Soil spectroscopy as a tool for the spatial assessment of soil erosion states in agricultural semi-arid Spain

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Introduction

• I come from the remote sensing community

• We do similar work, but of course with extension / application to remote sensing scale airborne or spaceborne

• Jargon is different
  – VNIR → ONLY 0.4-1.3 microns
  – VNIR – Short Wave Infrared (SWIR)
Background

• Soils
  – carry out a number of key environmental functions
  – Fragile soils in agricultural arid and semi-arid regions very sensitive to erosion processes
  – Processes monitoring and modeling requires a proven approach for soil properties estimation (applicable at all scales, repeatable, transferable)

• VNIR-SWIR spectroscopic methods as a soil analytical tool for the accurate estimation of surface soil properties
  – Proven capability to derive key soil variables
  – Capabilities to infer deposition and erosion stages not demonstrated

• High relevance nowadays
  – Digital soil mapping and soil monitoring initiatives
  – Upcoming availability of next generation orbiting hyperspectral sensors e.g. EnMAP 2017
SEDMEDHY - Soil Erosion Detection within MEDiterranean agricultural areas using Hyperspectral data

• EU-FP7 EUFAR Transnational Access project (Lead: CIEMAT)

• Main objective: Examine the potential of soil spectroscopy for the mapping and identification of soil erosion and deposition states, Analyses of the spatial distribution of combined varying surface soil properties (OM, CaCO3, texture, Fe)

• Scientific issues
  – Discriminate crop residue, sparse vegetation, bare soil types
  – Integrate detailed terrain information for small scale topographic variations
  – Definition of soil surface characteristics as indicators of soil erosion stages
  – Determination of a map of soil erosion assessment
  – Address scaling issues of future spaceborne hyperspectral sensors
Methods: HYSOMA software interface

- Experimental toolbox
- To provide non-expert spectroscopy users (hyperspectral users) with a suite of tools for soil applications
- Download: www.gfz-potsdam.de/hysoma
## HYSOMA soil algorithms

<table>
<thead>
<tr>
<th>Soil Chromophores</th>
<th>Soil Algorithm</th>
<th>Spectral Region (nm)</th>
<th>Estimated soil parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iron oxides</td>
<td>Redness Index (RI)</td>
<td>477, 556, 693</td>
<td>Hematite content (Madeira et al., 1997; Matthieu et al., 1998)</td>
</tr>
<tr>
<td></td>
<td>Spectral feature analysis 1</td>
<td>460 - 620</td>
<td>Iron oxide content</td>
</tr>
<tr>
<td></td>
<td>Spectral feature analysis 2</td>
<td>760 - 1050</td>
<td>Iron oxide content</td>
</tr>
<tr>
<td>Clay Minerals</td>
<td>SWIR Fine Particle Index (SWIR FI)</td>
<td>2209, 2133, 2225</td>
<td>Clay mineral content (Levin et al., 2007)</td>
</tr>
<tr>
<td>Al-OH content</td>
<td>Spectral feature analysis</td>
<td>2120 - 2250</td>
<td>Clay mineral content</td>
</tr>
<tr>
<td>Carbonates</td>
<td>Spectral feature analysis</td>
<td>2300 - 2400</td>
<td>Carbonate content</td>
</tr>
<tr>
<td>Mg-OH content</td>
<td>Normalised SM Index (NSMI)</td>
<td>1800, 2119</td>
<td>Soil moisture content</td>
</tr>
<tr>
<td></td>
<td>SM Gaussian Model (SMGM)</td>
<td>~1500 - 2500</td>
<td>Soil moisture content</td>
</tr>
<tr>
<td>Soil moisture content</td>
<td>Spectral feature analysis SOC 1</td>
<td>400 - 700</td>
<td>Organic matter content</td>
</tr>
<tr>
<td>Organic Carbon</td>
<td>Spectral feature analysis SOC 2</td>
<td>400, 600</td>
<td>Organic matter content</td>
</tr>
<tr>
<td></td>
<td>Spectral feature analysis SOC 3</td>
<td>2138, 2209</td>
<td>Indirect organic matter content</td>
</tr>
</tbody>
</table>

→ Currently 11 automatic soil functions for identification and semi-quantification
→ Fully quantitative mapping using field data for calibration (Option: “Generate calibration file”)
Study area: Camarena test site

Traditional rainfed agricultural activities:
- Wheat/ Barley crops
- Vineyards
- Olive Groves

Mediterranean climate:
- Avg. annual temp of 15.4°C
- Avg. annual precipitation of 357 mm

Undulating topography, avg. ele.v. 625m a.s.l.
Study area: Soils

→ Mostly evolved soils such as Calcic Haploxeralfs or Calcic Luvisols

→ Typical soil profile (arcosic area)

- A Horizon
  - Moderate Organic Matter Content
  - Coarse Textured

- Bt Horizon
  - Fine-textured
  - Rich in Fe-Oxides

- Ck Horizon
  - Rich in Carbonates
  - Coarse Textured

- C Horizon
  - Arcosic Sediment

→ Erosion features (water erosion) associated with contrasting soil horizons
Erosion model

→ Soil profile modification by tillage along the slope (De Alba et al., 2004)

1- Soil truncation due to net soil loss
2- Substitution of surface horizons
3- Inversion of horizons
4- Soil accumulation
Data

- **Field and laboratory data**
  - Field and laboratory spectroscopic analyses at selected sites linked with geo- and bio-geochemical analyses (soil characterisation, LAI, crop production)
  - Soil sampling (0-10, 20-30, 30-50 cm) in the different erosional stages
  - Soil characterisation: pH, EC, OM, CaCO$_3$, Fe oxides, coarse fragments, texture, color, description, soil mineralogy
  - Spatial multiscale sampling protocol

- **Airborne data**
  - NERC AISA Eagle and Hawk hyperspectral data (400-2400 nm) at different altitudes: 1.5 and 3 m Low Alt, 3 and 6 m High Alt
  - LIDAR ALS50 (DEM <1m)

LA Eagle mosaic (Aug.8/2011)

HA Eagle mosaic (Aug.10/2011)
Analyses at selected sites

NORTH
E1/s2 location: Arcosic area

SOUTH
SU location: Carbonatic area

pH~5.5, B-horizons (clay & iron-rich) exposed at top slope,
Sands in accumulation areas, locally carb precipitates

pH~8 at SU2 point, carbonate horizons at top slope situation (Ck)
due to net soil loss
Multitemporal observations

SU location: Carbonatic area

(SU2) Subsurf soil horizon outcrop (Ck)

SU test site in fallow (08.Aug.11) and with wheat cultivation (23.Mar.12)

Same area identified by condition of wheat crop (chlorosis)

→ Soil surface characteristics can be related with soil erosion states, land management and vegetation conditions
Mapping of soil properties based on AISA images

Camarena reflectance cube and predicted clay and iron spatial content
Definition of soil erosional stages classes

<table>
<thead>
<tr>
<th>SAMPLE</th>
<th>pH</th>
<th>EC</th>
<th>CaCO3</th>
<th>organic matter</th>
<th>Fe oxides</th>
<th>TEXTURE (% in &lt;2mm fraction)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CRA</td>
<td>(H2O 1:2,5)</td>
<td>µS/cm</td>
<td>(% w/w)</td>
<td>(% w/w)</td>
<td>(Holmgren, 1967)</td>
<td>CLAY</td>
</tr>
<tr>
<td>S2P1_C</td>
<td>6,71</td>
<td>27</td>
<td>0,9</td>
<td>0,23</td>
<td>0,15</td>
<td>11</td>
</tr>
<tr>
<td>S2P2_C</td>
<td>6,69</td>
<td>43</td>
<td>1,0</td>
<td>0,30</td>
<td>0,27</td>
<td>36</td>
</tr>
<tr>
<td>S2P3_C</td>
<td>8,21</td>
<td>111</td>
<td>9,7</td>
<td>0,17</td>
<td>0,15</td>
<td>32</td>
</tr>
<tr>
<td>S2P4_C</td>
<td>6,92</td>
<td>59</td>
<td>1,1</td>
<td>0,61</td>
<td>0,43</td>
<td>39</td>
</tr>
<tr>
<td>SU2_C</td>
<td>8,32</td>
<td>174</td>
<td>31,8</td>
<td>1,1</td>
<td>0,08</td>
<td>20</td>
</tr>
</tbody>
</table>

Image endmember reflectance spectra
Mapping of soil erosional stages

High
Intermediate-high
Intermediate Bt
Intermediate B
Accumulation
Mapping of soil erosional stages (outlook)
Summary/Outlook

• Results
  – Spatial distribution of combined variable occurrences in clay, carbonate, iron and sand content can be successfully detected at the field level and in most case at the remote sensing level
  – Depending on lithological background, identification and mapping of different soil horizons could be tentatively linked to soil erosion states and accumulation areas
  – Use of classification methods vs. quantification

• Next steps
  – Prediction accuracy: Validation using representative number of locations
  – More generic approaches (SVM)
  – Upscale to higher spatial scale (3m – 6m – 30m)
    → Transferability/ Application of the approach to other lithological and environmental background
    → Link with hydrological and erosion modeling
Thank you for your attention!