Change Detection

IRS Chapter 15

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Introduction to Change Detection in Remote Sensing

- **Change detection**: Identifies changes in surface features over time.
- Key applications:
  - Land use change
  - Vegetation monitoring
  - Environmental management

Bitemporal vs. Multitemporal Change Detection

- **Bitemporal Detection**:
  - Compares images from two specific dates.
  - Suitable for detecting abrupt changes.
- **Multitemporal Detection**:
  - Analyzes multiple dates for trend analysis.
  - Ideal for gradual or seasonal changes.
- Increasingly accessible data enables broader applications.

Conditions for Effective Change Detection

- **Consistent Sensor Data**: Same or calibrated sensors.
- **Seasonal Consistency**: Images taken in similar seasons.
- **High Co-registration Accuracy**: Preferably within 0.2 pixels.
    - This accuracy threshold comes from studies (e.g., Dai and Khorram, 1999)
- **Cloud-Free**: Clear skies over the area of interest.
- **Reflectance Correction**: Corrected to surface reflectance.

Preprocessing Steps for Change Detection

- **Image Calibration**: Ensure radiometric consistency.
- **Co-registration**: Align images to sub-pixel accuracy.
- **Reflectance Correction**: Adjust to surface reflectance.
- **Cloud Removal**: Clear cloud cover from images.
- **Noise Reduction**: Minimize environmental variation.

Visual Interpretation in Change Detection

- **Multidate Color Composite**: Combines bands from two dates.
- **Image Swiping/Flickering**: Overlay images for change visualization.
- **Side-by-Side Comparison**: View images in parallel for analysis.
- **Heads-Up Digitizing**: Manually identify and classify changes.

Image Swiping/Flickering Example

Annual NCLD Land Conver Data (from USGS) -- Oxford Area Land Cover from 2014

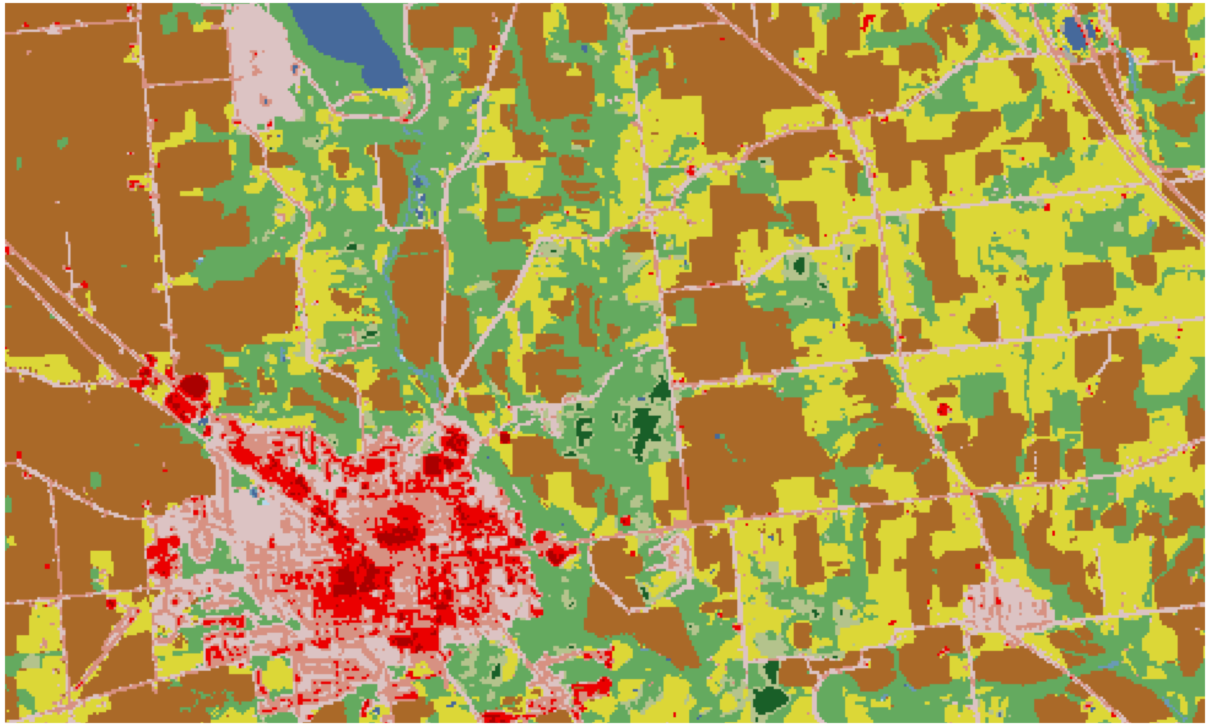


Image Swiping/Flickering Example

Annual NCLD Land Conver Data (from USGS) -- Oxford Area Land Cover from 2023

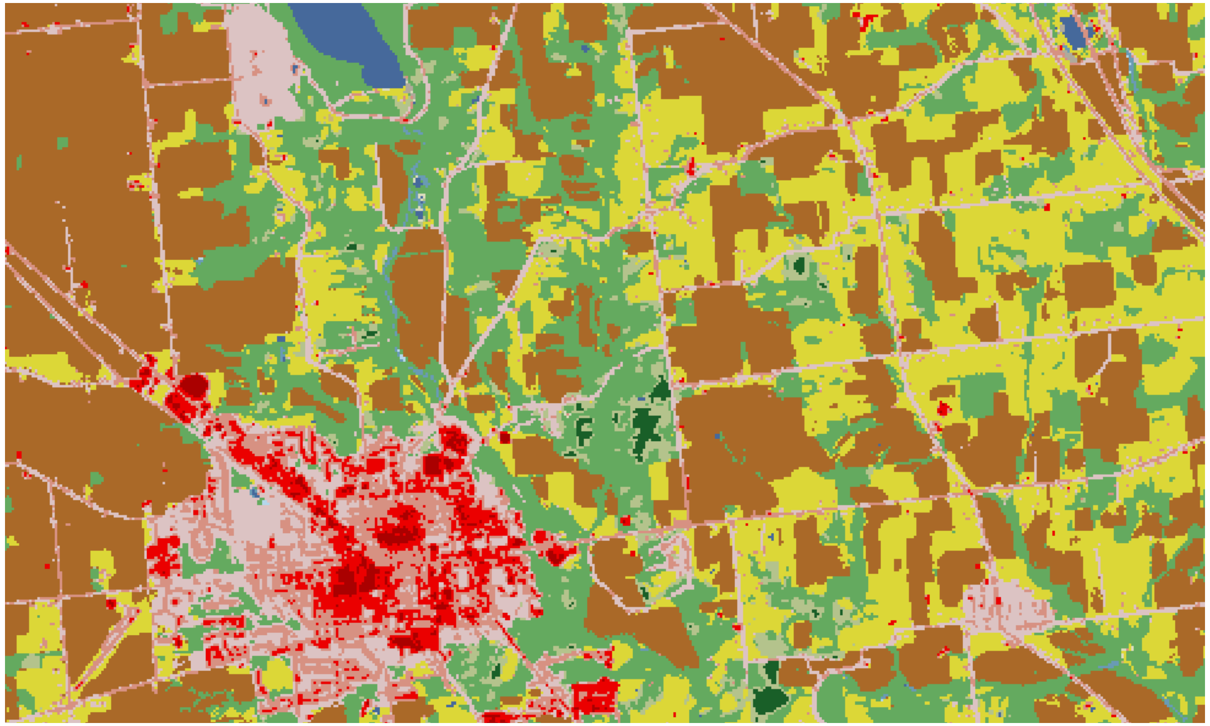


Image Swiping/Flickering Example

Aside: As programmers we can and should be able to do better

- Use `ffmpeg` to make videos or animated GIFs
- Save images as `feame-0001.png`, `frame-002.png` and so on.

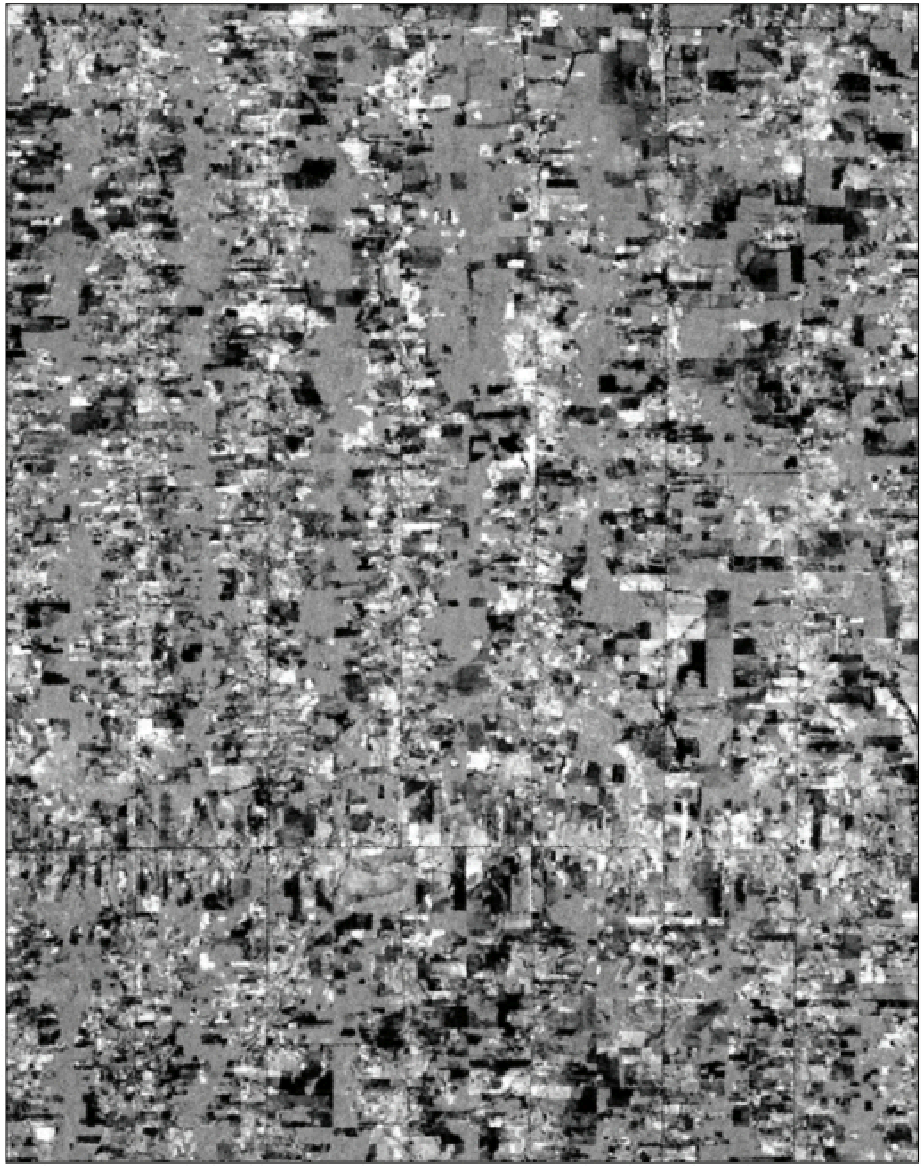
```
ffmpeg -framerate 2 -i frame-%04d.png -loop 0 output.gif
```

Image Algebra for Change Detection

- **Image Differencing**: Subtract pixel values between dates.
- **Image Ratioing**: Divide pixel values across dates. (Less sensitive to lighting & atmosphere)
- **Euclidean Distance**: Measures spectral distance.

$$D = \|x_1 - x_2\|_2 = \sqrt{(x_1 - x_2)^T (x_1 - x_2)}$$

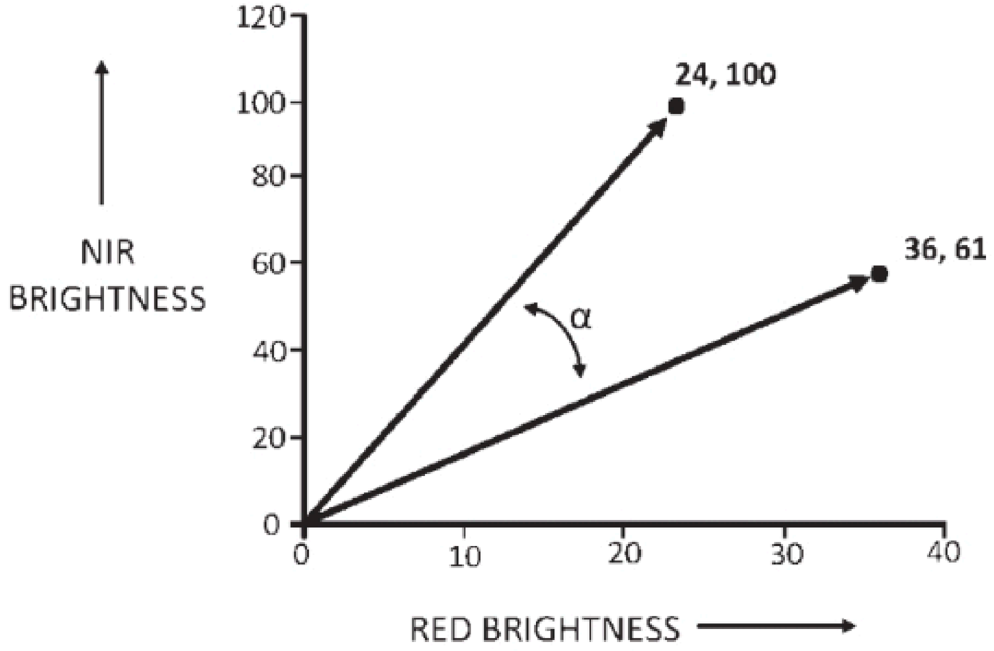
> The figure shows NDVI difference (brighter(+) = increase in vegetation, darker(-)= decrease, gray=no change)



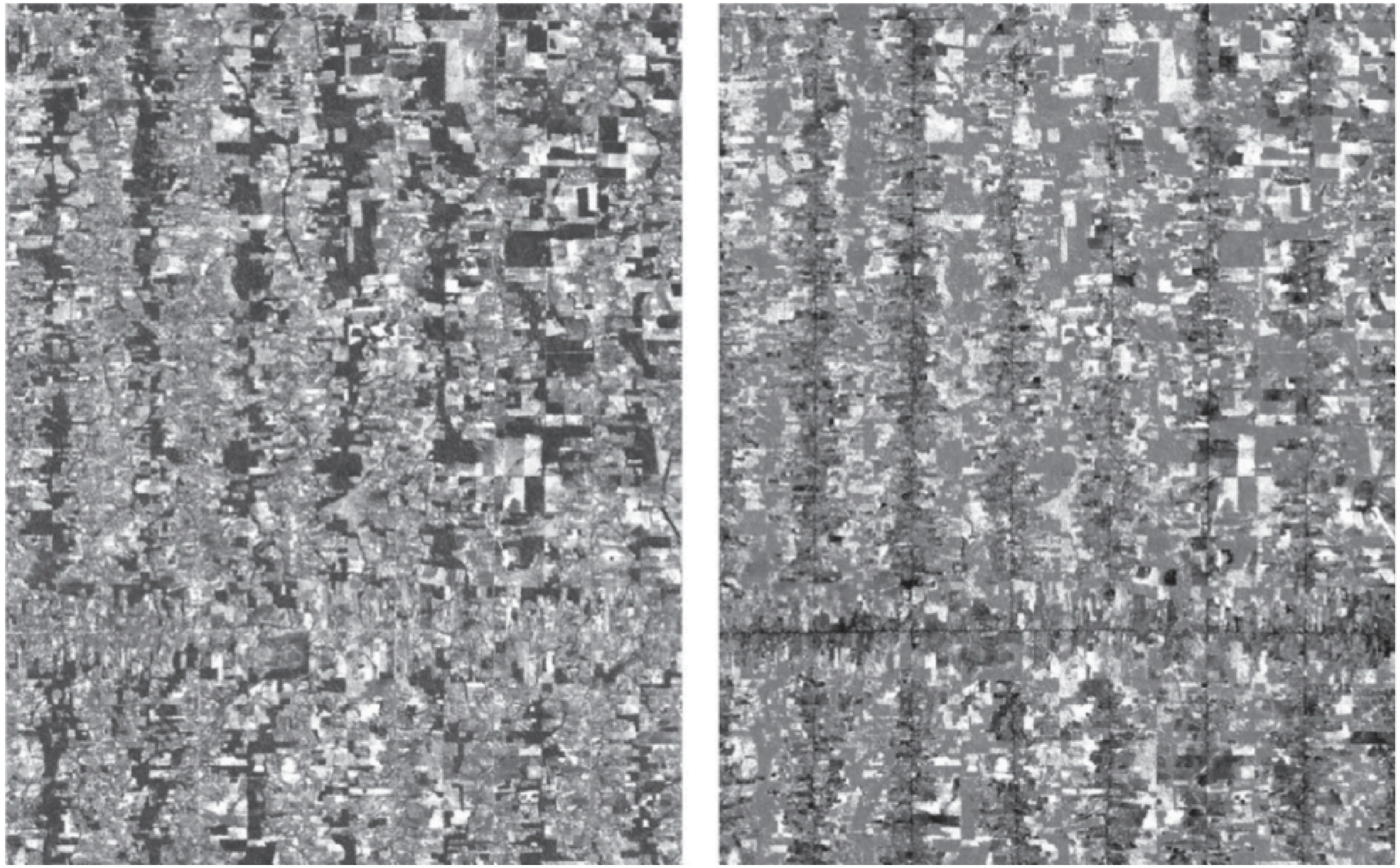
Change Vector Analysis (CVA)

- **Direction and Magnitude**: Captures change orientation.
- **Angle Measurement**: Uses cosine similarity.

$$\alpha = \cos^{-1}\left(\frac{x_1^T x_2}{\|x_1\|\|x_2\|}\right)$$



Change Vector Analysis (CVA)



(LEFT) Euclidean distance, (RIGHT) Spectral Angle Measurment

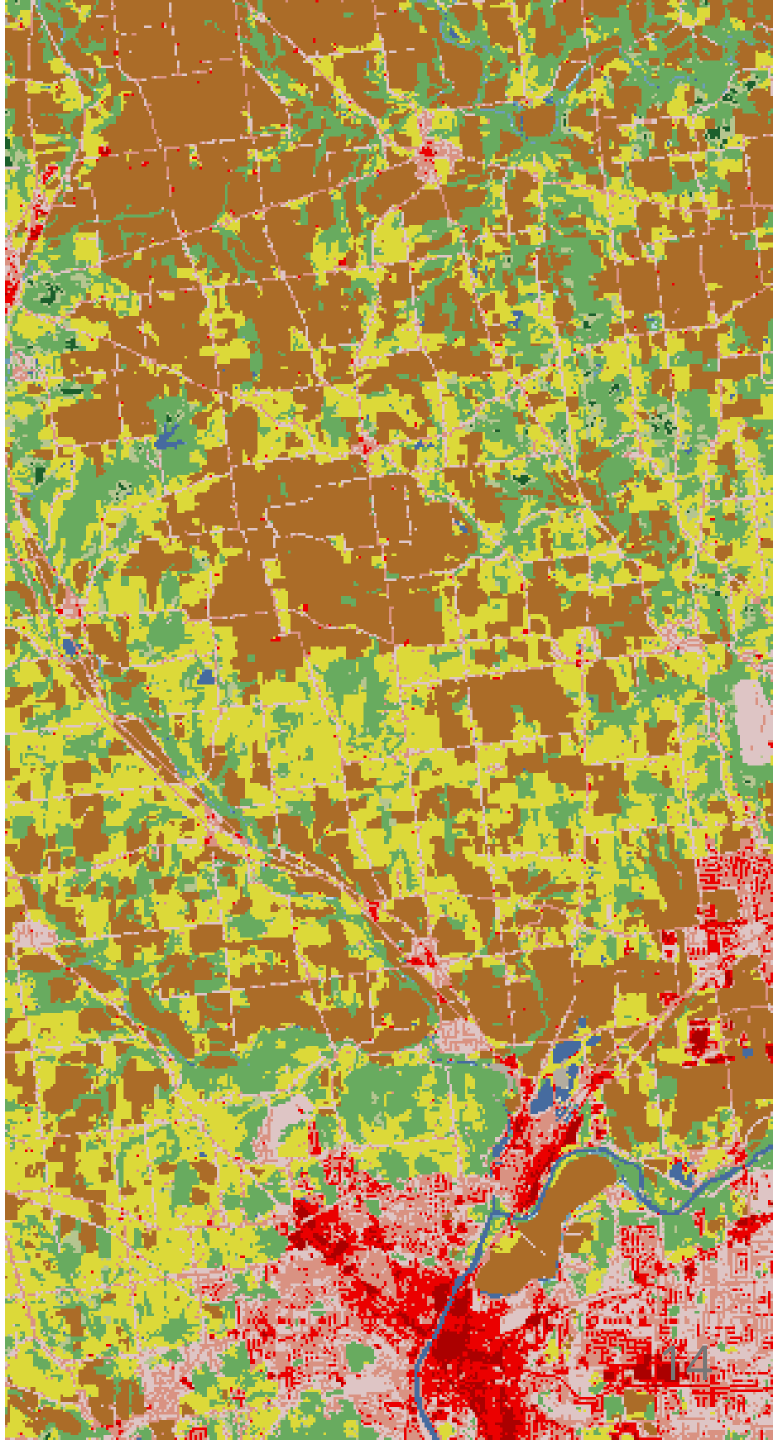
Why didn't the book include the the source images? 🤷

Transformation and Data Reduction

- **Principal Component Analysis (PCA)**: Reduces data to key components.
- **Tasseled Cap (TC) Transformation**: Analyzes brightness, greenness, wetness.
- Enables detection of prominent changes.
- These transformations simplify change detection by focusing on components that emphasize key landscape changes.

Classification in Change Detection

- **Powerful for Change Attribution**: Identifies type of land cover change.
- **Whole Area vs. Targeted Classification**:
    - Whole area: Classify all then look for changes
    - Targeted: First identify changed areas then classify the change
- **When to use each?**:
    - If whole area classification can be done accurately, this is often preferred



Statistical Techniques in Change Detection

- Focus on a single band for interpretability (for now)
    - Can reduce multiband images by e.g. NDVI or PCA
- **Pearson Correlation**: Between -1 and 1 (no change)

$$\text{cov}_{12} = \frac{\sum(x_1 - \bar{x}_1)(x_2 - \bar{x}_2)}{n-1}$$

$$r = \frac{\text{cov}_{12}}{s_1 s_2}$$

- $\bar{x}_1$, $\bar{x}_2$ -- are the mean instensities for image 1 and image 2
- s_1, s_2 are the standard deviations. *Why not σ?* 🤷 ¯_(ツ)_/¯

Multitemporal Change Detection: Benefits

- **Enhanced Change Detection**: Detects low-magnitude trends.
- **Gradual Change Capture**: Monitors slow processes (e.g., vegetation growth).
- **Aligned with Socioeconomic Cycles**: Annual analysis supports policy planning.

Multitemporal Change Detection: Challenges

- **Cloud Cover**: Persistent clouds complicate analysis.
- **Data Volume**: Large datasets require robust processing.
- **Phenological Effects**: Seasonal changes can obscure results.

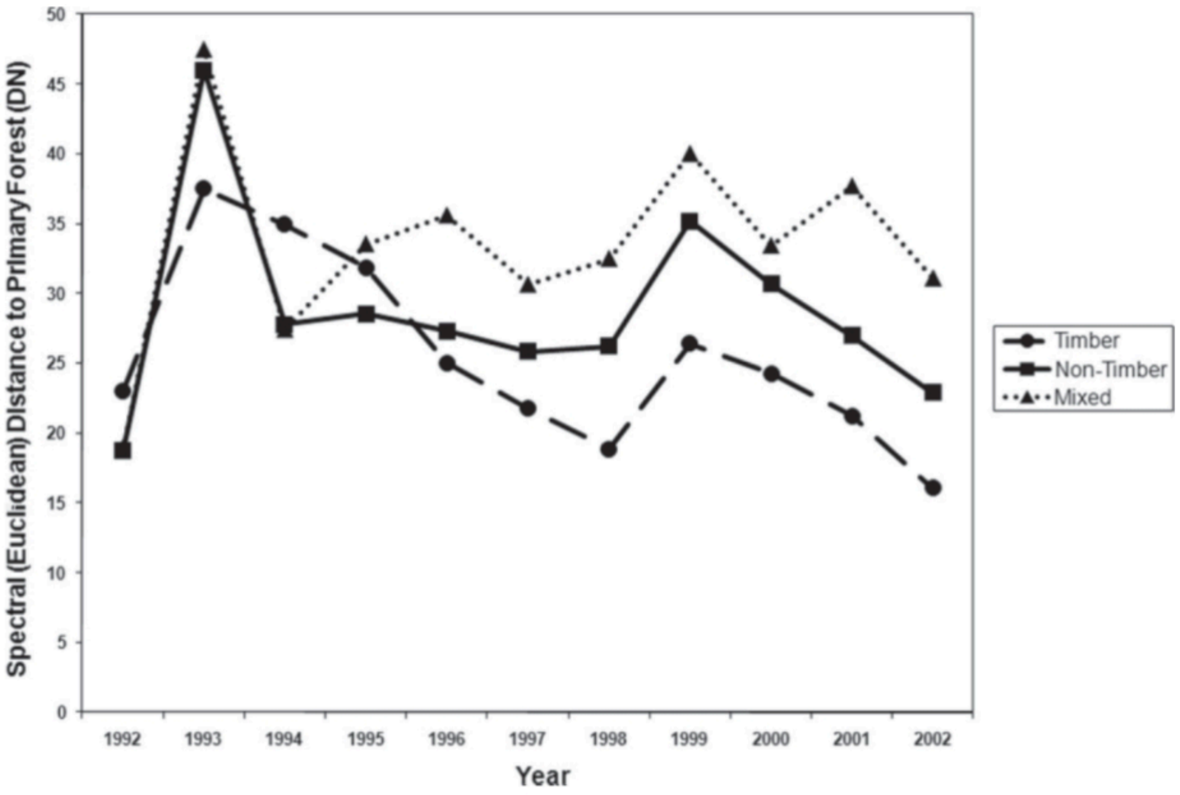
Preprocessing for Multitemporal Detection

- **Take Care Collecting Images**: Aim for the same season, time of day. Register.
- **Image Co-Registration**: Also include e.g. histogram matching etc.
- **Cloud Removal**: Manual and automated techniques.
- **Image Normalization**: Adjusts for atmospheric or seasonal variance.
- **Segmentation (optional)**: Groups pixels with similar trajectories.
- **Band Selection (optional)**: Focus on a single band or derived value to simplify analysis.

Cloud Cover Analysis in Multitemporal Change Detection

- **Challenge**: Cloud cover limits clear imagery, especially with one image per year.
- **Image Selection**: Choose the clearest annual image available.
- **Gap Handling Options**: (To fill the hole left when clouds are removed)
  - **Pixel Interpolation**: Use nearby pixels in the same image.
  - **Date Interpolation**: Use nearby dates' images for missing areas.
  - **EWMA** Exponentially weighted moving average
    (fancy versions of temporal interpolation)

Example from the book….



Mean spectral distance from primary forest by agroforestry group

Time Series Analysis Basics

- **Kernel Regression**: Linear combination of basis functions.
- **Top-Down Methods**: Whole-series approximation, then partition.
- **Bottom-Up Methods**: Builds larger structures from smaller ones.

Least Squares (LS) Solution for Basis Functions

- **Goal**: Minimize error between observed values $ y $ and model predictions $\hat{y}$.
- **Model Representation**: Express $\hat{y}_x$ as a sum of basis functions:

$$\hat{y}_x = a_0 f_0(x) + a_1 f_1(x) + \cdots + a_n f_n(x)$$

- **Objective**: Find coefficients a_i that minimize the sum of squared residuals.

Example: Monomial Basis Functions in LS Solution

- **Monomial Basis Functions**: Use powers of x: $1, x, x^2, x^3$.
  - $f_i(x) = x^i$
- **Observations:** $\{(x_i, y_i) \mid \quad i = 1 \ldots m\}$
  - Note I use x rather thant t, whatever!
- **Three Cases**:
  - **Underdetermined**: Fewer points than functions (insufficient data).
  - **Exactly Determined**: Same number of points as functions.
  - **Overdetermined**: More points than functions (more data than needed).

Setting Up the Matrix for LS Solution

- **Matrix Setup**: Each element (i, j) is $f_j(x_i)$.

$$\mathbf{A} = \begin{bmatrix} f_0(x_1) & f_1(x_1) & \dots & f_n(x_1) \\ f_0(x_2) & f_1(x_2) & \dots & f_n(x_2) \\ \vdots & \vdots & \ddots & \vdots \\ f_0(x_m) & f_1(x_m) & \dots & f_n(x_m) \end{bmatrix}$$

- **Objective**: Solve $\mathbf{A}\mathbf{a} = \mathbf{y}$ for coefficients $\mathbf{a}$.

Solving with the Normal Equations

- **Normal Equations**: Used when the system is overdetermined.

$$\mathbf{A}^T\mathbf{A}\mathbf{a} = \mathbf{A}^T\mathbf{y}$$

- **Interpretation**: Projects $\mathbf{y}$ onto the space spanned by the basis functions.
- **Underdetermined Systems**: Require additional constraints or regularization.

$$(\mathbf{A}^T\mathbf{A} + \lambda\mathbf{I})\mathbf{a} = \mathbf{A}^T\mathbf{y}$$

Harmonic Basis Functions

- **Cosine and Sine Functions** as Basis:

$$\hat{\rho}_x = a_0 + a_1 \cos\left(\frac{2\pi}{T}x\right) + a_2 \sin\left(\frac{2\pi}{T}x\right)$$

- **Periodicity**: Fits seasonal changes in time series data.
- **Coefficients** a_0, a_1, a_2: Control the overall value and seasonal oscillation.
- T **(Period)**: Defines the cycle length, e.g., $T = 365$ for annual data.

Harmonic Basis and Fourier Transform

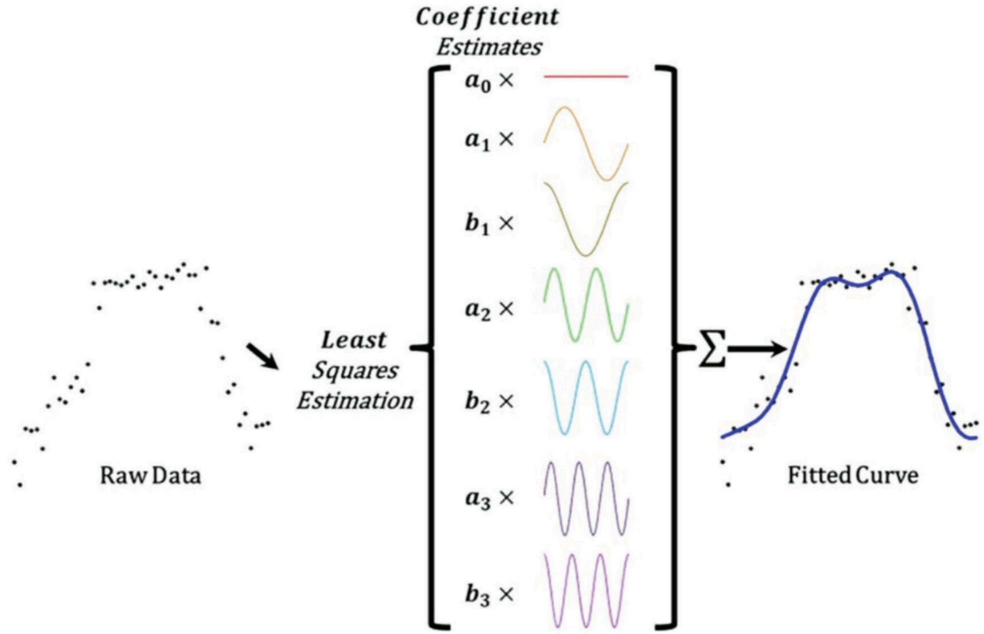
- **Fourier Transform**: Decomposes signals into sine and cosine functions.
- **Relation to Harmonic Regression**:
  - Harmonic basis functions approximate seasonal data.
  - Fourier transform captures all frequencies, extending harmonic regression’s single frequency.
- **Application**: Harmonic regression is a simplified case of Fourier analysis.

Harmonic Regression for Change Detection

- **Models Seasonal Trends**:

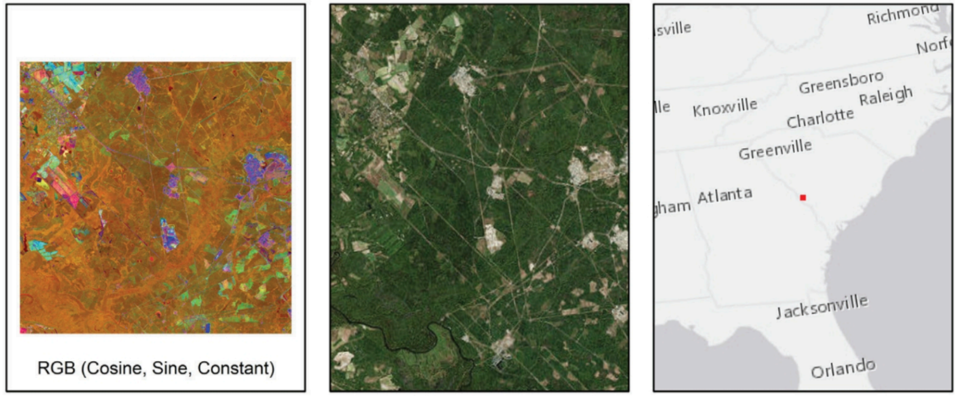
$$\hat{\rho}_x = a_0 + a_1 \cos\left(\frac{2\pi}{T}x\right) + a_2 \sin\left(\frac{2\pi}{T}x\right)$$

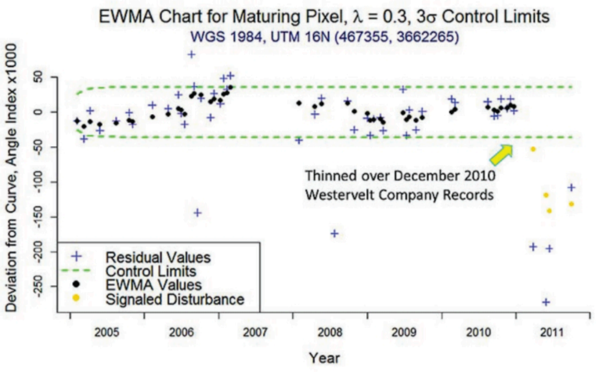
- Note that you can add new bases for different periods (months, seasons, weeks, etc)

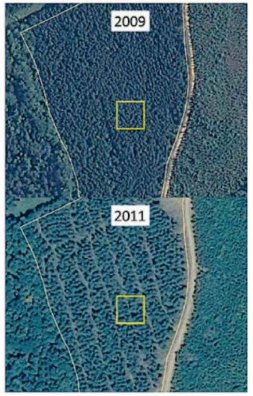


Control-Chart Change Detection

- **EWMA Control Charts**: Detect small shifts.
- **Shewhart X-bar Charts**: Detect larger process shifts.







Summary of Change Detection in Remote Sensing

- Change detection supports environmental and urban planning.
- **Bitemporal**: Suitable for abrupt changes.
- **Multitemporal**: Captures long-term trends.
- Increasing data availability enhances capability.