Remote Sensing for Soil Survey Applications

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Landsat 7 ETM+ Bands 3, 2, 1 w/DEM = Visible light RGB

Gypsic Soil

Rock Outcrop
Landsat 7 ETM+
Bands 3, 2, 1 w/DEM
= Visible light RGB

Landsat 7 ETM+
Bands 7, 5, 1 w/DEM
= SWIR (2.02-2.35 µm), Blue

Gypsic Soil
Rock Outcrop
Overview

1. Models of soil formation and distribution
2. Remotely sensed (RS) spectral data on biophysical properties
   - Organisms
   - Parent Material
   - Soil
3. Spectral band ratios
4. RS in digital (predictive) soil mapping
Factors of Soil Formation (Jenny 1941)

• Soils are a function of 5 environmental factors: 
  \[ S = f (C_l, O, R, P, T) \]
  – **Climate** (Precipitation, Temperature)
  – **Organisms** (Vegetation)
  – **Relief** (Topography)
  – **Parent Material**
  – **Time**

• Conceptual model
  – Traditional soil survey: “tacit knowledge”
Soil Forming Factors

• Often inter-related
  – E.g., Circle Cliffs, UT
    • Arid climate (Cl)
    • Pinyon-juniper community (O)
    • Highly dissected landscape (R)
    • Fe-oxide-rich shale (P)
    • Shallow, rocky soils (S)

• Feedbacks
SCORPAN (McBratney et al., 2003)

- **Soil**, at a specific point in **space** and time,
  - Soil classes, **Sc**
  - Soil attributes, **Sa**
- Empirical **quantitative** function of **environmental** covariates:
  - Soil (class, directly or remotely sensed property, data from old maps)
  - Climate
  - Organisms
  - Relief
  - Parent Material
  - **Age**
  - **N** = Spatial Position
Organisms: Vegetation

- Plants primary producers of organic carbon
- Healthy green vegetation
  - Reflects NIR (0.7-1.1 µm)
  - Chlorophyll absorbs visible (0.4-0.7 µm), especially red
- Dead/senescent vegetation
  - Reflects more in visible
Organisms: Vegetation

Absorbs Red

Reflects Near Infrared (NIR)

Organisms: Vegetation

- Relative abundance
  - Normalized Difference Vegetation Index (NDVI)
  - \((\text{NIR}-\text{Red})/(\text{NIR}+\text{Red})\)
  - Landsat: \((4-3)/(4+3)\)

- E.g., Powder River, WY: NDVI
  - **Black** = no vegetation
  - **White** = high vegetation density
  - **Gray** shades = intermediate vegetation density
    - Darker, lower density
    - Lighter, higher density
Organisms: Biological Soil Crusts

- Community of organisms in upper few cm of soil
  - Cyanobacteria
  - Lichen
  - Mosses
  - Algae
  - Other
    - Species, relative composition depends on parent materials, climate

- Cyanobacteria
  - Phycobilin pigments increase reflectance in blue region (Karnieli et al., 1999)
Organisms: Biological Soil Crusts

Cyanobacterial Crust Index = (Red-Blue)/(Red+Blue) [left]
vs. NDVI [right]

Canyonlands National Park
Parent Material

- Spectral response of mineralogy varies

- E.g. San Francisco Mts., Great Basin, UT:
  - Sedimentary rocks
  - Igneous intrusions
  - Mixed basin fill

- Principle component analysis (PCA) of Landsat bands 1-5, 7:
  - Igneous intrusion (andesite)
  - Andesite influence on alluvium composition
Parent Material and/or c) Soil

- Spectral properties of different minerals vary

http://ldcm.usgs.gov/tools_viewer.php

Short-wave Infrared (SWIR)
Explore Spectral Libraries

- **ASTER and USGS Spectral Libraries**
  - View plots
    - Qualitatively compare spectra to band profiles
  - Download spectral data files
    - X = Wavelength (micrometers)
    - Y = Reflectance (percent)
    - Plot spectra vs. wavelength band intervals of sensors
      - Excel, etc.
Parent Material

• Simple or normalized band difference ratios
  – Customized

• E.g., Great Basin, UT: Landsat: \((5-2)/(5+2)\)
  – Darker = Igneous Rocks (Andesite)
  – Lighter = Sedimentary Rocks (Dolomite, Quartzite)
  – Fill sources varies, indicated by tone
Soil

- Chemical, physical soil properties
- Surface, very near-surface
  - Silicate clays
  - Iron oxides
  - Salts
  - Gypsum
  - Carbonates
- E.g., San Rafael Swell, UT
  - Gypsum near soil surface
    - Diagnostic spectrum in SWIR
  - Landsat (5-7)/(5+7)
Landsat 7 ETM+
Bands 3, 2, 1 w/DEM
= Visible light RGB

Landsat 7 ETM+
Bands 7, 5, 1 w/DEM
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Gypsic Soil
Rock Outcrop
Thematic Output for Gypsic Index

Surficially gypsiferous

Rock outcrop
Relief

- Elevation
  - E.g., Photogrammetric, IFSAR, LiDAR sources
- Ancillary data derived from elevation (many possible)
  - Slope
  - Curvature
  - Wetness Index
  - Ruggedness Index
  - Aspect
  - Landform
  - Relative Elevation, etc.
- E.g., Powder River Basin, WY
  - Elevation vs. Slope

Elevation:
Blue = 1109m
White = 1141m

Slope:
Blue = 0%
White = 128%
Climate

• Elevation
  – E.g., Photogrammetric, IFSAR, LiDAR sources
• Regional climate models (ancillary data)
  – E.g., PRISM Data
    • [http://www.prism.oregonstate.edu/](http://www.prism.oregonstate.edu/)
• Solar radiation models (ancillary data)
  – Several available
    • E.g., ArcGIS used to calculate annual, monthly solar radiation
Human Factors

• Humans alter landscape and landcover
  – E.g., Las Vegas, NV
    • Destroy petrocalcic horizon
    • Irrigation alters
      – Soil properties
      – Hydrology

• Image sequence
  – Age

• Landuse
  – Soil properties
    • E.g., Desirable soil properties in agricultural areas
Remote Sensing in Soil Survey

- Powder River Basin, Wyoming, USA
  - 60,000 ha east of Big Horn Mountains
  - Energy development on public lands
Identify soil-landscape units
Environmental Covariate Data Layers

• Relief
  – DEM-derived data
    • Slope, aspect, relative elevation, compound topographic index (CTI), Landform Index

• Organisms
  – Landsat
    • Fractional Vegetation Index (FVI) - %
      – Uses Normalized Differenced Vegetation Index (NDVI)

• Parent Material
  – Landsat: Simple Band Ratios
    • Soil Enhancement Ratio
      – Band 3/ Band 2: Carbonate radical
      – Band 3 / Band 7: Ferrous iron
      – Band 5 / Band 7: Hydroxyl radical
Knowledge Engineer in Imagine
### Final Map and Rules Defining Map Units

Rules used in knowledge-based decision tree classification for generalized soil associations and the eight specific map unit classes evaluated in the accuracy assessment.

<table>
<thead>
<tr>
<th>Map Unit Number</th>
<th>Class Name</th>
<th>Classification Rules</th>
</tr>
</thead>
<tbody>
<tr>
<td>NA</td>
<td>Fluvial Soils</td>
<td>Relative elevation to Powder River &lt;= 6m and slope &lt; 2%, or &lt;= 3m from Powder River, or &lt;= 5m in height and &lt;= 50m distance of small streams.</td>
</tr>
<tr>
<td>NA</td>
<td>Badland soils</td>
<td>Soil enhancement band 2 (iron) &gt;= 67 and slope &gt;= 8% and not Fluvial Soils</td>
</tr>
<tr>
<td>NA</td>
<td>Uplands</td>
<td>Relative elevation to &gt;= 60m and not Fluvial and not Badland Soils</td>
</tr>
<tr>
<td>NA</td>
<td>Alluvial fans</td>
<td>Not Fluvial and not Badland and Not Upland Soils</td>
</tr>
<tr>
<td>938</td>
<td>Water</td>
<td>Ten meter buffer of Powder River Line Coverage.</td>
</tr>
<tr>
<td>611</td>
<td>Draknab sandy loam, 0-3% slopes</td>
<td>Fluvial soils = true and soil enhancement band 2 &gt; 113 and relative elevation to Powder River &lt;= 5m, or, fluvial soils = true and relative elevation to &lt;= 1 and orthophoto value &gt; 150 in blue band, does not meet the requirements of any previous decision.</td>
</tr>
<tr>
<td>613</td>
<td>Haverdad-Kishona loams, 0-3% slopes</td>
<td>Fluvial soils = true and relative elevation to the river &gt;= 10m, or fluvial soils = true and slopes &gt; 6%, does not meet the requirements of any previous decision.</td>
</tr>
<tr>
<td>616</td>
<td>Clarkelen-Draknab complex, 0-10% slopes</td>
<td>Fluvial soil = true and Near infrared Landsat &gt; 60 and Fractional vegetation &gt; 38, or, Fluvial soils with CTI &lt; 1, does not meet the requirements of any previous decision.</td>
</tr>
<tr>
<td>612</td>
<td>Clarkelen fine sandy loam, 0-3% slopes</td>
<td>Fluvial soils = true and fractional vegetation &gt; 34, does not meet the requirements of any previous decision.</td>
</tr>
<tr>
<td>649</td>
<td>Haverdad-Clarkelen complex, 0-3% slopes</td>
<td>Other fluvial soils dominated (dominated by sage and grass community), does not meet the requirements of any previous decision.</td>
</tr>
<tr>
<td>684</td>
<td>Samday-Shingle-Badland complex, 10-45% slopes</td>
<td>Badland soils with slopes &gt;= 15 and mean slope length factor &gt; 1.85, or, badlands having slopes &gt; 50 %, does not meet the requirements of any previous decision.</td>
</tr>
<tr>
<td>709</td>
<td>Theedle-Shingle loams, 3 to 30% slopes</td>
<td>Badland soils = true and mean slope length factor &gt; .8 and &lt; 1.75, does not meet the requirements of any previous decision.</td>
</tr>
</tbody>
</table>
Digital (Predictive) Soil Mapping

- Objective field sampling methods
  - Conditioned Latin Hypercube Sampling
- Environmental covariates
  - Remote sensing of biophysical properties
- Models for predicting soil distribution
  - Objective
  - Quantitative
  - Estimate uncertainty of predictions
- Developing products
  - Derive maps to meet client needs