EO-1 Hyperion globally distributed spectral time series for assessment of the seasonal changes in vegetation function and productivity

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The EO-1 Image Archive

EO-1 Hyperion collected 90,995 scenes
Distribution of Hyperion Scenes by FLUX Site

> 9,600 Hyperion scenes have been collected over FLUX sites

<table>
<thead>
<tr>
<th>Site Name (code)</th>
<th>Ecosystem type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mongu, Zambia, Africa (ZM-Mkt)</td>
<td>Kalahari/Miombo woodland</td>
</tr>
<tr>
<td>Skukuza, South Africa (ZA-Kru)</td>
<td>Grassland savanna steppe</td>
</tr>
<tr>
<td>Park Falls, Wisconsin, US (US-Pfa)</td>
<td>Mixed Deciduous Broadleaf</td>
</tr>
<tr>
<td>Greenbelt, MD, USA (USDA/BARC)</td>
<td>Corn, C4</td>
</tr>
</tbody>
</table>

7 PFTs
300+ images

- 1 - 7
- 8 - 20
- 20 - 40
- 40 - 60
- 60 - 90
- 90 - 135
Goal: to monitor and compare vegetation function and productivity for different functional types.

Q1. What are the seasonal changes in vegetation reflectance associated with changes in function and CO$_2$ sequestration ability?

Q2. What are the key environmental factors driving the changes?

Q3. What are the observations needed to monitor vegetation function?

**DS07: VQ2, VQ4 and CQ4 → DS17: E-1a, E-2 and E-3**
Workflow

EO-1 Hyperion seasonal time series (TOA rad) → Atmospheric correction, Pre-processing (TOC reflectance) → Reflectance continuous (D, CR/FD) discrete (VIs) (SBIs)

FLUX tower measurements (CO₂ flux, µmol m⁻² s⁻¹) → CO₂ FLUX parameters (NEP, GEE, etc.)

Relationship between CO₂ FLUX parameters & Hyperion SBIs

EO-1 Hyperion: Spectral Time Series for Mongu, Zambia

Estimated NEP (µmol m⁻² s⁻¹)

0 12

Mongu

MODELS
Statistical (PLSR)
Bio-physical (RTMo - SCOPE)
Parameters Capturing the Seasonal Dynamics of Ecosystem Productivity and Function

**Objective:** observe the change in a suite of spectral parameters or features

**Tools:**
- Reflectance and derivatives
- Continuum removal and spectral feature analysis
- Vegetation indices (VIs)
- Models – statistical & biophysical

O% N, feature FWHM = 129.33, Area = 93829
100% N, feature FWHM = 141.92, Area = 102911
Reflectance Time Series Capturing the Range in Photosynthetic Function (7 PFTs, 267 images)

The 680 nm feature area (FA) is associated with canopy chlorophyll and GEP for all 7 PFTs.

Time series are required to capture the dynamics in GEP across the season.

Feature depths and areas were derived using the USGS PRISM tools (Kokaly et al. 2011)
VIs Associated with GPP are Related to a Suite of Different Bio-physical Parameters

**Spectral Parameters**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>$R^2$ to GEP</th>
</tr>
</thead>
<tbody>
<tr>
<td>FD680 (PRISM)</td>
<td>0.75 *</td>
</tr>
<tr>
<td>FA680 (PRISM)</td>
<td>0.82 *</td>
</tr>
<tr>
<td>Phyt=$(R724-R654)/(R724+R654)$</td>
<td>0.71</td>
</tr>
<tr>
<td>G32=$(R750-R445)/(R700-R445)$</td>
<td>0.78 *</td>
</tr>
<tr>
<td>NDWI=$(R819-R1649)/(R819+R1649)$</td>
<td>0.74</td>
</tr>
<tr>
<td>NDVI=$(TM4-TM3)/(TM4+TM3)$</td>
<td>0.65</td>
</tr>
</tbody>
</table>

**Key bio-physical parameters**

- canopy chlorophyll
- water content
- but also phytochrome, lignin and cellulose

Example from Skukuza (ZA-Kru)
The derivative index D22 associated with chlorophyll content (green line) captured the CO₂ dynamics related to vegetation phenology at Mongu.
PLSR Models - Use with Reflectance Time Series
Predicted vs. Observed Canopy GEP

PLSR models were derived and evaluated using the methods and tools developed by the group of P. Townsend (Singh et al. 2015)
Bio-physical Model - Use with Reflectance Time Series

Reflectance time series

RTMo

Simulated reflectance + canopy bio-physical parameters

SCOPE

GEP predicted

? ≈

GEP measured

Measured

EO-1 Hyperion reflectance

Simulated

SCOPE, RTMo

RMSE<0.02

RTMo is a part of SCOPE, including:

- 4SAIL – canopy radiative transfer
- Fluspect/PROSPECT5 - leaf optical
- GSV - soil reflectance

The SCOPE modeling framework provides the ability to:
- identify the driving factors, and
- validate/confirm the findings against field and eddy covariance measurements.
Predicted vs. Observed Canopy GEP
Bio-physical model: RTMo + SCOPE

The SCOPE model framework was implemented using tools developed by C. van der Tol et al. (2009, 2014, 2016)
Bio-physical Parameters Associated with GPP

EO-1 Hyperion; Example for Corn, OPE3, USDA/ARC

**Bio-physical parameters (in order of importance)**

- **Senescent material - Cs (a.u, 1&2)**
- **Total Chlorophyll - Cab (µg cm\(^{-2}\), 3)**
- **Dry mater - Cdm (g cm\(^{-2}\), 4)**
- **Leaf inclination - LIDF (5)**
- **Canopy water content - Cw (g cm\(^{-2}\), 6)**
- **Leaf Area Index - LAI (7)**

**Graphs:**
- **Senescent material - Cs (a.u, 1&2)**
  - Formula: \( y = -0.0048x + 0.3985 \)
  - \( R^2 = 0.794 \)
- **Leaf Chlorophyll - Cab (µg cm\(^{-2}\), 7)**
  - Formula: \( y = 1.1251x + 2.4092 \)
  - \( R^2 = 0.776 \)
- **LAI (6)**
  - Formula: \( y = 0.0745x + 1.3977 \)
  - \( R^2 = 0.6541 \)
Confirmation and Dynamics of the Bio-physical Parameters at OPE3

\[ y = 2.304x - 2.8397 \quad R^2 = 0.8693 \]

Photosynthetic pigments (Cab and Cca, \( \mu g \text{ cm}^{-2} \))

Year and DOY

LAI Observed

LAI Predicted
Hyperion Spatial Distribution Maps, Capturing the Seasonal Range of $\text{CO}_2$ Absorbed by the Vegetation

**GEP at Skukuza**
($\mu\text{mol m}^{-2} \text{s}^{-1}$)

![Image of GEP at Skukuza map](image_url)
Combined Modeling and Observation of Bio-physical Parameters and Productivity (GEP)

- EO-1 Hyperion reflectance time series (TOA radiance)
- Atmospheric correction Pre-processing (TOC reflectance)
- Canopy Reflectance Spectral features Derivative spectra Vegetation indices
- FLUX tower measurements (CO₂ flux, µmol m⁻² s⁻¹)
- Canopy Function and Productivity (NEP, GEP, LUE etc.)
- Canopy LAI, Photosynthetic vs non-photosynthetic component
- Field Measurements
  - Leaf Chlorophyll Water, Nitrogen
  - Statistic (R, PLSR) + Biophysical (RTMo)
  - Models calibration and validation of observables
  - Observables: time series of canopy chlorophyll and water
  - Use: vegetation function and GEP
- spatial and temporal extend

GEP at Mongu (µmol m⁻² s⁻¹)
Summary

• The parameters with strongest relationships to GPP were derived using continuous spectra, and were associated with canopy water, chlorophyll content and senescent material.

• PLSR models provided highly transferable equations across the 7 PFTs. SCOPE performed well across seasons for each PFT and provided indication of the key bio-physical parameters, which can be validated against field measurements. The complimentary use of both is beneficial for monitoring of vegetation function and GEP.

• Common (global) spectral approaches to compare vegetation function across PFTs and estimate GEP would require:
  – reflectance capturing simultaneously the parameters indicative of vegetation function – chlorophyll, water + others for GEP
  – a diverse spectral coverage, representative of the major ecosystem types
  – spectral time series, to cover the phenological dynamics within a cover type

Future direction: increased PFT diversity, higher frequency time series (TS of spectra + VI), TS including more complete suite of traits (AVIRIS NG), Field validation
Canopy Chlorophyll and Water Content
Preliminary Science Traceability matrix

1. Characteristics of proposed information product(s):
   • Products: vegetation canopy chlorophyll and water content
   • Frequency: weekly/monthly/seasonal
   • Spatial: 30 to 60 m
   • Units: g m$^{-2}$
   • Geographic domain: terrestrial ecosystems and agriculture

2. Currently – high frequency VI time series are used to determine the length of the growing season, and detect stress and limitations in function and productivity. The information is used in precision agriculture, carbon modeling, productivity forecasts; and for efficient and timely response to stress and planning of resources (recovery from nitrogen and water deficiency, forest air-pollution damage mitigation).

3. Determine utility of time series of canopy chlorophyll and water content, derived through combined spectroscopy and models, and evaluate/calibrate the standard VIs and single-model approaches for improving the assessment of vegetation function and productivity. Canopy chlorophyll and water can be derived spectroscopically and validated, their accuracy quantified and improved, to improve GEP prediction.

4. Science Question and Objective – see slide 4

5. Future research – to document observables and their requirements and make the case that they can be used to address the hypotheses/objectives.
Orbital (@ ~ 700 km)

Global spatial extend, **systematic** repeat for time series (TS)

**Space station** (@ 400 km)

Spatial coverage, repeat

Low - Mid - High Altitude (@ 500 m – 5 km)

Spatial coverage

**UAV** (@ 10 – 120 m)

Spatial coverage & TS

site & region

**Automated/Fixed Tower** (@ 10 - 120 m)

canopy/site, TS

**Leaf - canopy** (@ ~ 10 m)

leaf – canopy – site

consistent TS

Consistent spectral measurements across ALL spatial scales and environmental conditions
**EO-1** Hyperion Level-2 Surface Radiance and Reflectance

**USGS/EROS**

- **Level 0**
- **Hyperion Level 1R**
- **Radiance (L1R)**

**EO-1/MSO NASA/GSFC**

- **Hyperion Level 1R**
- **Hyperion Level 1Gst**

**FLAASH**

- R (%)
- Accurate geology, vegetation and land cover characterizations (near-nadir acquisitions)

**ATREM**

- R (%)
- Fast response - geology, vegetation and land cover characterizations (also off-nadir acquisitions)

**ACORN**

- R (%)
- Accurate spectral time series - cal/val, veg. physiology and canopy chemistry (nadir acquisition)

Future

**ATCOR**

- For rugged terrain, geo-coded data & Digital Elevation Model (DEM)
- Future

**Proprietary**

**S6 based, Bo-Cai Gao**

- new version, Dave Thompson

**For select sites, requests NASA/ACCP and FLUX sites**

**SENTINEL-2**

- Atmospheric CORrection (ATCOR)

**FLAASH fast**: 2014+ available at ftp://matsu.opensciencedatacloud.org/

for low-latency/real-time applications, optimized for the targeted lat/lon

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HyspIRI Reflectance Time Series at Calibration Sites

Evaluating the consistency/stability of derived reflectance from Hyperion

Railroad Valley Playa

EO-1 Hyperion Spectral Bands

- Blue447
- Green549
- Red651
- NIR854
- FR1003
- FR1679
- FR2204

0 10 20 30 40 50 60 70 80 90 100

Jul. day

Year


Acquisition (Julian day)
EO-1 increased precession started in 2011. Acquisition time at RRVP declined from 10:05 to 8:40, approximately.

Mean reflectance and standard deviation for RRVP (2001-2008 data, n=15, ~10:05 am MLT acquisition)

The difference in reflectance continues to be within ± 5-9% of the mean prior to Δ precession.

The regions of highest spectral stability (e.g. green, red edge, NIR) remain the same.
## Bio-indicators of Photosynthetic Function

### Loblolly Pine (LP)

<table>
<thead>
<tr>
<th>Index</th>
<th>Bands (nm)</th>
<th>$R^2$ [NEP (GPP) $LUE$]</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>NDVI</td>
<td>NIR, Red</td>
<td>0.19 (0.48) L</td>
</tr>
</tbody>
</table>

### Hardwoods (HW)

<table>
<thead>
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<th>Index</th>
<th>Bands (nm)</th>
<th>$R^2$ [NEP (GPP) $LUE$]</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>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>
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**Equations:**

$y = 0.0241x - 0.2437$  (LP, $R^2 = 0.85$)  
$y = 0.0085x - 0.0058$  (NL, $R^2 = 0.7486$)  

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**Legend:**

- PRI: Pigment Ratio Index
- DPI: Difference Pigment Index
- NDVI: Normalized Difference Vegetation Index
- EVI: Enhanced Vegetation Index
- NEP: Net Ecosystem Production
- GPP: Gross Primary Production
- $LUE$: Light Use Efficiency
- NL: Natural Logarithm
- $R^2$: Coefficient of Determination
Duke Forest – PRI & NEP

A. Winter (DOY 34)

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

PRI 

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

B. Summer

FCC (760, 650, 550 nm)

PRI_{670}