# Mapping Of Urban Expansion Using Multi-Decadal Landsat And Nightlights Data Over North America

**Cristina Milesi**, California State University at Monterey Bay/NASA Ames Research Center

**Christopher Small**, Lamont Doherty Earth Observatory, Columbia University

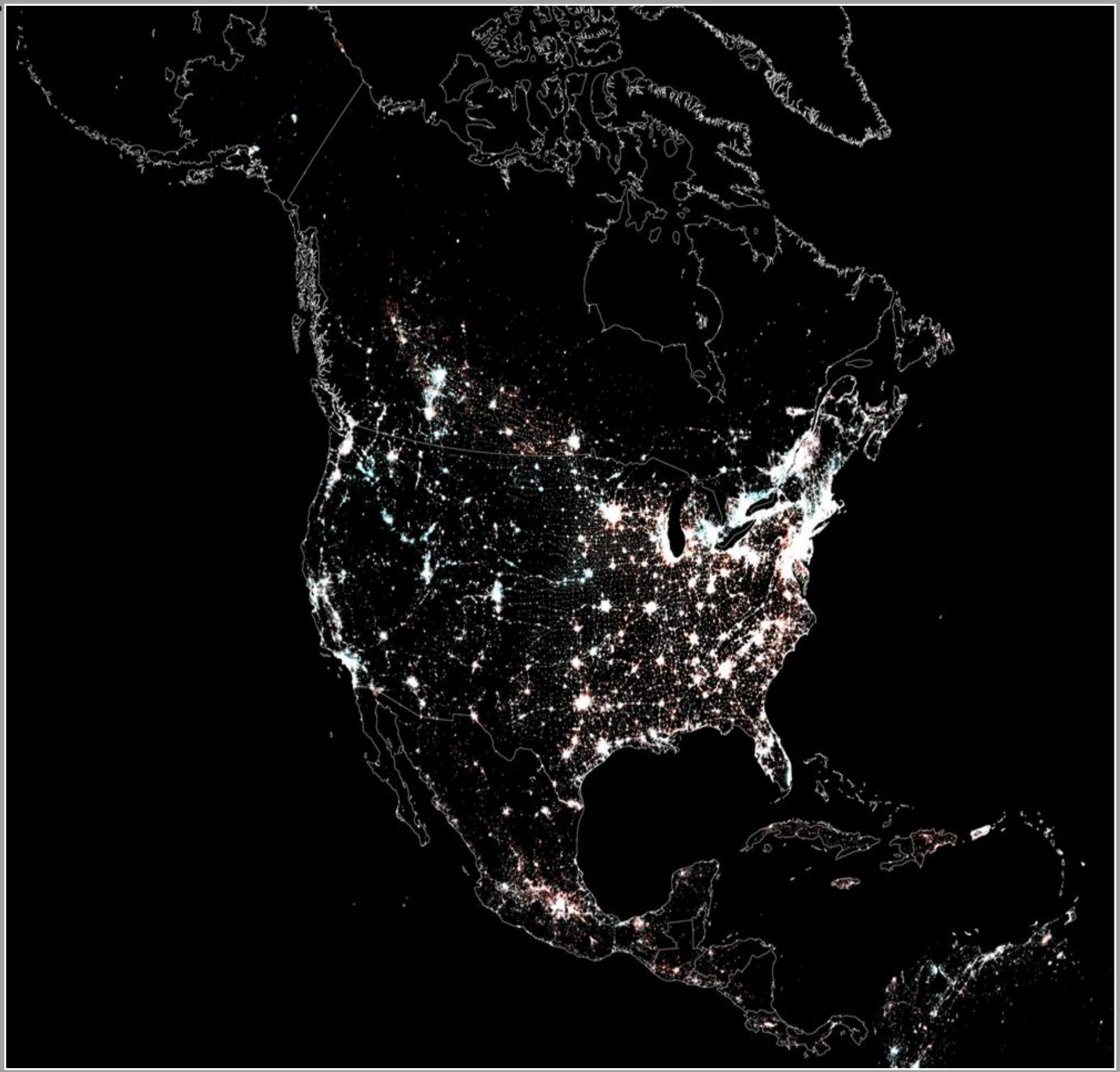
In collaboration with: **Christopher Elvidge**, NOAA

LCLUC Spring Science Team Meeting, Rockville MD, April 3, 2012

# Motivation

- The world population is increasingly becoming urban -- projected at 70% by 2050
- Urban land transformation is permanent
- Built environment alters surface fluxes of heat, water, and carbon with effects on climate, weather, water, carbon and energy cycles
- Globally, urbanization still poorly characterized, with little information on:
  - rates of expansion of built environment
  - horizontal expansion versus increase in density
  - effect of urbanization on biophysical properties (changes in impervious versus vegetation fractions)

**Goal:** To develop a scalable, physically-based methodology for characterization of urban expansion using Landsat observations from 1990 to present over North America, with the potential of adapting the methodology globally.



# Objectives

- Develop an urban land cover change detection approach that will be adaptable to, and informed by, the high spectral heterogeneity of urban areas across different geographic, environmental and socio-economic regions;

- Provide the tools for understanding the biophysical changes brought on by urbanization by distinguishing between the built-up and vegetation fractions components of urban areas, and the effects of these fractions on albedo;

- Identify hotspots of urban growth to understand where the most rapid land cover changes are taking place and what land covers are being replaced.

Landsat

Quickbird

# Linear Spectral Mixture Models

*The integrated radiance of a spectrally heterogeneous surface can be described as a linear combination of spectral endmember radiances.* *(7, 8, 1, 2)*

$$R(\lambda) = f_1E_1(\lambda) + f_2E_2(\lambda) + f_3E_3(\lambda)$$

*Spectral endmembers can be inferred from the apexes of a spectral mixing space defined by the Principal Components of a multispectral image (5, 8, 3, 4).*

*If the number of spectral endmembers (E) is less than the number of spectral bands ($\lambda_1 \ldots \lambda_N$), the model is **overdetermined** and the endmember fractions (f) for each pixel can be estimated by inverting a linear mixture model to minimize the misfit ε between model & data.* *(1, 8, 6, 3, 4)*

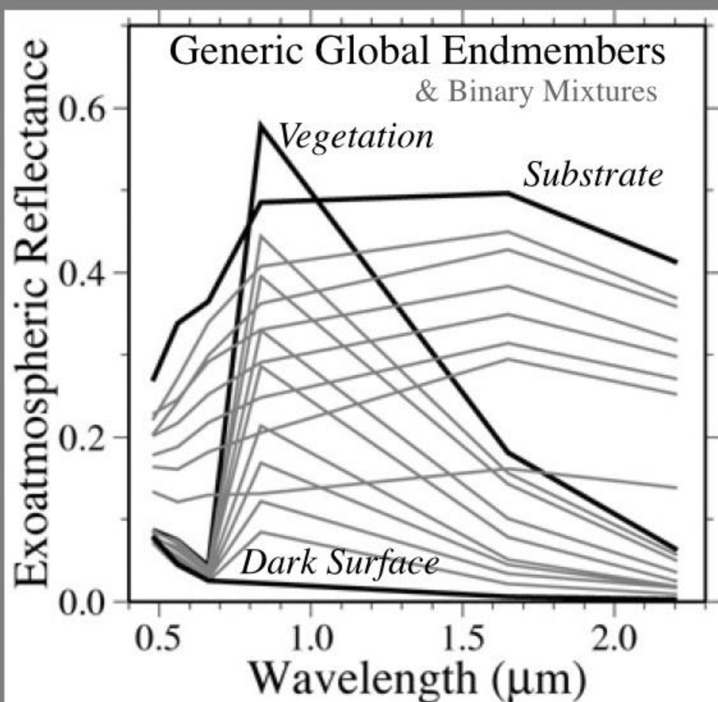
$$r = f\,E + \varepsilon \qquad\qquad f = (E^TE)^{-1}\,E^Tr$$

$$\begin{matrix} f_1\mathbf{E}_{1\lambda1} & & f_2\mathbf{E}_{2\lambda1} & & f_3\mathbf{E}_{3\lambda1} & & R_{\lambda1} \\ f_1\mathbf{E}_{1\lambda2} & & f_2\mathbf{E}_{2\lambda2} & & f_3\mathbf{E}_{3\lambda2} & & R_{\lambda2} \\ f_1\mathbf{E}_{1\lambda3} & + & f_2\mathbf{E}_{2\lambda3} & + & f_3\mathbf{E}_{3\lambda3} & = & R_{\lambda1} \\ f_1\mathbf{E}_{1\lambda4} & & f_2\mathbf{E}_{2\lambda4} & & f_3\mathbf{E}_{3\lambda4} & & R_{\lambda4} \\ f_1\mathbf{E}_{1\lambda5} & & f_2\mathbf{E}_{2\lambda5} & & f_3\mathbf{E}_{3\lambda5} & & R_{\lambda5} \\ f_1\mathbf{E}_{1\lambda6} & & f_2\mathbf{E}_{2\lambda6} & & f_3\mathbf{E}_{3\lambda6} & & R_{\lambda6} \end{matrix}$$

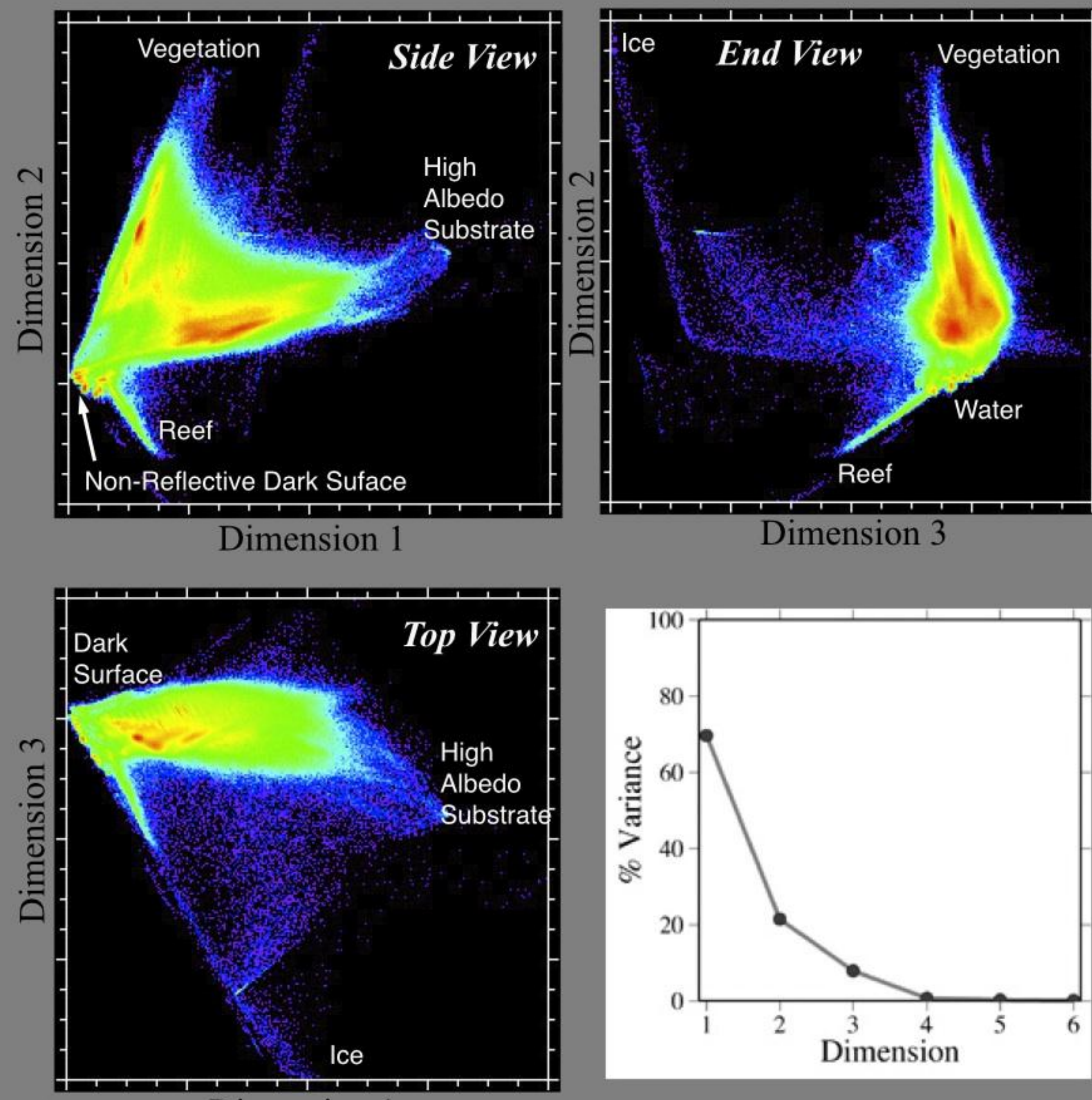

1) Adams et al, 1985
2) Adams & Smith, 1986
3) Boardman, 1993
4) Boardman, 1994
5) Johnson et al, 1985
6) Settle & Drake, 1993
7) Singer & McCord, 1979
8) Smith et al, 1985

# The Landsat ETM+ Global Mixing Space

- *30 Environments*
- *27,000 square kilometers*
- *30,000,000 spectra*
- *3 dimensions contain >98% spectral variance.*




3D Visible/IR mixing space




*Small (2004)*

# Urban Spectral Diversity and Heterogeneity

The composite urban mixing space strongly resembles the composite global mixing space:

Same endmembers & topology

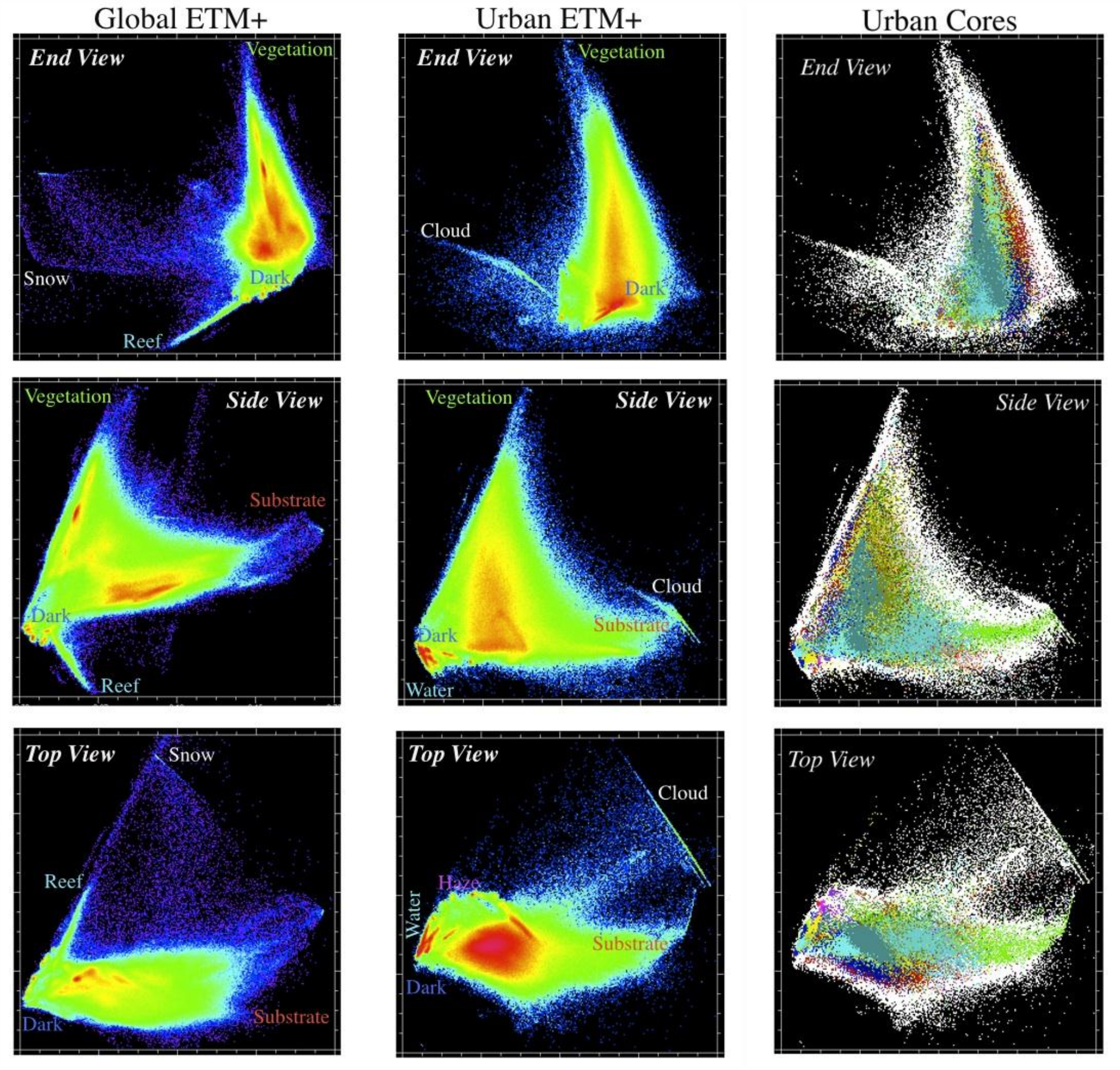
Strongly linear mixing of dark surface (shadow) with vegetation and high albedo substrates

Heterogeneous internal structure

10x10 km urban cores almost as diverse as full mixing space - But different cities occupy different regions w/in space.

Most spectrally pure pixels at the periphery of the space are associated with urban periphery and surrouding land covers.

*Small (2008)*

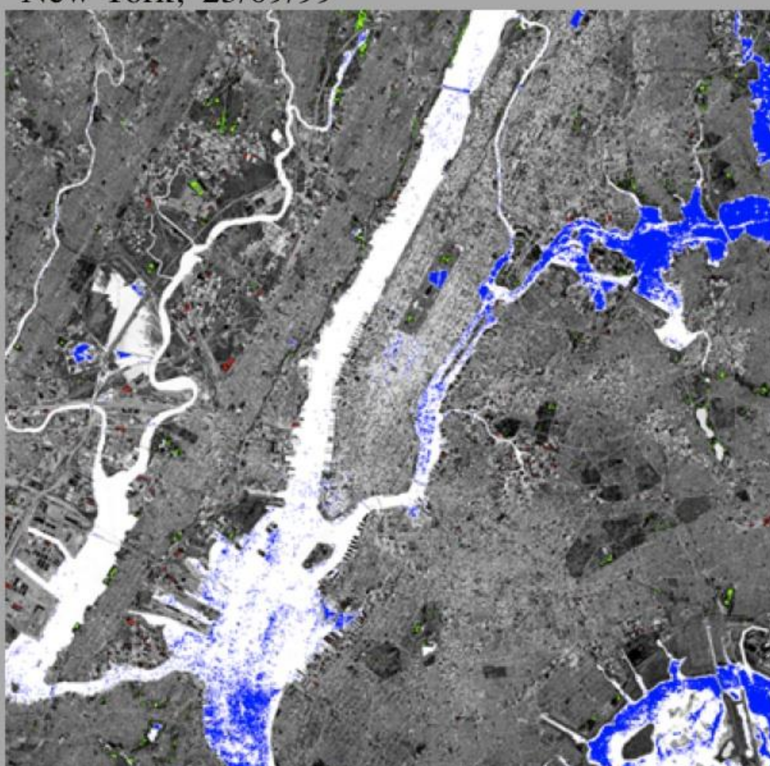


# Spectral Mixture Analysis

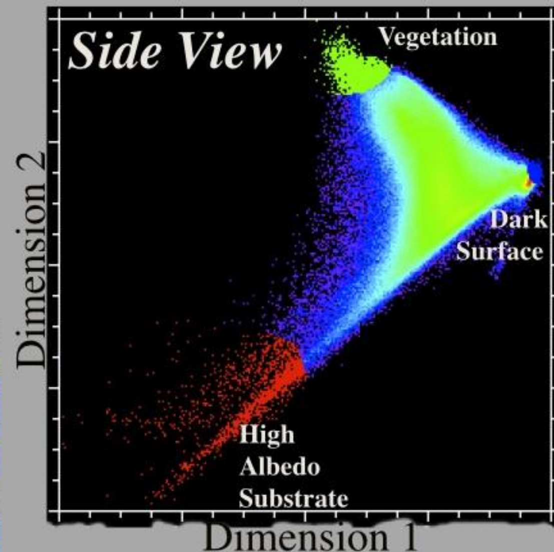
- Spectral mixing space topology is defined by endmember specra at apexes and mixed pixels interior.
- Mixed spectra can be described as linear mixtures of endmembers.

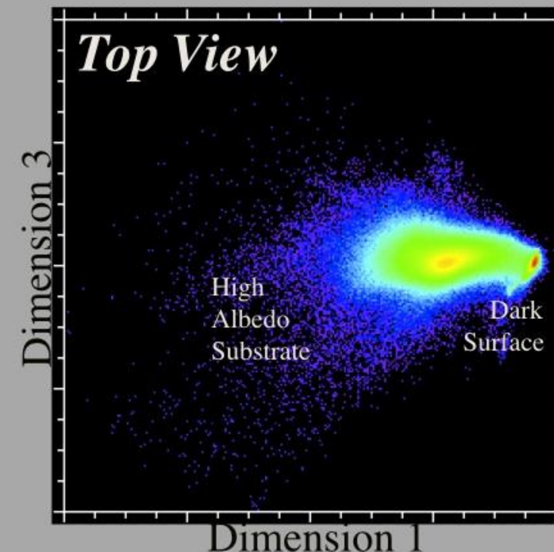
- Low order Principal Components contain most of the variance (information) in high dimensional optical imagery. *6D to 3D mixing space*

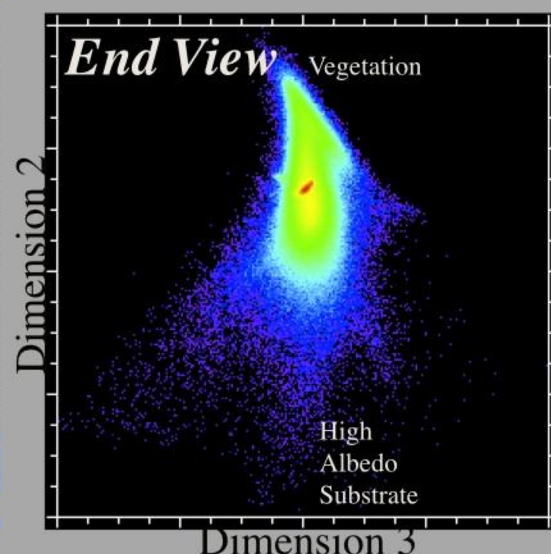
New York, 23/09/99



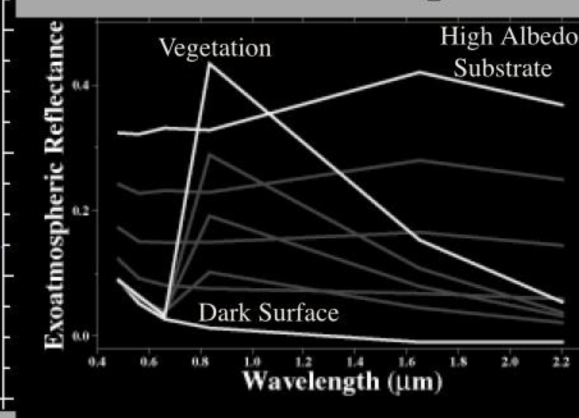
*Small (2000, 2001)*




## Endmember Spectra



# Validation of Vegetation Fractions

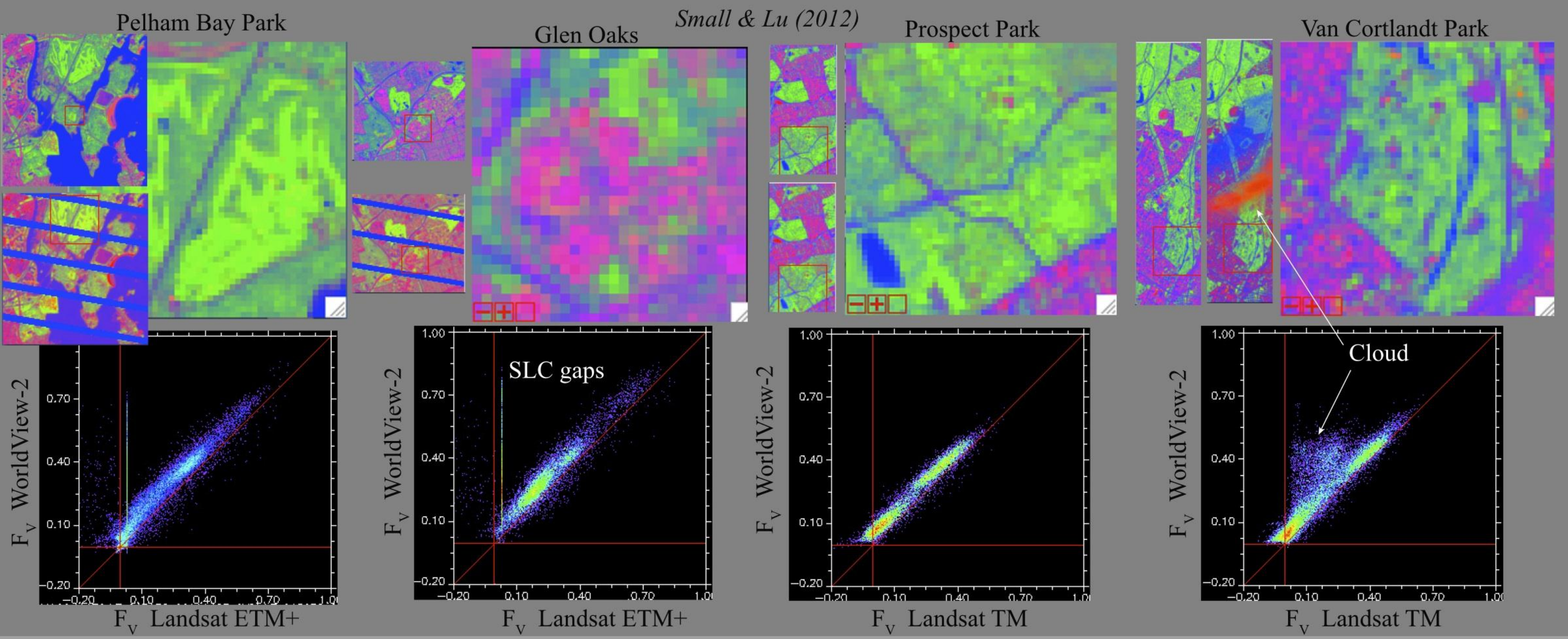
## WorldView-2 vs Landsat TM & ETM+ Vegetation Fractions

Orthorectification of both WorldView2 & Landsat reduces terrain displacement and improves spatial coregistration.

Use of global vegetation EM for Landsat more closely approximates spectrally pure illuminated foliage.

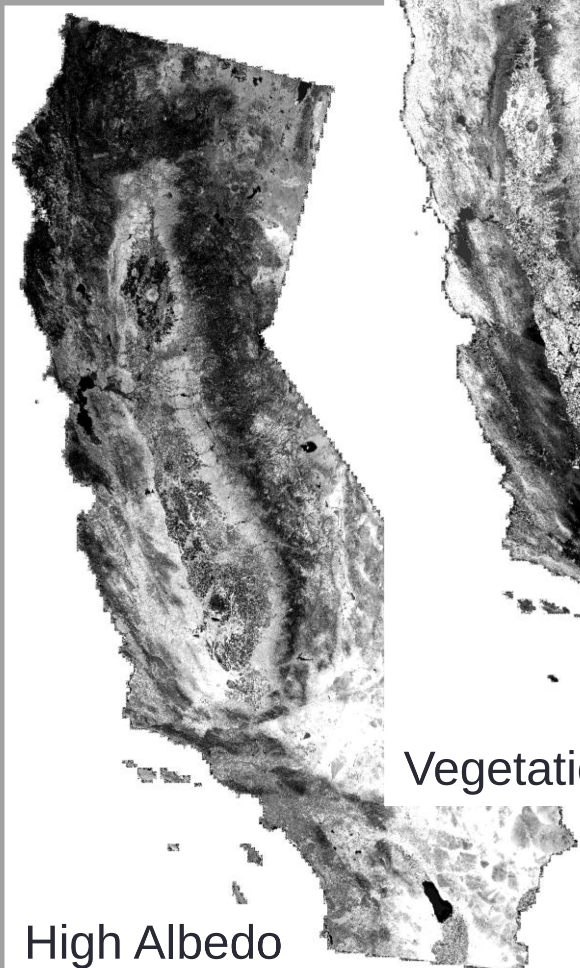
Improved radiometric calibration of TM and ETM+ sensors improves consistency with global endmembers.

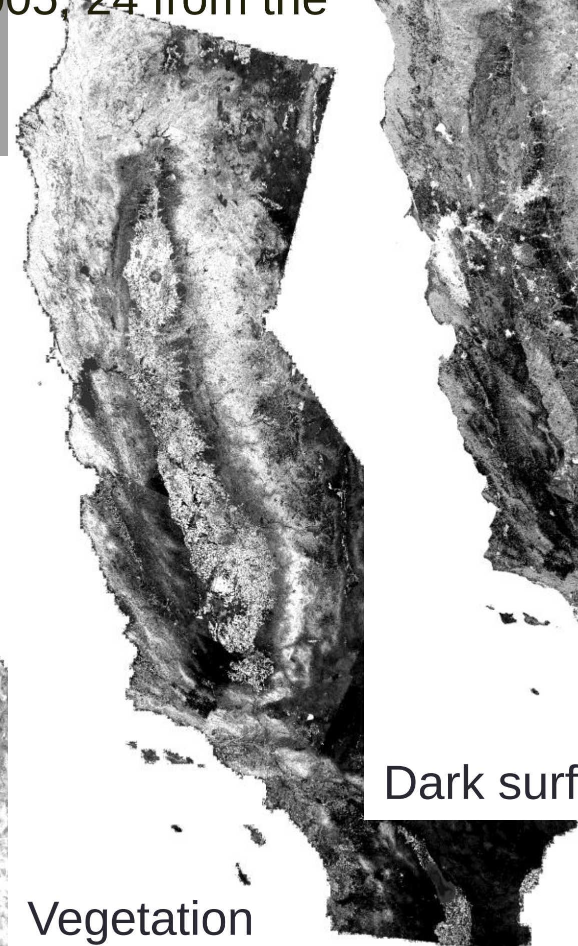
Landsat fractions consistently ~4% low but with only ~2% misfit at all fractions. Simple bias correction.

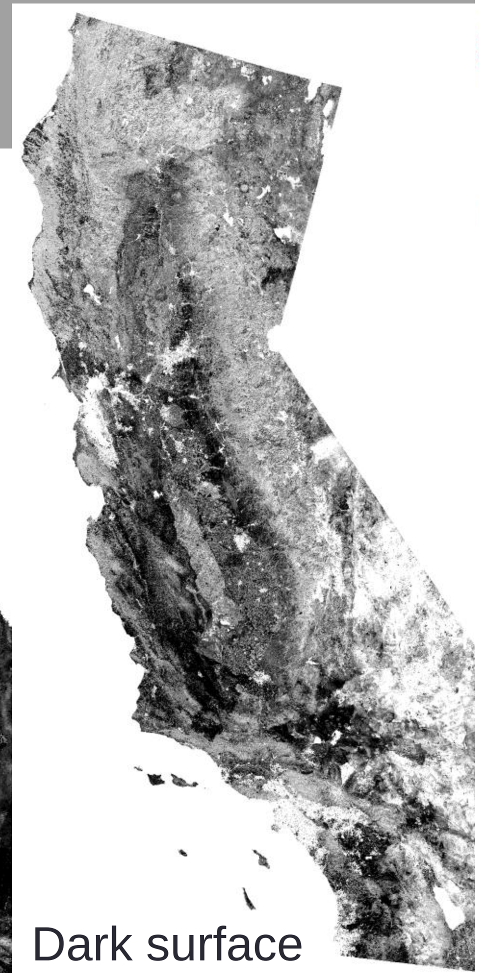


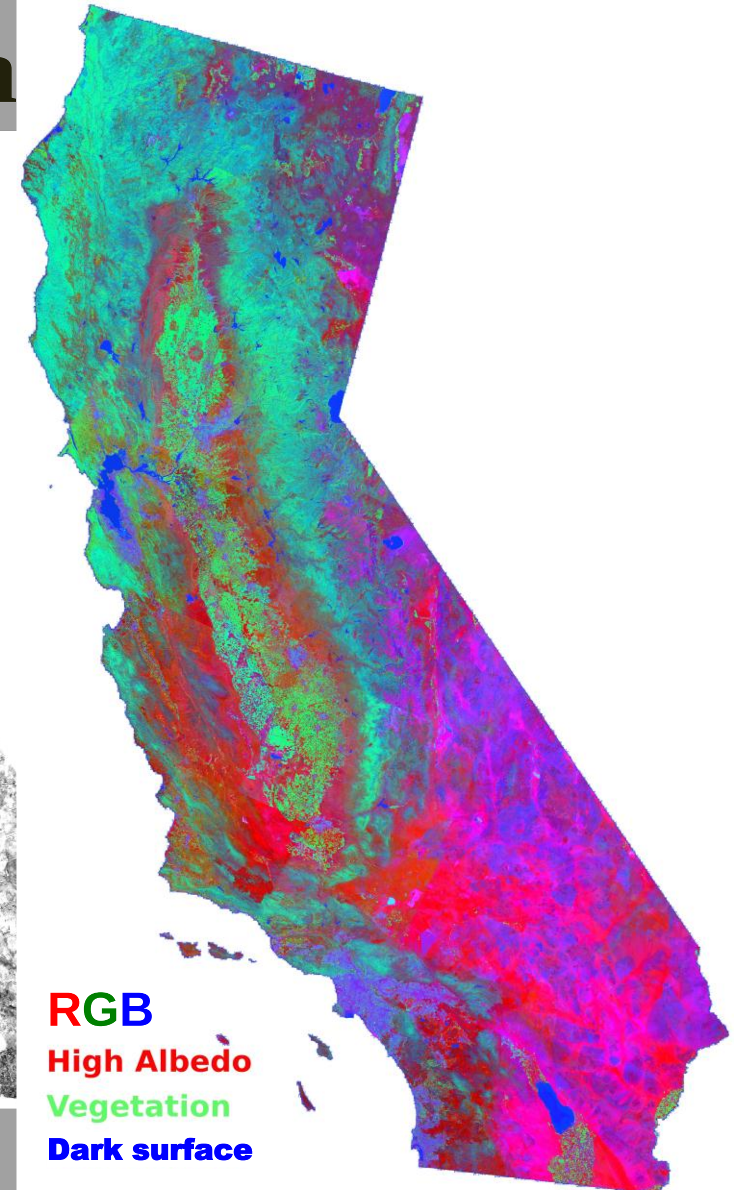
# Applying SMA to California

43 TM and ETM+ scenes from summer 2004-2006, 19 from GLS 2005, 24 from the archive

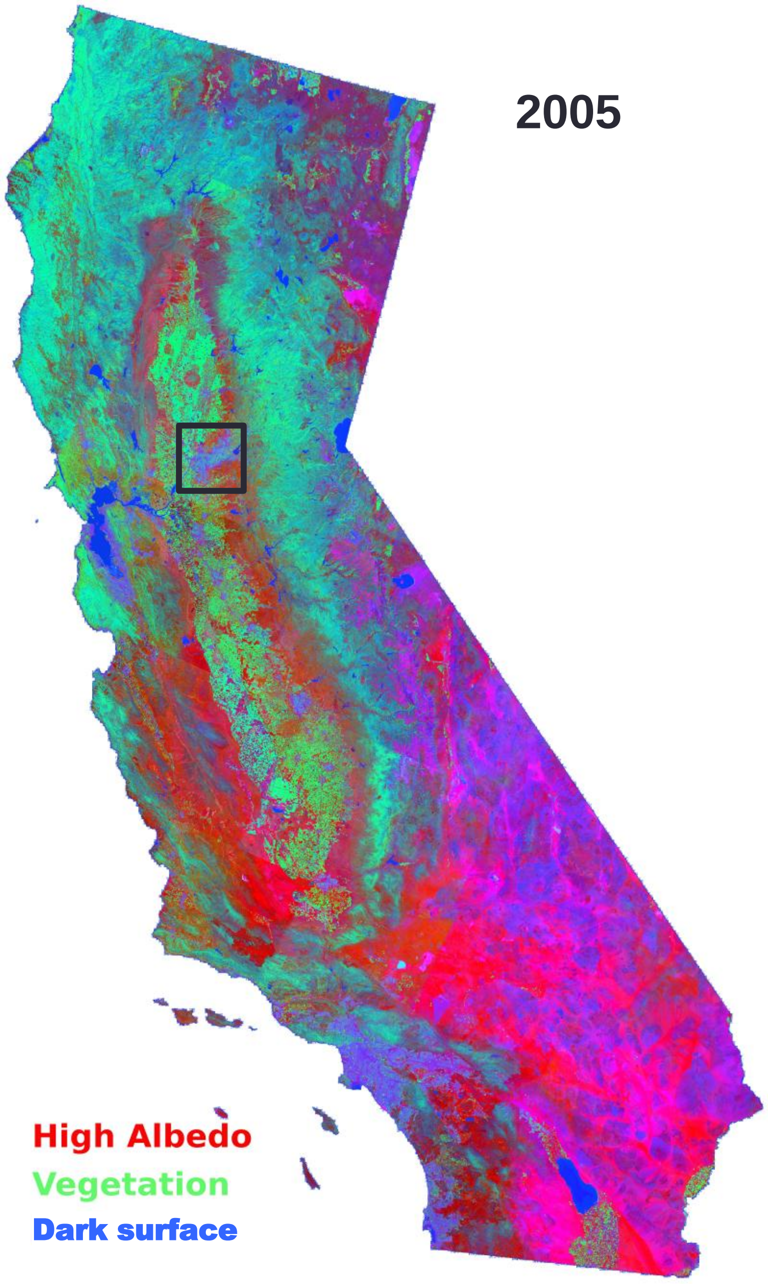


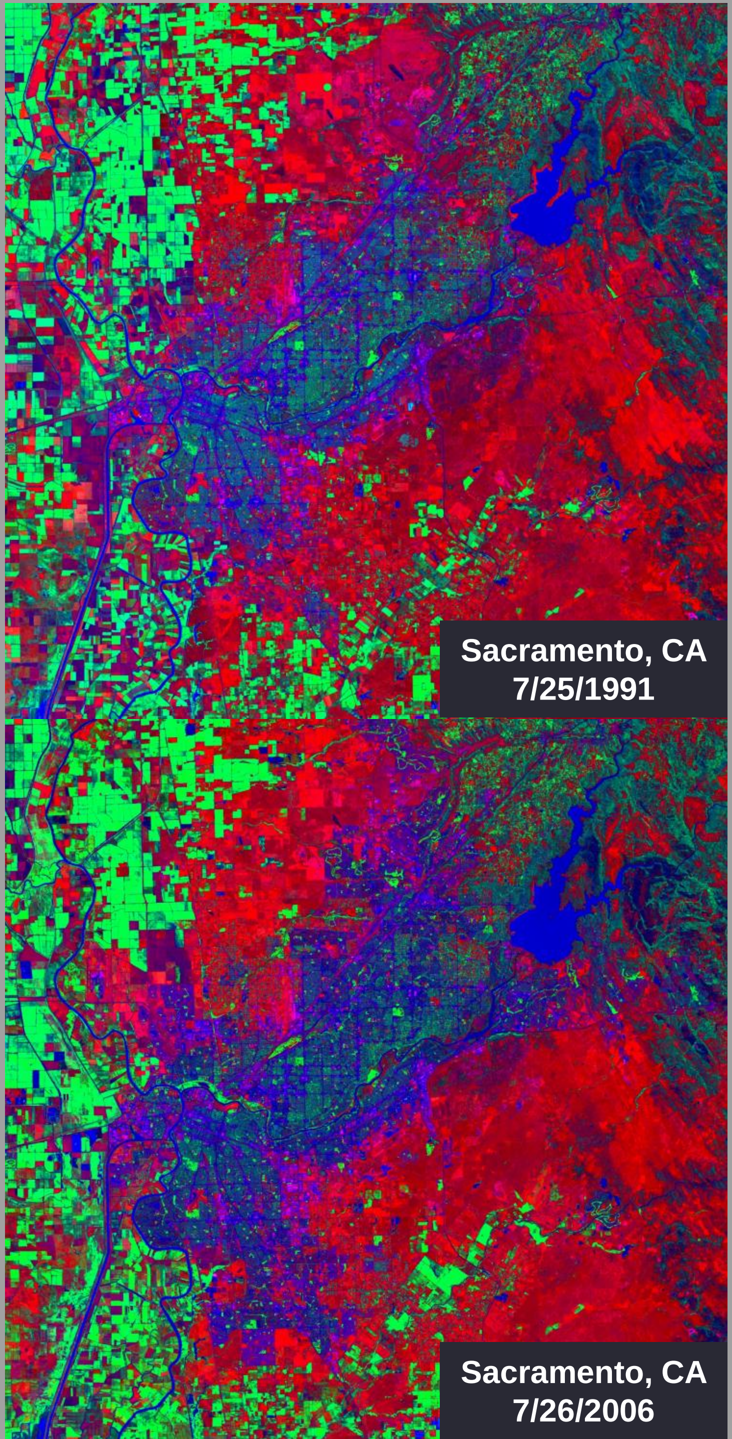



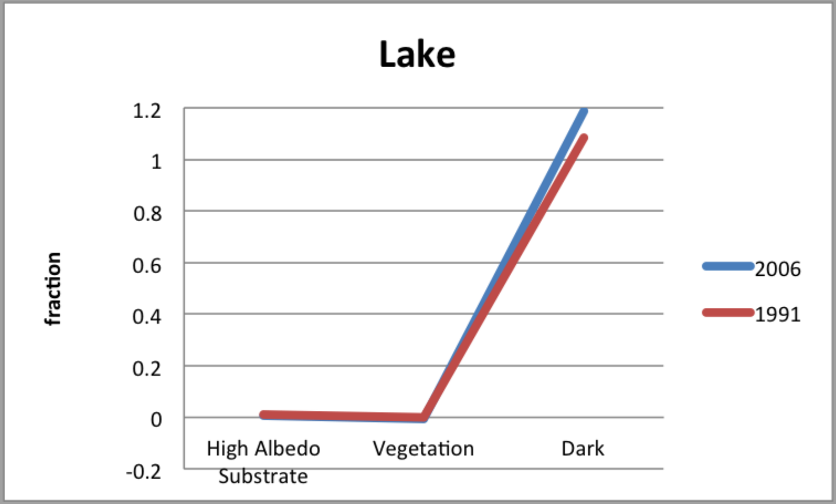



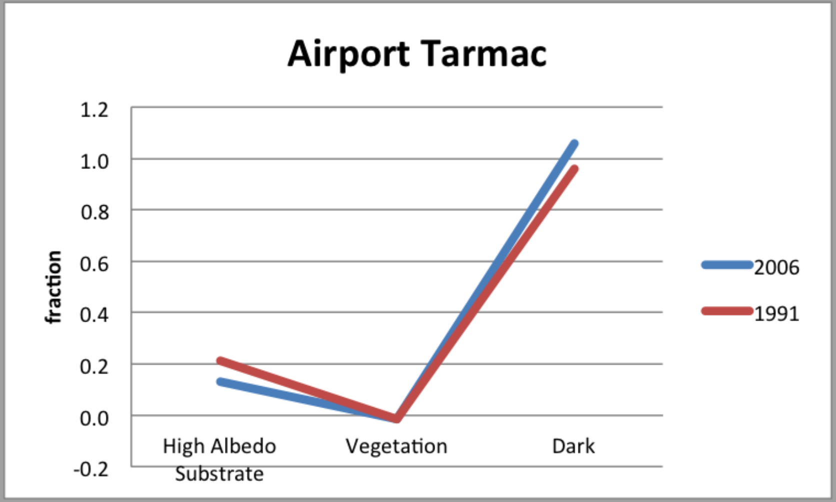
# SMA to map urban change

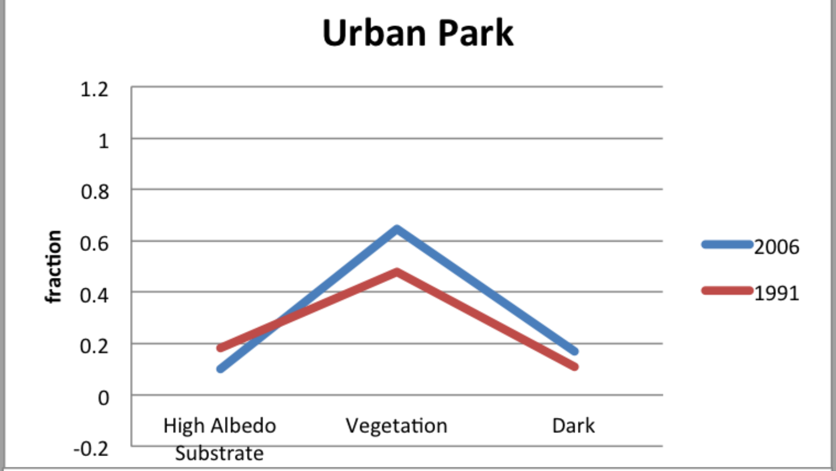


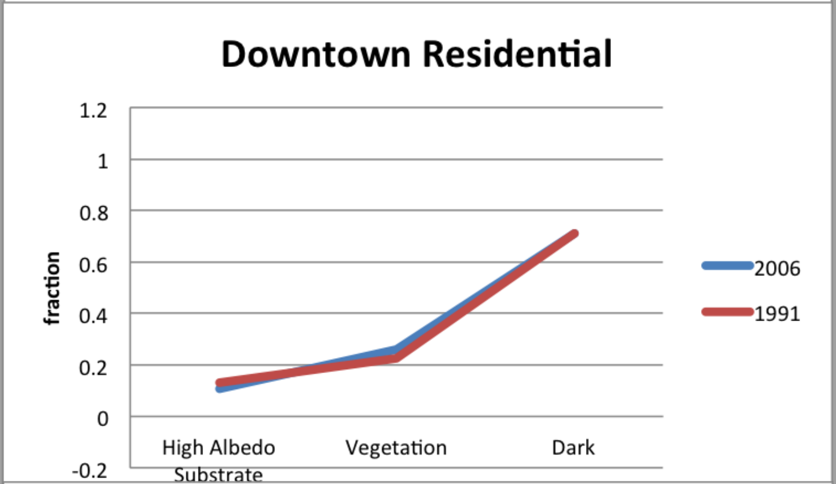



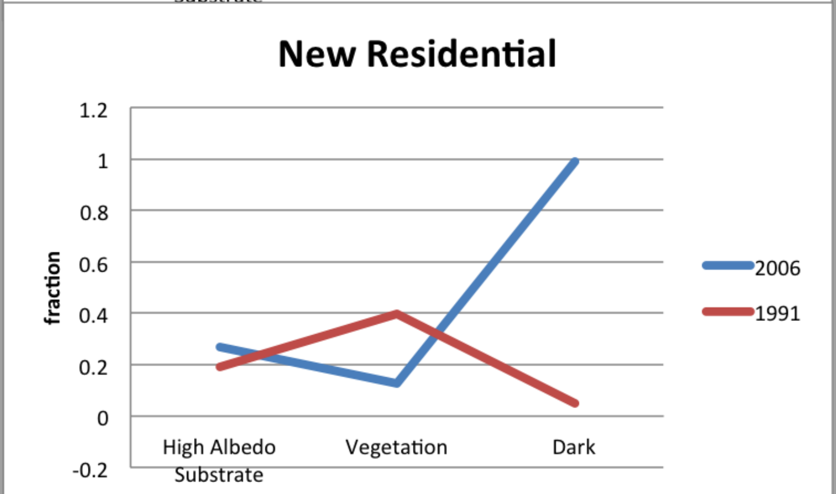
# Fractional changes by land cover



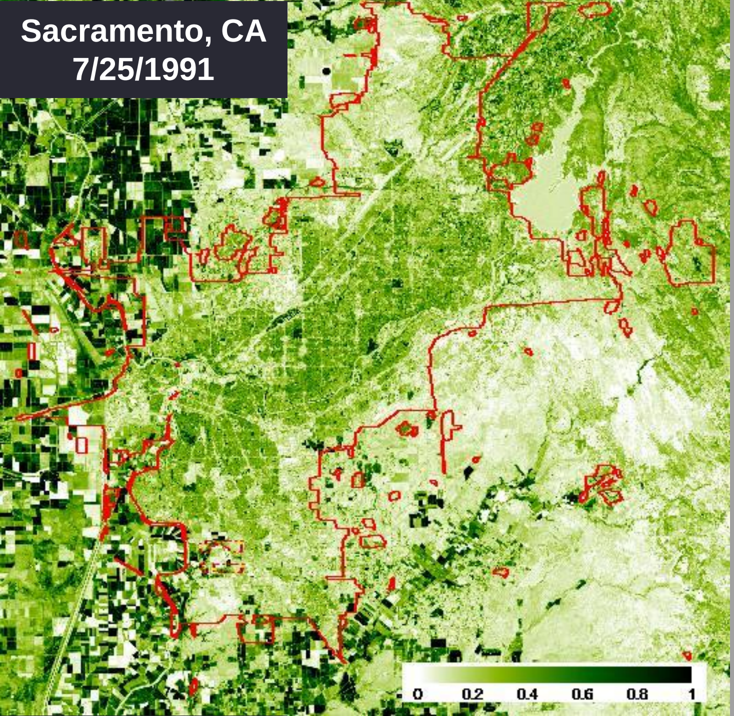



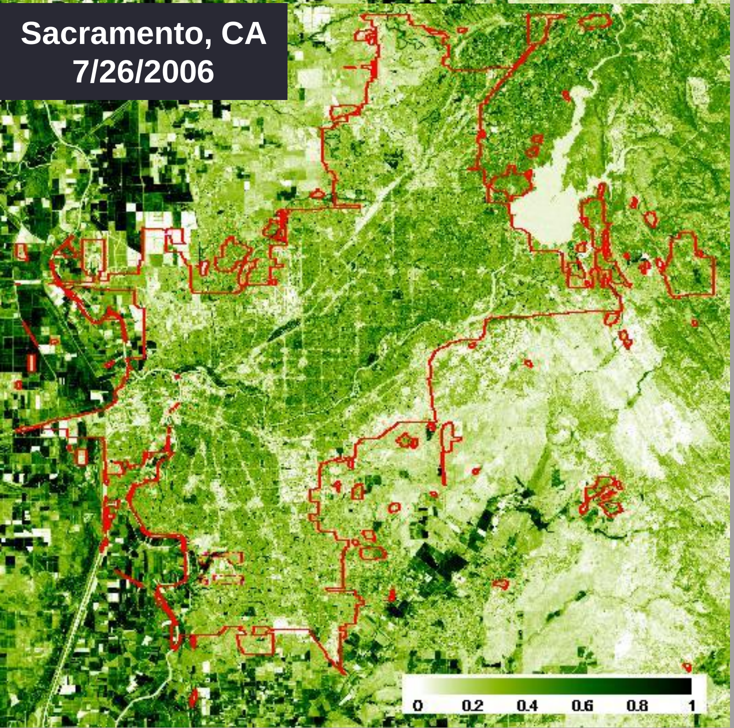



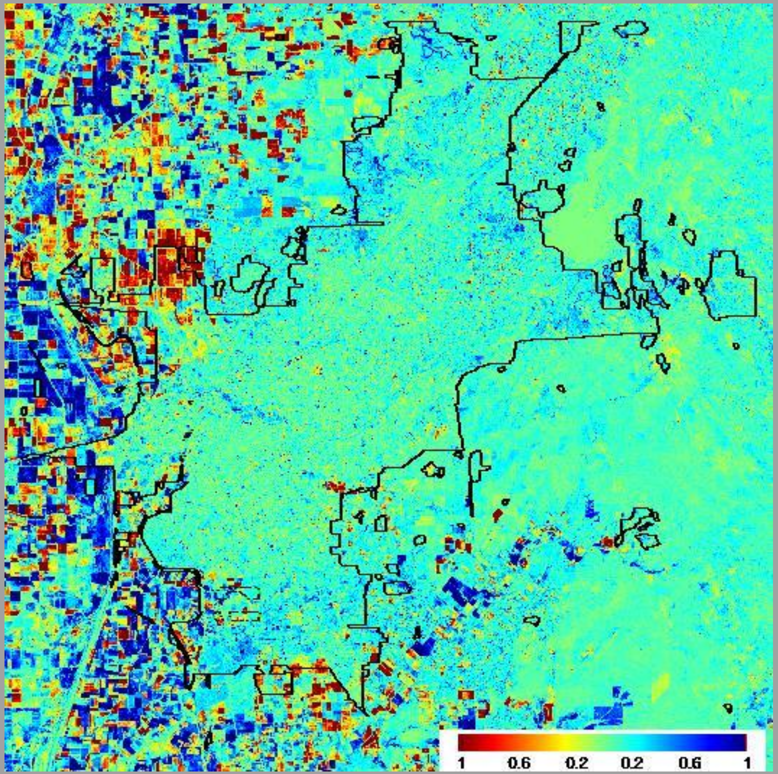



# SMA Vegetation change

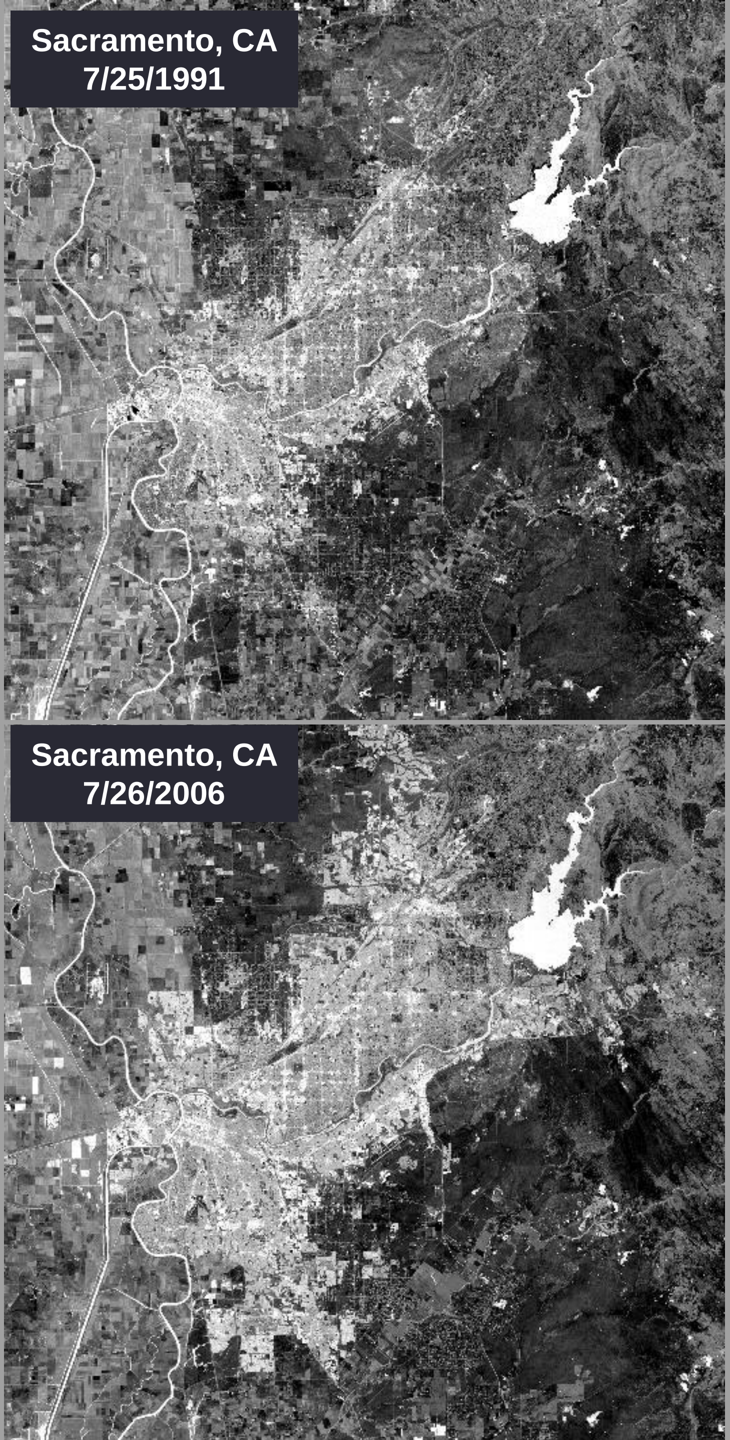



## 1991 to 2006



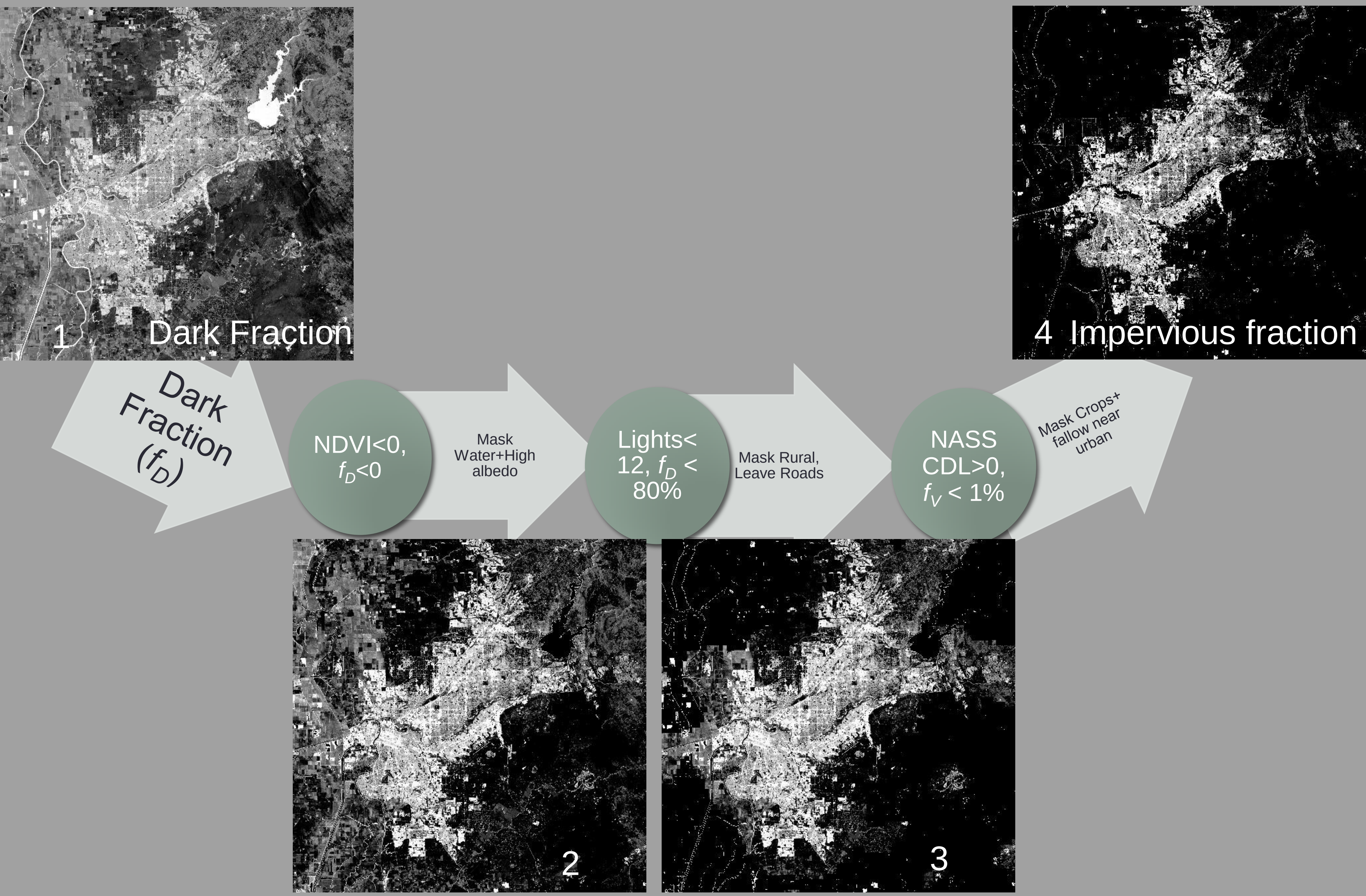

- Crop rotations dominate vegetation changes
- Need to control for climatic effects on phenology




# SMA Built-up change

- The metropolitan area is dominated by dark reflective surfaces
- Need to separate dark impervious surfaces due to built construction from other surfaces

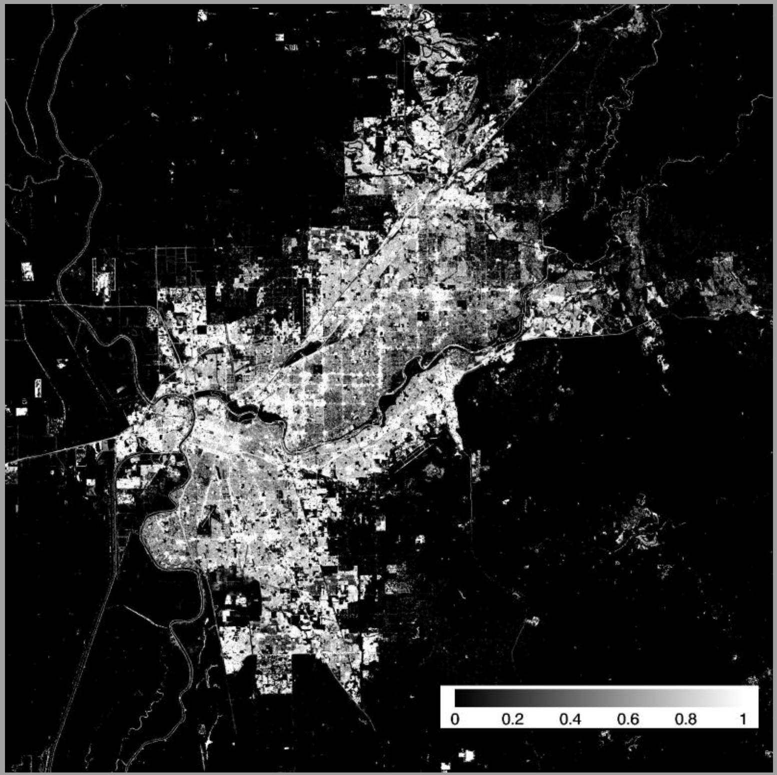
# From Dark fraction to Impervious fraction



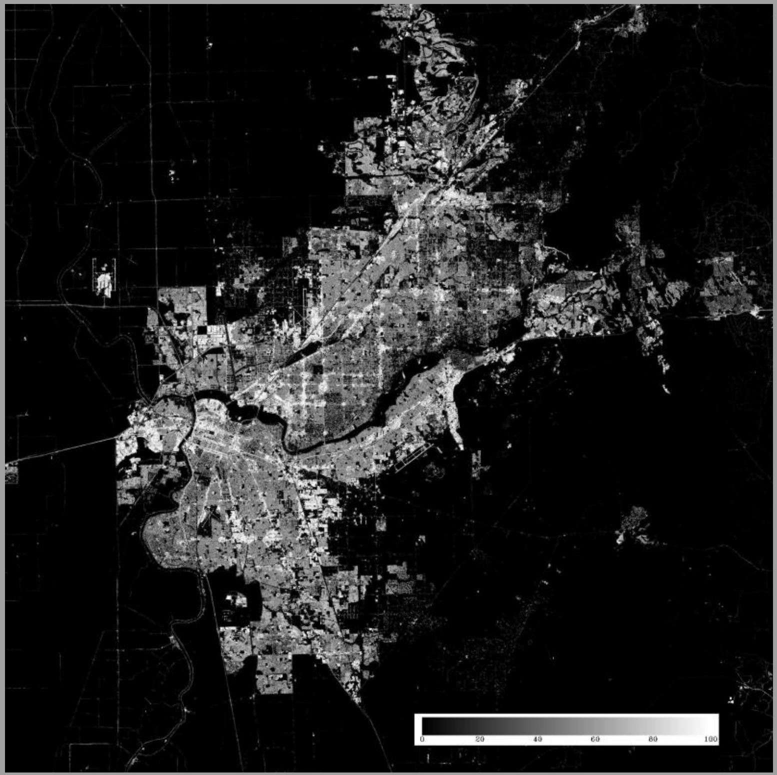
# SMA vs NLCD 2006 Impervious fraction

SMA 2006 impervious displays very strong similarities with NLCD 2006 ISA, but overall higher values.

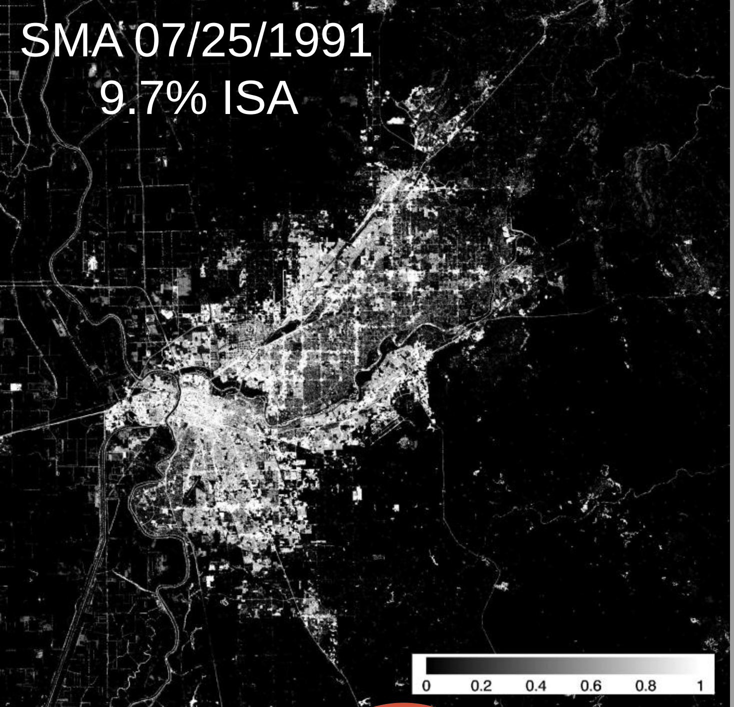
SMA 2006
14.2% of the scene is impervious

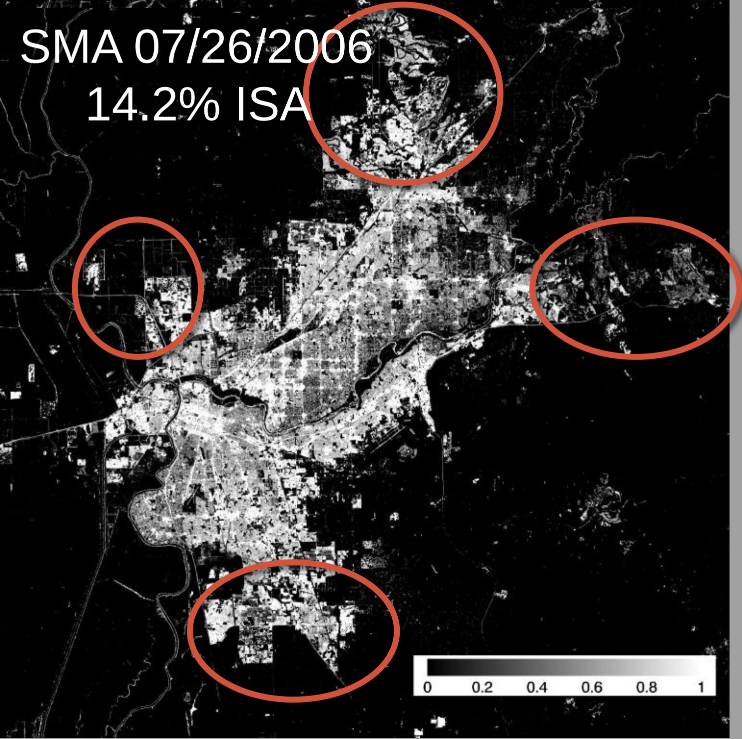



NLCD 2006
10.2% of the scene is impervious

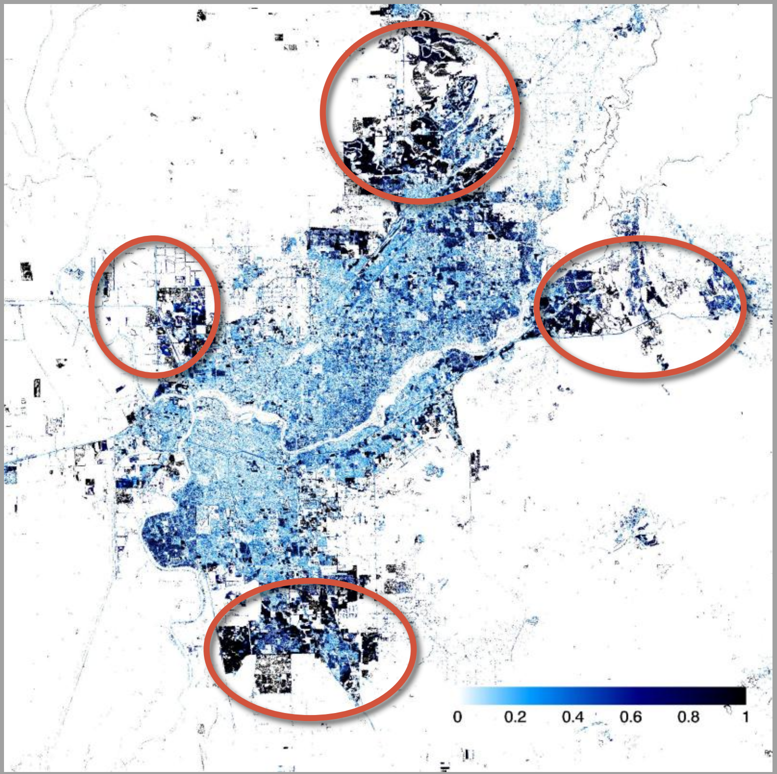


# SMA Impervious change




## 1991 to 2006



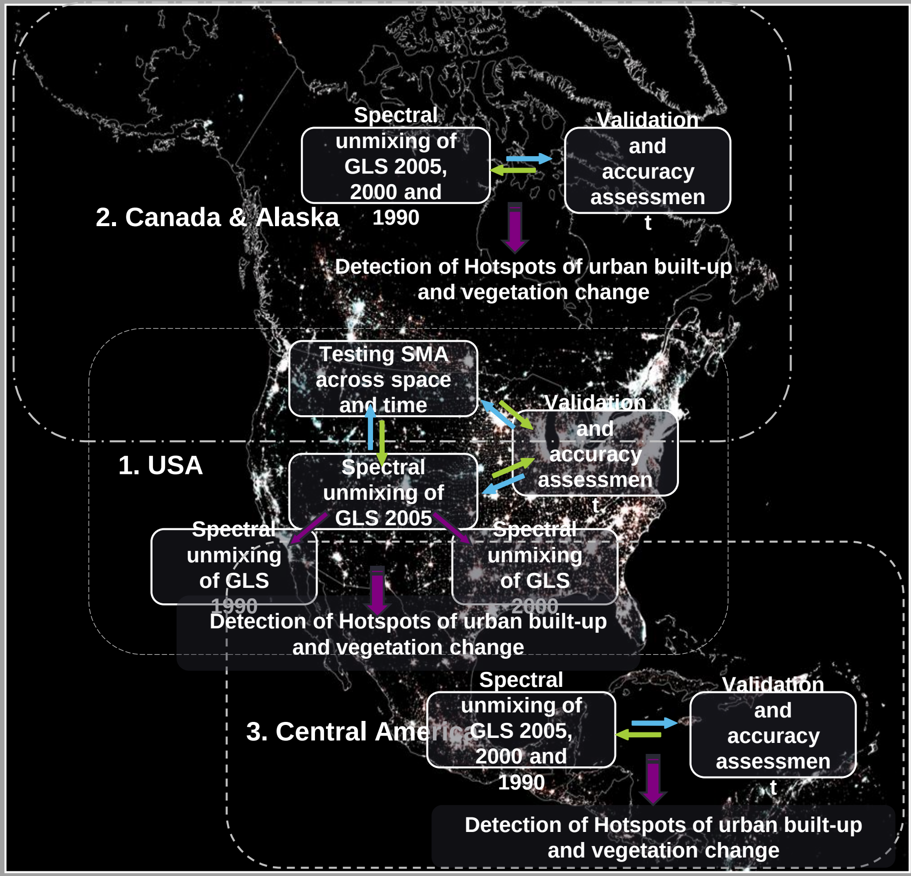

- Largest growth at the periphery
- Some intensification of previously urbanized pixels

# Conclusions

- SMA offers a robust method to map urbanization translating spectral radiance into physical measure of the areal fractions of landcovers, and requires minimum training and assumptions
- The dark fraction strongly relates to impervious surfaces
- Biophysical changes of urbanization through the relative fractions of impervious, vegetation fractions, albedo
- Preliminary vicarious validation of vegetation fractions from Landsat with WV-2 for NYC shows accuracy of 96%

# Next Steps

- Refine the selection of endmembers for atmospherically corrected global Landsat mixing space
- Vicariously validate impervious fractions with multispectral high resolution commercial imageries from WARP database in collaboration with de Colstoun
- Extend the multi-temporal analysis to 1991, 2000, 2010 to all of US, Canada and Mexico




# Thank you!