Connecting infrared spectra with plant traits to identify species


ITC - Faculty for Geoinformation Science and Earth Observation
University of Twente
WHISPERS - September 2018

Buitrago et al. (2018): ISPRS JPRS
CONTEXT

- Leaf traits differentiate plant species and plant health.

- Conventional methods are expensive and time-consuming.

- Spectroscopic methods are accurate and faster?
WHY THERMAL INFRARED SPECTROSCOPY?

VNSWIR range: change in pigments and water (commonly done)

Infrared: Changes in water, chemicals and microstructure.

Plants have spectral info in LWIR!

(work of e.g. Ribeiro da Luz; Ullah Saleem et al (2012))

Source: Saleem et al., 2012: RSE
SETUP

- **GOAL:**
  - establish link between leaf traits and spectral response in IR

- **Experiment**
  - 19 plant species
    - Herbaceous - woody; deciduous – evergreen; tropical-temperate
  - Spectroscopic measurements: DHR reflectance (1.4-16.0 µm).
  - Leaf traits (14)
    - Structural: Leaf thickness, cuticle thickness, leaf area, bundle area.. etc..
    - Chemical: lignin, cellulose, nitrogen, leaf water content, … etc..
MEASUREMENTS:

Spectral measurements

Directional – hemispherical reflectance measurements (converted to emissivity)
MEASUREMENTS:

Microscopic and chemical measurements

Microscopic and chemical measurements

Tangential and transversal cut of the leaf

Leaf trait measured

<table>
<thead>
<tr>
<th>Code</th>
<th>Leaf trait</th>
</tr>
</thead>
<tbody>
<tr>
<td>LWC</td>
<td>Leaf water content</td>
</tr>
<tr>
<td>lig</td>
<td>Lignin content</td>
</tr>
<tr>
<td>cel</td>
<td>Cellulose content</td>
</tr>
<tr>
<td>lig/cel</td>
<td>Lignin/cellulose ratio</td>
</tr>
<tr>
<td>N</td>
<td>Nitrogen content</td>
</tr>
<tr>
<td>C/N</td>
<td>Carbon/nitrogen ratio</td>
</tr>
<tr>
<td>lt</td>
<td>Leaf thickness</td>
</tr>
<tr>
<td>ct</td>
<td>Cuticle thickness</td>
</tr>
<tr>
<td>et</td>
<td>Epidermis thickness</td>
</tr>
<tr>
<td>vt</td>
<td>Vein thickness</td>
</tr>
<tr>
<td>ba</td>
<td>Bundle area</td>
</tr>
<tr>
<td>ss</td>
<td>Stomata size</td>
</tr>
<tr>
<td>sd</td>
<td>Stomata density</td>
</tr>
<tr>
<td>la</td>
<td>Leaf area</td>
</tr>
</tbody>
</table>
RESULTS (TRAITS):

Examples: leaf thickness (structural); cellulose (chemical)

Intra vs inter species variability!
RESULTS (SPECTRA):  

Herbaceous vs. Woody species
RESULTS: Selecting bands that separate plant species

Tukey Sign. Diff. test between 2 species (171 combinations)
If more than 75% of combinations different => wavelength flagged
RESULTS: Selecting bands that separate plant species

Ball: significantly different than other 18 species
Flag: more than 50% species have a ball
RESULTS: NARROW DOWN AND CLASSIFY

- Take all flagged bands
- Use a stepwise Quadratic Differentiation Analysis (QDA) => reduce number of bands (to ca. 5)
- QDA => Classify into species

- IR Full: 1.50, 2.15, 5.40, 8.54, 9.78 um : Kappa = 0.96
- SWIR: 1.50, 1.52, 2.00, 2.15, 2.29 um : Kappa = 0.93
- MWIR: 3.05, 3.68, 4.87, 5.26, 5.40 um : Kappa = 0.84
- LWIR: 6.91, 8.54, 9.78, 12.14, 12.76 um: Kappa = 0.94
RESULTS: CORRELATE WITH TRAITS

a) Correlation matrix between stepwise QDA bands and traits
b) Known chemical vibrational bonds and associated molecules reported

<table>
<thead>
<tr>
<th>Wavelength (µm)</th>
<th>1.50</th>
<th>1.52</th>
<th>2.00</th>
<th>2.15</th>
<th>2.29</th>
<th>3.05</th>
<th>3.68</th>
<th>4.87</th>
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<td>-0.39</td>
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<tr>
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<td>-0.44</td>
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<td>-0.02</td>
<td>-0.09</td>
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<td>0.06</td>
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<td>0.16</td>
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<td>0.17</td>
<td>0.19</td>
</tr>
</tbody>
</table>

**Chemical bond reported at this wavelength**
- O-H stretch, C-H stretch: Cellulose, N, Protein
- N-H stretch: N, protein
- O-H deformation: Cellulose, lignin, starch
- C-O, C-H and O-H stretch: Cellulose, lignin, starch, N
- O-H stretch: Cellulose, polysaccharides, water
- C-H out of plane vibration: (12.16) Lignin
CONCLUSIONS:

- This study shows that:
  - infrared spectra of fresh leaves of 19 investigated plant species differentiate and classify species.
  - More different in SWIR and LWIR than in MWIR
- Bands can be linked to leaf traits
  - Strongest correlations:
    - Cellulose and Leaf thickness (SWIR)
    - Nitrogen (MWIR)
    - LWC (LWIR)
- Remote Sensing:
  - SWIR works and is easier (sensor complexity and availability)
  - The LWIR: species demonstrated particular features that can further improve classification accuracy. Effect of Canopy?
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