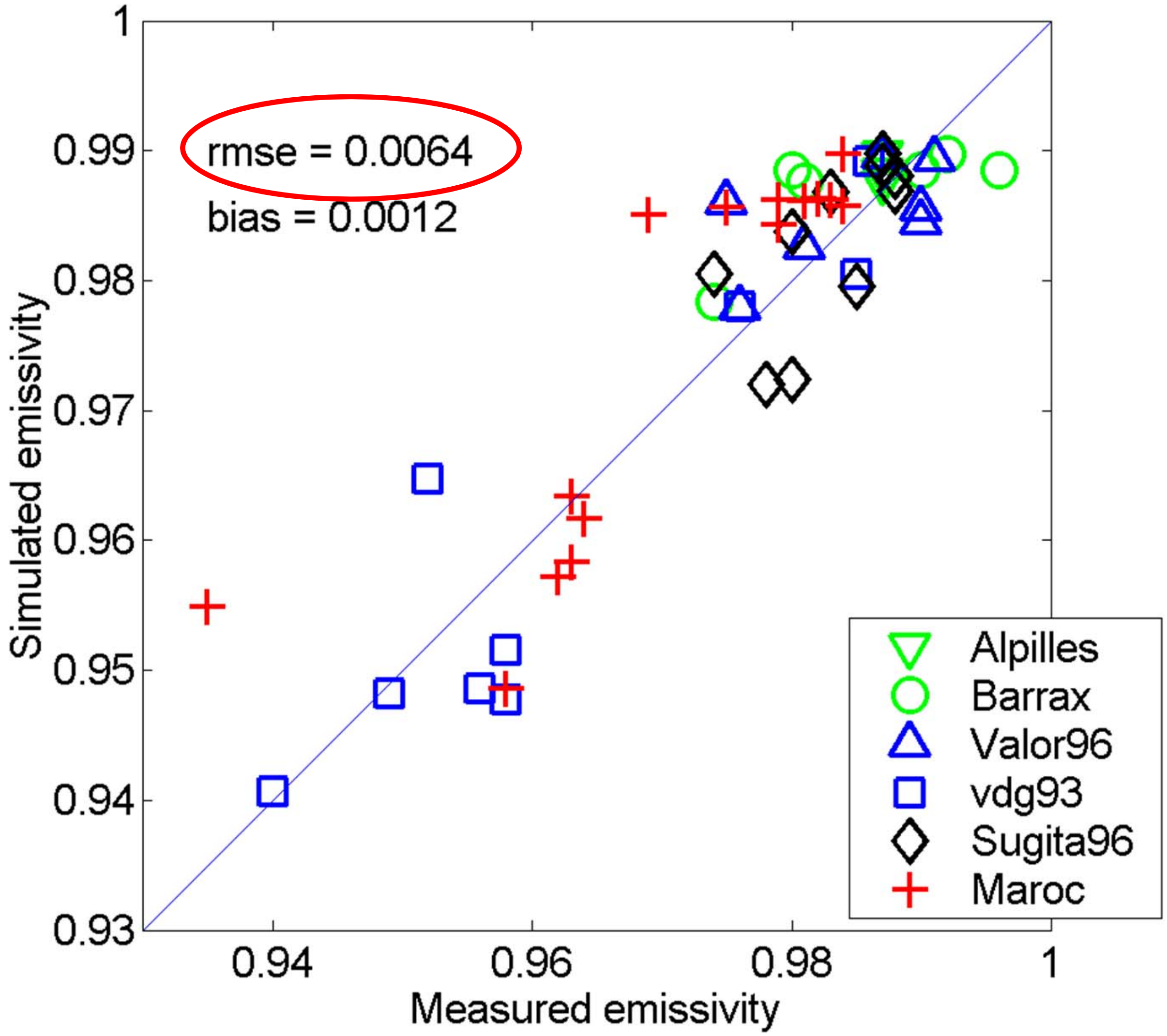
Impact of leaf drying

→ **leaf emissivity is lower for dry leaf**



All data together

simulation for mean values (leaf emissivity =0.97 (wet) and 0.91 (dry), spherical canopy)



Simulation of land surface emissivity spectra

- LSE spectra are used as background in many methods to estimate LSE value

  ex:
  - → the TES method for deriving surface temperature from multispectral data
  - → the spectral LSE atlas developped at University of Wisconsin

- There is no measurements of hyperspectral LSE really available for documentation or evaluation

- we propose to use SAIL-Thermique

- SAIL-Thermique is a monospectral model

- but it may be used for simulating emissivity at any TIR wavelength as soon as leaf and soil spectral properties are known

Simulation of land surface emissivity spectra

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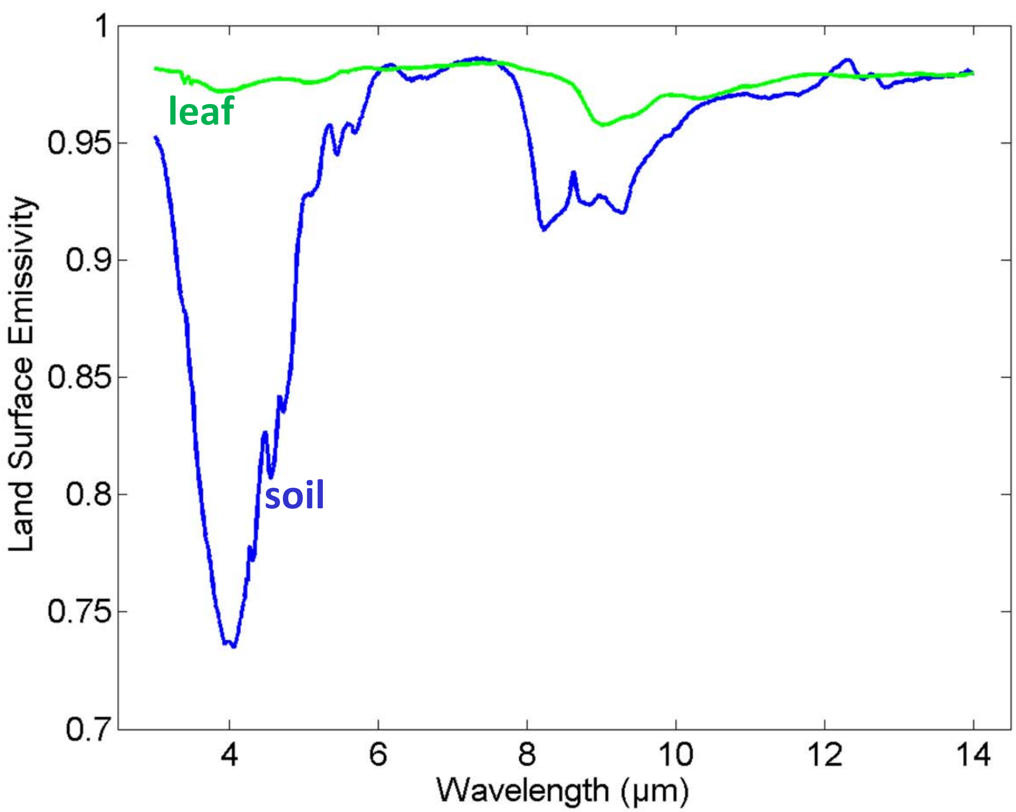

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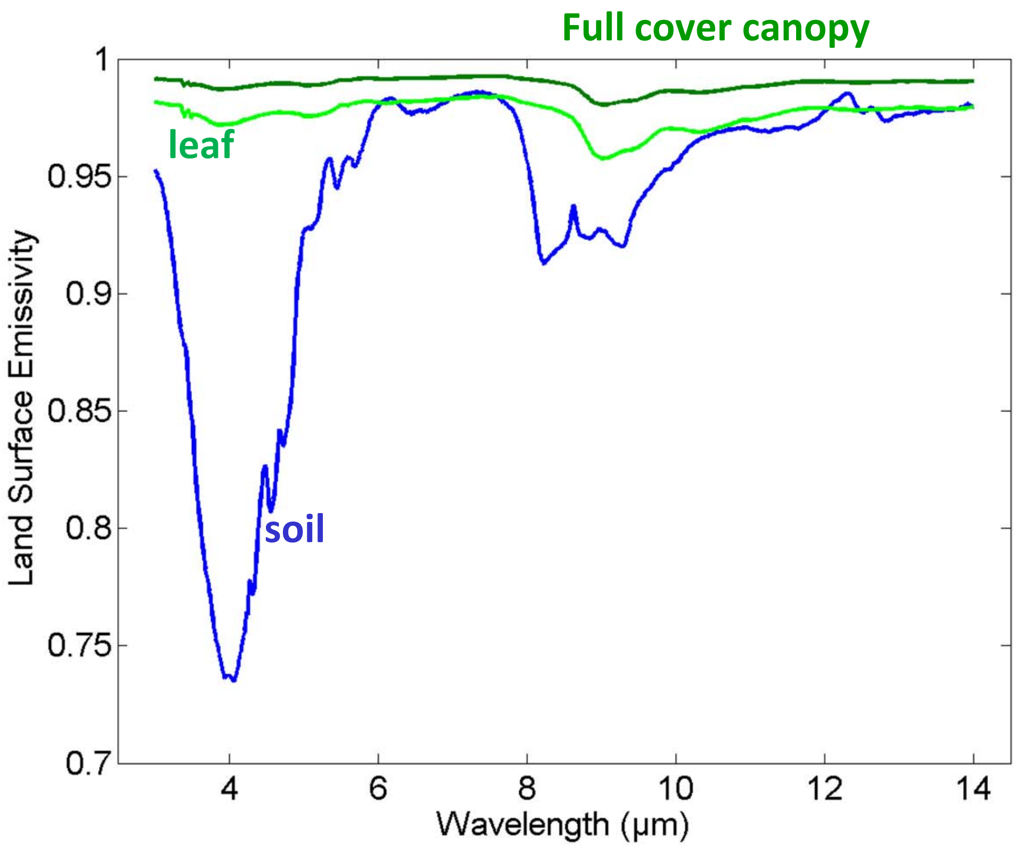

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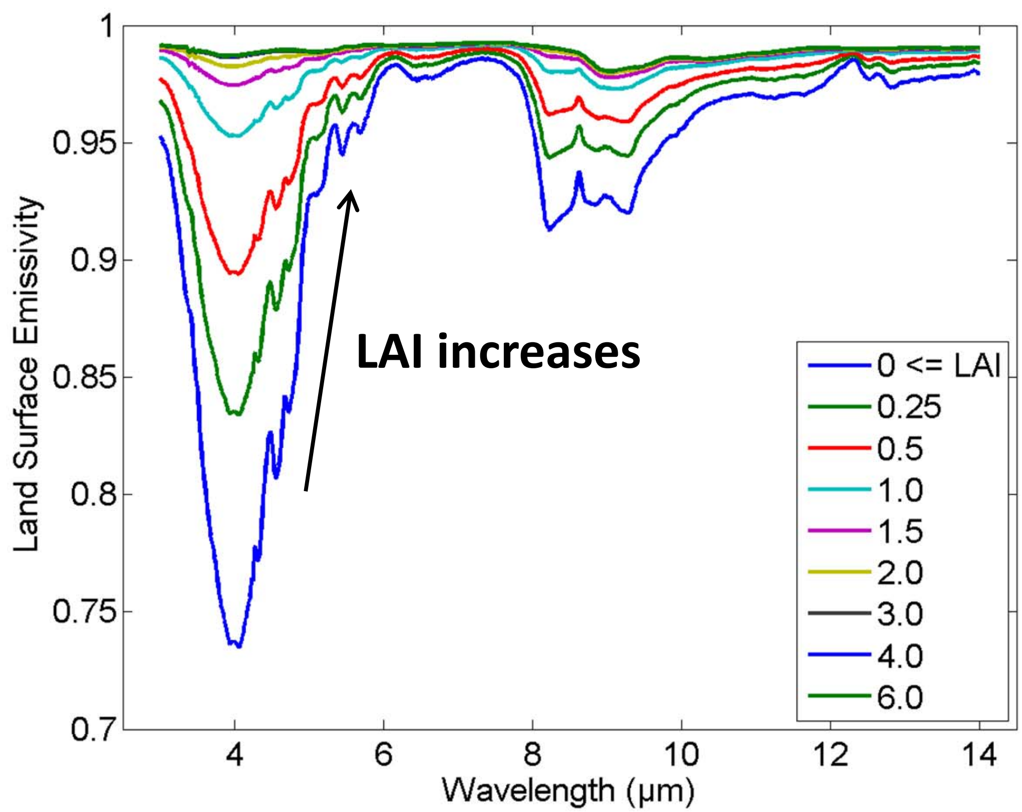
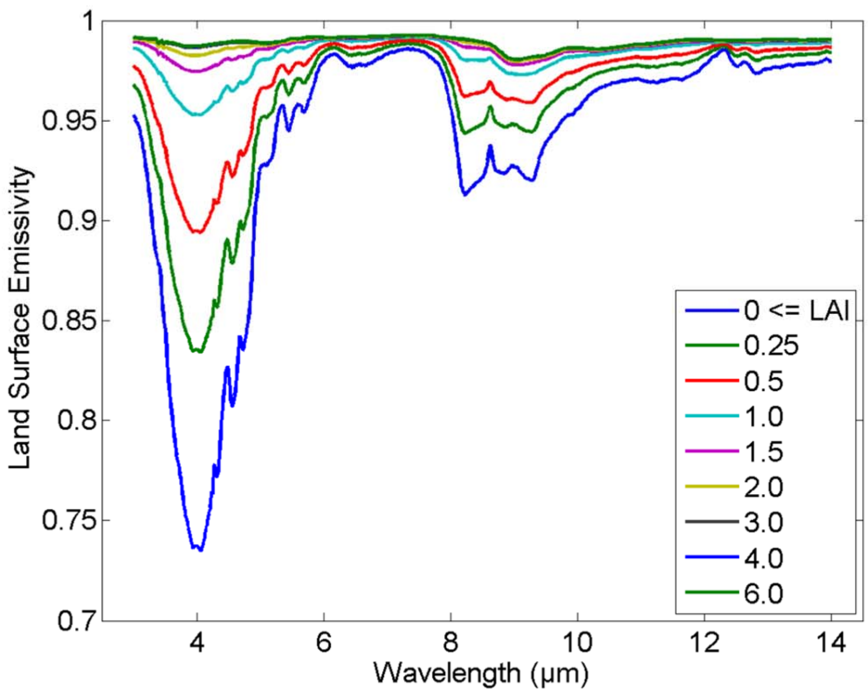
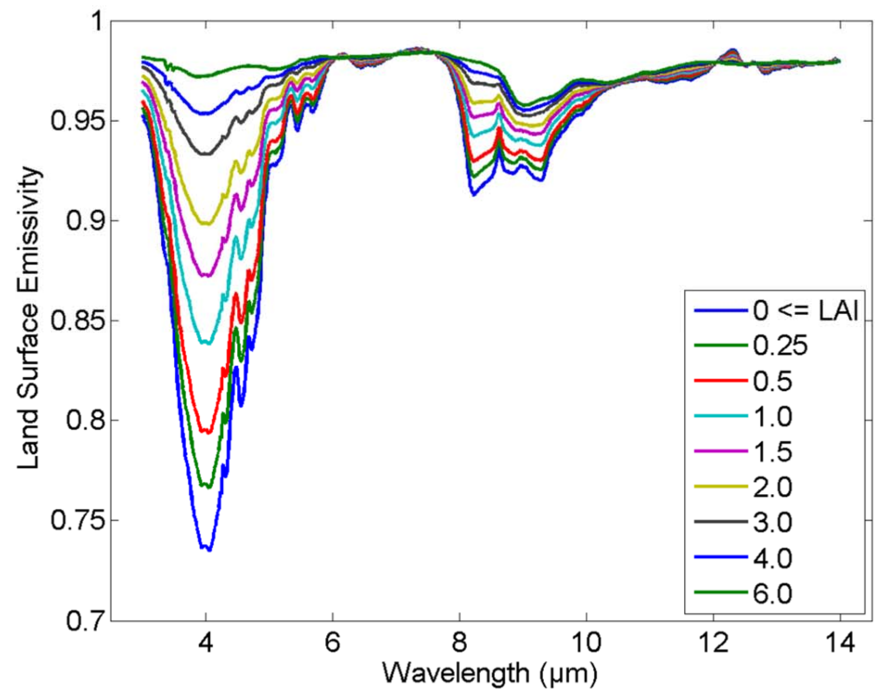


Comparison to standard linear mixing with soil and leaf samples

Radiative transfer calculations

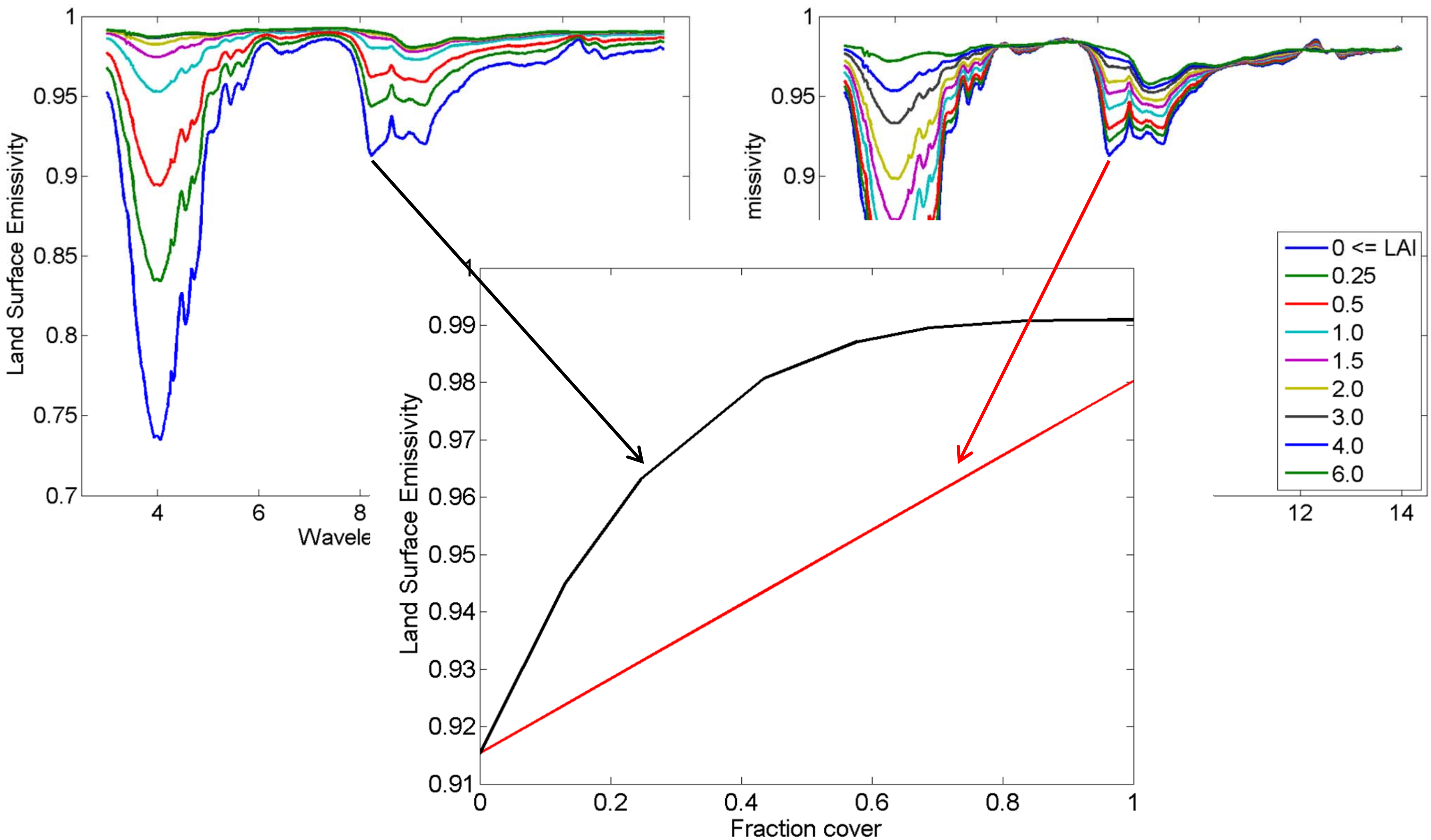


linear mixing from samples



Comparison to standard linear mixing with soil and leaf samples

Radiative transfer calculations | **linear mixing from samples**



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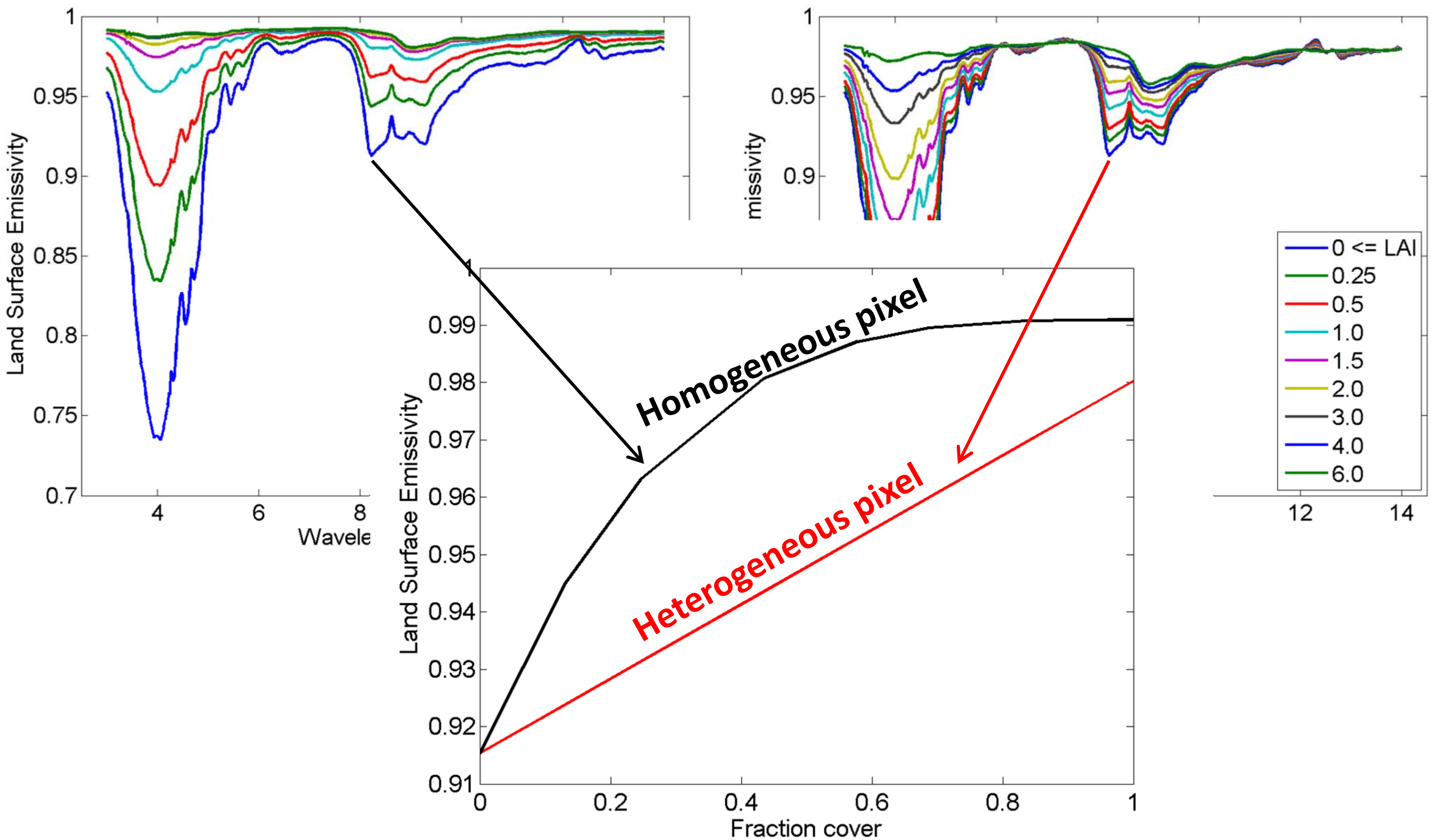

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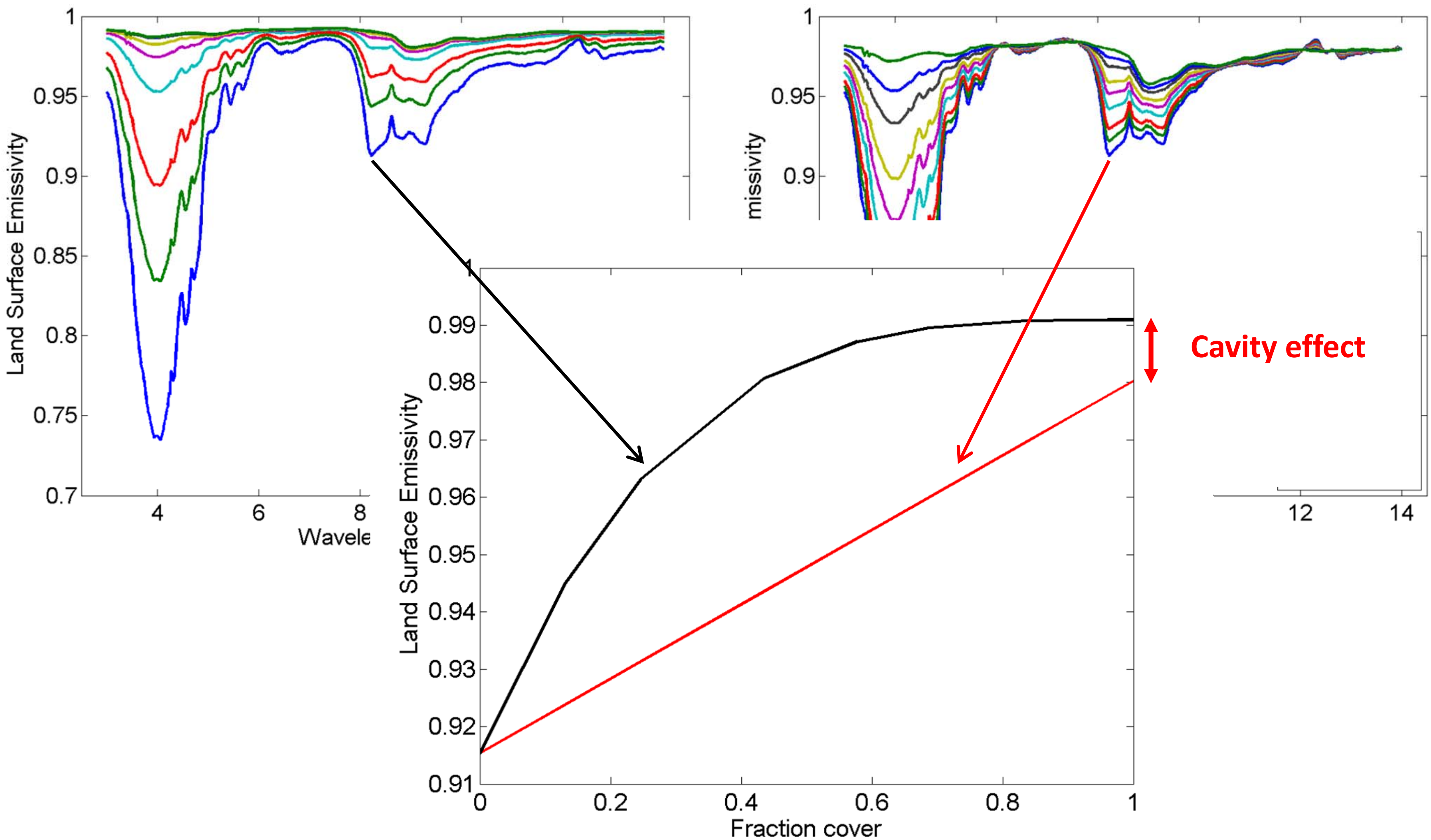

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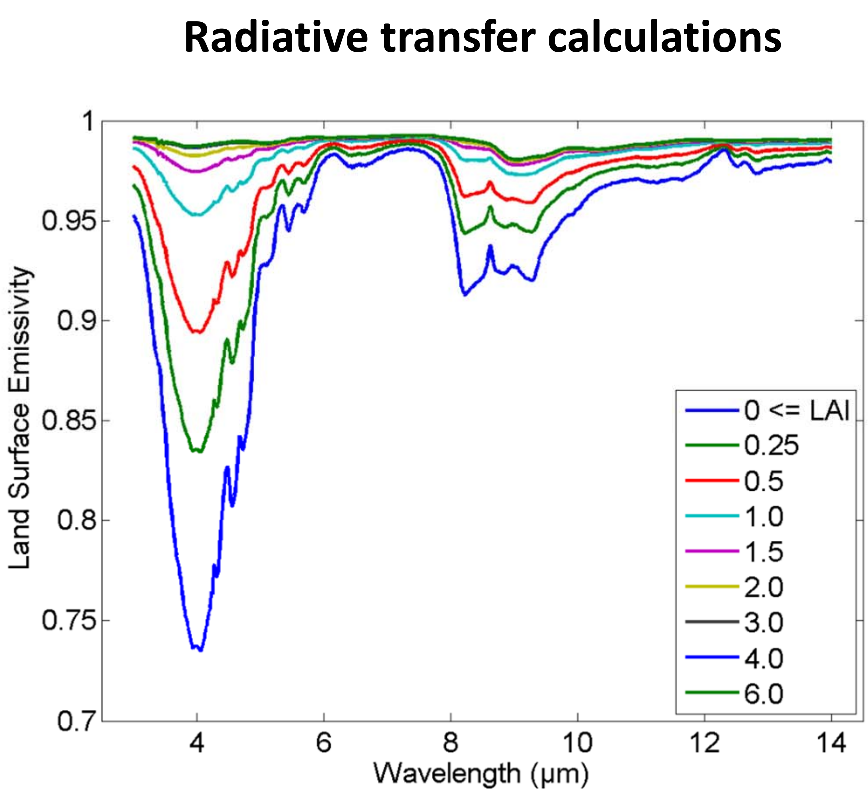

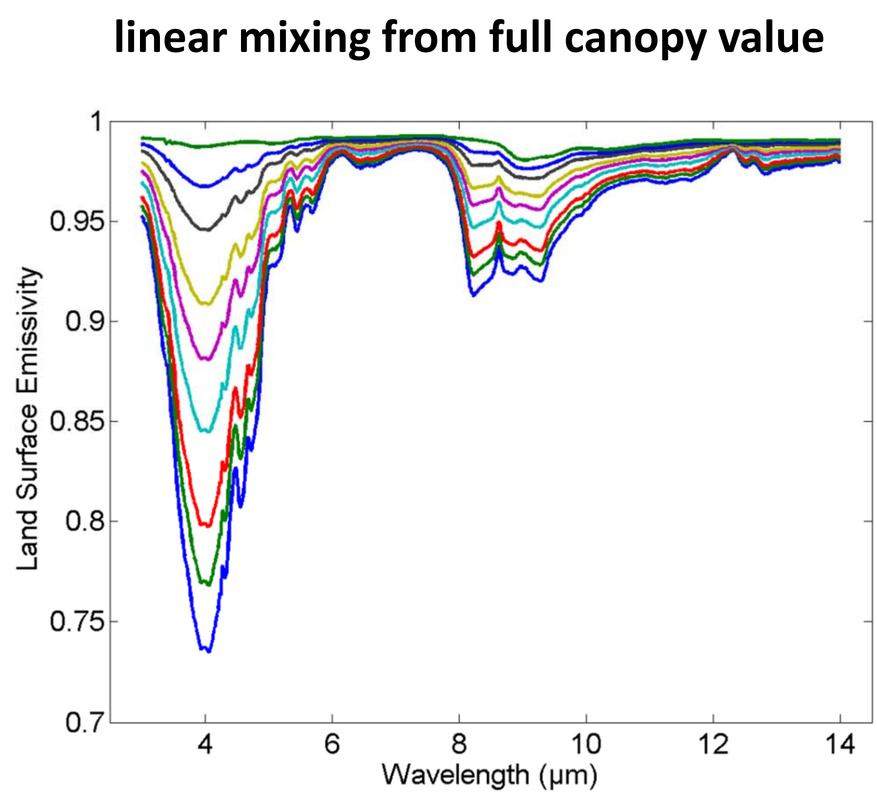

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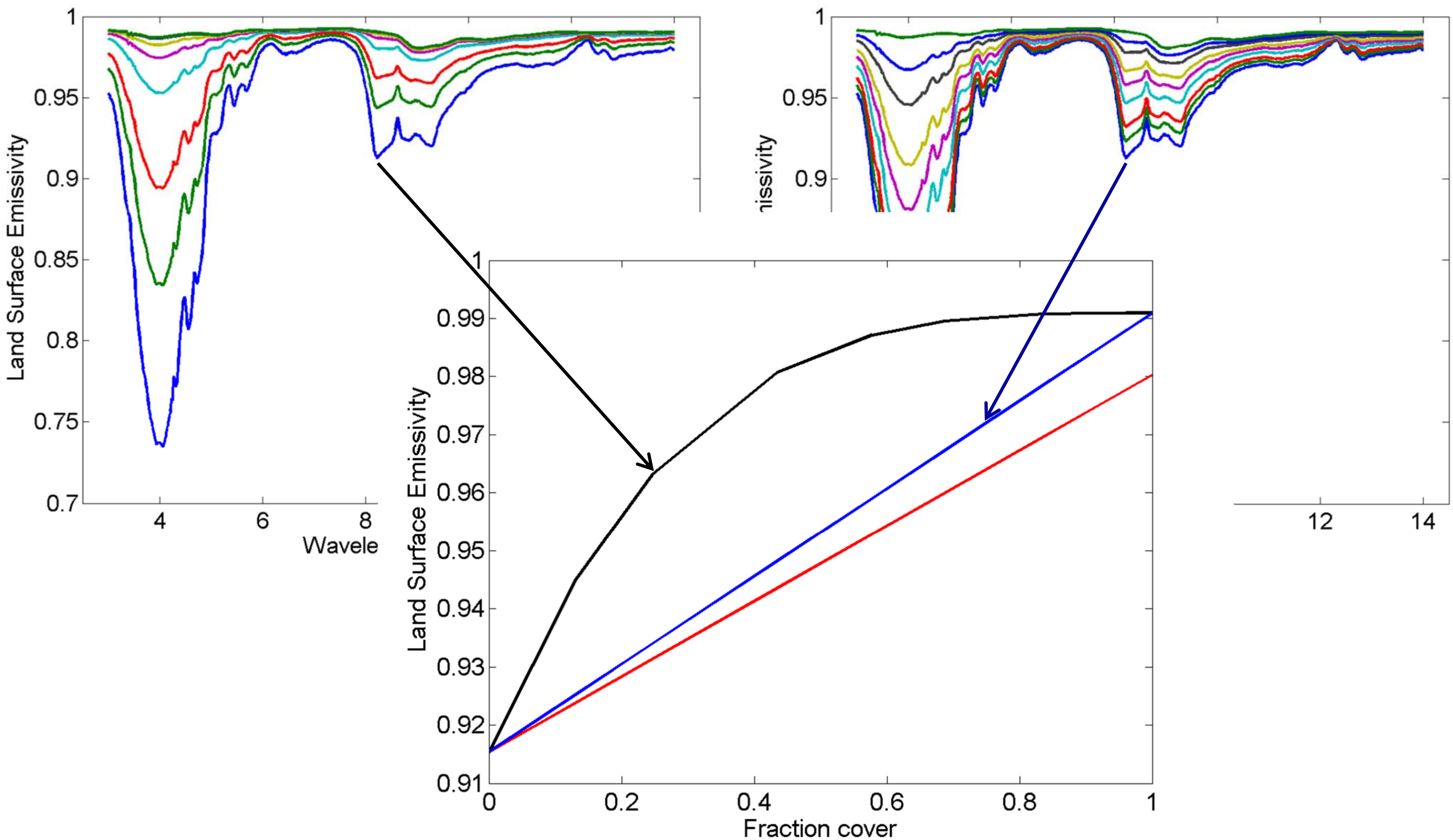
Radiative transfer calculations | **linear mixing from full canopy value**



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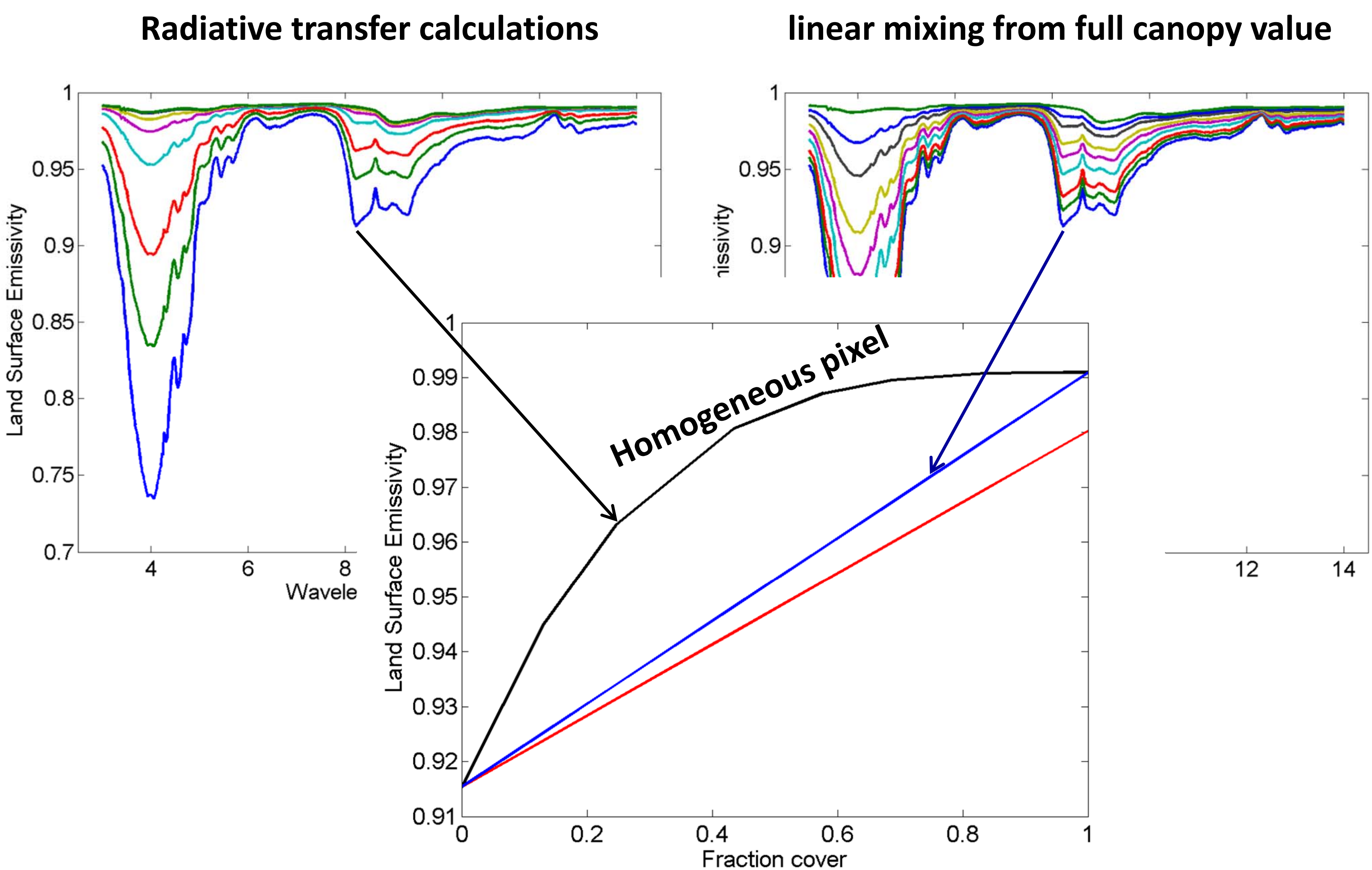

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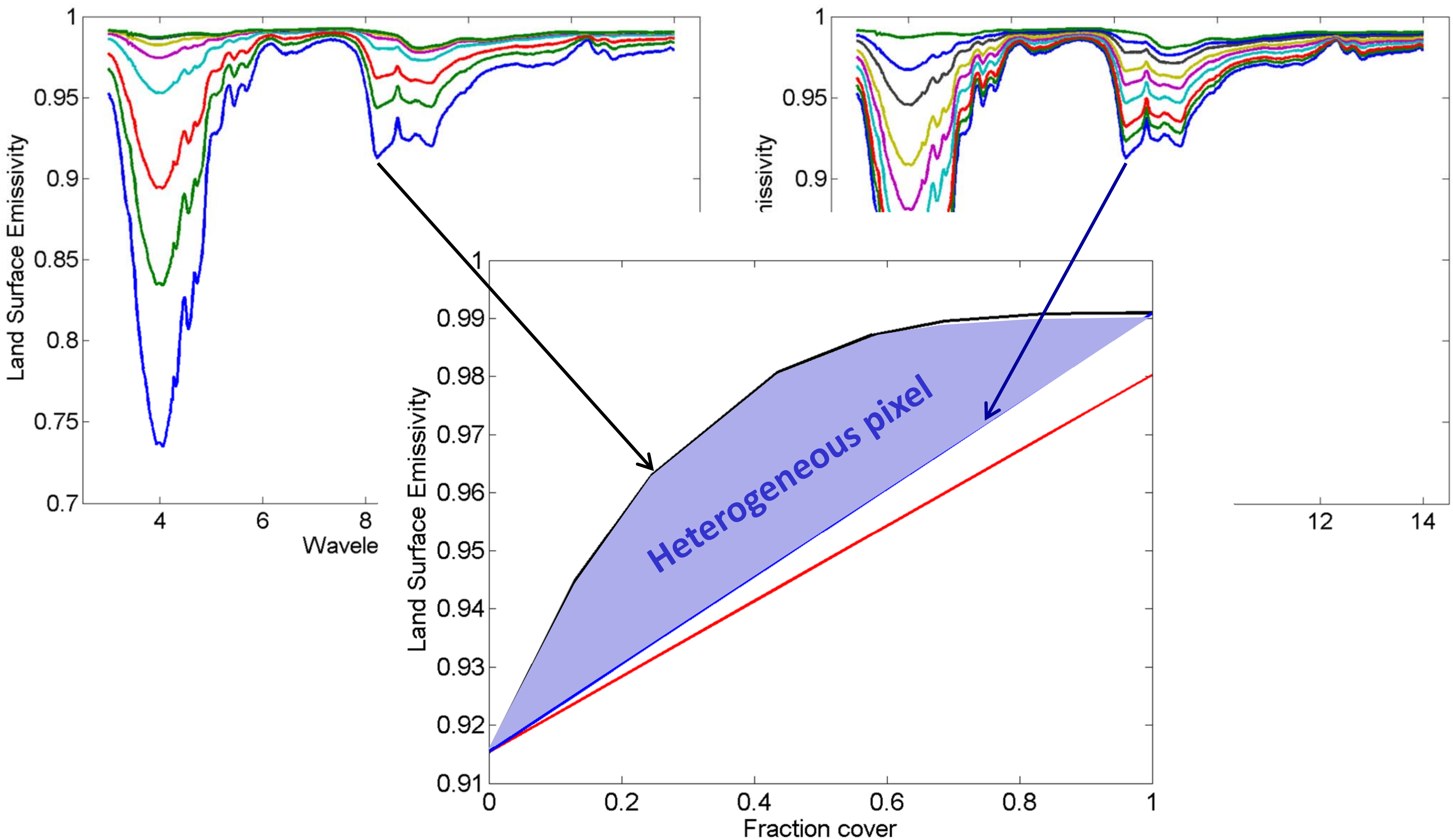
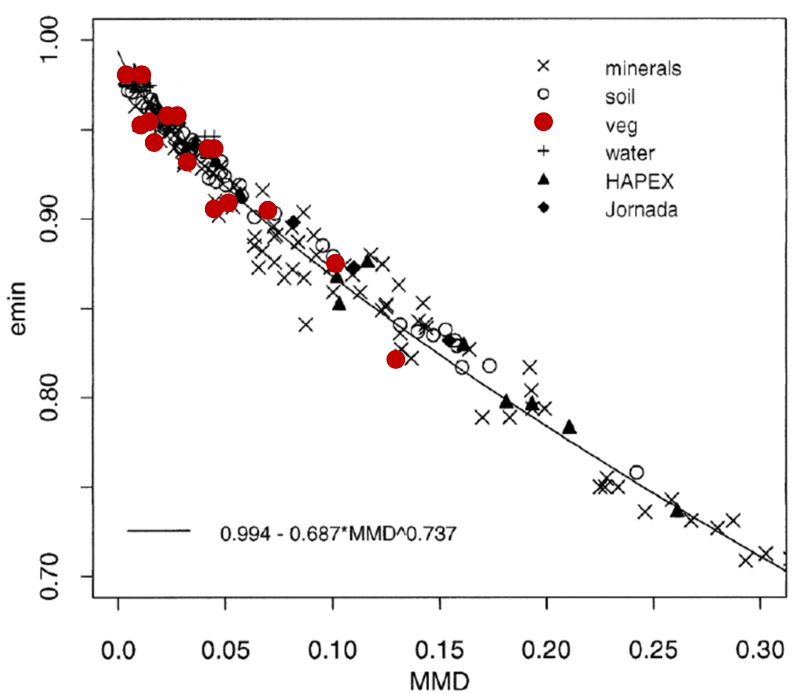


Application to the Temperature – Emissivity Separation (TES) algorithm

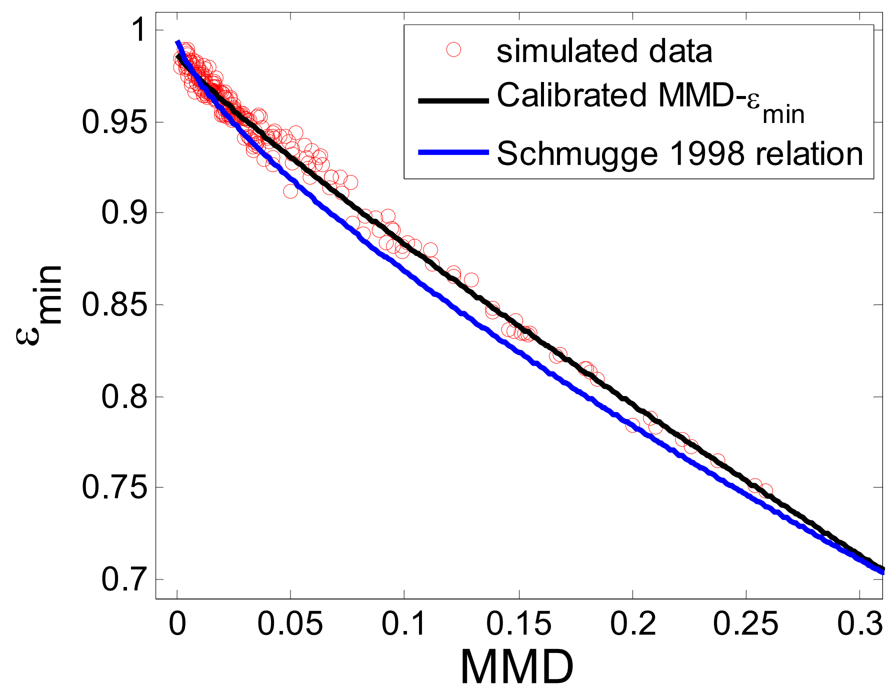
Jacob et al., RSE, 2017

- **Simulation of land surface emissivity spectra for vegetation surfaces**
- **Training of the MMD - ε_{min} relationship used in the TES algorithm for ASTER**
- **Evaluation of the new algorithm for emissivity and temperature retrievals**

Original relation (Schmugge et al. 1998)



(Jacob et al. 2017)



Application to the TES algorithm

Evaluation of the new algorithm for emissivity and temperature retrievals

RMSE (Bias)	Channel 1 8.28 µm	Channel 2 8.63 µm	Channel 3 9.07 µm	Channel 4 10.65 µm	Channel 5 11.28 µm	Ts
Schmugge et al.	0.015 (0.009)	0.013 (0.008)	0.011 (0.007)	0.011 (0.008)	0.011 (0.008)	0.60 K (-0.37 K)
New	0.008	0.007	0.006	0.006	0.006	0.33 K

When accounting of canopy impact on LSE

-> error on LSE and LST retrieval were reduced by a factor 2

-> retrieved LSE were increased

-> retrieved LST were decreased

Concluding remarks

- Yes, it is possible to use a "standard" Radiative Transfer models for simulating land surface emissivity in presence of vegetation canopy

- The SAIL-Thermique model is a simple model that can be applied to homogeneous canopy

- The model may be used for helping in the analysis of TIR multispectral data
    - variation of emissivity as a function of plant canopy structure and sensor characteristics
    - in an inverse mode for deriving plant component spectra

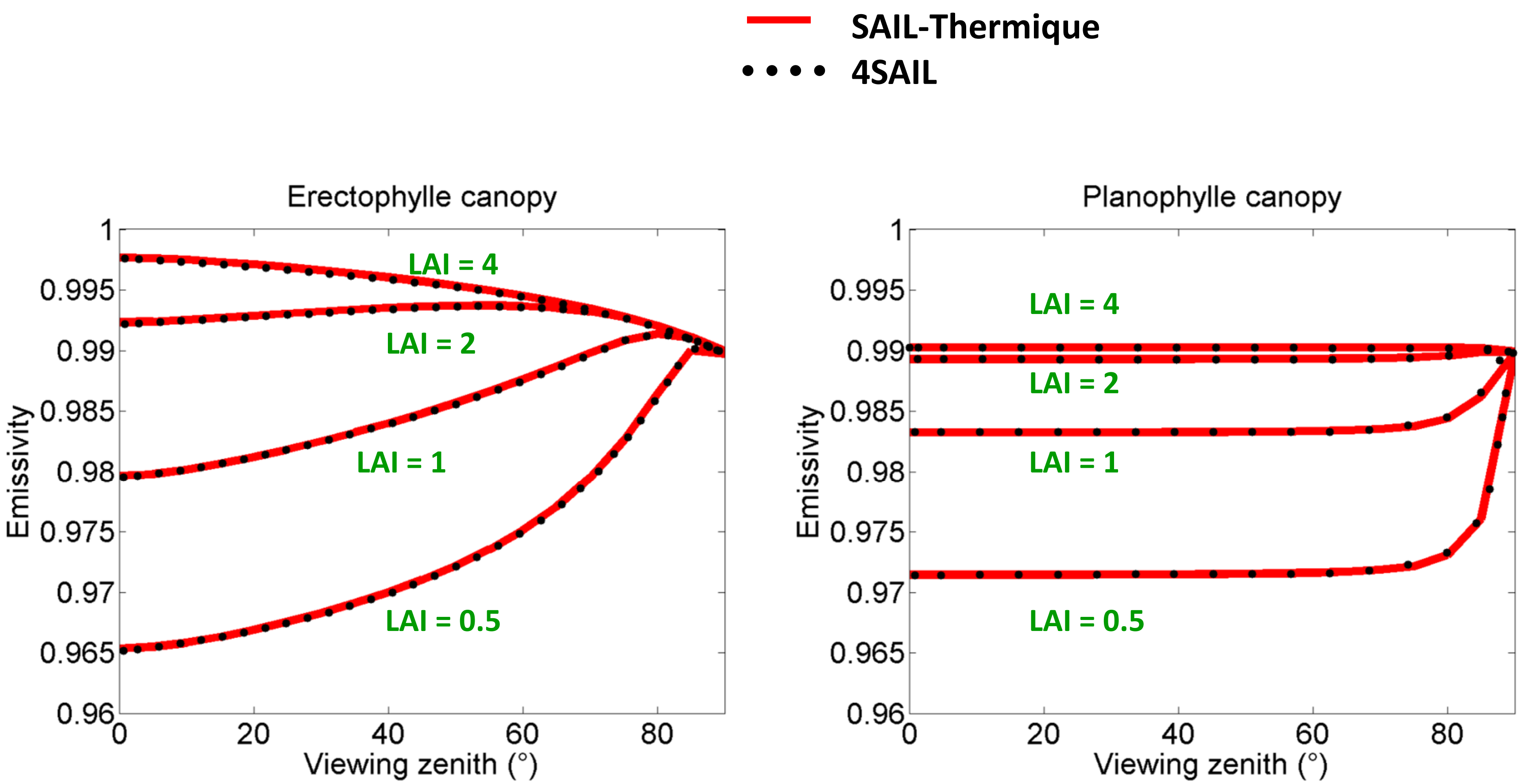
- The model was used for deriving a new version of the TES algorithm by improving the representativity of the MMD – ε_{min} relationship for vegetated areas.

  Can be applied to any multispectral sensors (MODIS, MISTIGRI, HyspIRI, MASTER, HyTES…)

- Would this be useful for TIR hyperspectral atmospheric sounders ?

- We have to go further in understanding leaf and soil optical properties in the thermal infrared domain (e.g. response to drying) and <u>we need measurements on vegetation</u>

Evaluation of SAIL-Thermique against 4SAIL



Evaluation of SAIL-Thermique against 4SAIL

SAIL-Thermique:

$$\varepsilon = 1 - \rho_{sd} - \frac{\tau_{ss} r_{sd} + \tau_{sd} r_{dd}}{1 + \rho_{dd} r_{dd}} \tau_{dd}$$

4SAIL:

$$\varepsilon_o = \gamma_o + \frac{(\tau_{do} + \tau_{oo})}{1 - r_s \rho_{dd}} r_s \gamma_d + \frac{(\tau_{do} + \tau_{oo})}{1 - r_s \rho_{dd}} \varepsilon_s.$$

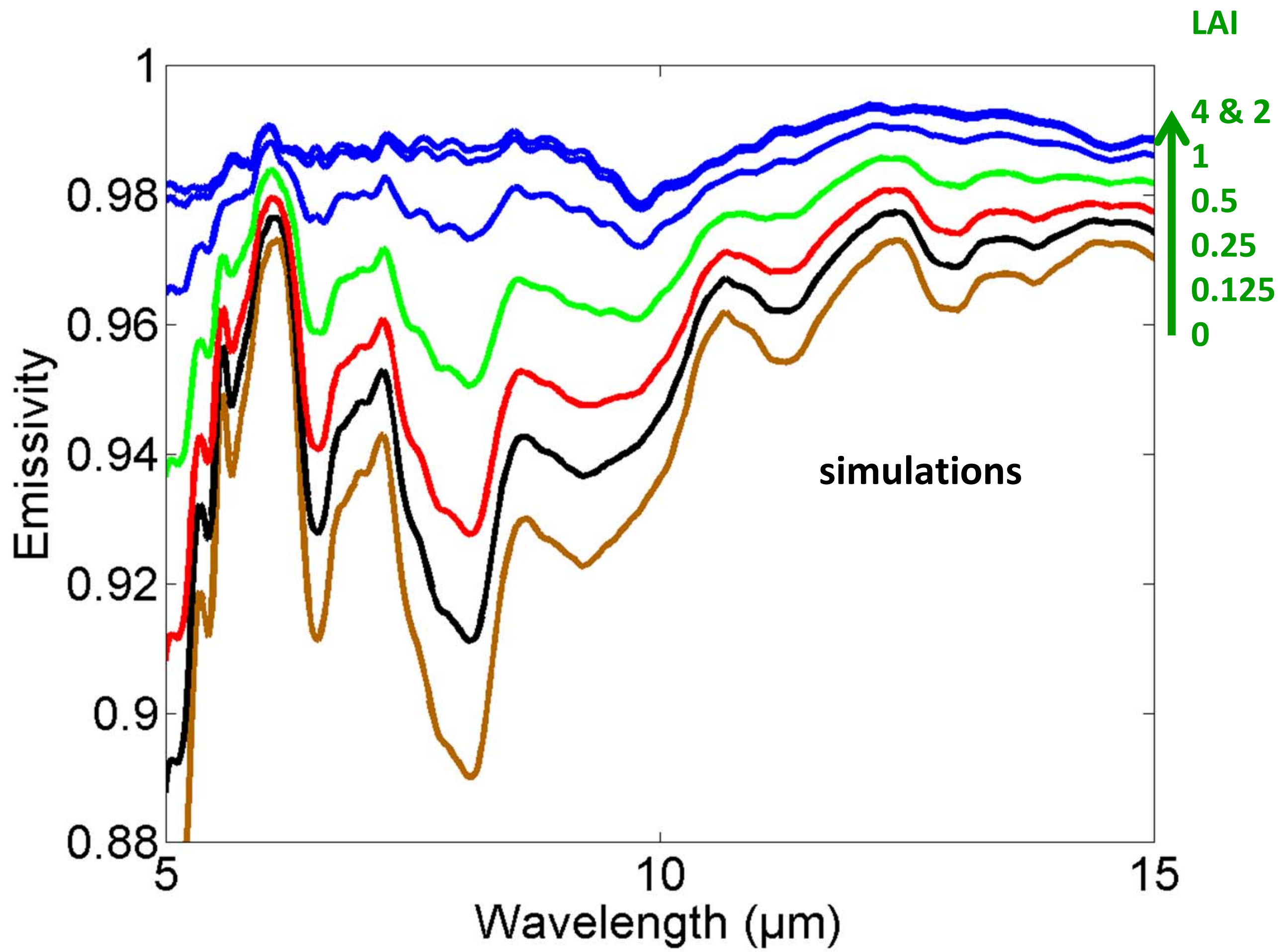
$$\gamma_d = 1 - \rho_{dd} - \tau_{dd}$$

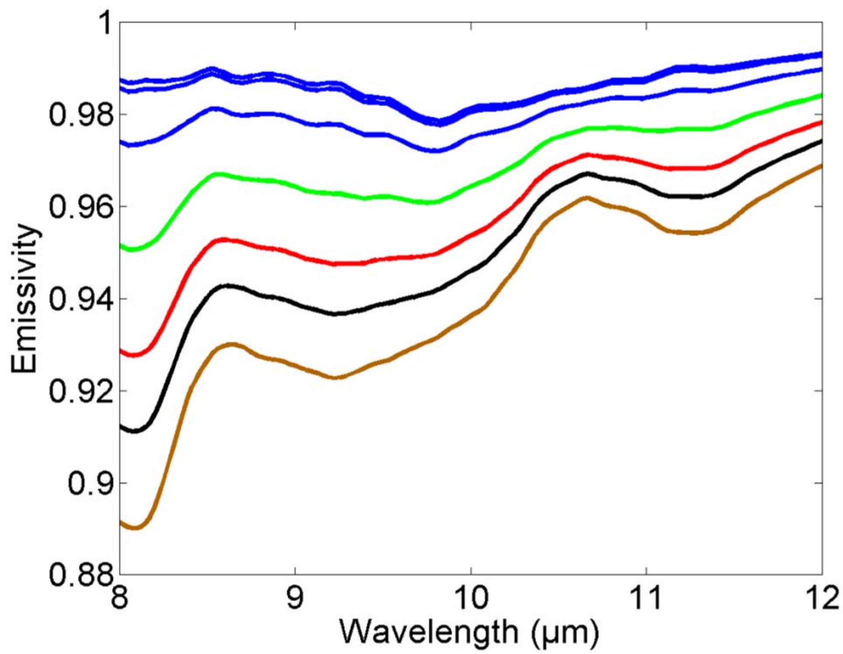
$$\gamma_o = 1 - \rho_{do} - \tau_{do} - \tau_{oo}.$$

Evaluation with multispectral measurements

Soybean data in Avignon, with different LAI

Leaf and soil spectra and 6 band radiometer measurements above canopy

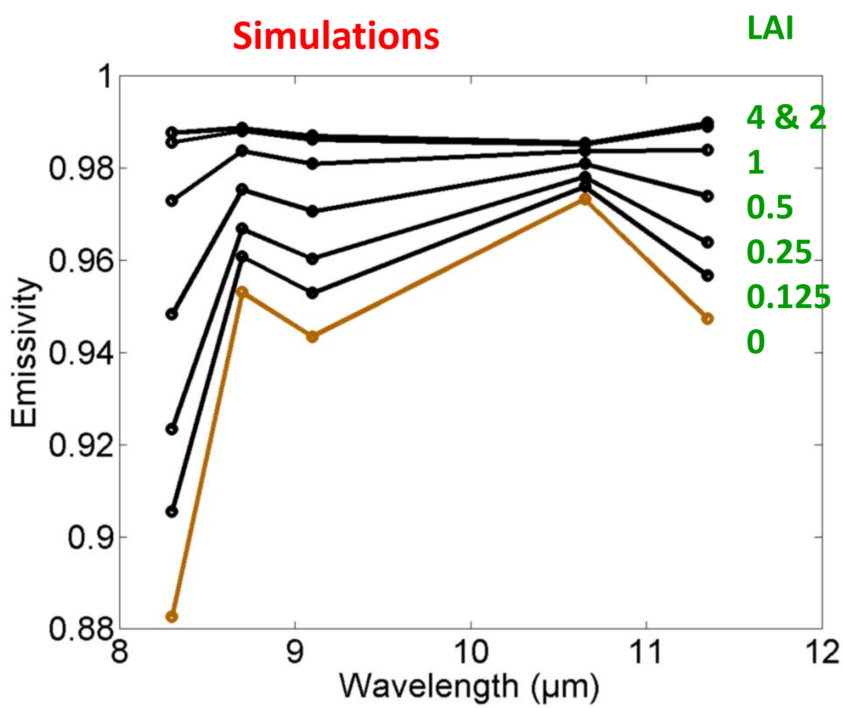


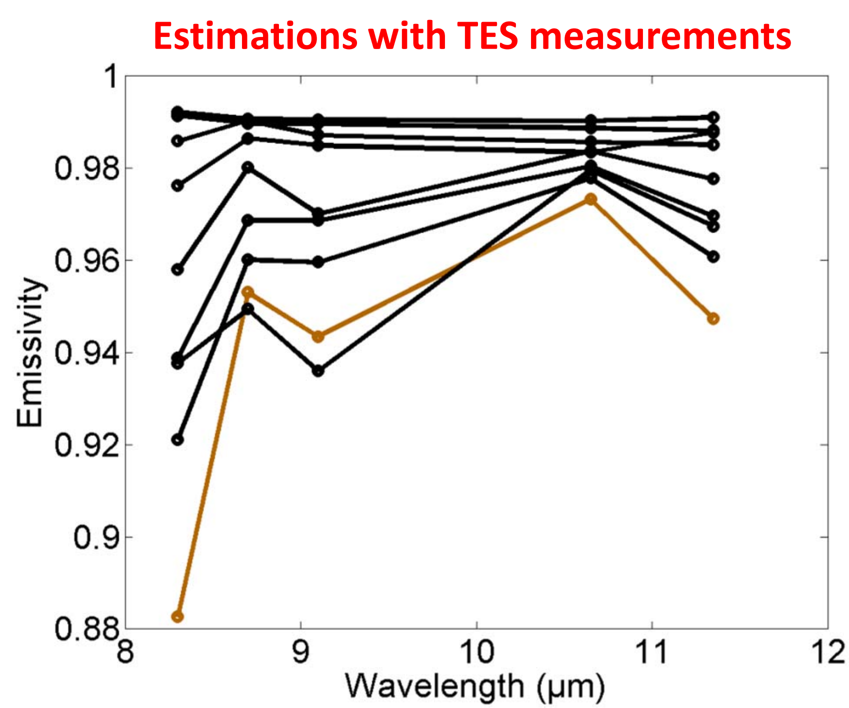


Evaluation with multispectral measurements

Soybean data in Avignon, with different LAI

TES method applied from radiometetric measurements above canopy in ASTER bands





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Remote Sensing of Environment

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Spectral reflectance and emissivity features of broad leaf plants: Prospects for remote sensing in the thermal infrared (8.0–14.0 μm) ☆

Beatriz Ribeiro da Luz *, James K. Crowley

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Remote Sensing of Environment 114 (2010) 404–413

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Identification of plant species by using high spatial and spectral resolution thermal infrared (8.0–13.5 μm) imagery ☆

Beatriz Ribeiro da Luz *, James K. Crowley

IEEE GEOSCIENCE AND REMOTE SENSING LETTERS, VOL. 8, NO. 1, JANUARY 2011

Influence of Water Content on Spectral Reflectance of Leaves in the 3–15-μm Domain

Sophie Fabre, Audrey Lesaignoux, Albert Olioso, and Xavier Briottet

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Modeling directional–hemispherical reflectance and transmittance of fresh and dry leaves from 0.4 μm to 5.7 μm with the PROSPECT-VISIR model

F. Gerber [a,b], R. Marion [b], A. Olioso [c], S. Jacquemoud [a,*], B. Ribeiro da Luz [d], S. Fabre [e]

International Journal of Remote Sensing
Vol. 34, No. 7, 10 April 2013, 2268–2285

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Influence of soil moisture content on spectral reflectance of bare soils in the 0.4–14 μm domain

Audrey Lesaignoux[a,b]*, Sophie Fabre[a], and Xavier Briottet[a]

Remote Sensing of Environment 198 (2017) 160–172

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Reassessment of the temperature-emissivity separation from multispectral thermal infrared data: Introducing the impact of vegetation canopy by simulating the cavity effect with the SAIL-Thermique model

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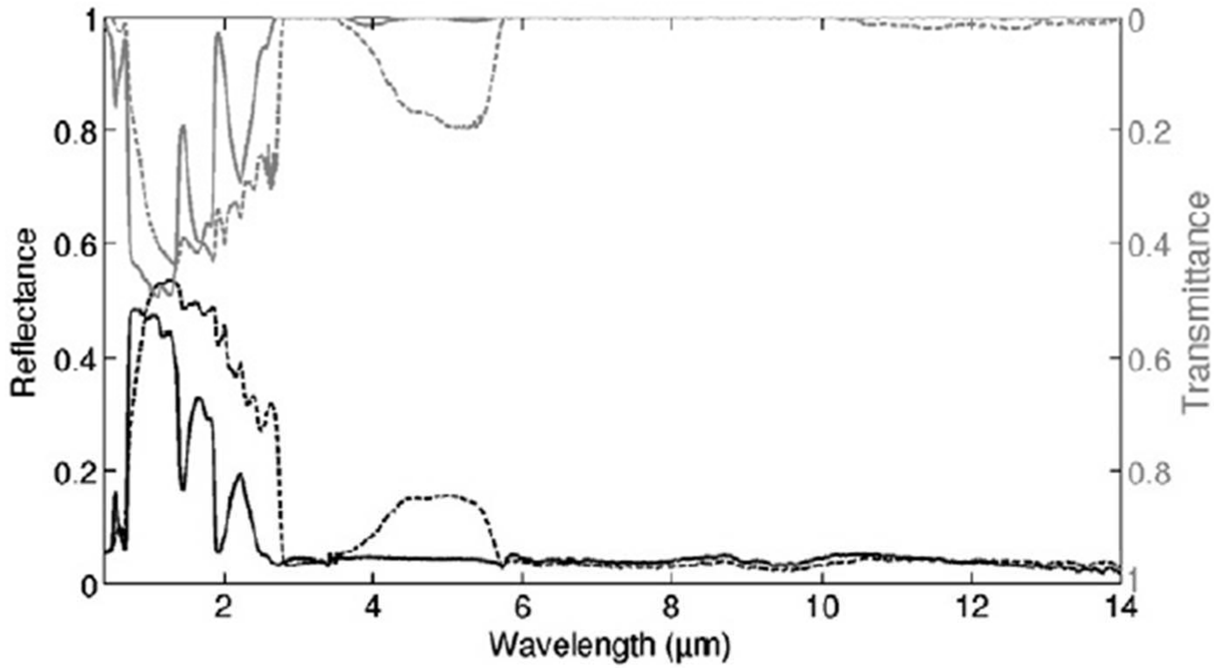

Fig. 3. DHR (black) and DHT (grey) of fresh (plain line) and dry (dashed line) *Catalpa* leaves from the USGS dataset.

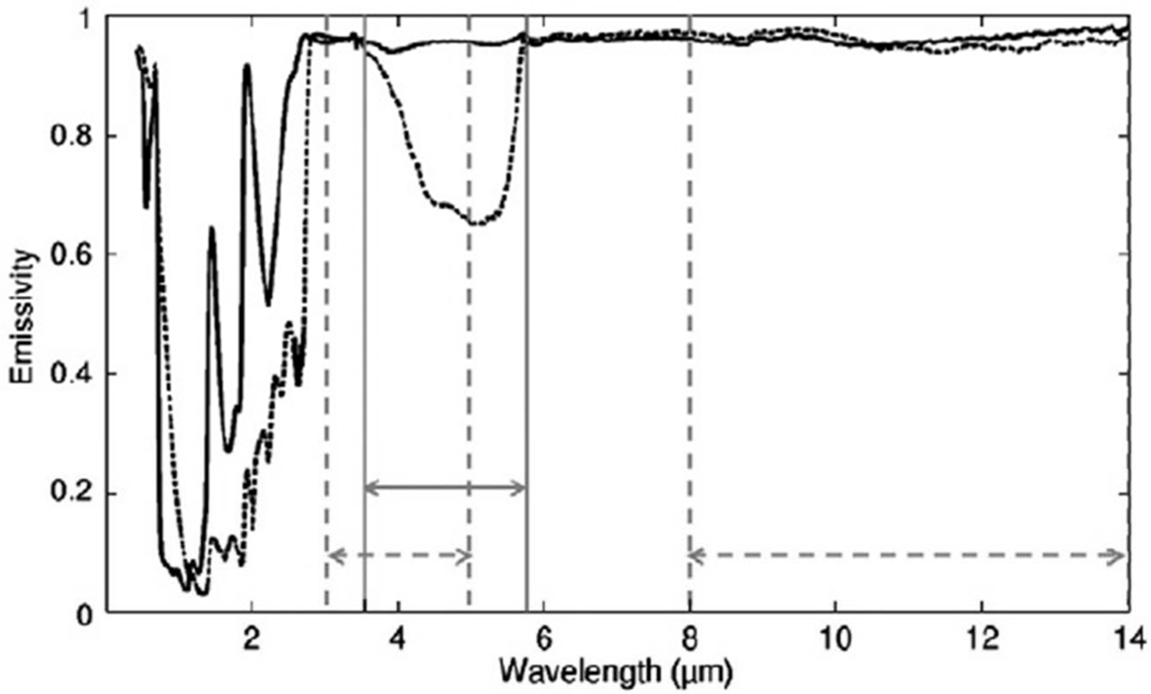

Fig. 6. Emissivity of fresh (plain black line) and dry (dashed black line) *Catalpa* leaves from the USGS dataset. The spectral ranges of interest are marked by lines (3.5–5.7 μm, 3–5 μm, and 8–14 μm). See Table 2 for emissivity statistics for these ranges.

Table 2
Statistics about leaf emissivity in three spectral domains.

Spectral range	Minimum	Maximum	Mean	Standard deviation
Fresh leaves				
3.5–5.7 μm	0.89	0.97	0.95	0.02
3–5 μm	0.92	0.97	0.95	0.01
8–14 μm	0.93	0.98	0.96	0.01
Dry leaves				
3.5–5.7 μm	0.67	0.90	0.79	0.06
3–5 μm	0.75	0.97	0.90	0.06
8–14 μm	0.89	0.96	0.94	0.02

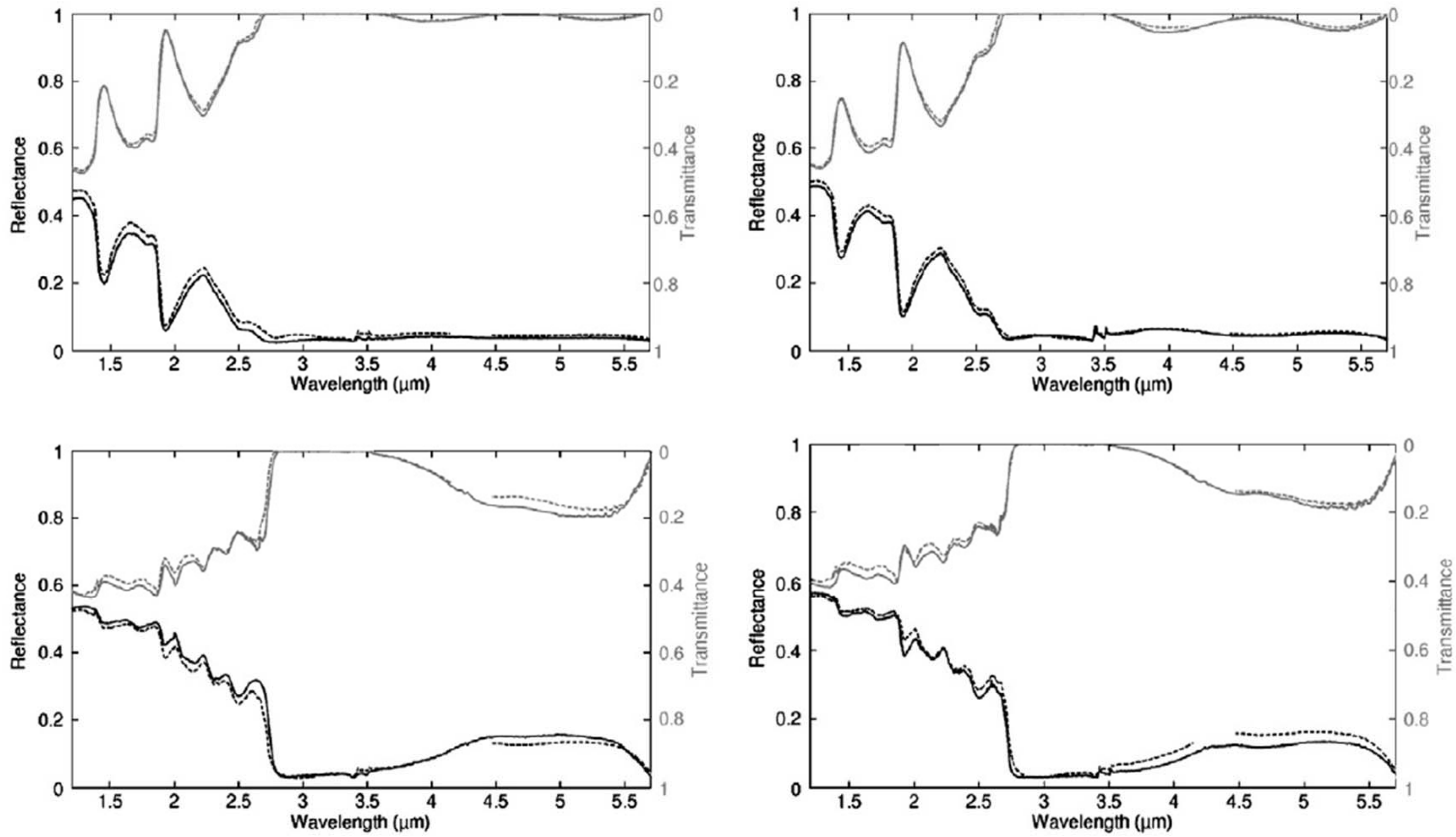

Fig. 10. Simulated (dashed line) vs. measured (plain line) reflectance and transmittance of fresh (top left: *Catalpa*, top right: *Tillia*) and dry (bottom left: *Catalpa*, bottom right: *Acer platanoides*) leaves.

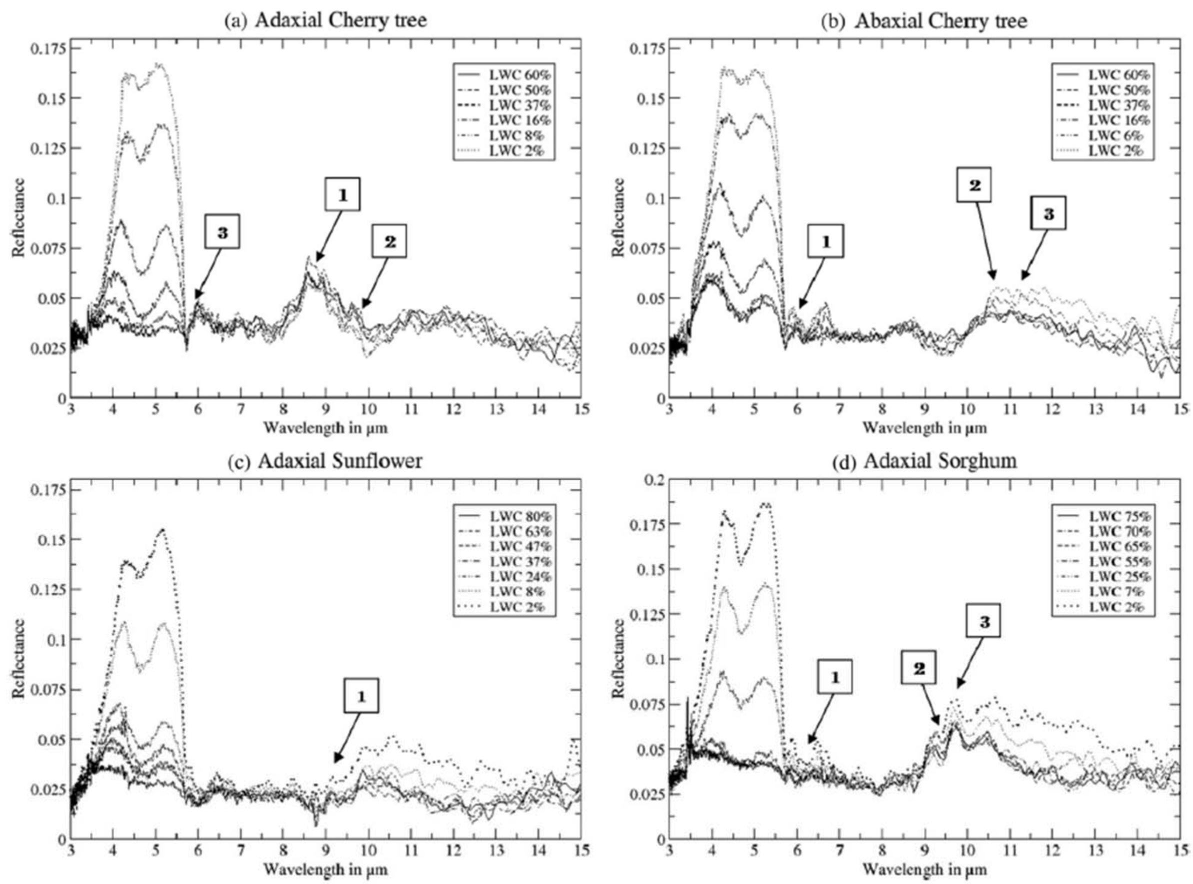

Fig. 2. Spectral reflectances of leaves for several water contents in the thermal domain. (a) Adaxial and (b) abaxial sides of cherry tree, (c) adaxial side of sunflower, and (d) sorghum leaf samples. Arrow labels locate a specific behavior, detailed in the document.

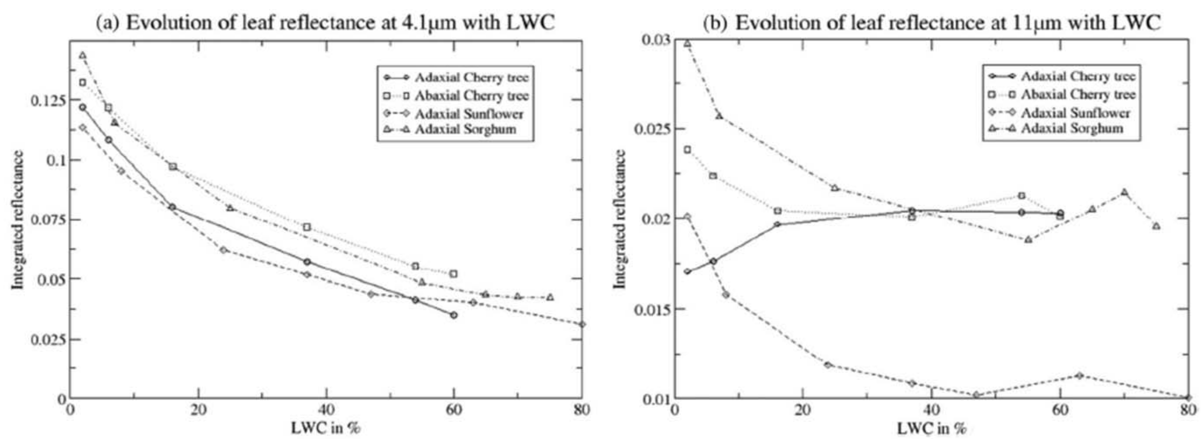

Fig. 3. Leaf reflectances at (a) 4.1 and (b) 11 μm as a function of LWC (wavelengths chosen in atmospheric window only).

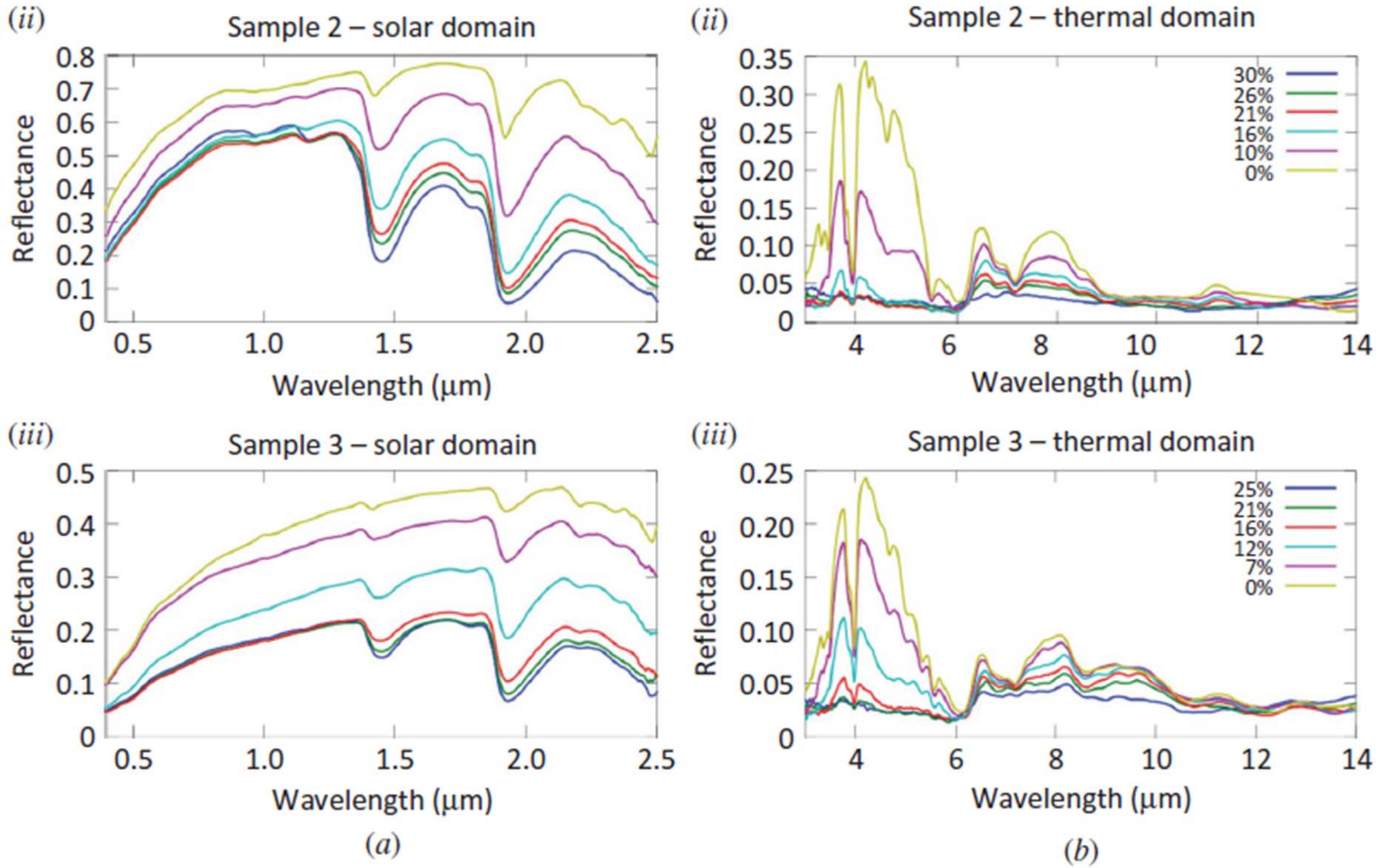

Figure 3. Spectral signatures of three soil samples (the so-called samples 1, 2, and 3) depending on SMC (values in %), in the solar (*a*) and the thermal (*b*) domains.