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

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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
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.

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

Solar domain [0.4 - 2.5 \( \mu m \)]

Methods based on spectral reflectance

Spectral bands exploitation
- Analytical methods
  - Liu et al. 2002
  - Liu et al. 2003
- Spectral index
  - Bryant et al. 2003
  - Khanne 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

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

Thermal domain [\( 15 \text{ } - \text{ } 3 \text{ } \mu m \)]

Methods based on surface temperature

ΔT

Method based on spectral emissivity

\[ \Delta \theta - \Delta \mu \text{m} \text{ exploitation} \]

- Correlation analysis
  - Xiao et al. \( \gamma \cdot \gamma \)
  - Ogawa et al. \( \gamma \cdot \gamma \)
- Spectral ratio
  - Urai et al. 1997
  - Mira et al. \( \gamma \cdot \gamma \)
State of art
Spectral database related to SMC

Approaches validation

Lab measurements of spectra of bare soils at different moisture contents

- Few data set in [8 – 15 \( \mu m \)] (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 \( \mu m \)] depending on SMC
Lab measurements

Description

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**

<table>
<thead>
<tr>
<th>INSTRUMENT</th>
<th>ACCURACY</th>
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</thead>
<tbody>
<tr>
<td>ASD</td>
<td>∆λ ± 1 nm</td>
</tr>
<tr>
<td>Bruker</td>
<td>Error &lt; 3%</td>
</tr>
<tr>
<td>Lab oven</td>
<td>Residual moisture ~ 2%</td>
</tr>
</tbody>
</table>
Lab measurements
Method (1/2)

- Spectral reflectance measurement

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

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Lab measurements
Method (2/2)

Moisture content measurement

- Gravimetric method: Soil Moisture Content 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 saturating with water)
2. Weighing with balance
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
Lab measurements

Analysis & Results


- **Analysis**

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

- 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)*
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]
Lab measurements
Soil spectra classification (2/2)

Example

Group 1

Solar domain

Thermal domain

Group 2
Calcereous
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

<table>
<thead>
<tr>
<th></th>
<th>VIS</th>
<th>NSWIR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean of max spectra deviations</td>
<td>0.13±0.04</td>
<td>0.31±0.08</td>
</tr>
<tr>
<td>Mean of min spectra deviations</td>
<td>0.03±0.04</td>
<td>0.12±0.03</td>
</tr>
</tbody>
</table>

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

Fe$^{3+}$, Fe$^{2+}$
Lab measurements

Impact of SMC on spectral reflectance (2/2)

Thermal domain: 3 - 15 µm

For all samples between dry and saturated sample

<table>
<thead>
<tr>
<th></th>
<th>MWIR</th>
<th>LWIR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean of max spectra deviations</td>
<td>0.17±0.05</td>
<td>0.05±0.01</td>
</tr>
<tr>
<td>Mean of min spectra deviations</td>
<td>-0.01±0.01</td>
<td>-0.03±0.01</td>
</tr>
</tbody>
</table>

Peaks detection is almost impossible if SMC is upper 20 %

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

  \[ \text{LN(spectra)} = \text{Continuum}(c_1, \ldots, c_n) + \sum \text{Gaussians}(g_1, \ldots, g_m) \]

  - Determine continuum with convex hull method to apply “Continuum removal” method.
  - Use 1\textsuperscript{st} and 2\textsuperscript{nd} derivative spectra (continuum removed spectrum) to determine extrema for initial parameters of Gaussians (\(g_m \equiv \text{centers, amplitudes, fwhm}\)).
  - Determine empirical laws link SMC with \(c_n\) and \(g_m\) (currently linear).

Simulations for a soil group.
Lab measurements
Empirical model (2/2)

- Less of absorption peaks at 1.8 µm and 2.2 µm
- Difference level “seems” weak but error must be defined

Current works

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