REMOTE SENSING FOR SOIL SCIENCE

Remote Sensing (GRS-20306)
Outline

- Soils
- RS & soils
- How to derive soil information from (remote) sensing data
- Instructions for the Exercise
Why is soil so important?

- Vital part of the natural environment
- Influences plant growth / plant distribution
- Controls flow of water and chemical substances between atmosphere and earth

- Changing constantly through time
- Some changes are of short duration and reversible, others are more permanent
Soil sampling

We want to have:
• Spatially continuous information
• Regular updates
• Quantitative information

➢ Traditional soil sampling can’t offer this
• Expensive
• Time consuming
Soil Sensing

- Electro magnetics
- Gamma Rays
- Drilling
- Reflectance
Scales

REMOTE SENSING

PROXIMAL SENSING

LAB. Spectroscopy
Soil & optical remote sensing

**Soil** - (i) The unconsolidated mineral or organic material on the immediate surface of the Earth that serves as a natural medium for the growth of land plants. (Soil Science Glossary, Soil Science Society of America)
Soil reflectance during the RS course

[Graph showing soil, vegetation, and water reflectance across different wavelengths with LAI values (0, 0.5, 1.0, 2.0, 4.0, 8.0).]
Info about soils from remote sensing
(between 0.400 µm and 2.500 µm)

By observations of:

- Crop cover and vegetation
  - Relation between crop or vegetation and soil
  - Relation between crop development and soil
- Bare soil surface
  - Relation between soil surface and soil
- Topography (relief differences)
  - Relation between topography and soil
Info about soils from remote sensing - Vegetation

Landsat 5 TM 1995: bands 4,5,3 -> R,G,B
Info about soils from remote sensing – Vegetation development

\[ y = -0.0209x + 0.8577 \]
\[ R^2 = 0.6765 \]
Info about soils from remote sensing – Bare soil

ROSIS: RGB = 60, 40, 20
Quantitative estimates from bare soil

Lorraine – Sandy clay / loam

RGB Aerial Photo
SUMVIS
NDRG
R-B
R/B
Org. M.

Use of aerial photographs for assessment of soil organic matter, Bartholomeus & Kooistra, EGU-2012
Radiance of Exposed Bare Soil

\[ L_t = L_p + L_s + L_v \]

- \( L_t \) = at-sensor radiance of a pixel of exposed soil
- \( L_p \) = atmospheric path radiance, usually needs to be removed through atmospheric correction
- \( L_s \) = radiance reflected off the air-soil interface (boundary layer)
  - Soil organic matter and soil moisture content significantly impact \( L_s \); typically characterize the O horizon, the A horizon (if no O), or lower levels if A and O are nonexistent.
- \( L_v \) = volume scattering, EMR which penetrates a few mm to cm.
  - penetrates approximate 1/2 the wavelength
  - Function of the wavelength (so RADAR may penetrate further), type and amount of organic/inorganic constituents, shape and density of minerals, degree of mineral compaction, and the amount of soil moisture present.

Source: ERS 186 Environmental Remote Sensing; S. Ustin
Radiance of Exposed Soil

Downwelling Sun and Sky Irradiance

Total Radiance

$L_t = L_P + L_S + L_V$

$E_{sun}$ and $E_{sky}$

Atmosphere

$L_P$

$L_S$

$L_V$

Surface

$\frac{1}{2} \lambda$

few cm

$O$ horizon

$A$ horizon

a. Soil with well-developed $O$ and $A$ horizons

b. Thin $O$ horizon over less developed $A$ and $B$ horizons

c. Very thin $O$ horizon over subsoil and weathered bedrock

Source: ERS 186 Environmental Remote Sensing; S. Ustin
Main factors influencing soil reflectance

- For bare soils:
  - Roughness and texture
  - Organic matter content
  - Moisture condition (re-reflecting, OH⁻)
  - Mineralogical composition (OH⁻, CO₃²⁻, Fe²⁺, Fe³⁺, ...)

- Causes of specific absorption bands:
  - Electronic processes: short wavelength; absorption bands
    - Fe: UV, 0.400 µm – 1.000 µm
  - Vibrational processes: long wavelength, (relatively) narrow bands.
    - OH: 1.450 µm, 1.950 µm
    - OH: >1.000 µm (minerals containing OH, H₂O)
Surface Roughness

- A rough surface generally reflects less, due to self-shadowing effects and multiple scattering.
- If a surface is smooth (particles smaller than wavelength), specular reflection is important.
  - No return – surface dark – unless sensor correctly positioned and pointed in specular direction.
  - Smooth soil surfaces tend to be clayey or silty, often are moist and may contain strong absorbers such as organic content and iron oxide.
- Conversely, a rough surface scatters EMR and thus appears bright.

Source: ERS 186 Environmental Remote Sensing; S. Ustin
Organic Matter

Spectral Signature for three soils with varying SOC content

- increase in organic matter -> decrease in R
- Above 2% masking of other absorption features
- No distinct absorption features
Quantitative estimates from bare soil

Lorraine – Sandy clay / loam

RGB Aerial Photo
SUMVIS
NDRG
R-B
R/B
Org. M.

Use of aerial photographs for assessment of soil organic matter, Bartholomeus & Kooistra, EGU-2012
Determining Soil Organic Carbon in Partially vegetated Fields

\[ R_{soil} = \frac{R_{pixel} - (f\text{Cover} \times R_{maize})}{(1 - f\text{Cover})} \]
Soil Moisture

- Water ‘coats’ particles, filling air spaces and reducing the amount of multiply scattered light, so soils with more moisture will be darker in the VNIR and SWIR than drier soils.
- Moist soils will also be darker in the SWIR region where water absorption increases significantly with increasing wavelength.
- The depths of the water absorption bands at 1.4, 1.9 and 2.7 μm can be used to determine soil moisture.
  - (But why is this often not possible??)

Source: ERS 186 Environmental Remote Sensing; S. Ustin
Soil Moisture and Texture

- Clays hold more water more ‘tightly’ than sand
- Thus, clay spectra display more prominent water absorption bands than sand spectra
- for quantifying these absorption features hyperspectral data are needed

Source: ERS 186 Environmental Remote Sensing; S. Ustin
Mineral composition
Mineralogical composition – iron (Fe)

Fieldspectra of soils with varying iron content

Reflectance

Wavelength (nm)

350 750 1150 1550 1950 2350

11.80%
15.30%
19.50%
Continuum Removal is used to normalize reflectance spectra to allow comparison of individual absorption features from a common baseline.

The continuum is a convex hull fit over the top of a spectrum utilizing straight line segments that connect local spectra maxima.

The first and last spectral data values are on the hull and therefore the first and last bands in the output continuum-removed data file are equal to 1.0.

(Source: ENVI online help)
For the Exercises: Continuum removal

Continuum removed lab spectra with varying iron content

Fieldspectra of soils with varying iron content

Continuum removed value

Reflectance

Wavelength (nm)

Continuum Removed Chlorophyll Absorption

Continuum

Green Vegetation

Scanned by WAGENINGEN UNIVERSITY
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Mineralogical composition – iron (Fe)

Reflectance spectra of iron bearing minerals (Goetz, 1989)
Mineralogical composition – iron (Fe)
Characteristic bare soil curves

The characteristic soil bidirectional reflectance spectra of Stoner and Baumgardner (1981).
Curve A: soils having high (>2%) organic-matter content and fine texture.
Curve B: soils having low (<2%) organic-matter content and low (<1%) iron-oxide content.
Curve C: soils having low (<2%) organic-matter content and medium (1 to 4%) iron-oxide content.
Curve D: soils having high (>2%) organic-matter content, low (<1%) iron-oxide content, and moderately coarse texture.
Curve E: soils having high (>4%) iron-oxide content and fine texture.
(Reproduced from “Characteristic Variations in Reflectance of Surface Soils” by E.R. Stoner and M.F. Baumgardner, Fig. 1, Soil Science Society of America Journal, Volume 45, No. 6. Pages 1161-1165 by permission of the Soil Science Society of America, Inc.)
Measuring soil reflectance in the field

Saves lab time, needs a profile exposure

Problems: Need open profile.

Spectral diversity

Ben-Dor and Heller, 2005: *Optical Approach for Soil Survey Missions*

First Joint Dutch-Israeli workshop on Spatial, Temporal & Spectral Scale in SVAE, Wageningen Sept 14-16 2005
Practical Measurement

Ben-Dor and Heller, 2005: **Optical Approach for Soil Survey Missions**
First Joint Dutch-Israeli workshop on Spatial, Temporal & Spectral Scale in SVAE, Wageningen Sept 14-16 2005
Conclusions / Remarks

- For general information about soil types Landsat-type data can be used.
- For *quantitative* retrieval of soil parameters (organic matter, iron, moisture) detailed spectral measurements are needed (imaging spectrometry).
- Analysis within one soil-type is usually straightforward, models are not always *(seldom??)* applicable on several soil types.
- Vegetation is on the one hand disturbing, but can be a source of information as well.
Questions?
Continuum Removal is used to normalize reflectance spectra to allow comparison of individual absorption features from a common baseline.

The continuum is a convex hull fit over the top of a spectrum utilizing straight line segments that connect local spectra maxima.

The first and last spectral data values are on the hull and therefore the first and last bands in the output continuum-removed data file are equal to 1.0.

(Source: ENVI online help)
For the Exercises: Continuum removal

Continuum removed lab spectra with varying iron content

- 0.5
- 0.6
- 0.7
- 0.8
- 0.9
- 1

400 500 600 700 800 900 1000 1100 1200
wavelength (nm)

continuum removed value
- 11.80%
- 12.30%
- 15.30%

Continuum Removed Chlorophyll Absorption

Continuum
Green Vegetation
Reflectance-curves
Answers: influence of roughness and water