Spectral time series for the study of ecosystem function, using EO-1 Hyperion

Petya Campbell & K. Fred Huemmrich (UMBC) and Elizabeth Middleton (NASA/GSFC)
EO-1 Acquisitions, Dec 2000 – Current
> 70,000 Hyperion scenes have been collected
Differences between Rolo model and Hyperion measurements remain stable (within 5%) over time.

Lawrence Ong 2013
• Level 1R Hyperion data were atmospherically corrected using the Atmosphere CORrection Now (ACORN) model.

• Reflectance spectra were extracted in the vicinity of the existing flux towers, from 30-50 pixels depending on the site size.
Temporal Profile of Selected Hyperion Bands

Calibration converts those images from pretty pictures to accurate data sets that can be used for a variety of scientific purposes such as ...

D. Helder

Spectral Time Series at CEOS Cal/Val Sites
Reflectance spectro-temporal Separability Index comparing native vs. invasive tree species in Hawaii, demonstrating that phenology is a key to spectral separability analysis. 

*Somers & Asner, 2013*

NDVI and Endmember abundance maps for vegetation and soil 

*Torres-Madronero et al. 2012*
Science Questions

- Is there a common (global) spectral approach to trace vegetation function, and it’s CO₂ sequestration ability?

- How do species and biodiversity composition within ecosystems respond spectrally to the seasonal environmental changes?

- How do spectral properties and temporal dynamics of vastly different ecosystems compare?
FLUXNET is a "network of regional networks" for regional and global analysis of observations from micrometeorological tower sites. The flux tower sites about 545 (~410 active) use eddy covariance methods to measure the exchanges of carbon dioxide (CO$_2$), water vapor, and energy between terrestrial ecosystems and the atmosphere.

LaThuile Fluxnet Synthesis: A global network of about 250 flux sites with standardized flux calculations and gap filling for all sites (data 1982-2008)
Hyperion & Fluxnet

The time series include more than 90 sites globally, with >40 sites providing observations over flux tower sites

- PLS: 79 images of 33 different LaThuile flux tower sites, data from 2001 to 2007, matched flux data with available Hyperion imagery
- Spectral time series and VIs, 450+ images, 15 flux tower sites
CO₂ Flux Data Processing

• Net Ecosystem Production (NEP, μmol m⁻² s⁻¹) is the CO₂ absorbed by the vegetation, measured by the flux tower.

• Ecosystem Respiration (Re) was calculated from relationships developed between nighttime Net Ecosystem Exchange (NEE) and air temperature.
  – When available, soil moisture was also used to determine Re

• Gross Ecosystem Production (GEP) is calculated from the observed NEE and Re.
Carbon Flux Variables

We looked at Light Use Efficiency (LUE, ε) derived from the tower data

\[ \varepsilon = \frac{\text{GEP}}{f_{\text{APAR}} \text{PAR}_{\text{in}}} \]

Where:
- GEP is the gross ecosystem production (calculated from tower data)
- \( \text{PAR}_{\text{in}} \) is the incident Photosynthetically Active Radiation (measured at tower)
- \( f_{\text{APAR}} \) is the fraction of PAR absorbed by vegetation (used MODIS \( f_{\text{APAR}} \) values)
Partial Least Squares – LUE

Partial Least Squares is an approach that utilizes all of the spectral information. PLS regressions against daily LUE were calculated for all spectral bands for random subsets of half of the data (n=39) – resulted in similar weighting factors for the spectral bands.
Remote Sensing of Fluxes: Hyperion and Fluxnet

Using matched flux data from LaThuile Fluxnet Synthesis with Hyperion imagery for 33 globally distributed flux tower sites

LUE Histogram for full scene

LUE Histogram for km² around tower

Light Use Efficiency (LUE) estimated from reflectance using PLS regression of spectra to observed LUE from flux towers

Huemmrich, Campbell & Middleton
Partial Least Squares – LUE

Tests where specific vegetation types were removed from training datasets often performed poorly when applied to the test data.

Black points – training data
Red points – Evergreen Broadleaf Forests

Black points – training data
Red points – Crops and Grasslands
<table>
<thead>
<tr>
<th>Spectral indicator</th>
<th>Formula</th>
<th>NEP</th>
<th>GEP</th>
<th>LUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dmax</td>
<td>Max D in the 650-750 nm</td>
<td>0.72 L+</td>
<td>0.77 L+</td>
<td>0.76 L+</td>
</tr>
<tr>
<td>DP22</td>
<td>Dmax/D(max + 12)</td>
<td>0.64 L+</td>
<td>0.73 NL+</td>
<td>0.70 L+</td>
</tr>
<tr>
<td>NDWI</td>
<td>R(870-1240)/R(870-1240)</td>
<td>0.75 NL+</td>
<td>0.66 NL+</td>
<td>0.62 L+</td>
</tr>
<tr>
<td>MCARIa</td>
<td>Chlorophyll, R bands at 700, 670, and 550</td>
<td>0.42 L+</td>
<td>0.75 L+</td>
<td>0.77 L+</td>
</tr>
<tr>
<td>PRI4</td>
<td>(R531-R670)/(R531-R670)</td>
<td>0.66 NL+</td>
<td>0.62 NL+</td>
<td>0.49 NL+</td>
</tr>
</tbody>
</table>
| NDVI              | (NIR-R)/(NIR+R)  
NIR= Av. 760..900, R=Av. 620..690 | 0.56 NL+ | 0.59 NL+ | 0.44 NL+ |
Duke, NC

Pine site

Hardwood site

Loblolly Pine

DOY
- 162
- 180
- 203
- 290
- 300
- 6
- 34

Wavelength (nm)

Reflectance

Mixed Hardwoods

DOY
- 6
- 34
- 162
- 180
- 290
- 203
- 300

Wavelength (nm)
Bio-indicators of *Photosynthetic Function*

### Loblolly Pine (LP)

<table>
<thead>
<tr>
<th>Index</th>
<th>Bands (nm)</th>
<th>( R^2 ) [NEP (GEP) LUE]</th>
</tr>
</thead>
<tbody>
<tr>
<td>PRI1</td>
<td>531, 570</td>
<td>0.84 (0.73) L</td>
</tr>
<tr>
<td>PRI4</td>
<td>531, 670</td>
<td>0.75 (0.63) 0.73 L</td>
</tr>
<tr>
<td>DPI</td>
<td>D 680, 710, 690</td>
<td>0.91 (0.44) NL</td>
</tr>
<tr>
<td>NDWI</td>
<td>870, 1240</td>
<td>0.76 (0.60) L</td>
</tr>
<tr>
<td>NDVI</td>
<td>NIR, Red</td>
<td>0.19 (0.48) L</td>
</tr>
</tbody>
</table>

### Hardwoods (HW)

<table>
<thead>
<tr>
<th>Index</th>
<th>Bands (nm)</th>
<th>( R^2 ) [NEP (GEP) LUE]</th>
</tr>
</thead>
<tbody>
<tr>
<td>PRI4</td>
<td>531, 670</td>
<td>0.84 (0.48) NL</td>
</tr>
<tr>
<td>Dmax</td>
<td>D max (650…750 nm)</td>
<td>0.83 (0.40) NL</td>
</tr>
<tr>
<td>NDII</td>
<td>820, 1650</td>
<td>0.79 (0.34) L</td>
</tr>
<tr>
<td>EVI</td>
<td>NIR, Red, Blue</td>
<td>0.84 (0.41) L</td>
</tr>
<tr>
<td>NDVI</td>
<td>NIR, Red</td>
<td>0.63 (0.19) L</td>
</tr>
</tbody>
</table>

\[
\text{HW}, y = -0.0005x^2 + 0.0213x - 0.0593, \quad R^2 = 0.94
\]

\[
\text{LP}, y = 0.0241x - 0.2437, \quad R^2 = 0.85
\]

\[
\text{HW+LP}, y = -0.0007x^2 + 0.0316x - 0.1863, \quad R^2 = 0.74
\]

*Campbell et al. 2012*
Seasonal dynamics in PRI

**Duke, Loblolly Pine (D lp)**

**Duke, Hardwoods (D hw)**

Campbell et al. 2012
Duke Forest: \( \text{PRI}_{670} \) & \( \text{NEP} \)

A. Winter (DOY 34)

\( \text{FCC} (760, 650, 550 \text{ nm}) \)

\( \text{PRI}_{670} \)

\[ y = 92.67x^2 + 44.73x + 7.24, \quad R^2 = 0.70 \]

B. Summer (DOY 203)

\( \text{NEP} (\mu\text{mol m}^{-2} \text{s}^{-1}) \)

Campbell et al. 2012
Seasonal Spectral Dynamics at Konza
<table>
<thead>
<tr>
<th>Index</th>
<th>Bands (nm)</th>
<th>$R^2$ [NEP (GEP) $LUE$]</th>
</tr>
</thead>
<tbody>
<tr>
<td>G94</td>
<td>R 800, 700</td>
<td>0.95 (0.90) 0.75 NL</td>
</tr>
<tr>
<td>Dmax</td>
<td>D max</td>
<td>0.93 (0.95) 0.94 L</td>
</tr>
<tr>
<td>EVI</td>
<td>NIR, Red, Blue</td>
<td>0.83 (0.92) 0.88 NL</td>
</tr>
<tr>
<td>NDWI</td>
<td>R 870, 1240</td>
<td>0.86 (0.91) 0.85 NL</td>
</tr>
<tr>
<td>NDVI</td>
<td>Av. R760-900, Av. R620-690</td>
<td>0.63 (0.67) 0.68 L</td>
</tr>
</tbody>
</table>

The equation $y = -0.0006x^2 + 0.0338x + 0.1831$ has a $R^2$ value of 0.91.
Derivative Maximum

Konza (K), Mongu (M), Duke (D)

\[ y = -8 \times 10^{-5}x^2 + 0.0171x + 0.1821 \]

\[ R^2 = 0.72 \]
Conclusions

• In different ecosystems, continuous reflectance data and a variety of spectral bio-indicators had strong correlation to CO$_2$ flux parameters (e.g. NEP, GEE, etc.).

• The PLS regression provides a consistent global approach for estimating CO2 fluxes.

• The bio-indicators with strongest relationships were calculated using continuous spectra, using numerous wavelengths associated with chlorophyll content and/or derivative parameters.

• Common (global) spectral approach to trace vegetation function and estimate it’s CO$_2$ sequestration ability is feasible. It requires:
  
  - a diverse spectral coverage, representative of the major ecosystem types,
  - spectral time series, to cover the dynamics within a cover type.
Future Work

- Expand the tests over additional ecosystem types, including rain forest, temperate and sub-arctic vegetation types.
- Test the importance of specific phenologic periods (or times of year) for systematic estimation of ecosystem functional potential and productivity.
- Test the ability of additional spectral approaches to trace the dynamics in vegetation condition.
- Strategy to assess/confirm the accuracy of the produced maps.
The spectral bio-indicator associated with chlorophyll content (G32, green line) best captured the CO₂ dynamics related to vegetation phenology.
<table>
<thead>
<tr>
<th>Bio-indicator</th>
<th>Bands (nm)</th>
<th>$R^2$ [NEP (GEP)]</th>
</tr>
</thead>
<tbody>
<tr>
<td>G32</td>
<td>R750, 700, 450</td>
<td>0.83 (0.81) NL</td>
</tr>
<tr>
<td>Dmax</td>
<td>D max (650…750 nm)</td>
<td>0.77 (0.87) NL</td>
</tr>
<tr>
<td>Dmax / D704</td>
<td>D(690-730)</td>
<td>0.79 (0.80) NL</td>
</tr>
<tr>
<td>mND705</td>
<td>R750, 704, 450</td>
<td>0.75 (0.79) NL</td>
</tr>
<tr>
<td>RE1</td>
<td>Av. R 675…705</td>
<td>0.71 (0.56) NL</td>
</tr>
<tr>
<td>EVI</td>
<td>R (NIR, Red, Blue)</td>
<td>0.73 (0.88) L</td>
</tr>
<tr>
<td>NDVI</td>
<td>Av. R760-900, R620-690</td>
<td>0.52 (0.60) NL</td>
</tr>
</tbody>
</table>

**G32, Associated with Chlorophyll**  
*Gitelson et al. 2003*