2nd Workshop on Remote Sensing and Modeling of Surface Properties
9 - 11 June 2009 , Météo France, Toulouse, France

Soil moisture impact on reflectance of bare soils in the optical domain [0.4 – 15 μm]

A. Lesaignoux[1,3], ***S. Fabre*[1], *X. Briottet*[1] and *A. Olioso*[2]**
[1] ONERA, Toulouse, France
[2] INRA, Avignon, France
[3] Université de Toulouse, France

Contact : Audrey.Lesaignoux@onera.fr

Contents

I.Context

I.State of art

- Problem and approaches
- Spectral database related to soil moisture content

I.Laboratory measurements

- Description
- Method
- Analysis & Results:
  - ✓ Spectra classification from dry samples
  - ✓ Impact of soil moisture content on spectral reflectance
  - ✓ Empirical model

I. Conclusions and perspectives

Audrey.Lesaignoux@onera.fr

Context

➢ *Main objective*

Development of a method estimating moisture of soils (bare soils and/or sparse vegetation) in the optical domain [0.4 – 15 µm] from hyperspectral data

Hyperspectral data [0.4 - 15 µm] → Atmospheric compensation → Ground spectral reflectance → Surface Soil Moisture extraction → Mapping for several applications

➢ *Applications*

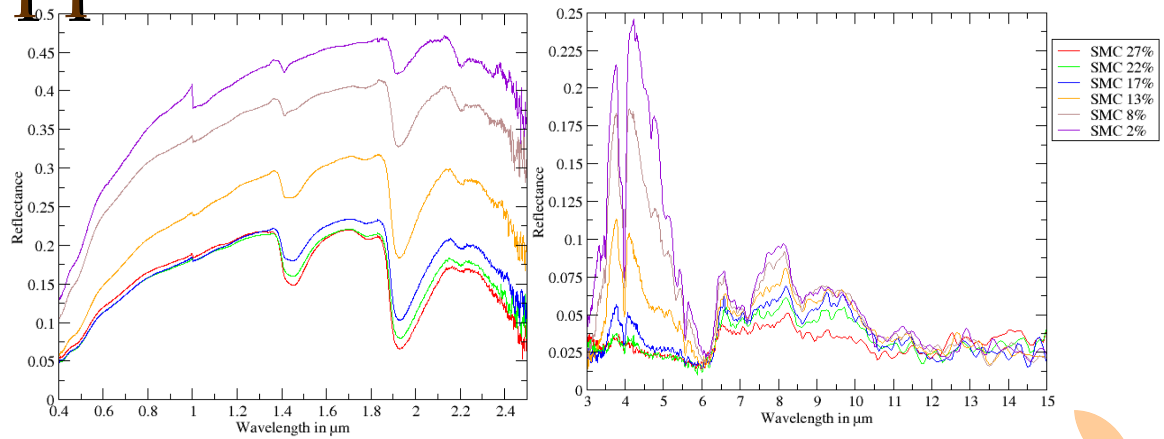
- Biomass estimation
- Vegetation cover health
- Trafficability: Define link between soil characteristics (moisture, composition…) and a given vehicle with its passing number, to provide the information:

« GO » or « NO GO »

2nd Workshop on RSMSP, Météo France, Toulouse, 9-11 June 2009

Problem and approaches

Soil Moisture Content (SMC) of bare soils from spectra ?



Spectra of sample's bare soils at different moisture contents in the solar (left) and thermal domain (right) (Lab measurements)

Solar domain [0.4 - 2.5 µm]

Methods based on spectral reflectance

Spectral bands exploitation

- **Analytical methods**
  Liu et al. 2002
  Liu et al. 2003
- **Spectral index**
  Bryant et al. 2003
  Khanna et al. 2007
  Haubrock et al. 2008

Spectral models

- **Exponential**
  Muller 2000
  Lobell et al. 2002
- **Inverse gaussian «SMGM» model**
  Whiting et al. 2003

Geostatistical methods

- **VNIRA method**
  Ben-Dor et al. 2002
- **Geostatistical analysis**
  Brocca et al. 2006

Thermal domain [٥ - ١٣µm]

Methods based on surface temperature

Triangle method (Sandholt et al. ٢٠٠٢)

Index (Kimura et al. ٢٠٠٧)

Method of thermal inertia (Tramutoli et al. ٢٠٠٠)

Method based on spectral emissivity

[٥ - ٨µm] exploitation

- **Correlation analysis**
  Xiao et al. ٢٠٠٣
  Ogawa et al. ٢٠٠٦
- **Spectral ratio**
  Urai et al. ١٩٩٧
  Mira et al. ٢٠٠٧

Audrey.Lesaignoux@onera.fr

Spectral database related to SMC

➢ *Approaches validation*

Lab measurements of spectra of bare soils at different moisture contents

- **Many** data set in [0.4 – 2.5 μm] (Angstrom 1925, Liu et al. 2002, Lobell et al. 2002, Whiting et al. 2003, Khanna et al. 2007, Haubrock et al. 2008)
- **Few** data set in [8 – 15 μm] (VanBavel et al. 1976, Chen et al. 1989, Mira et al. 2007)

➢ *Synthesis*

- Not enough information in the thermal domain
- No measurement covering at **once** solar and thermal domains

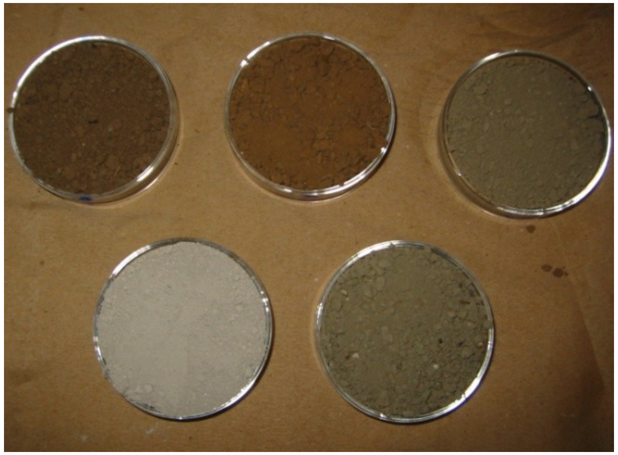
⬇

Necessity to build a database of spectral reflectances of bare soils in [0.4 – 15 μm] depending on SMC

Audrey.Lesaignoux@onera.fr

Lab measurements

Description


Different samples of bare soils

Samples description

- **32** samples of **bare soils**
- Collected over 8 locations in France (from South-West to South-East)
- Covering several ranges of composition and coloration

Measurements (August 2008)

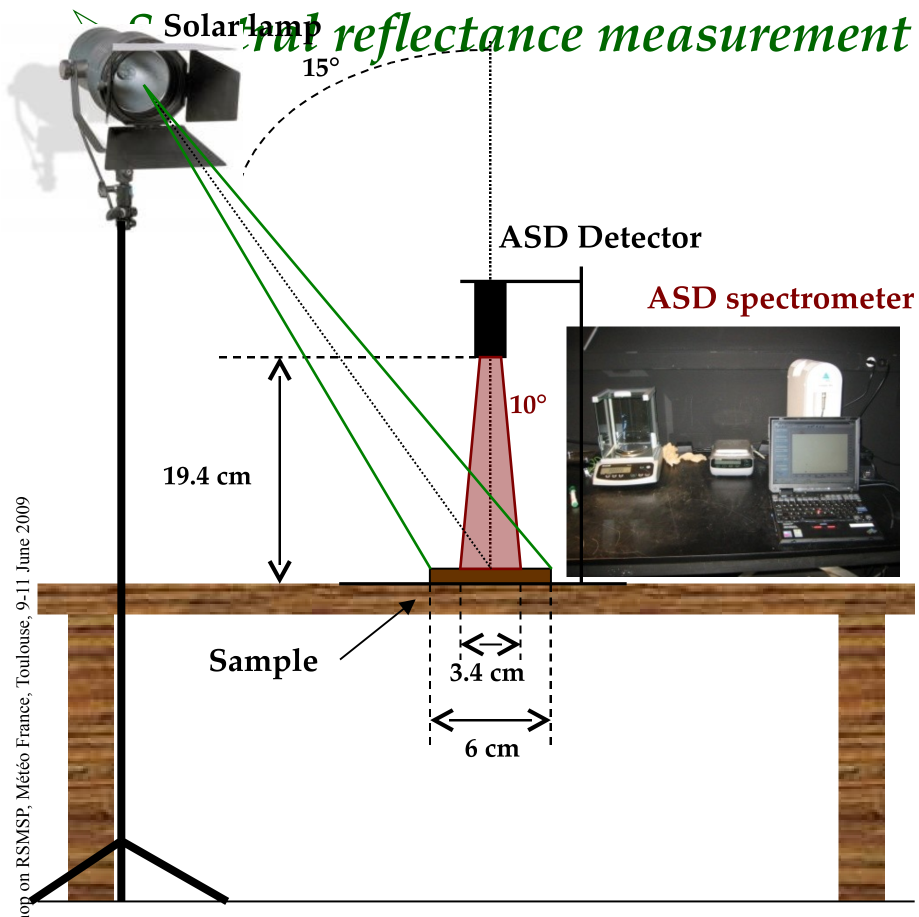
- [0.4 – 2.5 μm] : **ASD** FieldSpec Pro (bi-conical reflectance)
- [3 – 15 μm] : **Bruker** Equinox 55 (directional-hemispherical reflectance)
- Drying process from a **lab oven**

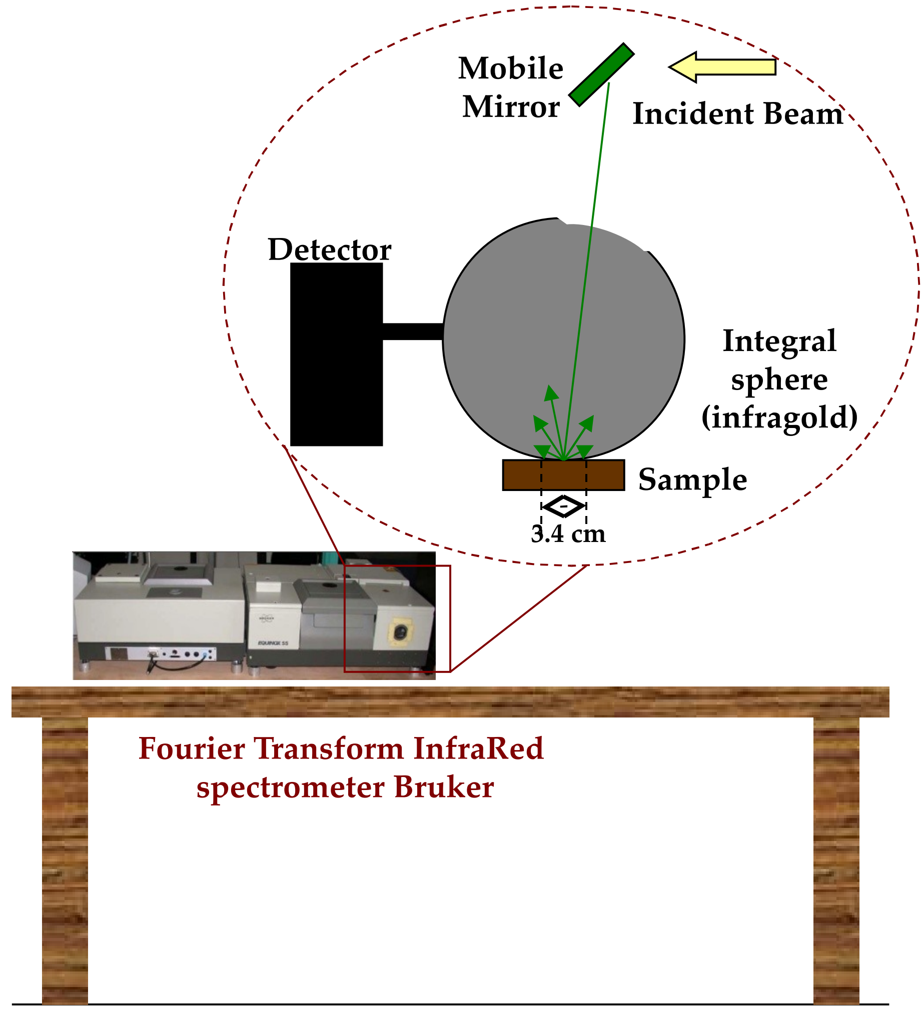
INSTRUMENT	ACCURACY
ASD	$\Delta\lambda \pm 1$ nm
Bruker	Error < 3%
Lab oven	Residual moisture ~ 2 %

Audrey.Lesaignoux@onera.fr

Lab measurements

Method (1/2)





Measurement of **bi-conical** reflectance in solar domain (left) and **direct-hemispherical** reflectance in thermal domain (right)

2nd Workshop on RSMSP, Météo France, Toulouse, 9-11 June 2009

Lab measurements

Method (2/2)

➢ *Moisture content measurement*

- Gravimetric method : **S**oil **M**oisture **C**ontent in %

$$SMC = \frac{m_W - m_D}{m_W} \times 100$$

Where m_w : weight of the **wet** sample
m_D : weight of the **dry** sample (after a 24 hours drying period at 60°C)

➢ *Measurement protocol description*

1. Preparation of the measurements tools and the samples (cleaning and saturing with water)
2. Weighing with balance
3. **Brucker** measurement [3 – 15 µm]
4. Weighing with balance
5. **ASD** measurement [0.4 – 2.5 µm]
6. Weighing with balance
7. Drying sample during 35 min at 60°C with **lab oven**
8. Return step 2 until the sample is completely dry (~2%)

Measured spectra at several moisture contents

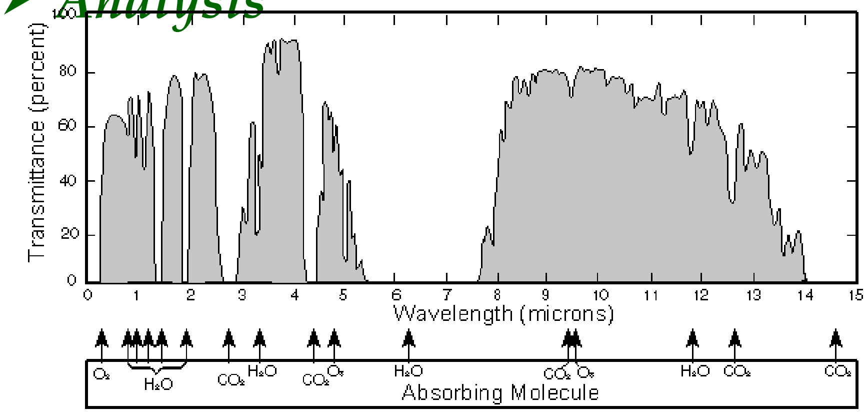
- **5** or **6** levels of SMC (%)
- **390** spectral signatures have been measured and analyzed

2nd Workshop on RSMSP, Météo France, Toulouse 9-11 June 2009

Analysis & Results

➢ ***Measurement validation from literature*** (Courault et al. 1988, Guyot et al. 1989, Liu et al. 2002, Whiting et al. 2003, Khanna et al. 2007, Haubrock et al. 2008, Salisbury et al. 1992, 1994)

➢ ***Analysis***



- VIS: [0.4 – 0.8 µm] *(VISible)*
- NSWIR:[0.8 – 2.5 µm] *(Near and ShortWave InfraRed)*
- MWIR: [3 – 5 µm] *(Medium Wavelength InfraRed)*
- LWIR: [8 – 15 µm] *(Long Wavelength InfraRed)*

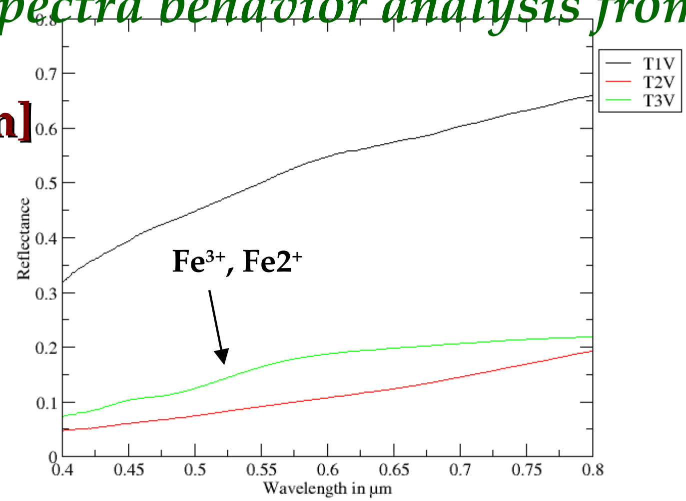
1. **Informal soil spectra classification from dry samples (SMC ~ 2%)**
2. **Study of SMC impact on spectral reflectance**
3. **Empirical model of spectral reflectance of bare soils related to SMC**

Lab measurements

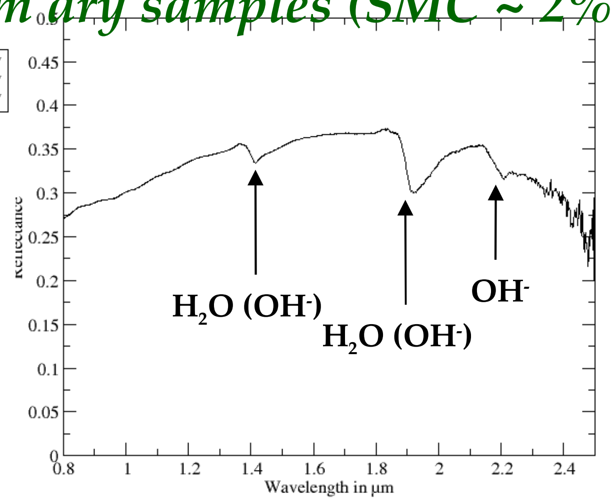
Soil spectra classification (1/2)

- *Soil spectra behavior analysis from dry samples (SMC ~ 2%)*

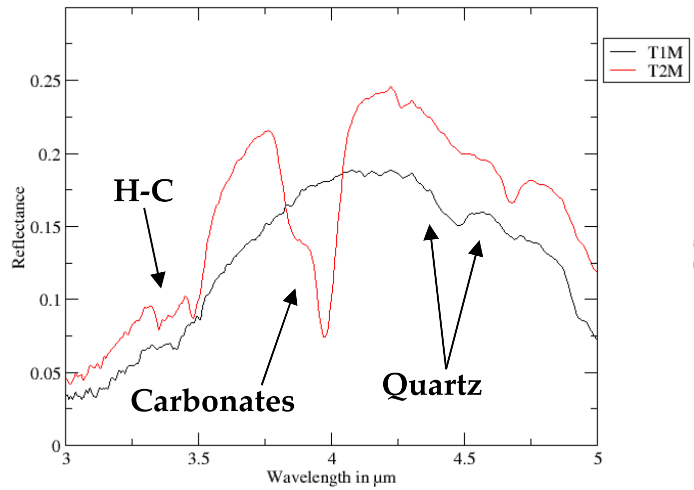
VIS
[0.4 – 0.8 µm]



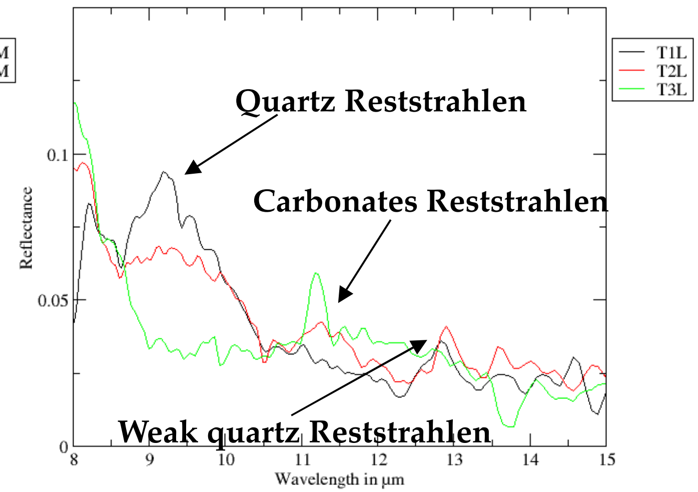
NSWIR
[0.8 – 2.5 µm]



MWIR
[3 – 5 µm]



LWIR
[8 – 15 µm]



Audrey.Lesaignoux@onera.fr

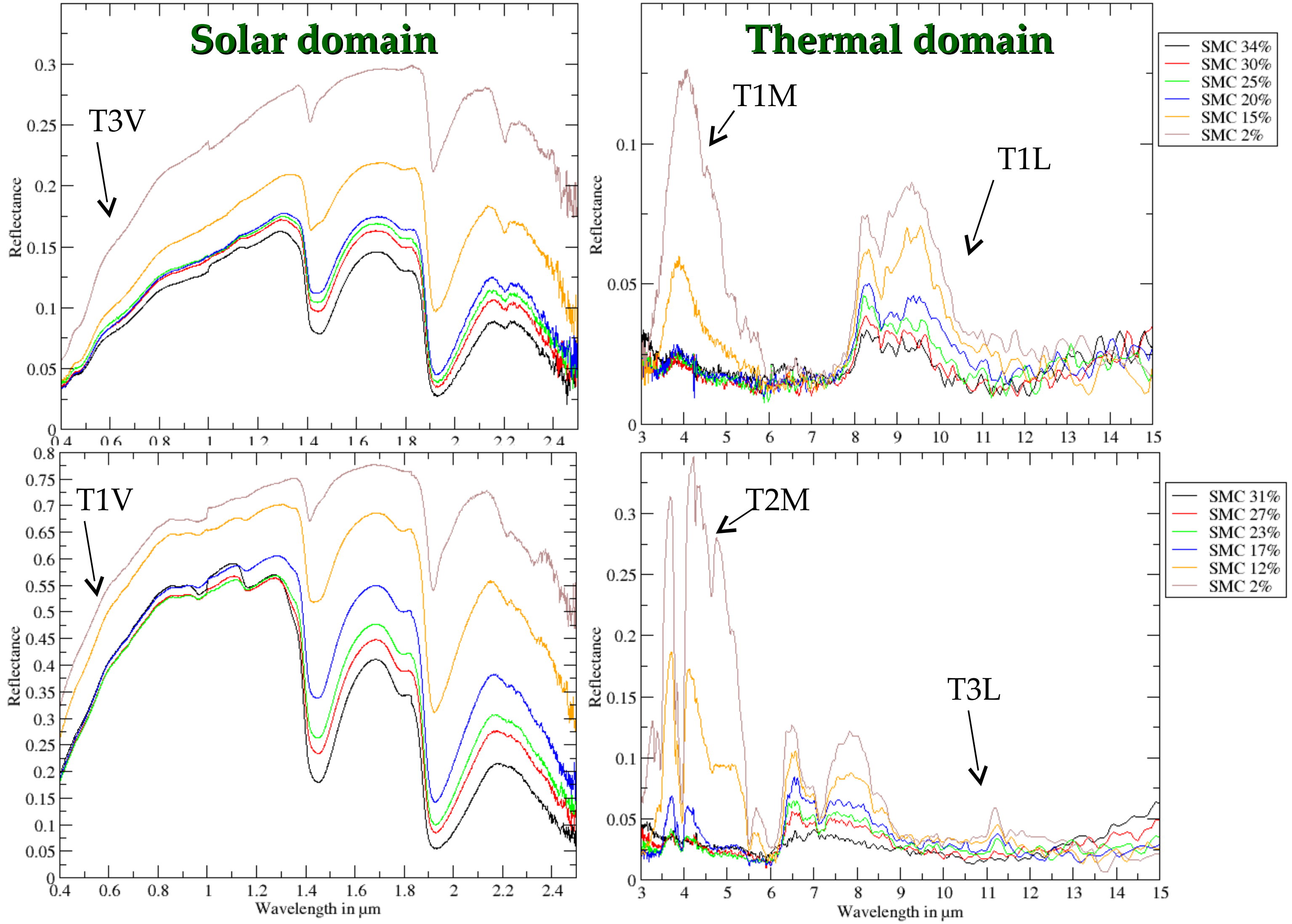
Lab measurements

Soil spectra classification (2/2)

- *Example*

Group 1

Group 2
Calcareous



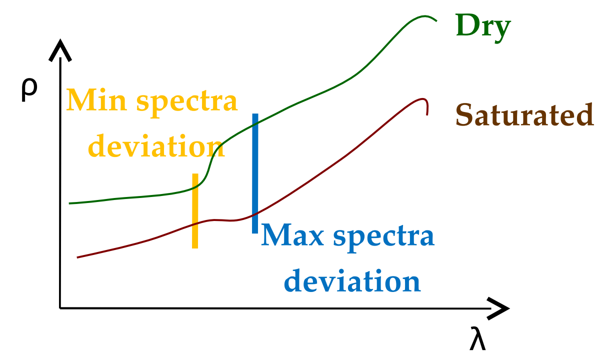
Audrey.Lesaignoux@onera.fr

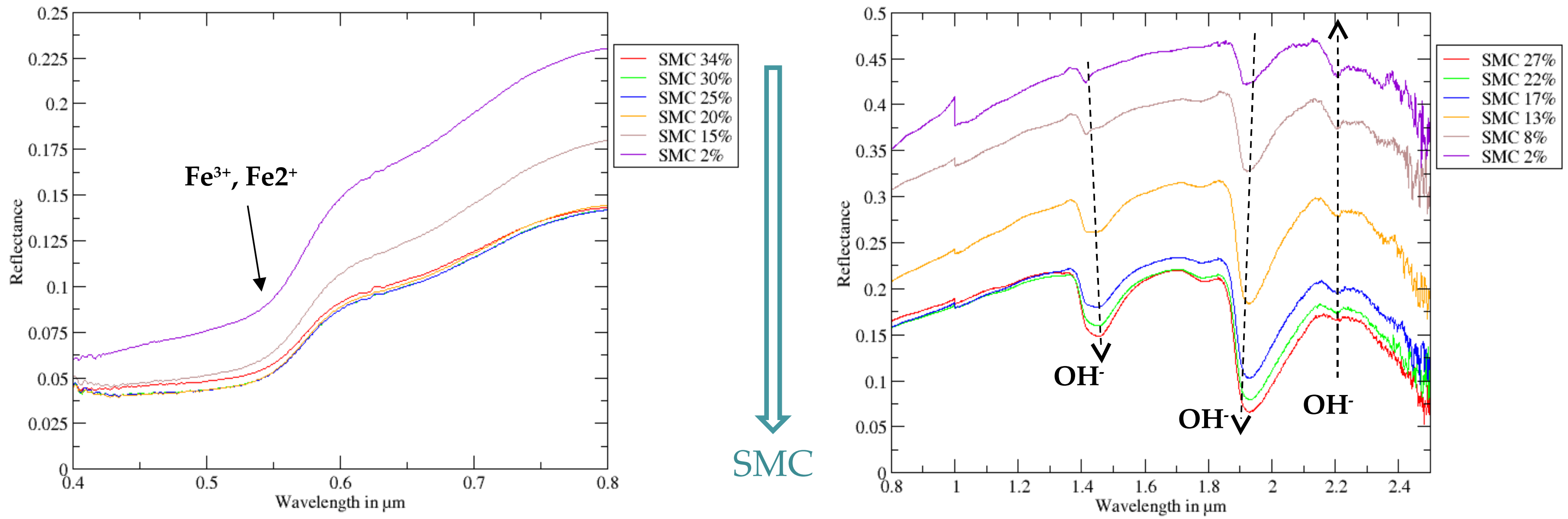
Lab measurements

Impact of SMC on spectral reflectance (1/2)

➢ *Solar domain: 0.4 - 2.5 µm*

For all samples between dry and saturated sample	**VIS**	**NSWIR**
Mean of max spectra deviations	0.13±0.04	0.31±0.08
Mean of min spectra deviations	0.03±0.04	0.12±0.03





Spectral reflectance at different moisture content in the **VIS** (left) and **NSWIR** (right) domain

2nd Workshop on RSMSP, Météo France, Toulouse, 9-11 June 2009

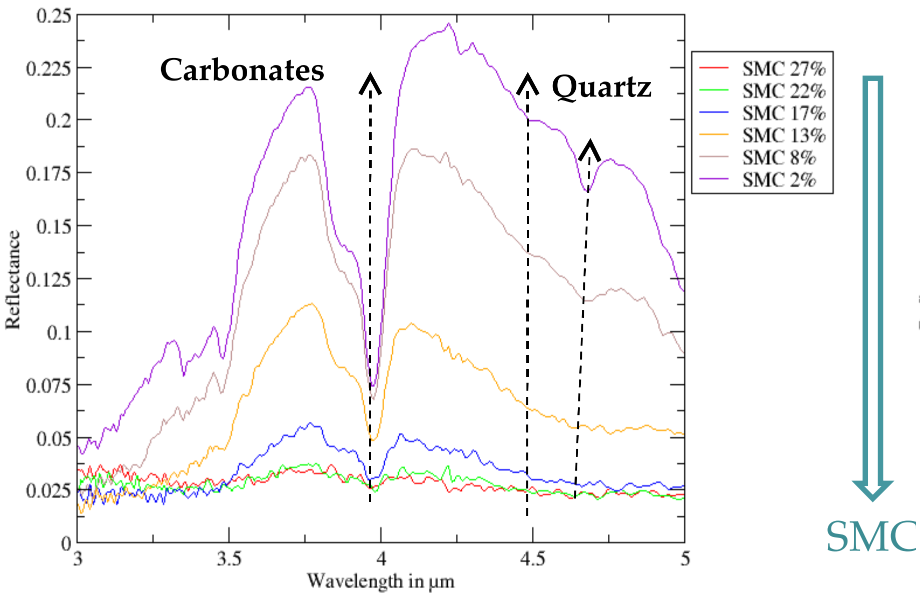
Lab measurements

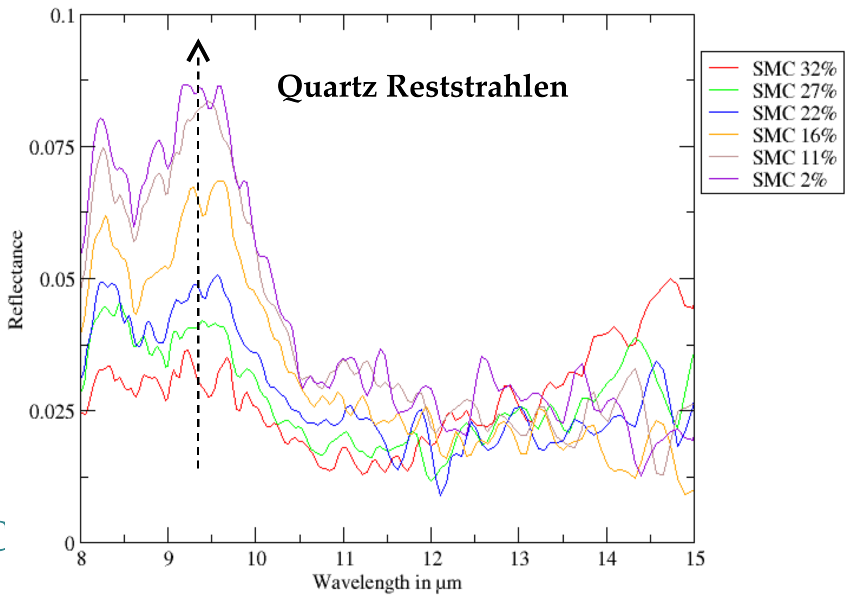
Impact of SMC on spectral reflectance (2/2)

- ***Thermal domain: 3 - 15 µm***

For all samples between dry and saturated sample	**MWIR**	**LWIR**
Mean of max spectra deviations	0.17±0.05	0.05±0.01
Mean of min spectra deviations	-0.01±0.01	-0.03±0.01

Peaks detection is almost impossible if SMC is upper 20 %





Spectral reflectance at different moisture content in the **MWIR** (left) and **LWIR** (right) domain

2nd Workshop on RSMSP, Météo France, Toulouse, 9-11 June 2009

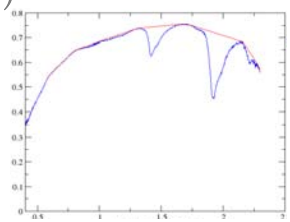
Lab measurements

Empirical model (1/2)

➢ ***Objective:*** Determine an equation which simulate spectral reflectance of bare soils at a SMC given, of which parameters are linked to SMC with empirical laws

→ **From a soil's composition (classification & chemical analysis) and a SMC we could simulate spectral reflectance in [0.4 – 15 µm] domain**

➢ ***Methodology in Solar domain*** (Modified Gaussian Model, Sunshine et al. 93)



$$\mathbf{LN(spectra) = Continuum(c_1,\ldots,c_n) + \Sigma\ Gaussians(g_1,\ldots,g_m)}$$

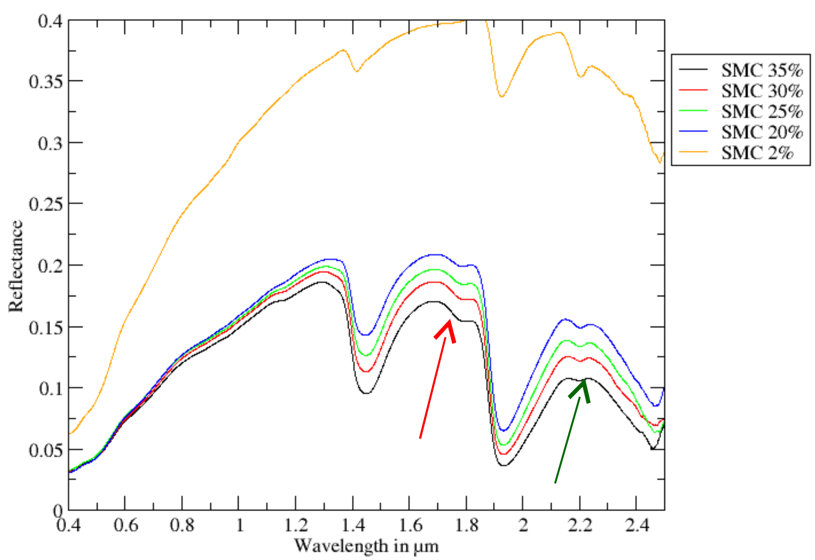
- Determine continuum with convex hull method to apply "Continuum removal" method
- Use 1st and 2nd derivative spectra (continuum removed spectrum) to determine extrema for initial parameters of Gaussians ($g_m \equiv$ centers, amplitudes, fwhm)
- Non linear Least-squares approximation of Gaussians and Least-squares approximation of Continuum (polynomial degree 4)
- Determine empirical laws link SMC with c_n and g_m (currently linear)
- Simulations for a soil group

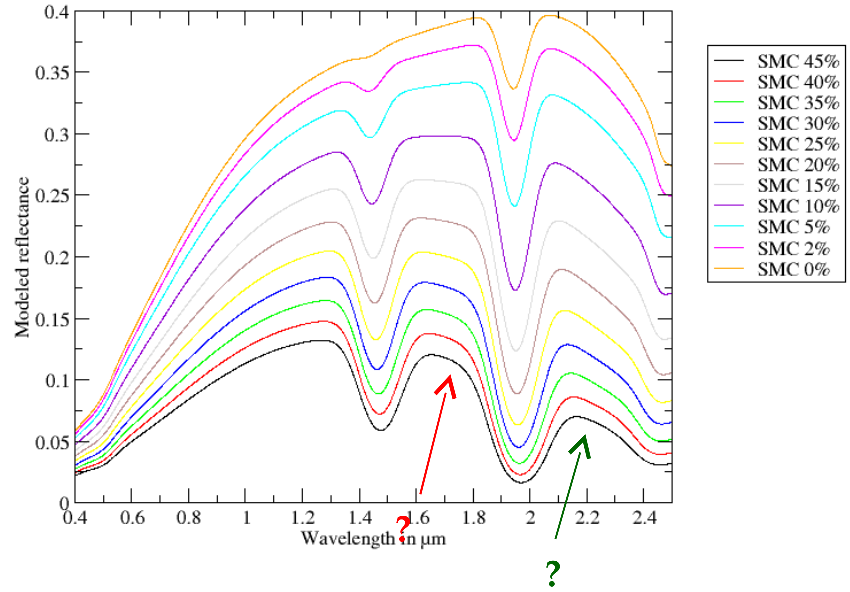
Audrey.Lesaignoux@onera.fr

Lab measurements

Empirical model (2/2)

Measurement





Model

- Less of absorption peaks at 1.8 μm and 2.2 μm
- Difference level "seems" weak but error must be define

Current works

- Improve algorithm to determination of Gaussian parameters
- Determine "non linear " empirical laws between SMC and some parameters
- Develop algorithm for thermal domain

Audrey.Lesaignoux@onera.fr

Conclusions and perspectives

- ***New database:*** **32** soils – **390** spectral signatures (informal spectra classification)

Spectral reflectances of bare soil related to SMC in [0.4 – 15 μm]

- ***Impact of increase SMC on spectral reflectance:***
  - Reduction of reflectance level (mean of maximum reflectance deviation < 0.3)
  - Growth of depth and spreading absorption peaks at **1.4** μm and **1.9** μm
  - Diminution of depth absorption peaks of minerals in **NSWIR** and **MWIR**
  - Diminution of Reststrahlen bands of quartz and carbonates in **LWIR**

- ***Empirical model:***
  - Improve algorithm to determination of Gaussian parameters
  - Determine "non linear " empirical laws between SMC and some parameters
  - Develop algorithm for thermal domain

Audrey.Lesaignoux@onera.fr