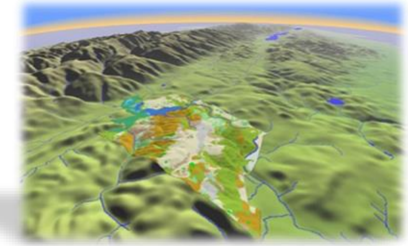
NICHOLAS SCHOOL OF THE ENVIRONMENT AND EARTH SCIENCES
DUKE UNIVERSITY



ENVIRON 761:
Monitoring & Change Detection

Instructor: John Fay

Monitoring & Change detection

Mind-Blowing Satellite Pictures Show How Cities Grow Over Time

Gus Lubin and Christine Jenkins | Mar. 3, 2011, 11:36 AM | 243,826 | 10

Share Tweet +1 Email More

Cities are booming. Around the world and even in America, urban areas are expanding at rate never seen in history.

This incredible growth was pictured using time-lapse satellite photos by NASA.

We've collected pictures of boom cities including Dubai, Cairo, Las Vegas, Jakarta, Chengdu, Sacramento and Calgary.

Dubai in October 2002

https://earthengine.google.com/timelapse/

Time Lapse Satellite Photos Show How Humans Are Destroying The World

Christine Jenkins | Mar. 23, 2011, 1:14 PM | 397,769 | 42

Share Tweet +1 Email More

It takes a lot to provide for 7 billion humans.

Mankind is destroying rainforests, draining marshes and drilling into mountains to provide timber, water, coal and other resources.

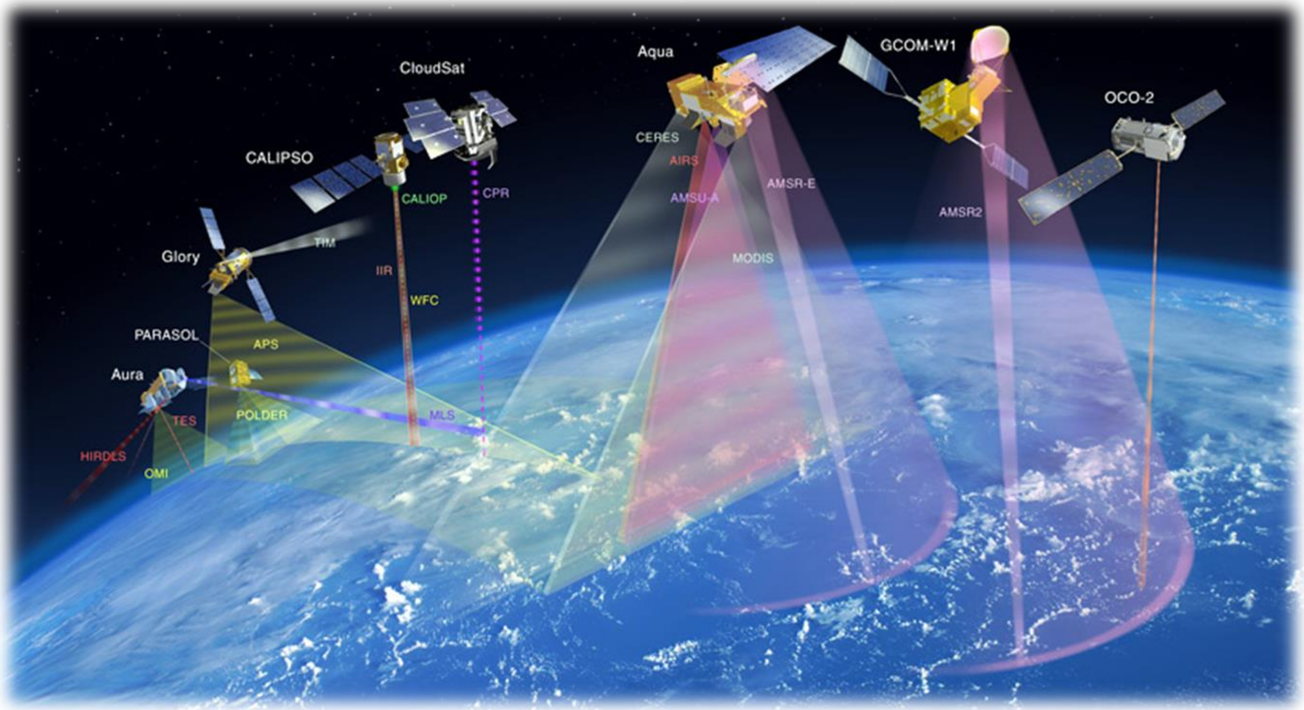
Some of this destruction has been captured in before and after satellite photos.

Monitoring & Change Detection

Overview

- Monitoring: Remotely Sensed Data
- What is “Change detection”?
- Importance of measuring change
- How is change measured?
  - Data required…
  - Techniques used…

I. Monitoring with Remotely Sensed Data

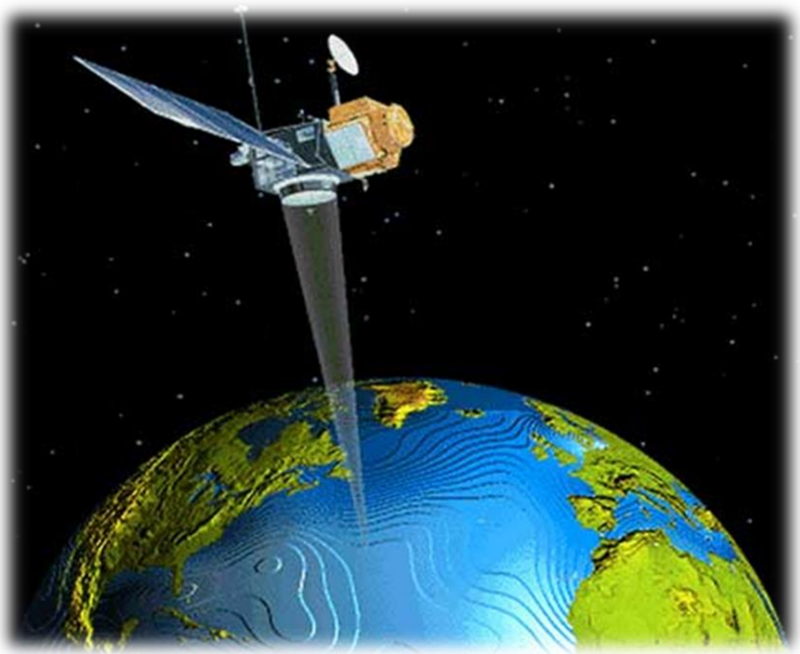


- Generalities of Remote Sensing
- Remote sensing for environmental management

What is *remote sensing*?

“Obtaining information from an object without being in direct contact with it.”

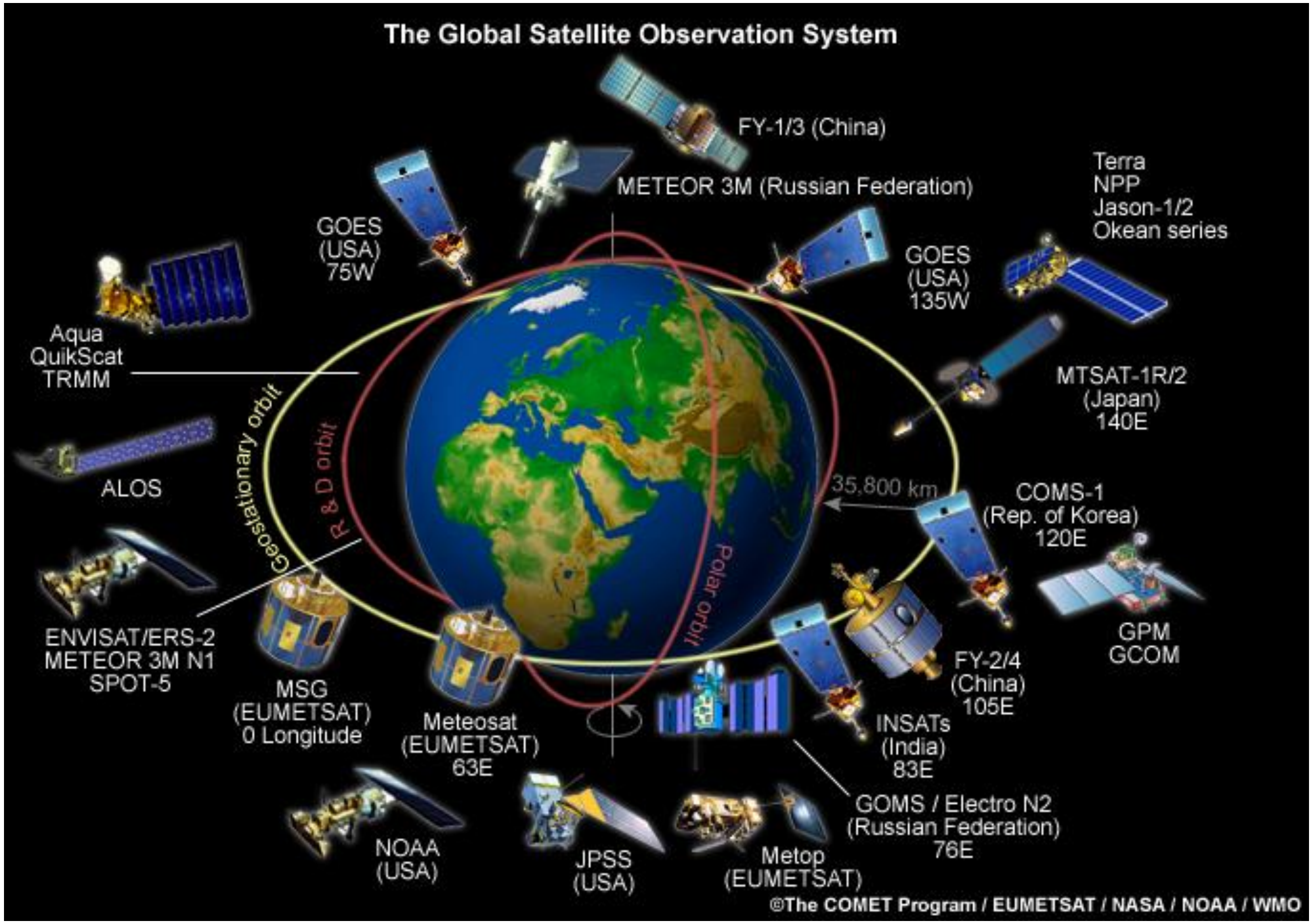
More specifically, *“obtaining information from the land surface through sensors mounted on aerial or satellite platforms.”*



Describing remotely sensed products

Types of *resolution*:

- Spatial
- Spectral
- Radiometric
- Temporal



Spatial Resolution

Pixel size meters

1000 MODIS (Moderate Resolution Imaging Spectroradiometer)

60 Landsat MSS (Multi Spectral Scanner)

30 Landsat TM (Thematic Mapper)

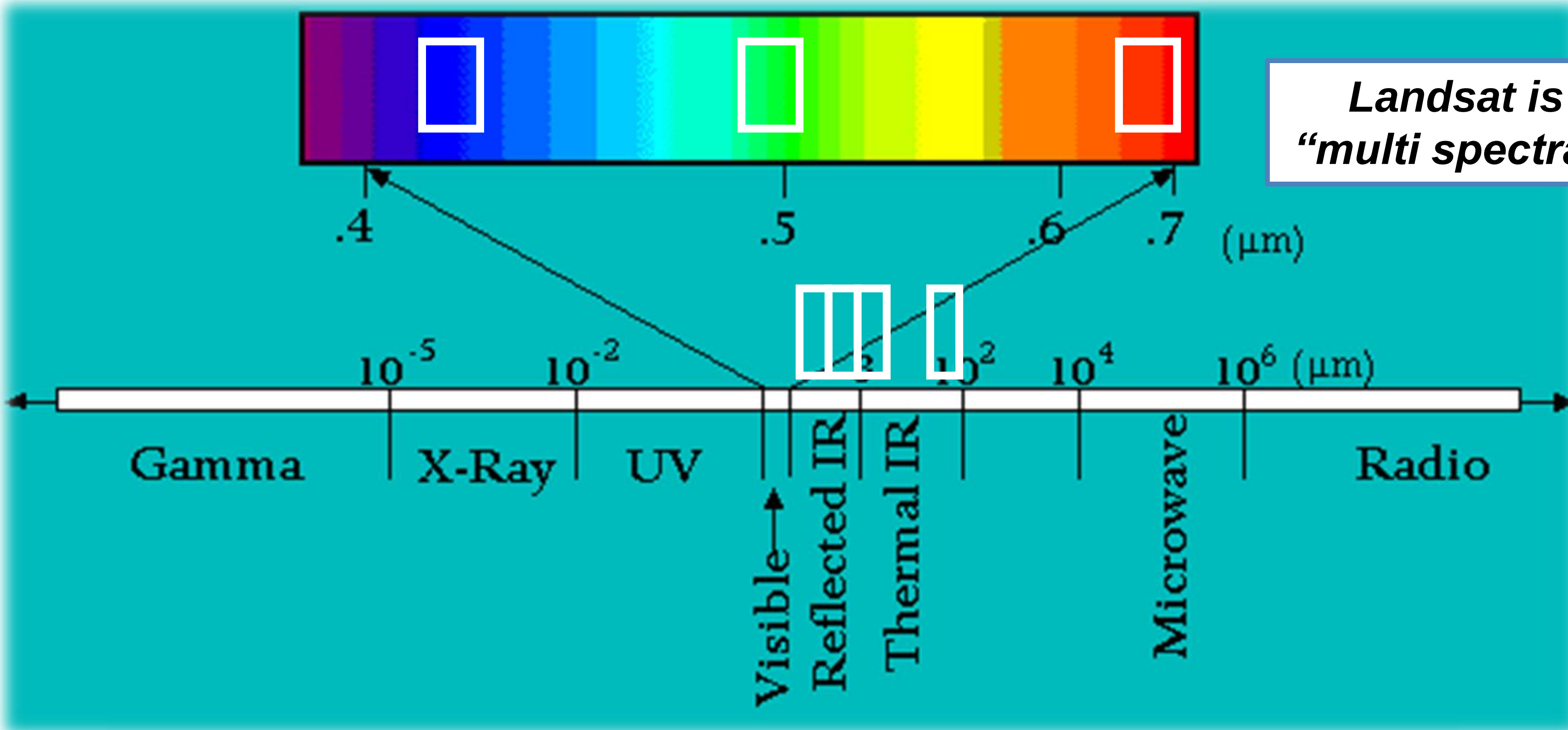
25 SPOT (French, multispectral 25m)

IKONOS, GeoEye, 2 – 0.5 m

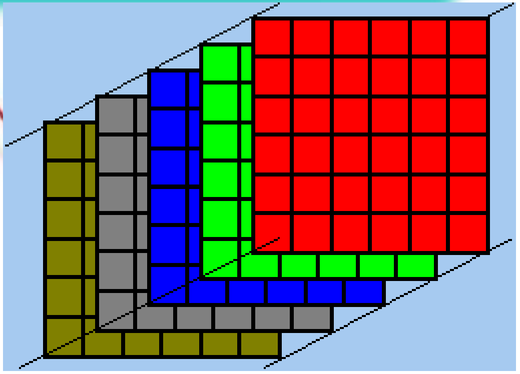
Hyper-spatial imagery < 1m

[Center for Biodiversity & Conservation tool]

Spectral Resolution



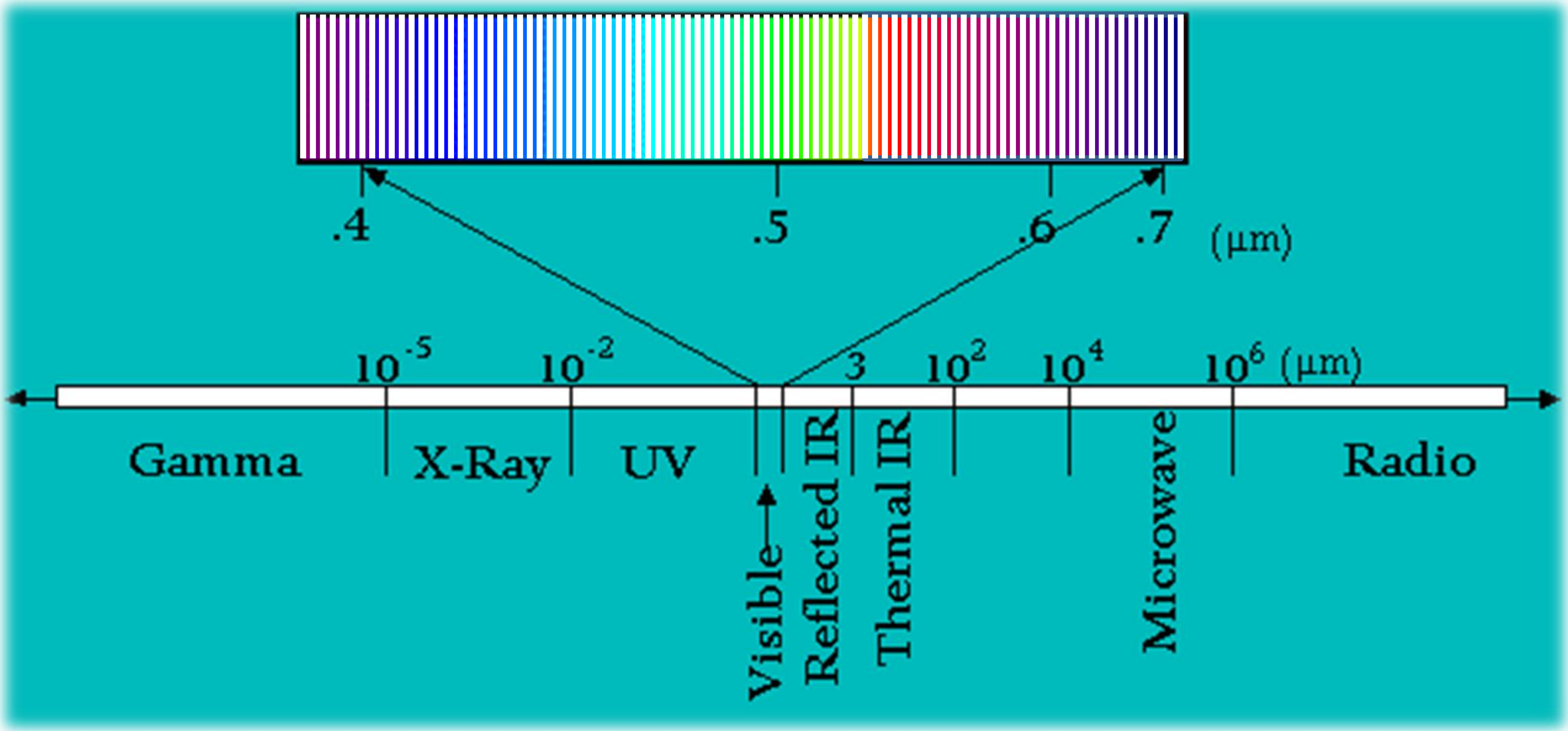
Landsat is "multi spectral"



1 m = 1×10^{6} μm

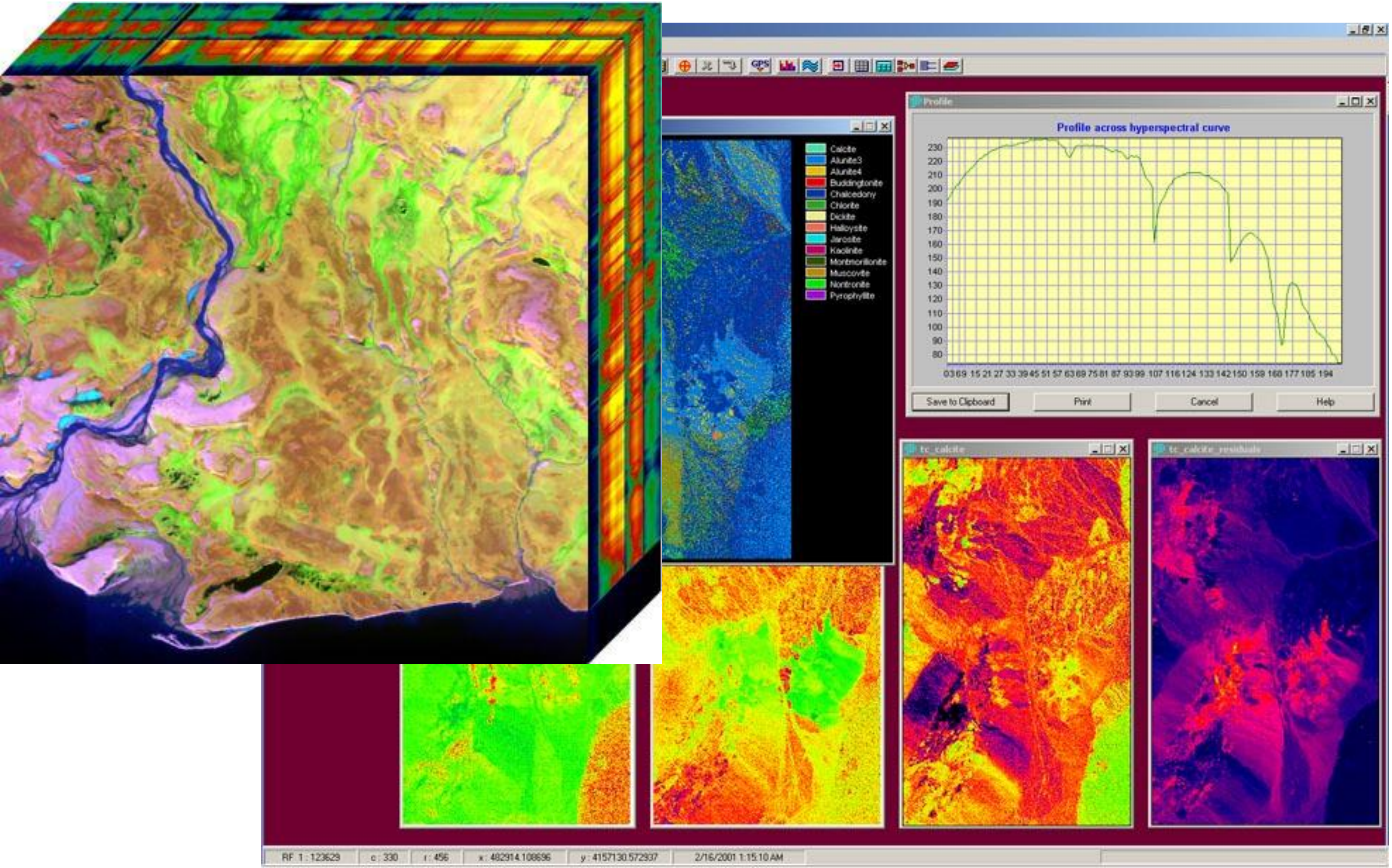
1μm = 1×10^{-6}m

Spectral Resolution: *Hyperspectral*



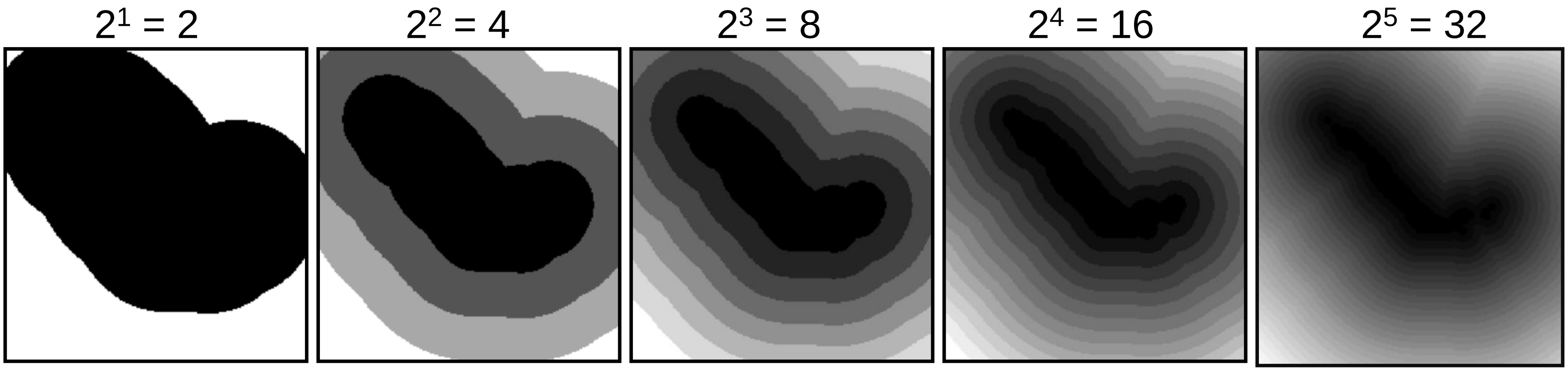
Chopping up the spectrum into 100+ narrow bands

Spectral Resolution: *Hyperspectral*



Radiometric Resolution

The number of digital levels used to express the data collected by the sensor (often expressed in *bits*)



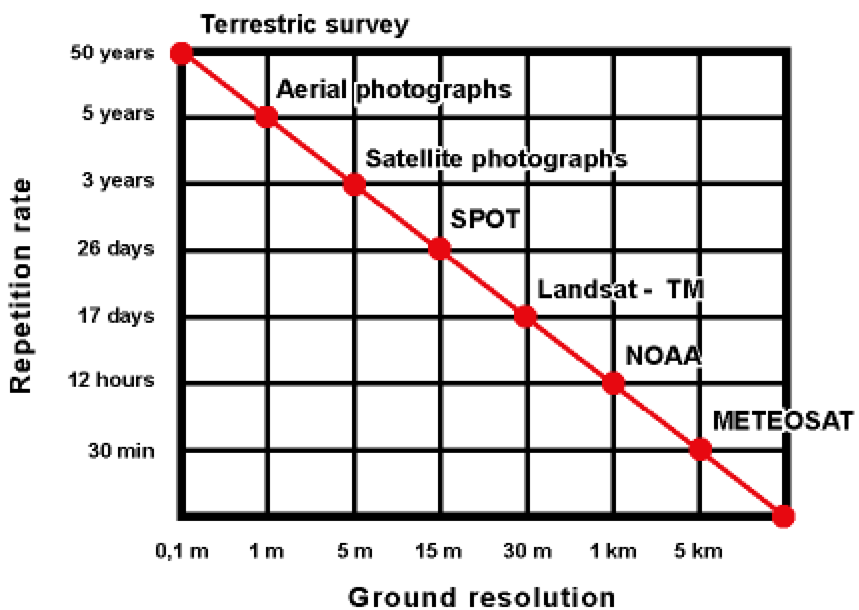
e.g. Landsat → 8 bit

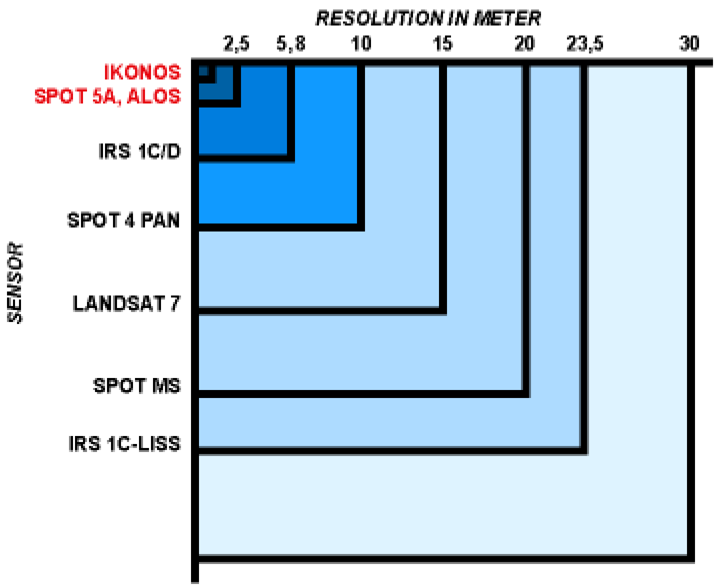
$2^8 = 256$ possible values (for each band)

Temporal Resolution

Revisit frequency for a specific location

- "High": < 24 hours - 3 days
- "Medium": 4 – 16 days
- "Low": > 16 days



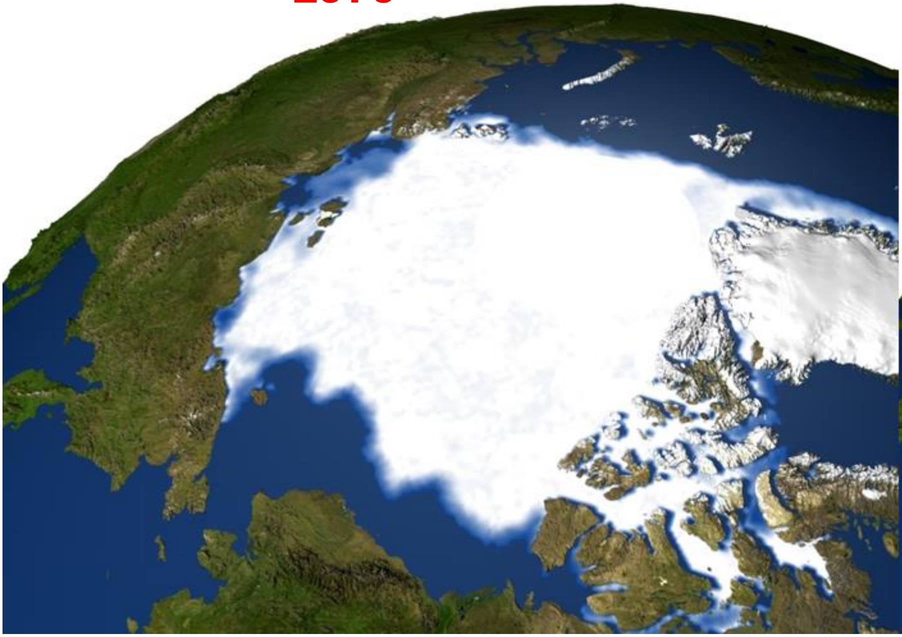


http://dib.joanneum.ac.at/edtr/satsys.html

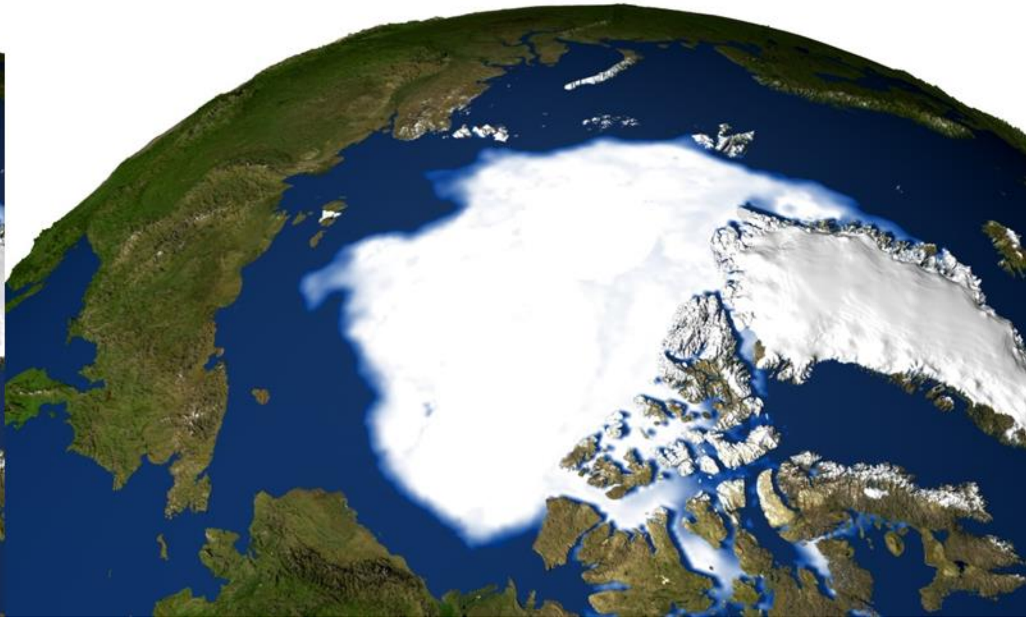
Remote Sensing & Environmental Mgmt.

- Monitoring long term events

1979



2005

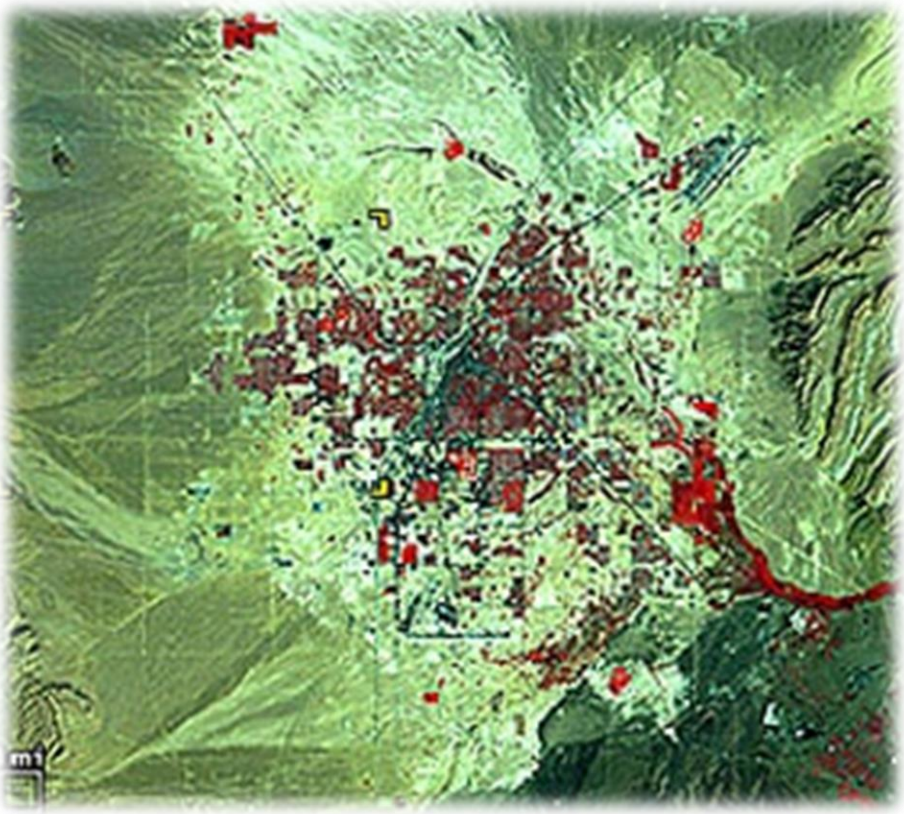


Remote Sensing & Environmental Mgmt.

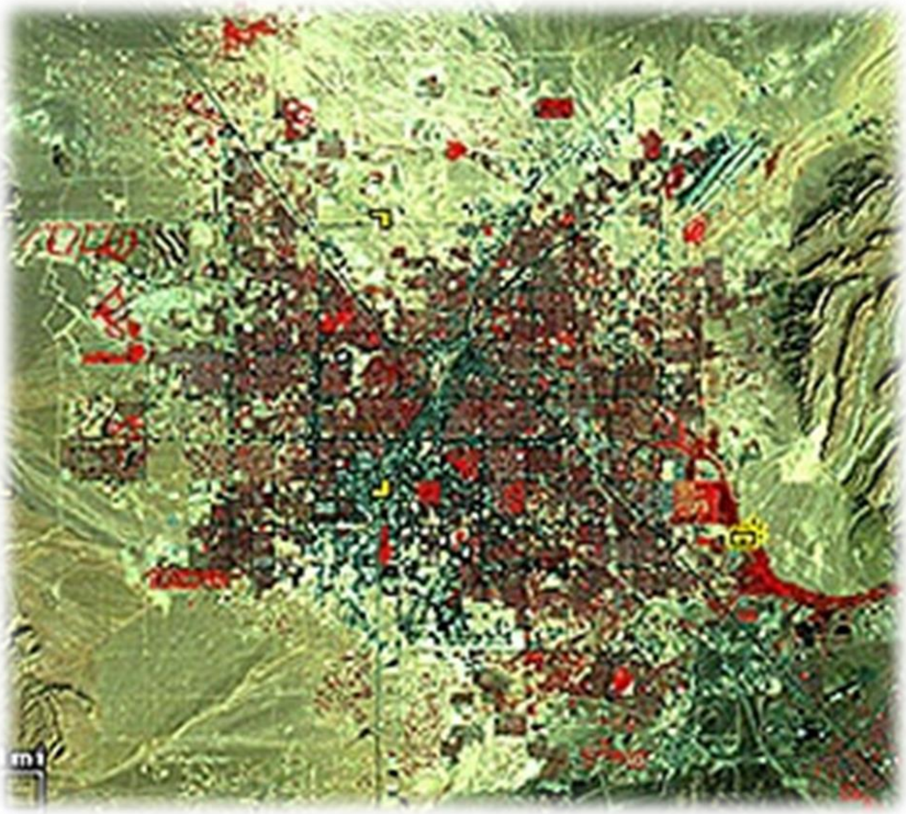
- Viewing threats and stresses

Las Vegas urban expansion

1972

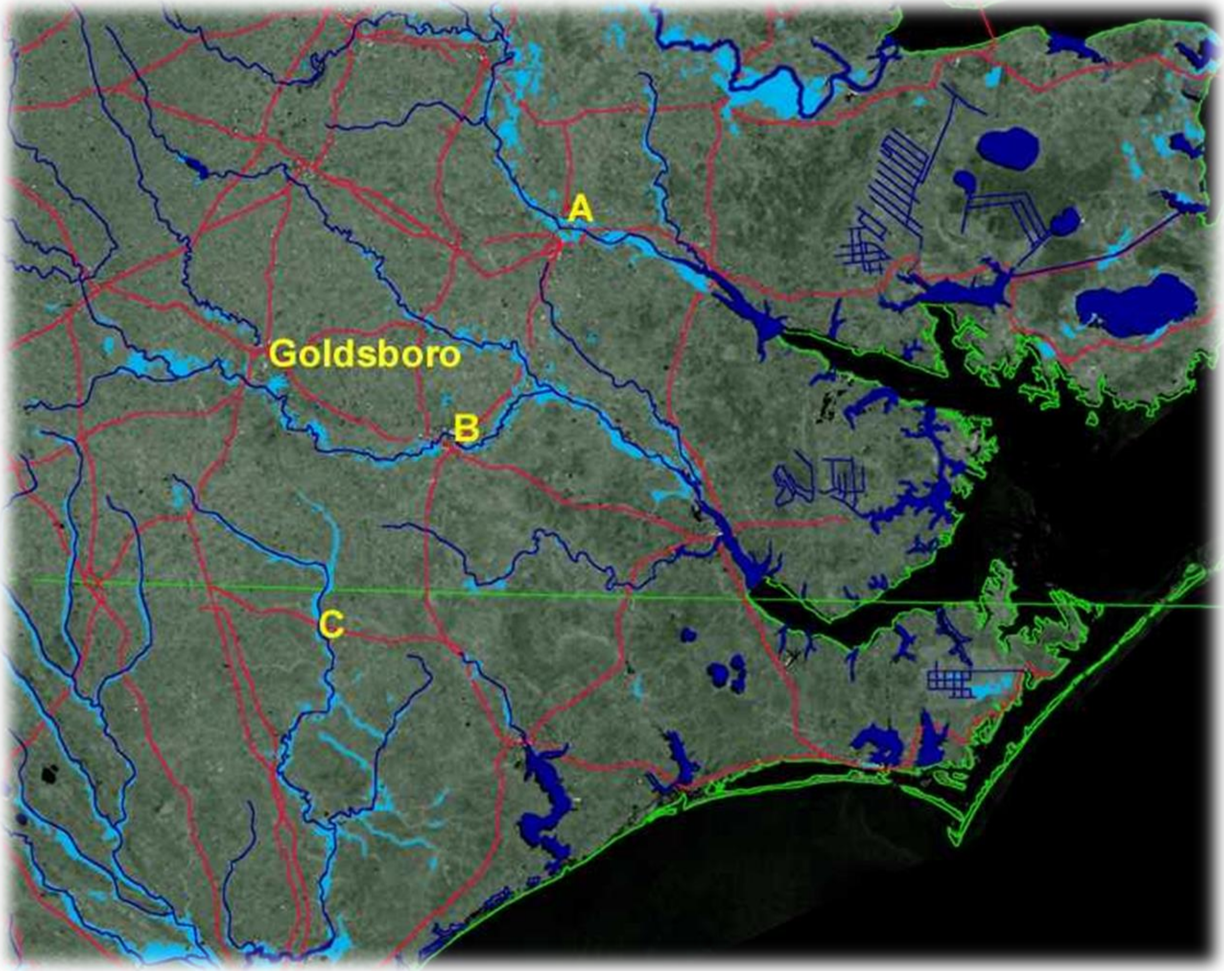


1995



Remote Sensing & Environmental Mgmt.

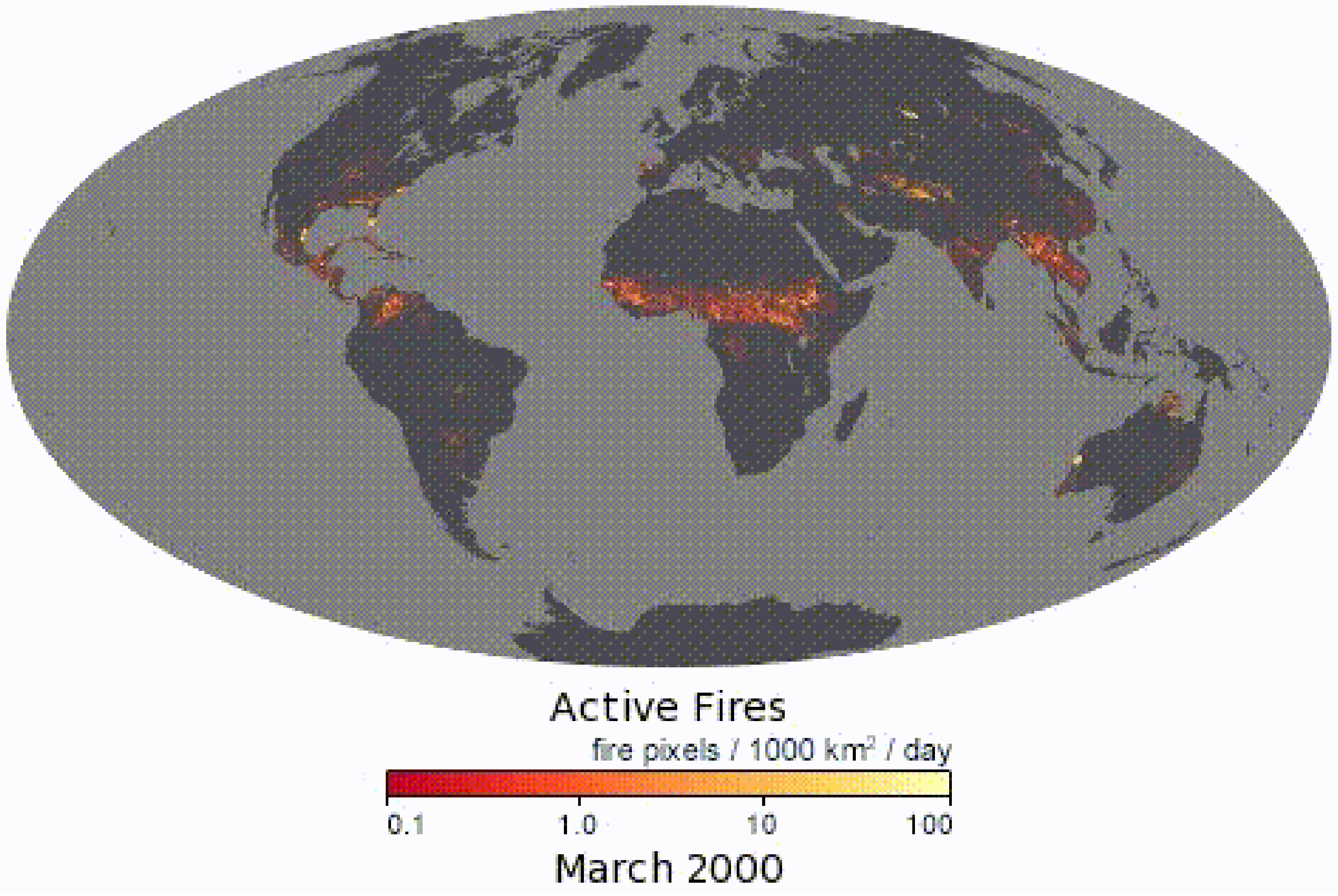
- Monitoring short term events: *Flooding*



NC flooding 1999 RADARSAT-1 Imagery

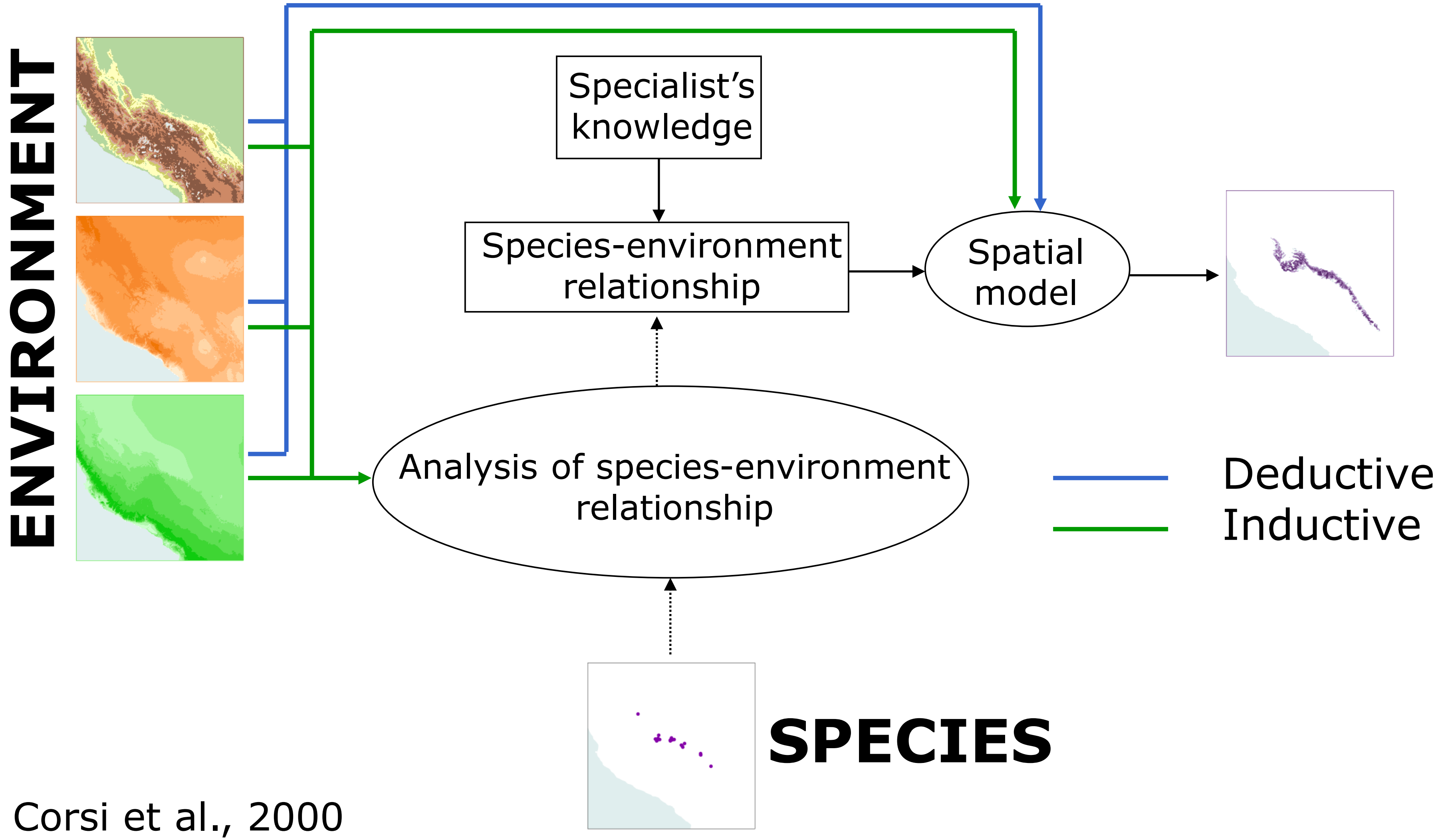
Remote Sensing & Environmental Mgmt.

- Monitoring short term events: *Wildfires*



Remote Sensing & Environmental Mgmt.

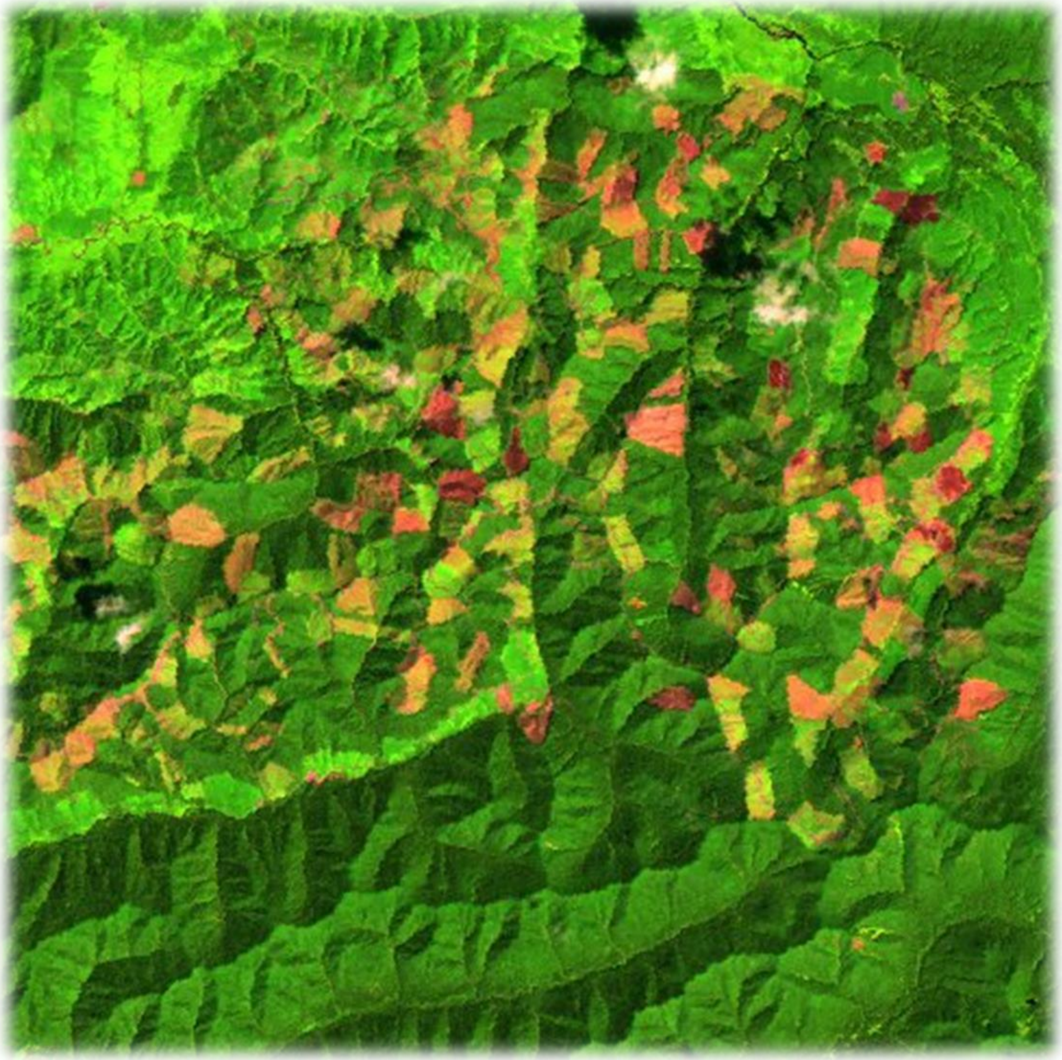
- Species distribution modeling



Corsi et al., 2000

Remote Sensing & Environmental Mgmt.

- Forestry
  - *Forest inventory*
  - *Clear cut mapping*
  - *Burn delineation*
  - *Biomass estimation*



Landsat 5 NASA

Remote Sensing & Environmental Mgmt.

- Forest structure

  - Height
  - Vertical distribution of canopy
  - Wildlife use
  - Good biomass estimates

  Difficult to estimate from optical sensors…

http://terraweb.forestry.oregonstate.edu/amresults.htm

Remote Sensing & Environmental Mgmt.

- Ecosystem modeling

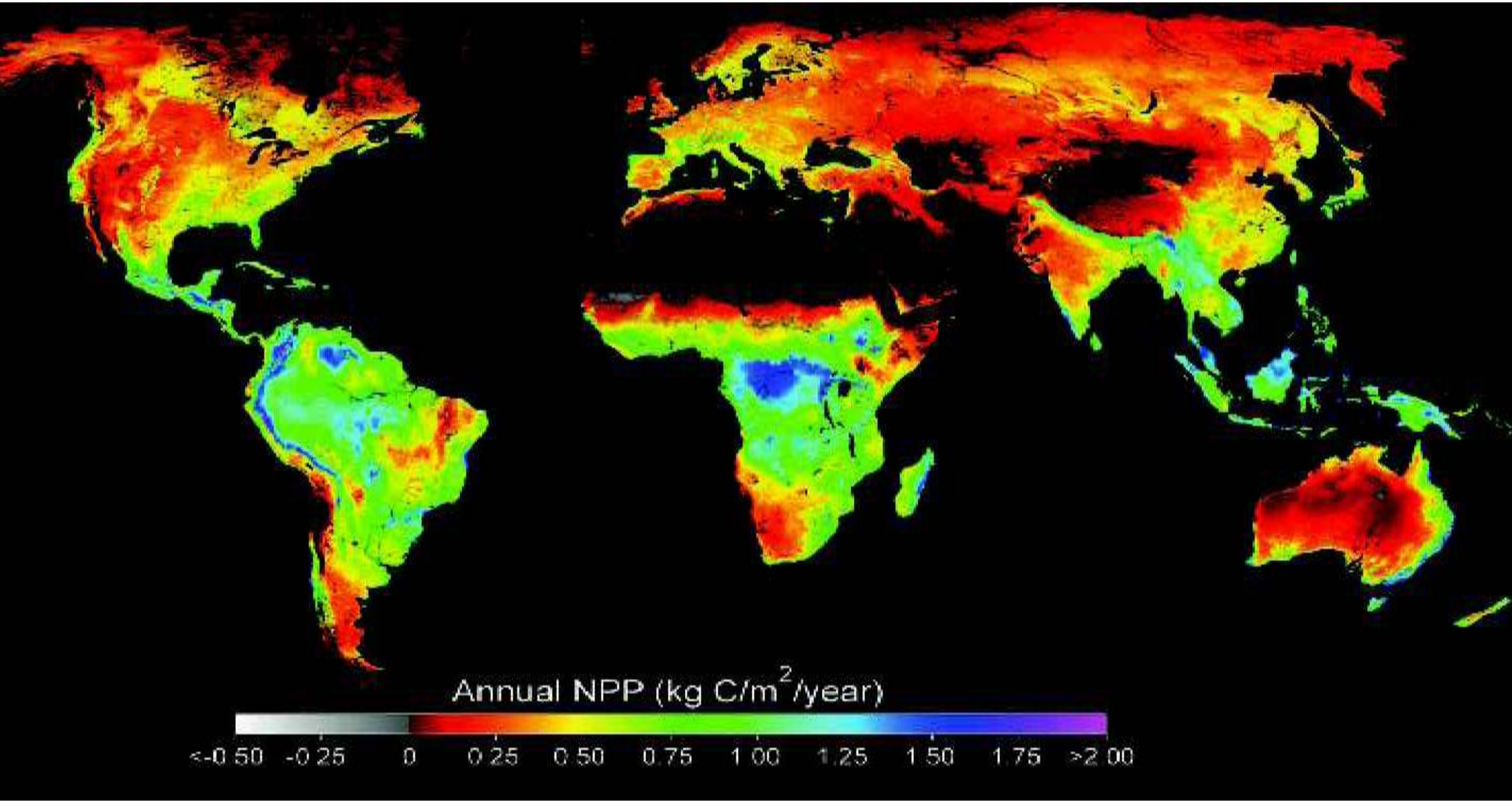
Input

- Land cover
- NDVI (Normalized Difference Vegetation Index)

Estimates

- APAR (absorbed photosynthetically active radiation)
- LAI (regulates stomatal gas exchange)
- NPP (net primary production)
- Standing biomass (carbon storage)

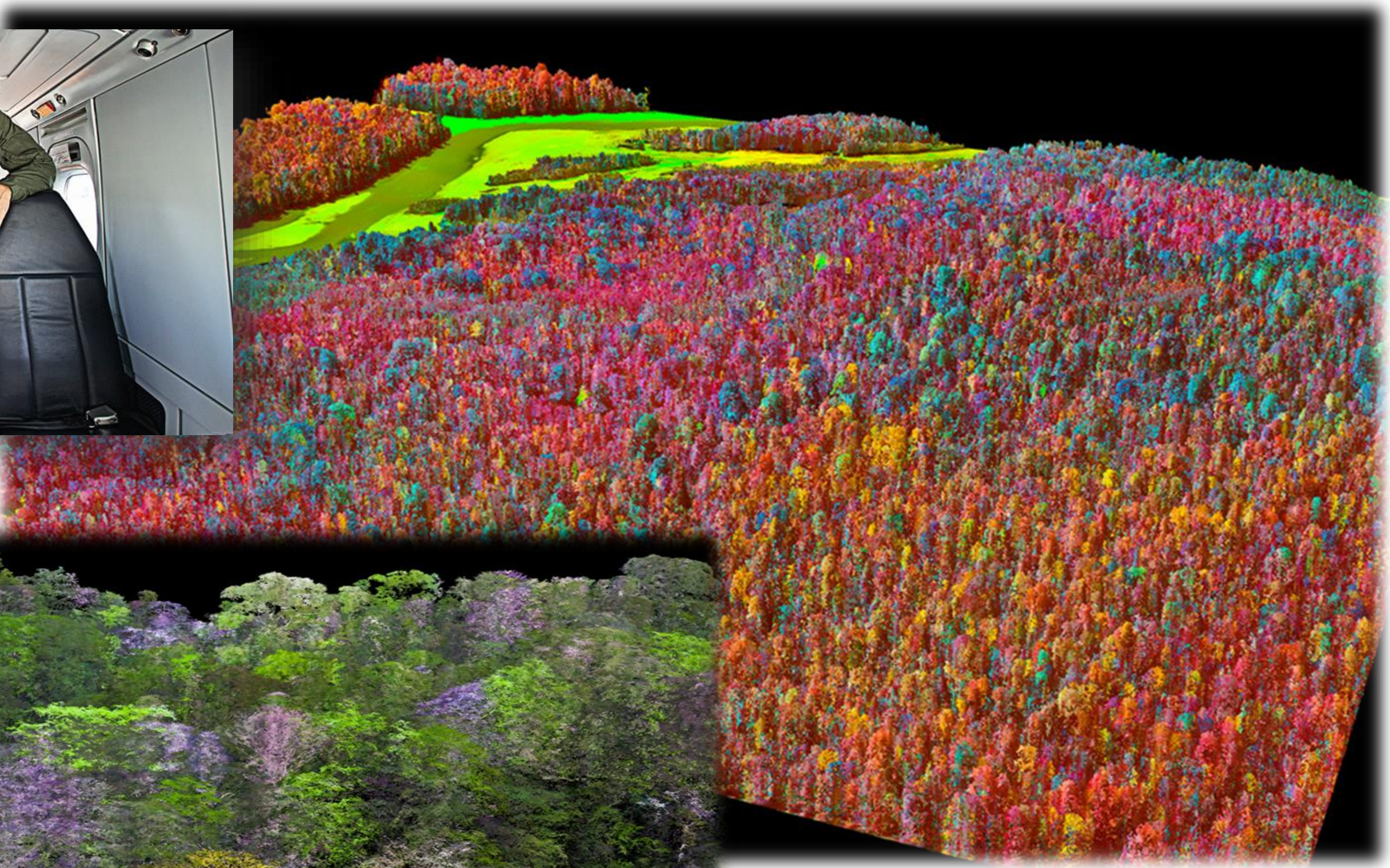
Remote Sensing & Environmental Mgmt.

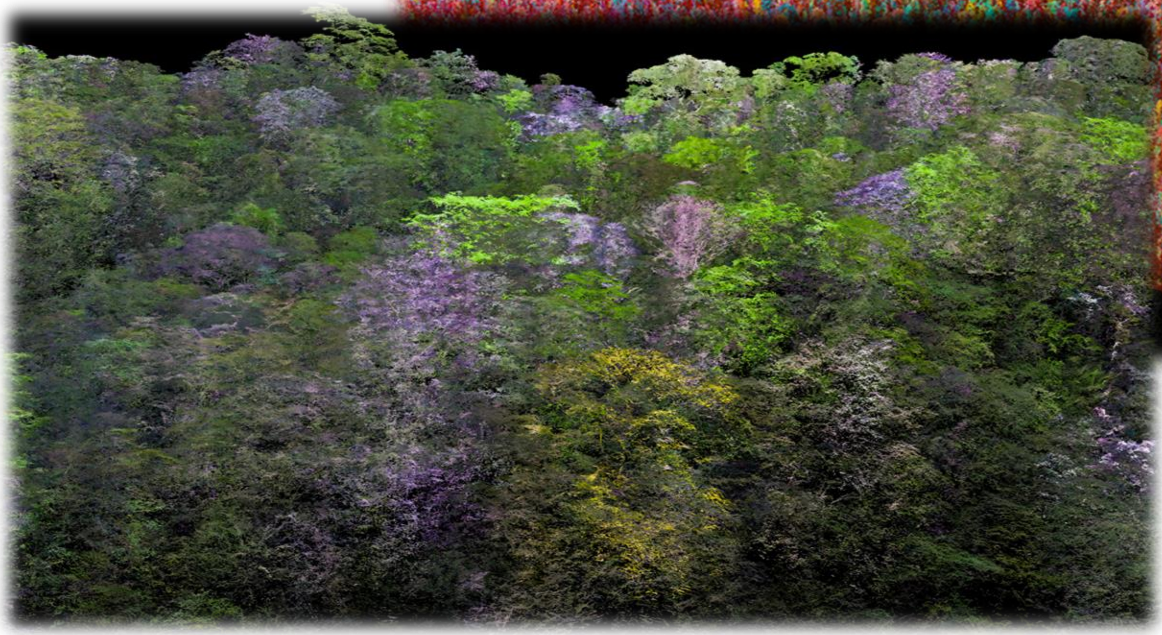


Global terrestrial net primary production (NPP) over 110 million square kilometers for 2002, computed from MODIS (Moderate Resolution Imaging Spectroradiometer) data.

CARNEGIE AIRBORNE OBSERVATORY

https://cao.carnegiescience.edu/



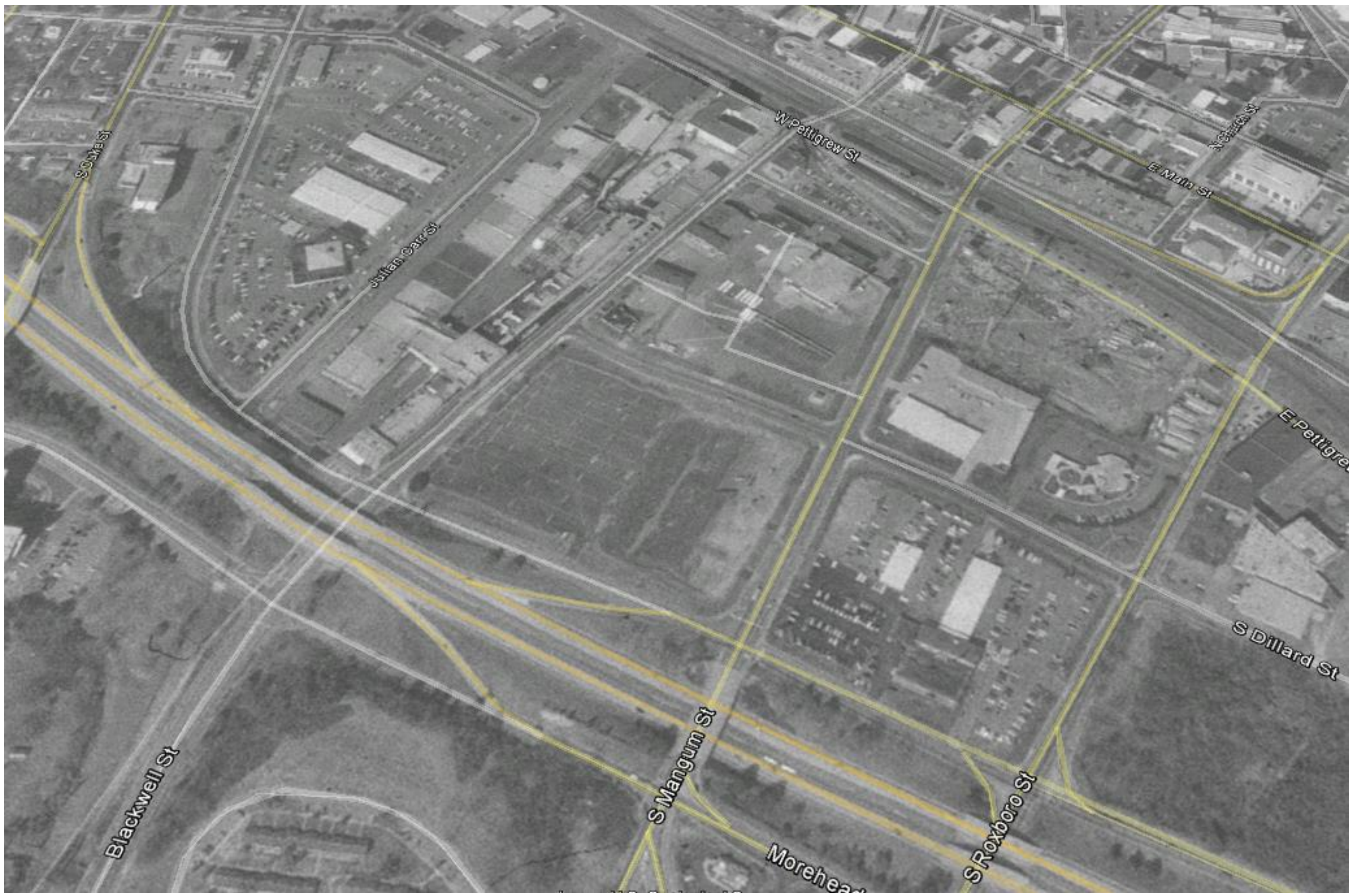


II. Change Detection & GIS

- What is change detection
- Methods for detecting change
- Lab Exercise…

What is change detection?

Identifying and quantifying changes in spatial features…



What is change detection?

Also, *categorizing change* (e.g., of land cover)

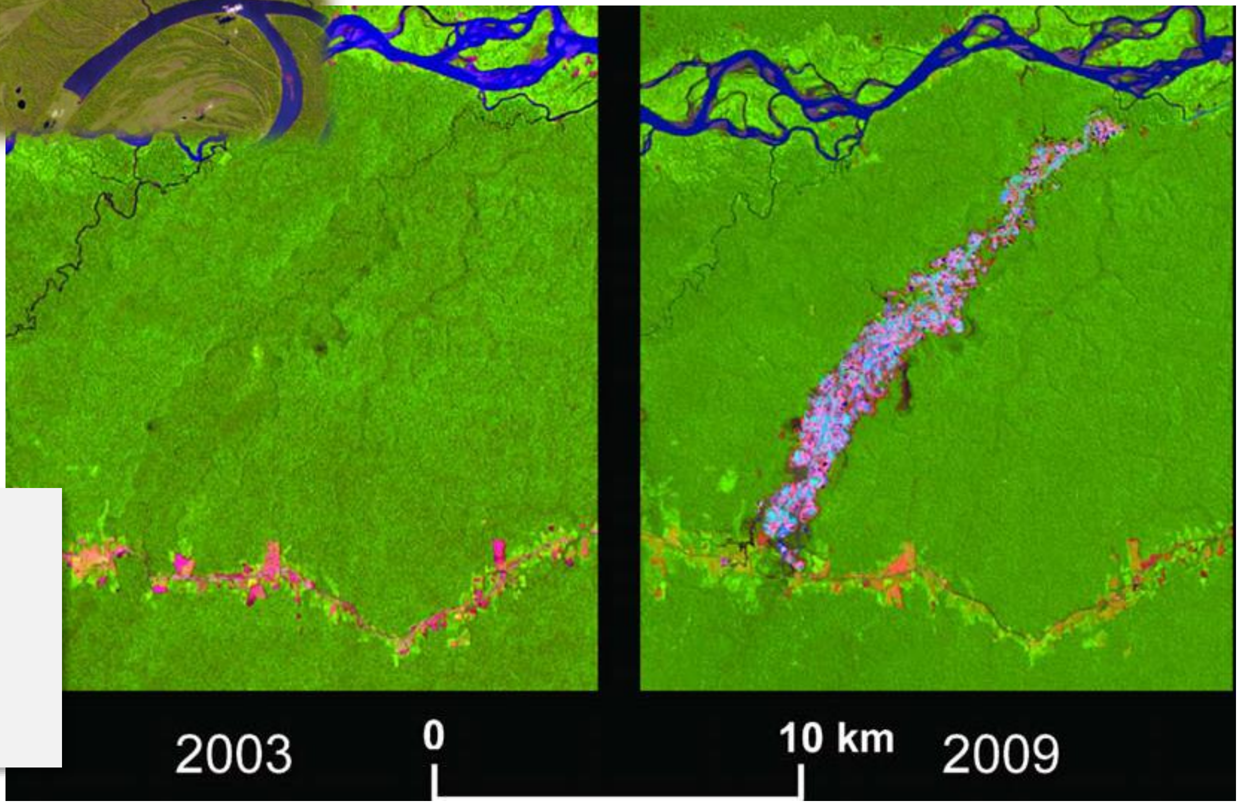
	Land cover/use in 2007								
Land cover/use in 1982	Cropland	CRP land	Pastureland	Rangeland	Forest land	Other rural land	Developed land	Water areas & Federal land	1982 total
Cropland	326,196.4 ±2,675.3	30,168.6 --	30,344.7 ±1,148.8	6,895.4 ±1,025.2	8,922.7 ±617.8	4,136.4 ±428.5	11,117.5 ±403.8	1,765.2 --	419,546.9 ±2,441.3
CRP land	--	--	--	--	--	--	--	--	--
Pastureland	18,526.6 ±1,055.1	1,351.6 --	78,372.2 ±2,050.0	5,085.3 ±943.5	17,760.5 ±1,039.9	2,036.1 ±384.5	6,845.0 ±338.0	919.0 --	130,896.3 ±1,493.8
Rangeland	7,430.8 ±1,292.5	1,124.5 --	3,369.1 ±719.4	391,615.0 ±3,681.9	3,379.4 ±802.1	2,272.5 ±565.5	5,201.0 ±544.1	3,507.2 --	417,899.5 ±3,741.7
Forest land	2,121.7 ±328.4	144.4 --	4,847.6 ±841.7	2,175.6 ±970.1	371,660.4 ±2,942.2	2,229.1 ±464.3	17,083.5 ±417.1	3,117.3 --	403,379.6 ±2,731.8
Other rural land	1,685.2 ±231.3	56.4 --	1,159.0 ±265.6	915.5 ±422.1	3,310.2 ±372.2	38,734.9 ±1,262.4	1,077.8 ±110.2	304.1 --	47,243.1 ±1,308.6
Developed land	264.1 ±22.3	0.0 --	163.7 ±19.1	176.6 ±22.9	442.6 ±27.7	18.4 ±6.9	69,896.9 ±783.7	1.8 --	70,964.1 ±779.7
Water areas & Federal land	798.7 --	4.7 --	359.4 --	2,256.0 --	934.6 --	212.2 --	29.5 --	443,139.6 --	447,734.7 --
2007 total	357,023.5 ±2,688.7	32,850.2 --	118,615.7 ±2,347.0	409,119.4 ±3,992.9	406,410.4 ±3,065.4	49,639.6 ±1,359.1	111,251.2 ±1,499.4	452,754.2 --	1,937,664.2 ±163.8

Summary Report
2007 National Resources Inventory
December 2009

Change detection & environmental mgmt.

Riparian dynamics

Brazilian Amazon meandering river and oxbow lakes



Human footprints

Peruvian Amazon, Swenson et al. 2011

Change detection & environmental mgmt.

- Are protected areas being protected?

March 22, 2004

Change detection & environmental mgmt.

- CO_2 offsets: *Additionality* calculations…

NICHOLAS INSTITUTE FOR ENVIRONMENTAL POLICY SOLUTIONS
DUKE UNIVERSITY

Reforestation Afforestation Project Carbon On-Line Estimator

Welcome to the Reforestation/Afforestation Project Carbon On-Line Estimator (RAPCOE)

The Reforestation/Afforestation Project Carbon On-line Estimator allows you to estimate the net carbon offset produced by a reforestation or an afforestation project in the United States. For the purposes of this tool, reforestation and afforestion are the same activity, that of converting cropland and/or pasture to forest. The net offset is equivalent to the amount of carbon sequestered by the conversion to forest (gross carbon offset), less the amount of carbon estimated to have been sequestered had no project occurred (baseline), and less any CO2 released elsewhere as a result of this project occurring (leakage deduction).

With this tool, net offsets can be estimated for both (1) proposed reforestation/afforestation projects, for which gross offsets are not known and must be estimated from existing carbon stock accumulation tables (pre-project planning)-- and (2) projects already underway -- where the gross offsets have been measured or verified (post-project monitoring). Click the appropriate tab below to choose the net offset calculation you wish to execute.

Pre-project planning tool

Click to estimate net offsets for a planned project.

Post-project monitoring tool

Click to estimate net offsets for an existing project with known gross carbon

Project Status Reset

Project location:

State:

County:

MLRA:

Baseline afforestation rates:

From cropland: -

From pasture: -

Leakage rate:

-

Areas planted:

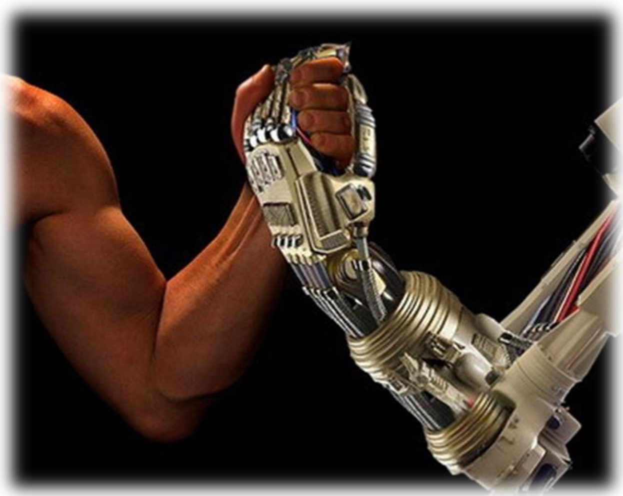
Cropland: -

Pasture -

RAPCOE v.1.0 © 2007 This product was prepared under contract to the U.S. Environmental Protection Agency

How to detect change?

- **Data:**
  - Two or more snapshots in time…
- **Techniques:**
  - Identify difference in these snapshots…

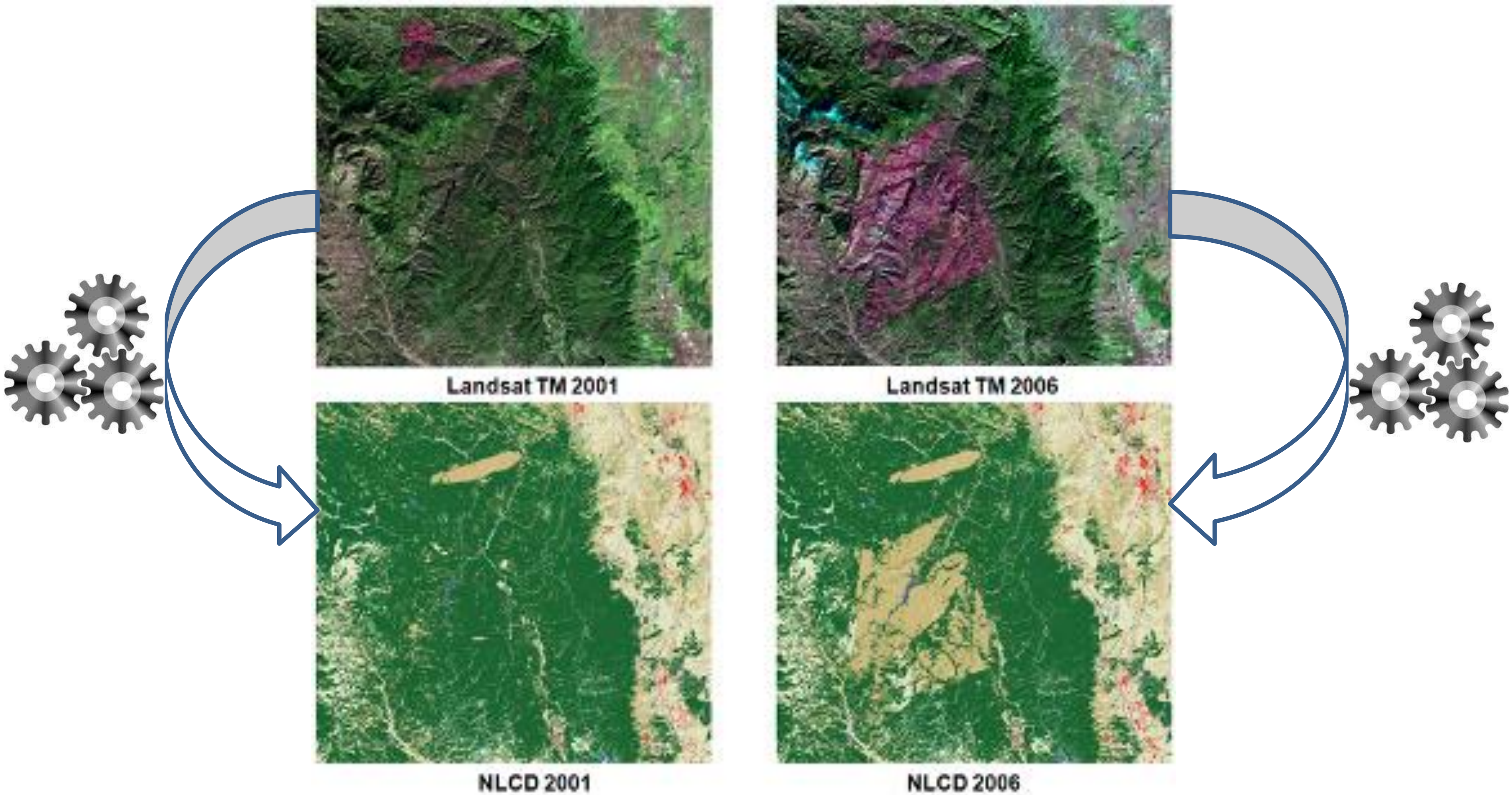


Simple, right?

Well, perhaps not…

Detecting change: Data

- Remotely sensed imagery:

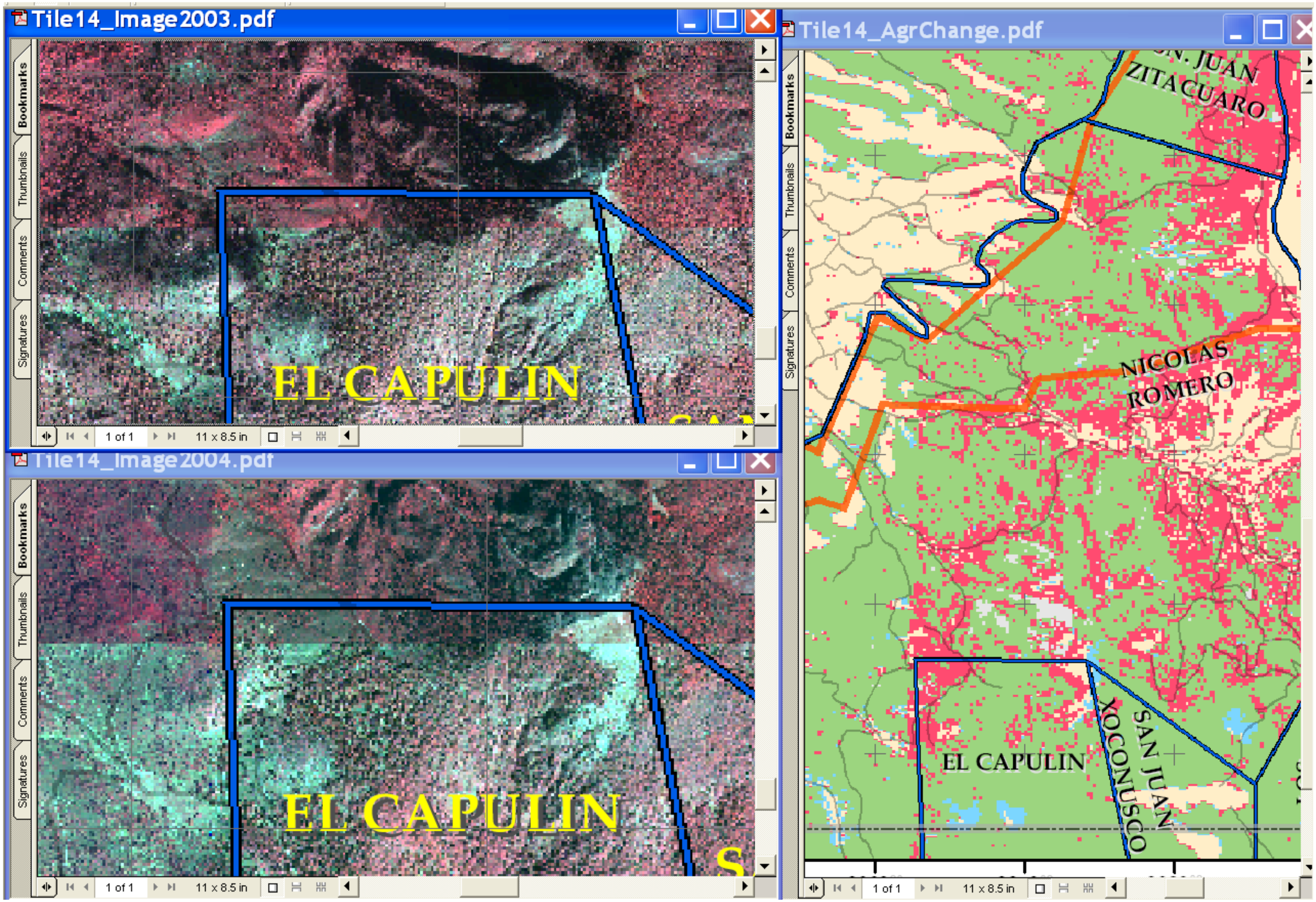


Detecting change: Data

- Data should be acquired:
  - *On anniversary dates*
  - *At the same time of day*
  - *Same sensor*
  - *Same bands & resolution*

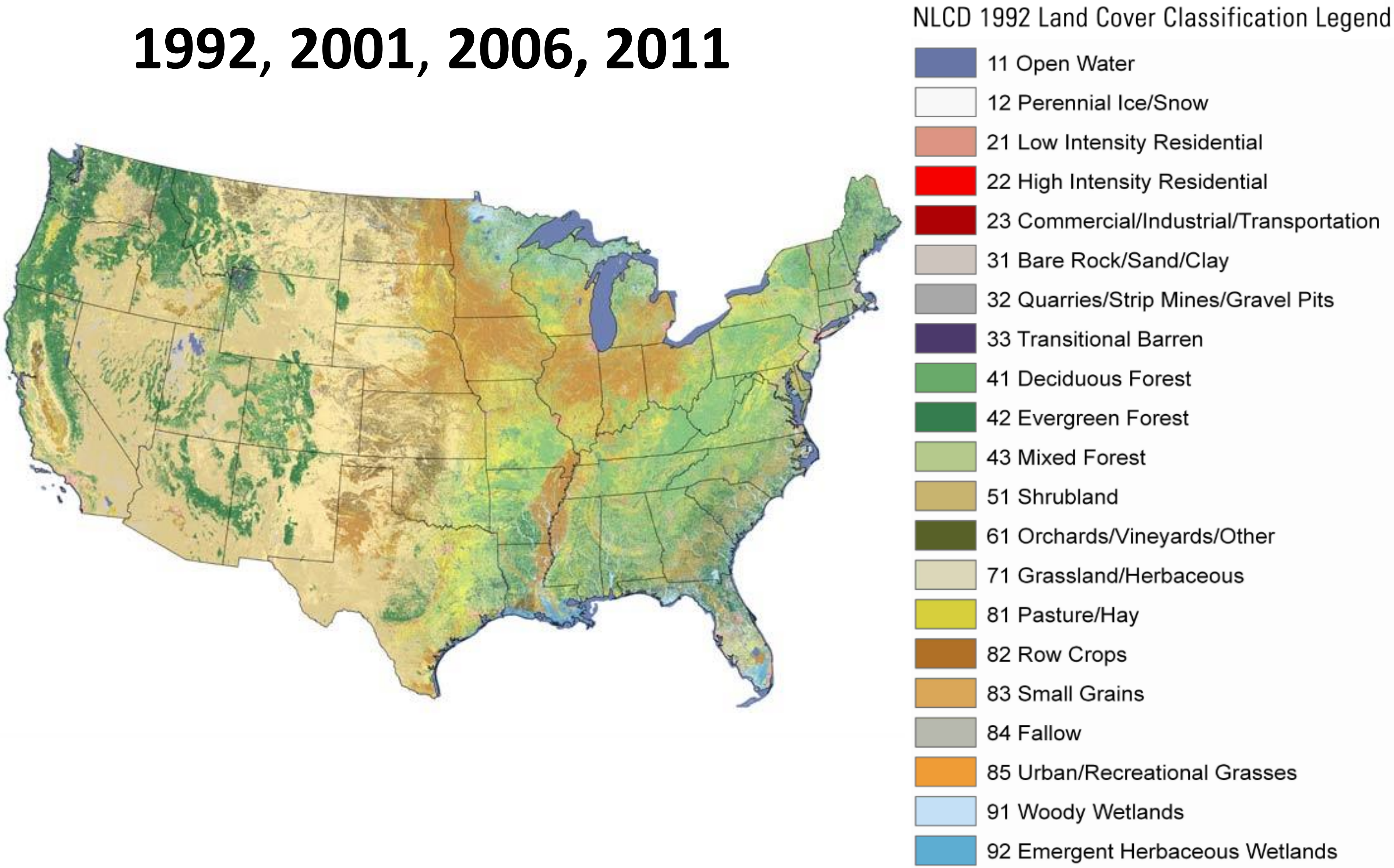
- Images should be:
  - *Precisely registered*
  - *Correctly calibrated (radiometrically corrected)*

Detecting change: Data



Change detection with NLCD

1992, 2001, 2006, 2011



NLCD classifications

NLCD 1992 Land Cover Classification Legend

- 11 Open Water
- 12 Perennial Ice/Snow
- 21 Low Intensity Residential
- 22 High Intensity Residential
- 23 Commercial/Industrial/Transportation
- 31 Bare Rock/Sand/Clay
- 32 Quarries/Strip Mines/Gravel Pits
- 33 Transitional Barren
- 41 Deciduous Forest
- 42 Evergreen Forest
- 43 Mixed Forest
- 51 Shrubland
- 61 Orchards/Vineyards/Other
- 71 Grassland/Herbaceous
- 81 Pasture/Hay
- 82 Row Crops
- 83 Small Grains
- 84 Fallow
- 85 Urban/Recreational Grasses
- 91 Woody Wetlands
- 92 Emergent Herbaceous Wetlands

NLCD Land Cover Classification Legend

- 11 Open Water
- 12 Perennial Ice/ Snow
- 21 Developed, Open Space
- 22 Developed, Low Intensity
- 23 Developed, Medium Intensity
- 24 Developed, High Intensity
- 31 Barren Land (Rock/Sand/Clay)
- 41 Deciduous Forest
- 42 Evergreen Forest
- 43 Mixed Forest
- 51 Dwarf Scrub*
- 52 Shrub/Scrub
- 71 Grassland/Herbaceous
- 72 Sedge/Herbaceous*
- 73 Lichens*
- 74 Moss*
- 81 Pasture/Hay
- 82 Cultivated Crops
- 90 Woody Wetlands
- 95 Emergent Herbaceous Wetlands

Change detection with NLCD

http://www.epa.gov/mrlc/change.html

NLCD Change (NLCD 1992 versus NLCD 2001)

Direct, pixel-to-pixel comparison of NLCD 1992 and NLCD 2001 land cover is not recommended for several reasons: 1) NLCD 1992 was based on an unsupervised classification algorithm, whereas NLCD 2001 was based on a supervised classification and regression tree algorithm; 2) terrain corrections were based digital elevation models (DEM) with a 90-meter spatial resolution for NLCD 1992, whereas terrain correction for NLCD 2001 used 30-meter DEMs; 3) the impervious surface mapping that is part of NLCD 2001 resulted in the identification of many more roads than could be identified in NLCD 1992, however, most of these roads were present in 1992; 4) NLCD 2001 imagery was corrected for atmospheric effects prior to classification, whereas NLCD 1992 imagery was not, and; 5) there are subtle differences between the NLCD 1992 and NLCD 2001 land-cover legends. These factors result in substantially different pixel-by-pixel labeling in the two dataset, much of which is probably not genuine land-cover change, as shown in the pictures below.

Direct, pixel-to-pixel comparison of NLCD 1992 and NLCD 2001 land cover is not recommended

1992	2001, 2006, 2011
Unsupervised	Supervised
90 m DEMs	30 m DEMs
No atmospheric correction	Atmospherically corrected
Fewer features identified	More feature identified

Change detection with NLCD

NLCD 1992/2001 Retrofit Land Cover Change Product

http://www.mrlc.gov/nlcdrlc.php

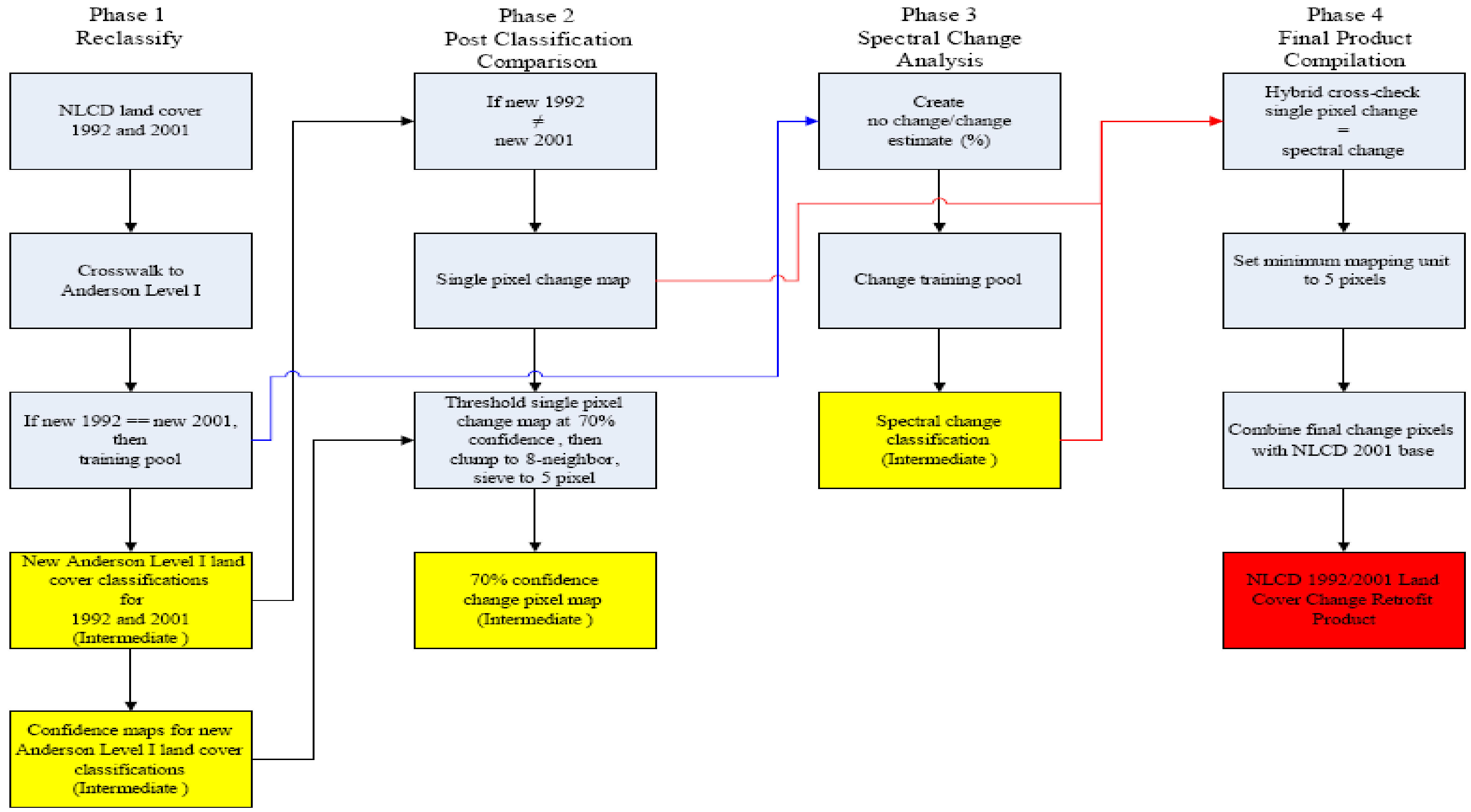


Figure 1. Generalized processing flow for the National Land Cover Database (NLCD)—Land Cover Change Retrofit (LCCR) product. The blue and red flow lines indicate additional use of the intermediate product in a later process step.

Change detection with NLCD

NLCD 1992/2001 Retrofit Land Cover Change Product

http://www.mrlc.gov/nlcdrlc.php

Table 2. National Land Cover Database Land Cover Change Retrofit (NLCD–LCCR) "from-to" class code matrix. The first number in the code is the 1992 "from" retrofit land cover class code and the second number in the code is the 2001 "to" retrofit land cover class code. (More detail regarding NLCD–LCCR change class codes is available from the Multi-Resolution Land Characteristics (MRLC) Consortium at: *http://www.mrlc.gov*)

[ALI, Anderson Level I]

			2001 "to" class							
			Open water	Urban	Barren	Forest	Grass/ shrub	Agricul- ture	Wetlands	Ice/snow
		ALI	1	2	3	4	5	6	7	8
1992 "from" class	Open water	1		12	13	14	15	16	17	18
	Urban	2	21		23	24	25	26	27	28
	Barren	3	31	32		34	35	36	37	38
	Forest	4	41	42	43		45	46	47	48
	Grass/shrub	5	51	52	53	54		56	57	58
	Agriculture	6	61	62	63	64	65		67	68
	Wetland	7	71	72	73	74	75	76		78
	Ice/snow	8	81	82	83	84	85	86	87	

Change detection with NLCD

NLCD 1992/2001 Retrofit Land Cover Change Product

http://www.mrlc.gov/nlcdrlc.php

Table 3. Change results matrix for the conterminous United States. Unchanged pixels are a percentage of all pixels, while changed pixels are a percentage of all changed pixels.

[%, percent]

1992 "from" class	2001 "to" class: Open water (%)	Urban (%)	Barren (%)	Forest (%)	Grass/shrub (%)	Agriculture (%)	Wetlands (%)	Ice/snow (%)	Row totals (%)
Unchanged									
	5.03	4.86	1.13	25.22	34.48	21.79	4.48	0.02	**97.01**
Changed									
Open water		0.06	0.49	0.15	0.60	0.46	0.87	0	**2.63**
Urban	0.13		.02	.17	.12	.48	.13	0	**1.05**
Barren	.25	.04		.06	.34	.08	.06	.01	**.84**
Forest	.42	3.53	.99		23.09	10.31	2.46	0	**40.80**
Grass/shrub	1.30	1.54	.61	6.66		11.39	1.84	.12	**23.46**
Agriculture	2.60	3.00	.26	7.16	10.87		3.03	0	**26.92**
Wetland	.70	.38	.09	.97	.96	1.13		0	**4.23**
Ice/snow	0	.00	.02	0	.05	0	0		**.07**
Column totals	**5.40**	**8.55**	**2.48**	**15.17**	**36.03**	**23.85**	**8.39**	**.13**	**100.00**

Change detection with NLCD - 2006

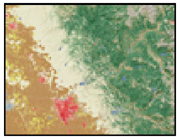
http://www.mrlc.gov/nlcd06_data.php

National Land Cover Database 2006 (NLCD2006)

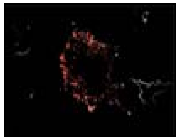
Product Data Downloads

NOTE: NLCD2001 Version 2.0 products must be used in any comparison of NLCD2001 and NLCD2006 products.

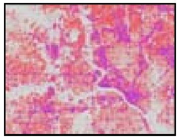
Conterminous United States



NLCD2006 Land Cover (1.1Gb)
The 2006 land cover layer for the conterminous United States for all pixels.



NLCD2006 Land Cover Change (99.5MB)
Land cover layer containing only those pixels identified as changed between NLCD2001 Land Cover Version 2.0 and NLCD2006 Land Cover products for the conterminous United States.



NLCD2006 Percent Developed Imperviousness (696MB)
An updated circa 2006 percent developed imperviousness estimate layer for the conterminous United States for all pixels.

NLCD2006 From – To Change Index (1.25Gb)
A raster layer identifying a from and to land cover class index value label for each pixel in the conterminous United States based on a matrix for all possible land cover class label change combinations.

Beyond NLCD…

Long-term land cover dynamics by multi-temporal classification across the Landsat-5 record

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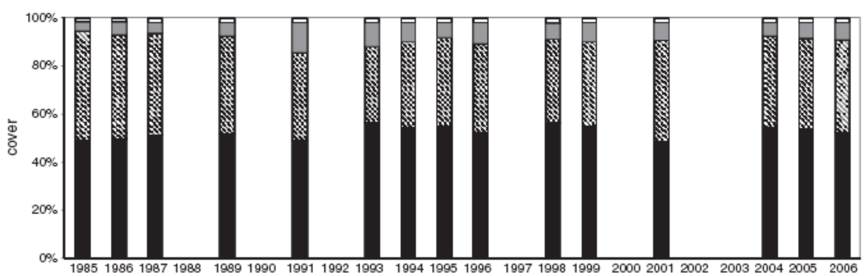
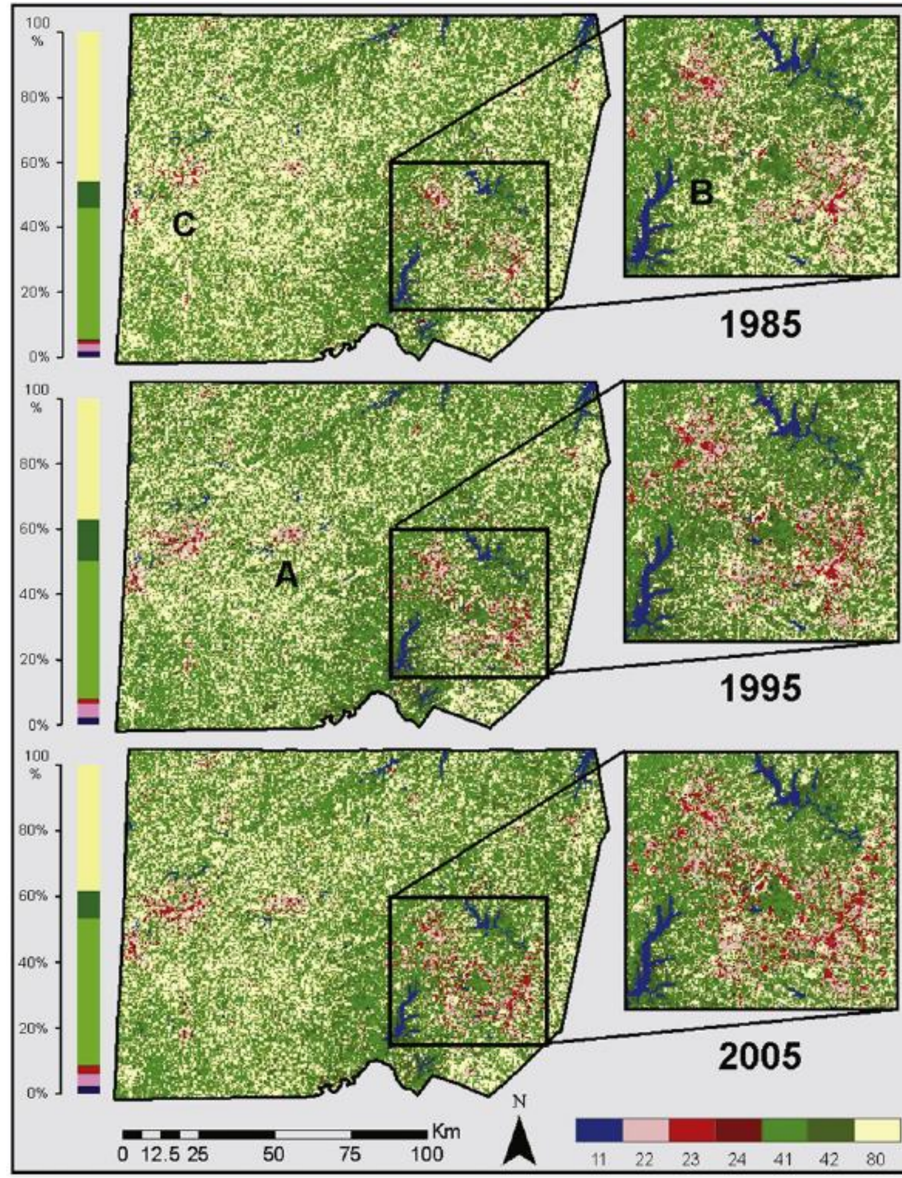
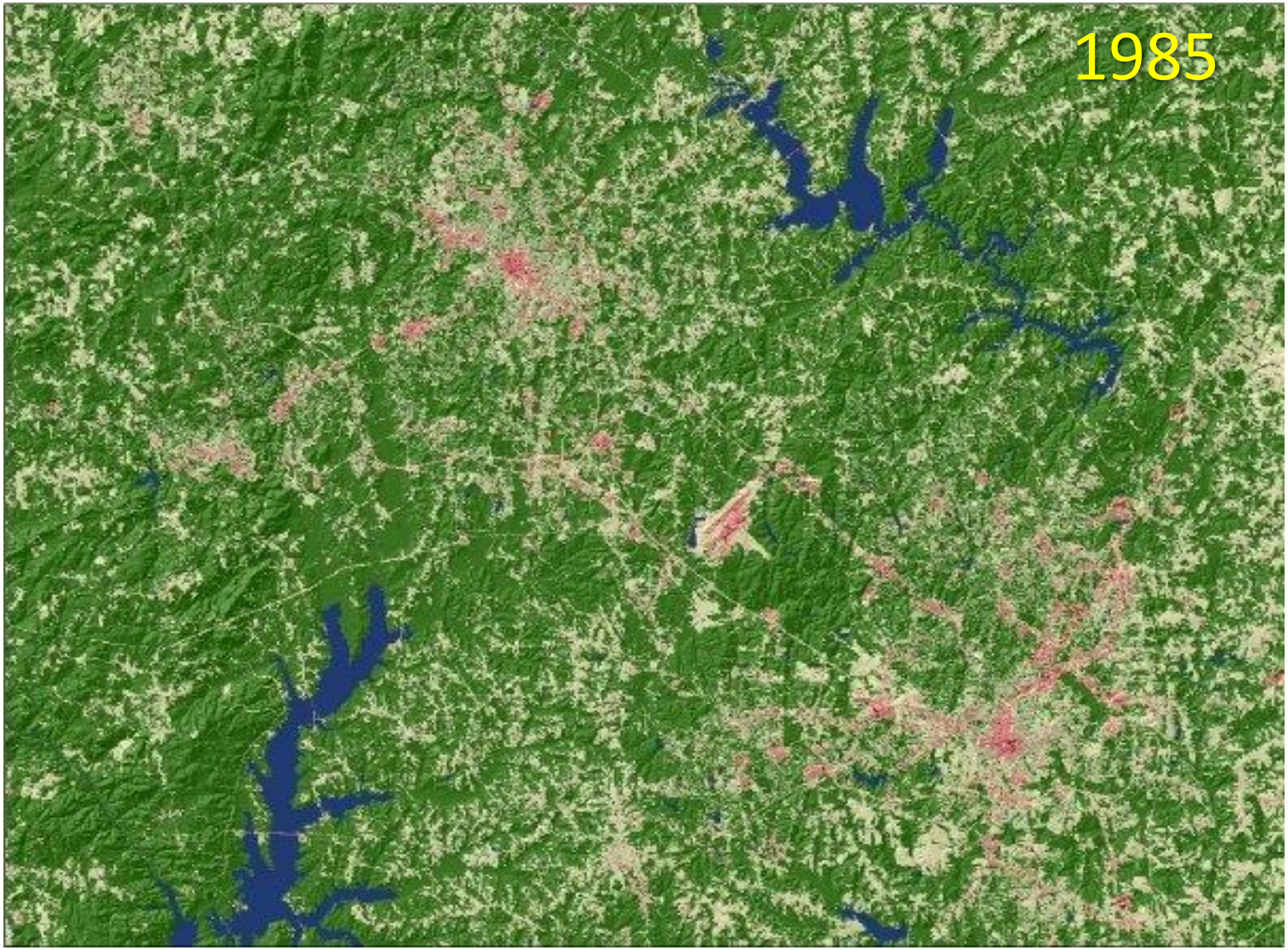


	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
□Water	1.8	1.8	1.9		2.1		2.1		2.1	2.1	2.1	2.1		2.2	2.1		2.1			2.0	2.1	2.1
▥Urban	3	5	5		6		12		10	8	6	8		7	8		7			6	6	7
▨Field	46	44	42		41		37		32	36	37	37		35	35		42			38	38	39
■Forest	49	49	51		52		49		56	54	55	52		56	55		49			54	53	52

Fig. 5. Landcover change among generalized classes within the study area from 1985 to 2006.



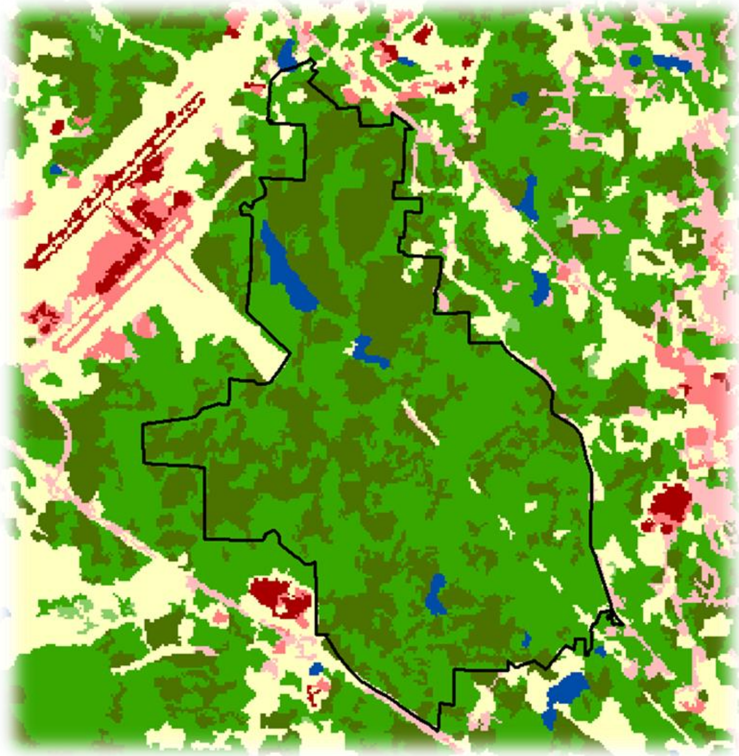
Land use change in the Triangle



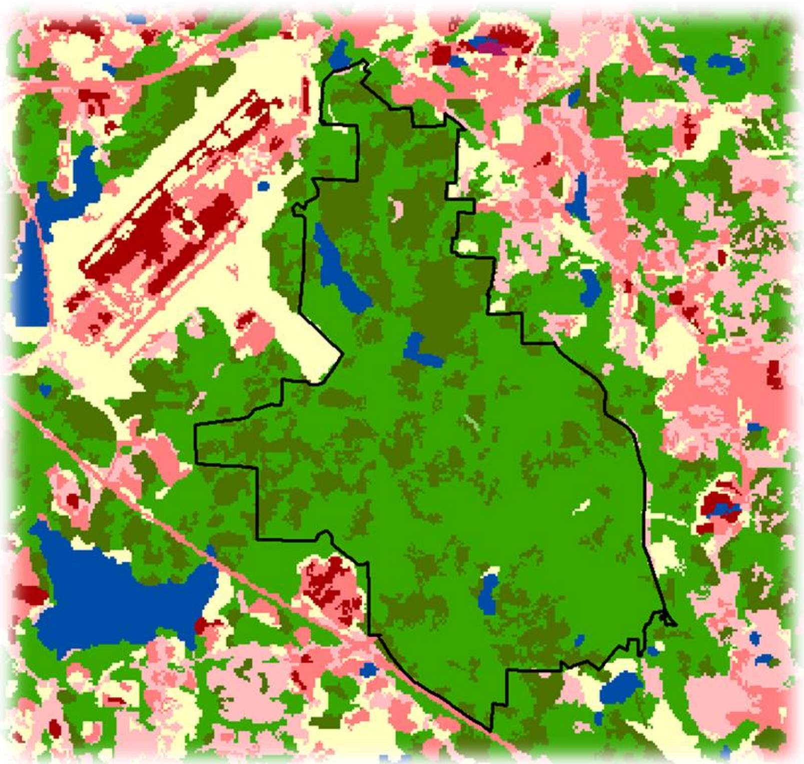
Credit: Joe Sexton (PhD '09) and Mike Donohue (MEM '08)

This week's lab exercise…

- Encroaching development



1985



2005

Measuring change

Discrete change: change in type

- land cover conversion (deforestation, development)
- detection depends on how the types are defined

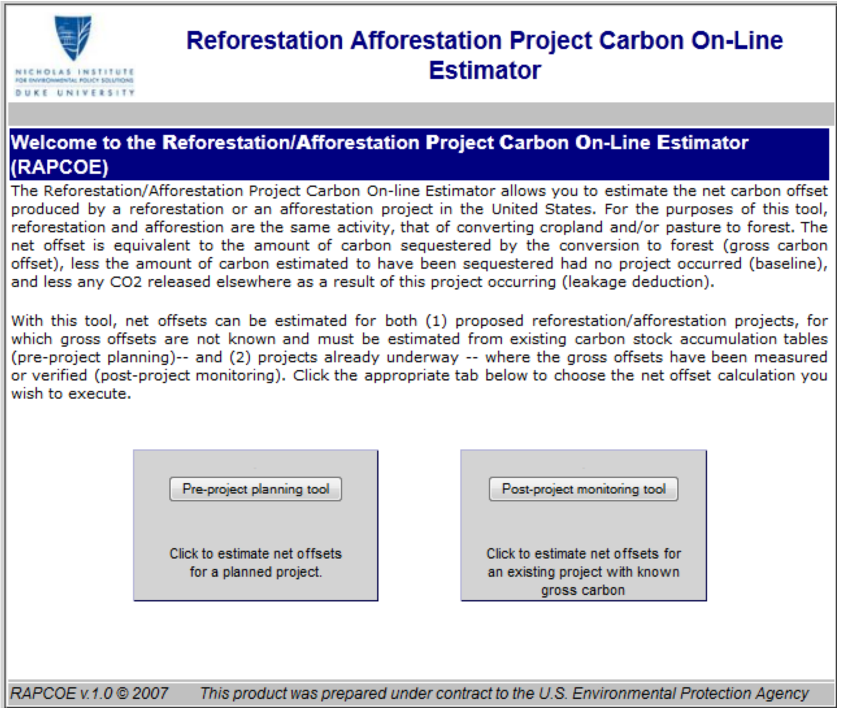
Continuous change: change in condition

- biomass accumulation
- changes in leaf area, canopy structure
- changes in fuel loads or understory density
- changes in species composition

Discrete change

Detection:

- Create <u>difference maps</u> from two time periods
- Recode the changes to make visual sense
  - forest → developed
  - ag → developed
  - ag → forest
  - and so on …
- The *pattern* of change is interesting:
  - where are the changes?
  - patch sizes?



Discrete change

Summary:

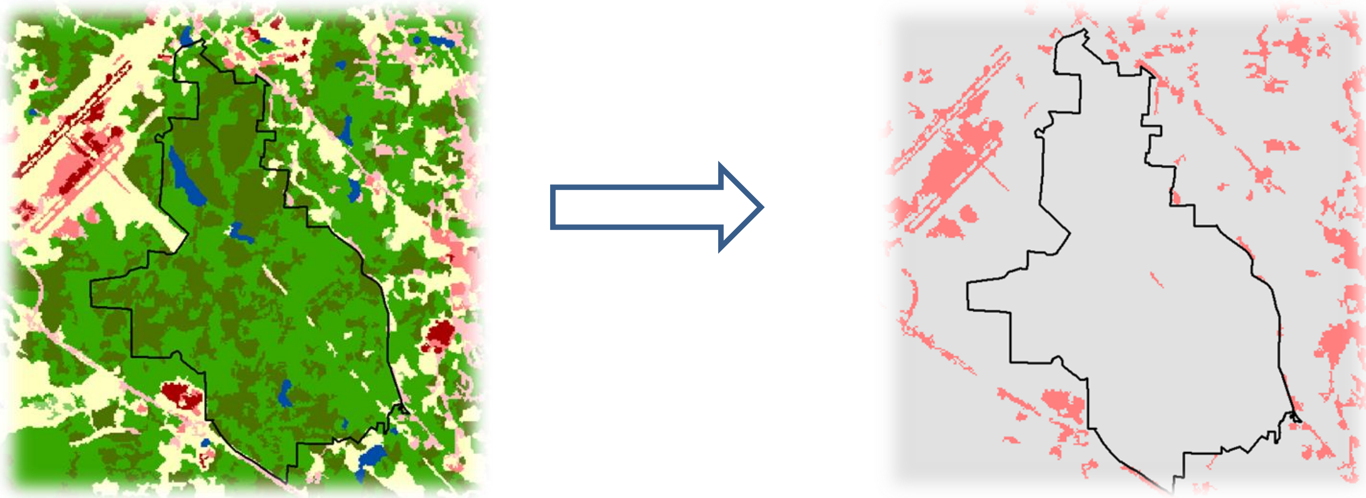
- Tally type per sample in each time period
- Construct transition matrix (Markov model):

from:

to:	1	2	3	4	5
1					
2					
3					
4					
5					

Change in the triangle → Development

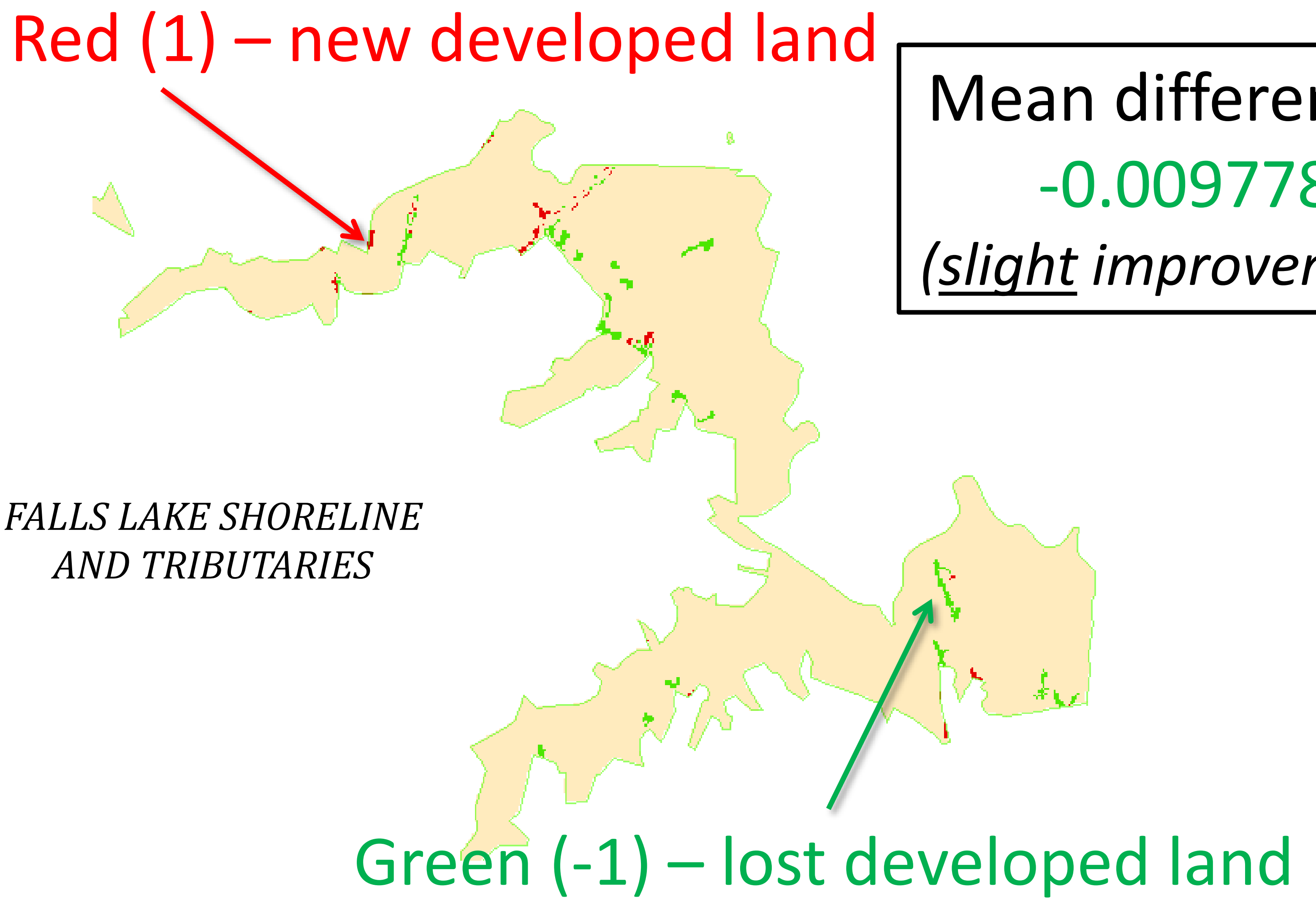
1. Convert land cover maps into binary developed, not-developed maps



2. Subtract early date (1985) from later date (2005)

	2005	
1985	**Developed (1)**	**Non-Developed (0)**
Developed (1)	0	-1
Not-Developed (0)	1	0

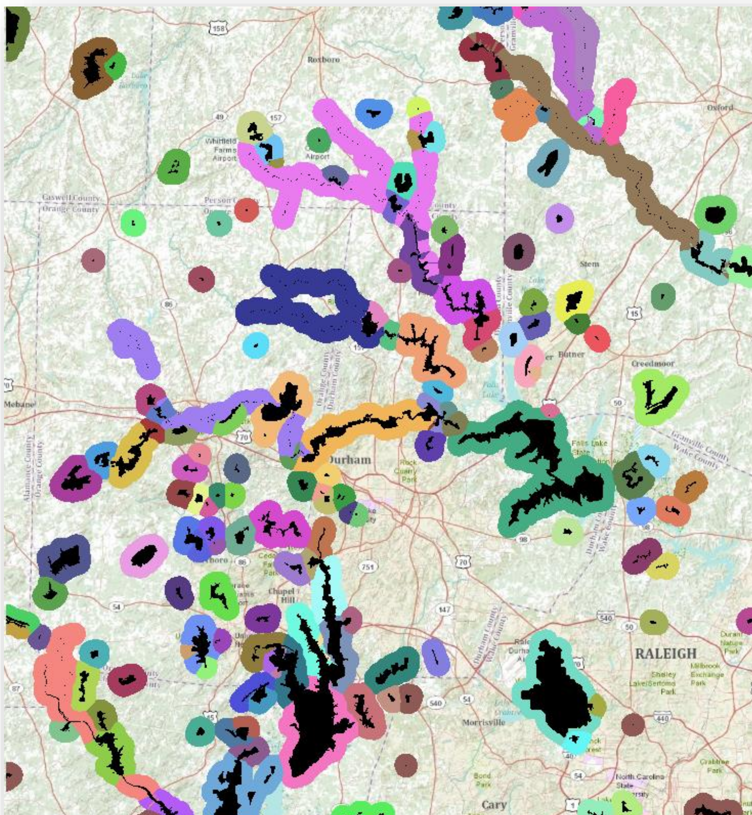
Measuring Change

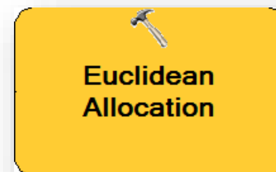


Mean difference:
-0.009778
(slight improvement)

Encroachment

<u>Method 1</u>:
Extend the boundaries of the SNHA's and tabulate the net gain/loss of developed area within a set proximity (e.g. 1km).



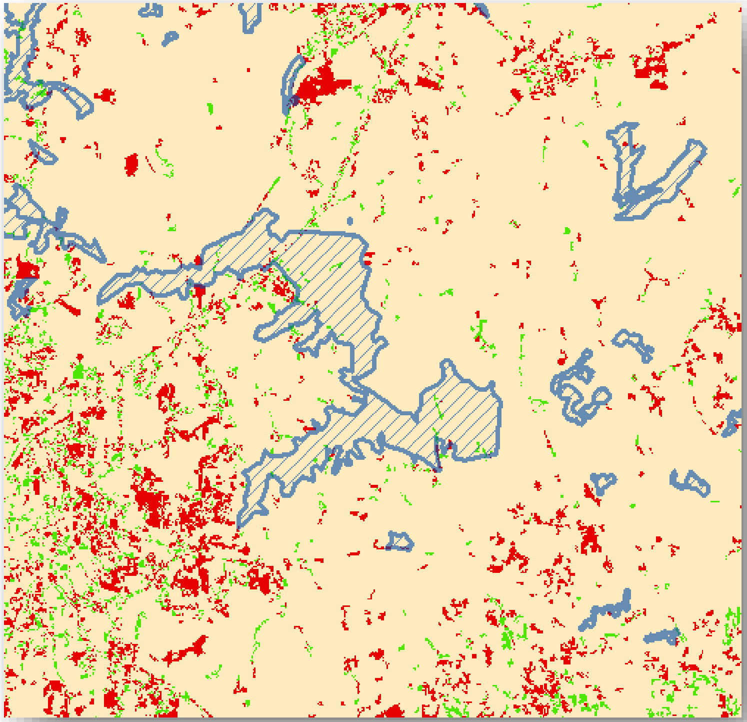


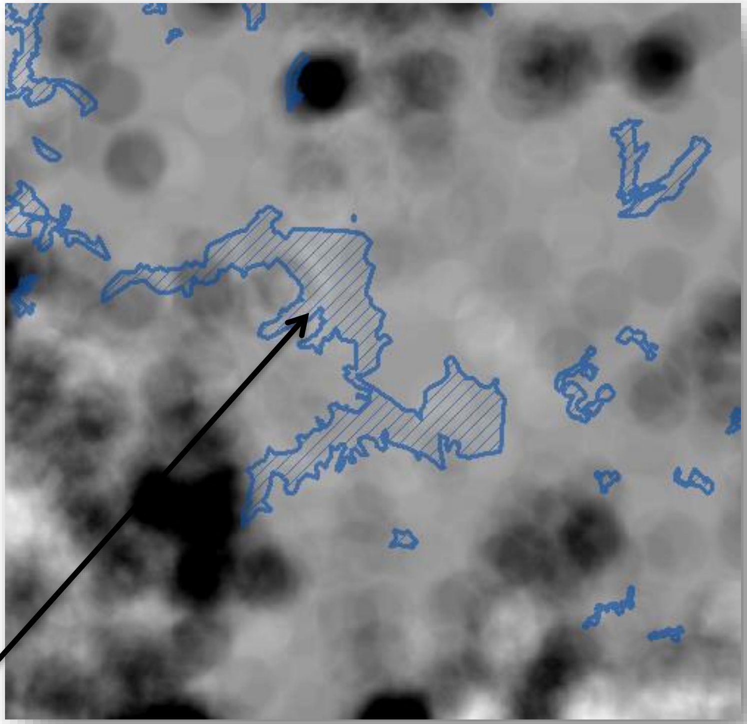
Then measure the mean of the developed gain/loss values within the adjacent areas.

Encroachment

Method 2:

Use focal analysis to extend the influence of developed gain/loss into the SNHA…





Mean value = 0.000331

Assignment: Discrete change

- For each method, indicate (e.g. via a map legend) the SNHAs with top 20% most encroaching development over the period of 1985 to 2005? Which comprise the lowest 20%?
- Do both approaches indicate the same SNHAs in the most encroached 20%?
- What drawbacks, if any, are there in using the Euclidean allocation approach?
- What drawbacks, if any, are there in using the focal statistic approach?
- A third approach involves creating 1km *vector* buffers from each SNHA polygon. What would be the major challenge in using this approach? Can this challenge be overcome? If so how? If not, why not.

Discrete vs. Continuous Change

- Discrete change, while dramatic, can miss subtle (continuous) changes in ecological condition
  - natural succession or disturbances
  - effects of management or restoration efforts

- Conservationists are often more interested in *condition* than *type*
  - measurement involves similar data collection methods
  - the analytic framework is slightly different

Continuous change: Lab Exercise

- Evaluate forest quality (greenness) within SNHAs
  - In which SNHAs are forests regenerating?
  - Are there SNHAs where forests are declining?
  - Are the new forests evergreen or deciduous?

Measuring Continuous Change

- NDVI → Greenness

- Evaluate the change in greenness over time
  - Subtract 1985 NDVI from 2005
    - Positive values → gain in greenness over time

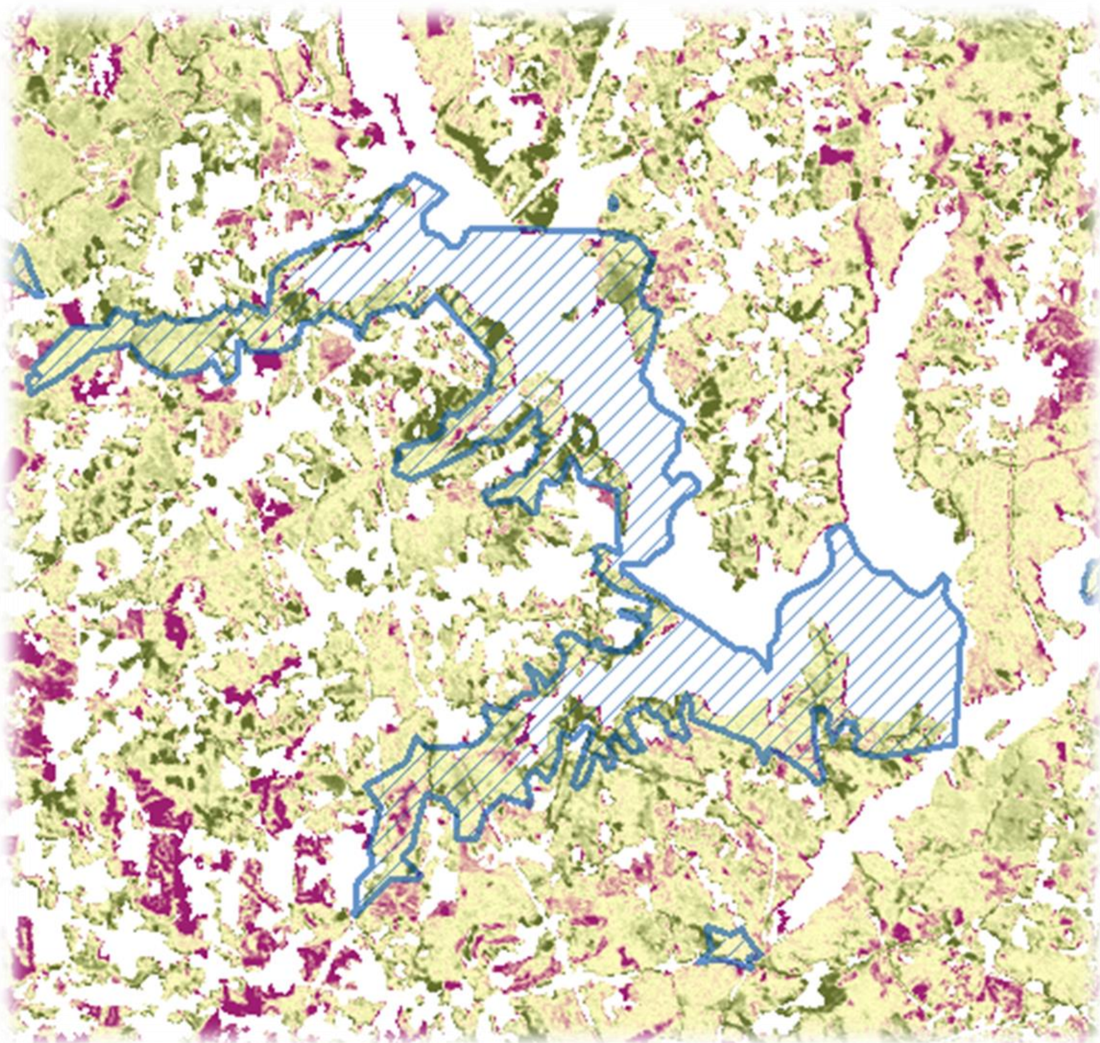
  - Examine only forest pixels; change in greenness in other types are not interesting ecologically

  - Compare summer to summer, winter to winter
    - Positive values in summer difference → increase in forest
    - Positive values in winter → increase in evergreen only
    - Δ Summer - Δ Winter → increase in deciduous only?

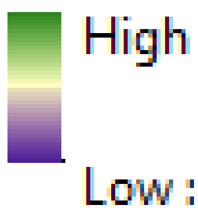
Change in NDVI

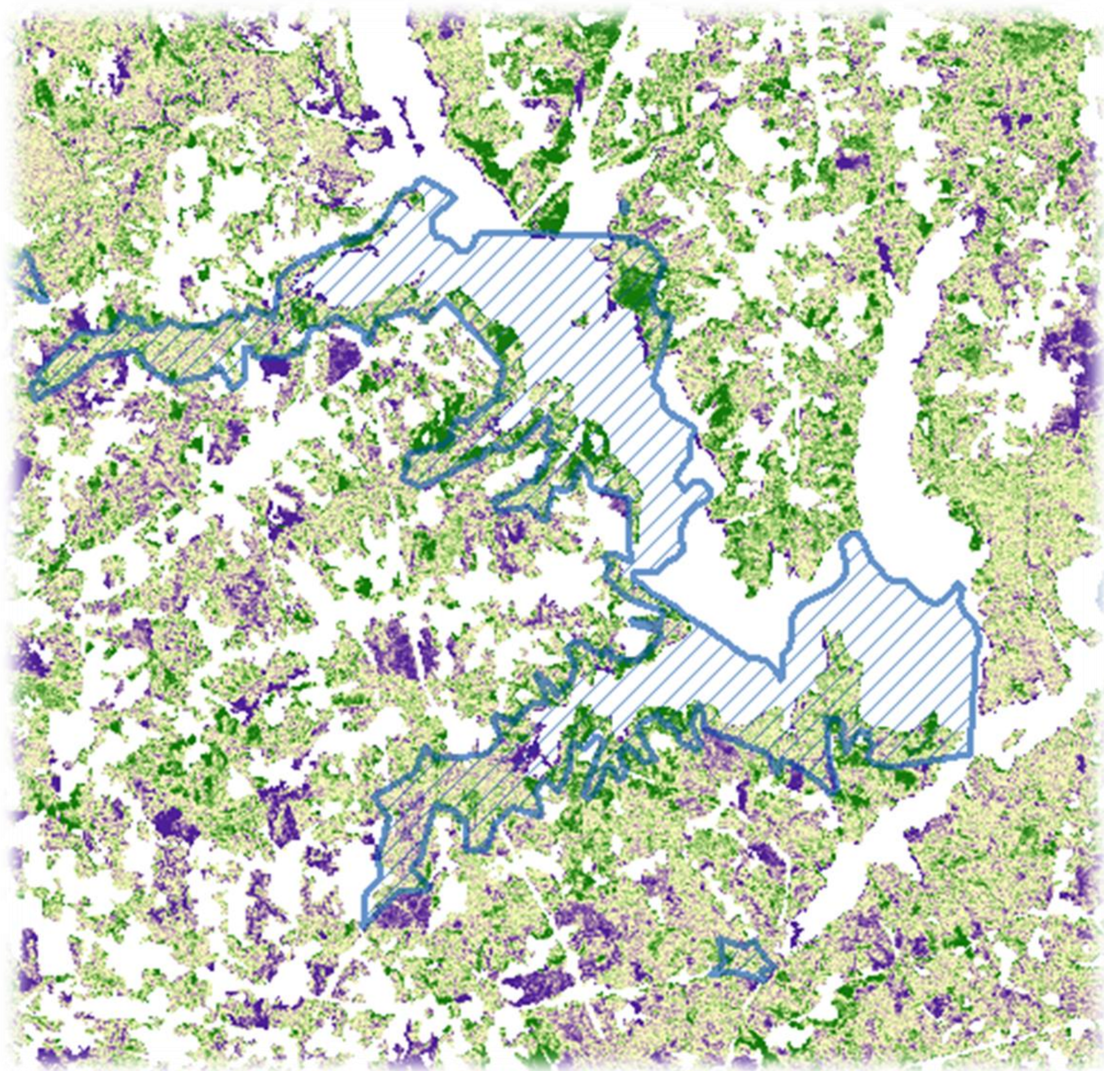
- Isolate pixels that were forest in either 1985 or 2005.
  - Other areas will change in greenness, but we’re not concerned
- Subtract 1985 NDVI from 2005 NDVI within those areas
  - Difference in summer NDVI → All forest types
  - Difference in winter NDVI → Evergreen only

Change in Summer NDVI

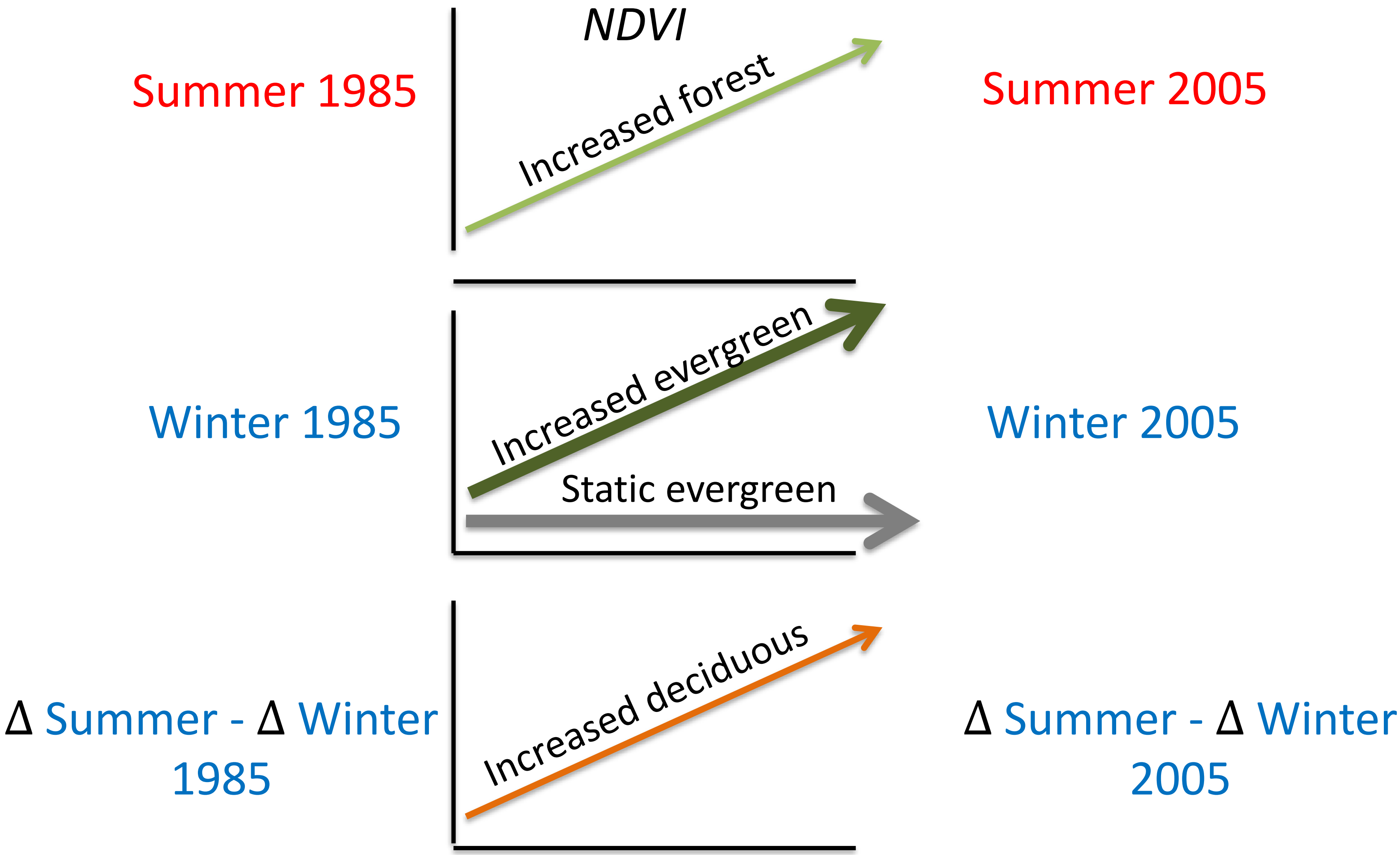


Change in Winter NDVI

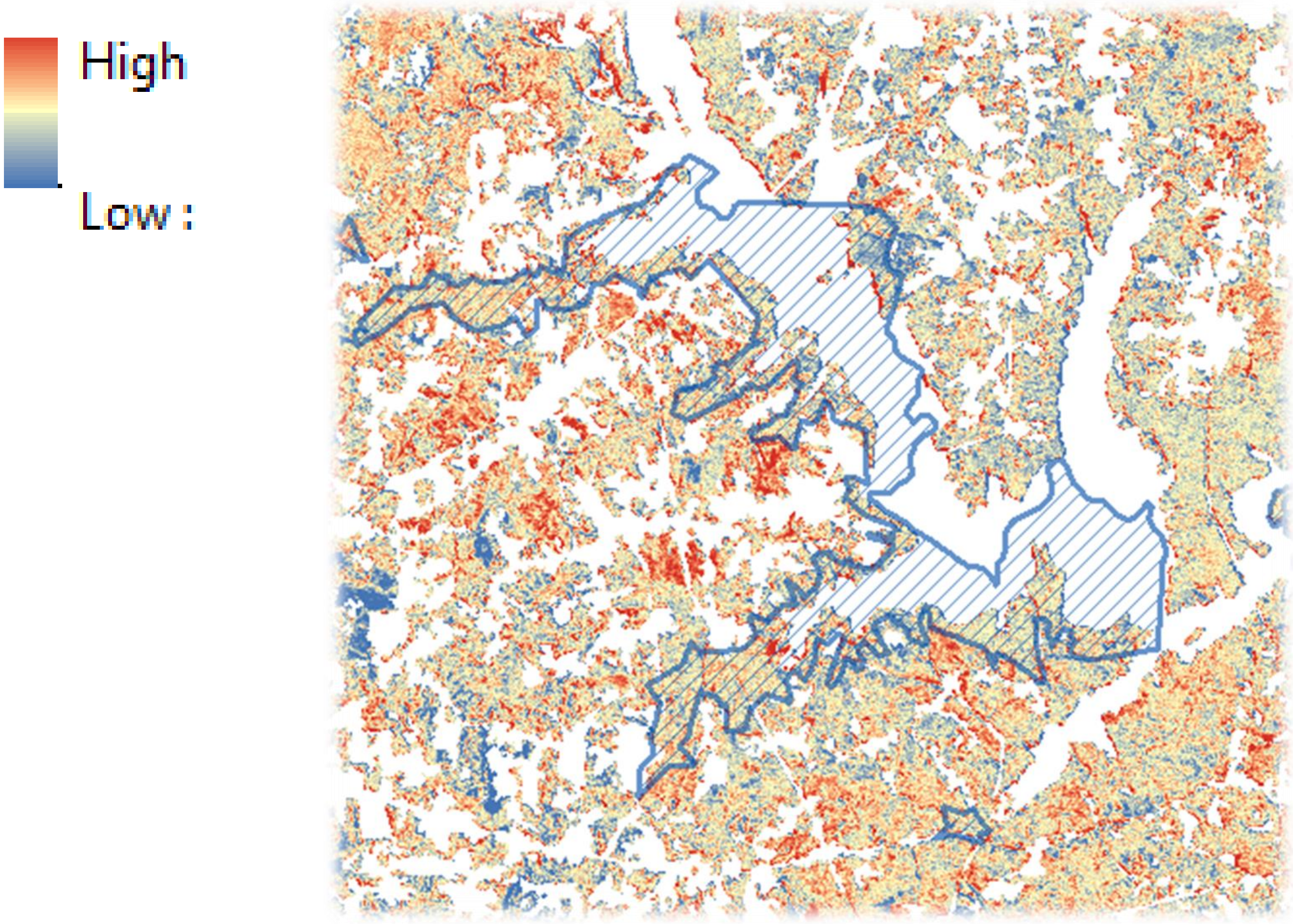




Change vectors



Δ Summer NDVI - Δ Winter NDVI



Assignment: Continuous change

- Create maps showing changes in NDVI values for Umstead State Park and its surroundings
- Describe what the maps show…
  - …in terms of forest gain/loss within the park boundaries vs. immediately surrounding it.
  - …in terms of forest succession within the park boundaries vs. immediately surrounding it.

Assignment: Continuous change *(cont'd)*

- Create a map with **two** frames:

  1. *Highlight two SNHA's*: one "healthy", and another that has lost a lot of greenness from 1985-2005.

  2. *Highlight two SNHA's*: one that has undergone succession, and another where increased greenness appears to be mostly from evergreens.

Predicting change…

- Agent based models (cellular automata)
  - SLEUTH/FUTURES
  - California Urban Futures model

- “Human” habitat models
  - Deforestation models