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

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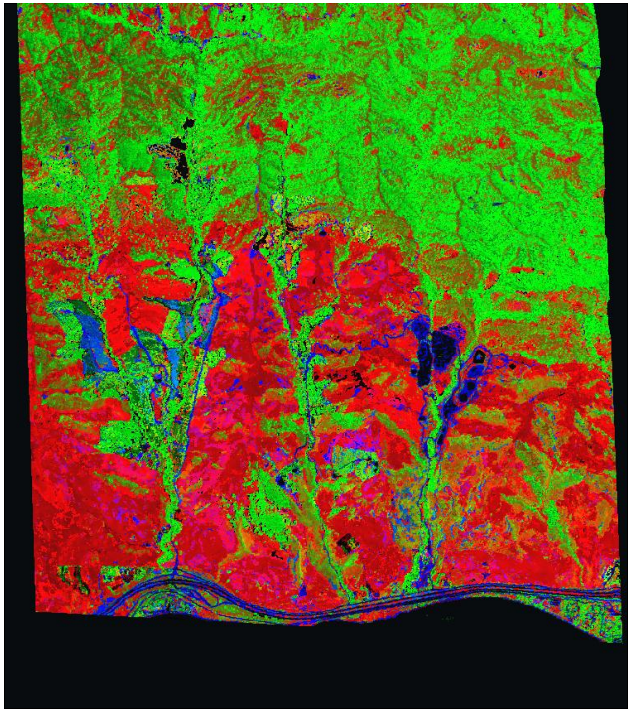


Project Goals

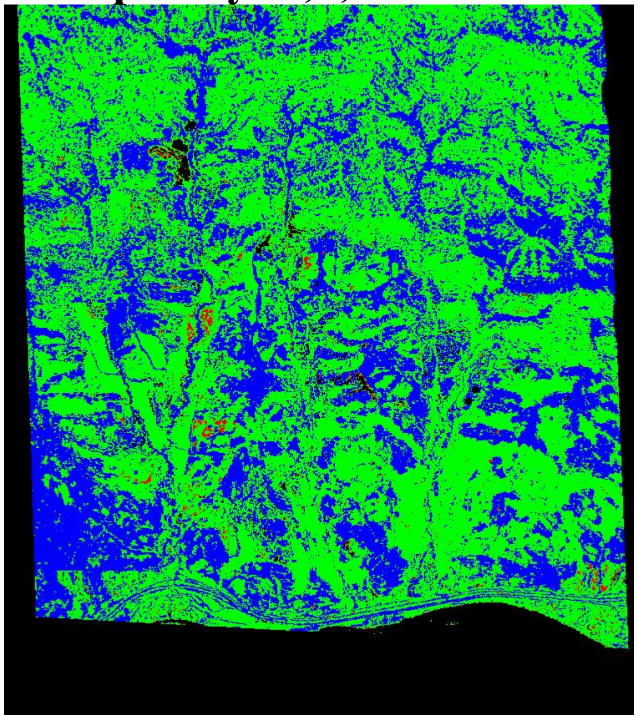
- **To Develop a Standard Fractional Cover Product for AVIRIS-C, AVIRIS-NG and future Global Missions**
  - **Green (Photosynthetic) Vegetation**
    - **Canopy Interception, Latent/sensible Heat Flux, Plant production, Carbon balance**
  - **Non-photosynthetic Vegetation**
    - **Plant residues, Resistance 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

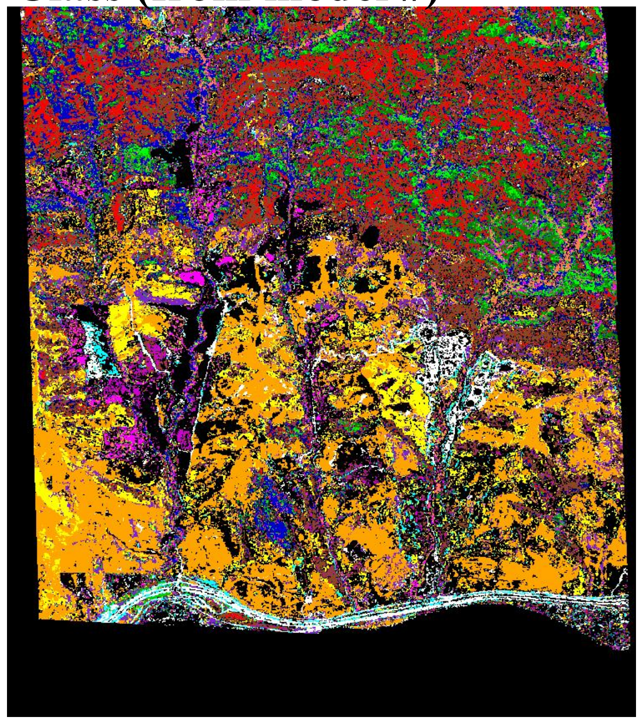
- **JPL: David Thompson, Robert Green, Ryan Pavlick, Natasha Stavros, Dave Schimel**
  - **Code development, spectral library development and validation subset of products**
- **UCSB: Dar Roberts, Zachary Tane**
  - **Spectral library development, GV, NPV, Impervious surfaces, soils**
  - **Fraction 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)

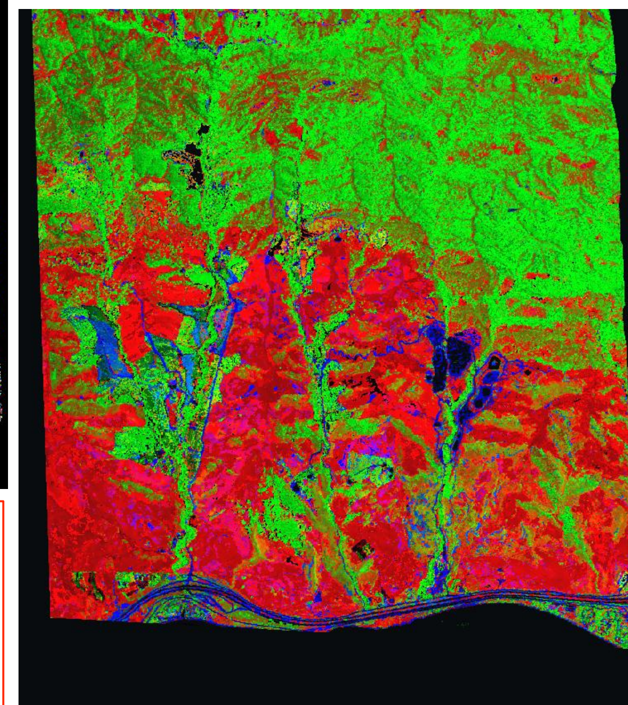
Complexity: 3,2,1 RGB



Class (from model #)



Composition: NPV-GV-Soil RGB

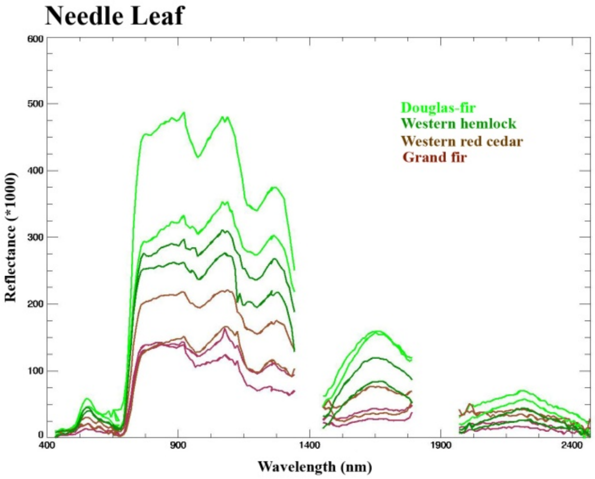


- **Extension of Linear Spectral Mixture Analysis**
- **Allows the number and types of Endmembers to vary per pixel**
  - **Candidate models must meet fit and fraction constraints**
- **Models selected on minimum RMS**
- **Complexity level based on change in RMS**

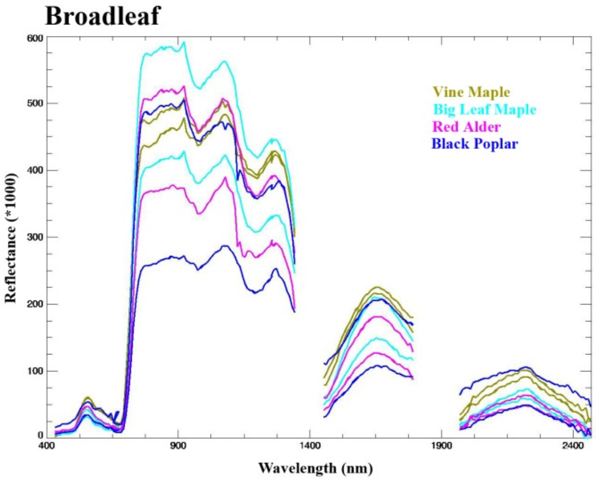
Why MESMA? Endmember Variability

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

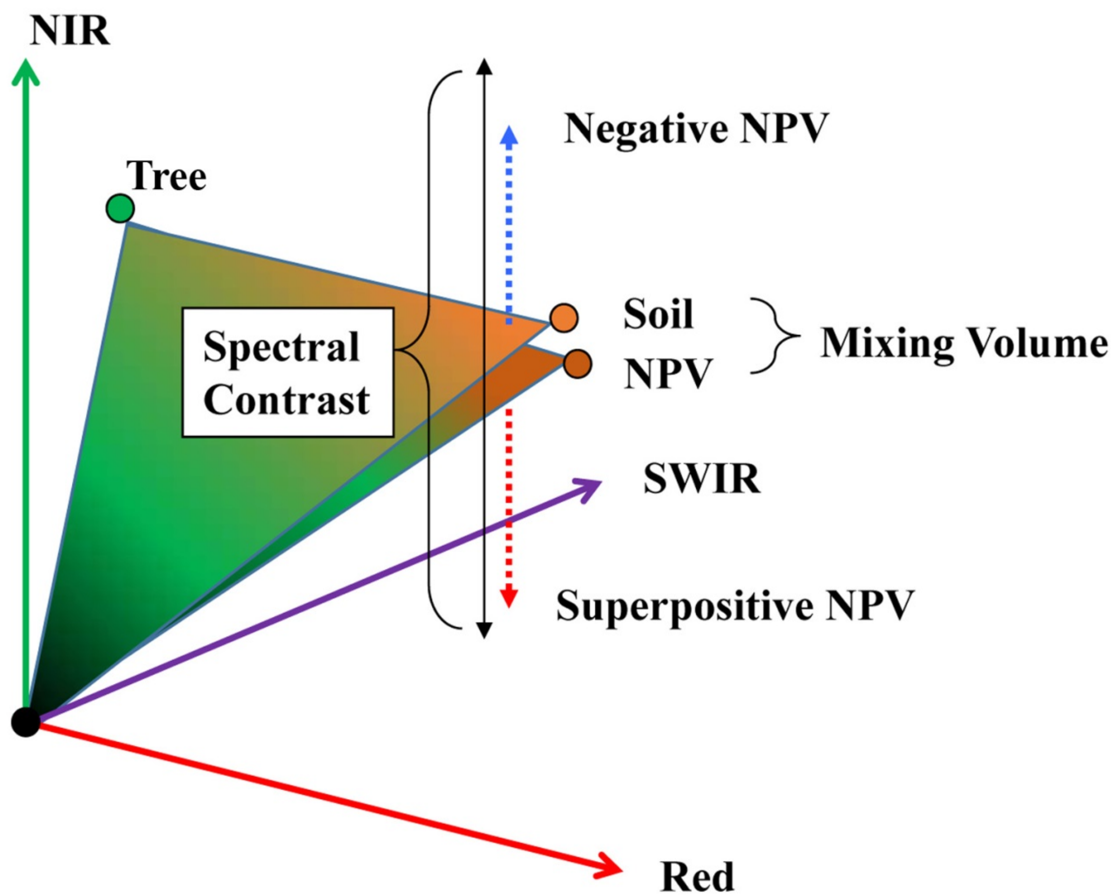
Douglas-fir



Red Alder



Why MESMA? Dimensionality



How many Endmembers do you need?

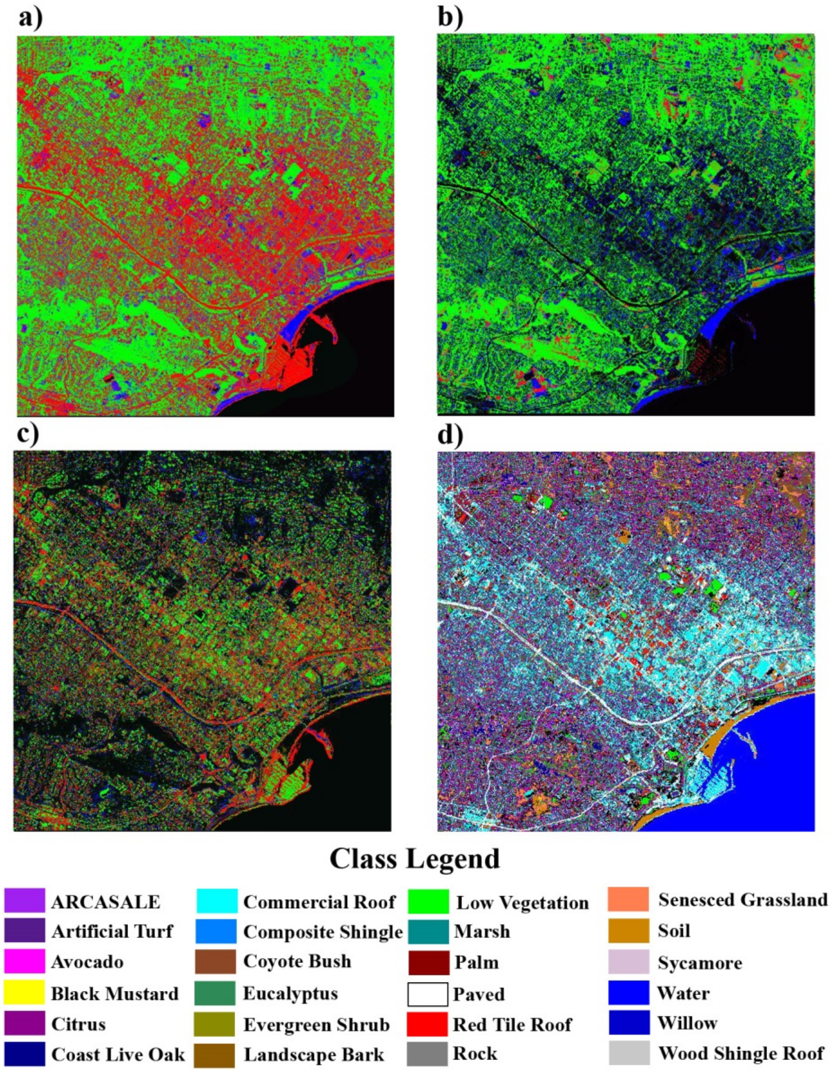
Spectral Contrast: Ability to discriminate two or more materials based on significant spectral differences

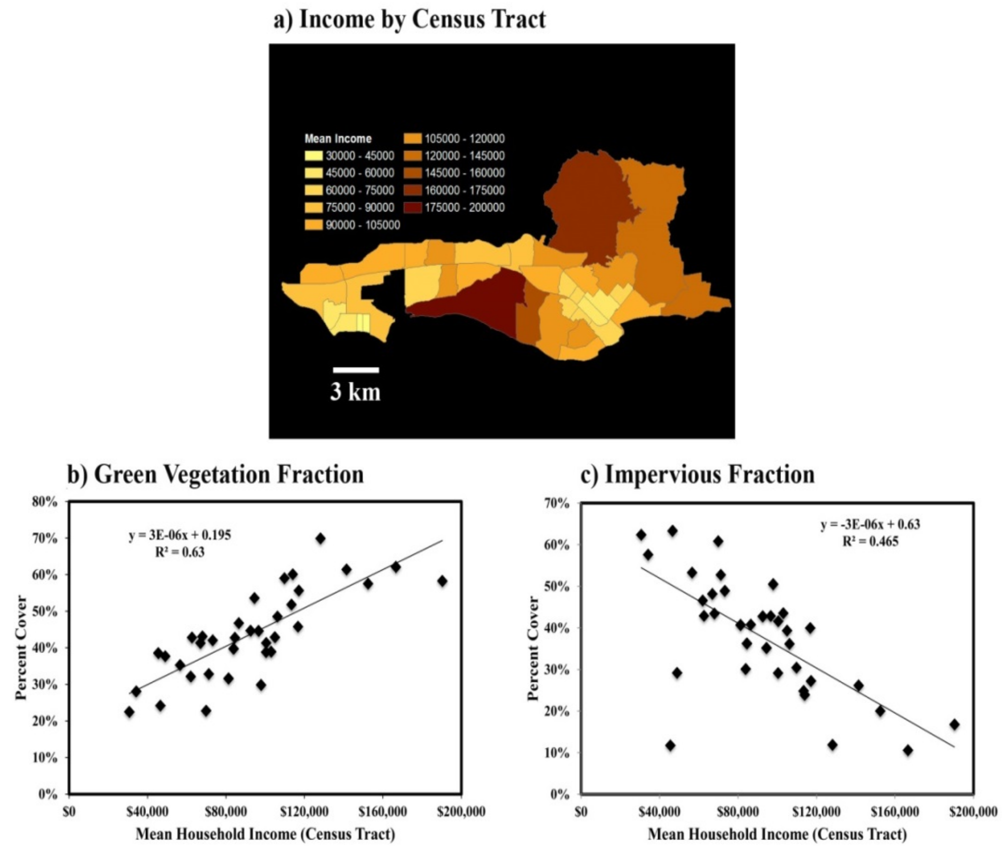
Spectral Degeneracy: In ability to discriminate materials because they are either not spectrally distinct, or can be modeled as a combination of other endmembers

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



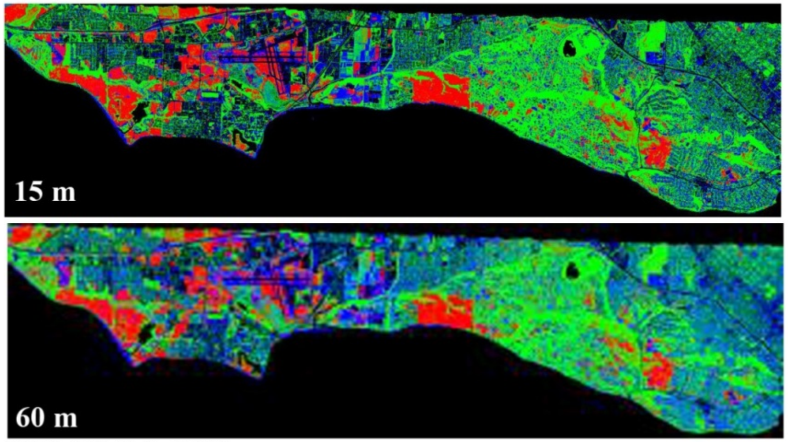


GV & Impervious vs Household Income

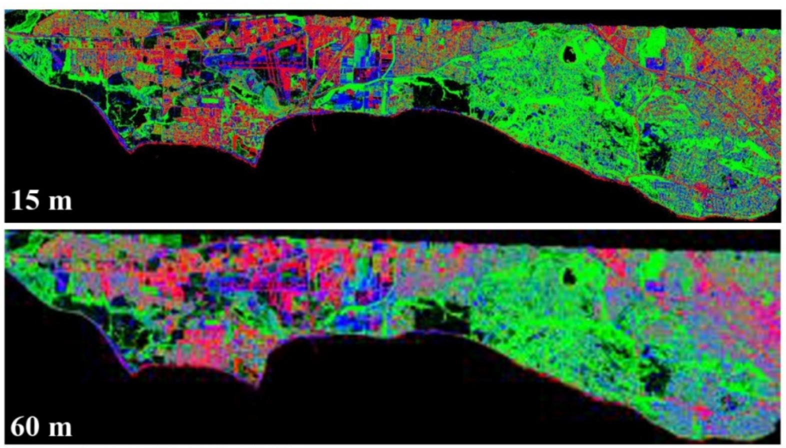
Roberts et al., 2016

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

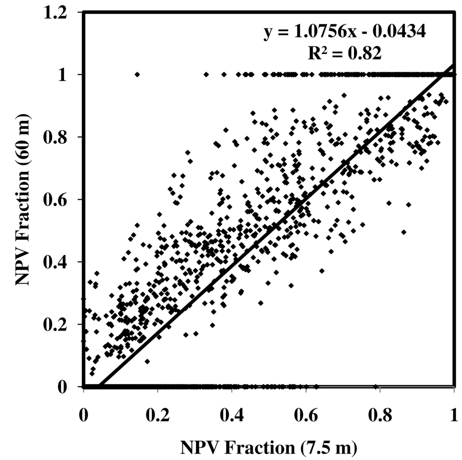
Fractions Scale

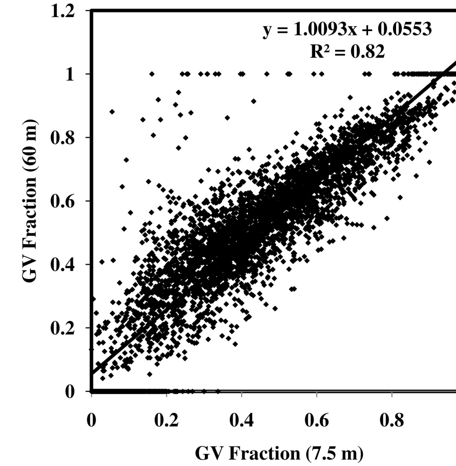


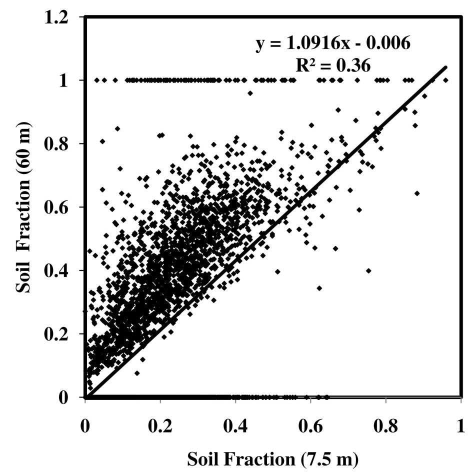
NPV, GV, Soil :RGB

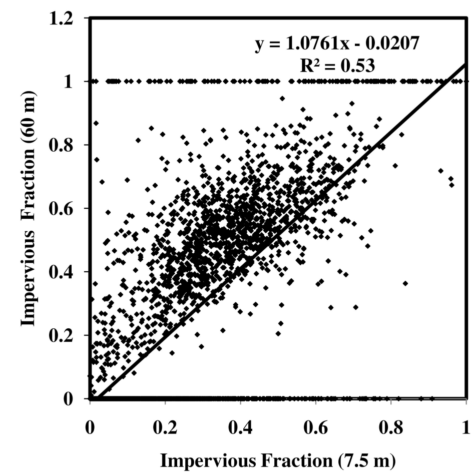


Impervious, GV, Soil: RGB





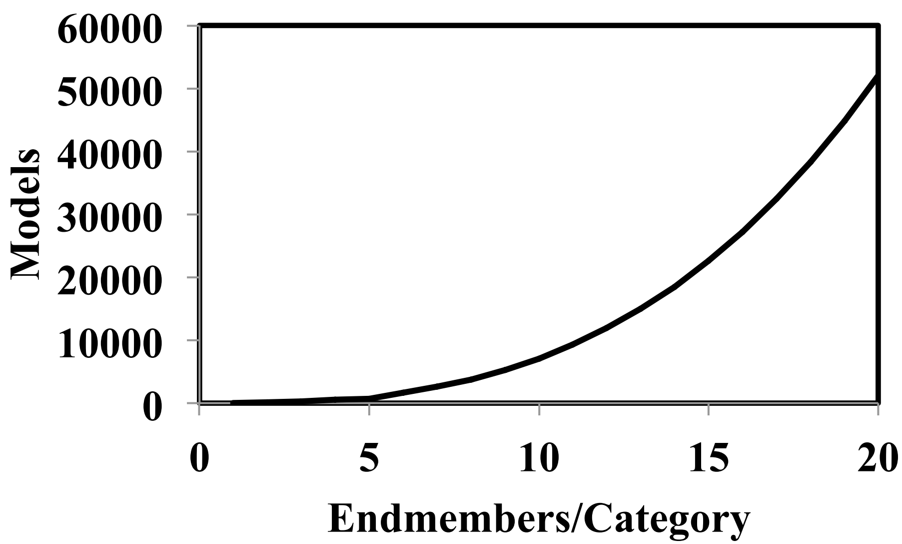




Roberts et al., 2012

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

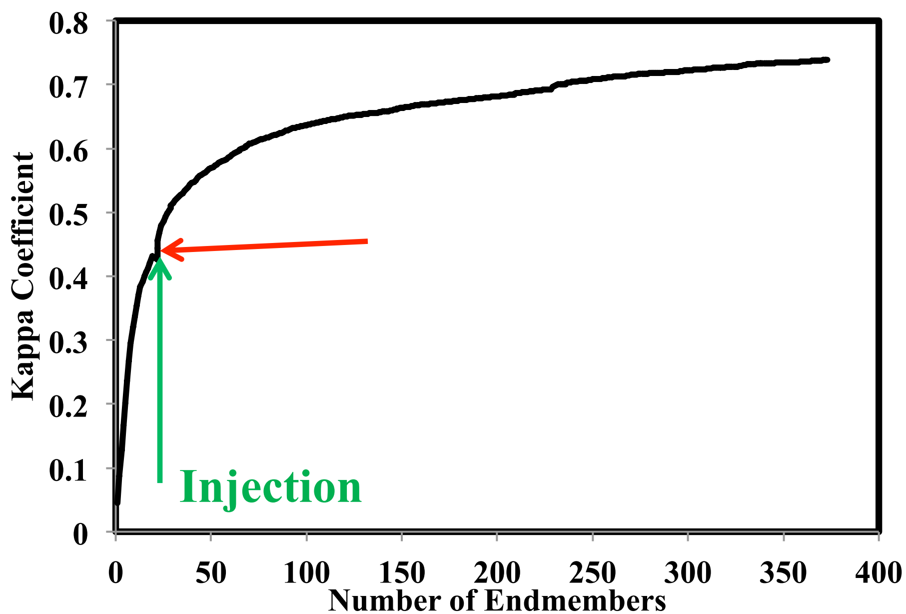
- **Endmember Sub-selection**
  - Endmember Average RMS (EAR: Dennison and Roberts, 2003)

$$\mathrm{EAR}_{A_i,B} = \frac{\sum_{j-1}^{n} \mathrm{RMSE}_{A_i,B_j}}{n-1}$$

  - Minimum Average Spectral Angle (MASA: Dennison et al., 2004)

$$\mathrm{Min}\ \bar{\theta}_{A_i,B} = \frac{\sum_{j-1}^{n} \theta_{A_i,B_j}}{n-1}$$

  - Count Based Endmember Selection (COB: Roberts et al., 2003)
  - Iterative Endmember Selection (IES: Roth et al., 2012)



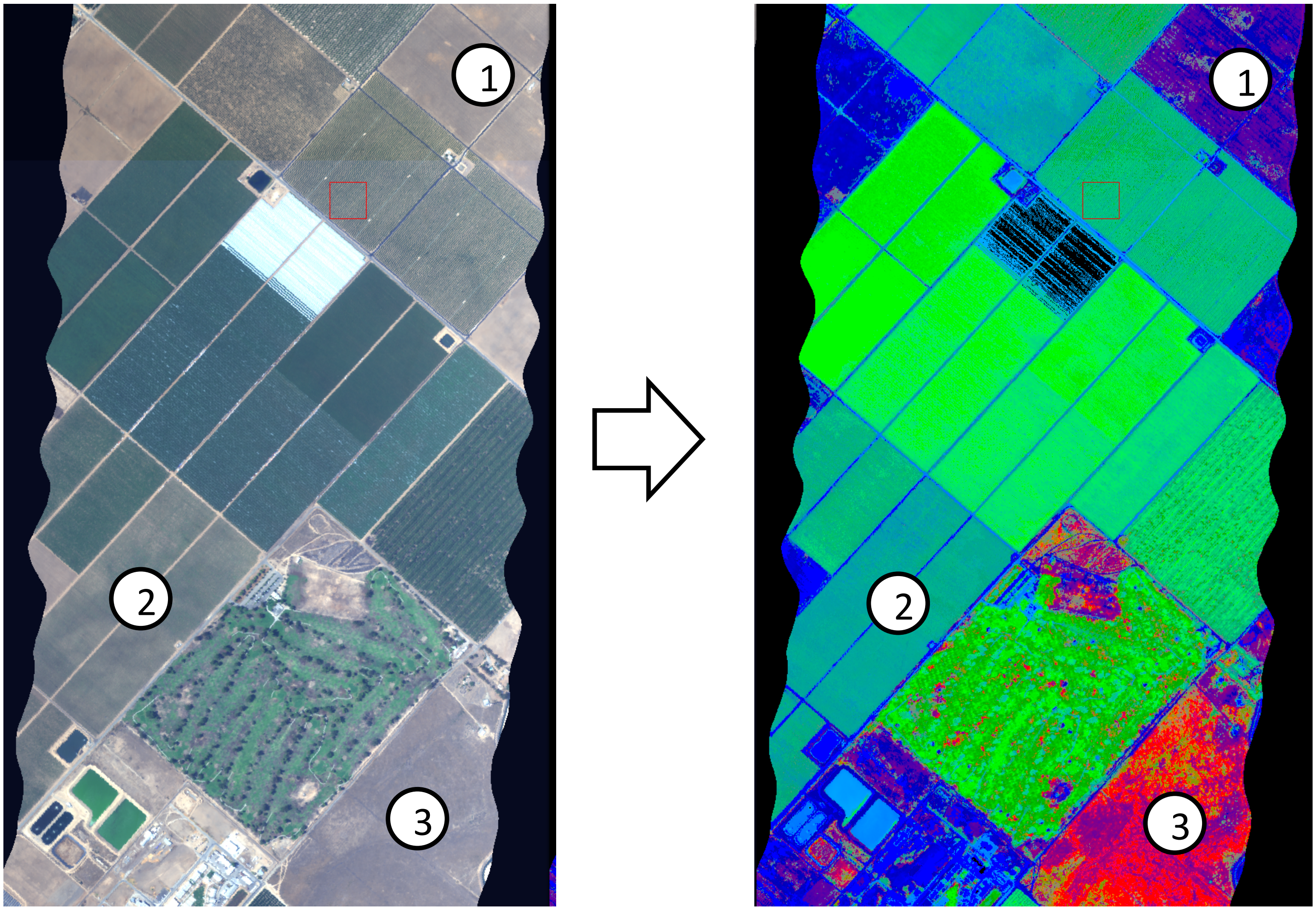
- **Band Sub-selection**
  - Stable Zone Unmixing (Somers et al., 2010)

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**

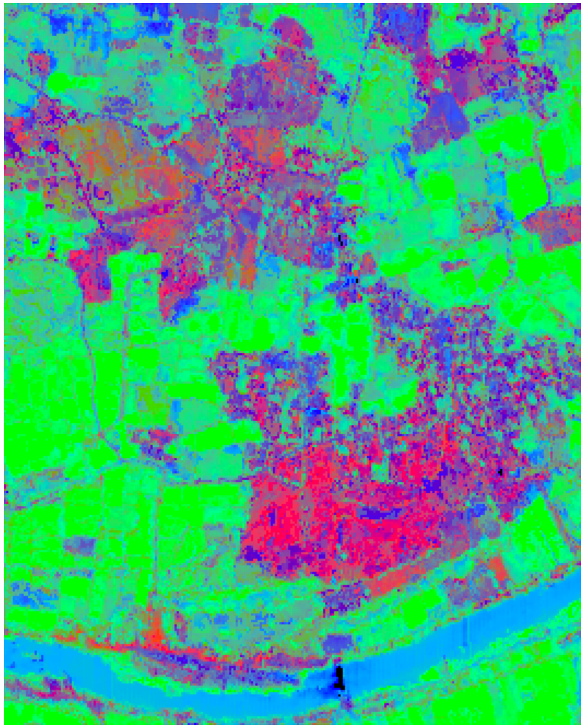


Spectrum reconstruction error

Permits user-tunable confidence filters

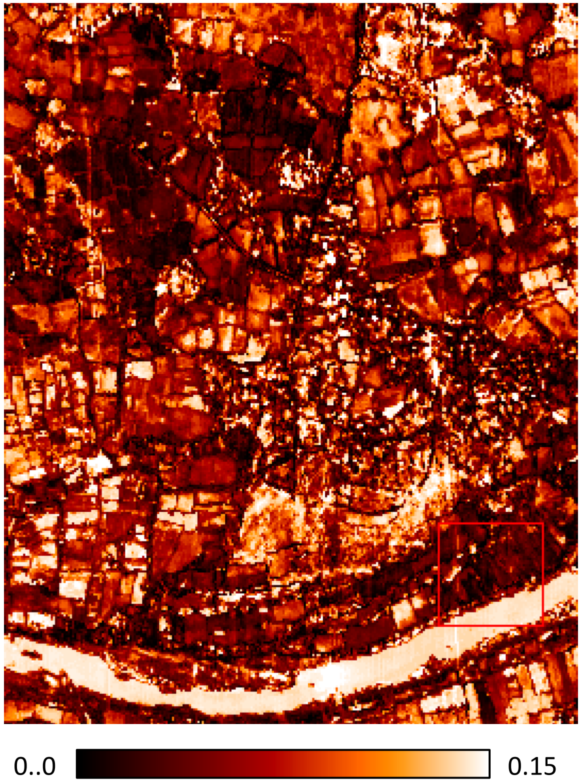
AVIRIS-NG RGB Image

Unmixing Result

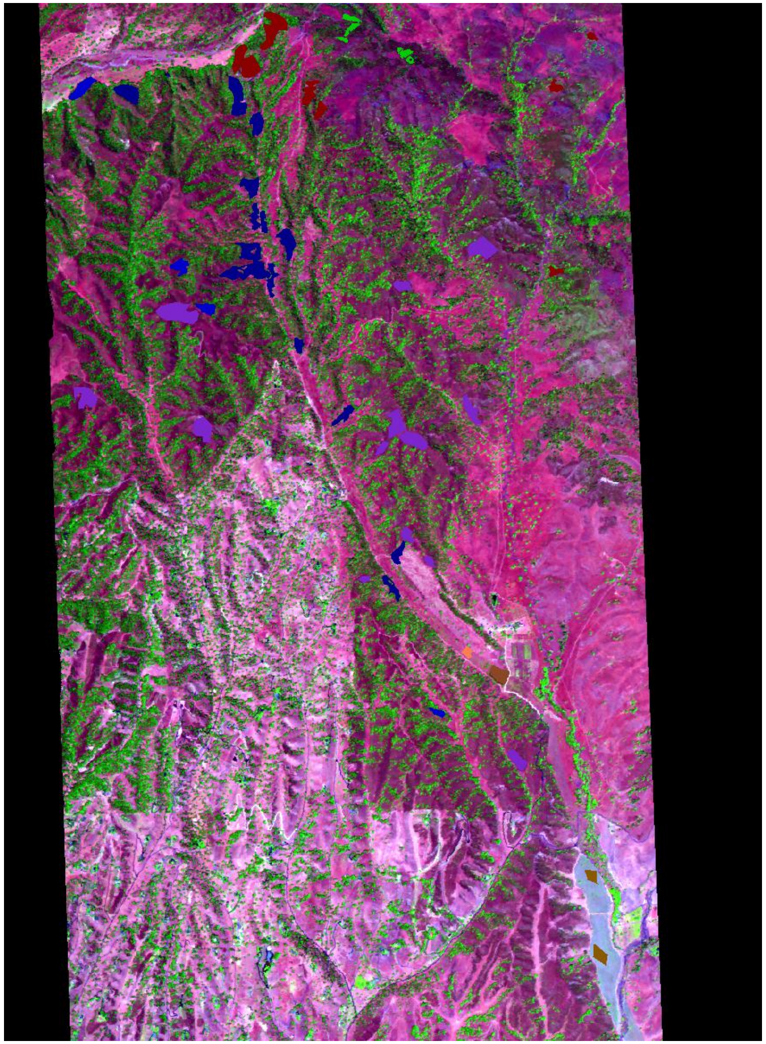


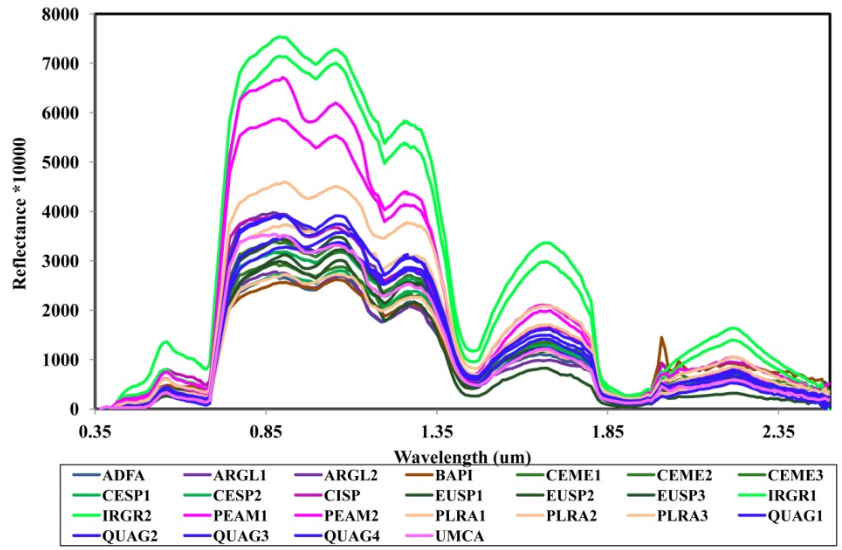
NPV PV Substrate

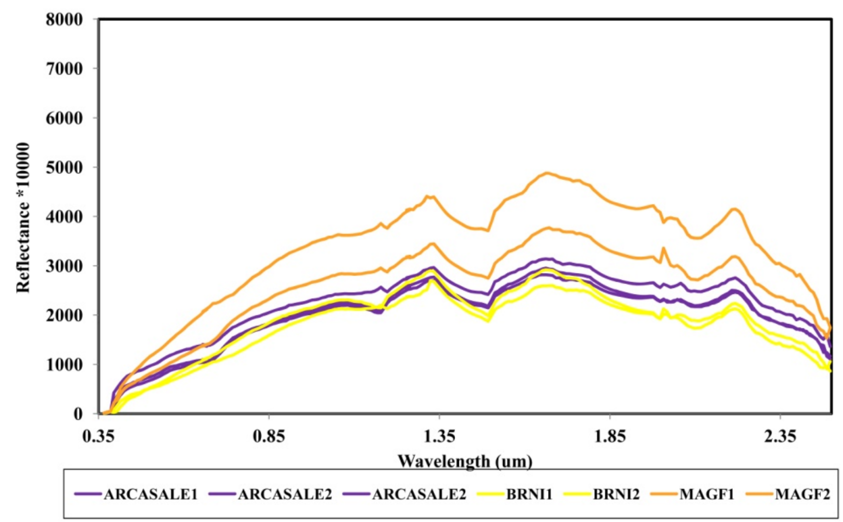
RMSE



Building Spectral Libraries: Image Sources





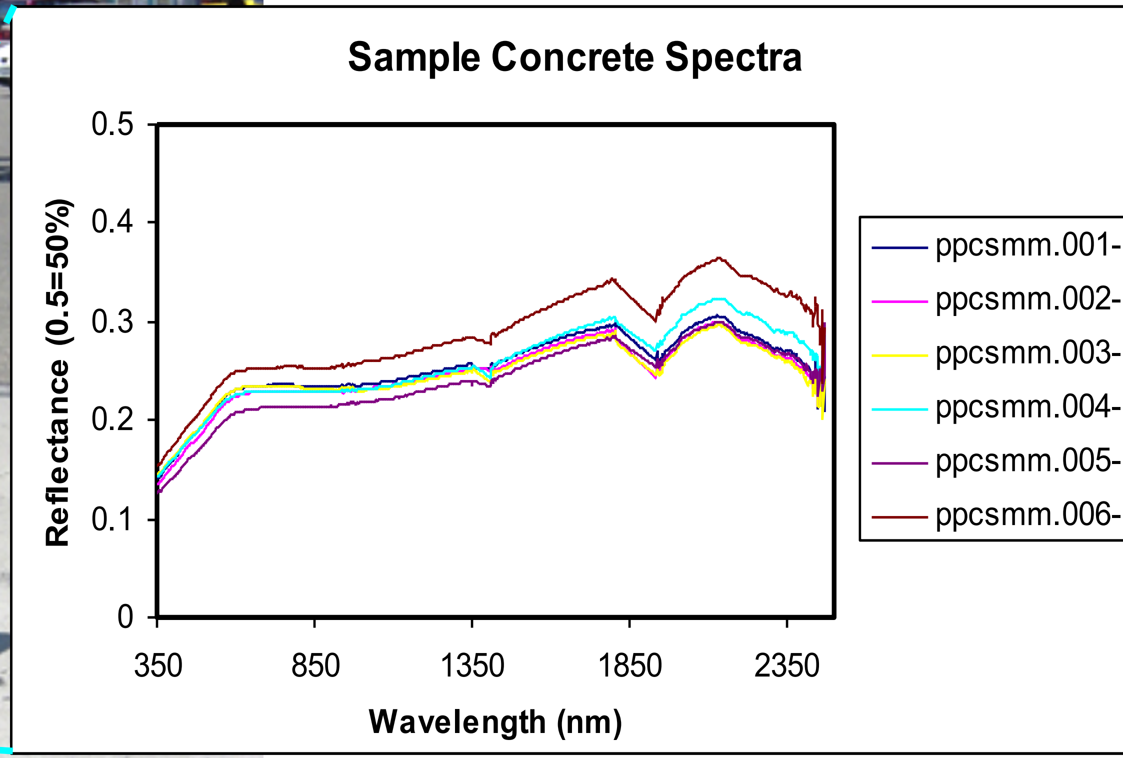


Roberts et al., 2015

Building Spectral Libraries: Field Sources

Field Spectra Collection

ASD Full-Range Spectrometer



Roberts and Herold, 2004

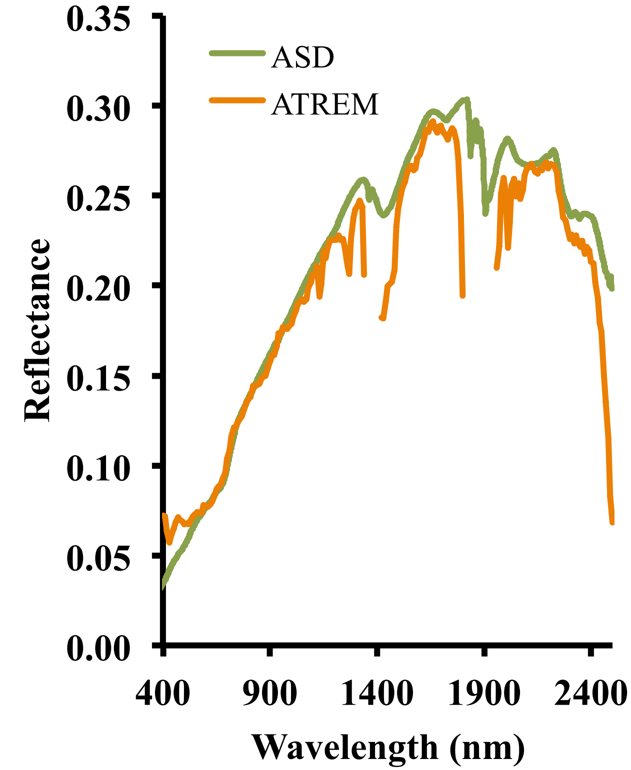
Fraction Validation Strategy

- **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

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

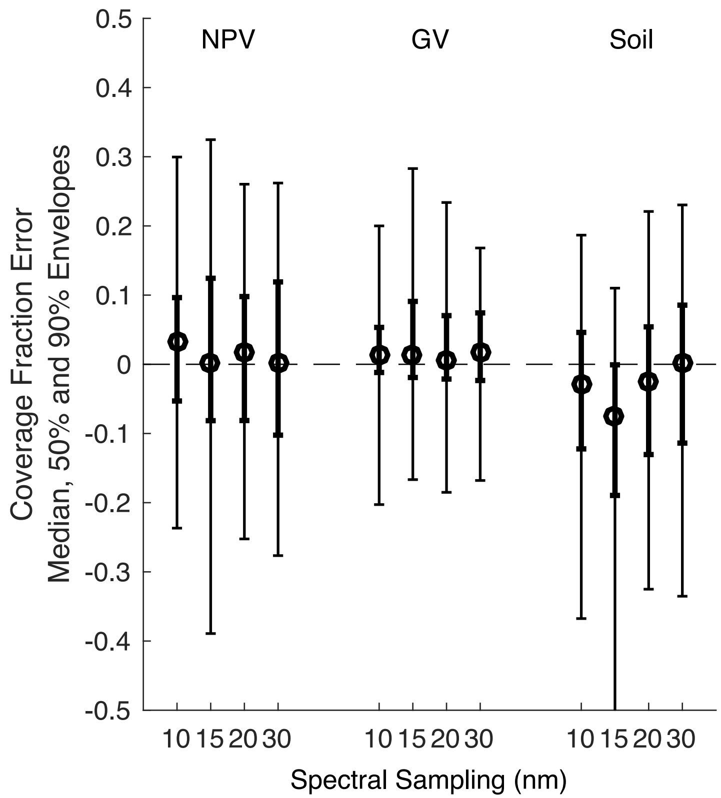
Fraction Validation: Numerical Simulations (Dennison)

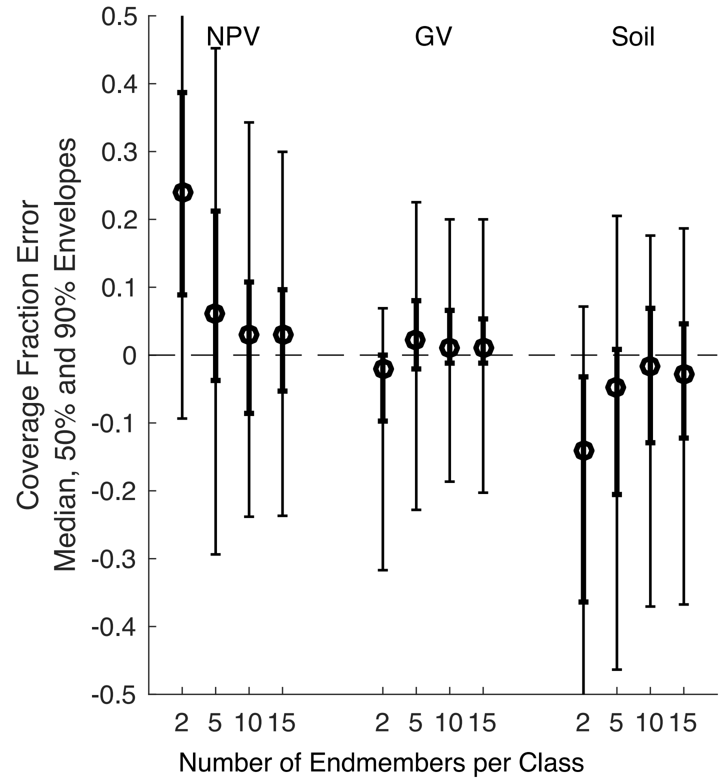
- 619 field spectra from agricultural (Daughtry) and rangeland (Kokaly) sites
- Each spectrum has field-assessed GV, NPV, and soil fractional cover
- Field spectra were used to model HyspIRI spectra, including noise, at 10, 15, 20, and 30 nm band spacing and FWHM
- Preliminary results show moderate correlations 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**