Developing Methods for Fractional Cover Estimation Toward Global Mapping of Ecosystem Composition

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Project Goals

- To Develop a Standard Fractional Cover Product for AVIRIS-C, AVIRIS-NG and future Global Missions
  - Green (Photosynthetic) Vegetation
    - Canopy Interception, Latent/sensible Heat Flux, Plant production, Carbon balance
  - Non-photosynthetic Vegetation
    - Plant residues, Resistance to erosion, Carbon balance
  - Substrate (S)
    - Soil: Soil degradation, Erosion potential
    - Ash/char: Burn products, Fire severity
    - Impervious: Roof, Roads, Urban energy balance, Transportation and runoff
  - Snow
    - Snow covered area, Water resources
The Team

• **JPL: David Thompson, Robert Green, Ryan Pavlick, Natasha Stavros, Dave Schimel**
  – Code development, spectral library development and validation subset of products

• **UCSB: Dar Roberts, Zachary Tane**
  – Spectral library development, GV, NPV, Impervious surfaces, soils
  – Fraction Validation
    • Impervious surface and GV cover, urban areas
    • NPV fractions, Sierra Nevada

• **Univ. Utah Phil Dennison**
  – Spectral library development, GV, NPV, soils
  – Product Validation
    • Soils and NPV
Multiple Endmember Spectral Mixture Analysis (MESMA)

- Extension of Linear Spectral Mixture Analysis
- Allows the number and types of Endmembers to vary per pixel
  - Candidate models must meet fit and fraction constraints
- Models selected on minimum RMS
- Complexity level based on change in RMS
Why MESMA? Endmember Variability

- Endmember variability is a product:
  - Leaf level chemistry and anatomy (Asner)
  - Phenology
  - Architecture

Douglas-fir

Red Alder
Why MESMA? Dimensionality

How many Endmembers do you need?

**Spectral Contrast:** Ability to discriminate two or more materials based on significant spectral differences

**Spectral Degeneracy:** Inability to discriminate materials because they are either not spectrally distinct, or can be modeled as a combination of other endmembers
MESMA: The Good

• Urban Remote Sensing
  – Powell et al., 2007; Franke et al., 2009; Roberts et al., 2012; Demarchi et al., 2012; Okujeni et al., 2013; Fan and Deng, 2014
• Vegetation species, structure and disturbance
  – Dennison and Roberts, 2003a/b, Li et al., 2005; Sonnentag et al., 2007; Youngentob et al., 2011; Roth et al., 2012; Somers and Asner, 2013/2014; Antonrakis et al., 2014
• Wildfire, including Active Fires, Fuel Types, Fire Severity and Post-fire Recovery
  – Roberts et al., 2003; Dennison et al., 2006; Eckmann et al., 2008/2010; Veraverbeke et al., 2013; Quintano et al., 2013
• Arid Lands Remote Sensing
  – Okin et al., 2001; Ballantine et al., 2005; Thorp et al. 2013
• Snow-covered Area and Grain Size
  – Painter et al., 1998, 2003
• Coastal Marine/Kelp
  – Cavanaugh et al., 2011
• Environmental Damage by Mining
  – Fernandez-Manso et al., 2012
• Precision Agriculture
  – Tits et al., 2012
• Thermal Remote Sensing
  – Collins et al., 2001
An Example From Santa Barbara

a) Modified VIS Model; b) NPV-GV-Soil; c) Paved-Roof-Rock; c) Classification

GV & Impervious vs Household Income

Roberts et al., 2016
Fractions Scale

Roberts et al., 2012
MESMA: The Bad

• Requires a Comprehensive Spectral Library
  – Radiative Transfer: MEMSCAG
  – Reference Polygons: AVIRIS as a source
  – Field/laboratory Spectra: ASTER/USGS, Contributed

• Is Computationally Inefficient
  – Tries all possible combinations for all complexity levels

• Computationally Infeasible for Large Spectral Libraries
  – Endmembers in each category combine multiplicatively
    • 4 EM: 10 GV, 10, NPV, 10 Soil, 10 Impervious, 10 Ash = 7050 models

• Spectral Degeneracy
  – Endmembers that are distinct at 2 em, may have little impact on fractions at higher levels of complexity
MESMA: Reducing Complexity

- **Endmember Sub-selection**
  - Endmember Average RMS (EAR: Dennison and Roberts, 2003)
  - Minimum Average Spectral Angle (MASA: Dennison et al., 2004)
  - Count Based Endmember Selection (COB: Roberts et al., 2003)
  - Iterative Endmember Selection (IES: Roth et al., 2012)

\[
\text{EAR}_{A_i, B_j} = \frac{\sum_{j=1}^{n} \text{RMSE}_{A_i, B_j}}{n - 1}
\]

\[
\text{Min} \bar{\theta}_{A_i, B_j} = \frac{\sum_{j=1}^{n} \theta_{A_i, B_j}}{n - 1}
\]

- **Band Sub-selection**
  - Stable Zone Unmixing (Somers et al., 2010)
Global MESMA: The Challenge

• What Spectral Library will be Used?
  – Must be robust across multiple ecosystems/ecoregions
  – Must be robust across multiple years and seasons
  – Must include sufficient wavelengths (AVIRIS-C, AVIRIS-NG, ASD?)

• How will Spectral Libraries be Built?
  – Integrated from Existing Libraries
    • Soils/Rocks (ASTER, USGS)
    • Snow (Radiative Transfer: Painter et al.)
    • NPV, Daughtry, Roberts, Dennison other
    • Impervious: Herold et al., 2004
    • Ash/Char: Veravebeke et al., 2013
  – Reference Polygons
    • Compiled from multiple reference sets over source regions
  – Image Derived?
    • e.g. PCOMMEND, SPICE, Other

• How will Computational Efficiency be Improved?
  – Fraction Retrieval: Thompson and the JPL Team
  – Endmember Reduction: Thompson and the JPL Team

• How will fractions be validated?
  – Existing validation data sets (GV, NPV, Impervious, Ash)
  – Synthetic Mixtures (NPV & Soils)
Implementation

- Fully implemented in the JPL Science Data System
  - Optimized to exploit multi-core parallelism
  - Automated into AVIRIS-NG and AVIRIS-C science workflows

![Image of satellite data comparison](image-url)
Spectrum reconstruction error

Permits user-tunable confidence filters

AVIRIS-NG RGB Image  Unmixing Result  RMSE

NPV  PV  Substrate

0.0  0.15
Building Spectral Libraries: Image Sources

Roberts et al., 2015
Building Spectral Libraries: Field Sources

Field Spectra Collection
ASD Full-Range Spectrometer

Sample Concrete Spectra

Roberts and Herold, 2004
Fraction Validation Strategy

• **Existing high spatial resolution Fraction Reference sites**
  – Urban: Roberts et al., 2012/2016
    • DOQQ
  – Sierra Nevada Forest Mortality
    • WV2 (Tane)
  – Other
    • Snow covered area products
    • Validated burned products

• **Synthetic Mixtures**
  – NPV/Soil

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Figure showing three validation polygons
A: 44% NPV, 11.3% GV, 44.7% Soil
B: 50.45%NPV, 1.5% GV, 48%Soil
C: 4.8% NPV, 57.4% GV, 34.5% Soil, 3.3% Imp
Fraction Validation: Numerical Simulations (Dennison)

- 619 field spectra from agricultural (Daughtry) and rangeland (Kokaly) sites
- Each spectrum has field-assessed GV, NPV, and soil fractional cover
- Field spectra were used to model HyspIRI spectra, including noise, at 10, 15, 20, and 30 nm band spacing and FWHM
- Preliminary results show moderate correlations between fractions modeled by MESMA and field-assessed fractional cover
  - More effort is needed to improve endmember selection
Fraction Validation: Thompson Code

- Dennison simulated reflectance
- Indicates accuracy “sweet spot” at 10 Soil, NPV endmembers
- Spectral resolution to 30 nm is tolerable and may be preferable!
Summary

• Proposed development of a standard MESMA product from AVIRIS, AVIRIS-NG

• Requires comprehensive spectral libraries
  – Differing strategies are required for different materials
  – Will utilize different sources

• Will include extensive, targeted validation

• Key to success is identifying the minimum number of endmembers required to generate the highest accuracy
  – Reduces unnecessary run times
  – We need spectra that capture the variability for each category and no more