United States Department of Agriculture

Overview of detecting, mapping and quantifying change using remote sensing tools

Developed by remote sensing specialists at the USFS Geospatial Technology and Applications Center (GTAC), located in Salt Lake City, Utah

Forest Service

Land cover change: what is it?

- The change of one land cover type to another type of land cover
- Examples:
  - Changes in tree cover
    - Tree crop life cycle (e.g., palm oil and rubber)
    - Fires
    - Land clearing
  - Development (urbanization)

Examples of Land Cover Change

Krabi: ~20-30 year tree crop lifecycle

2007

2014

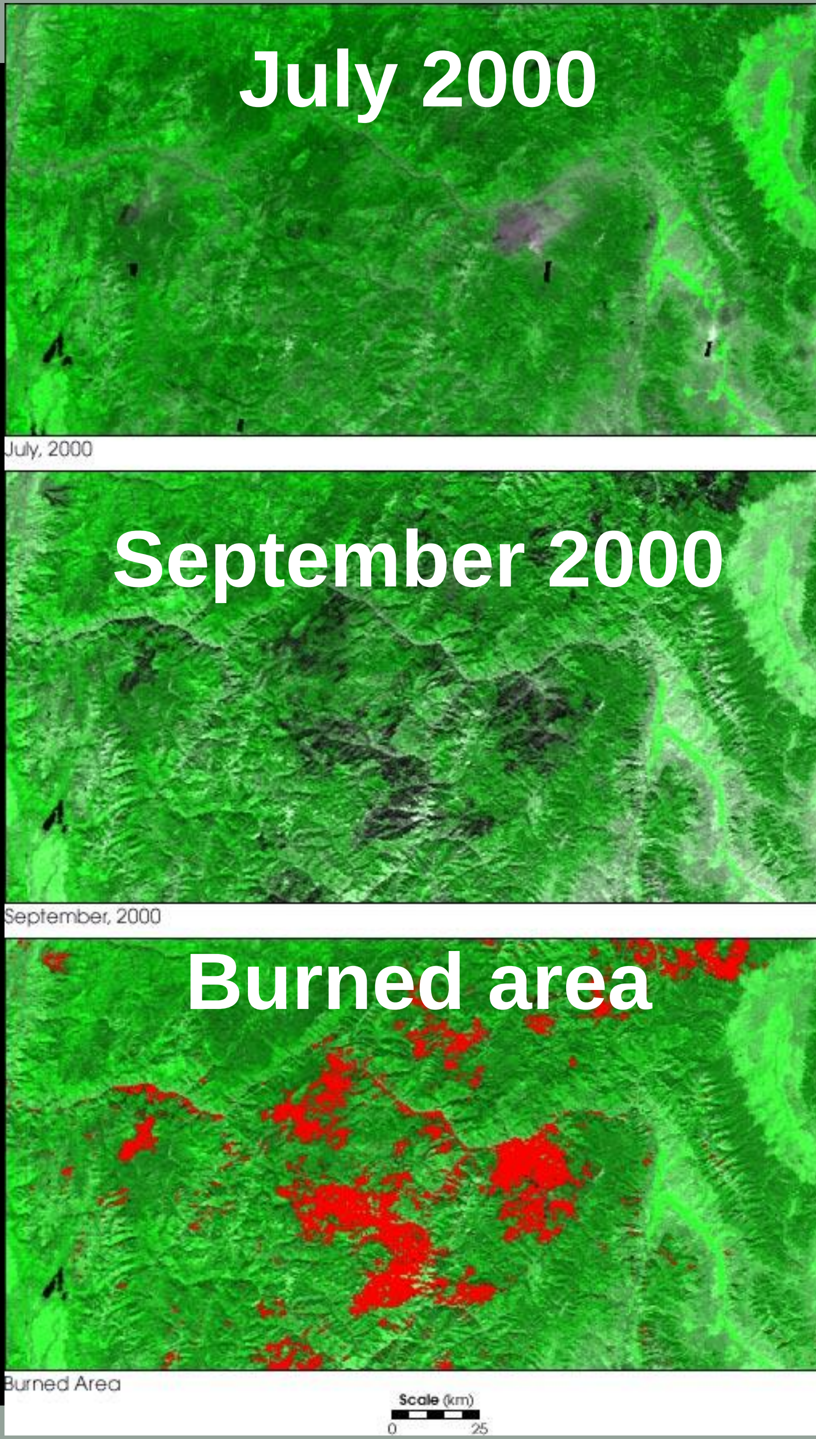
Volcanic Eruptions

- Eruption of Mt St. Helens, USA
  http://earthobservatory.nasa.gov/Features/GlobalLandSurvey/page3.php

July 22, 1975 | July 21, 2005

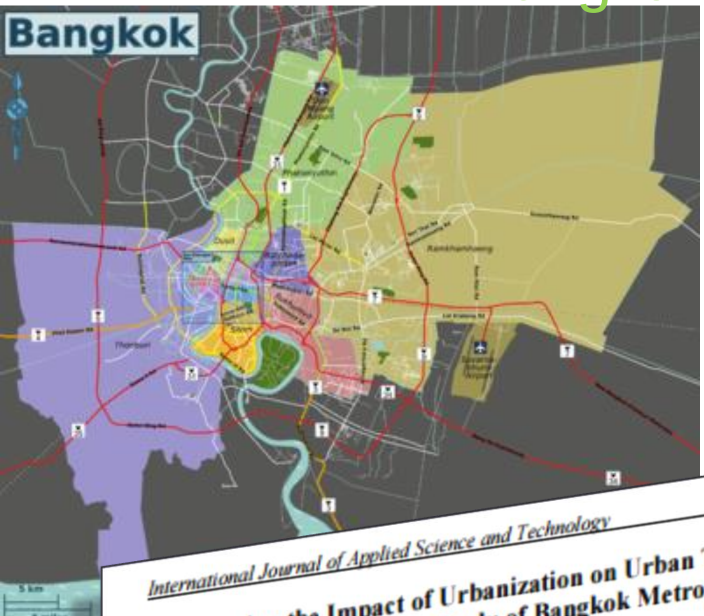
Fires

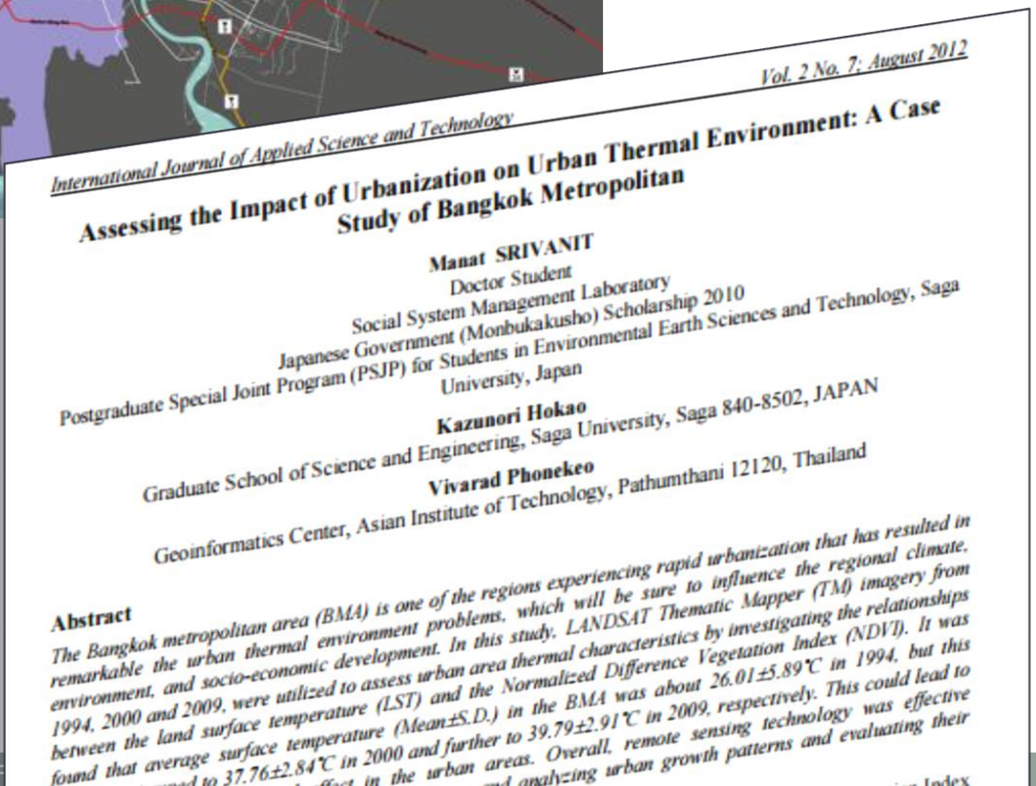
- Wildland fire in Montana and Idaho, USA
  http://earthobservatory.nasa.gov/IOTD/view.php?id=1309



Urban Growth:

Bangkok, Thailand

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Assessing the Impact of Urbanization on Urban Thermal Environment: A Case Study of Bangkok Metropolitan

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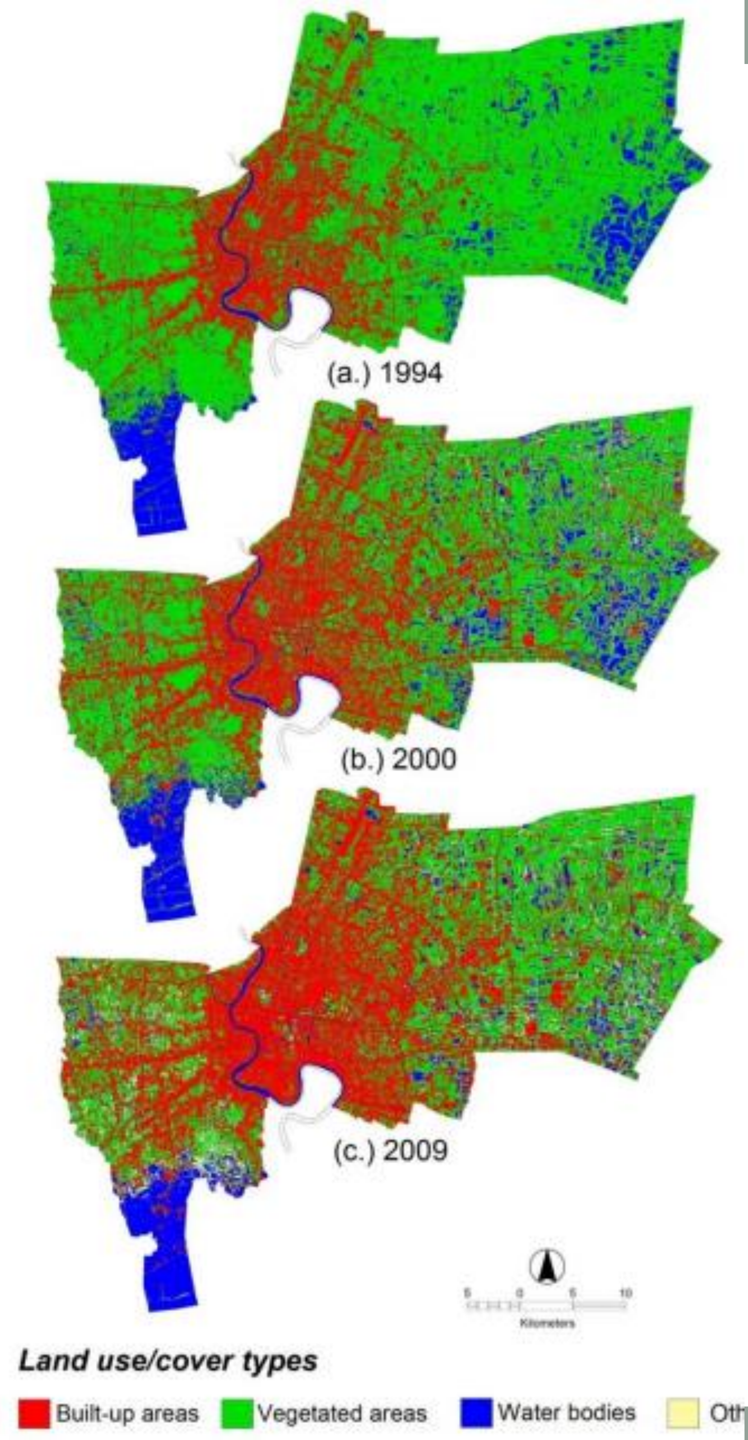
Abstract

The Bangkok metropolitan area (BMA) is one of the regions experiencing rapid urbanization that has resulted in remarkable the urban thermal environment problems, which will be sure to influence the regional climate, environment, and socio-economic development. In this study, LANDSAT Thematic Mapper (TM) imagery from 1994, 2000 and 2009, were utilized to assess urban area thermal characteristics by investigating the relationships between the land surface temperature (LST) and the Normalized Difference Vegetation Index (NDVI). It was found that average surface temperature (Mean±S.D.) in the BMA was about 26.01±5.89℃ in 1994, but this ... to 37.76±2.84℃ in 2000 and further to 39.79±2.91℃ in 2009, respectively. This could lead to ... effect in the urban areas. Overall, remote sensing technology was effective ... and analyzing urban growth patterns and evaluating their



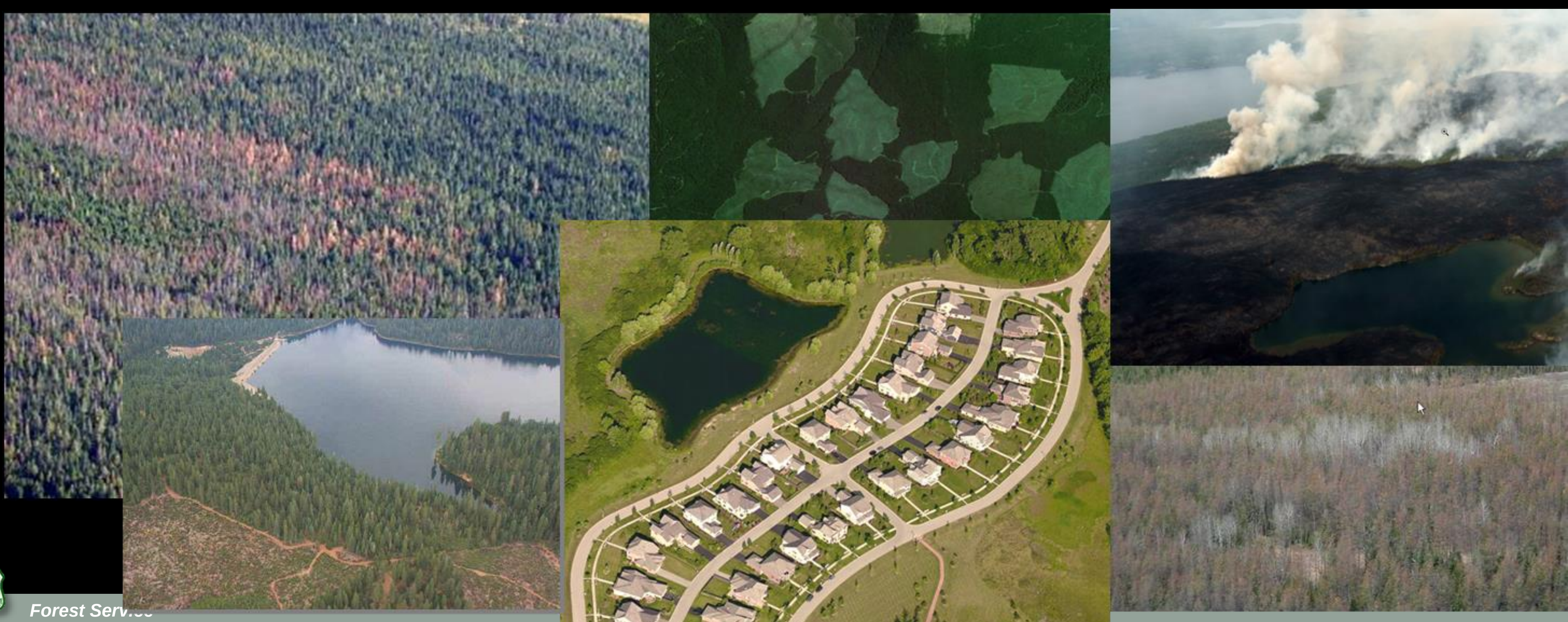
Why monitor resources over time?

Land cover is linked to:

- Economy (revenue from forestry, etc)
- Carbon emissions
- Urban heat island
- Habitat
- Water quality
- Many more

What are some change agents?

- Natural or Human Caused
  - Wildfire, insect outbreaks, succession, drought or climate change, regeneration, storms, etc.
  - Harvest, management, agriculture, development, invasive species, etc.



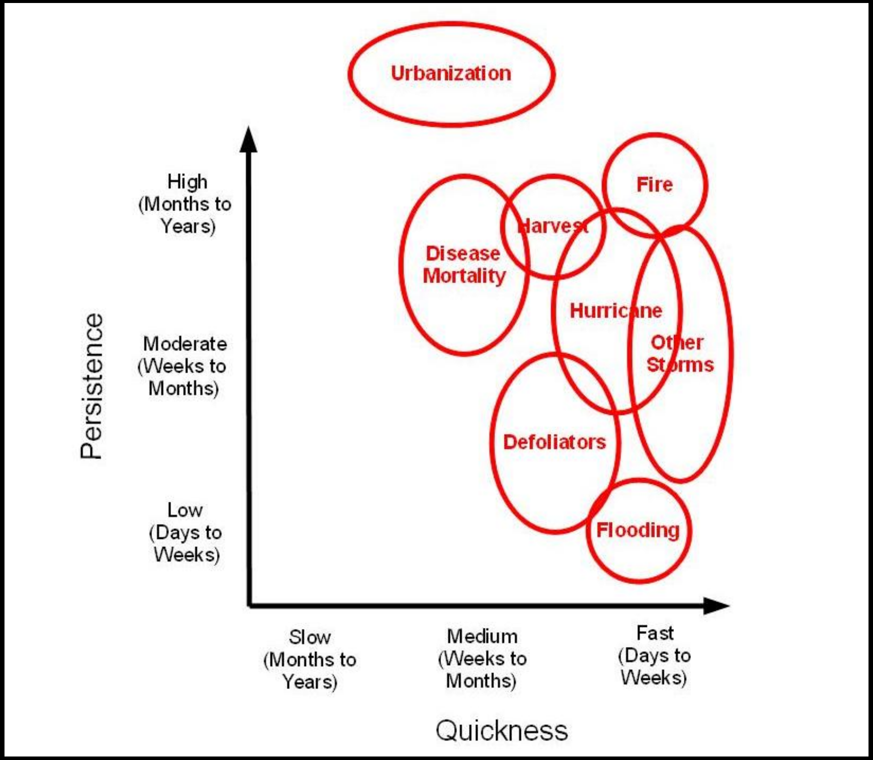
Broad categories of change

- Change in shape or size of patches of land cover types (urbanization)
- Slow changes in cover type or species composition (succession) vs. abrupt land cover transitions (fire)
- Slow changes in condition of a single cover type (forest degradation)
- Changes in timing or extent of seasonal processes (lake coverage, drought monitoring)

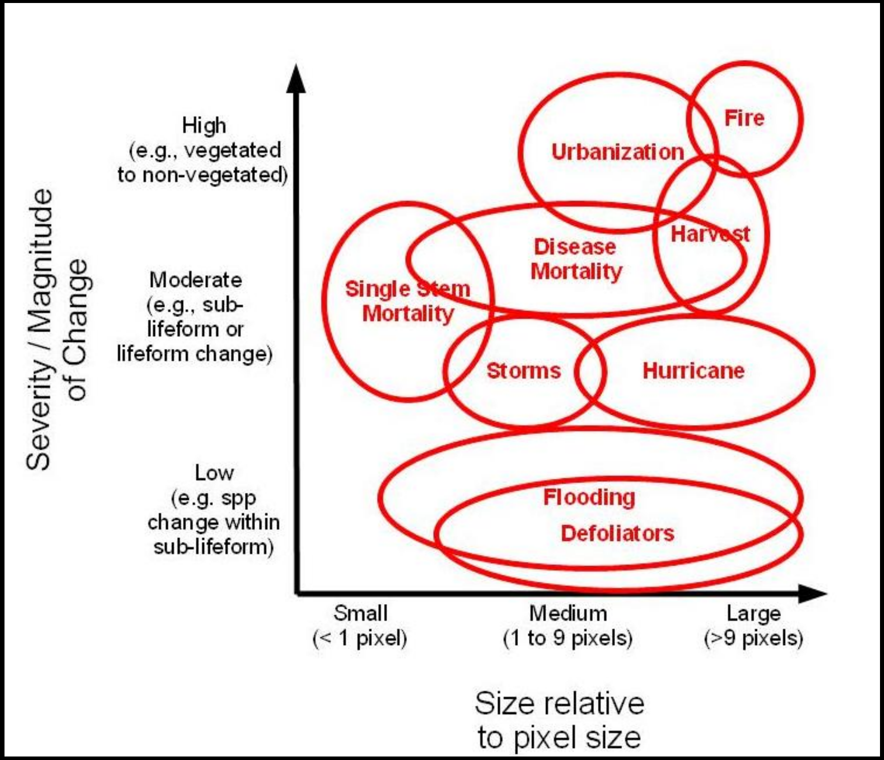
Kennedy et al 2009

Dimensions of Change

- Changes occur across variable spectral, spatial and temporal scales.



Temporal



Spatial

Potential change patterns

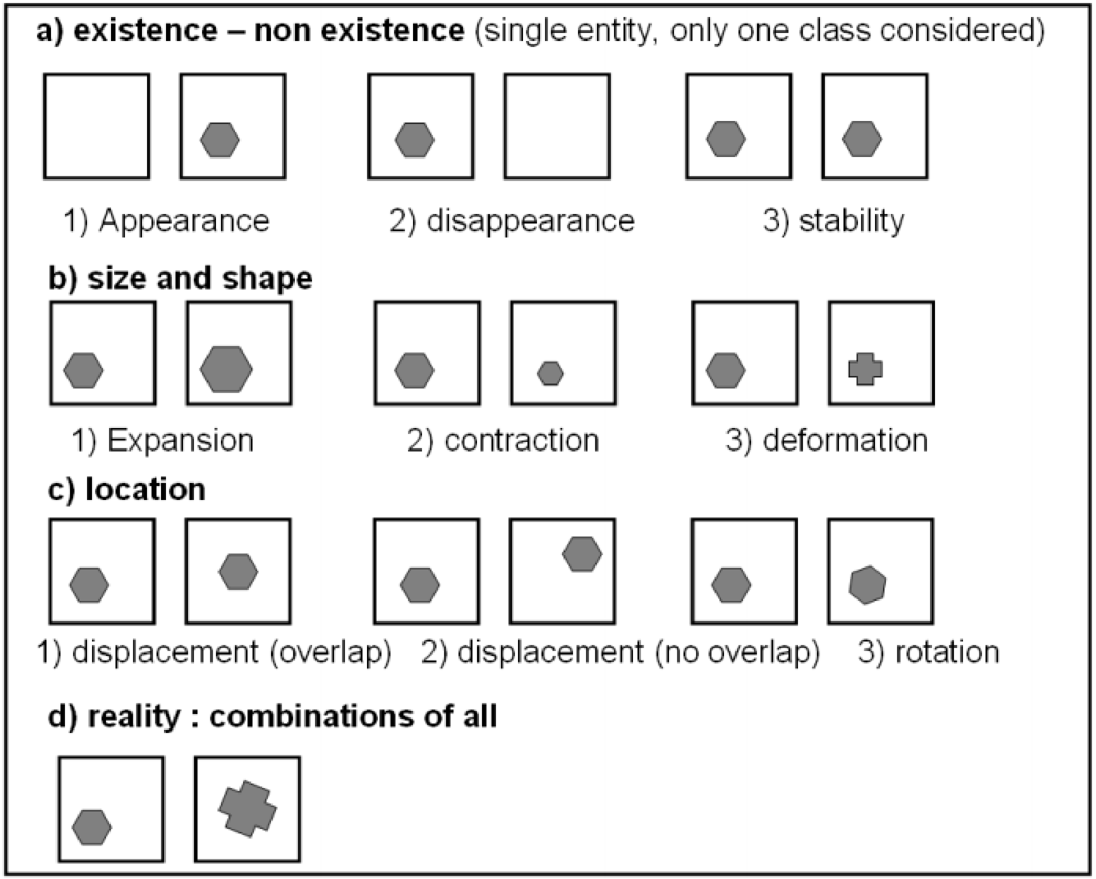


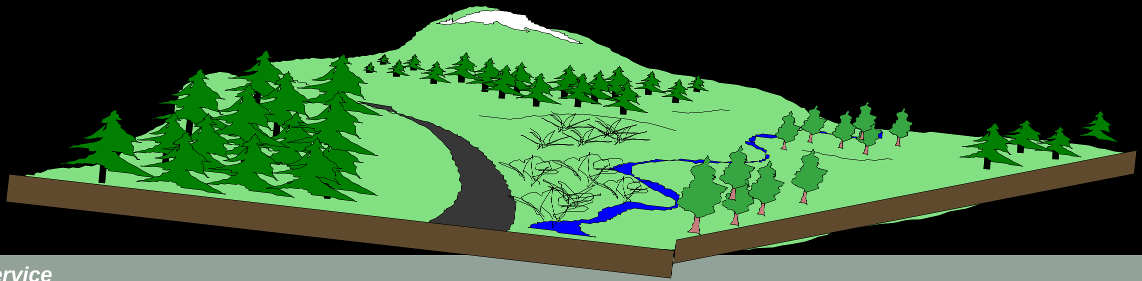
Figure 3. A typology of objects geometry changes

How do we assess land cover changes with remote sensing data and tools?

Review - Optical Remote Sensing Basics

Remote sensing relies on the fact that different targets have unique responses to Electromagnetic (EM) energy

We can distinguish landcover types spectrally and track them through time



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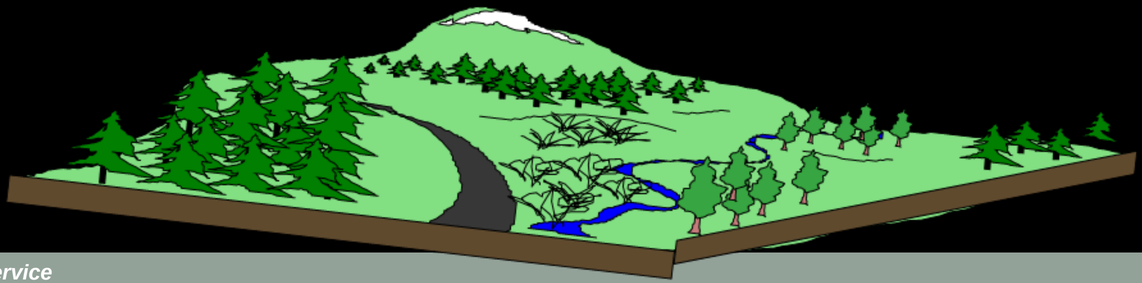

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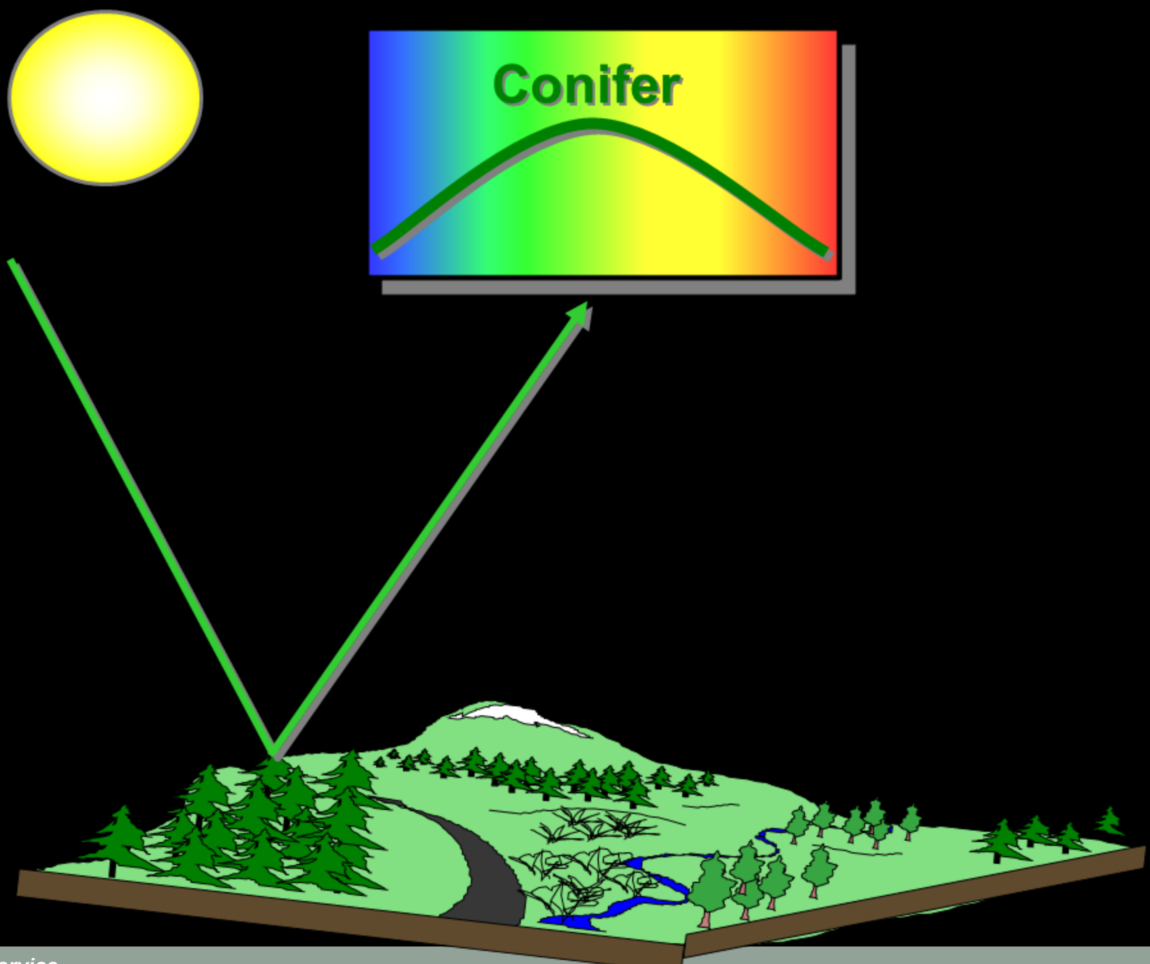

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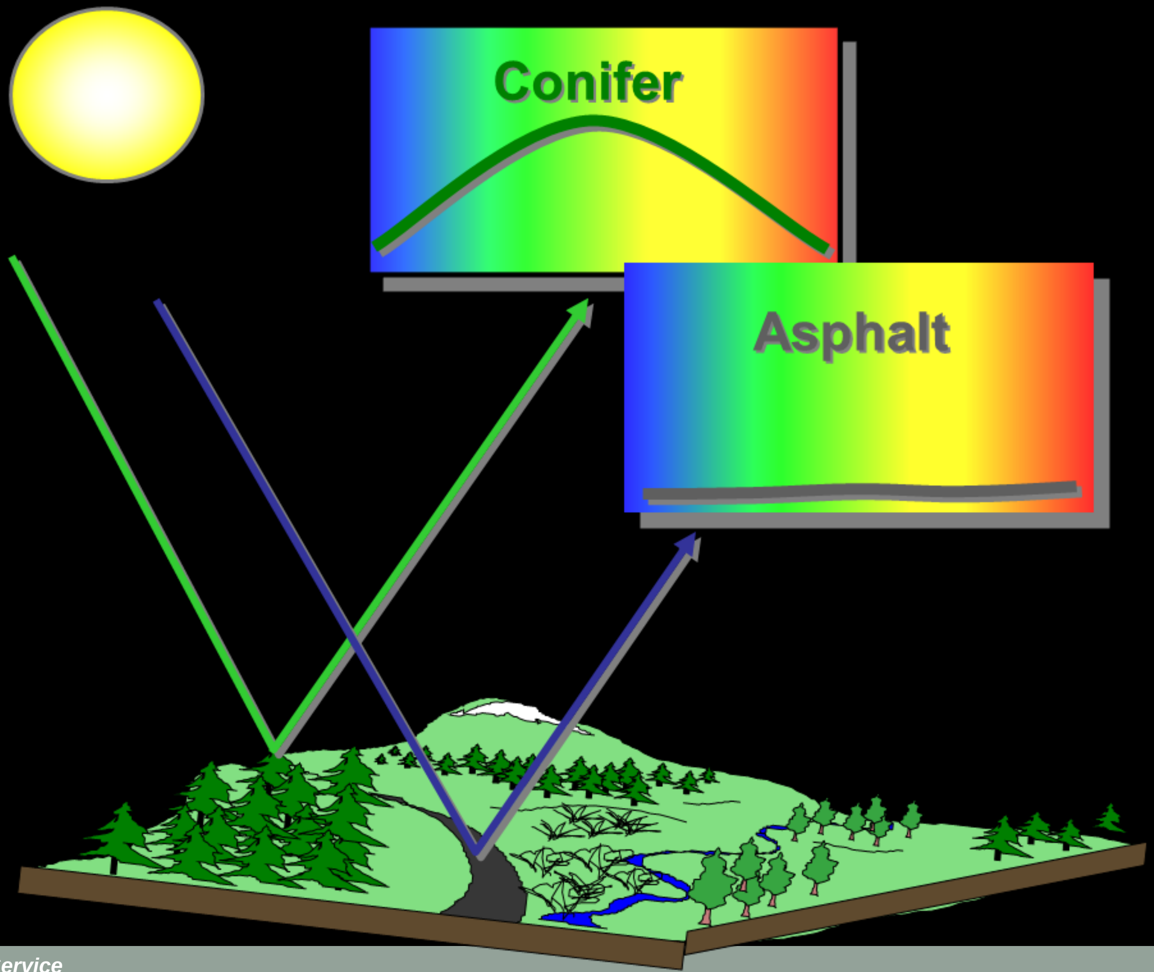

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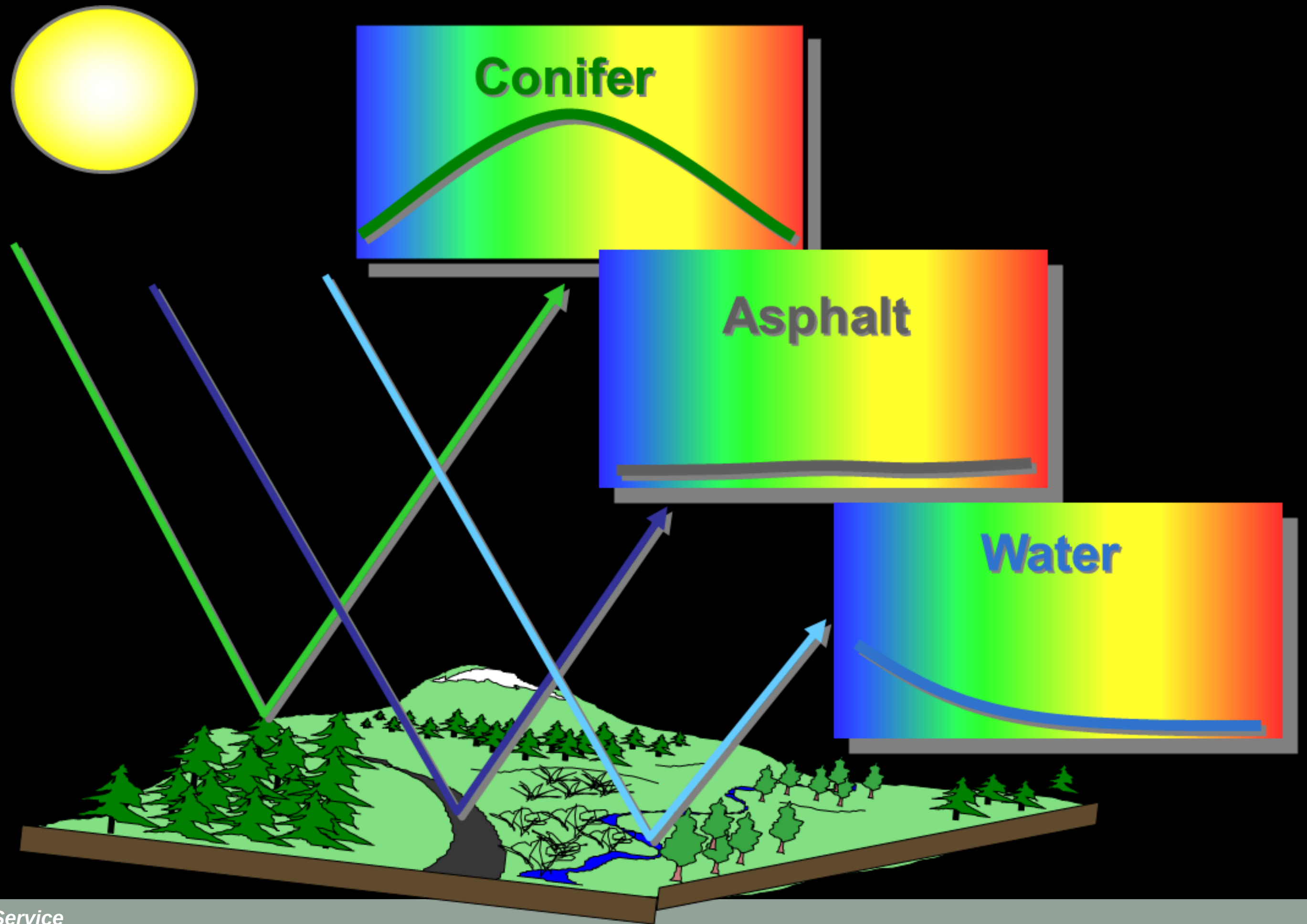
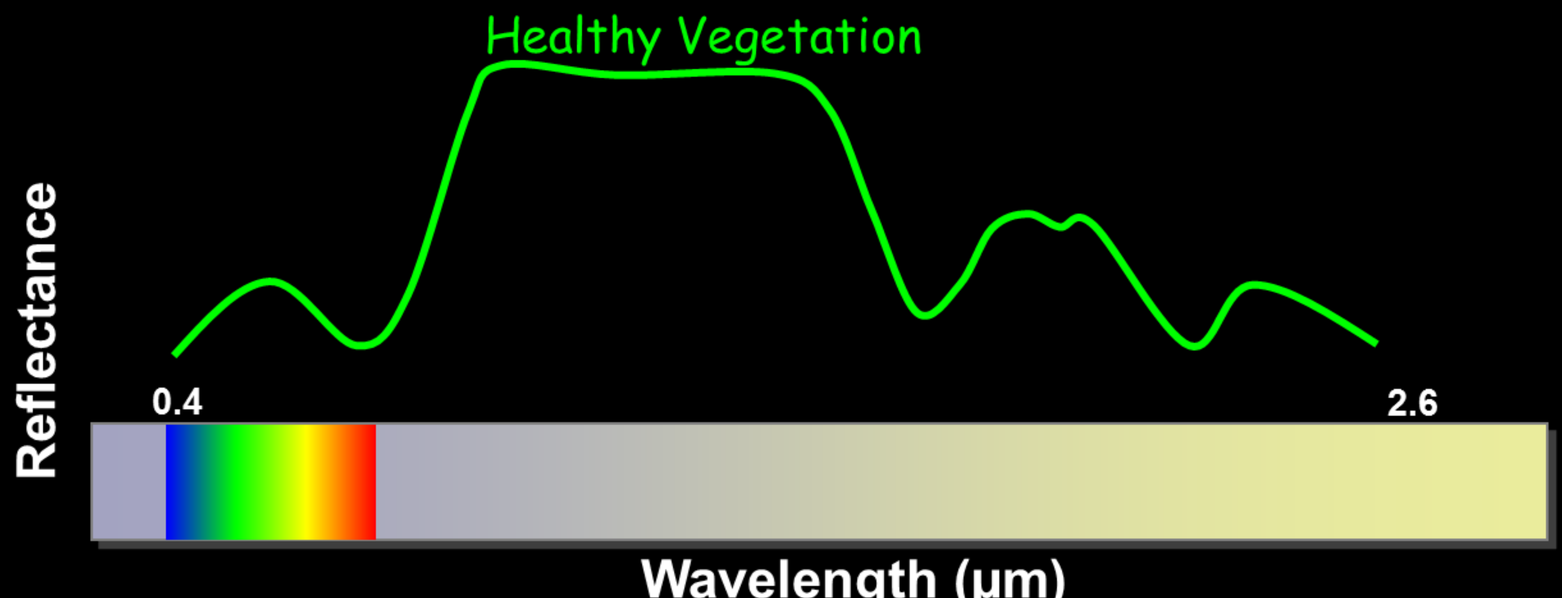


How do we detect change from imagery?

- Changes on the landscape can be detected as changes in the '*spectral space*' occupied by an image pixel



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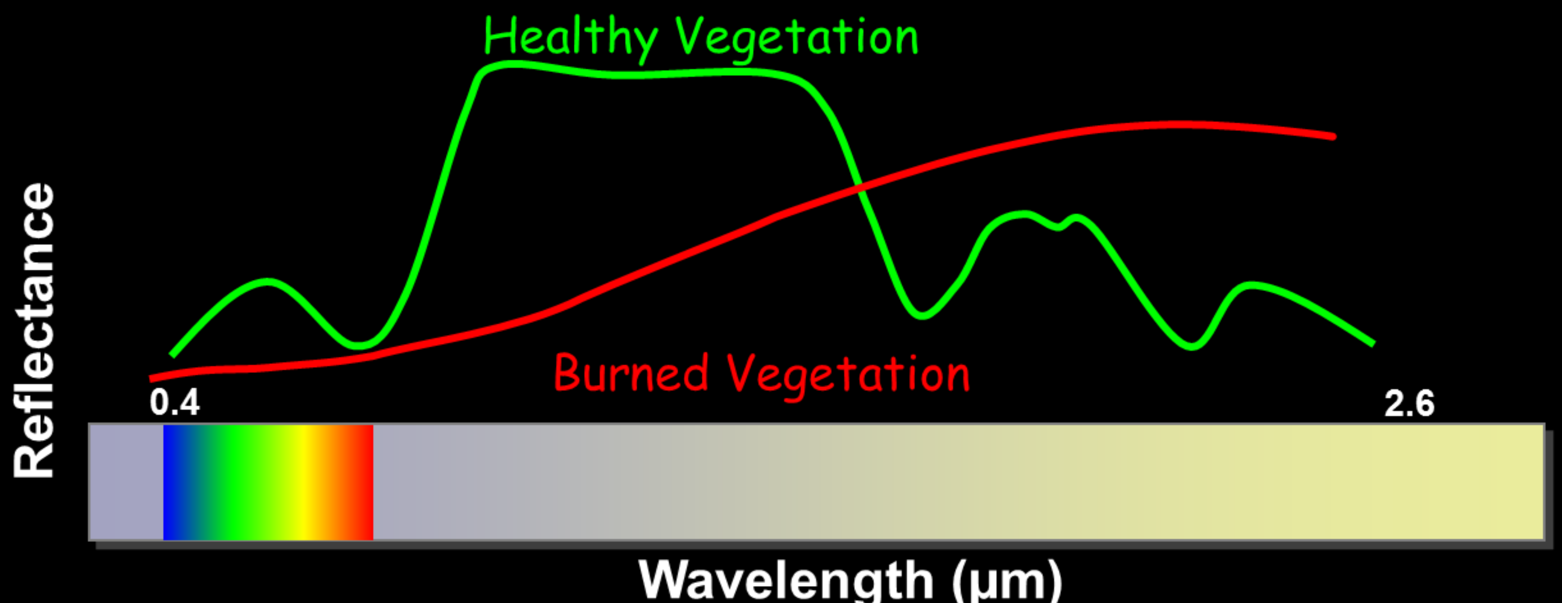


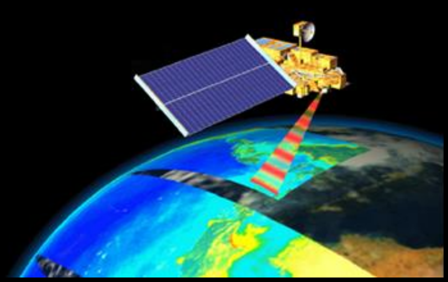
Detecting & Monitoring Change with Imagery

- Satellite and aerial sensors provide:
  - An ever-growing archive of imagery
  - Consistent, repeatable measurements

Several sensors/image programs available with different spatial scales, spectral resolutions and return intervals

Landsat

MODIS



SPOT

What is Change Detection with Remote Sensing?

- Identifying landscape change from remotely sensed images
  - Analyze images from different times to quantify and map change
  - Assumption:

Landscape change -> Spectral change

Coconino NF – Schultz fire effects

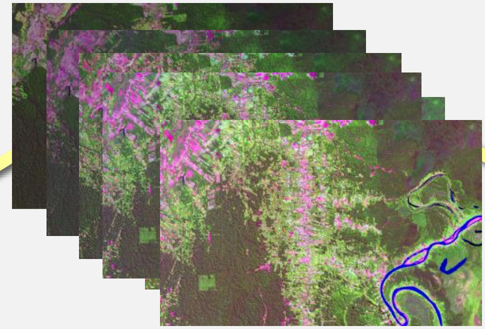
Landsat TM5 image – 1 year post fire

Approaches to Detecting Change

- Estimation: sampling mode to get statistical estimates of change (*e.g., CollectEarth)*
  - Method: change is estimated for a landscape (population) through image interpretation of a sample (number of plots)
  - Appropriate for comparing regions (Countries, Provinces, Parks, etc.)
- Mapping: wall-to-wall change map of study area
  - Method(s): 2-date pixel-based change or multi-date change and trend analysis
  - Appropriate when spatially explicit information required for management decision / action / map updates (fire fighting, modifying a land use map)

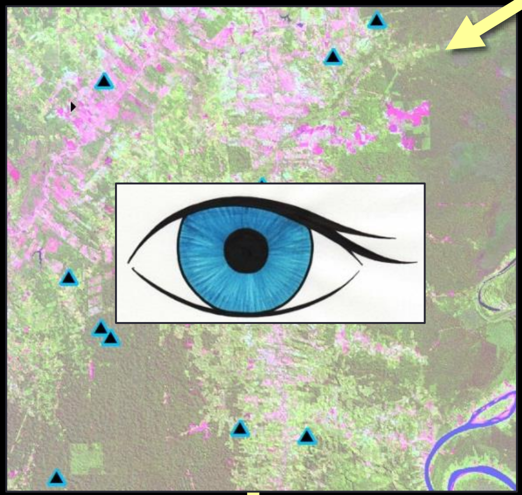
Estimation

Input data



Mapping

Image interpretation at sample locations



Change detection algorithm applied to imagery

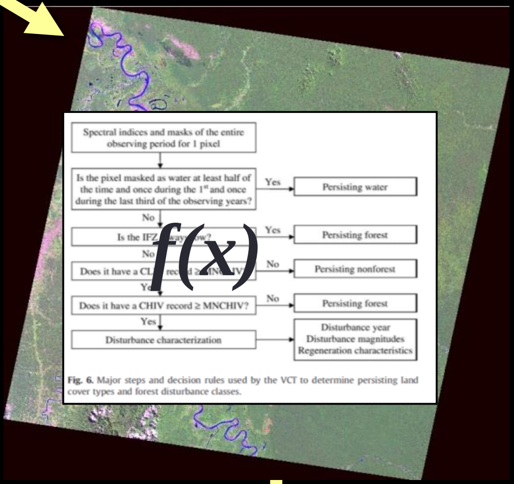
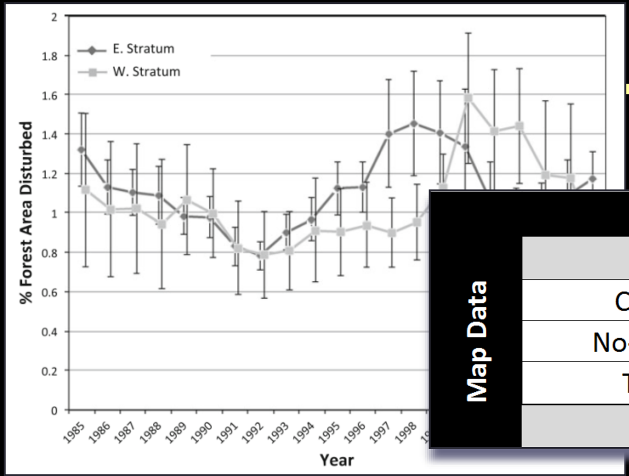
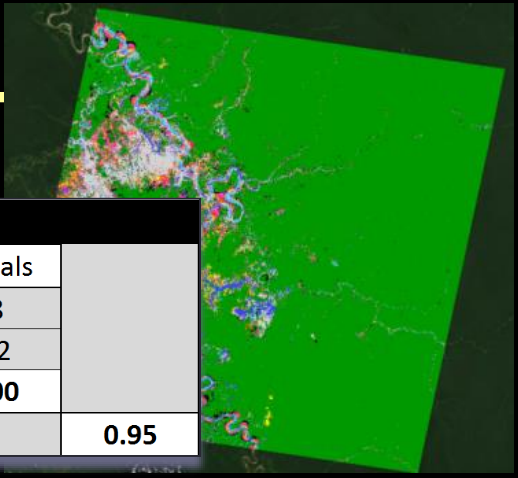


Table output and summary statistics



Output change map



Map validation

Map Data	Reference (TimeSync)			
		Change	No-Change	Totals
	Change	**5**	3	8
	No-Change	2	**90**	92
	Totals	7	93	**100**
				0.95

Estimation Example

Estimation example:

- Analyst compares an image pair from 2010 and 2014 to determine if there was a land cover change at the plot (following slide).
- If there was no change, the analyst proceeds with some minor interpretation (arrow on the left, following slide).
- If there was a change, the analyst proceeds with an interpretation of 45 more points to better characterize the change (arrow on the right, following slide).

Estimation: ICE Example

NAIP 2010

NAIP 2014

Is there a land use or land cover change on the plot?

NO

Including seasonal change

YES

Interpret 5 Points ~ 2min/plot

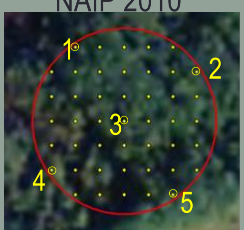
NAIP 2010

NAIP 2014

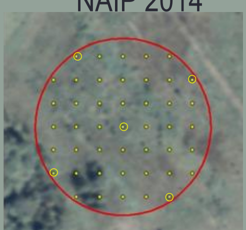
Plot #	Point #	Time1 LC	Time 2 LU	Agent of Change	Time 2 LC	Time 2 LU
11_20_999	1	Tree	Forest	no change	Tree	Forest
11_20_999	2	Tree	Forest	no change	Tree	Forest
11_20_999	3	Tree	Forest	no change	Tree	Forest
11_20_999	4	Tree	Forest	no change	Tree	Forest
11_20_999	5	Tree	Forest	no change	Tree	Forest
11_20_999	...	-(null)	-(null)	no change	-(null)	-(null)
11_20_111	45	-(null)	-(null)	no change	-(null)	-(null)

Interpret 45 Points ~ 8min/plot

NAIP 2010



NAIP 2014



Plot #	Point #	Time1 LC	Time 2 LU	Agent of Change	Time 2 LC	Time 2 LU
11_20_111	1	Tree	Forest	Harvest	Bare	Forest
11_20_111	2	Tree	Forest	Harvest	Bare	Forest
11_20_111	3	Tree	Forest	Harvest	Bare	Forest
11_20_111	4	Tree	Forest	Harvest	Shrub	Forest
11_20_111	5	Tree	Forest	Harvest	Bare	Forest
11_20_111	....	Tree	Forest	Harvest	Bare	Forest
11_20_111	45	Tree	Forest	Harvest	Bare	Forest

Mapping

- Mapping is a different approach to detecting change and produces a map output at the end. There are two general ways to detect and map these changes: 2-date (time 1 versus time 2) or multi-date image stacks (more than 2 images in a stack showing the trend of change [or not] over the time period).
- Inputs
  - 2-date image pairs

    or
  - Multi-date image stack

- Outputs
  - GIS-ready change product
    - Thematic map

      or
    - Continuous raster layer

Tradeoffs between Estimation and Mapping

- Estimation can generally depict change with a greater level of detail, but may introduce error due to a non-representative sample design
- Estimation can be used with much higher resolution imagery than pixel-based change detection because the human eye can detect even subtle change and differences due to misregistration and/or shadows, while automated algorithms generally cannot.
- Mapping can generally depict change with limited detail, but provides a spatially-explicit wall-to-wall map
- Mapping is faster but does not generally detect subtle change (e.g., forest degradation).
- Image Interpretation (and Sampling) is low-tech and in many ways more capable and reliable than automated methods
- Sampling is the most robust long-term monitoring method. Changes in image characteristics can be accommodated more readily than mapping methods.

Mapping: Two-date Change Detection

Multiple approaches with common core concepts:

- Identify spectral characteristics of significant change and separate it from *noise*

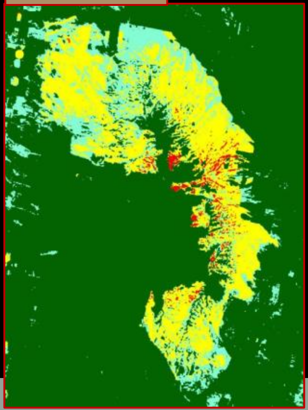
Focus of this course:

- Two-date image differencing
- Moderate resolution satellite imagery
- Provides a foundation for other methods
- Can be accomplished using readily available tools

Prefire

Postfire

Change



Steps to map land cover change

1. Data selection and acquisition
   - Imagery and reference data
2. Image processing and enhancement
   - Correction, normalization and transformation
3. Analysis
   - Quantify differences and create a change map
4. Evaluation
   - Accuracy assessment

Management goals determine best remote sensing imagery and tools

- Clearly define objectives
  - Identify the problem:
    - Change phenomena of interest
      - What is measured?
      - *e.g., fire effects, forest mortality, stream channel changes, etc.*
    - Define study area
      - Where?
    - Determine frequency for change analysis
    - When and how often?
      - *e.g., seasonal, annual, biennial, etc.*
    - Consider limitations
      - What problems may occur?

These considerations determine appropriate methods and whether or not change can even be detected

1. Data Acquisition Considerations

Goals:

- Capture the change of interest
  - Consider image and change phenomenon resolution (spatial, temporal and spectral)
- Minimize non-target change or ‘noise’
  - Select near anniversary dates to minimize illumination and seasonal differences

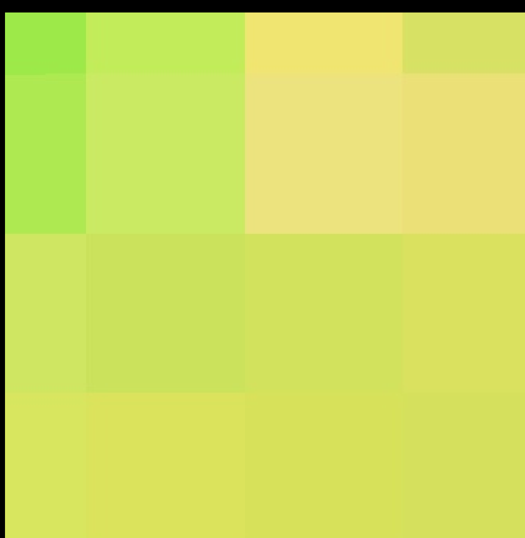
1. Data Acquisition Considerations

Images:
- Type
- Timing
- Quality
- Cost

Reference data:
- Type
- Timing
- Quality
- Cost

1. Data selection and acquisition

Images:
You should have wall-to-wall coverage



Reference data:
You can collect reference data from imagery, preferably high resolution or with field visits

1. Type of imagery

- Spatial character
  - Spatial grain ~ pixel size
  - Spatial extent ~ geographic scope
- Temporal character
  - Temporal grain ~ frequency of measurements
  - Temporal extent ~ historical depth of imagery
- Spectral attribute
  - Spectral grain ~ width of bands
  - Spectral extent ~ breadth of electromagnetic spectrum (red, blue, green, nir, etc)

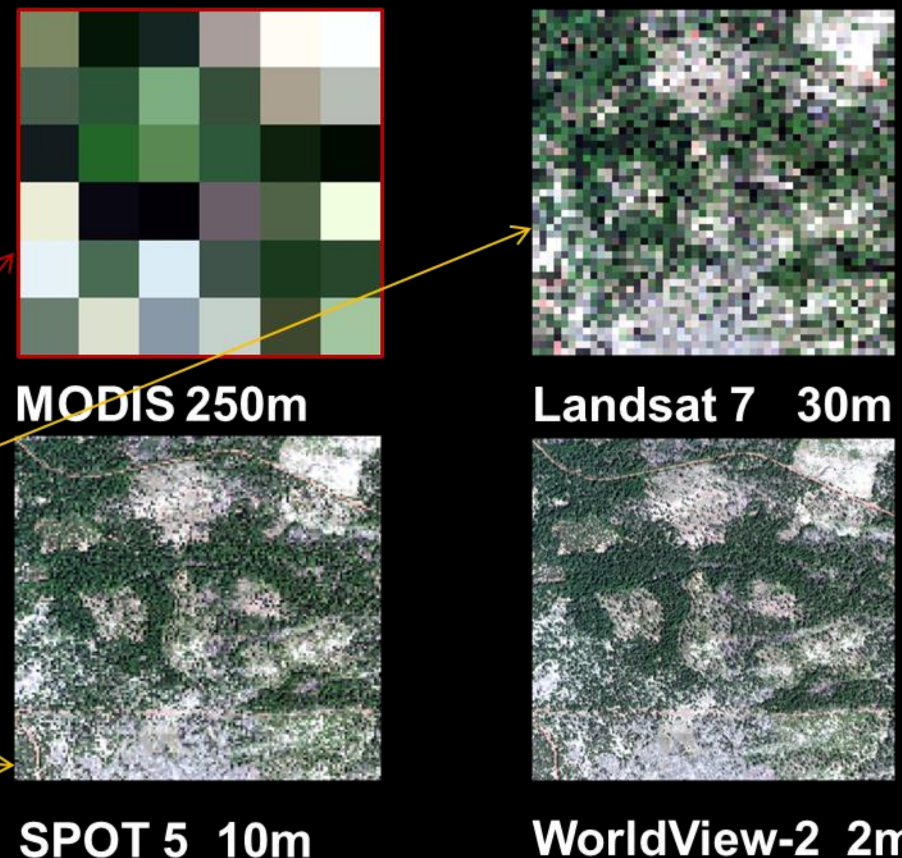
1. Imagery - Spatial Considerations

- Spatial resolution (pixel size)

- Extent

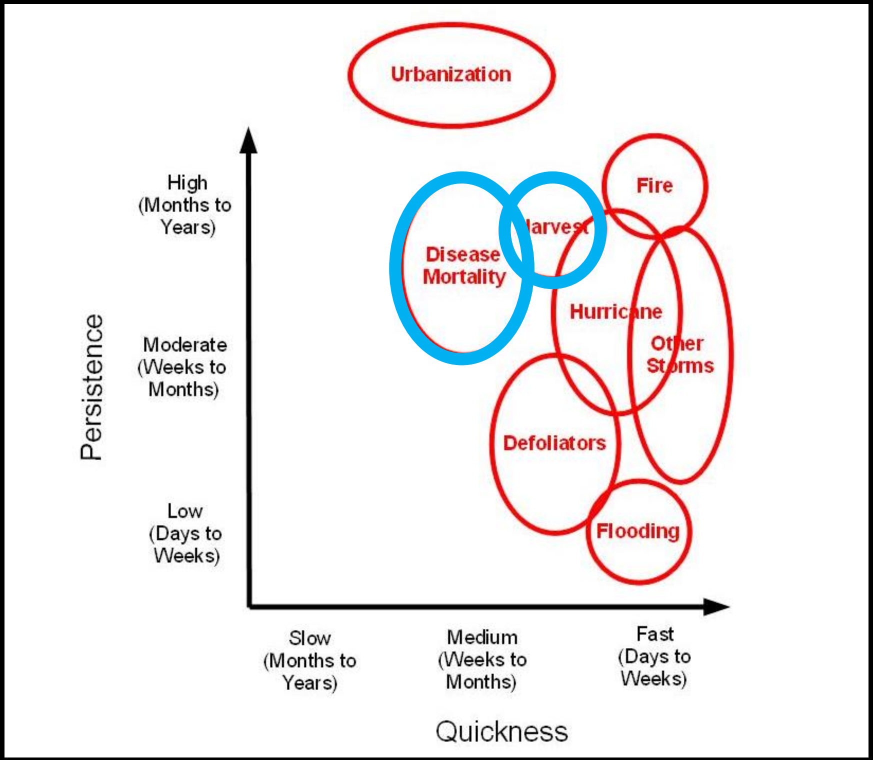
Trade-off between resolution and extent

Simulated MODIS, Landsat, SPOT and WorldView-2 data.

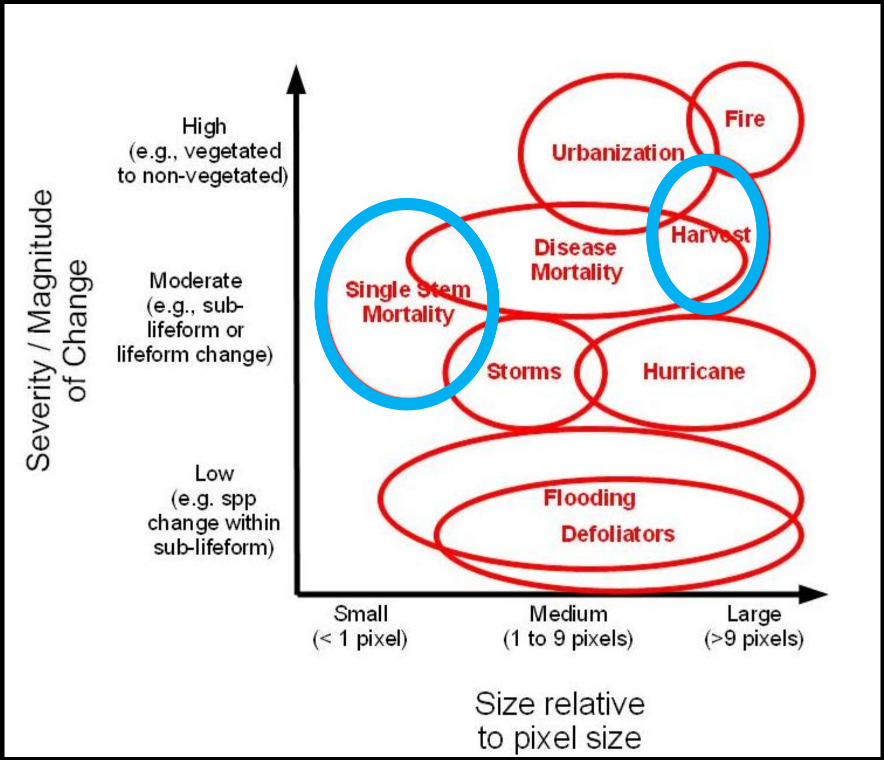


1. Objectives determine temporal and spatial data needs

- Changes occur across variable spectral, spatial and temporal scales.



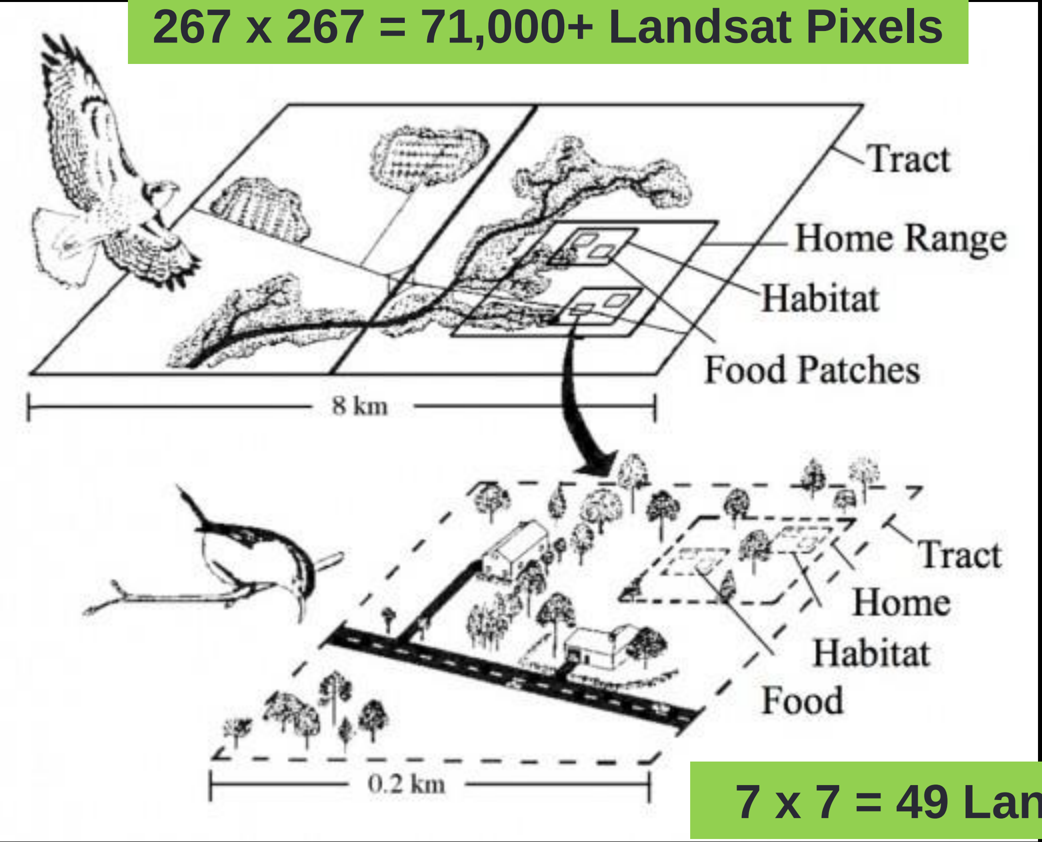
Temporal



Spatial

1. Spatial scale considerations

267 x 267 = 71,000+ Landsat Pixels



7 x 7 = 49 Landsat Pixels

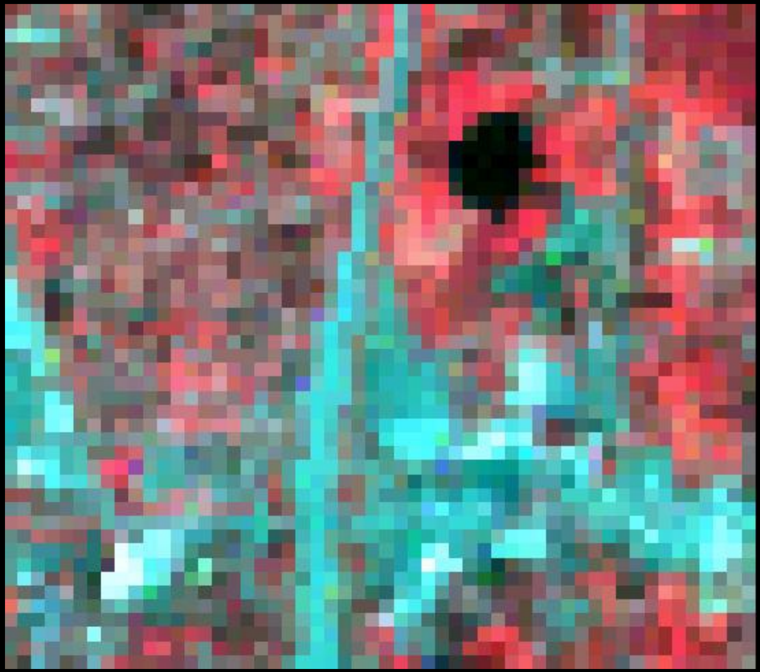
Depends on phenomenon of interest:

- E.g. The habitat patterns for a red-tailed hawk are much different from that of a Carolina wren

http://www.thenatureofcities.com/2014/01/15/a-matter-of-scale-connecting-human-decisions-with-decisions-made-by-wildlife/

1. Spatial resolution

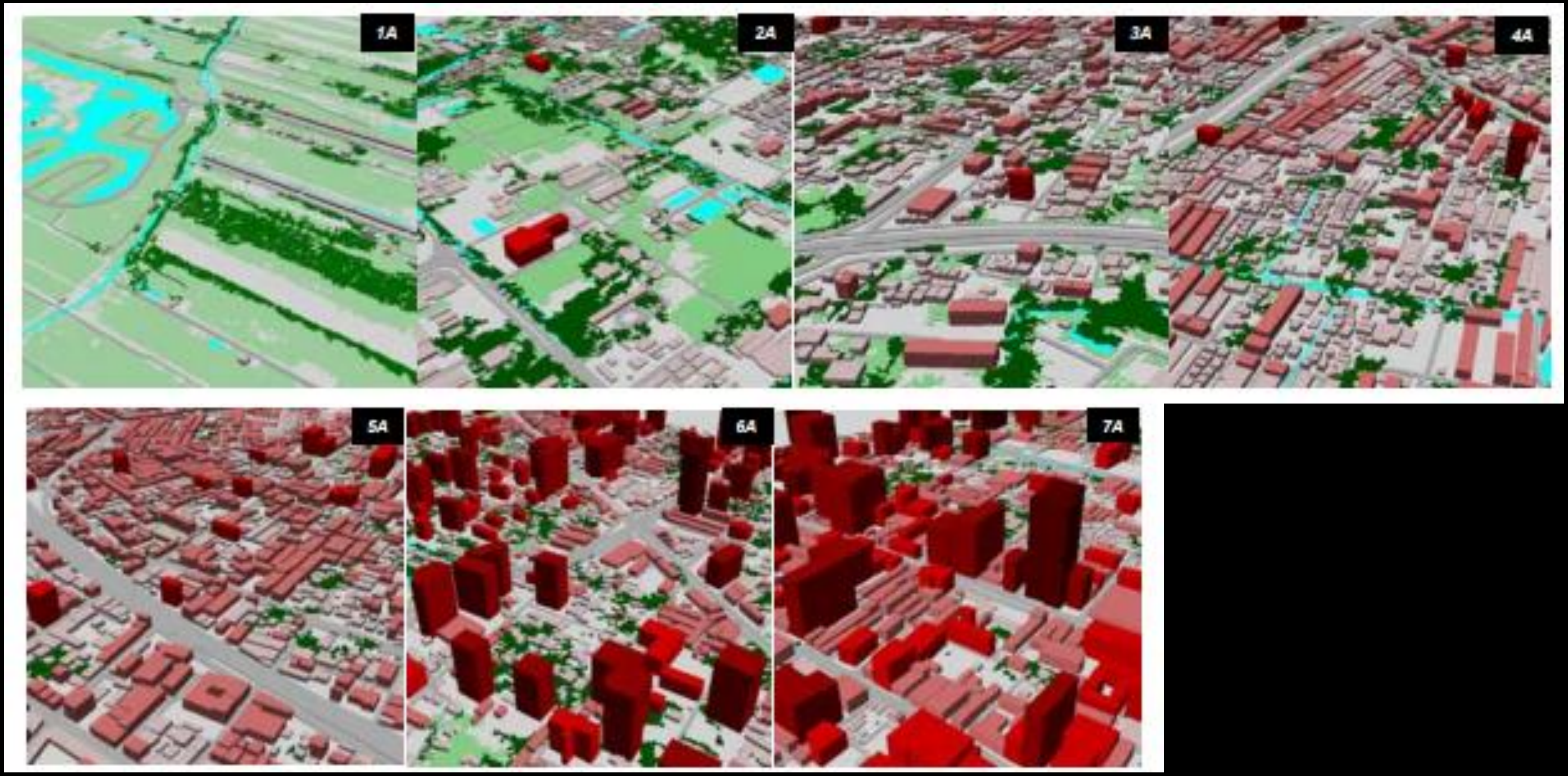
Landsat 7 (30m)
Only broad patterns are visible on the landscape with this lower spatial resolution

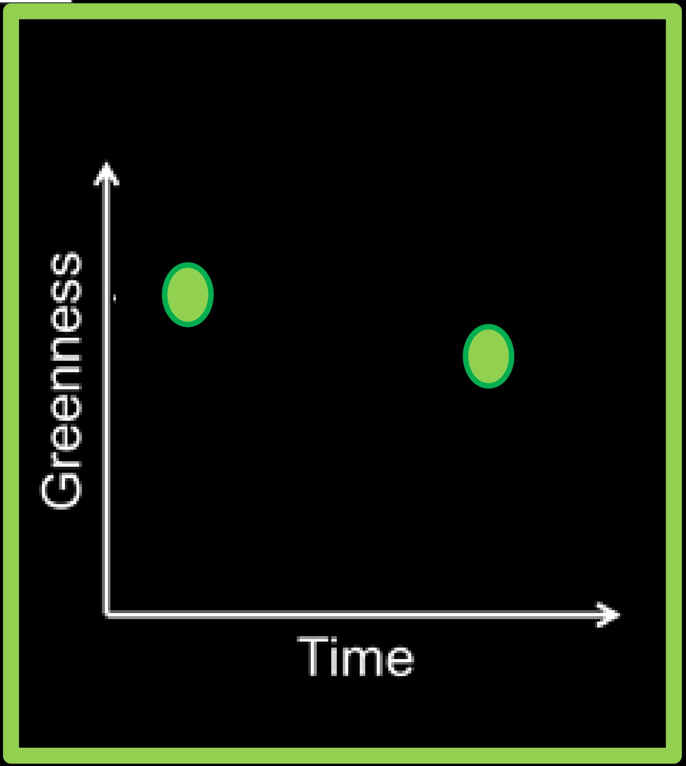


Ikonos (4m)
Individual buildings are visible with this higher spatial resolution

1. Spatial scale considerations

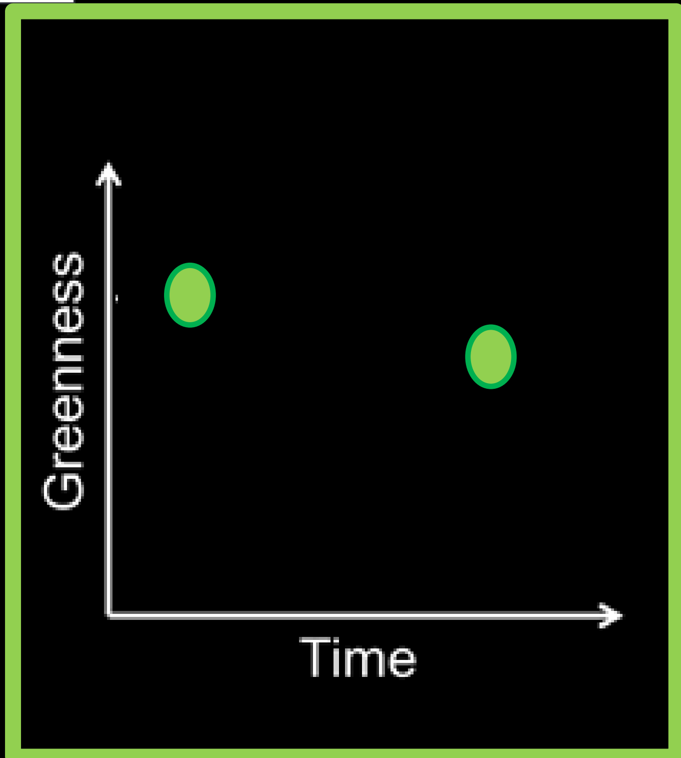
- (human) land use is heterogeneous, many scales of impact/change





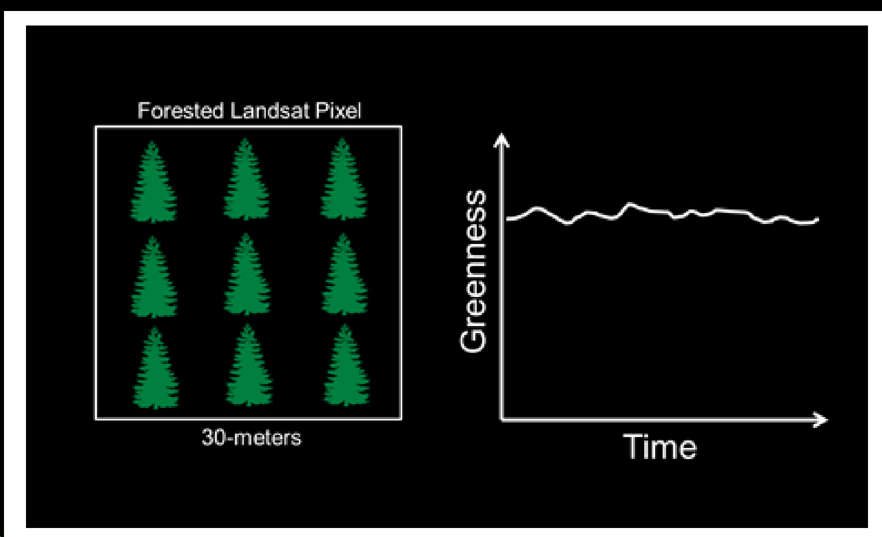
1. Temporal Scales

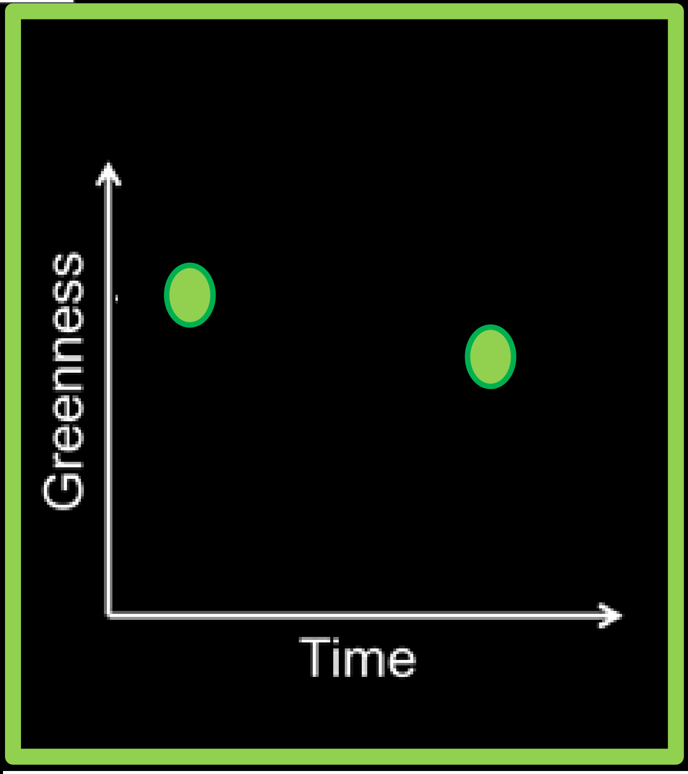
- Is this a land cover change? Or stable land cover?
- Having only two points of time to reference may not show us a clear picture of how things are changing



1. Temporal Scales

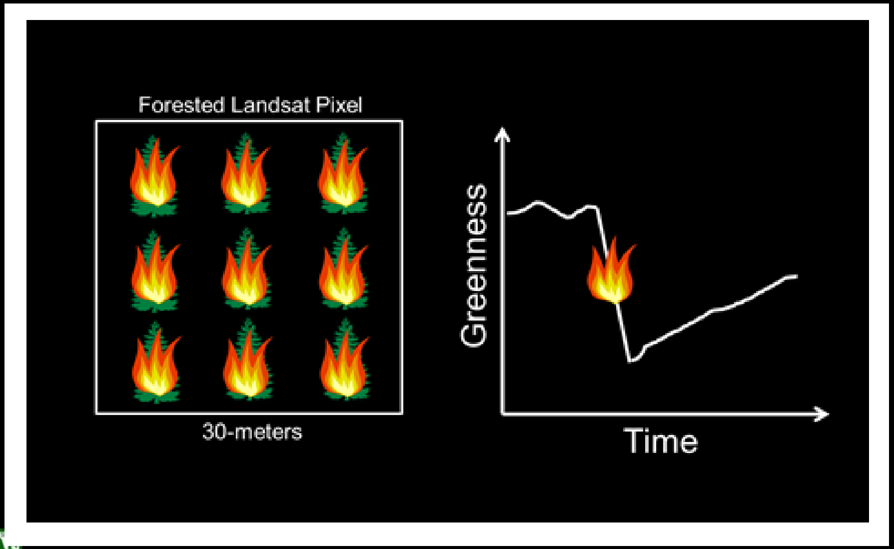
- In the example below, greenness (tree cover) is fairly stable over time and doesn’t fluctuate much

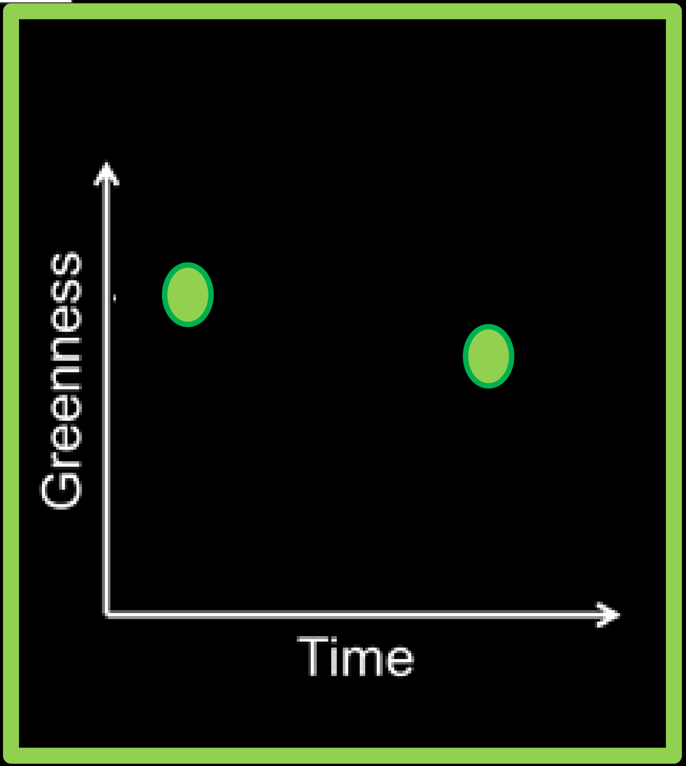




1. Temporal Scales

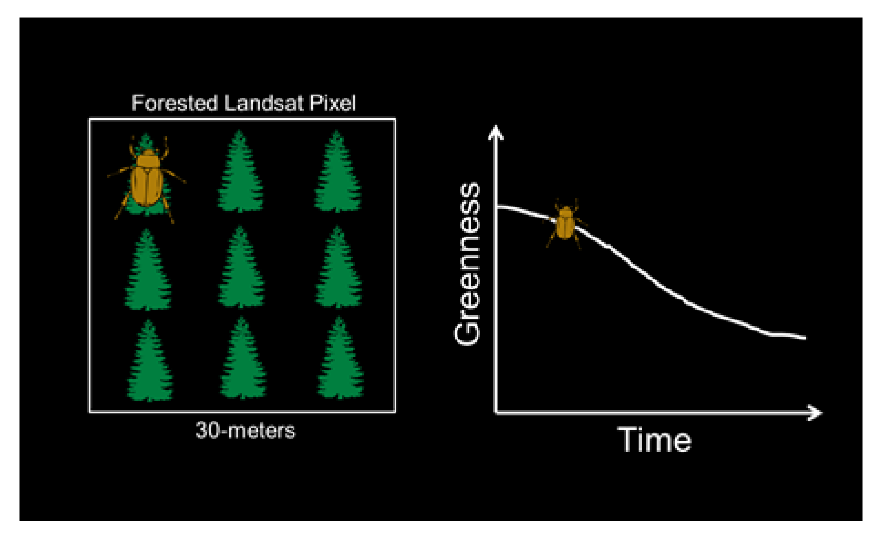
- In the example below greenness (tree cover) has a large change because of a fire, but then starts to recover. Multiple images would be required to track this change.





1. Temporal Scales

- In the example below greenness (tree cover) has a gradual change because of a pest outbreak. Multiple images would be required to track this change as well.



1. Imagery - Temporal Considerations

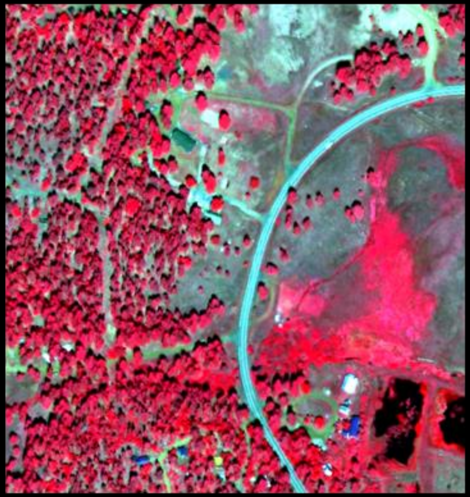
- Image timing must be chosen to minimize the influence of unwanted effects on spectral space, since such effects obscure real change or produce the false appearance of change

- Seasonal and environmental effects (e.g., soil moisture, phenology)

- Persistence of change phenomena
  (i.e., consider recovery and succession)

Seasonal mismatch - World View2

March 2011



September 2011

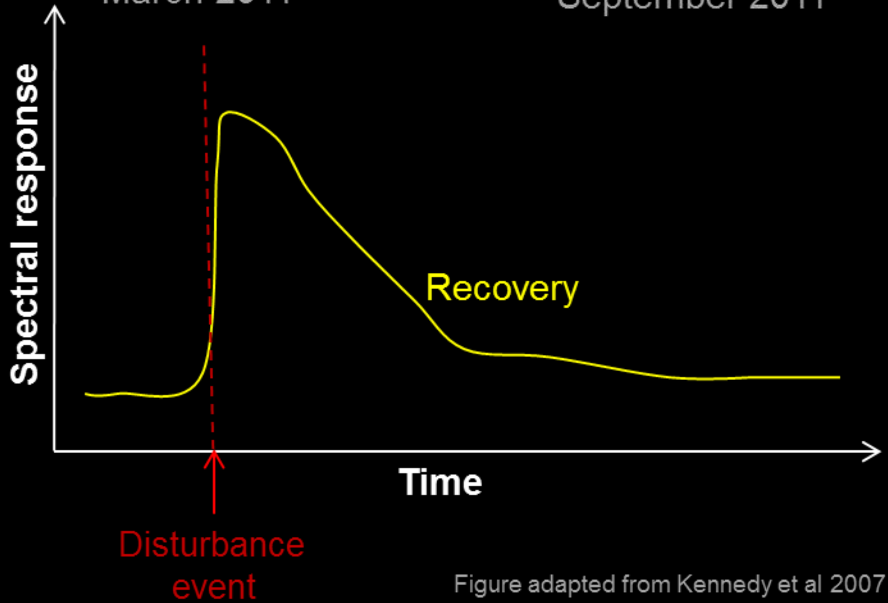
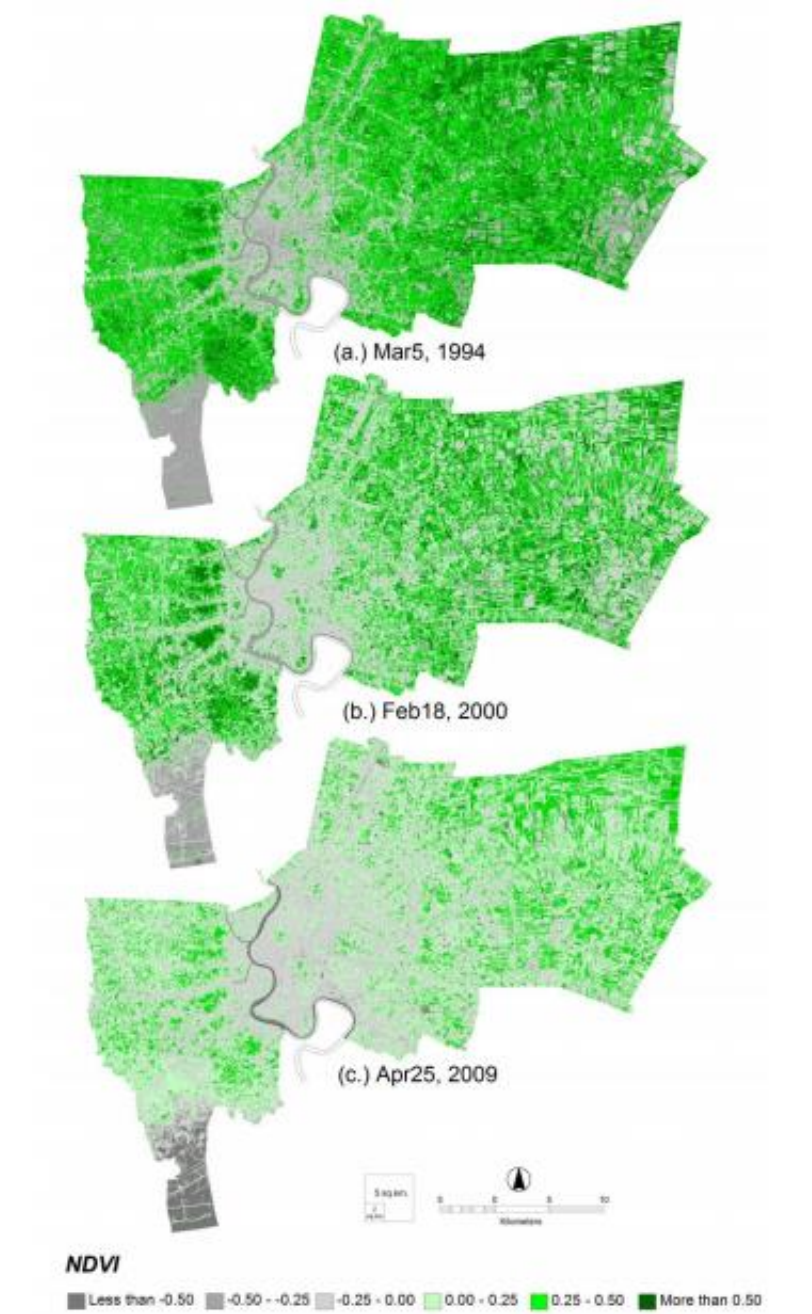


Figure adapted from Kennedy et al 2007

1. Spectral extent

- What are you mapping?
- What spectral bands are sensitive to the change in land cover(s) of interest?
- Vegetation ~ NDVI (red and NIR bands)



Figs.5. NDVI derived from Landsat TM (a,b,c) imagery for three different dates

Hokao, Kazunori, Vivarad Phonekeo, and M. Srivanit. "Assessing the impact of urbanization on urban thermal environment: a case study of Bangkok Metropolitan." *International Journal of Applied* 2.7 (2012).

1. Spectral extent

- Vegetation ~ NDVI
  (red and NIR)
- Make sure to have the right spectral extent for what you are wanting to measure/detect

Table 1. Summary of LANDSAT 7 Thematic Mapper (TM) bands and principal remote sensin

Band	Wavelength (µm/microns) R = Reflected E = Emitted	Nominal Spectral Location	Principal Applications
1	0.45 – 0.52 R	Blue (V)	Designed for water body penetratio water mapping. Also useful for soil/ forest type mapping and cultural fea
2	0.52 – 0.60 R	Green (V)	Designed to measure green reflectar vegetation discrimination and vigou cultural feature identification.
3	0.63 – 0.69 R	Red (V)	Designed to sense in a chlorophyll absorption region, aiding in plant species differentiation. Also useful for cultural feature identification.
4	0.76 – 0.90 R	Near Infrared (NIR)	Useful for determining vegetation type, vigour, and biomass content. For delineating water bodies, and for soil moisture discrimination.
5	1.55 – 1 .75 R	Short Wave Infrared (SWIR)	Indicative of vegetation moisture content and soil moisture discrimination, and thermal mapping applications.
6	10.4 – 12 .5 E	Thermal Infrared	Useful in vegetation stress analysis, soil moisture discrimination, and thermal mapping (heat loss, forest fires etc) applications.
7	2.08 – 2.35 R	Short Wave Infrared (SWIR)	Useful for discrimination of certain mineral and rock types. Also sensitive to vegetation moisture content.

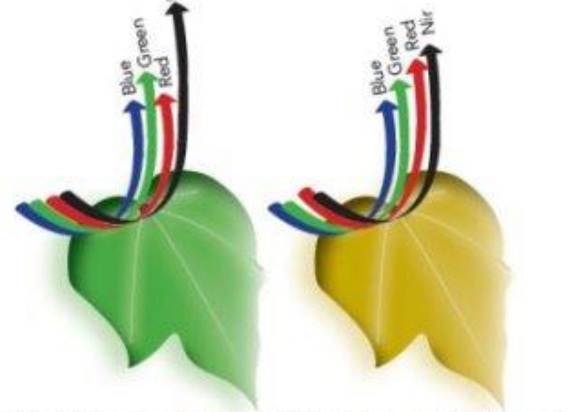


Figure 3a. Differences in reflected light between a healthy and unhealthy leaf.

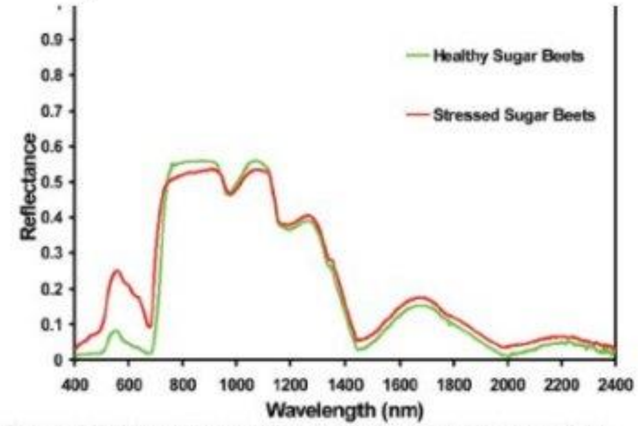
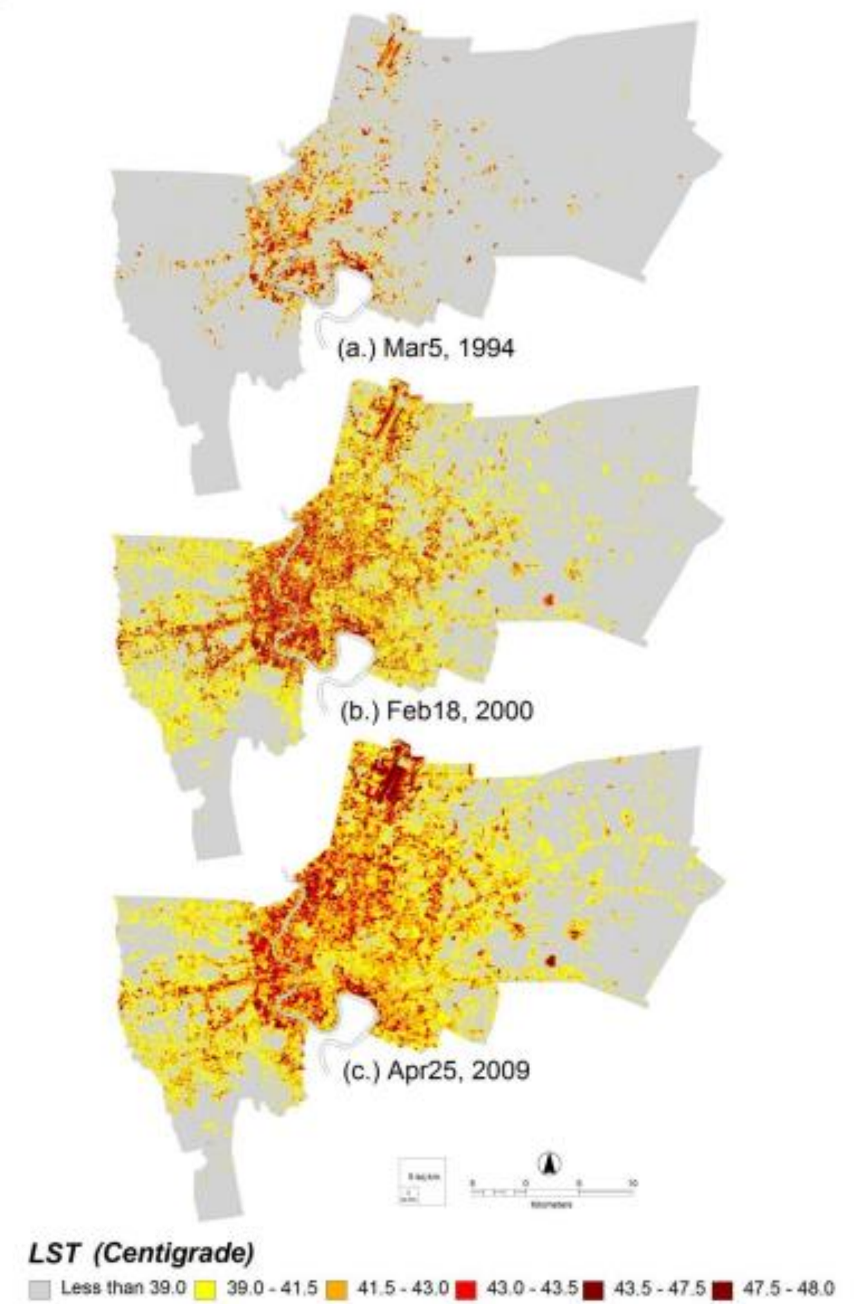


Figure 3b. Change in spectral reflectance for a portion of the EM spectrum for a healthy sugar beet plant and one under water stress.

1. Spectral extent

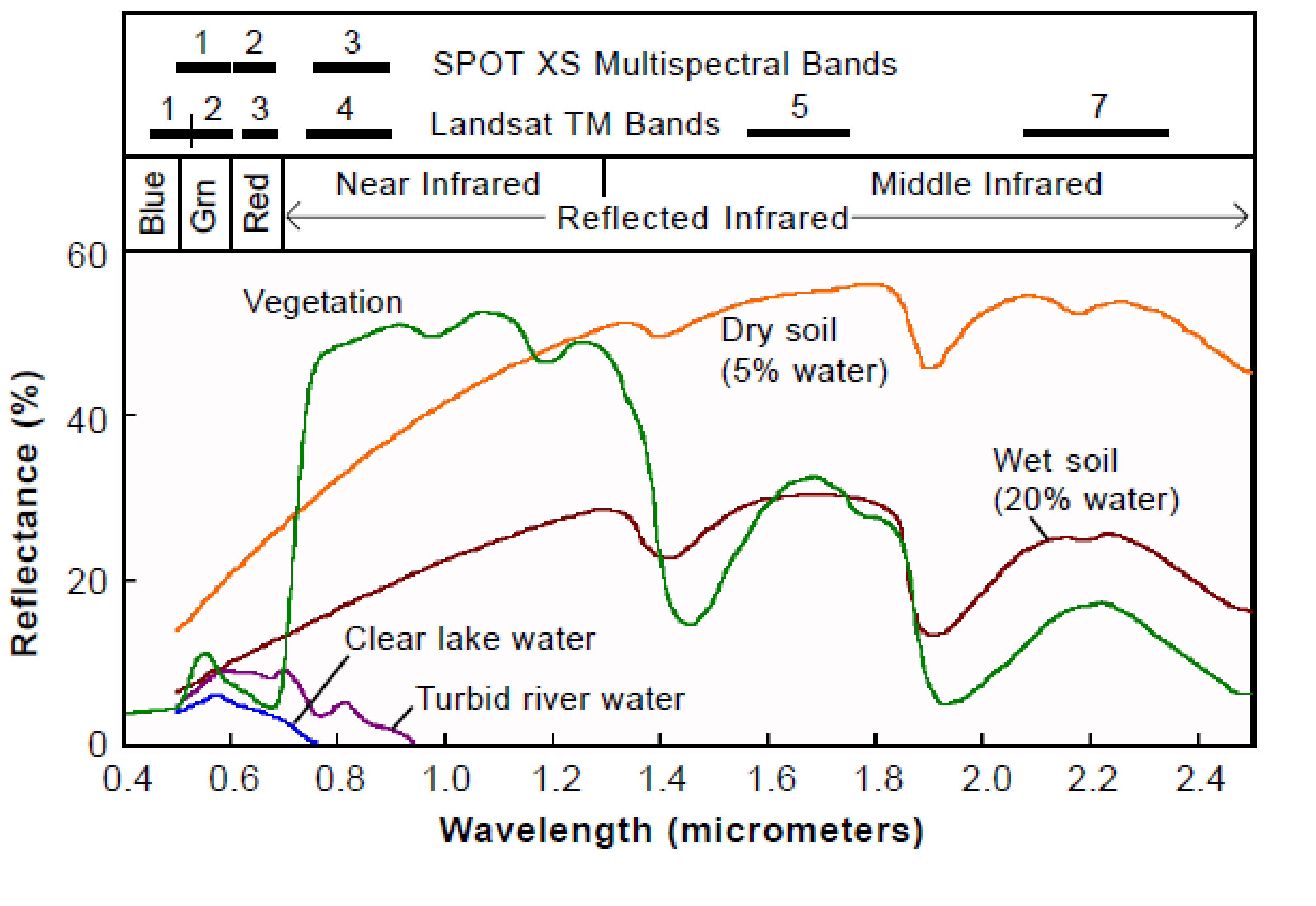
- Urbanization ~ can represent with the radiative skin temperature of the land surface (thermal band)



Figs.4. LST derived from Landsat TM (a,b,c) imagery for three different dates

Hokao, Kazunori, Vivarad Phonekeo, and M. Srivanit. "Assessing the impact of urbanization on urban thermal environment: a case study of Bangkok Metropolitan." *International Journal of Applied* 2.7 (2012).

1. Spectral Response of Common Materials



2. Challenge

- Separate ***real*** change from spectral change caused by:
  - Seasonal variation and phenology
  - Image misregistation
  - Clouds and shadows
  - Radiometric inconsistencies
    - Sensor
    - Variability in illumination (sun-angle, sensor position)
    - Atmospheric effects

2. Image pre-processing

- Goal: ensure that each pixel records the same type of measurement at the same location over time
  - Pre-processing steps are becoming automated and often are done before you receive an image

2. Image Enhancement or Transformation

- Derive and compare attributes highlighting scene features of interest
  - E.g., NDVI, NDMI, Tasseled Cap Greenness layers
- Advantages:
  - Reduce data and noise
  - Simplify comparisons

2. Normalized Difference Vegetation Index (NDVI)

1m NAIP imagery – 4band (blue, green, red, NIR)

1m NAIP NDVI – 1band (NDVI)

4band image NAIP image

↓

Single band NDVI image

NDVI = (NIR – Red) / (NIR + Red)

Vegetation appears bright (high values)

Non-vegetation appears dark (low values)

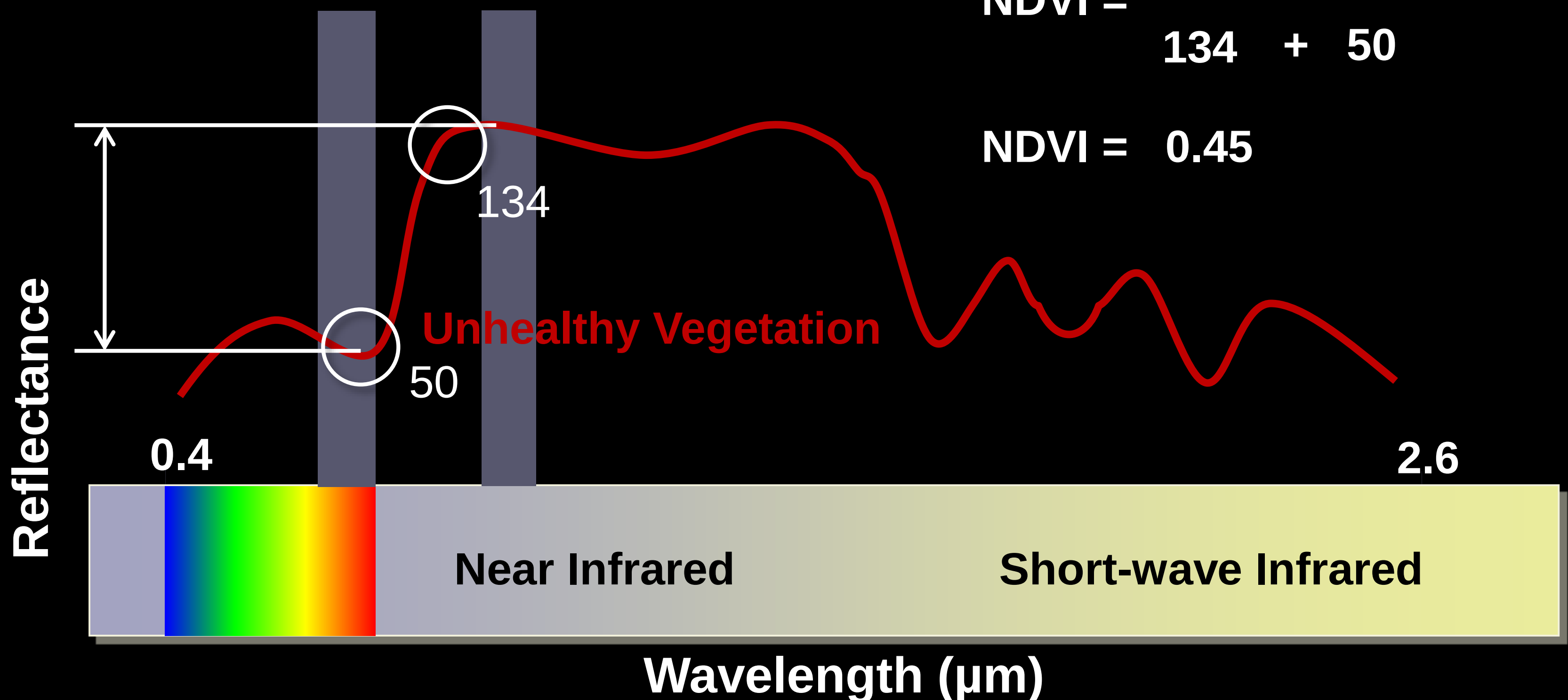
2. Band Ratios

We can make use of the spectral response of vegetation to obtain more information about the vegetation…

$$NDVI = \frac{NIR - Red}{NIR + Red}$$

$$NDVI = \frac{134 - 50}{134 + 50}$$

$$NDVI = 0.45$$



2. Variety of Image Transformations

These are examples of some other commonly used Image Transformations. This is not an exhaustive list, but it does show more widely used transformations

Transform	Formula	Purpose
Normalized Difference Vegetation Index (NDVI)	(NIR – RED) / (NIR + RED)	Differentiates between vegetated and non-vegetated land. Ranges from -1 to 1.
Normalized Burn Ratio (NBR)	(NIR-SWIR2) / (NIR+SWIR2)	Highlight burn scars and severity. Works well for other types of change as well.
Enhanced Vegetation Index (EVI)	2.5 * (NIR - RED) / (NIR + 6.0 * RED - 7.5 * BLUE + 1.0)	Alternative to NDVI for highlighting vegetation. It is intended to be sensitive to pixels with high biomass.
Tasseled Cap (Brightness, Greenness, Wetness)	See note below	Linear combinations of spectral bands that produce bands corresponding to the brightness, greenness, wetness (see note)

2. Image Transformations

- Tasseled Cap
  - Linear spectral transformation (each tasseled-cap band is created by the sum of image band 1 times a constant plus image band 2 times a constant, etc…)
  - Extracts components related to geophysical properties
  - First 3 bands of new image:
    - Brightness
    - Greenness
    - Wetness
  - Uses coefficients specific to the sensor

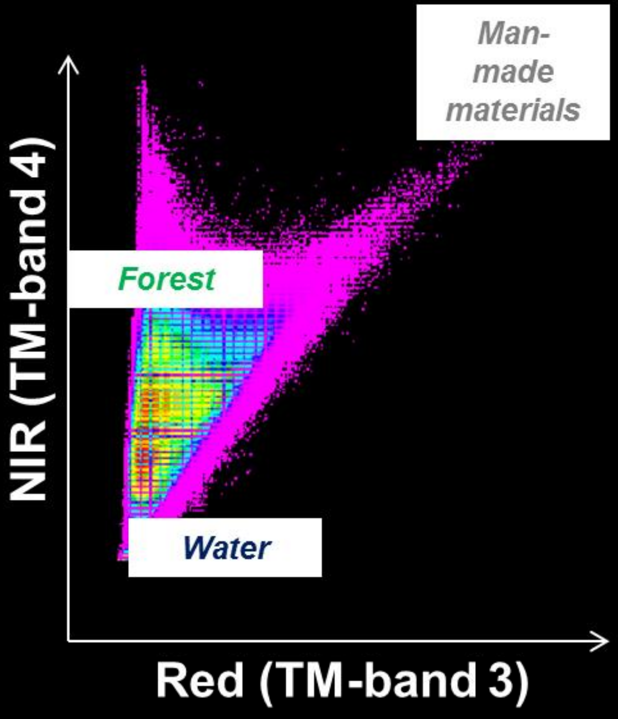
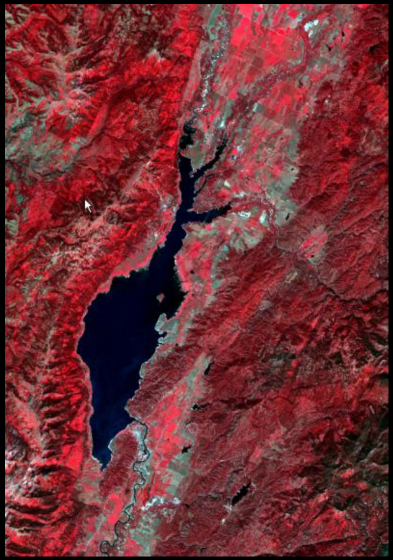


Table 6.3 Landsat-5 TM Tasseled Cap coefficient (*Source: Crist and Cicone, 1986*)

Feature	Coefficients						Additive term
	TM1	TM2	TM3	TM4	TM5	TM7	
Brightness	0.2909	0.2493	0.4806	0.5568	0.4438	0.1706	10.3695
Greenness	−0.2728	−0.2174	−0.5508	0.7221	0.0733	−0.1648	−0.7310
Wetness	0.1446	0.1761	0.3322	0.3396	−0.6210	−0.4186	−3.3828
Haze	0.8461	−0.0731	−0.4640	−0.0032	−0.0492	0.0119	0.7879
Fifth	0.0549	−0.0232	0.0339	−0.1937	0.4162	−0.7823	−2.4750
Sixth	0.1186	−0.8069	0.4094	0.571	−0.0228	0.0220	−0.0336

2. Image Transformations

7-band Landsat TM5 image



3-band Tasseled Cap image

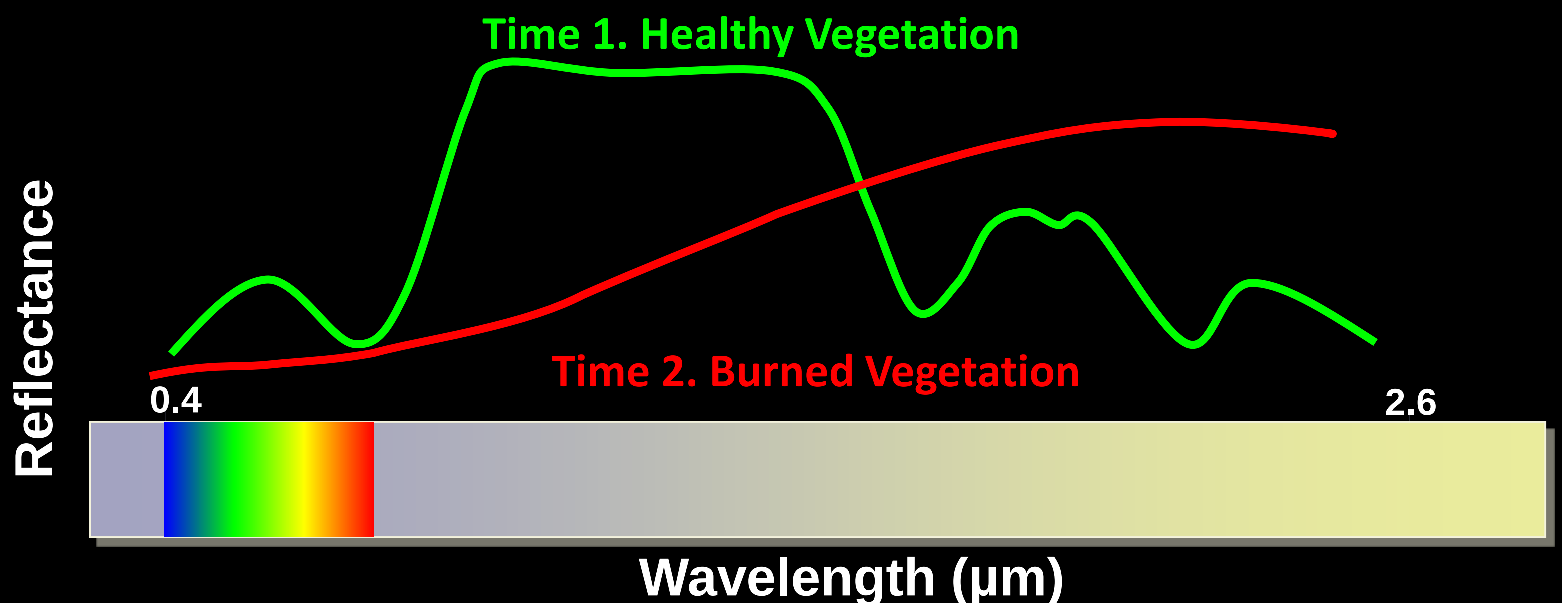
Brightness

Greenness

Wetness

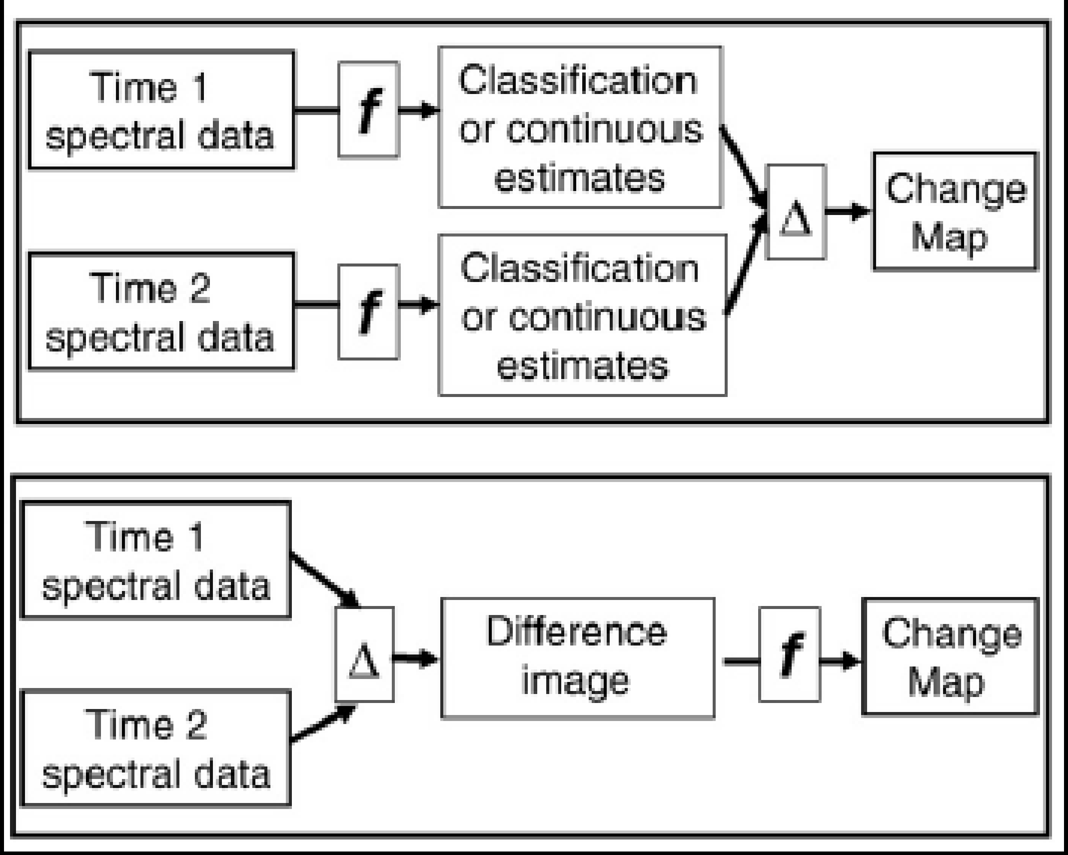
3. How do we detect change from imagery?

- Changes on the landscape can be detected as changes in the '*spectral space*' occupied by an image pixel



Analysis includes two steps (can be done in either order)

1. Subtraction (difference of time 1 and 2)
2. Modeling (subtract and then model)

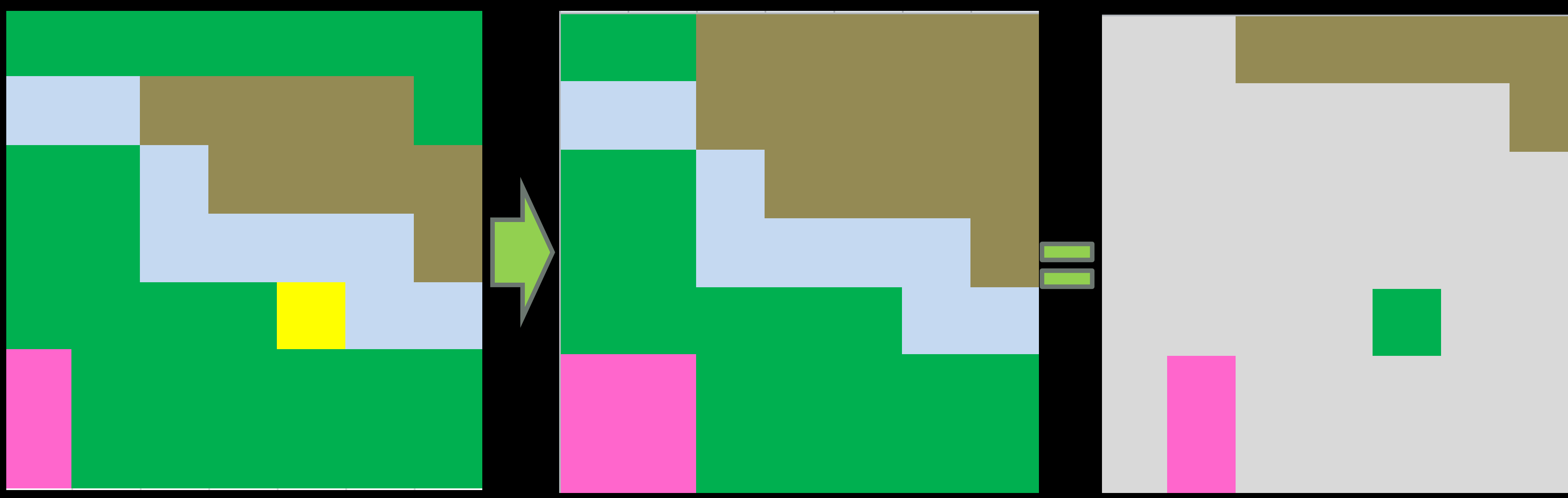


Model land cover, then subtract

Land Cover Time 1

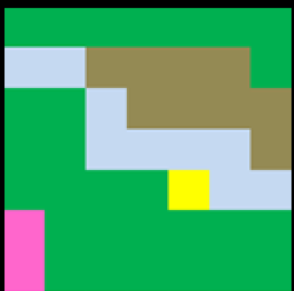
Land Cover Time 2

Change

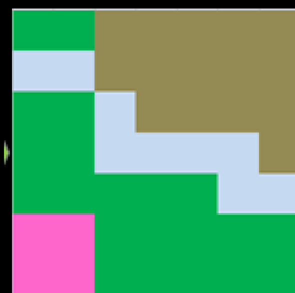


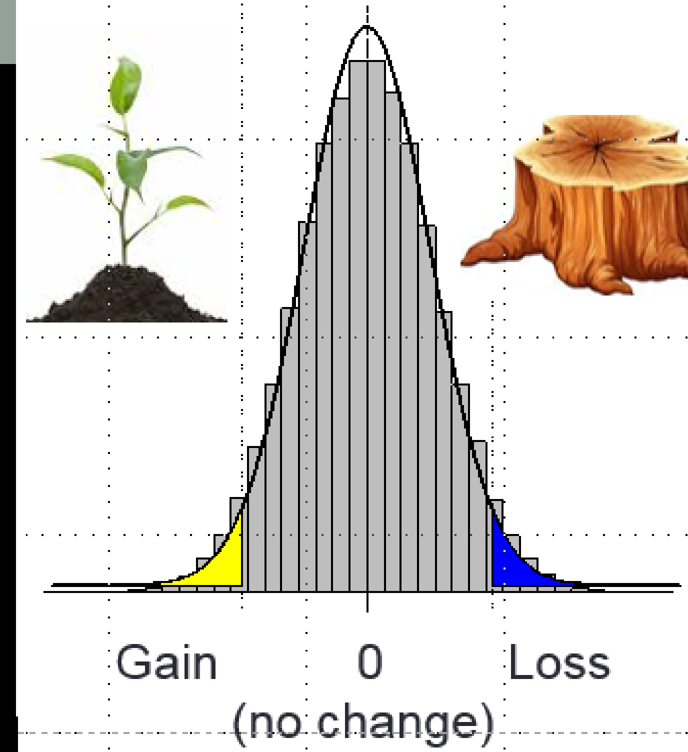
First Subtract, then Model

(unknown)
Land Cover
Time 1



(unknown)
Land Cover
Time 2





NDVI Time 1

1	1	1	1	1	1	1
0	0	0.5	0.5	0.5	0.5	1
1	1	0	0.5	0.5	0.5	0.5
1	1	0	0	0	0	0.5
1	1	1	1	0	0	0
-0.5	1		1	1	1	1
-0.5	1	1	1	1	1	1

NDVI Time 2

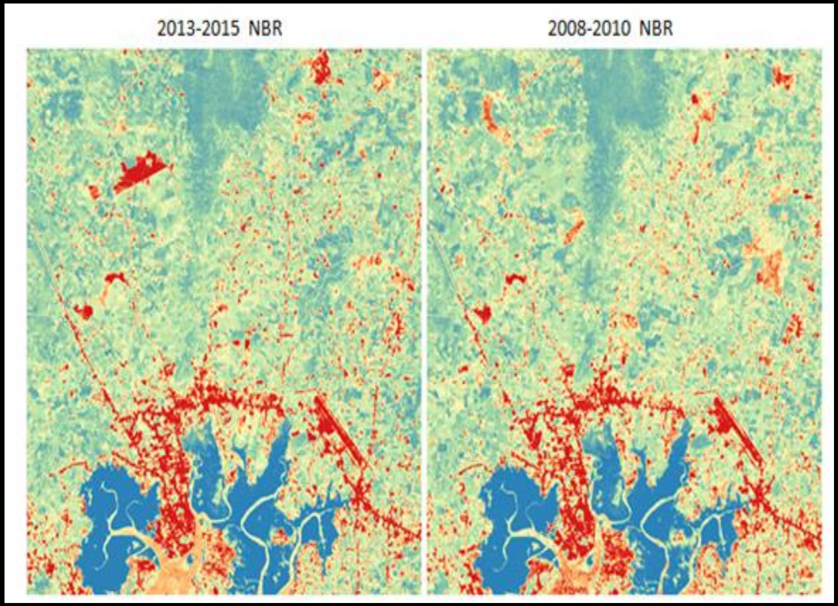
1	1	0.5	0.5	0.5	0.5	0.5
0	0	0.5	0.5	0.5	0.5	0.5
1	1	0	0.5	0.5	0.5	0.5
1	1	0	0	0	0	0.5
1	1	1	1	1	0	0
-0.5	-0.5		1	1	1	1
-0.5	-0.5	1	1	1	1	1

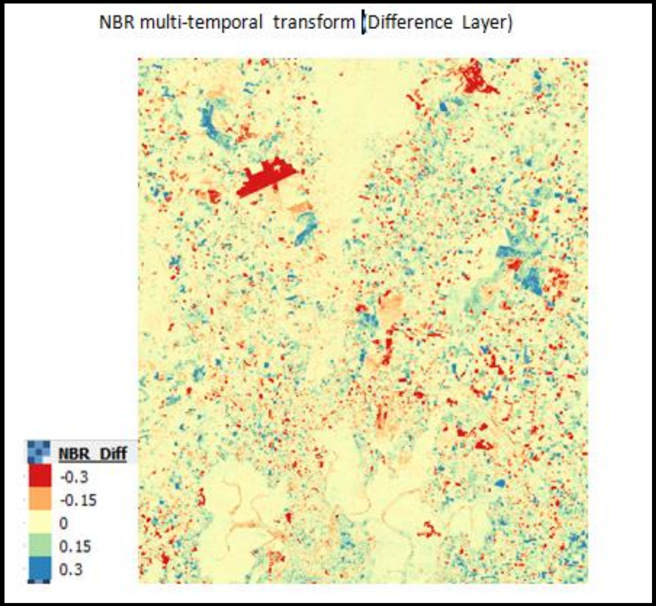
NDVI Change

0	0	0.5	0.5	0.5	0.5	0.5
0	0	0	0	0	0	0.5
0	0	0	0	0	0	0
0	0	0	0	0	0	0
0	0	0	0	-1	0	0
0	1.5	0	0	0	0	0
0	1.5	0	0	0	0	0

3. Image Differencing (multi-temporal transform)

- Normalized Burn Ratio (NBR)
- NBR from two different 3 year periods is analyzed to see differences





3. Change Analysis with Image Differencing (multi-temporal transform)

Example:

- Normalized Burn Ratio (NBR) = NBR = (NIR – SWIR) / (NIR + SWIR)
- Difference NBR = dNBR = Pre NBR – Post NBR
- Burn Severity = Thresholds applied to dNBR

Landsat

NBR

Pre-fire

6/8/2005

dNBR

Threshold applied - Burn Severity

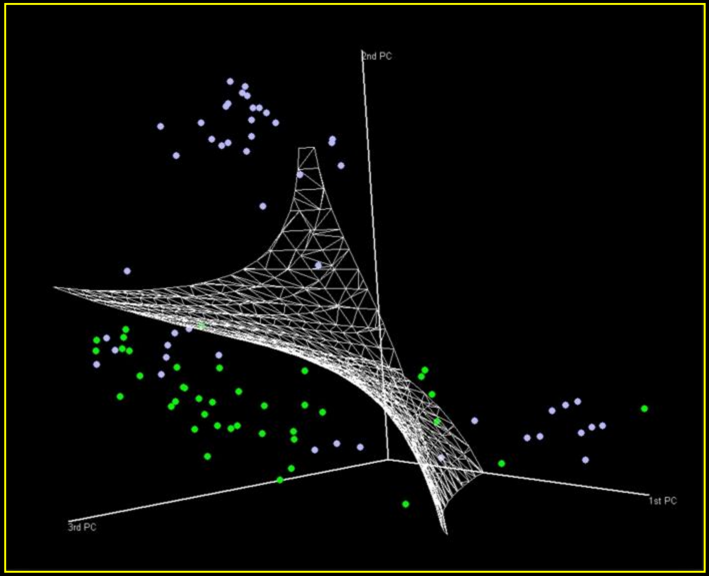
Difference

Post-fire

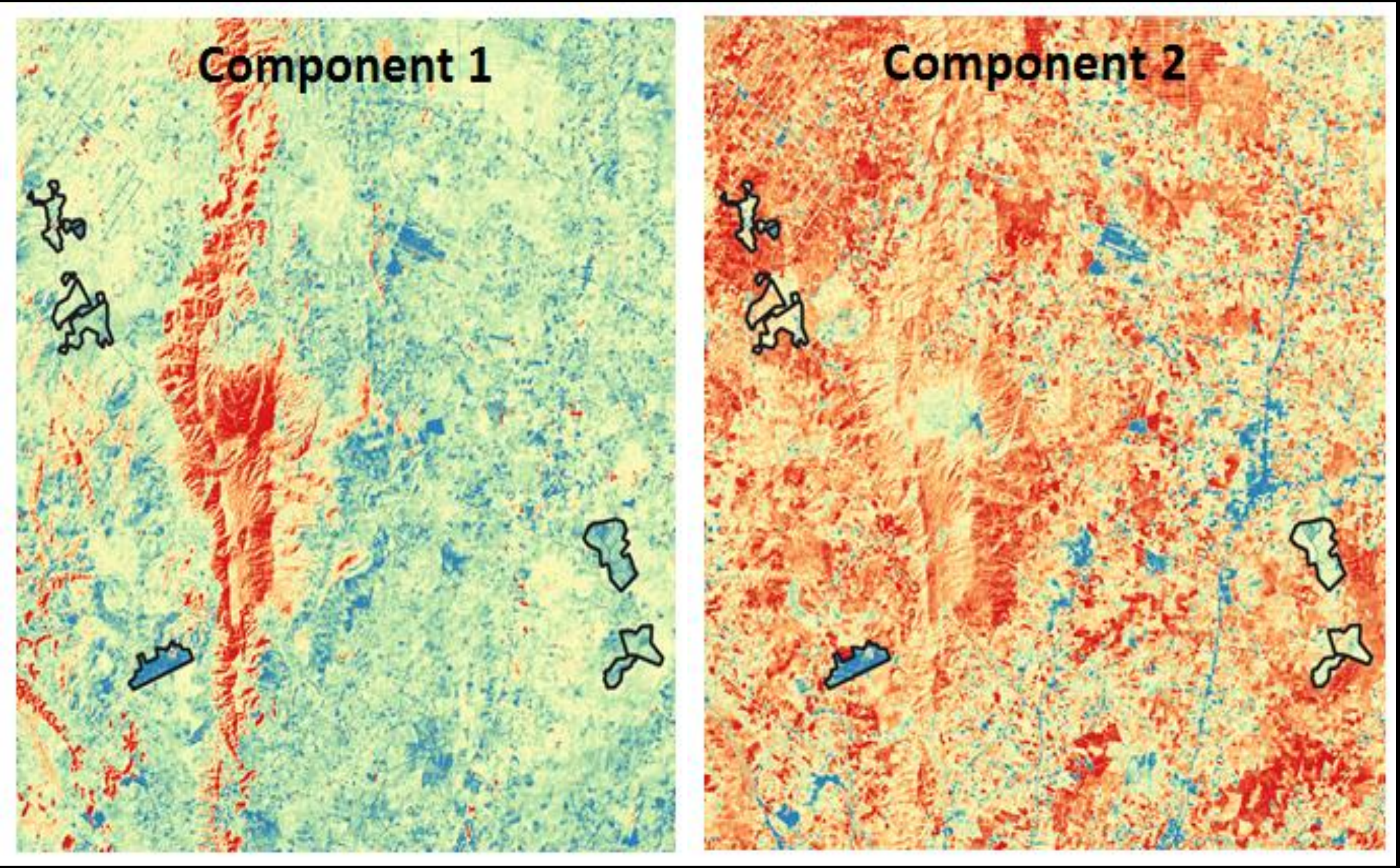
6/14/2007

3. Principle Components Analysis (PCA)

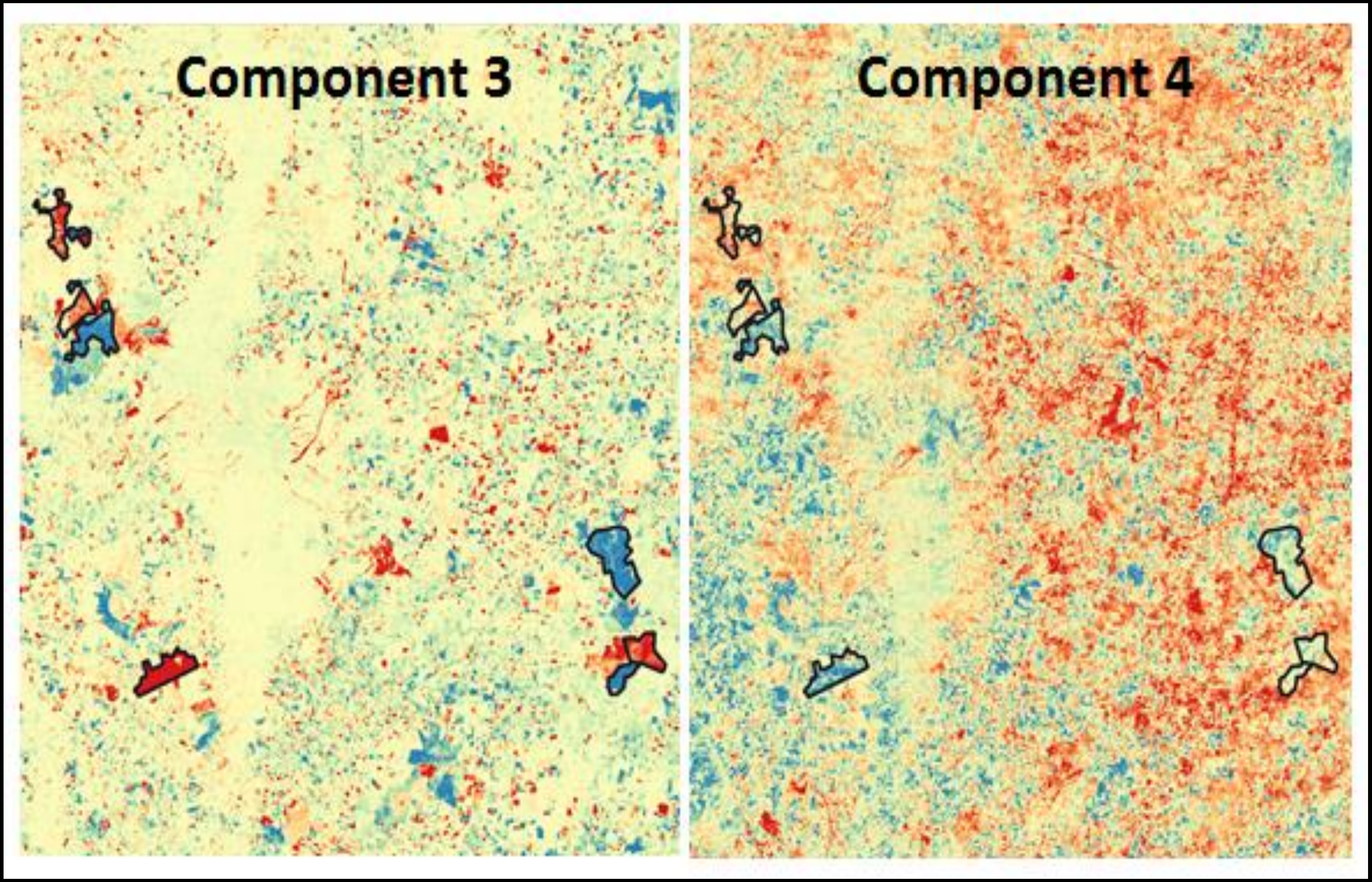
- Same multi-temporal transform can be done with PCA
- PCA transforms the spectral bands into new variables that are uncorrelated with one another.
- multi-date image stack.
  - Since areas of change will have low correlation between all the variables (spectral bands) when compared to stable pixels, these changes will be accentuated in the Principal Components.



3. Multi-temporal PCA "Bands"



3. Multi-temporal PCA "Bands"



4. Evaluation

- Compare map (results) to reference data
  - Evaluation of agreement vs. accuracy assessment
  - Not same data that was used to train classification process
  - Note: reference data assumed to be true, but reference data collection is also prone to error
- Can use reference data to update area estimates of land undergoing change

Change Detection - Summary

1. Articulate goals
2. Evaluate data and options for image processing
3. Refine or eliminate unrealistic paths
4. Assess cost and utility of different options

Change Detection - Summary

- Many considerations and approaches
  - Manual, automated, two-date and trend analysis methods
- A multistep process
  - Image selection/acquisition, preprocessing, enhancement/transformation, mapping change, validation

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