Remote Sensing of Fluxes: EO-1 Hyperion and Flux Towers

Question: Can we demonstrate robust algorithms driven by hyperspectral satellite data that can estimate carbon flux variables through the seasons and over a wide range of sites?

• How do spectral properties and temporal dynamics of different ecosystems compare?

• Are there common (global) spectral approaches to trace vegetation function?

Petya Campbell
K. Fred Huemmrich
University of Maryland Baltimore County
May 16, 2012
Data Summary

Preliminary results from studies matching Hyperion imagery to flux towers

Multi-site Historical study
• Match flux data from LaThuile Fluxnet Synthesis with Hyperion
  - 33 different flux tower sites during mid-growing season from 2001 to 2007

Time Series study
• Ongoing observations of 90 tower sites
  - Started 2008
  - Capture seasonal change
  - 20 sites processed
CO₂ Flux Data

Existing global network of flux towers measuring CO₂ flux using eddy covariance techniques provide a consistent ground dataset to work with

– Net Ecosystem Production (NEP, μmol m⁻² s⁻¹) is the total CO₂ flux measured by flux towers.

– Ecosystem Respiration (Reco), the CO₂ flux from the ecosystem to the atmosphere, is calculated from relationships developed between nighttime NEP and temperature.

– Gross Ecosystem Production (GEP), the CO₂ uptake by vegetation, was calculated from the observed NEP and Reco.

– Light Use Efficiency (LUE), the ratio of GEP to photosynthetically active radiation absorbed by vegetation
## Time Series at Flux Sites
*(examples from 3, 20 being processed)*

<table>
<thead>
<tr>
<th>FLUX Site Name</th>
<th>Location</th>
<th>Climate</th>
<th>Vegetation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Mongu</td>
<td>Zambia, Africa</td>
<td>Tropical/dry vs. wet seasons/hot</td>
<td>Kalahari/Miombo woodland</td>
</tr>
<tr>
<td>lat: -15.4377778, lon: 23.252778</td>
<td>25 images</td>
<td></td>
<td></td>
</tr>
<tr>
<td>lat: 35.977130, lon: -79.095240</td>
<td>7 images</td>
<td></td>
<td></td>
</tr>
<tr>
<td>lat: 39.0823925, lon: -96.560277</td>
<td>7 images</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Examples**
Mongu, Zambia

Reflectance

Wavelength (nm)

Reflectance and Precipitation

CO2 flux

DOY

25 images

- 141
- 163
- 173
- 191
- 225
- 253
- 284
- 296
- 302
- 40
- 107

Julian Day

0 100 200 300

-25 -20 -15 -10 -5 0 5 10

μmol/m²/s
<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>

Examined multiple Spectral Indices at each site
- Best for NEP at Mongu was G32
- Associated with Chlorophyll
  *(Gitelson et al. 2003)*

Campbell et al. 2012
The spectral bio-indicator associated with chlorophyll content (G32, green line) best captured the \( \text{CO}_2 \) dynamics related to vegetation phenology.
Mongu – Mapping Seasonal Change in NEP

A. Dry season (DOY 214)

B. Wet season (DOY 22)

\[
y = -0.214x^2 + 3.78x - 5.07, \quad R^2 = 0.67
\]

Campbell et al. 2012
### Top Performing Vegetation Indices (R² values) – Three Seasonal Sites Combined

<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>0.73 L+</td>
<td>0.77 L+</td>
<td>0.75 L+</td>
</tr>
<tr>
<td>DP22</td>
<td>Dmax/D(max + 12)</td>
<td>0.65 L+</td>
<td>0.74 NL+</td>
<td>0.71 L+</td>
</tr>
<tr>
<td>NDWI</td>
<td>R(870-1240)/R(870-1240)</td>
<td><strong>0.74 NL+</strong></td>
<td>0.67 NL+</td>
<td>0.63 L+</td>
</tr>
<tr>
<td>MCARIa</td>
<td>Chlorophyll, R bands at 700, 670, and 550</td>
<td>0.41 L+</td>
<td>0.75 L+</td>
<td><strong>0.77 L+</strong></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>
<tr>
<td>NDVI</td>
<td>(NIR-R)/(NIR+R)</td>
<td>0.56 NL+</td>
<td>0.59 NL+</td>
<td>0.44 NL+</td>
</tr>
</tbody>
</table>

*NIR= Av. 760..900, R=Av. 620..690*

*Campbell et al. 2012*
Combined Seasonal Sites – Derivative Maximum

\[ y = -8\times10^{-5}x^2 + 0.0171x + 0.1821 \]

\[ R^2 = 0.72 \]

Campbell et al. 2012

39 images
Multi-site – Vegetation Index and LUE

- Best index (out of 107 tried) for LUE at overpass time for 33 different sites was the first derivative at 732 nm divided by the derivative at 712 nm

![Graph showing the relationship between Overpass LUE*1000 and D732/D702 with the equation y = 6.2761x - 12.781 and R² = 0.5039, with 79 Points]
Multi-site – Vegetation Index and Reco

• Best index (out of 107 tried) for Reco at overpass time was the Normalized Difference Water Index (NDWI), using reflectances at 876 and 1245 nm
Multi-site – Partial Least Squares Overpass LUE

• An example of an approach that utilizes all of the spectral information

red - PLS coefficients  
black - sample reflectance spectra
Multi-site – Partial Least Squares Overpass Reco

red - PLS coefficients
black - sample reflectance spectra
Remote Sensing of Fluxes
Hyperion and Flux Towers

• Hyperion on EO-1 provides us with two important capabilities:
  – the capability of collecting hyperspectral observations of globally-distributed sites, and
  – the ability to make repeated measurements of a site
• Provides a dataset for testing and developing algorithms for global data products
• The strongest relationships with carbon uptake parameters used continuous spectra, numerous wavelengths associated with chlorophyll content, and/or derivative parameters.
• A common (global) spectral approach appears feasible. To derive it will require:
  – Diverse coverage, representing major ecosystem types, and
  – time series, to cover the dynamics within a cover type.
Recommendations

These studies utilize data from the existing flux tower network

For many HyspIRI products we will need more studies applying algorithms for a number of different landcover types

- Use ground, aircraft, and satellite spectral reflectance data
- Need to develop protocols for ground measurements of potential HyspIRI products
- Need to establish network of sites measuring these products
- These sites can grow into a HyspIRI cal/val network