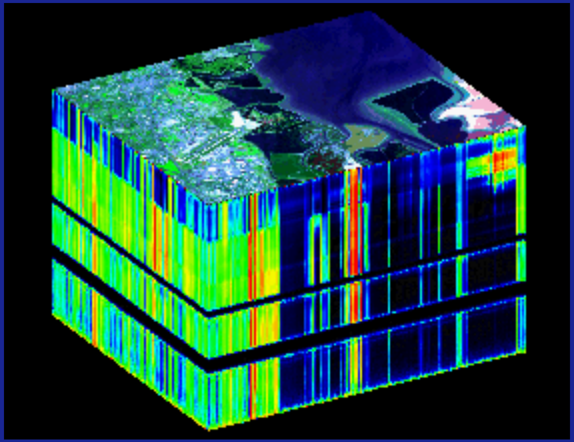


Incorporating Spatial Information in Hyperspectral Unmixing

Dr. Miguel Velez-Reyes

Professor

UTEP ECE Department

Collaborators

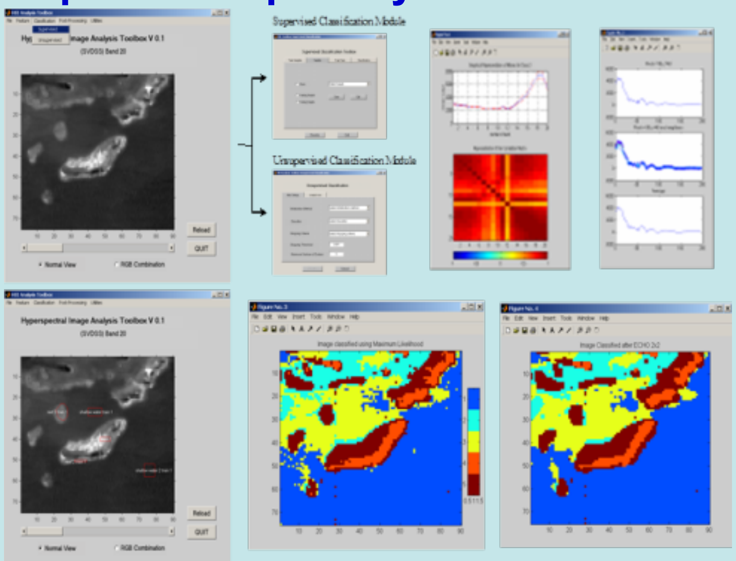
- Miguel Goenaga-Jimenez
- Mohammed Alkhatib
- Jiarui Yi

Outline

- Background
  - UTEP SenSAL
  - Hyperspectral Unmixing
- Non-convexity of the data cloud
- Exploring the spatial dimension
- Proposed unmixing approach
- Experimental results
- Final Remarks

Sensor and Signal Analytics Laboratory

Expertise/Capability



Research Goals

- Develop novel systematic information extraction algorithms from remote or minimally intrusive sensing and imaging systems
    - Advanced mathematical concepts
    - Novel computational methodologies
- Provide a multi-disciplinary environment for training and research to undergraduate and graduate students in state of the art tools and technologies
    - Partnerships with end users and industry
- Develop technology and tools to solve relevant societal problems
    - Environment, Homeland Security, Defense, Biomedical

Funders

- NSF
- NASA (with UPRM)
- UTEP Office of the Provost IDR
- UT System STARS

PARTNERS/COLLABORATORS

Linear Mixing Model

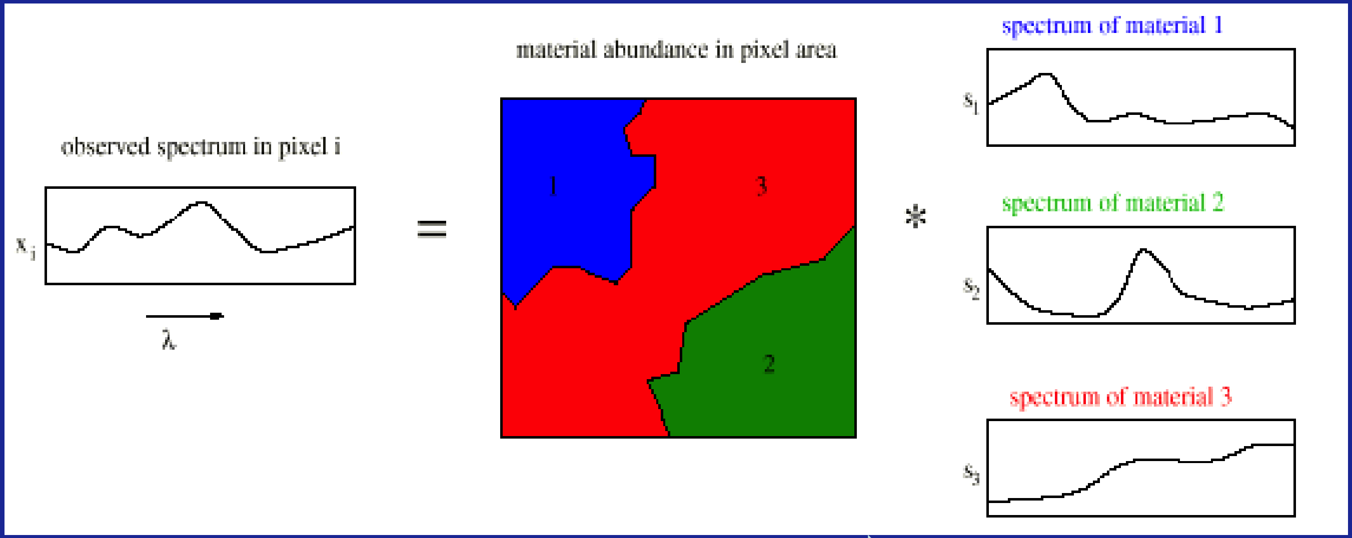
$$\mathbf{x} = \sum_{n=1}^{P} a_n \mathbf{s}_n$$

where

s_n endmember spectra

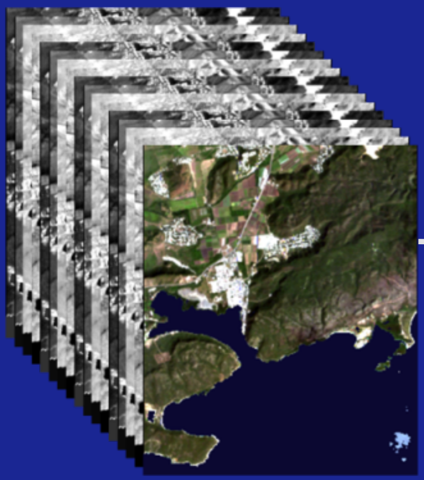
a_n fractional abundance

Mixing



Unmixing

Unmixing Algorithms

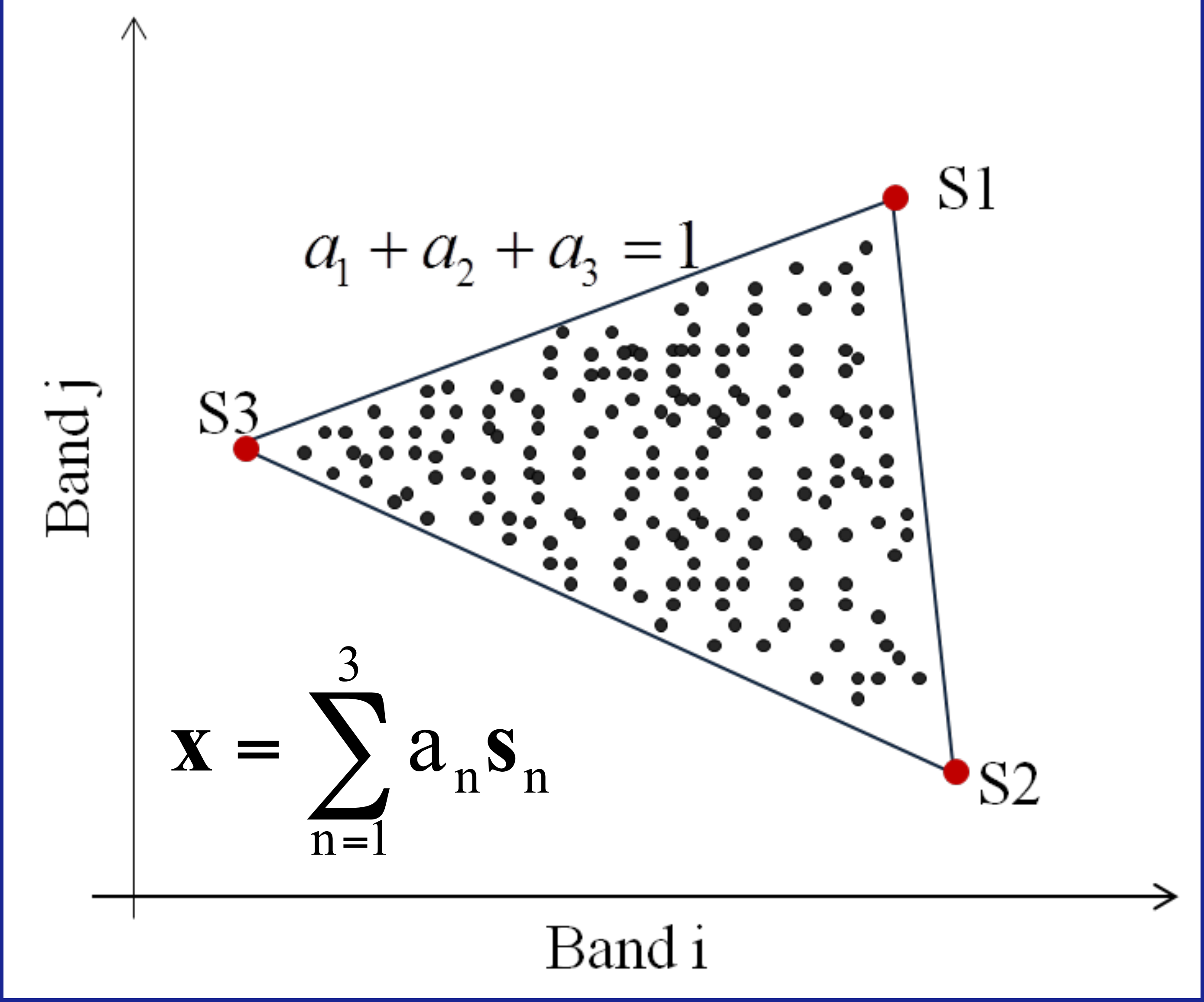


- Hyperspectral Unmixing
  - *Number of Endmember Estimation*
    - Signal Subspace
    - Matrix Rank
    - Positive Rank
  - *Endmember Extraction*
    - Geometric Methods
    - Parametric Methods
    - Spatial-spectral Methods
  - *Abundance Estimation*
    - Least Square Methods
    - Sparse Regression

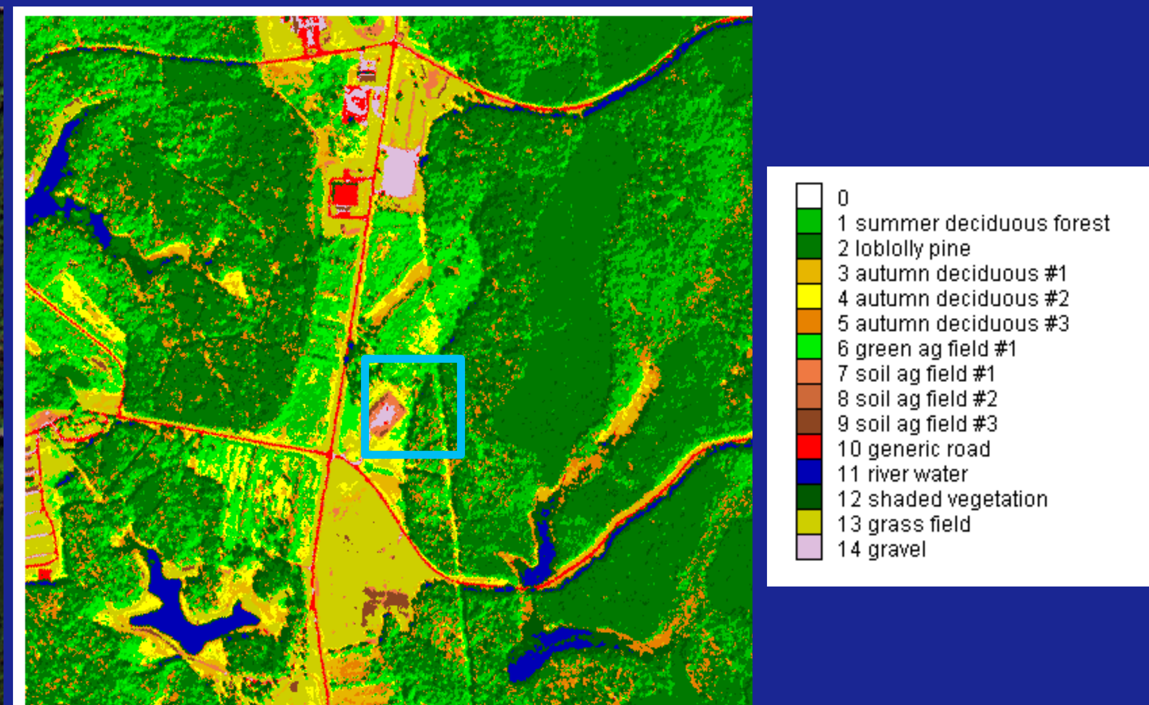
Main Goal

Develop algorithms for unsupervised unmixing of hyperspectral imagery

Geometry of Linear Mixing



Looking at Real Hyperspectral Imagery



- September, 2001 Fort A. P. Hill AVIRIS data collect
- Classification map derived using the PBSLv0 spectral library, see Cipar at al., 2004

Looking at Real Hyperspectral Imagery

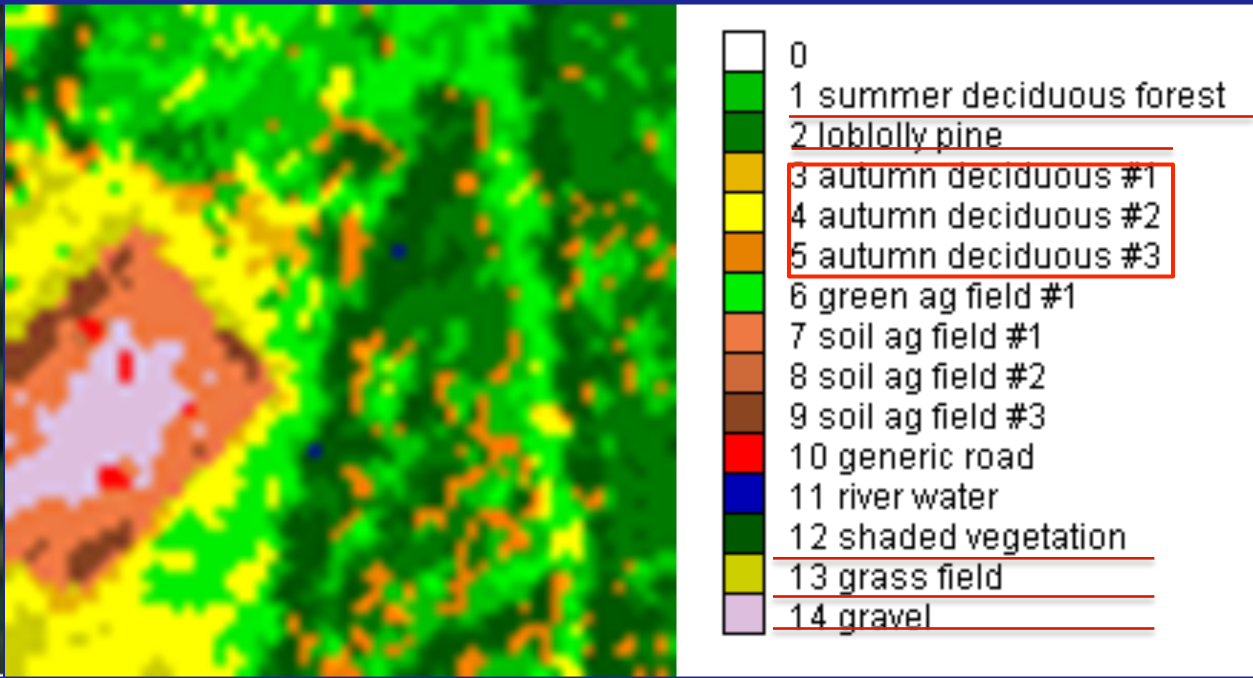
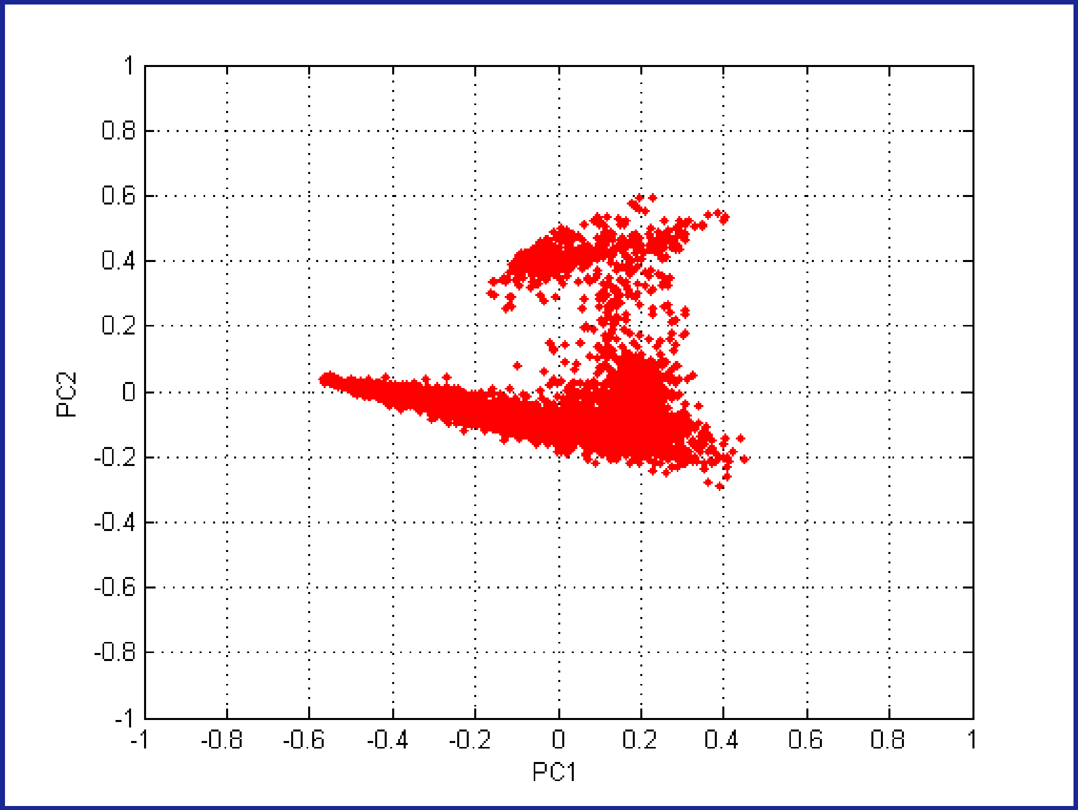


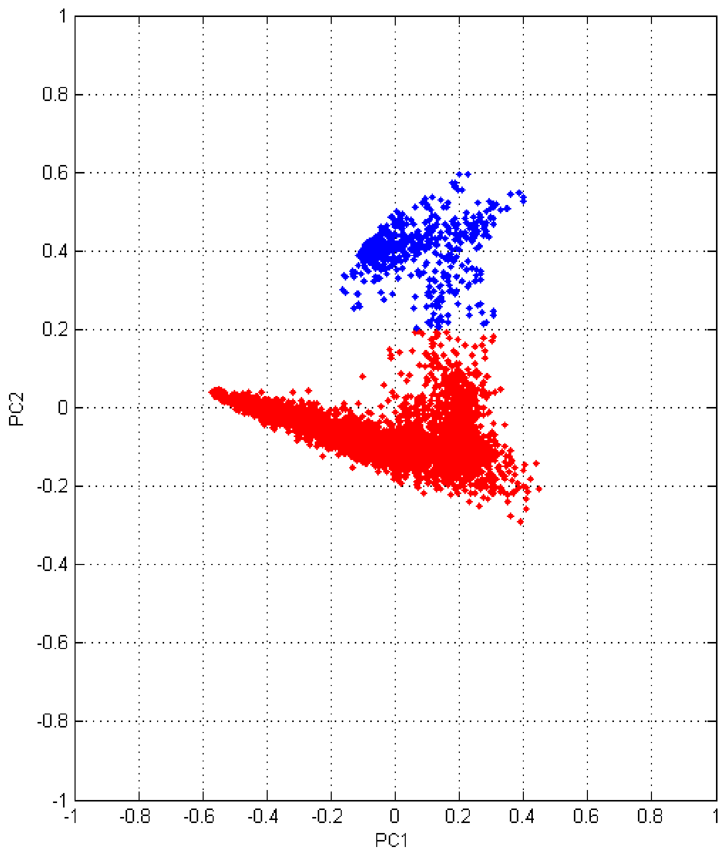
Image chip from Fort AP Hill AVIRIS Image

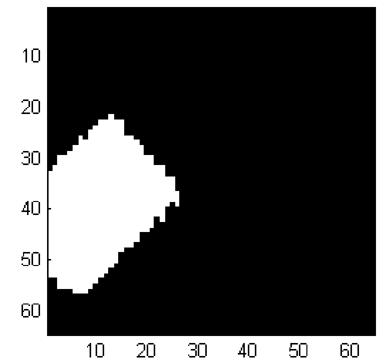
Looking at Real Hyperspectral Imagery

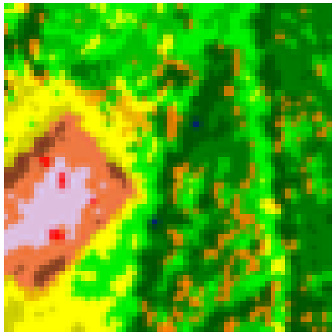


- Image chip from Fort AP Hill AVIRIS Image
- First 2 PCs explain 97.5% of the total variability.
- First 4 PCs explain 99.2% of the total variability

Spatial Dependencies
“Gravel Field”

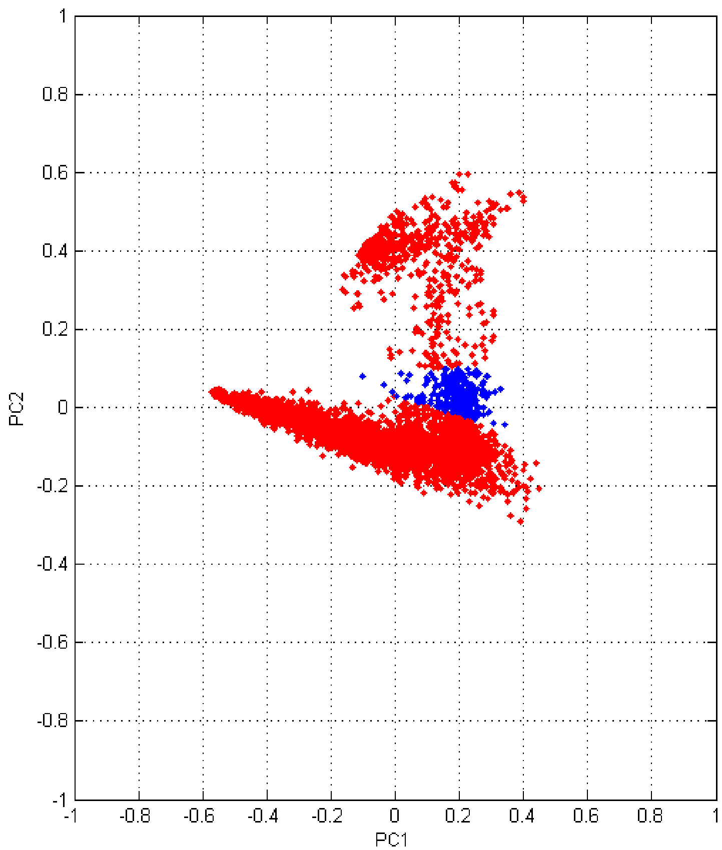


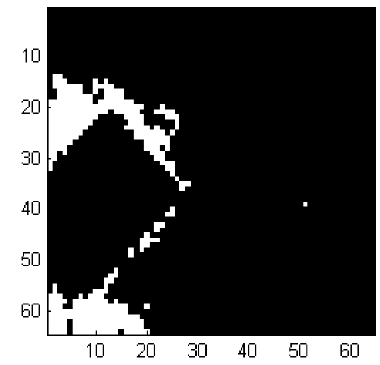


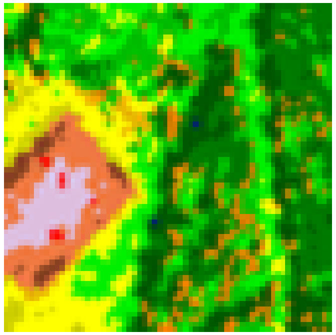


Pixel info: (X, Y) Pixel Value

Spatial Dependencies
“Grass Field”

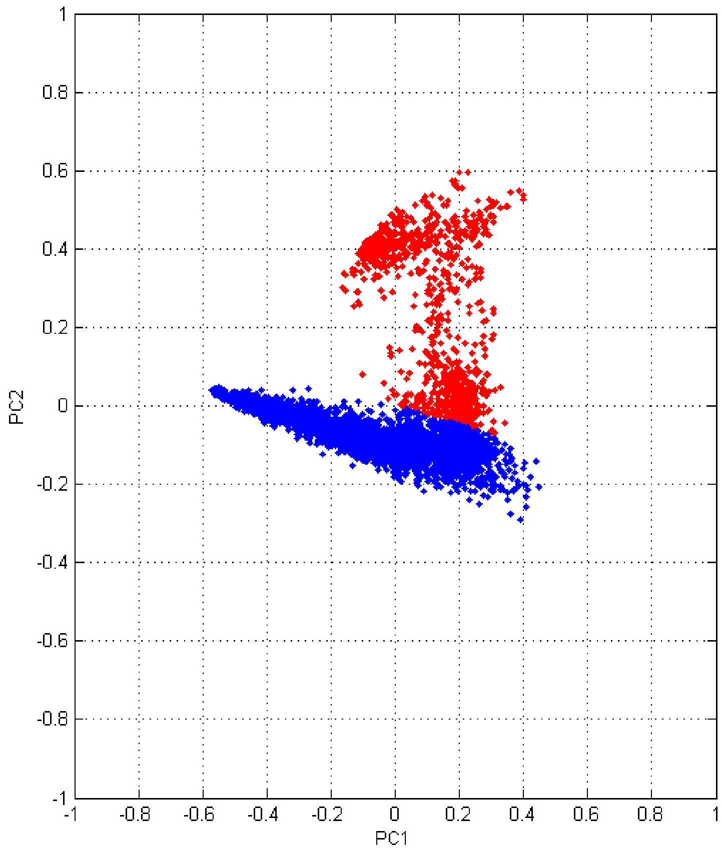


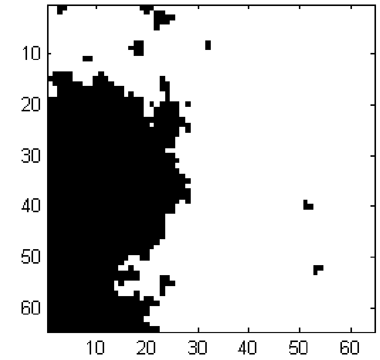


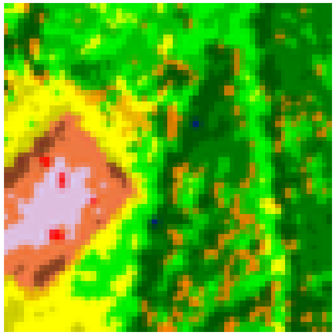


Pixel info: (X, Y) Pixel Value

Spatial Dependencies "Vegetation"

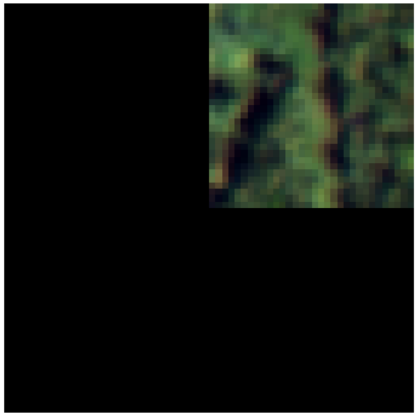


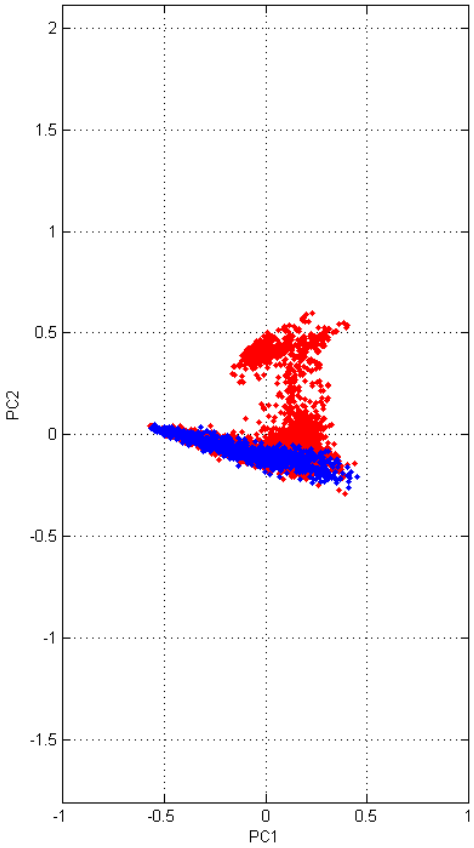


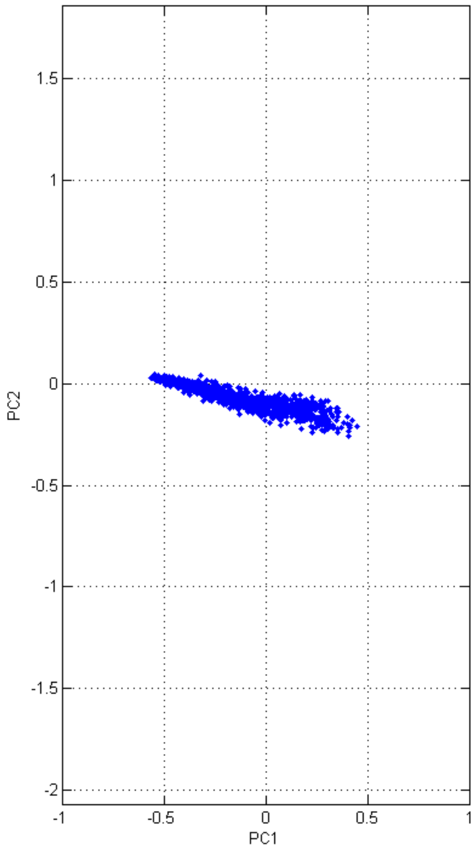


Pixel info: (X, Y) Pixel Value

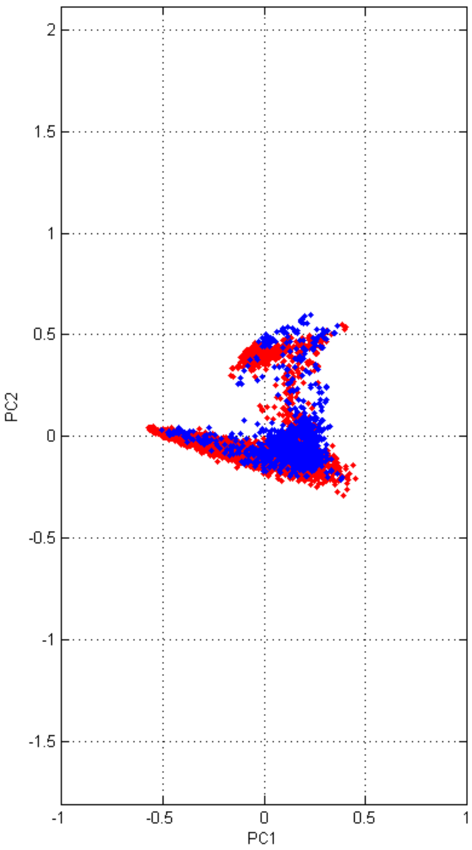
Spatial Dependencies: Simple Segmentation

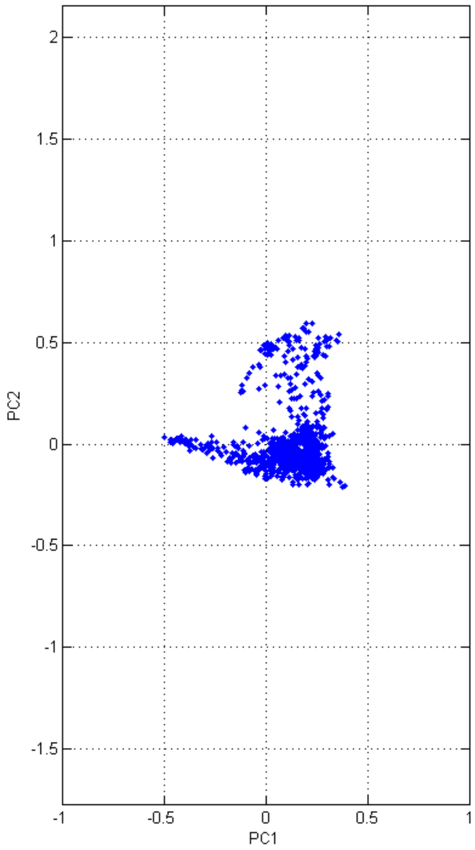




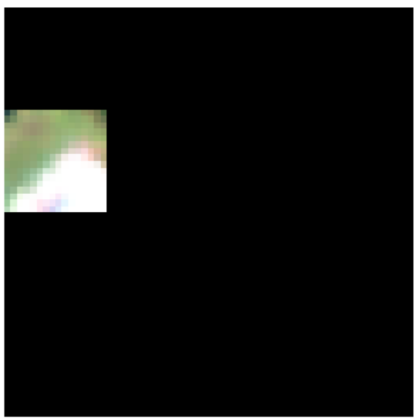


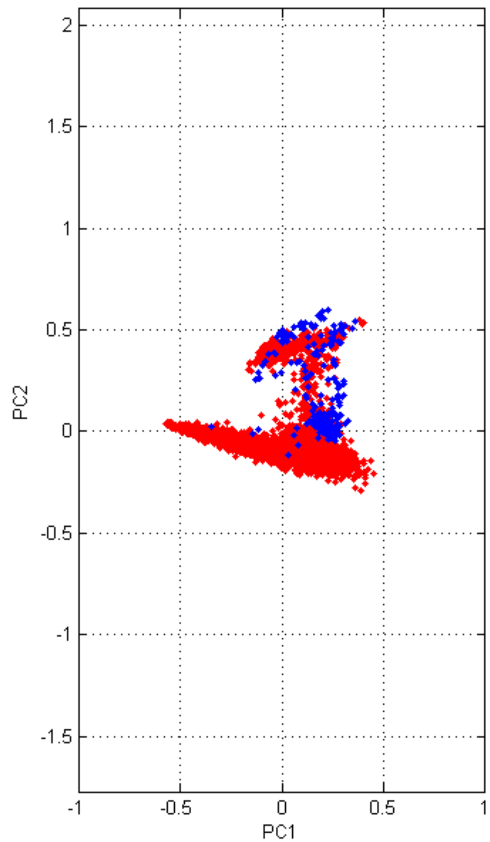
Spatial Dependencies: Simple Segmentation

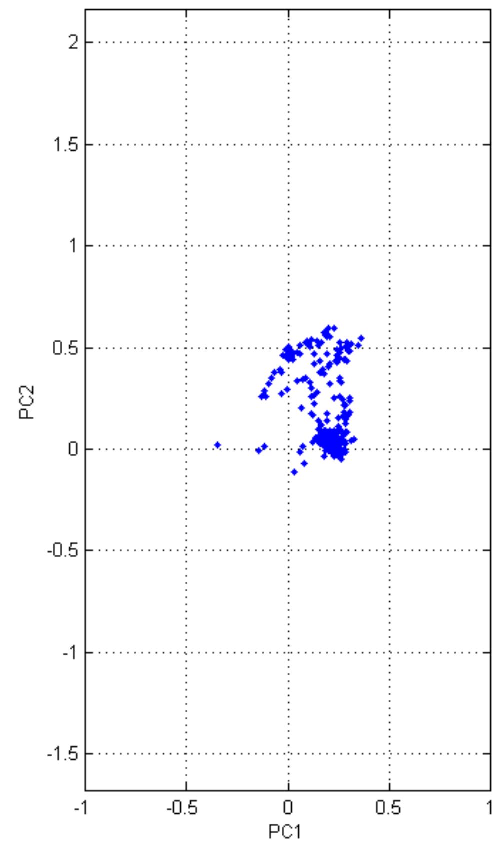




Spatial Dependencies: Simple Segmentation



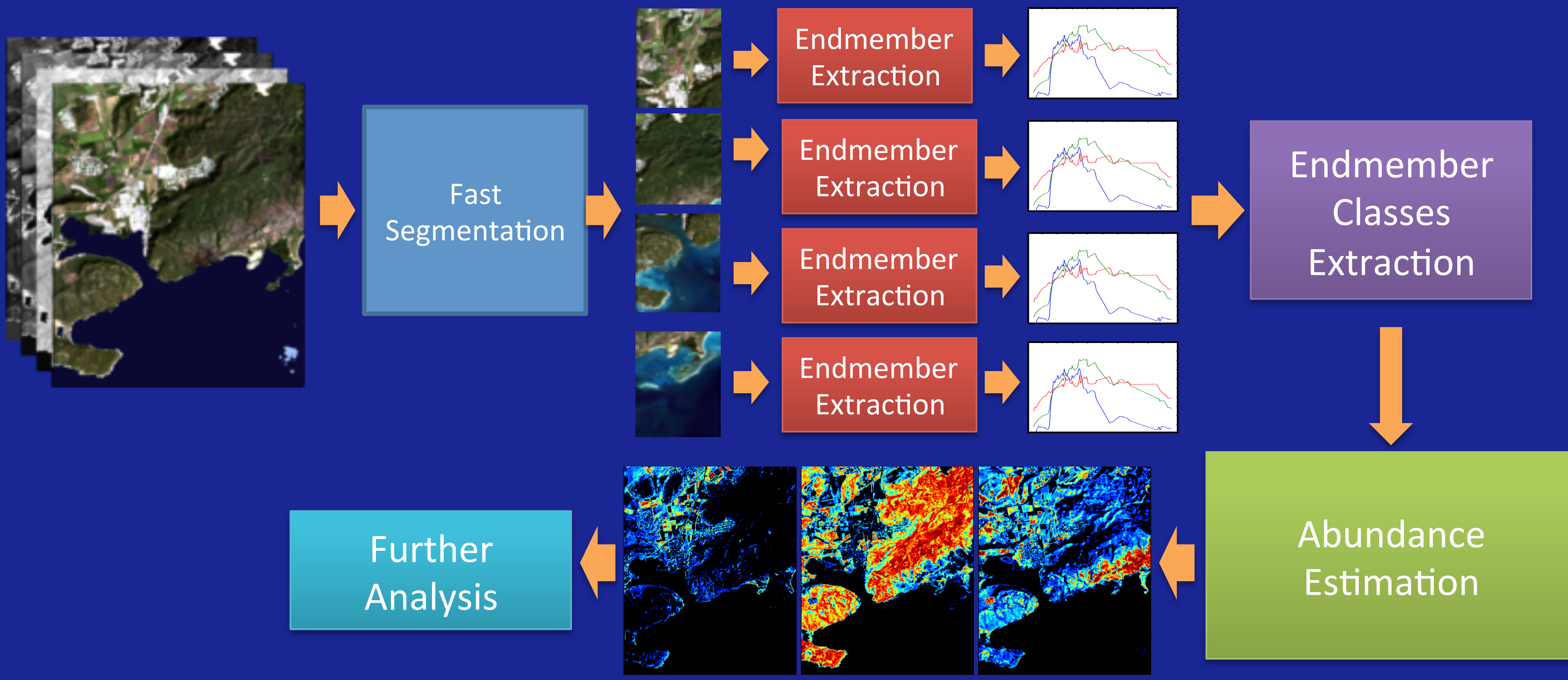




Observations

- Global image data cloud is not the convex hull of a group of endmembers
  - Materials mixing has a spatial dependency
  - Piecewise convex approximation (?)
- Convex regions in the global cloud → "local structure"

Proposed Idea



Simple Segmentation using Quadtree Partitioning

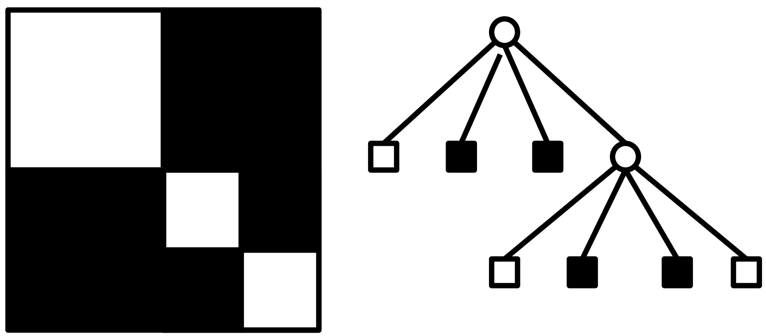


Image A

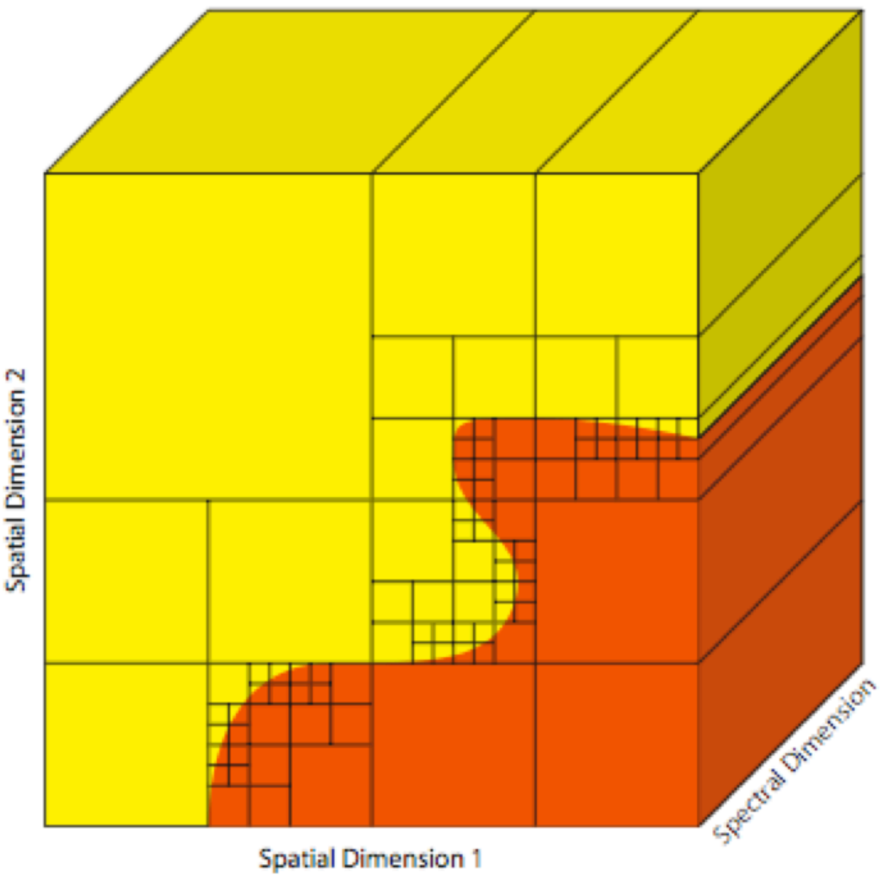
Quadtree of Image A

Tree leaves represent "homogeneous" tiles.

Shannon entropy [Palmer, M., et al, 2002]

$$H = -\frac{1}{N}\sum_{i=1}^{N_C} p_i \log(p_i)$$

Goenaga-Jimenez, M.A, and Velez-Reyes, M., "Comparing Quadtree Region Partitioning Metrics for Hyperspectral Unmixing," Proc. SPIE 8743, 1219- 1228 (2013).

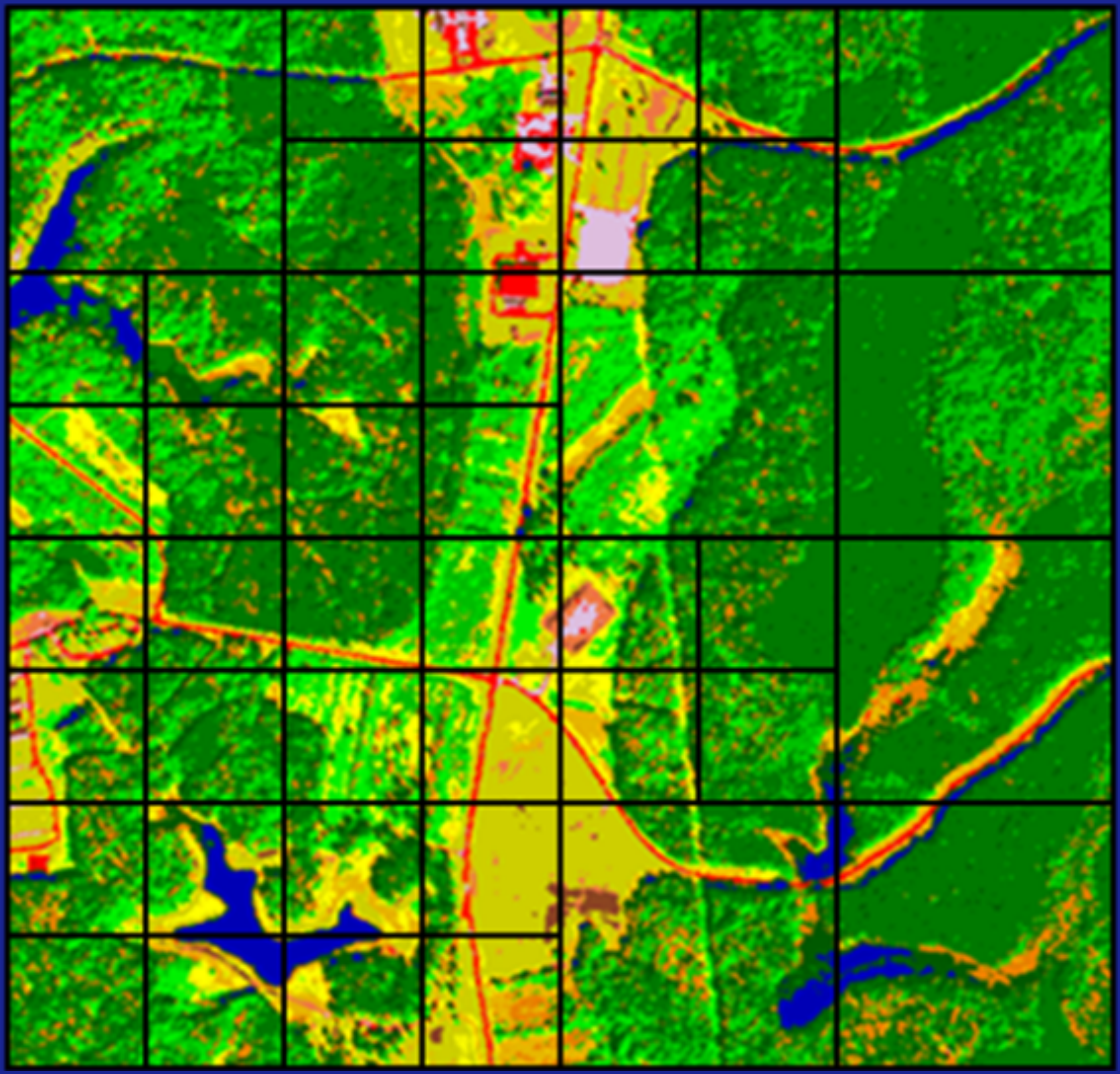


http://cnx.org/contents/f0bdfbd9-ec2c-40ca-bb1e-d7f025be17d9@4/Hyperspectral-imaging

Experiments with Fort AP Hill AVIRIS

- Comparison with published results
  - Cipar et al. 2004
  - Spatial distributions of extracted abundances and reported information classes
- Comparison with cNMF applied to the entire image

Quad-Tree Image Partitioning of Fort AP Hill



Stopping Criterion:

- Entropy of the tile is ≤ 90% of the total entropy, OR
- Tile size is 1/64 of the total image size.

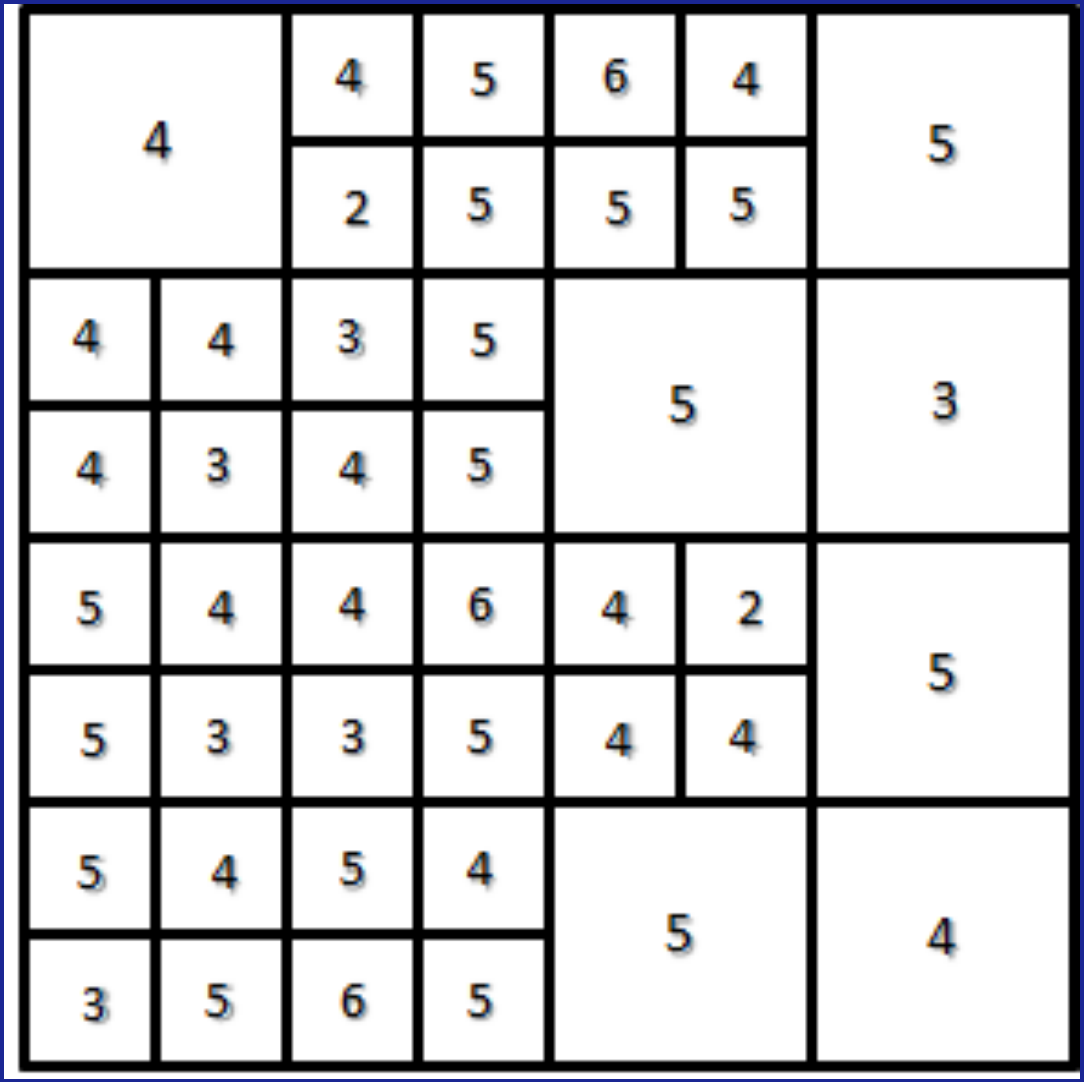
Endmember Extraction with cNMF

$$\left(\hat{\mathbf{S}}_p, \hat{\mathbf{A}}_p\right) = \arg\min_{\substack{\mathbf{S},\mathbf{A}\geq\mathbf{0} \\ \mathbf{A}^T\mathbf{1}\leq\mathbf{1}}} \left\|\mathbf{X} - \mathbf{S}\mathbf{A}\right\|_F^2$$

$$\mathbf{X} \in \mathrm{R}_+^{m\times n}, \mathbf{S} \in \mathrm{R}_+^{m\times p}, \mathbf{A} \in \mathrm{R}_+^{p\times n}$$

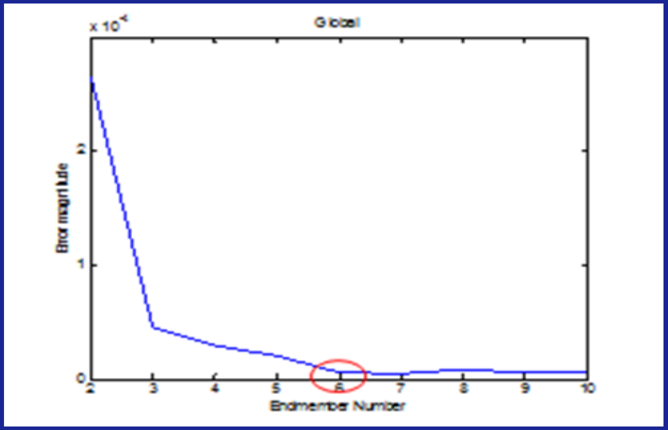
Used only for endmember extraction. You can use your favorite method.

Endmembers per Tile



Knee of the Fitting Error Curve Used to Determine the Number of Endmembers

$$E_p = \frac{\left\| \mathbf{X} - \hat{\mathbf{A}}_p \hat{\mathbf{S}}_p^T \right\|_F}{\left\| \mathbf{X} \right\|_F}$$



Endmember Classes

- 181 Spectral Endmembers extracted
- Spectral endmembers were clustered in 11 Endmember Classes
  - Hierarchical clustering using complete linkage and angle distance
  - Davies-Bouldin validity index
  - clusterdata from MATLAB was used
- Image has 14 information classes in the classification map.

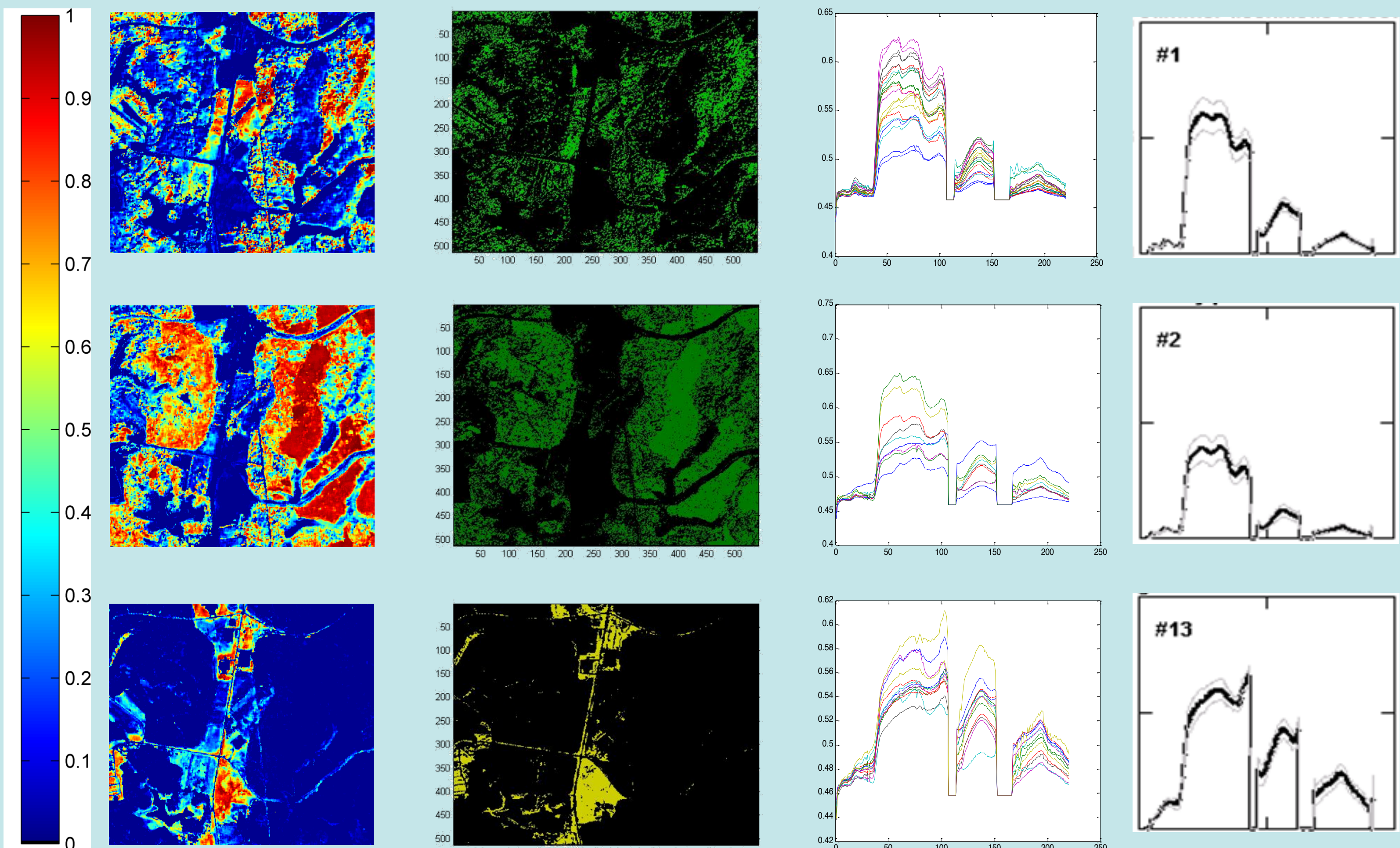
Experimental Results
Fort AP Hill

sacNMF | **Class Map** | **Extracted** | **Published**

summer deciduous forest

loblolly pine

grass field



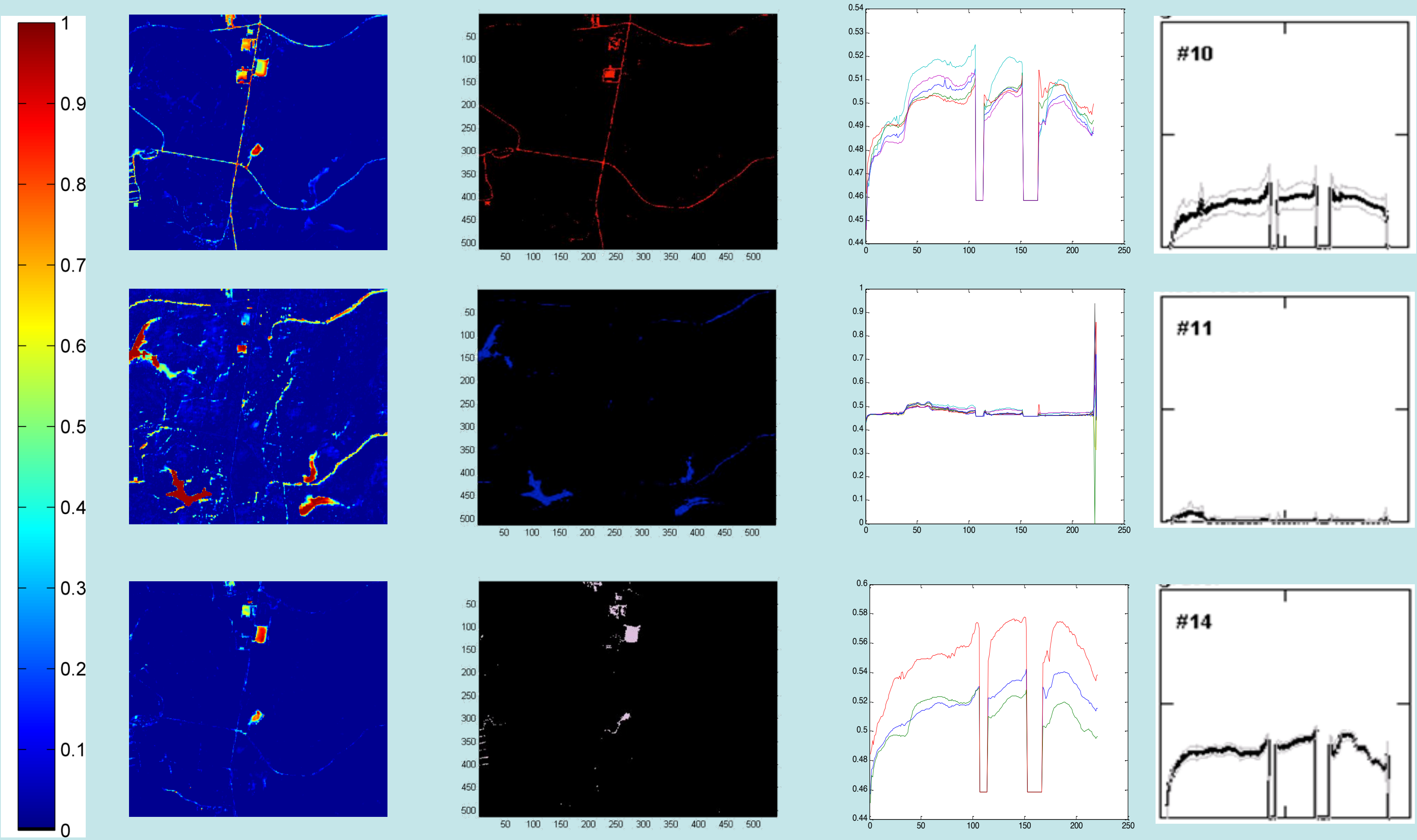
Experimental Results
Fort AP Hill

sacNMF | Class Map | Extracted | Published

generic road

river water

gravel



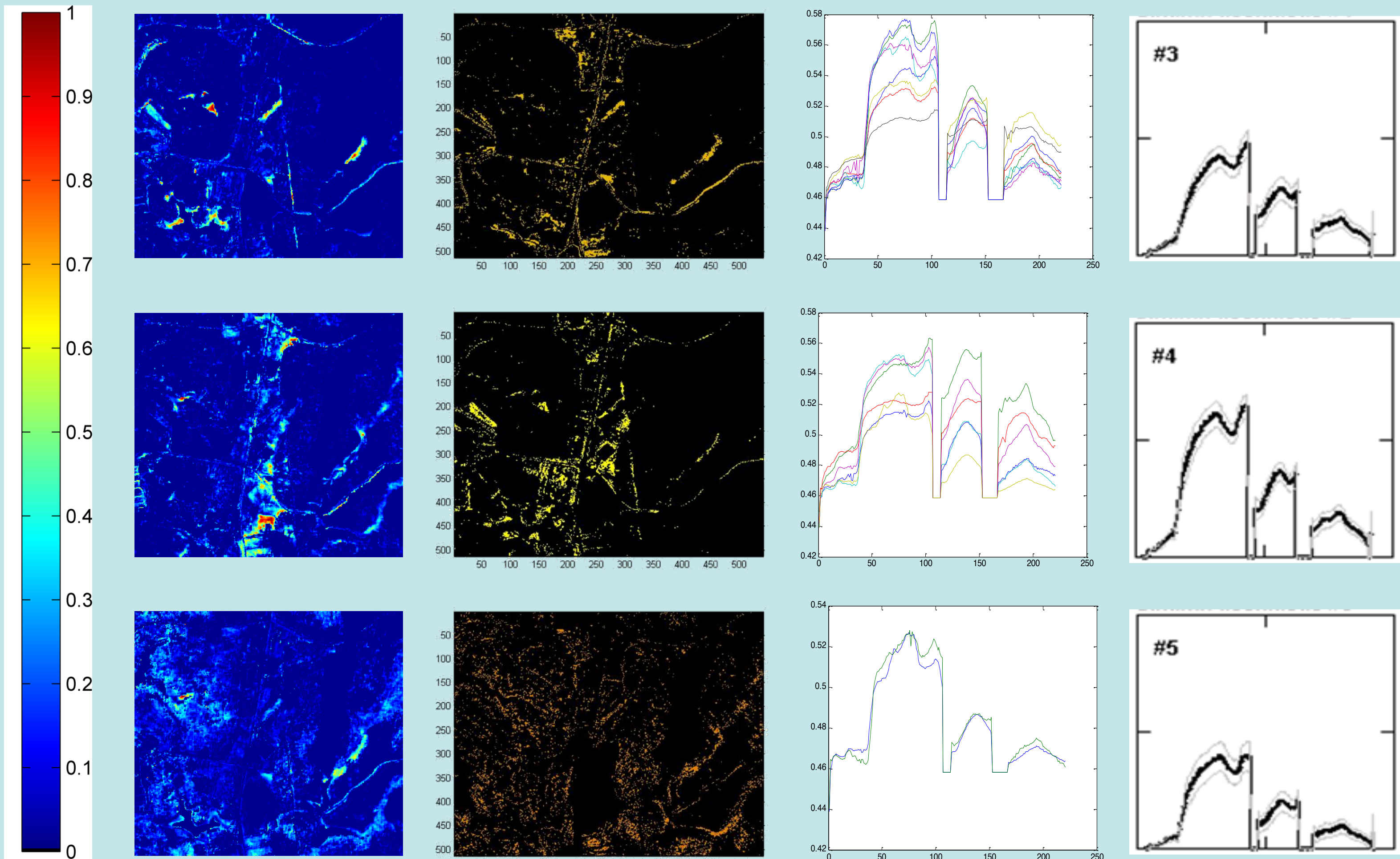
Experimental Results
Fort AP Hill

sacNMF | Class Map | Extracted | Published

autumn deciduous #1

autumn deciduous #2

autumn deciduous #3

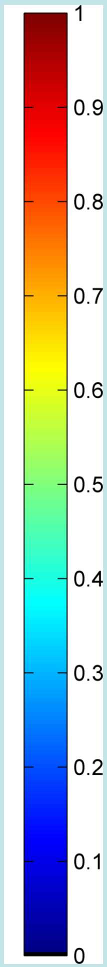


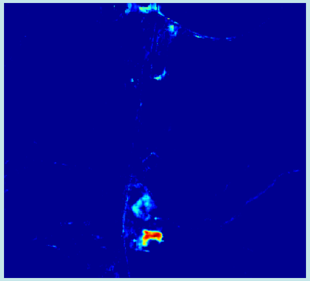
Experimental Results
Fort AP Hill

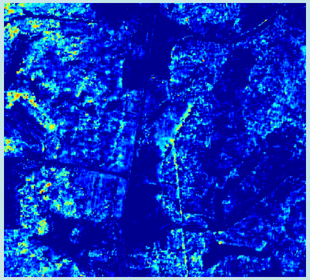
	sacNMF	Class Map	Extracted	Published

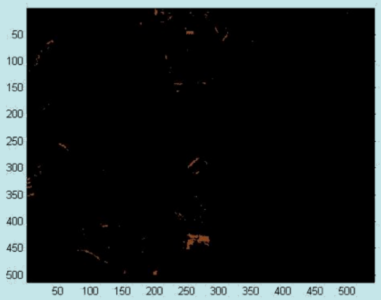
soil ag field #3

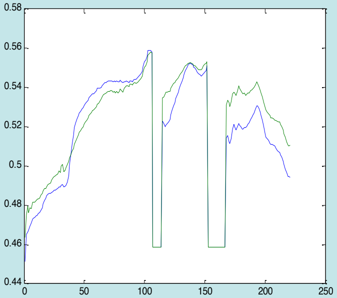
?

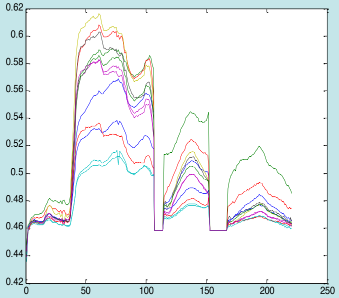


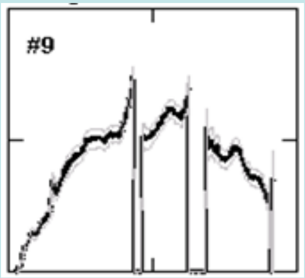




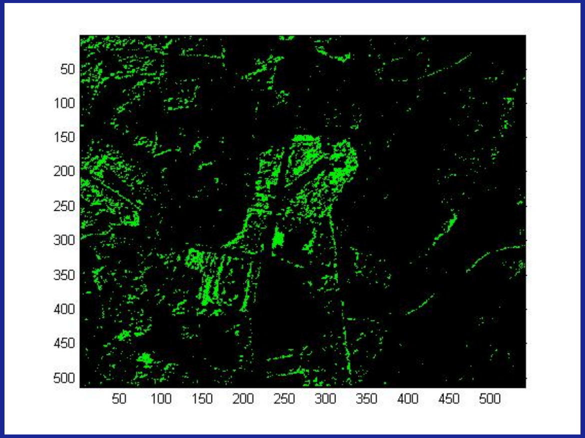


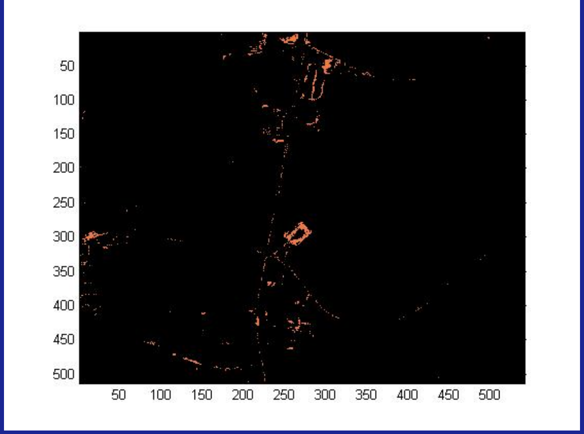


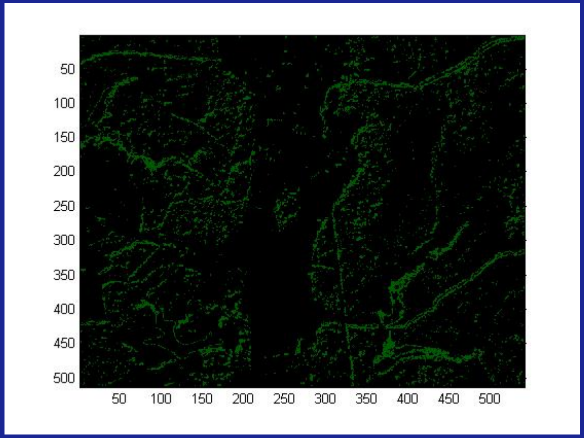




Not Extracted



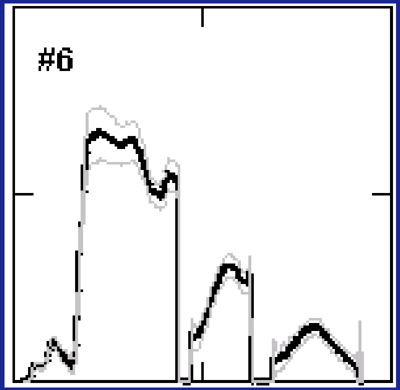


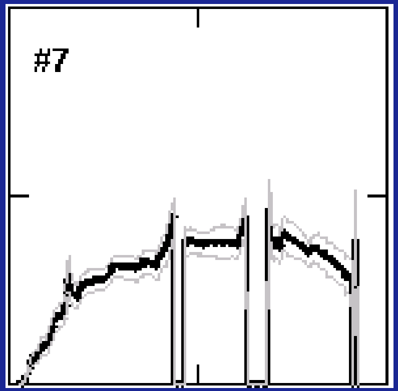


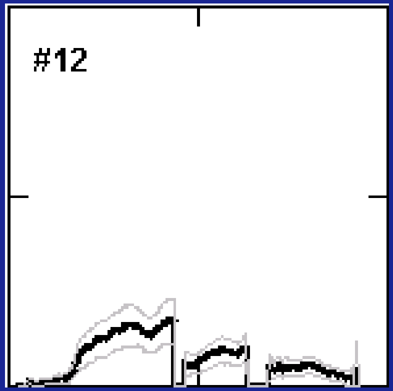
Green Ag Field #1

Soil Ag Field #1

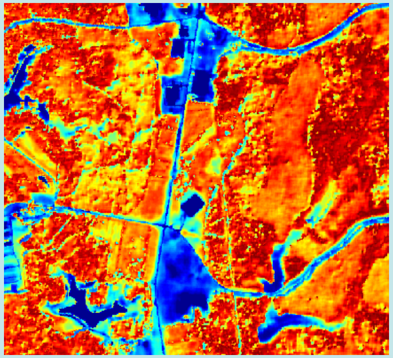
Shaded Vegetation

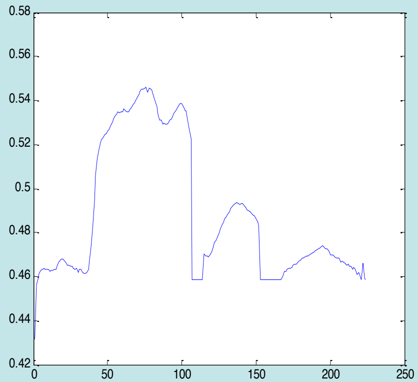


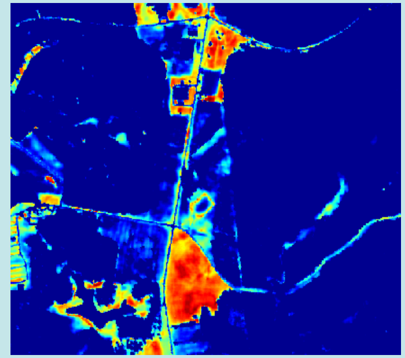


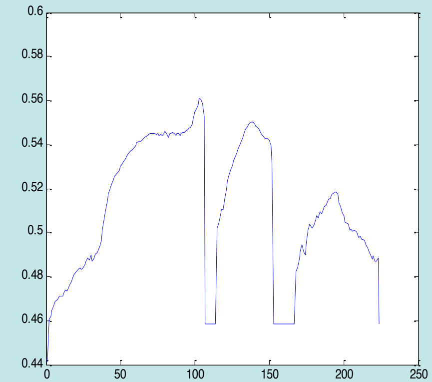


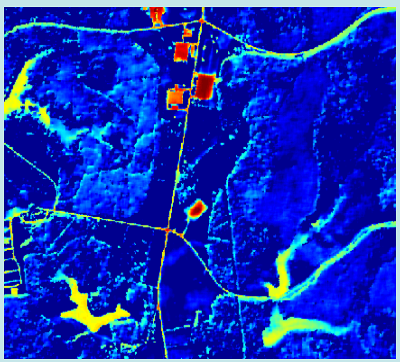
Global cNMF Unmixing Results

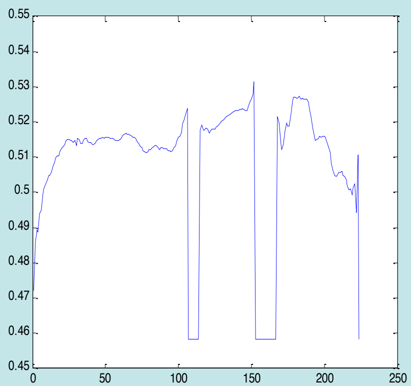


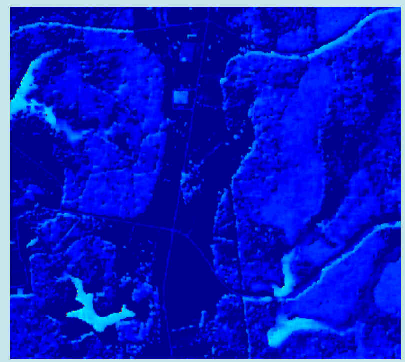


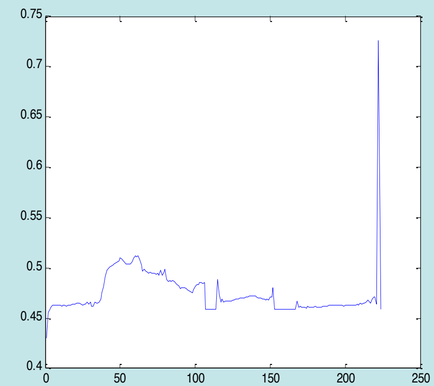


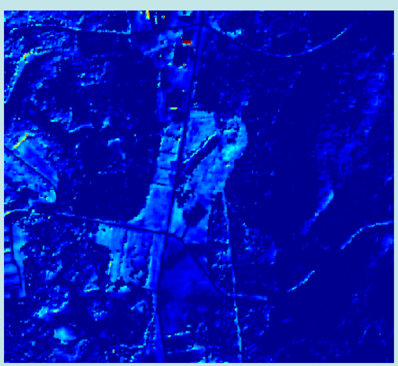


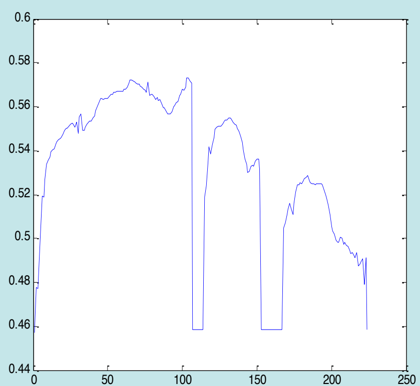








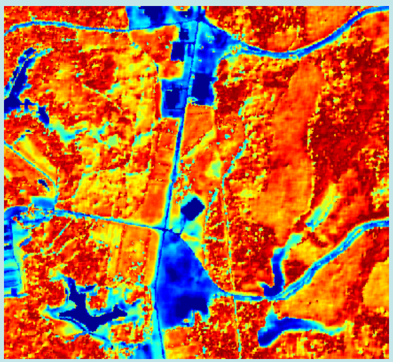




- **cNMF applied to the entire image**
- **Number of endmember estimated using fitting error**

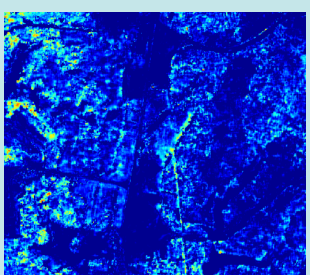
Comparison with cNMF

cNMF



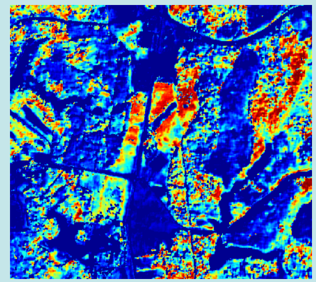
Vegetation

?

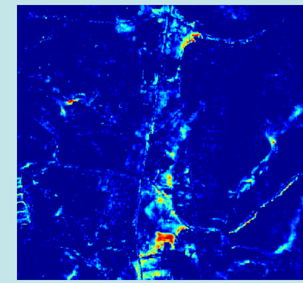


Proposed Approach

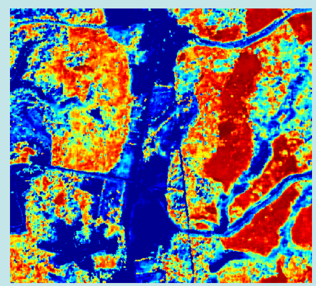
summer deciduous forest



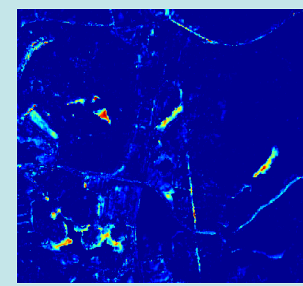
autumn deciduous #1



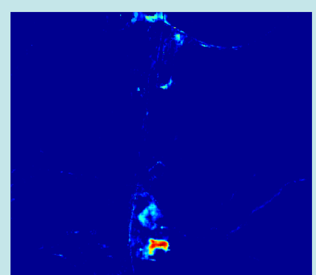
loblolly pine



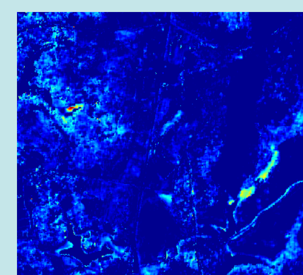
autumn deciduous #2

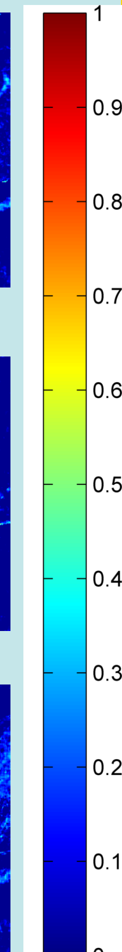


green ag field #3



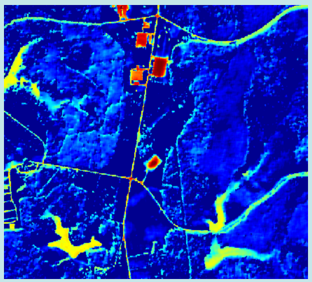
autumn deciduous #3

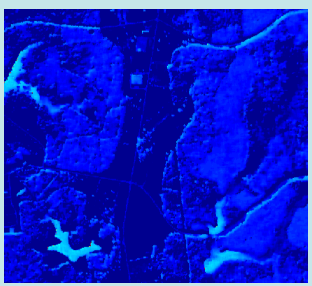


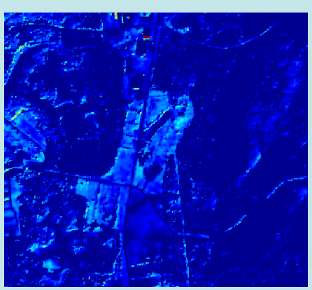


cNMF vs sacNMF

cNMF

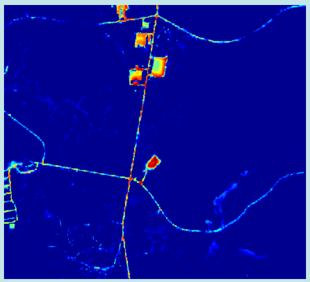




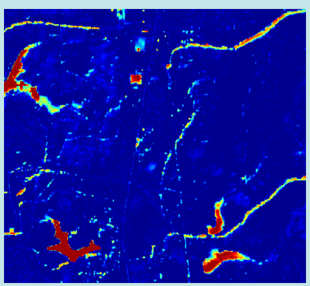


Proposed Approach

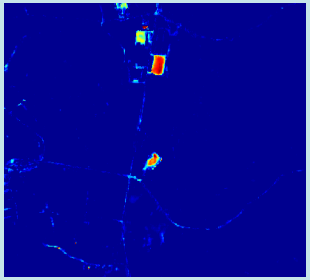
generic road

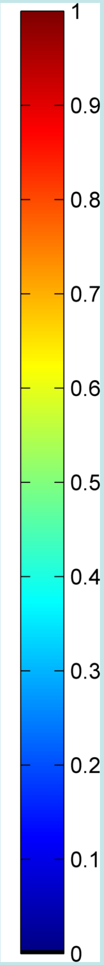


river water



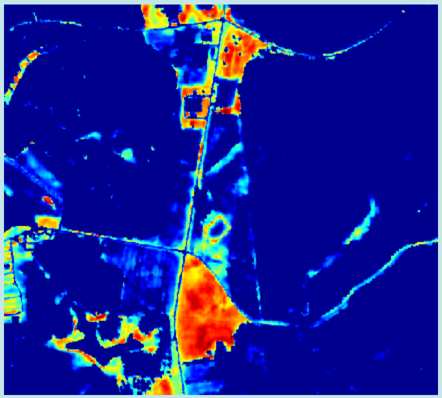
gravel





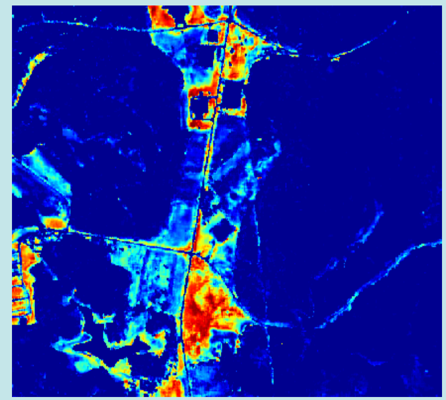
cNMF vs sacNMF

cNMF

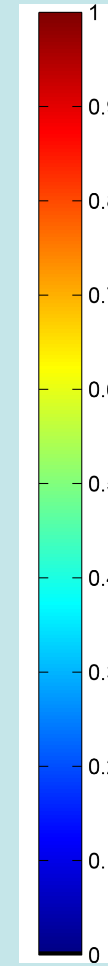


Grass Field

Proposed Approach



Grass Field



Final Comments

- cNMF + Spatial partitioning
  - Facilitates extraction of endmembers capturing local spectral features.
  - Masked on the global cNMF approach
- Experimental results
  - Extracted endmember classes and abundances have good agreement with published ground truth.
- Other combinations possible
  - Tried superpixel segmentation with interesting results

Final Remarks

- Thanks to the sponsors
  - NASA EPSCoR, UTEP,
    Univ of Puerto Rico at Mayaguez
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