Anticipated New HyspIRI Products
Examples for Ecological Applications

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2012 HyspIRI Products Symposium
New & Improved Ecosystem Products

1) Ecosystem nutrients and chemistry (nitrogen, water‡, etc.)

2) Biodiversity (improved species‡ and functional-type†)

3) Ecosystem health (physiological condition)
   - Canopy structure (improved LAI, fraction of green biomass‡)
   - Canopy pigments (e.g. chlorophyll‡, carotenoids†, anthocyanins†)
   - Canopy water‡
   - Lignin & cellulose‡, crop residue cover*
   - Nitrogen‡
   - General stress†

4) Temperature and emissivity estimates by vegetation components (species, functional groups, vegetation health class)

5) Relationships and feedbacks between canopy composition/function and canopy temperatures; predictive relationships between VSWIR and TIR indicators

*application ready  ‡advanced  †researched
Spectroscopic Measurements are Required for Global Ecosystem Assessments

Multi-spectral imaging is insufficient to derive the required terrestrial surface compositional parameters accurately.

- **Plant species and functional types** have biochemical and biophysical properties that are expressed as **reflectance, absorption and scattering features** spanning the spectral region from 380 to 2500 nm.
- **Individual bands** do not capture the **diversity of biochemical and biophysical signatures** of plant functional types, species or physiological condition.
- **Changes in the chemical and physical configuration of ecosystems** are expressed as **changes in the contiguous spectral signatures** related to plant functional types, physiological condition, vegetation health, and species distribution.

*Green et al.*
Spectral Time Series - Phenology of Summer Wheat

Kneubuhler, 2002
<table>
<thead>
<tr>
<th>Acronyms</th>
<th>VSWIR Methods</th>
<th>Objective / Use</th>
<th>Required</th>
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<td>1 ACORN</td>
<td>Atmospheric CORrection Now</td>
<td>radiometric calibration and atmospheric correction</td>
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<td>2 FLAASH</td>
<td>Fast Line-of-sight Atmospheric Analysis of Spectral Hypercubes</td>
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<td>3 SS&amp;R</td>
<td>Spectral sensitivity &amp; relationship to <em>in situ</em> measurements</td>
<td>knowledge of important spectral information</td>
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<td>4 CR &amp;FD</td>
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<td>analysis on specific absorption features</td>
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<td>5 SI, P-VI</td>
<td>Physiological Vegetation Indexes (P-VI)</td>
<td>reduce the number of bands but retain the most important spectral information</td>
<td>Spectral Hypercubes, SS&amp;R</td>
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<td>6 MNF</td>
<td>Minimum noise fraction (two-stage PCA)</td>
<td>reduce wavelength specific noise and dimensionality of data</td>
<td>Spectral Hypercubes</td>
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<td>7 SAM</td>
<td>Spectral Angle Mapper of spectral cubes</td>
<td>comparing spectra of image pixels to the spectra of reference endmembers</td>
<td>Spectral Hypercubes</td>
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<td>8 SMA, SUM, MESMA</td>
<td>Spectral Mixture Analysis and Unmixing Methods</td>
<td>derive apparent fractional abundance of specific endmember in a pixel</td>
<td>a priori known endmembers (b-1)</td>
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<td>9 MF</td>
<td>Matched Filters</td>
<td>maximizes target-to-background contrast</td>
<td>Spectral Hypercubes, known signatures to match</td>
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<td>10 MTMF</td>
<td>Mixture Tuned Matched Filtering</td>
<td>combines the strength of MF with physical constraints imposed by mixing theory</td>
<td>Knowledge of the target species endmembers</td>
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<td>11 MLc of MNF</td>
<td>Maximum Likelihood classification of MNF transformed images</td>
<td>species identification</td>
<td>MNF</td>
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<td>12 MLc of P-VI</td>
<td>MLc of P_VI Images</td>
<td>identification of physiological state</td>
<td>Physiological Vegetation Index Images</td>
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</table>
• **N determination**
Cover Fractions in Transition from Live/Green to Dry/Dead

Sevilleta LTER Site, N.M.

Asner et al.
**Reflectance and Derivative Analysis**

N (% of optimum)

- 0
- 12
- 25
- 50
- 75
- 100
- 125
- 150

**Vegetation Indices of function, structure and foliar chemistry**

- **REIP** = wavelength (in nanometers) of the maximum slope $D_{\text{max}}$ of the reflectance spectrum at wavelengths between 690 and 740 nm; $D = (R_n - R_{n-1})/(w_n - w_{n-1})$; in the 690-740nm range
- **Chlorophyll (Gitelson)** = $(R_{\text{NIR}}/R^{-1}_{720-730}) - 1$; Function, $PRI = (R_{531} - R_{570})/(R_{531} + R_{570})$; $NDWI = (R_{\text{nir}} - R_{1240})/(R_{\text{nir}} + R_{1240})$, etc.
- **TVDI** = $(Ts - Ts_{\text{min}})/(a + bNDVI - Ts_{\text{min}})$; $WSVI = NDVI/Ts$, where $Ts$ is the *brightness temperature at ~11 µm*
Color Infrared composite AVIRIS image with field boundaries.
549 nm — blue
646 nm — green
827 nm — red

Tillage intensity classification using CAI and NDVI (overall classification accuracy = 92%).

For dry and moist conditions CAI is adequate for assessing crop residue cover.

\[ \text{CAI} = 0.5(R_{2000} + R_{2200}) - R_{2100} \]

Crop Residue Cover vs. CAI for Hyperion Image Iowa – May 3, 2004

(Daughtry et al. 2001, 2006 and 2010)
Bio-indicators of Photosynthetic Function

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

\[ LP, y = 0.0241x - 0.2437 \]
\[ R^2 = 0.85 \]

\[ HW+LP, y = -0.0007x^2 + 0.0316x - 0.1863 \]
\[ R^2 = 0.74 \]
Duke Forest: PRI$_{670}$ & NEP

A. Winter (DOY 34)

- FCC (760, 650, 550 nm)
- PRI$_{670}$
- NEP ($\mu$mol m$^{-2}$ s$^{-1}$)

B. Summer (DOY 203)

- FCC (760, 650, 550 nm)
- PRI$_{670}$
- NEP ($\mu$mol m$^{-2}$ s$^{-1}$)

The relationship between PRI$_{670}$ and NEP is described by the equation:

$$y = 92.67x^2 + 44.73x + 7.24, \quad R^2 = 0.70$$
Forage quality in African savannas can be described in terms of nutrients that are limiting (nitrogen and phosphorus) and constrain the rate at which herbivores take in fiber. These forage quality nutrients are particularly crucial in the African dry season when their concentrations decline.

Using the Carnegie Airborne Observatory (CAO) Alpha sensor, in combination with ancillary data, researchers from ITC-University of Twente and the Carnegie Institution mapped grass forage nutrients in the early dry season within an African savanna.

Respectively, 65%, 57% and 41% of the variance in fiber, phosphorus and nitrogen concentrations could be explained.

In addition, for the first time, a landscape map of grassland fiber was created from CAO imagery.
Species Recognition

Landsat 7

Hyperion

AVIRIS

Goodenough et al. 2003
HyspIRI-like data provided range of indicators of plant function and showed temperature gradient of ~ 15° C between rural and urban areas in British Columbia.
NDWI = \frac{(R_{860} - R_{1240})}{(R_{860} + R_{1240})}

NDII = \frac{(R_{819} - R_{1649})}{(R_{819} + R_{1649})}

Gao, 1996


Temperature

\begin{align*}
\text{Temperature} & \quad T (^\circ \text{C}) \\
\text{low water content} & \quad \text{high water content}
\end{align*}

\begin{align*}
\text{Low water content} & \quad \text{High water content}
\end{align*}

Canopy Moisture & Temperature
Canopy Structure, Function & Temperature

Zarco-Tejada et al. 2012
Surface temperature distribution for Nagoya, Japan on (a) July 10, 2000 1055 JST

Artificial (UHI) increase in sensible heat flux for Nagoya, Japan on July 10, 2000.

Kato et al. 2005
LST and ET by Species, Functional type, PV/NPV & Land Cover Type

Integrating Local Ecosystem Processes – Ecosystem Type, Function & Dynamics

Relationships between $\rho$ & $\varepsilon$ indicators of stress for dominant species and ecosystem types -> key ecological variables, threshold s -> adaptive management

Models: Climate, C cycling, Radiative transfer

Operational Agencies & Management Practices
# HyspIRI Products for LPV

<table>
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<tr>
<th>LPV Focus Group / Product</th>
<th>VSWIR L 2/ 3</th>
<th>VSWIR L4</th>
<th>VSWIR Global</th>
<th>TIR L4</th>
<th>SWIR / TIR</th>
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<td><strong>LAND COVER</strong></td>
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<td>Fractional land cover / veg. cover</td>
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<td>Disturbance, PFT, hazard susceptibility</td>
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<td><strong>SURFACE RADIATION</strong></td>
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<td>Surface Reflectance</td>
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<td>Surface Albedo</td>
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<td><strong>BIOPHYSICAL</strong></td>
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<td>Gross / Net Primary Production</td>
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<td>fPAR</td>
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<td>LAI</td>
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<td>Water content, LUE, Pigments</td>
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<td><strong>FIRE</strong></td>
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<td>Detection of Fire events</td>
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<td>Fire fuel loads</td>
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<td><strong>LAND SURFACE TEMPERATURE</strong></td>
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<td>LST</td>
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<td>Emissivity</td>
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<td>Evapotranspiration</td>
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Existing Val Methods | Research Required

*J. Nightingale, 2011*
Summary

Existing:
1) Many approaches / tools / applications
2) Local to regional studies & pilot projects
3) Application demand for new ecosystem products

Needed:
1) To determine their sensitivity and application extend of the existing approaches we need large scale VSWIR/TIR data-sets for variety of ecosystems
2) Calibrated spectral products (establish a network producing *in-situ* biophysical measurements)
3) Establish seasonal VSWIR/TIR relationships for major species, functional groups, etc.
4) Long term VSWIR/TIR spectral time series to reveal normal & divergent ecosystem patterns
HyspIRI Ecosystem Products

1. Seamless global bi-directional reflectance, surface emissivity and temperature products

2. Global discrimination of species through phenology

3. Sub-pixel fractions of functional groups, species, photosynthetic & non-photosynthetic vegetation and bare soil, incl. detection thresholds

4. Seamless VSWIR suites of established stress indices (SI) - Estimations of biophysical variables

5. Temperature and emissivity estimates by vegetation components (species, functional groups)

6. Feedbacks between changes in canopy composition and canopy temperatures –

7. Complementary T, ET and VSWIR spectral indictors as measures of function, phenology and water use
HyspIRI Ecosystem Science Questions

• **Vq1.** What is the global spatial pattern of ecosystem and diversity distributions and how do ecosystems differ in their composition or biodiversity?

• **Vq2.** What are the seasonal expressions and cycles for terrestrial and aquatic ecosystems, functional groups, and diagnostic species? How are these being altered by changes in climate, land use, and disturbance?

• **Vq3.** How are the biogeochemical cycles that sustain life on Earth being altered/disrupted by natural and human-induced environmental change? How do these changes affect the composition and health of ecosystems and what are the feedbacks with other components of the Earth system?

• **Vq5.** How do changes in ecosystem composition and function affect human health, resource use, and resource management?

• **Cq1.** How do Inland, Coastal, And Open Ocean Aquatic Ecosystems Change Due To Local and Regional Thermal Climate, Land-Use Change, And Other Factors?

• **Cq4.** How do species, functional type, and biodiversity composition within ecosystems influence the energy, water and biogeochemical cycles under varying climatic conditions?