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

California State University Monterey Bay

NASA

Lamont-Doherty Earth Observatory
Columbia University | Earth Institute

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Motivation

- The world population is increasingly becoming urban
- Urban land transformation is permanent
- Urbanization still poorly characterized at regional to national scale:
  - rates of expansion of built environment
  - horizontal expansion versus increase in density
  - effect of urbanization on biophysical properties (changes in impervious versus vegetation fractions)

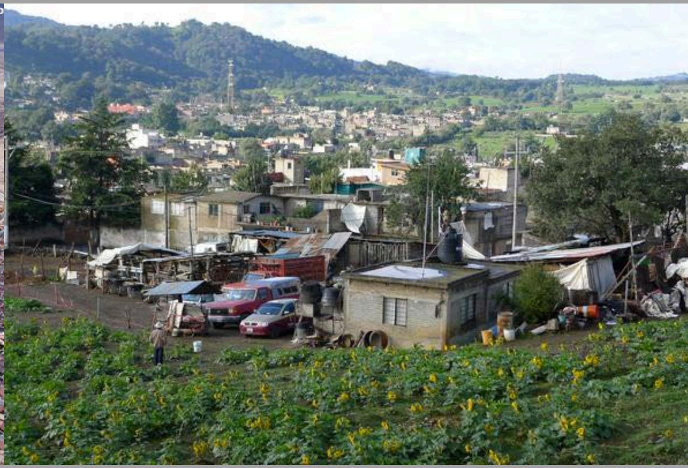



Challenges

- Modification of land cover takes many forms

- Many definitions of urban, application dependent

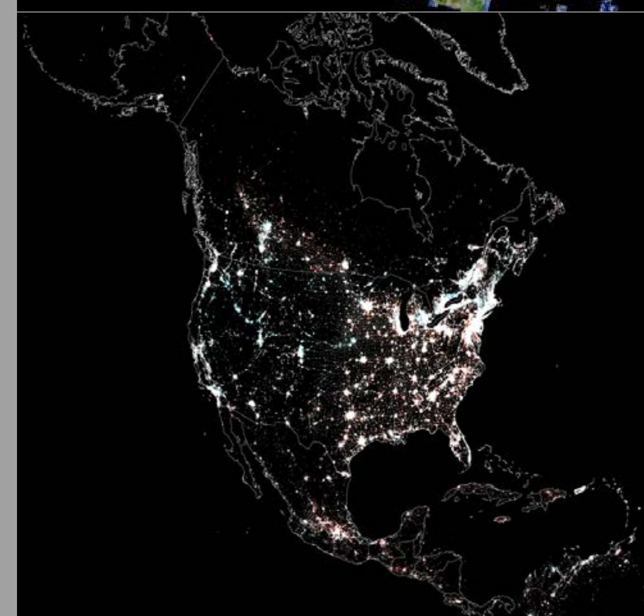
- Modification of land cover does not necessarily change the physical properties – natural materials are often used



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

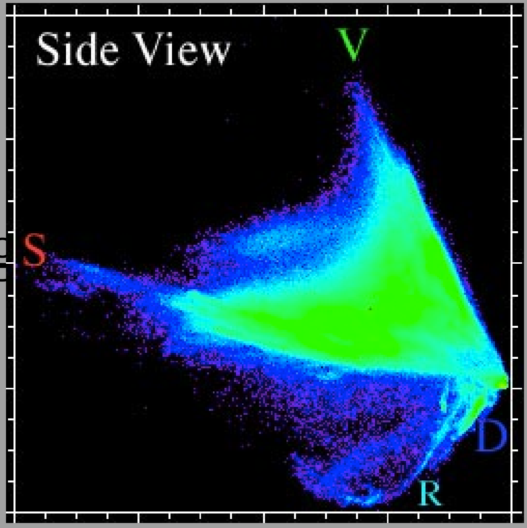
- Multi-Sensor
  - Landsat reflectance (30m)
  - DMSP-OLS and VIIRS-DNB night lights (~1km)

- Multi-Temporal
  - Characterize the evolution of urbanized landscapes identifying changes in stable physical properties derived from unmixing Landsat time stacks



The Standardized Linear Spectral Mixture Model

- Inverting a ***standardized*** linear mixture model converts the Landsat reflectance to subpixel fractions estimates of **Substrate** (**S**), **Vegetation** (**V**) and **Dark** (**D**) materials and shadows.

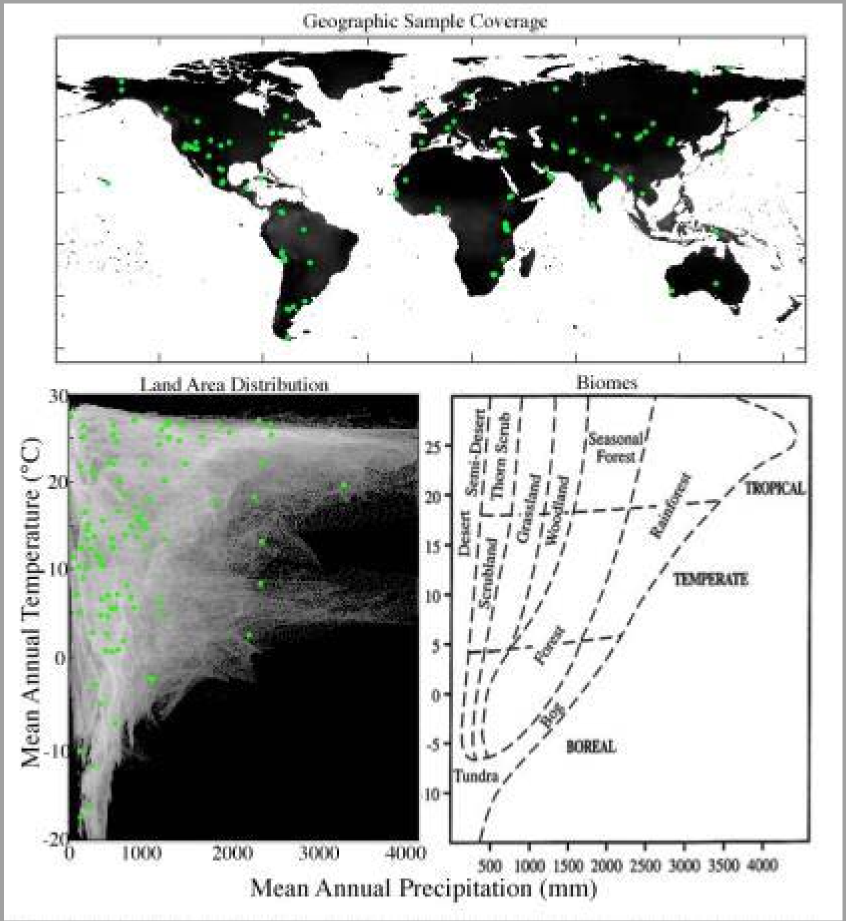


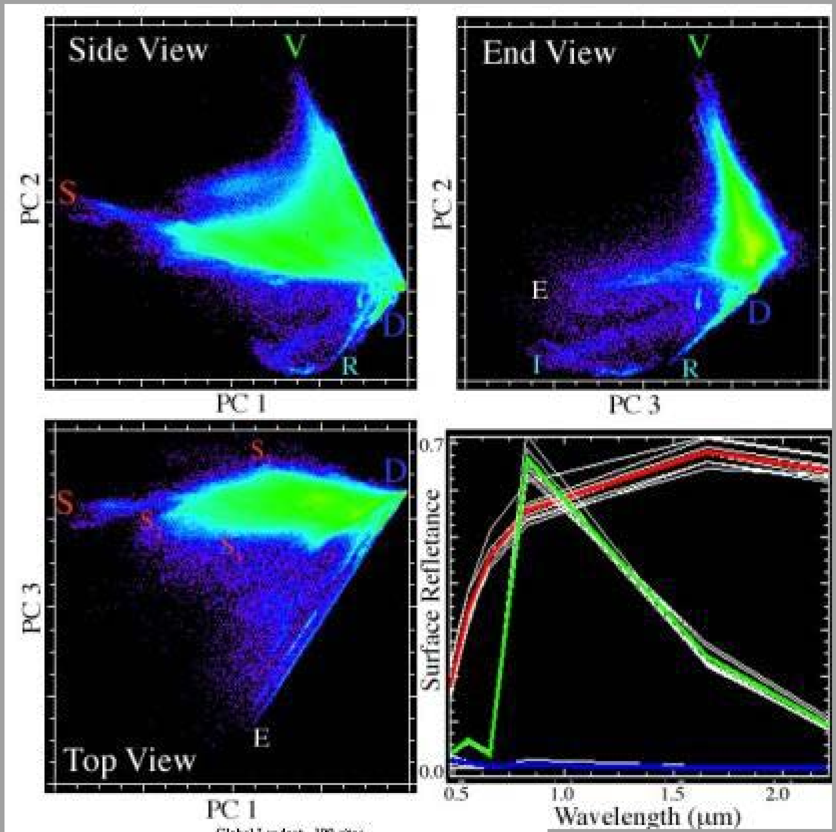
- Built areas generally contain relatively high fractions of impervious **Substrate** and inter-building **Dark** shadow with small but varying amounts of **Vegetation**.

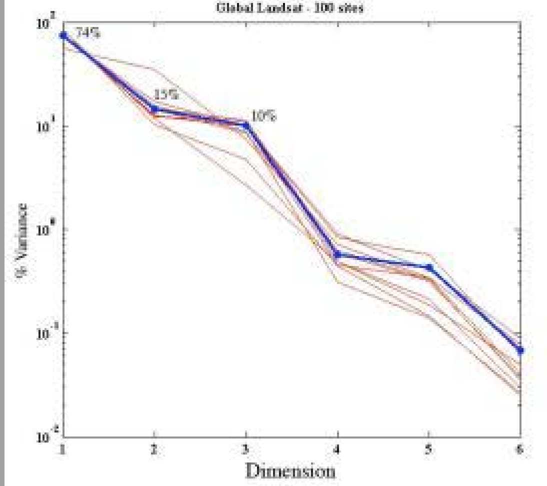
- Dark fractions can be redistributed to substrate and vegetation to reduce the mixing space to 2 fractions.

The Landsat ETM+ Global Mixing Space

- 100 Environments
- 100,000 spectra
- 3 dimensions contain > 98% of the variance







Small and Milesi, 2013 RSE

Urban Spectral Diversity and Heterogeneity

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

Same endmembers & topology

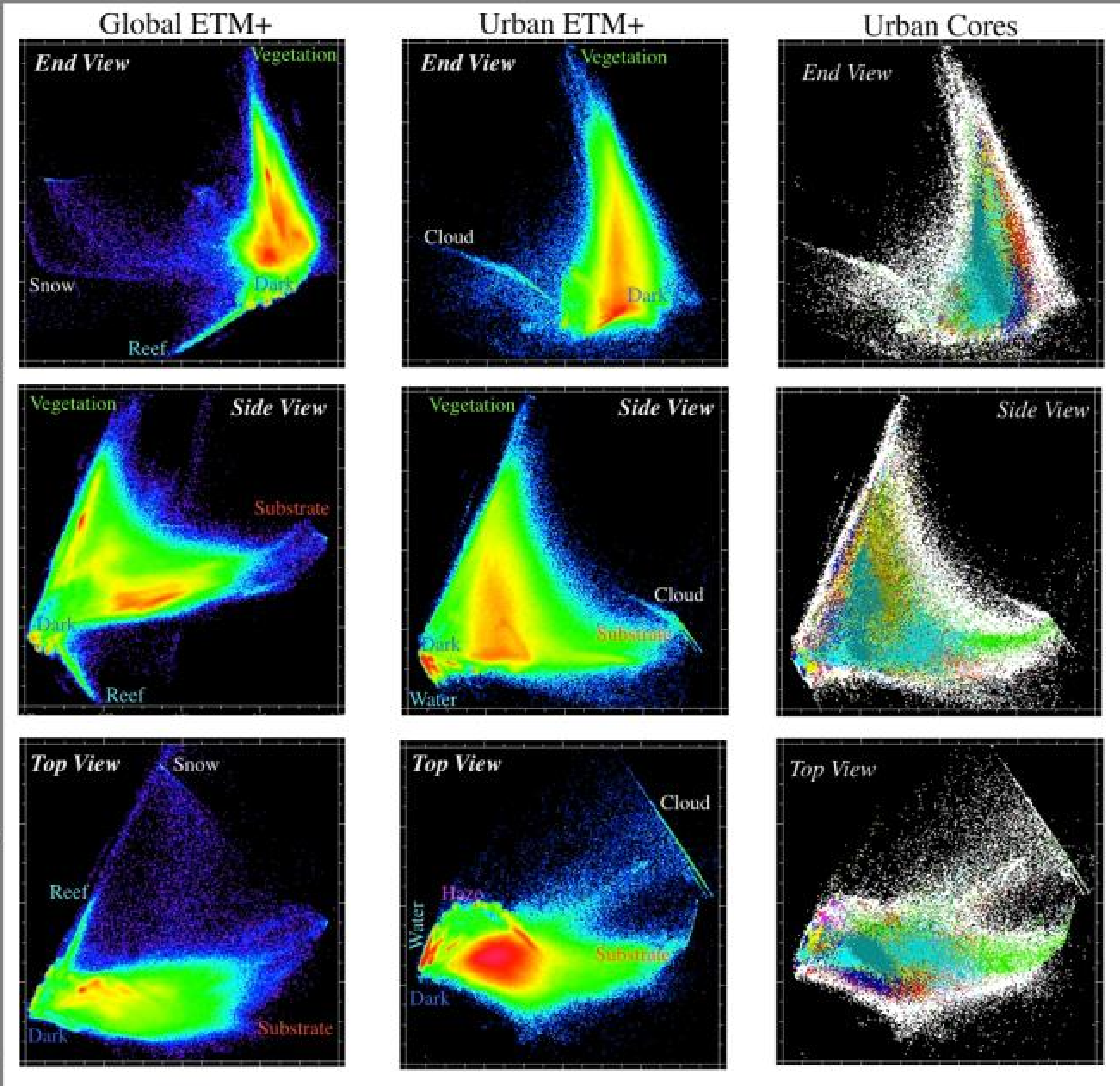
Strongly linear mixing of dark surface (shadow) with vegetation and high albedo substrates

Heterogeneous internal structure

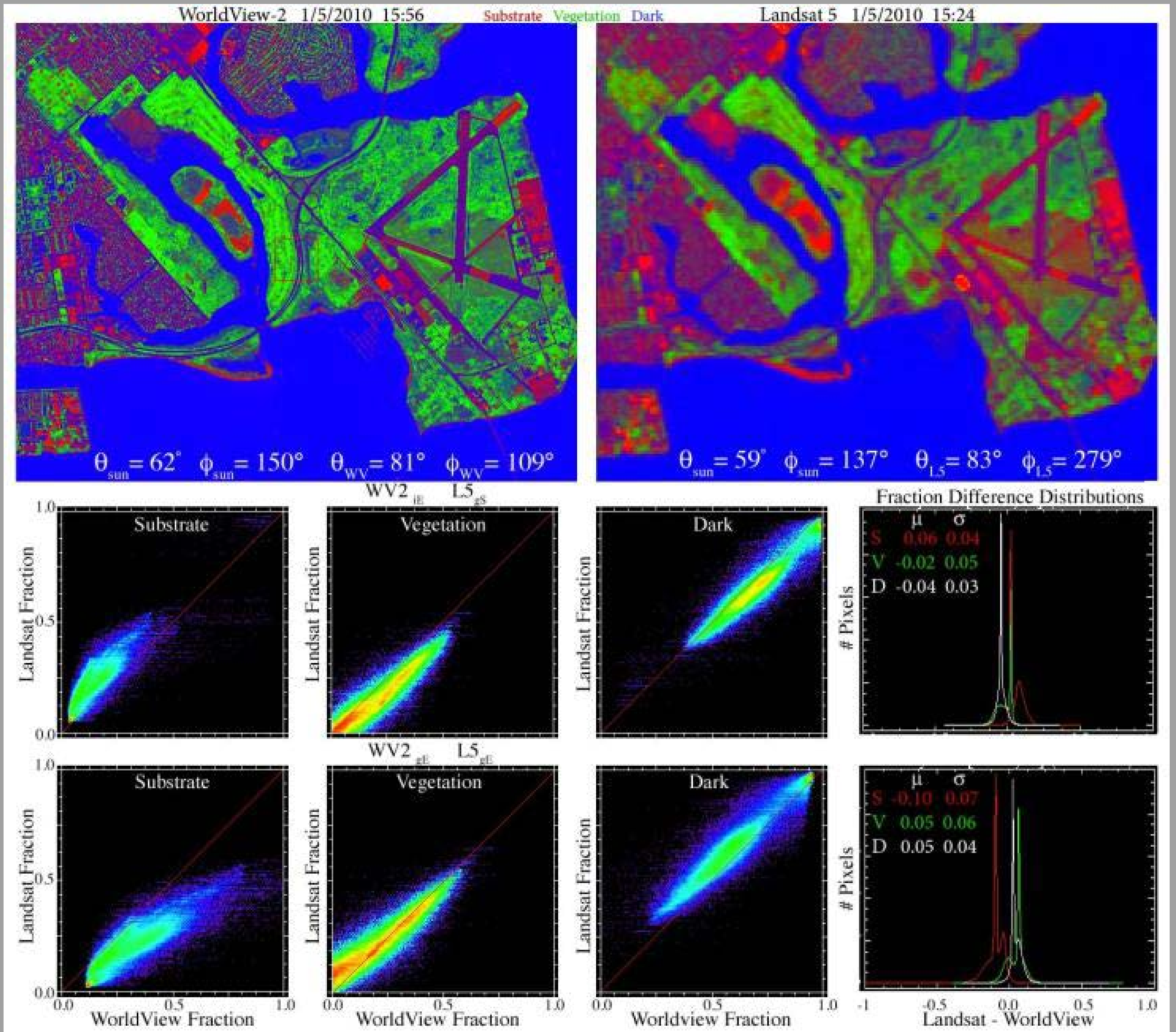
10x10 km urban cores almost as diverse as full mixing space - But different cities occupy different regions w/in space.

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

Small (2008)



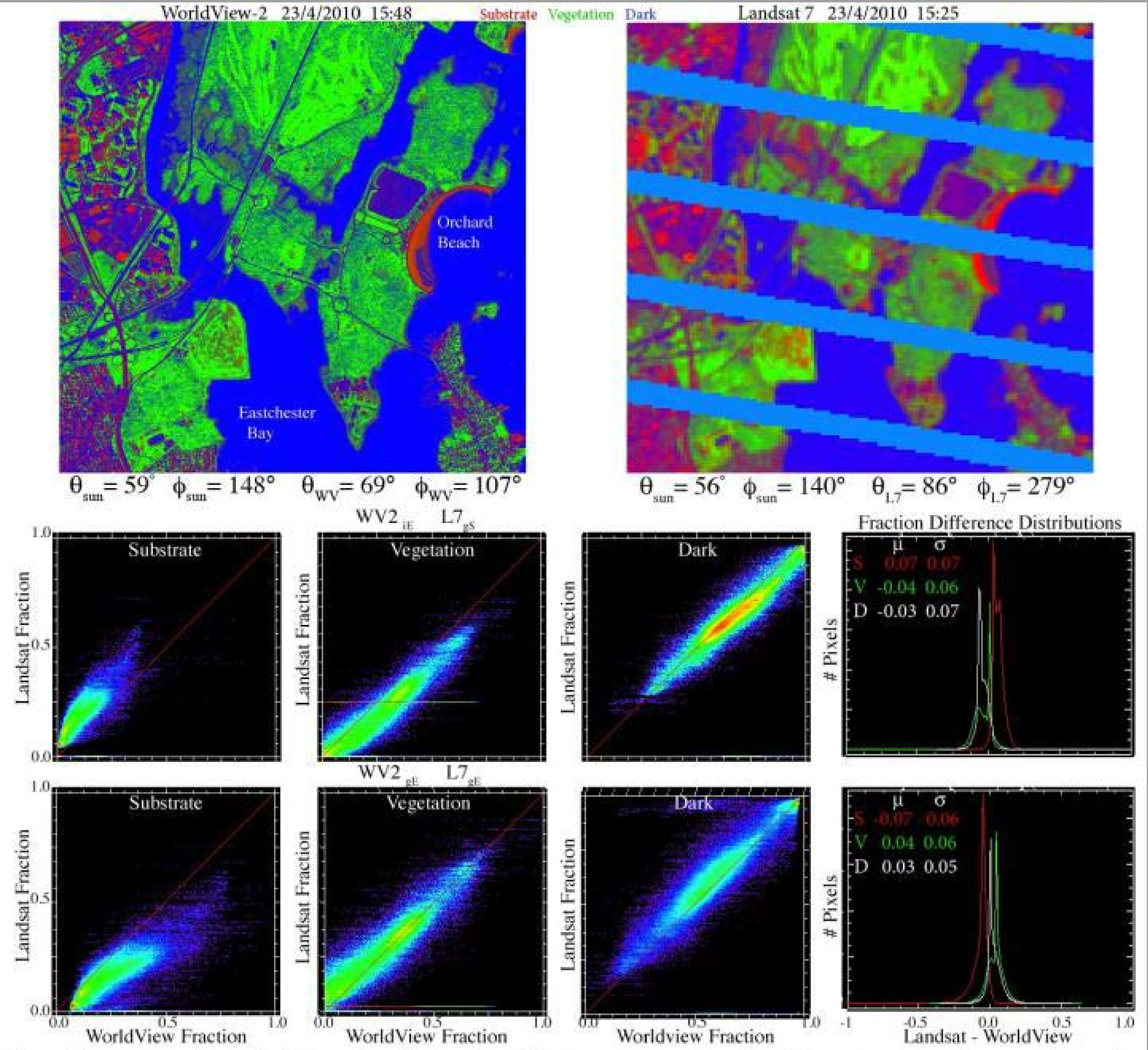
Vicarious validation with WorldView-2



WV-2 image endmembers (X-axis) vs.
Landsat 5 surface reflectance (Y-axis)

WV-2 global endmembers (X-axis) vs.
Landsat 5 TOA reflectance (Y-axis)

Vicarious validation with WorldView-2

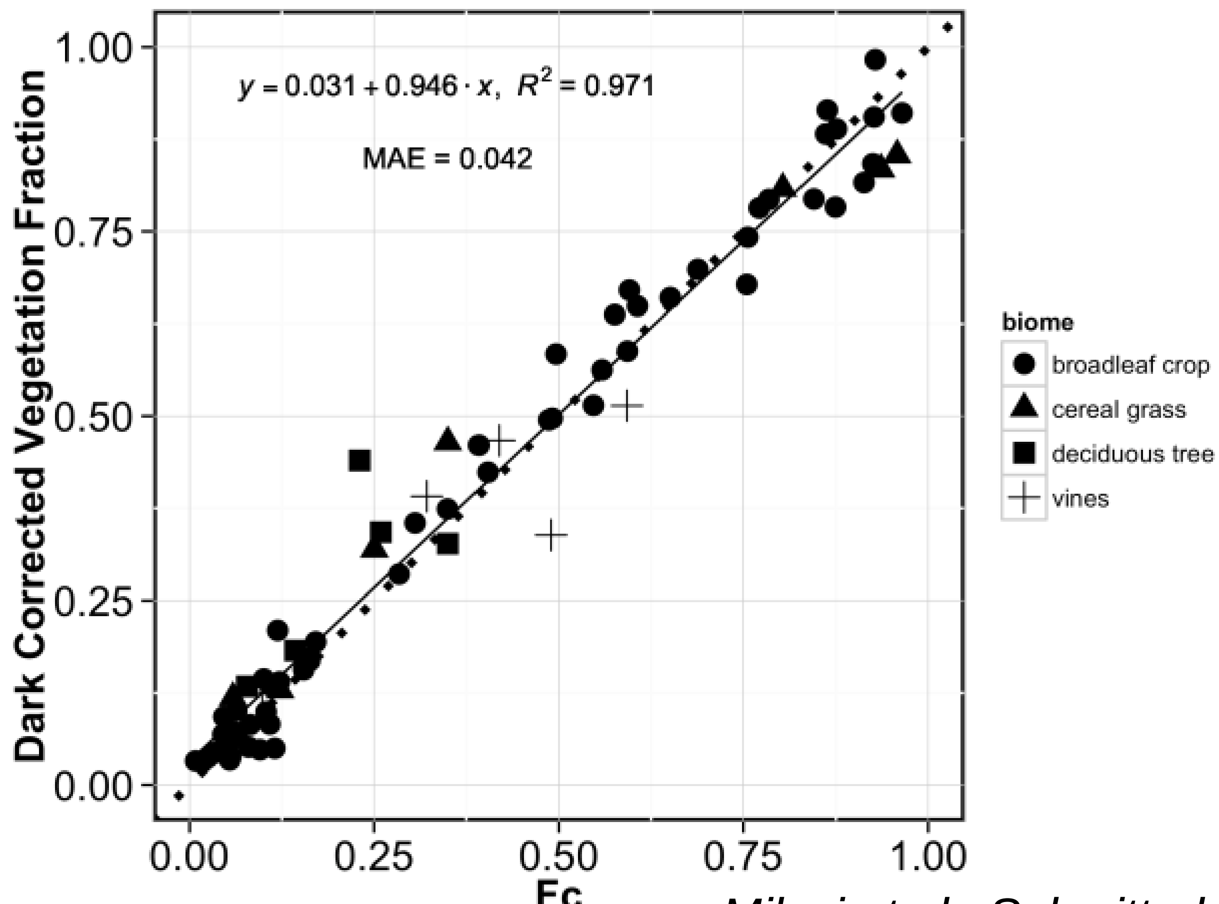


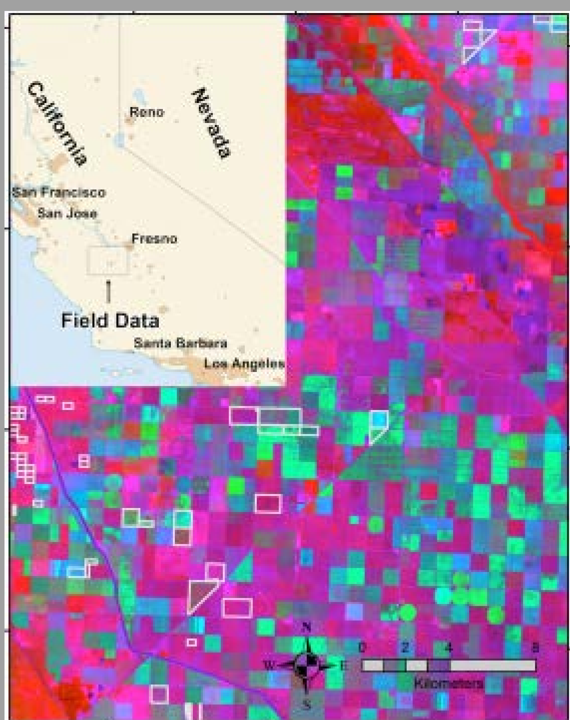
WV-2 image endmembers (X-axis) vs.
Landsat 7 surface reflectance (Y-axis)

WV-2 global endmembers (X-axis) vs.
Landsat 7 TOA reflectance (Y-axis)

Validation with Ground Observations

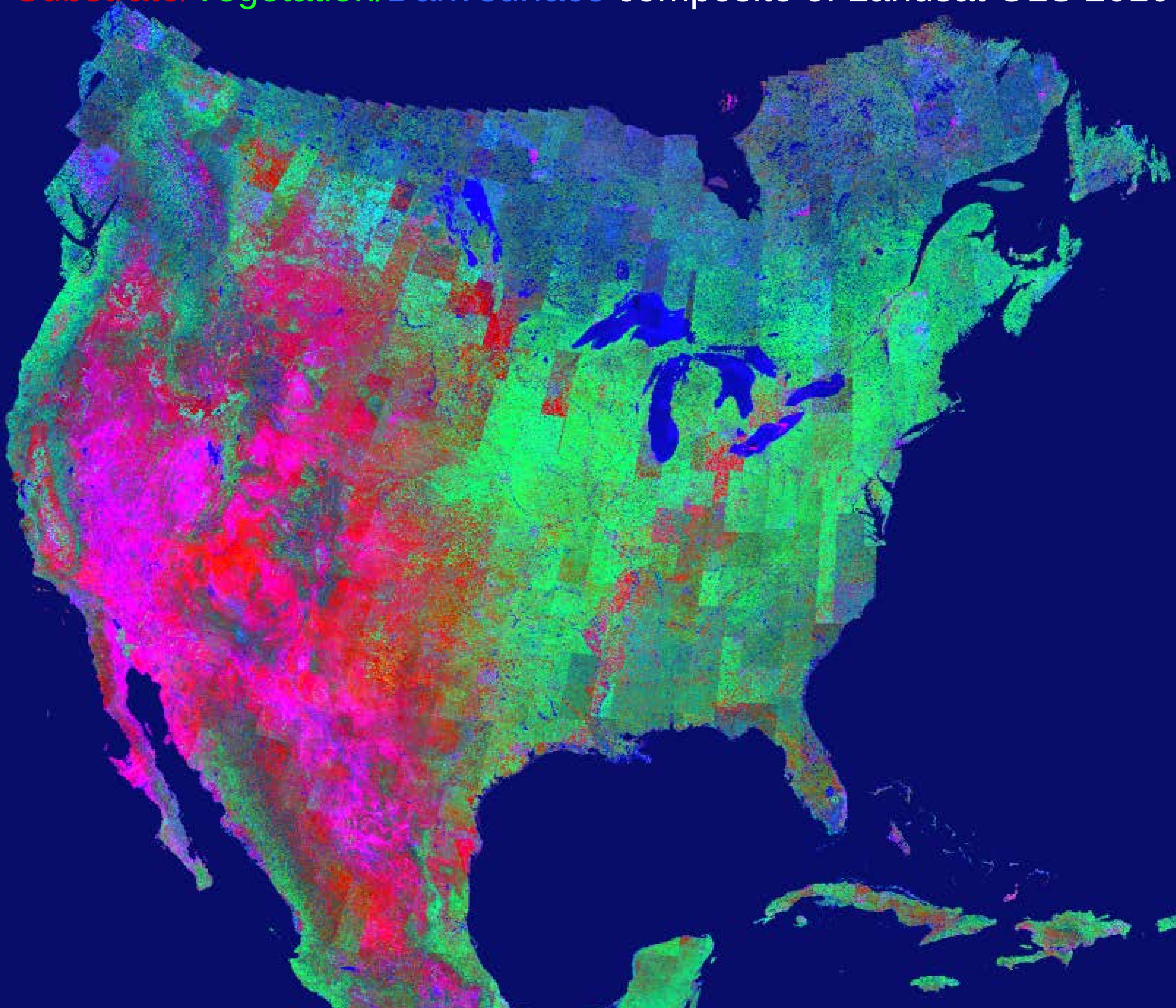
- 74 ground measurements of Fc
- 19 seasonal and perennial crops
- 11 dates between April and October 2008 coincidental with Landsat acquisitions



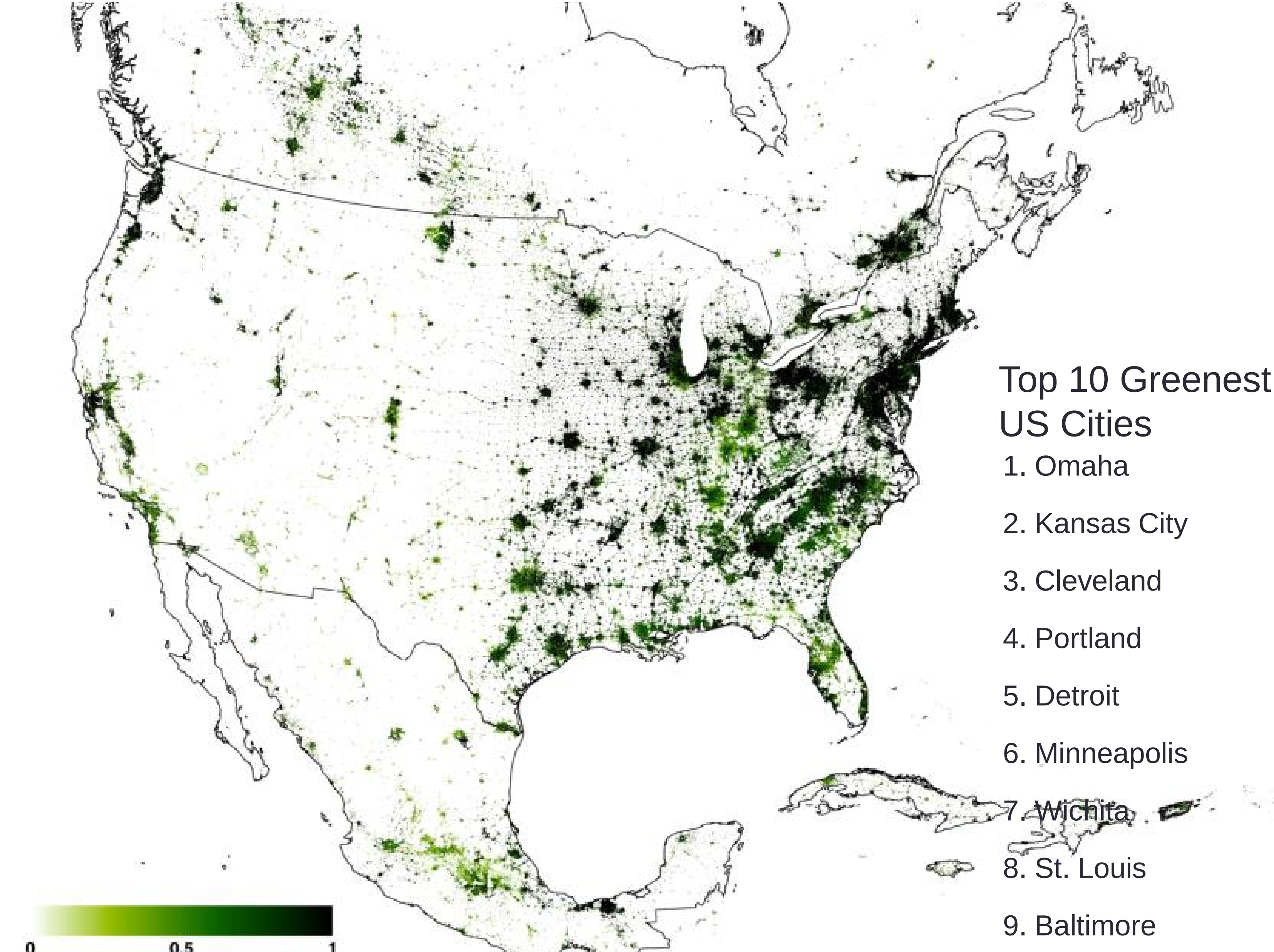


Milesi et al., Submitted

Substrate/Vegetation/Dark surface composite of Landsat GLS 2010



2010 Urban Vegetation Fraction



Top 10 Greenest US Cities

1. Omaha
2. Kansas City
3. Cleveland
4. Portland
5. Detroit
6. Minneapolis
7. Wichita
8. St. Louis
9. Baltimore
10. Washington, DC

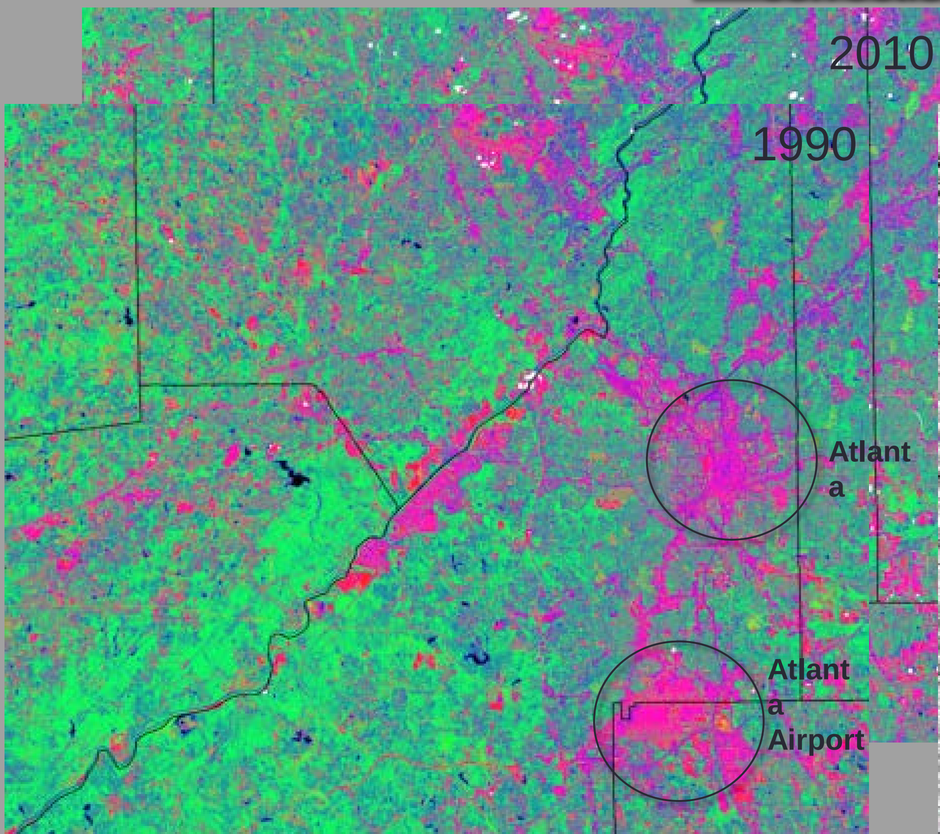
C. Milesi, CSUMB/NASA, cristina.milesi-1@nasa.gov
C. Small, Lamont Doherty/Columbia U., csmall@columbia.edu

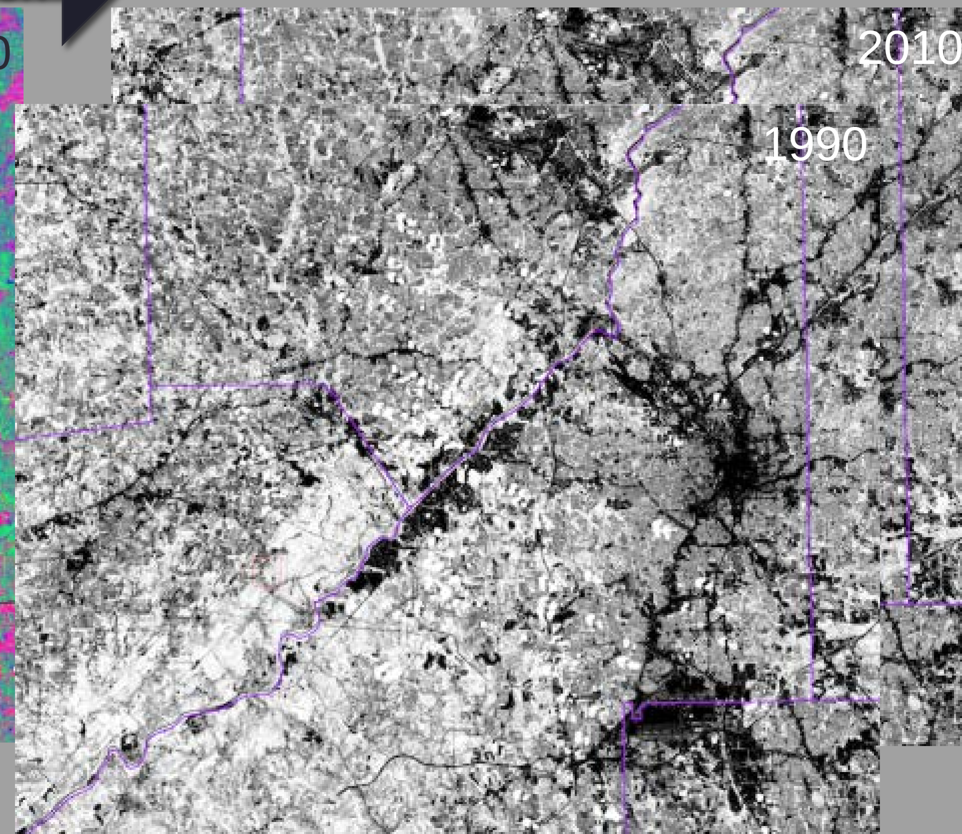
Atlanta, GA

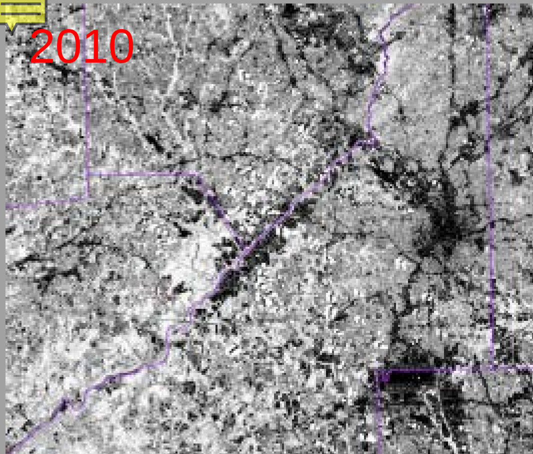
SVD

Dark correction

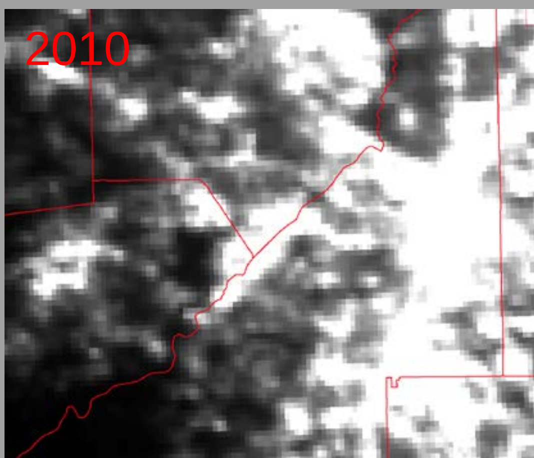
Vegetation Fraction



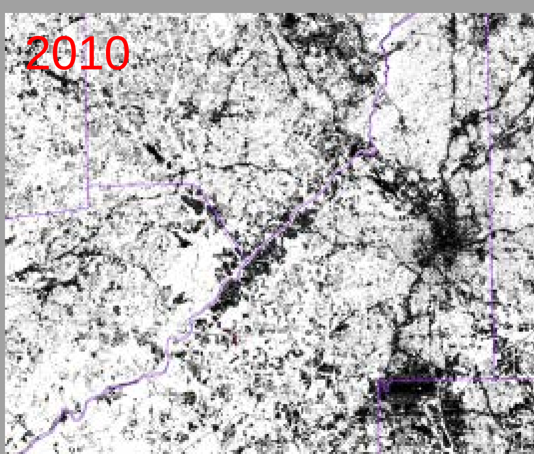




Continuous Vegetation fraction

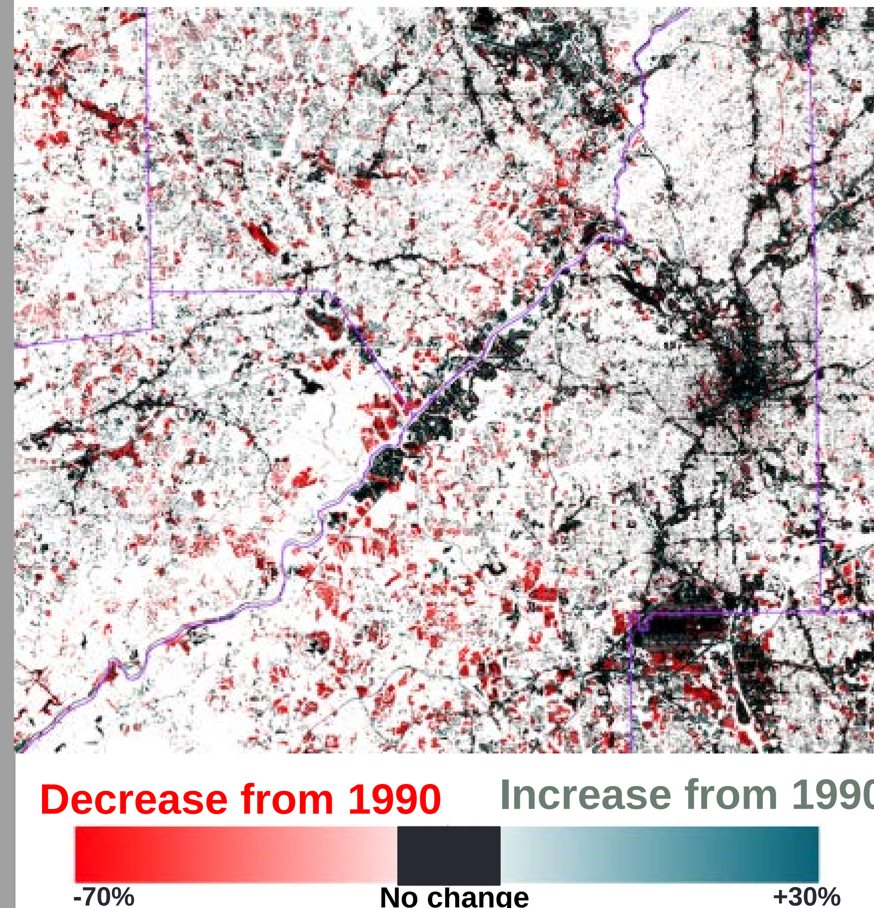


Use Night lights as a mask to urban land

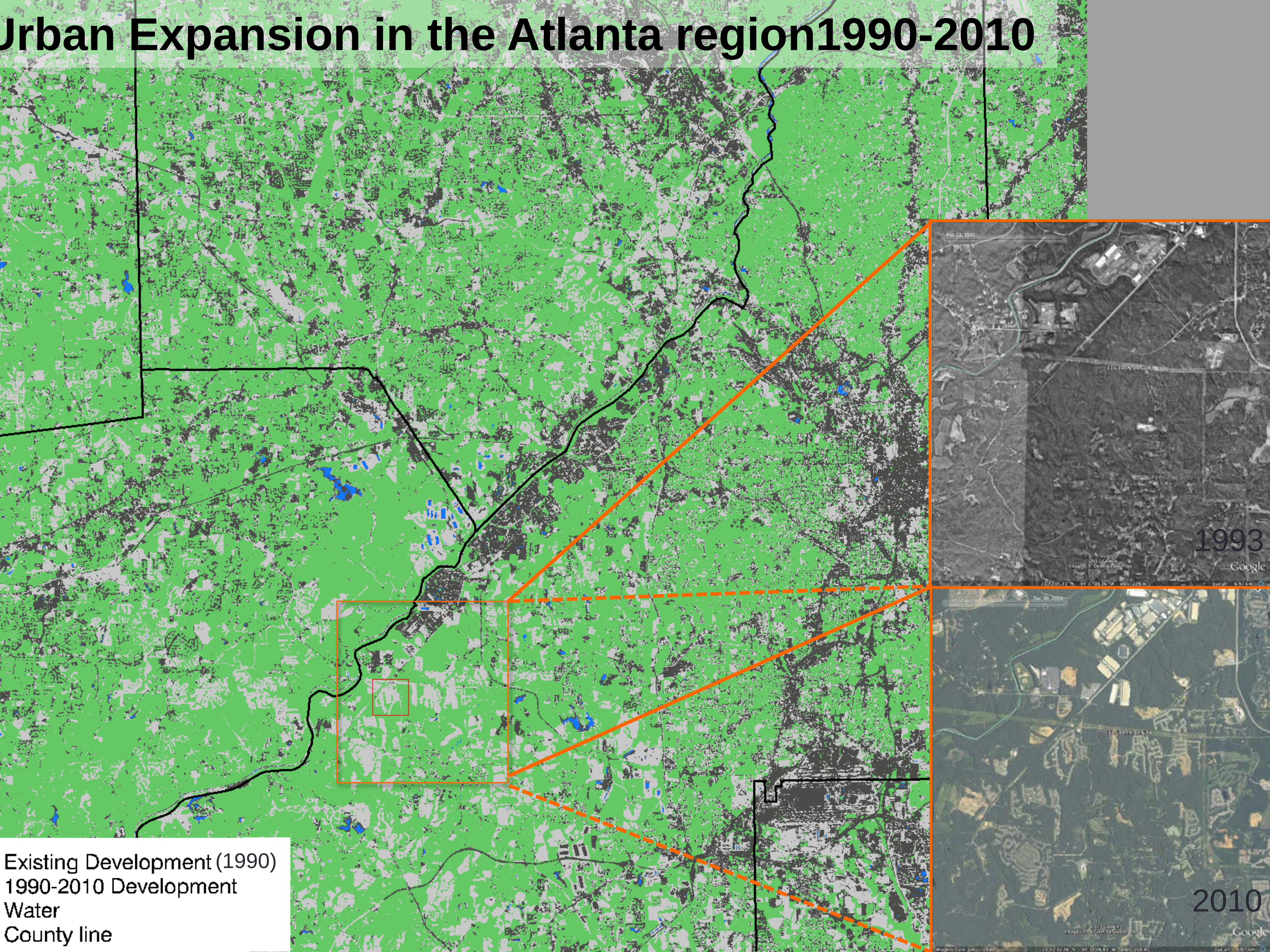


Urban vegetation fraction

Changes in urban vegetation fractional cover from 1990 to 2010



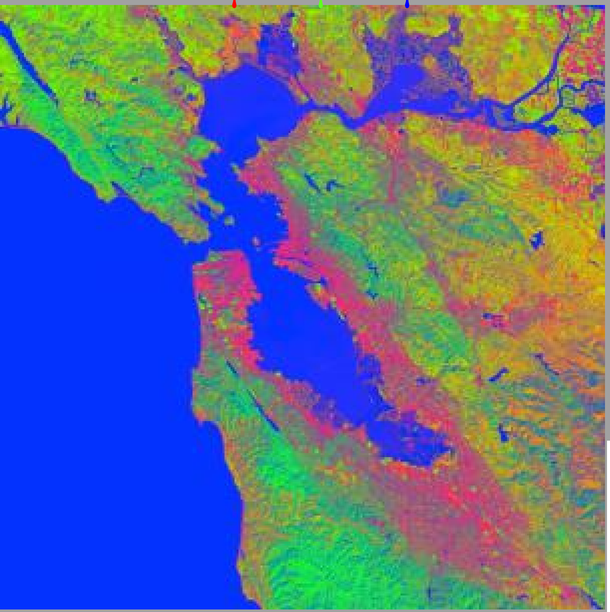
Urban Expansion in the Atlanta region1990-2010



San Francisco Bay Area

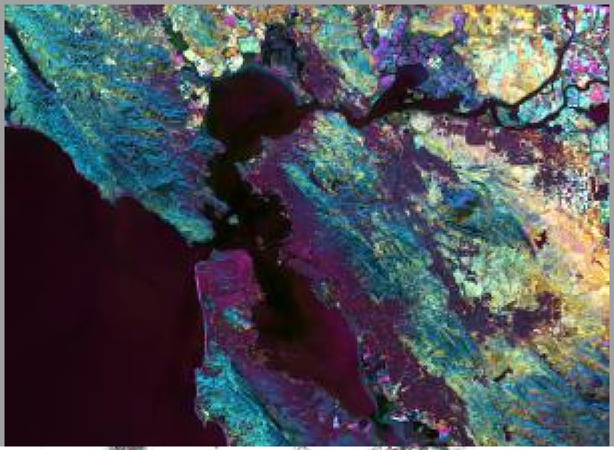
Seasonal Mean Fraction

2010 μ S μ V μ D

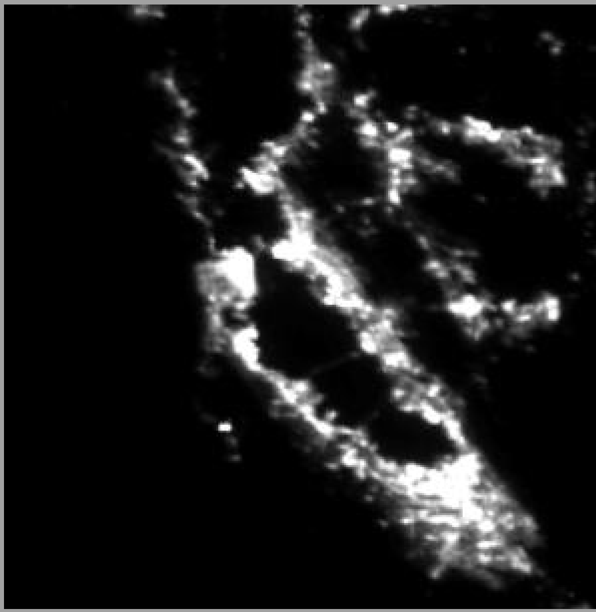


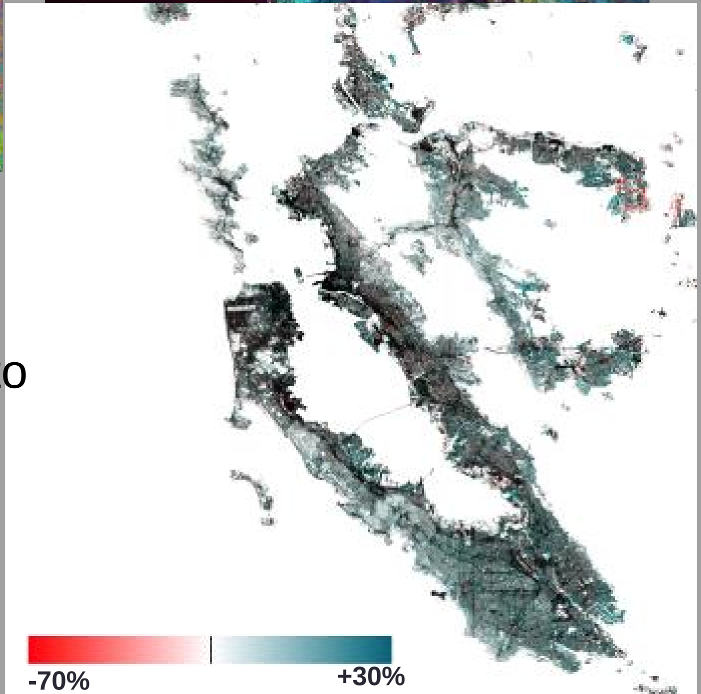
Seasonal Standard Deviation

2010 δ S δ V δ D

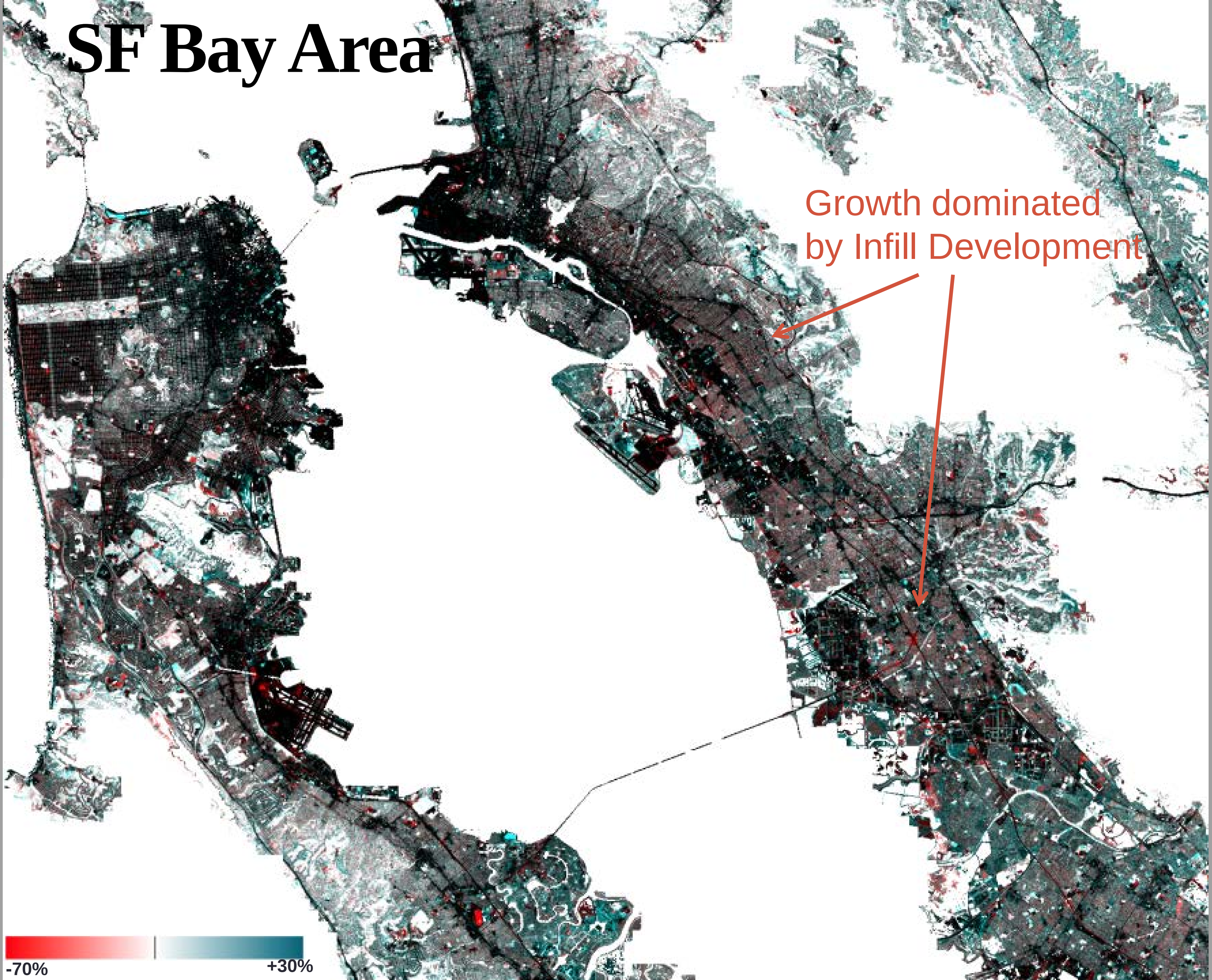


VIIRS Day/Night Band





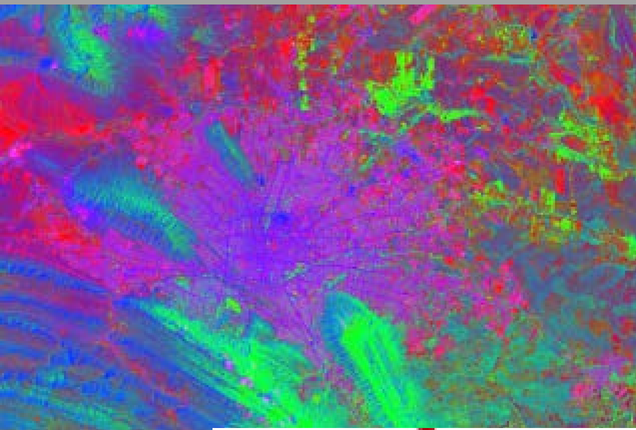
Nighttime lights combine with multi-temporal variability in SVD fractions to automate identification urbanization



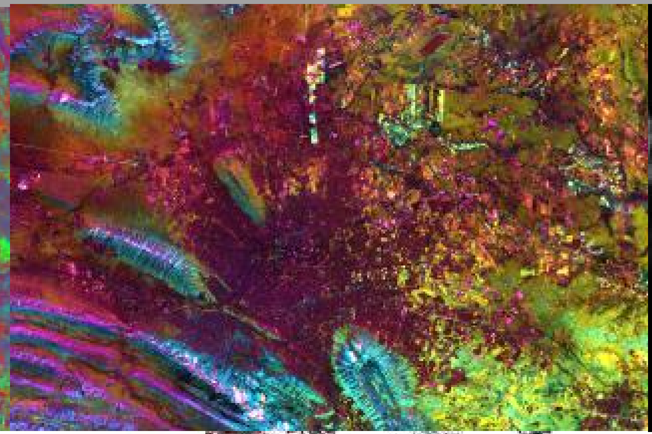
SF Bay Area
Growth dominated
by Infill Development
-70%
+30%

Monterrey, Mexico

2010 μ S μ V μ D



2010 δ S δ V δ D



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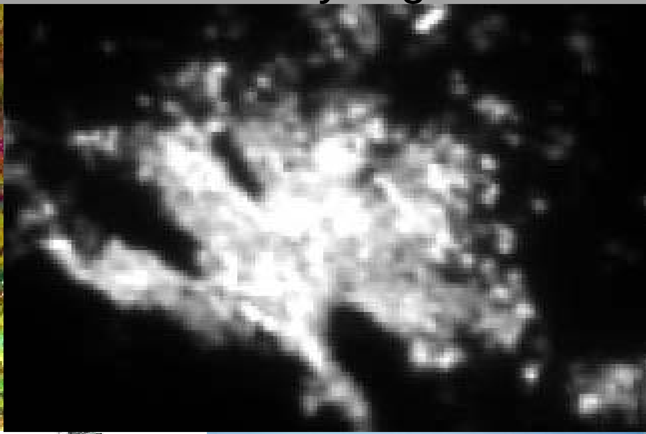
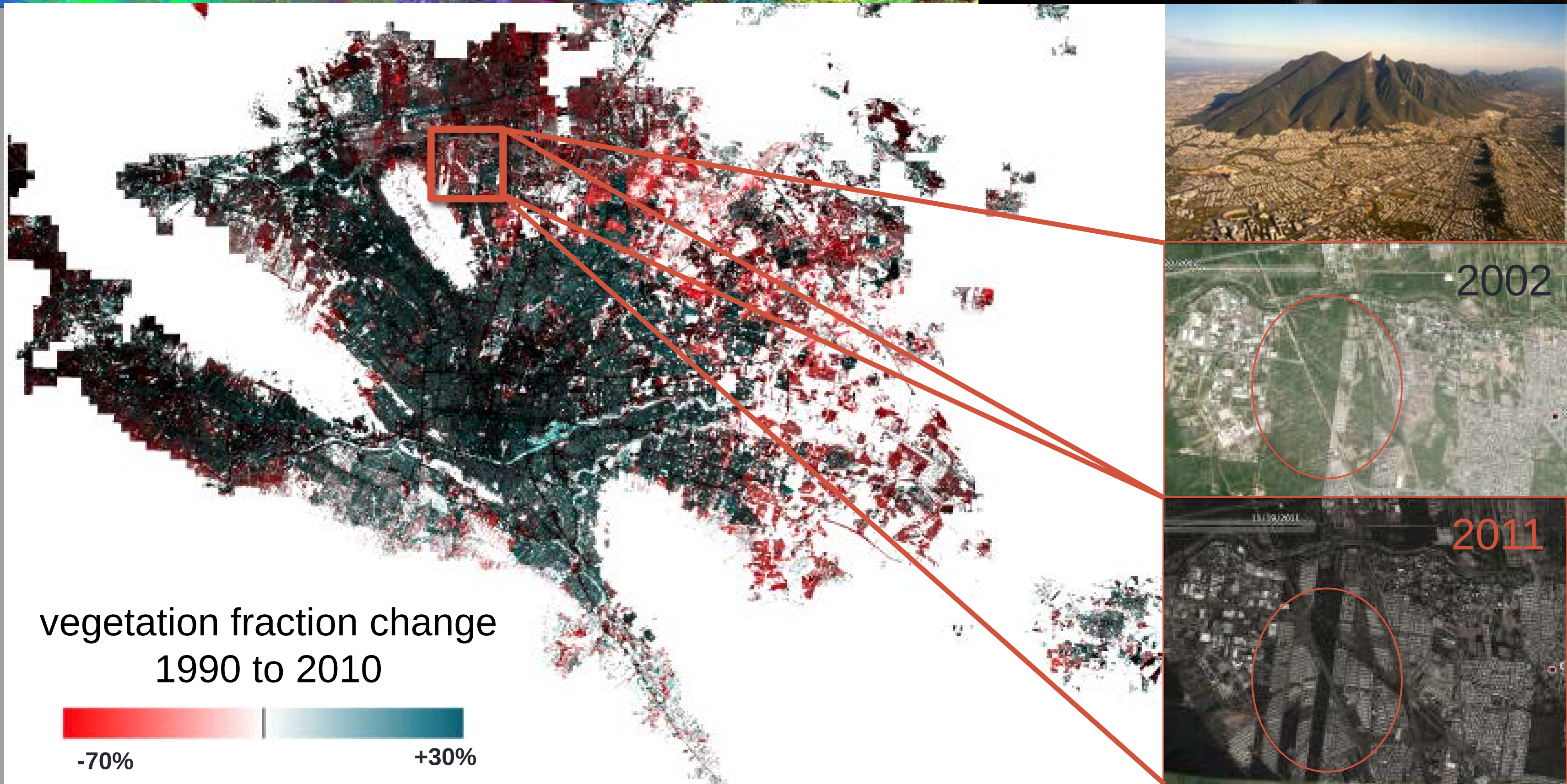
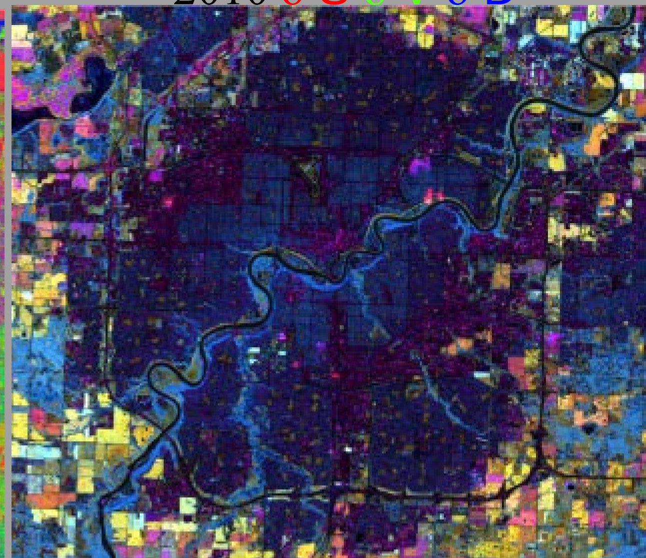




Edmonton, Canada

2010 μ S μ V μ D

2010 δ S δ V δ D



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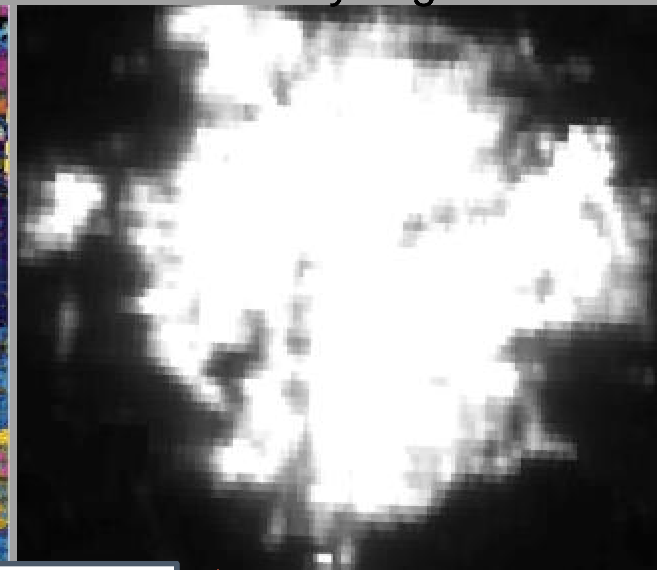
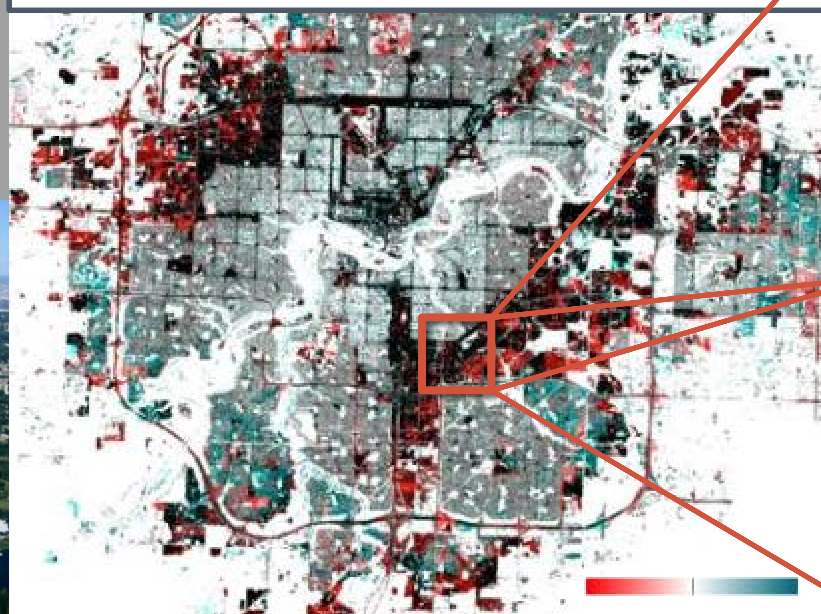
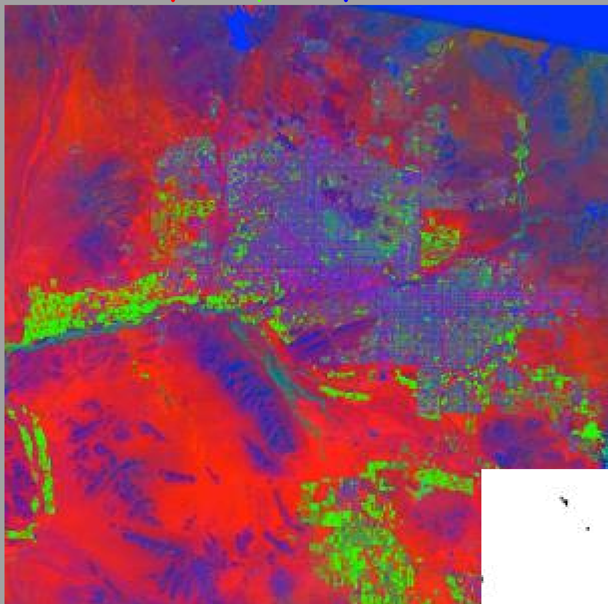


vegetation fraction change
1990 to 2010

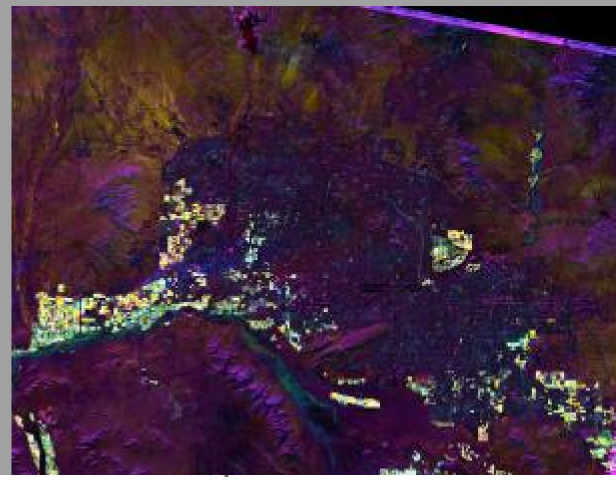


Phoenix, AZ

2010 μ S μ V μ D



2010 δ S δ V δ D



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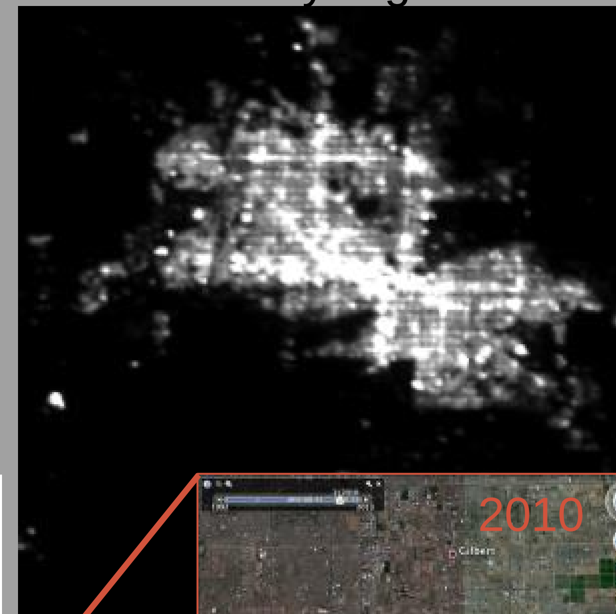
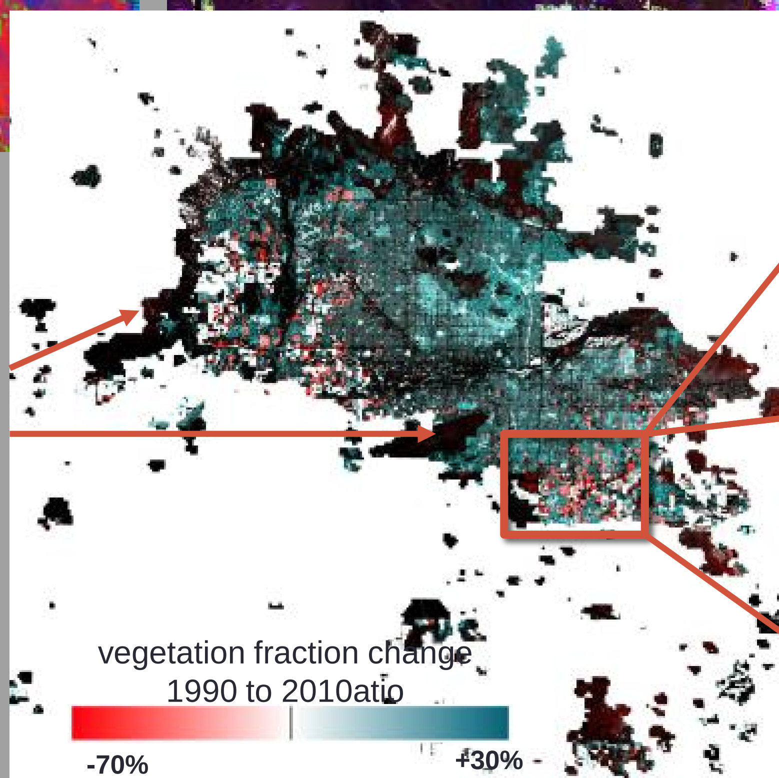
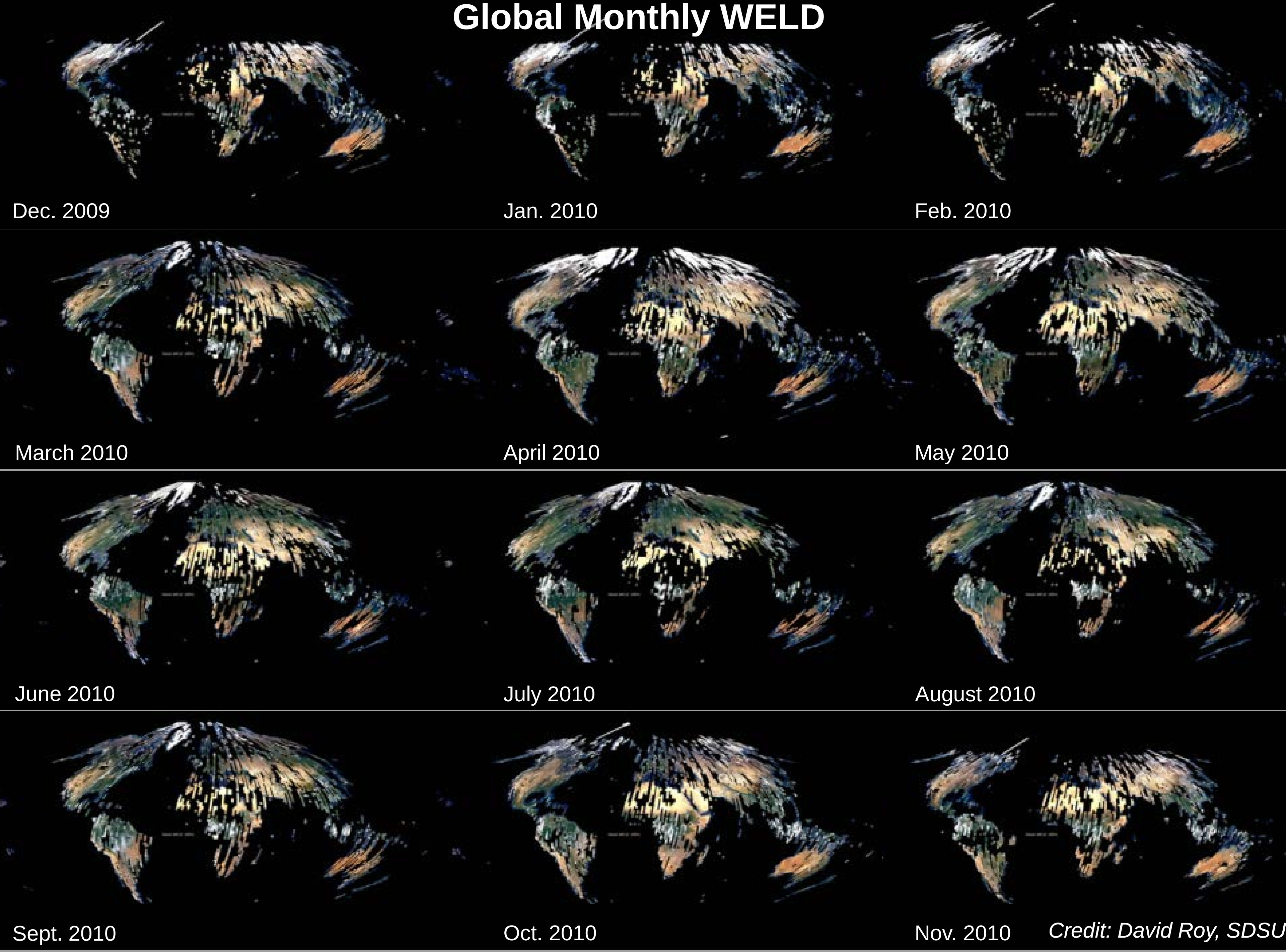




Current approach still to be refined for desert cities to avoid overestimation of urban development;

Global Monthly WELD



Conclusions

- Standardized approach based on multi-sensor characterization of human settlements requiring minimum training and assumptions tracks urbanization consistently over large regions.
- Multi-season characterization of mean reflectance properties and low variability distinguishes built environment from adjacent agricultural or undeveloped areas in most situations.
- Denser time series density of Landsat data needed to resolve reflectance ambiguity over desert cities.

Follow updates on data distribution at:

- https://nex.nasa.gov/nex/projects/1276/

Acknowledgements: Andrew Michaelis, Gong Zhang, Lee Johnson, Thomas Trout, the NASA Earth Exchange