Change Detection

- Earth is not static. Dynamic (e.g. time-dependent) processes are at work that change the surface.
- Most remote sensing systems can repeatedly observe the same portion of the Earth's surface at different times
- This allows us to monitor surface change and the processes that cause it.

General Steps Used to Conduct Digital Change Detection Using Remote Sensor Data

State the Change Detection Problem
- Define the study area
- Specify frequency of change detection (e.g. seasonal, yearly)
- Identify classes from an appropriate land cover classification system

Considerations of Significance When Performing Change Detection
- Remote Sensing System Considerations
  - Temporal resolution
  - Spatial resolution
  - Spectral resolution
  - Radiometric resolution
- Environmental Considerations
  - Atmospheric conditions
  - Soil moisture conditions
  - Phenological cycle characteristics
  - Tidal stage

Image Processing of Remote Sensor Data to Extract Change Information
- Acquire Appropriate Change Detection Data
  - *In situ* and collateral data
  - Remotely sensed data
    - Base year (Time n)
    - Subsequent Year(s) (Time n-1 or n+1)
- Preprocess the Multiple Date Remotely Sensed Data
  - Geometric registration
  - Radiometric correction (or normalization)
- Select Appropriate Change Detection Algorithm
- Apply Appropriate Image Classification Logic If Necessary
  - Supervised, unsupervised, hybrid
- Perform Change Detection using GIS Algorithms
  - Highlight selected classes using change detection matrix
  - Generate change map products
  - Compute change statistics

Quality Assurance and Control Program
- Assess Statistical Accuracy of:
  - Individual date classifications
  - Change detection products

Distribute Results
- Digital products
- Analog (hardcopy) products

Surface Change

- **1st step:**
  - **Define the study area.**
  - **Identify the processes/phenomenon to monitor → defines the time scale over which to observe.**
  - **Select the land-cover classes to observe e.g. what you are going to look at (vegetation? urban development? something else?).**

Surface Change

- **You need to consider the characteristics and limitations of the remote sensing system (your data).**

- **You need to consider environmental factors (e.g. atmosphere, temporal characteristics of the target process, etc.).**

Remote Sensing System Considerations

- **Ideally, the following parameters need to be constant between the images being analyzed for change:**
  - **Temporal resolution**
  - **Spatial resolution**
  - **Look angle**
  - **Spectral resolution**
  - **Radiometric resolution**

Temporal Resolution

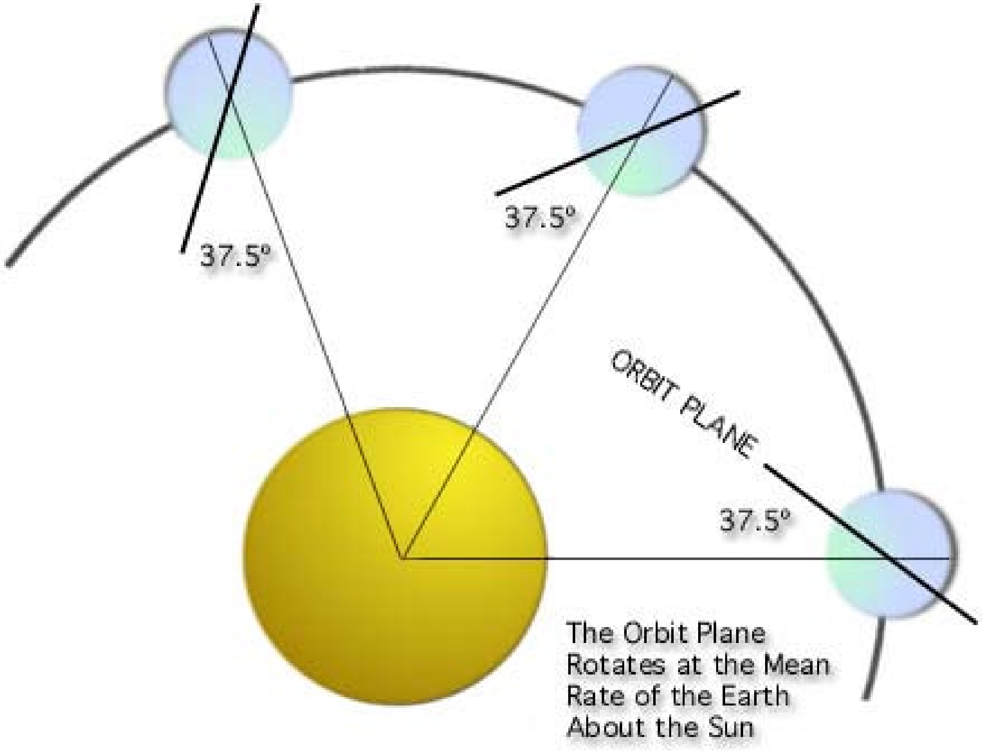
- **When using multiple dates of remotely sensed data you need to (when possible)…**
  - **Use data collected at the same time of day. This will eliminate diurnal (daily) variations in the sun angle that will affect reflectance values.**
  - **Use data collected on anniversary dates. This eliminates seasonal variations in sun angle and other (perhaps unwanted) effects like vegetation changes.**

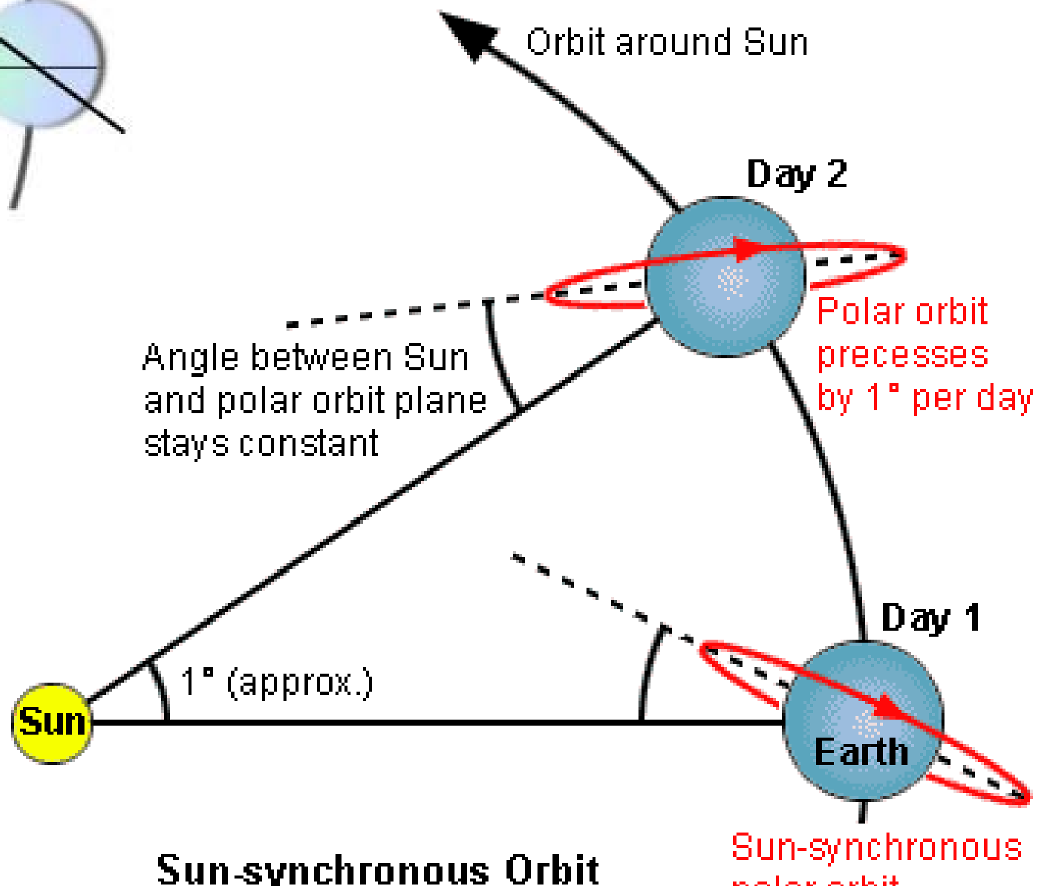
Temporal Resolution

- Terra (the spacecraft carrying ASTER) and most other remote sensing satellites are in sun-synchronous orbits.

- These orbits are designed such to cross the equator at the same local time each day. They maintain a constant relationship between the orbital plane of the spacecraft, the Earth, and the Sun.

- Terra's orbit crosses the equator at 10:30am (local) and passes over the same point every 16 days.


37.5°
37.5°
ORBIT PLANE
37.5°
The Orbit Plane
Rotates at the Mean
Rate of the Earth
About the Sun

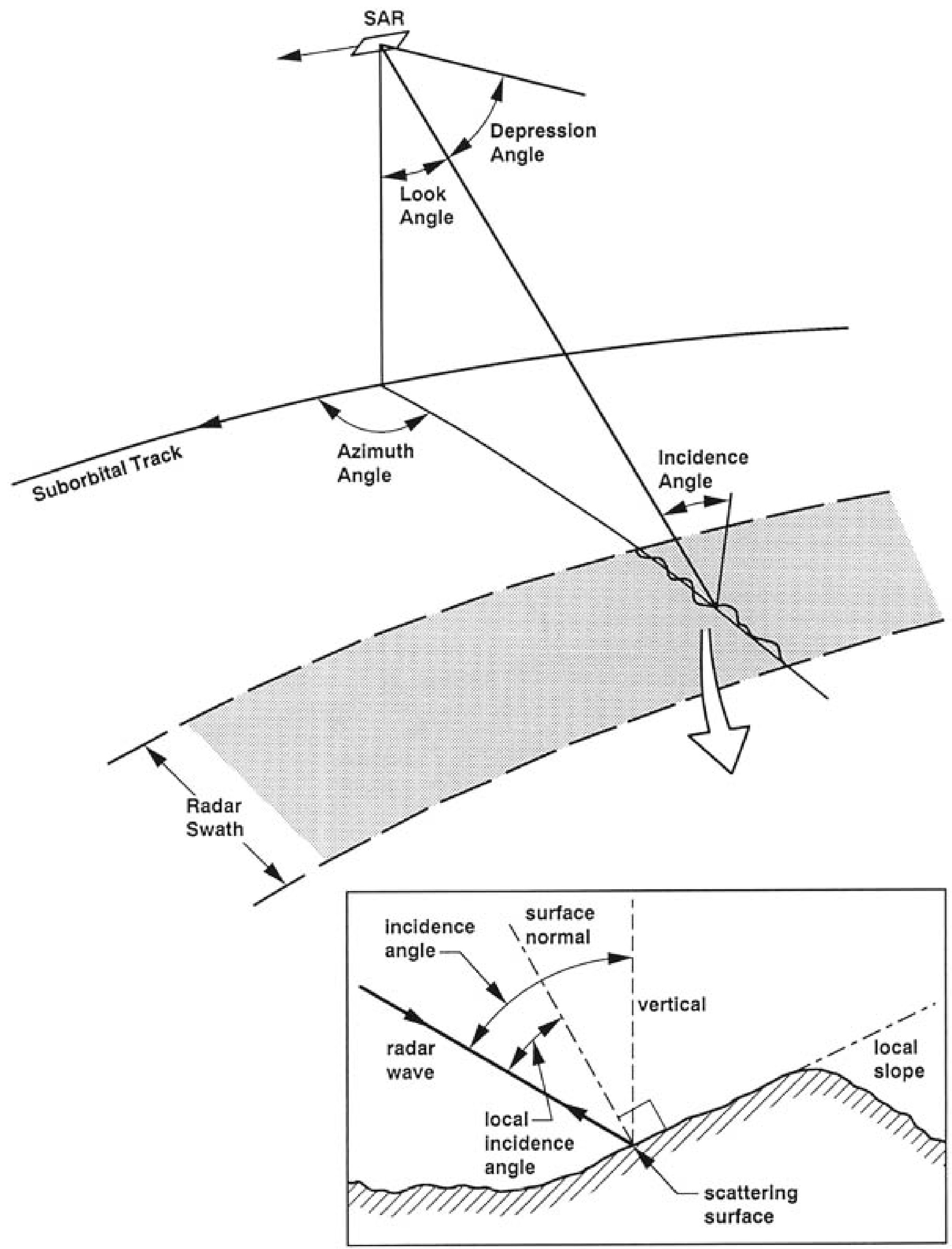

Orbit around Sun
Day 2
Polar orbit
precesses
by 1° per day
Angle between Sun
and polar orbit plane
stays constant
Day 1
1° (approx.)
Sun
Earth
Sun-synchronous Orbit
Sun-synchronous
polar orbit

Spatial Resolution

- **All images need to be precisely registered (to within 0.5 pixels).**
- **Both images must have the same resolution and must show the same field of view. Do this by spatial resampling.**
- **Misregistration and resampling effects can lead to spurious changed pixels.**

Look Angle

- Some systems can collect off-nadir data. When doing so, the sensor is not looking straight down, but at an angle.
- ASTER can do this. The VNIR instrument can look up to +/-24° to either side of the ground track (SWIR and TIR can only look +/-8°). In addition, band 3B looks 27.6° to the rear of where 3N looks.
- The look angle will determine the effective illumination geometry → differences in illumination produce differences in reflectance as seen at the sensor
- The look angle also determines the amount of parallax in the scene → produces pixel "shifts" (due to topography, etc.).


SAR
Depression Angle
Look Angle
Suborbital Track
Azimuth Angle
Incidence Angle
Radar Swath
incidence angle
surface normal
vertical
radar wave
local slope
local incidence angle
scattering surface

Spectral Resolution

- **Fundamental assumption of change detection: difference exists in the DN of a pixel on two different dates if the "biophysical" properties of that pixel has changed over that time.**

- **Requires**
  - **Measurement in bands that will be sensitive to the surface change process.**
  - **Observation of the same band on the two dates e.g. the same wavelength.**

Radiometric Resolution

- **Remember that digital imagery is recorded at a specific level of quantization, e.g. 8-bit, 12-bit, etc.**

- **Images used for change detection must have the same level of quantization (radiometric precision).**

Environmental Considerations

- **Need to take into account environmental factors other than the process you are monitoring.**
- **There is a suite of processes that can lead to apparent change between two images.**
- **Hold as many of these factors constant as possible.**

Atmospheric Conditions

- The water content of the atmosphere (clouds, humidity, haze) will affect the radiance received by the sensor → DN values.
  - Absorption
  - Attenuation
  - Shadowing
- The presence of different amounts of atmospheric water between two scenes will result in a false impression of surface change…
  - There *is* change, it's just in the atmosphere, not on the ground.

Atmospheric Conditions

- **Use of data collected on anniversary dates can ensure some level of confidence in equivalent atmospheric states between images.**

- **Atmospheric variation can be removed:**
  - **Quantitative atmospheric correction (ATREM, etc.) and illumination corrections.**

  - **Semi-quantitative corrections (empirical line, normalization – see Jensen Chapter 6, etc.) and illumination corrections.**

Multiple-Date Atmospheric Normalization

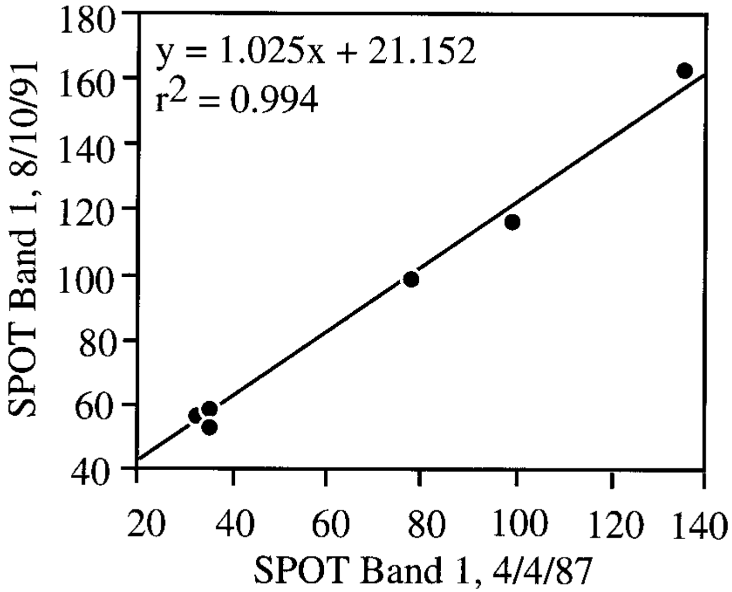
- **Uses linear regression of the DNs from two bands (images) to normalize scenes taken at different times.**
- **<u>Problem</u>: Historical data are usually taken on non-anniversary dates with varying environmental conditions.**
- **<u>Objective</u>: Normalize multiple data sets to a standard scene so variations are eliminated.**
- **<u>How</u>: Choose pseudo-invariant ground targets present in each image for normalization…**

Multiple-Date Atmospheric Normalization

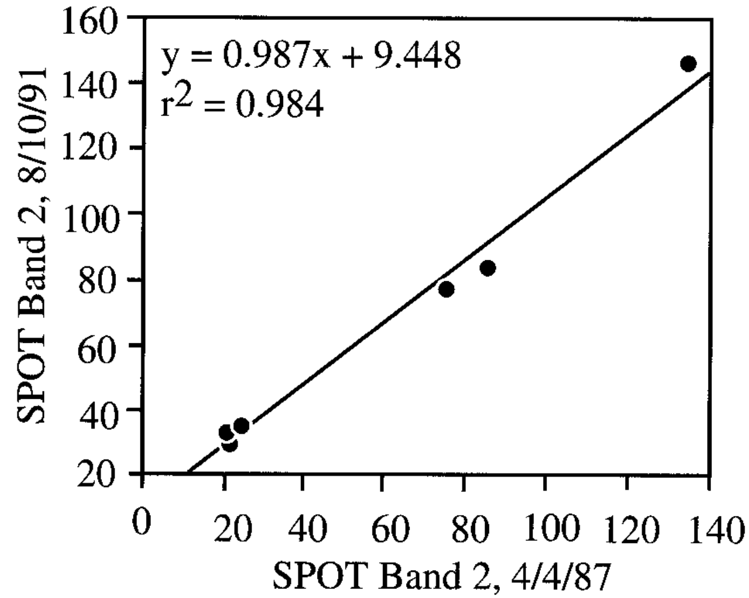
- Apply regression equations that predict what a given DN would be if it had been acquired under the same conditions as the standard scene.

- Equations developed based on the normalization targets.

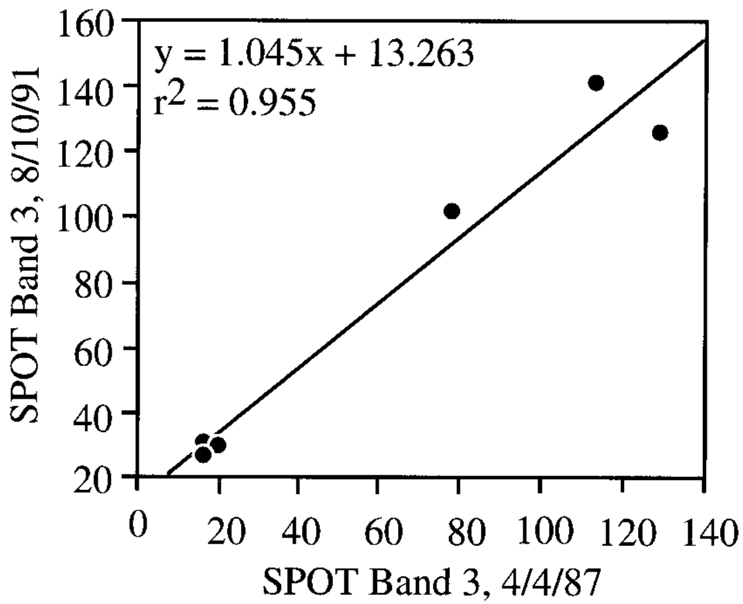
- Normalization targets assumed to be constant reflectors s.t. changes in their reflectance between images is due to atmospheric attenuation, etc.


y = 1.025x + 21.152
r2 = 0.994
SPOT Band 1, 8/10/91
180
160
140
120
100
80
60
40
20
40
60
80
100
120
140
SPOT Band 1, 4/4/87

(a)


y = 0.987x + 9.448
r2 = 0.984
SPOT Band 2, 8/10/91
160
140
120
100
80
60
40
20
0
20
40
60
80
100
120
140
SPOT Band 2, 4/4/87

(b)


y = 1.045x + 13.263
r2 = 0.955
SPOT Band 3, 8/10/91
160
140
120
100
80
60
40
20
0
20
40
60
80
100
120
140
SPOT Band 3, 4/4/87

(c)

Multiple-Date Atmospheric Normalization

- **Coefficients (gain) and intercepts (bias) of linear regressions between normalization scene "A" and uncorrected scene "B"…**

- **…used to compute normalized scene "B" with same spectral characteristics as "A".**

Soil Moisture Conditions

- **Should be identical between the two scenes.**
- **Therefore, precipitation records are an ancillary data set that can be used for interpretation of change processing results.**

2.1 Absolute atmospheric correction

- Solar radiation is largely unaffected as it travels through the vacuum of space. When it interacts with the Earth's atmosphere, however, it is selectively **scattered and absorbed**. The sum of these two forms of energy loss is called *atmospheric attenuation*. Atmospheric attenuation may 1) make it difficult to relate hand-held *in situ* spectroradiometer measurements with remote measurements, 2) make it difficult to extend spectral signatures through space and time, and (3) have an impact on classification accuracy within a scene if atmospheric attenuation varies significantly throughout the image.

- The general goal of ***absolute radiometric correction*** is to turn the digital brightness values (or DN) recorded by a remote sensing system into ***scaled surface reflectance*** values. These values can then be compared or used in conjunction with scaled surface reflectance values obtained anywhere else on the planet.

2.1.1 Radiative transfer-based atmospheric correction algorithms

- Much research has been carried out to address the problem of correcting images for atmospheric effects. These efforts have resulted in a number of ***atmospheric radiative transfer codes*** *(models)* that can provide realistic estimates of the effects of atmospheric scattering and absorption on satellite imagery. Once these effects have been identified for a specific date of imagery, each band and/or pixel in the scene can be adjusted to remove the effects of scattering and/or absorption. The image is then considered to be ***atmospherically corrected***.

- Unfortunately, the application of these codes to a specific scene and date also requires knowledge of both the sensor spectral profile and the atmospheric properties at the same time. Atmospheric properties are difficult to acquire even when planned. For most historic satellite data, they are not available. Even today, accurate scaled surface reflectance retrieval is not operational for the majority of satellite image sources used for land-cover change detection. An exception is NASA's Moderate Resolution Imaging Spectroradiometer (**MODIS**), for which surface reflectance products are available.

Cont'

- Most current *radiative transfer-based atmospheric correction algorithms* can compute much of the required information if a) the user provides fundamental atmospheric characteristic information to the program or b) certain atmospheric absorption bands are present in the remote sensing dataset. For example, most radiative transfer-based atmospheric correction algorithms require that the user provide:

  - latitude and longitude of the remotely sensed image scene,
  - date and exact time of remote sensing data collection,
  - image acquisition altitude (e.g., 20 km AGL)
  - mean elevation of the scene (e.g., 200 m ASL),
  - an atmospheric model (e.g., mid-latitude summer, mid-latitude winter, tropical),
  - radiometrically calibrated image radiance data (i.e., data *must* be in the form W m2 mm-1 sr-1),
  - data about each specific band (i.e., its mean and full-width at half-maximum (FWHM), and
  - local atmospheric visibility at the time of remote sensing data collection (e.g., 10 km, obtained from a nearby airport if possible).

Cont'

- These parameters are then input to the atmospheric model selected (e.g., mid-latitude summer) and used to compute the absorption and scattering characteristics of the atmosphere at the instance of remote sensing data collection. These atmospheric characteristics are then used to invert the remote sensing radiance to ***scaled surface reflectance***. Many of these atmospheric correction programs derive the scattering and absorption information they require from robust atmosphere radiative transfer code such as MODTRAN 4+ or Second Simulation of the Satellite Signal in the Solar Spectrum (6S).

- Examples include:
  - ACORN
  - ATCOR
  - ATREM
  - FLAASH (we have)

a. Before atmospheric correction. b. After atmospheric correction.

a) Image containing substantial haze prior to atmospheric correction. b) Image after atmospheric correction using ATCOR (Courtesy Leica Geosystems and DLR, the German Aerospace Centre).

2.1.2 Empirical Line Calibration

Absolute atmospheric correction may also be performed using ***empirical line calibration (ELC),*** which forces the remote sensing image data to match *in situ* spectral reflectance measurements, hopefully obtained at approximately the same time and on the same date as the remote sensing overflight. Empirical line calibration is based on the equation:

Reflectance (field spectrum) = gain x radiance (image) + offset

• If the in situ was not possible, you can use the Spectral library or measurements after.

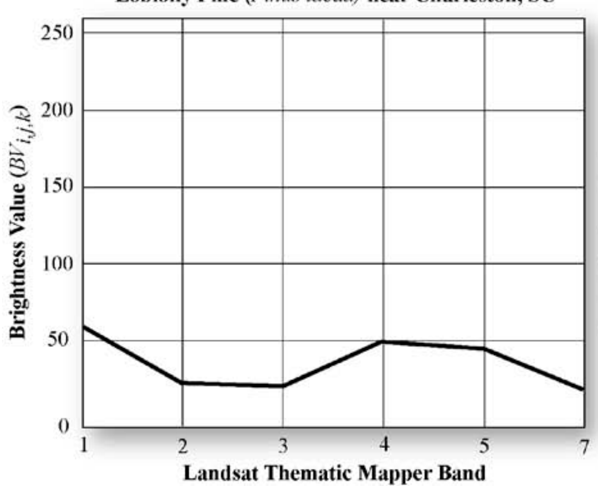
•The point is to find several homogeneous targets (white and black)

•The example here only used one pixel of water and one pixel of beach

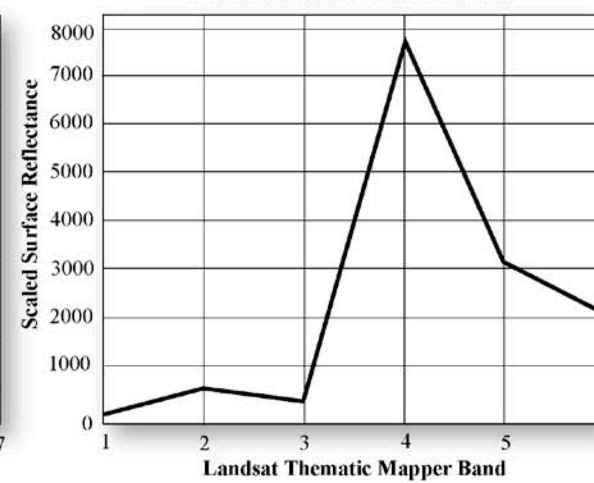
•Result indicates correct chlorophyll absorption in the blue (band 1) and red (band 3) portions of the spectrum and the increase in near-infrared reflectance

a. Empirical line calibrated Landsat Thematic Mapper band 4 image of Charleston, SC.

b.
Original Landsat TM Brightness Values
Loblolly Pine (*Pinus taeda*) near Charleston, SC



c.
Empirical Line Calibration of Landsat TM
Data to Scaled Surface Reflectance



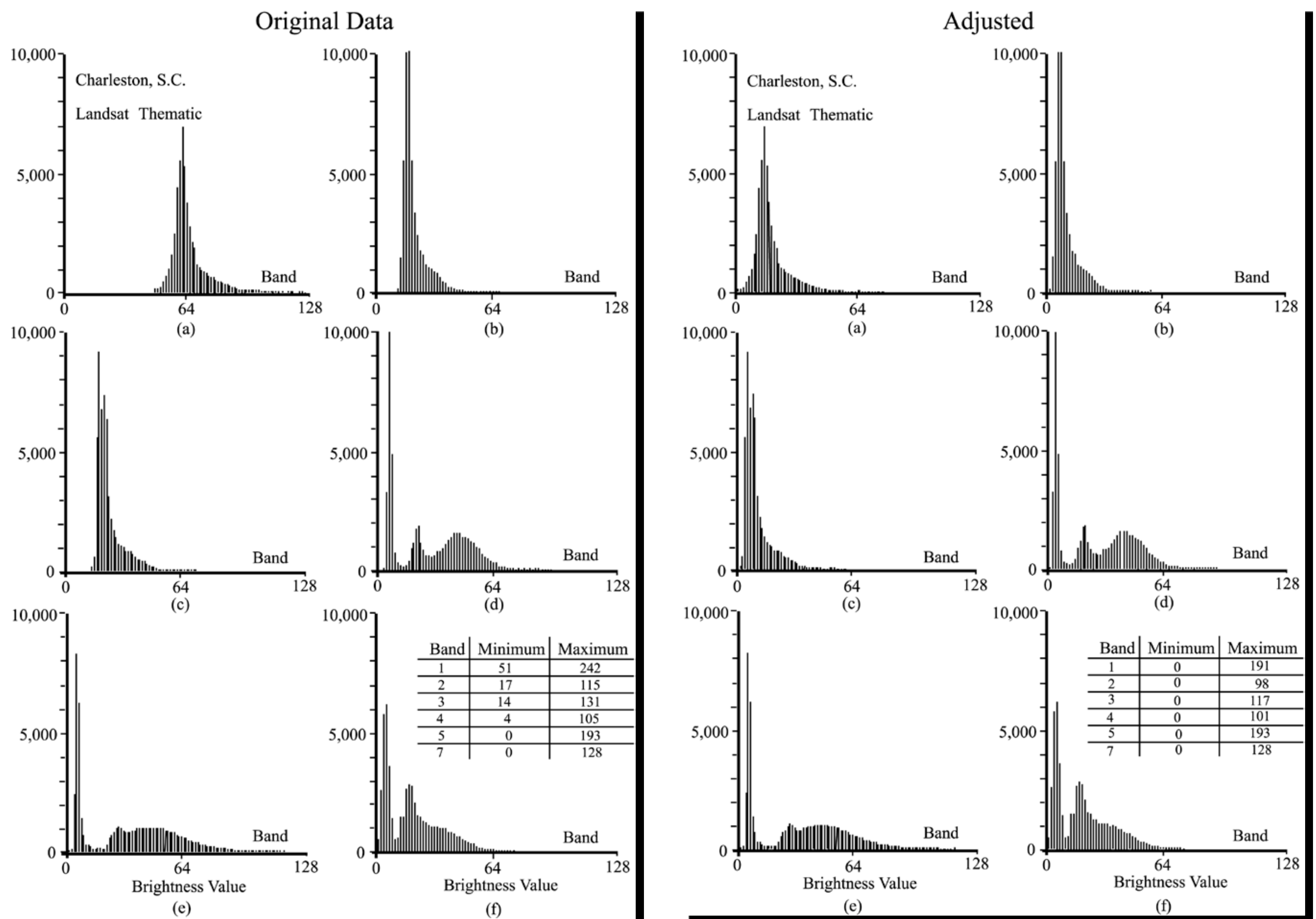
2.2 relative radiometric correction

- When required data is not available for absolute radiometric correction, we can do relative radiometric correction
- Relative radiometric correction may be used to
  - Single-image normalization using histogram adjustment
  - Multiple-data image normalization using regression

2.2.1 Single-image normalization using histogram adjustment

- The method is based on the fact that infrared data (>0.7 μm) is free of atmospheric scattering effects, whereas the visible region (0.4-0.7 μm) is strongly influenced by them.
- Use Dark Subtract to apply atmospheric scattering corrections to the image data. The digital number to subtract from each band can be either the band minimum, an average based upon a user defined region of interest, or a specific value

Dark Subtract using band minimum



Original Data:

Band	Minimum	Maximum
1	51	242
2	17	115
3	14	131
4	4	105
5	0	193
7	0	128

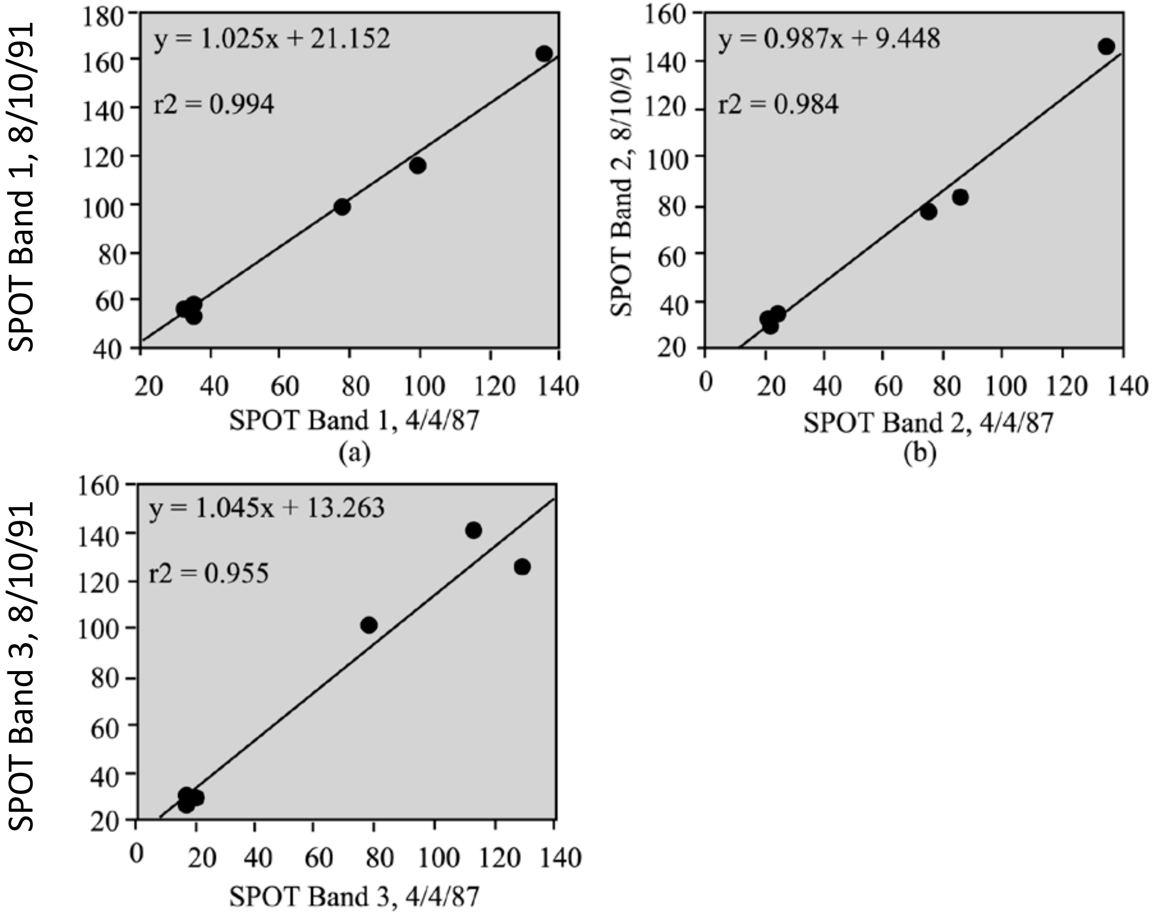
Adjusted:

Band	Minimum	Maximum
1	0	191
2	0	98
3	0	117
4	0	101
5	0	193
7	0	128

2.2.2 Multiple-data image normalization using regression

- Selecting a base image and then transforming the spectral characteristics of all other images obtained on different dates to have approximately the same radiometric scale as the based image.
- Selecting a pseudo-invariant features (PIFs) or region (points) of interest is important:
  - Spectral characteristic of PIFs change very little through time, (deep water body, bare soil, rooftop)
  - PIFs should be in the same elevation as others
  - No or rare vegetation,
  - The PIF must be relatively flat
- Then PIFs will be used to normalize the multiple-date imagery

Example



- SPOT image of 8/10/1991 is selected as the base image
- PIFs (wet and dry) were selected for generating the relationship between the base image and others
- The resulted regression equation will be used to normalize the entire image of 4/4/87 to 8/10/91 for change detection.
- The additive component corrects the path radiance among dates, and multiplicative term correct the detector calibration, sun angle, earth-sun distance, atmospheric attenuation, and phase angle between dates.

- Regression equations for all images, all based on the SPOT image of 8/10/91

Date	Band	Slope	y-intercept	r^2
3/22/73	MSS 1	1.40	31.19	0.99[a]
	2	1.01	23.49	0.98
	4	3.28	23.48	0.99
4/02/76	MSS 1	0.57	31.69	0.99
	2	0.43	21.91	0.98
	4	3.84	26.32	0.96
10/17/82	MSS 1	2.52	16.117	0.99
	2	2.142	8.488	0.99
	4	1.779	17.936	0.99
4/04/87	SPOT 1	1.025	21.152	0.99
	2	0.987	9.448	0.98
	3	1.045	13.263	0.95

[a]All regression equations were significant at the 0.001 level.

2.2.3 other relative radiometric correction methods (ENVI)

- Use Flat Field calibration to normalize images to an area of known "flat" reflectance. This is particularly effective for reducing hyperspectral data to relative reflectance. The method requires that you select a Region Of Interest (ROI) prior to execution. The average spectrum from the ROI is used as the reference spectrum, which is then divided into the spectrum at each pixel of the image

- Use IAR Reflectance calibration (Internal Average Relative Reflectance) to normalize images to a scene average spectrum. This is particularly effective for reducing hyperspectral data to relative reflectance in an area where no ground measurements exist and little is known about the scene. It works best for arid areas with no vegetation. An average spectrum is calculated from the entire scene and is used as the reference spectrum, which is then divided into the spectrum at each pixel of the image

3. Topographic correction

- Topographic slope and aspect also introduce radiometric distortion (for example, areas in shadow)
- The goal of a slope-aspect correction is to remove topographically induced illumination variation so that two objects having the same reflectance properties show the same brightness value (or DN) in the image despite their different orientation to the Sun's position
- Based on DEM, sun-

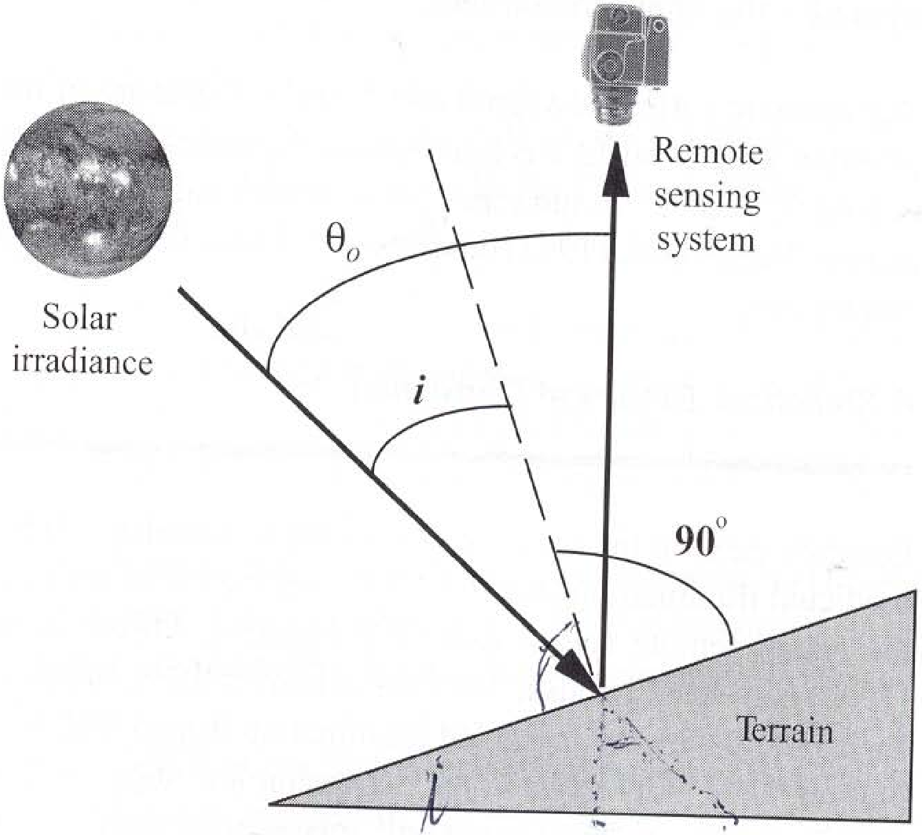


Figure 6-33 Representation of the Sun's angle of incidence, i, and the solar zenith angle, θ_o.

L_H = radiance observed for a horizontal surface (i.e., slope-aspect-corrected remote sensor data)

L_T = radiance observed over sloped terrain (i.e., the raw remote sensor data)

θ_o = Sun's zenith angle

i = Sun's incidence angle in relation to the normal on a pixel (Figure 6-33).

1. Cosine correction

$$L_H = L_T \frac{\cos\theta_0}{\cos i}$$

2. Minnaert correction

$$L_H = L_T \left(\frac{\cos\theta_0}{\cos i}\right)^k$$

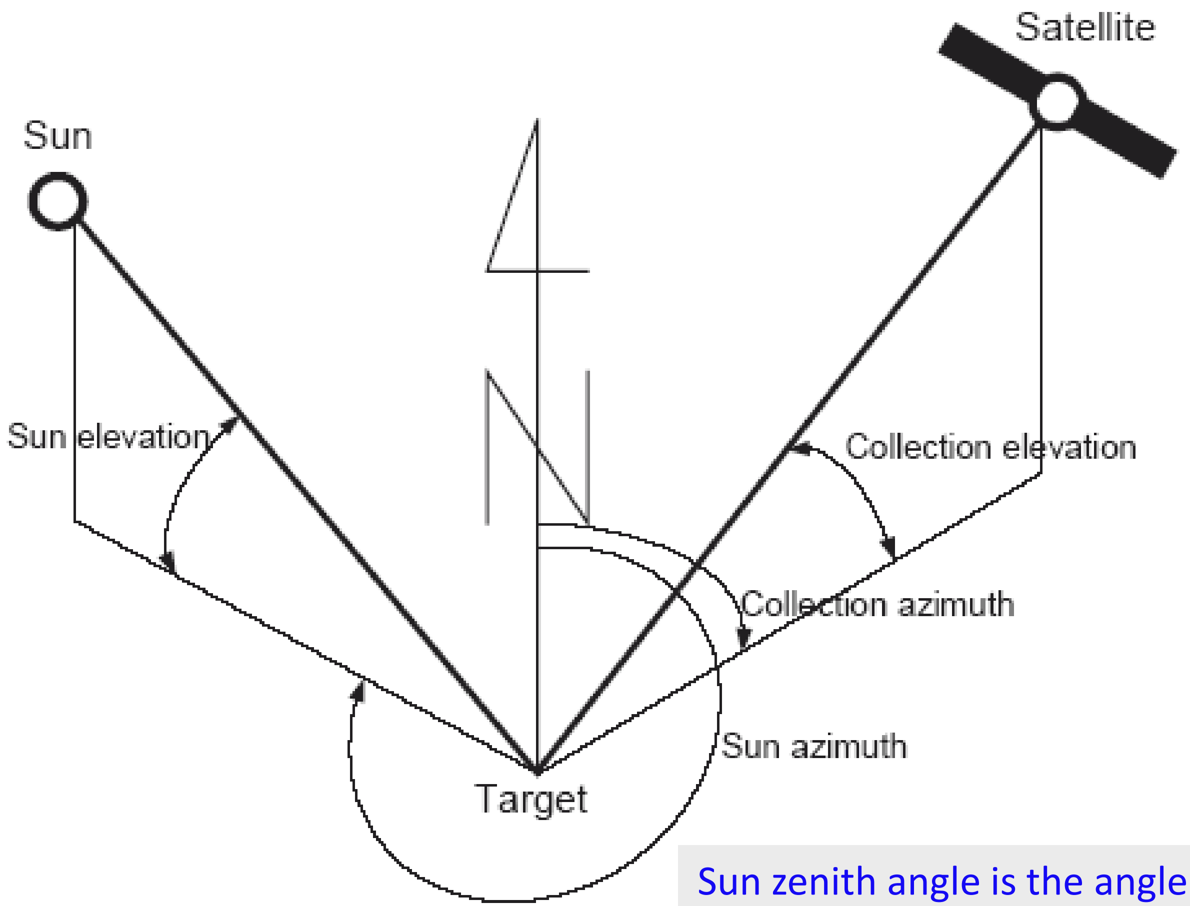
3. statistical-empirical correction

$$L_H = L_T - m\cos i - b + \overline{L_T}$$

4. C correction

$$L_H = L_T \frac{\cos\theta_0 + c}{\cos i + c}$$

Image acquisition geometry



Sun zenith angle is the angle of Sun away from vertical
Sun elevation angle is the angle of Sun away from horizontal
Sensor elevation angle is the angle away from horizontal
Sensor azimuth angle and Sun azimuth are clockwise from the north

Source: IKONOS geometry at http://www.utsa.edu/LRSG/Teaching/ES6973/geometry.pdf

computing the cosine of the solar incidence angle

$$\cos(i) = \sin(\delta)\sin(\phi)\cos(s) - \sin(\delta)\cos(\phi)\sin(s)\cos(\gamma)$$

$$+\cos(\delta)\cos(\phi)\cos(s)\cos(\omega)$$

$$+\cos(\delta)\sin(\phi)\sin(s)\cos(\gamma)\cos(\omega)$$

$$+\cos(\delta)\sin(\phi)\sin(s)\sin(\omega)$$

- where,
  - δ declination of the earth (positive in summer in northern hemisphere)
  - ϕ latitude of the pixel (positive for northern hemisphere)
  - s slope in radians, where s=0 is horizontal and s=π/2 is vertical downward (s is always positive and represents a downward slope in any direction)
  - γ surface azimuth angle. γ is the deviation of the normal to the surface from the local meridian, where γ = 0 for aspect that is due south, γ = - for east and γ = + for western aspect. γ = -π/2 represents an east-facing slope and γ = +π/2 represents an west-facing slope. γ = -π or γ = π represents a north-facing slope.
  - ω hour angle. ω = 0 at solar noon, ω is negative in morning and ω is positive in afternoon

Source: Duffie,J.A. and W.A.Beckman, 1991. Solar engineering of thermal processes. John Wiley and Sons, NY.

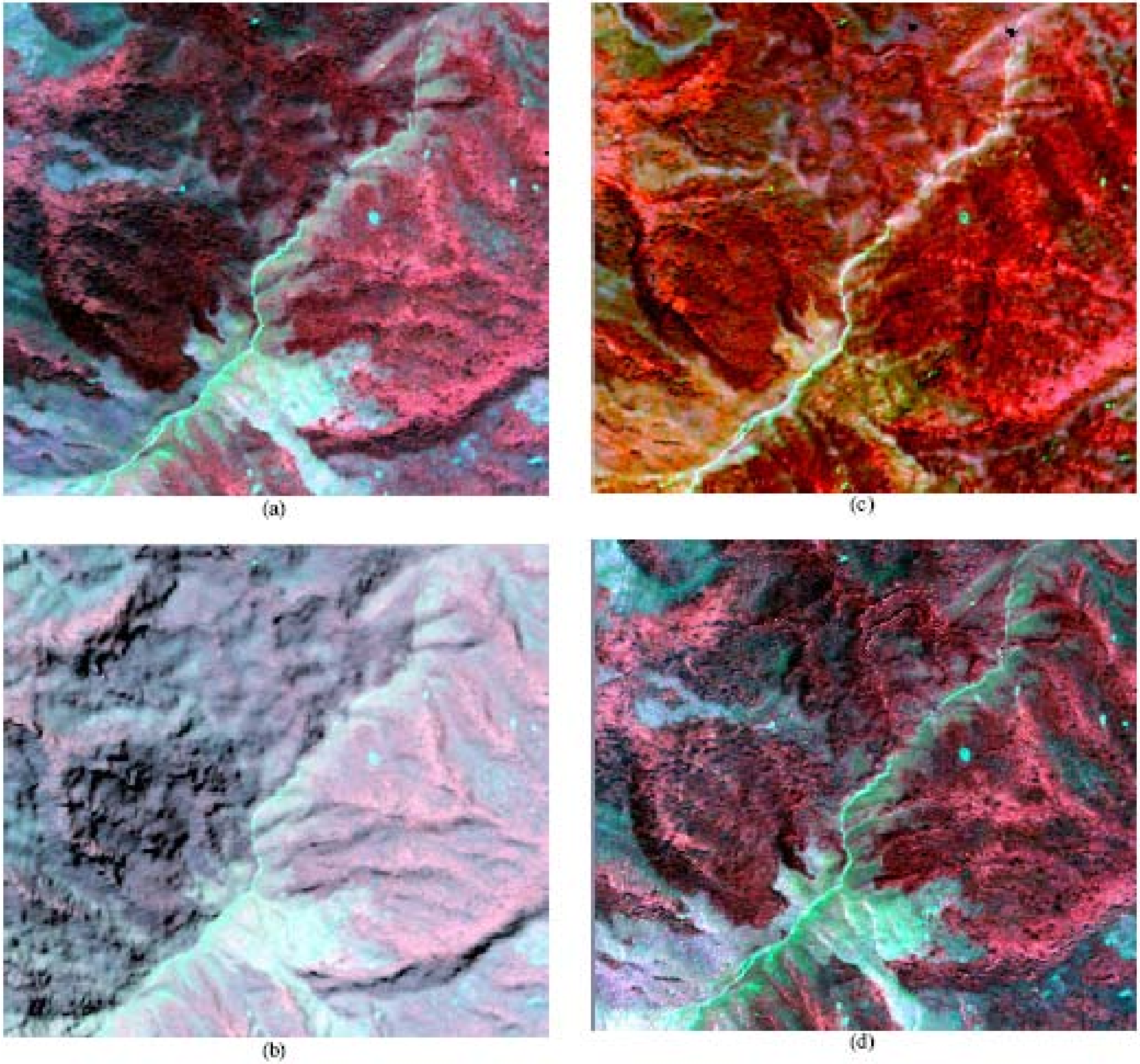


Figure 1. IKONOS False Colour Image, 7 Sept 2002, a ridge from top right to bottom left with sunlight coming from the bottom right, Lam Tseun Country Park. (a) Original image. (b) Result of cosine correction. (c) Result of Minnaert correction. (d) Result of 2-stage normalization

Phenological Cycles

- Seasonal cycles in vegetation, soils, water, etc.
- Developmental cycles in human activities.
- Coastal cycles.
- Many others – depends on environment.

Vegetation

- **Several superimposed cycles:**
  - Diurnal
  - Seasonal
  - Annual

- **Need to recognize that not all phenologic cycles are in phase with one another and will vary with species…**

- **Also need to consider crop cycles (planting, harvesting, etc.).**

Vegetation

- **For crops also should consider:**
  - **Was the field planted at the same time in the two images?**
  - **Is the crop all the same species?**
  - **Are the row spacings the same?**
  - **Etc.**

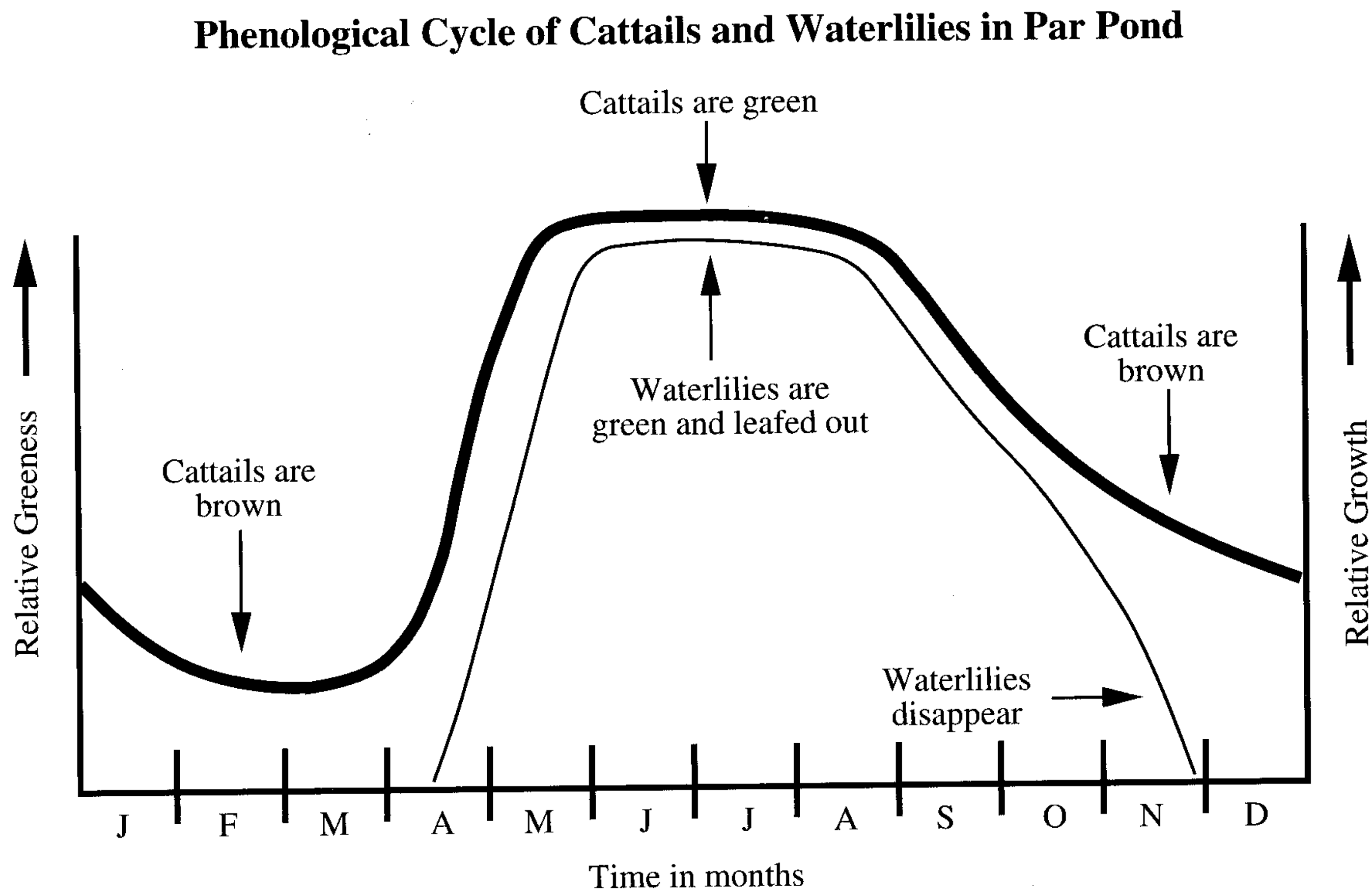


Figure 9-2 Yearly phenological cycle of cattails and waterlilies in Par Pond, S.C. (Jensen et al., 1993b).

Coastal Processes

- Tide stages are a problem:
  - They vary on a lunar cycle whereas most remote sensing satellites are sun-synchronous..
  - …Therefore imagery won't always be taken at the same tide, even if the images are on anniversary dates/times.

Change Detection Algorithms

- **A wide variety are available…**

- **Your choice will affect:**
  - **Whether change can be detected.**
  - **How the change is quantified.**
  - **Classification that can be performed.**
  - **If "To-From" information can be extracted.**

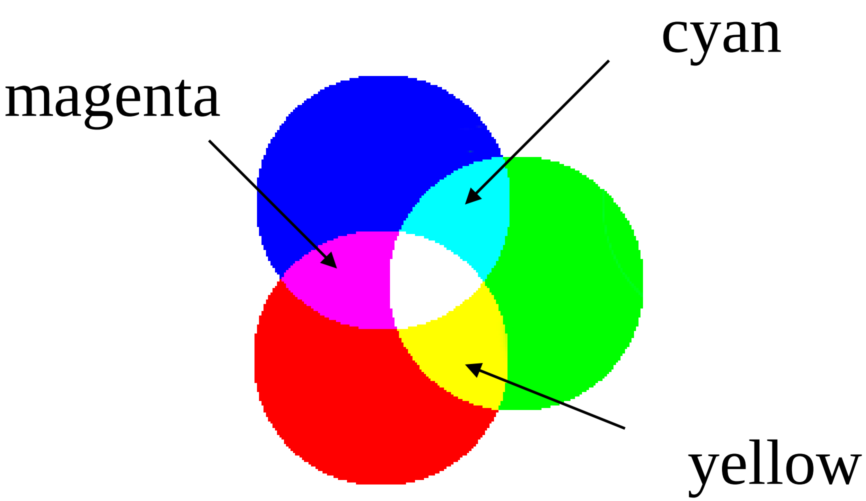
“Memory Insertion”

- Jensen gives this a complicated name, but it’s pretty much just the Red-Blue method in Lab 8.

- Load the same band from two (or three) different dates into RGB…
  - Time 1 in R.
  - Time 2 in G (and B).
  - (Time 3 in B).

- Interpretation…
  - Unchanged pixels will be a neutral color.
  - Pixels in which time 1 was brighter will be red.
  - Pixels in which time 2 was brighter will be green-(blue).
  - (Pixels in which time 3 was brighter will be blue).
  - Other colors need to be interpreted using additive color theory…

Additive RGB Color



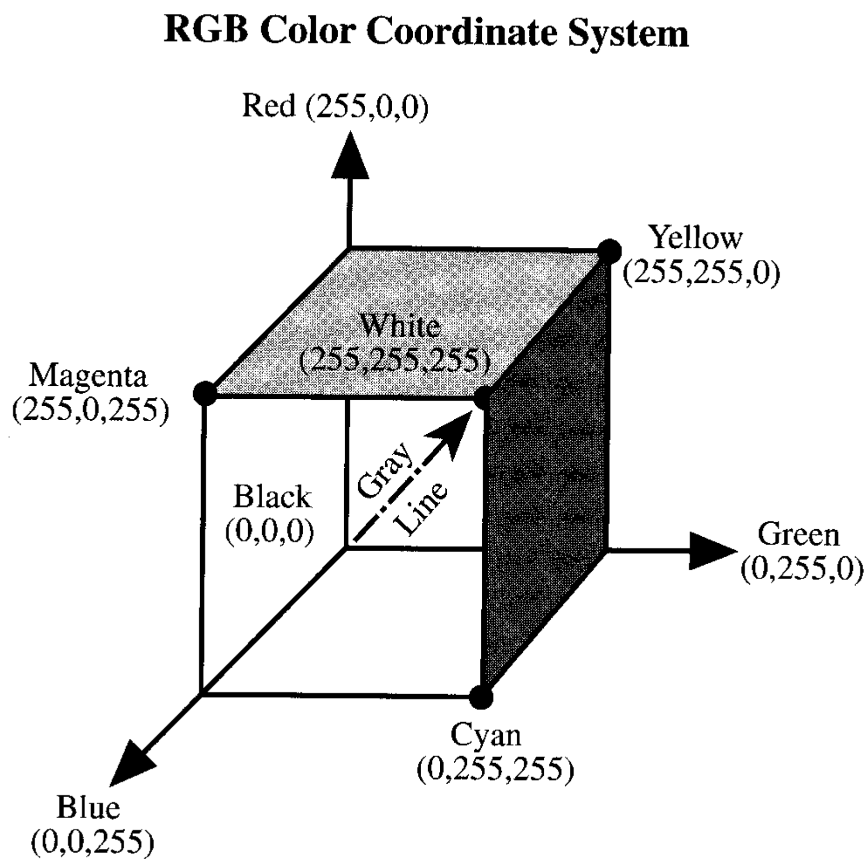
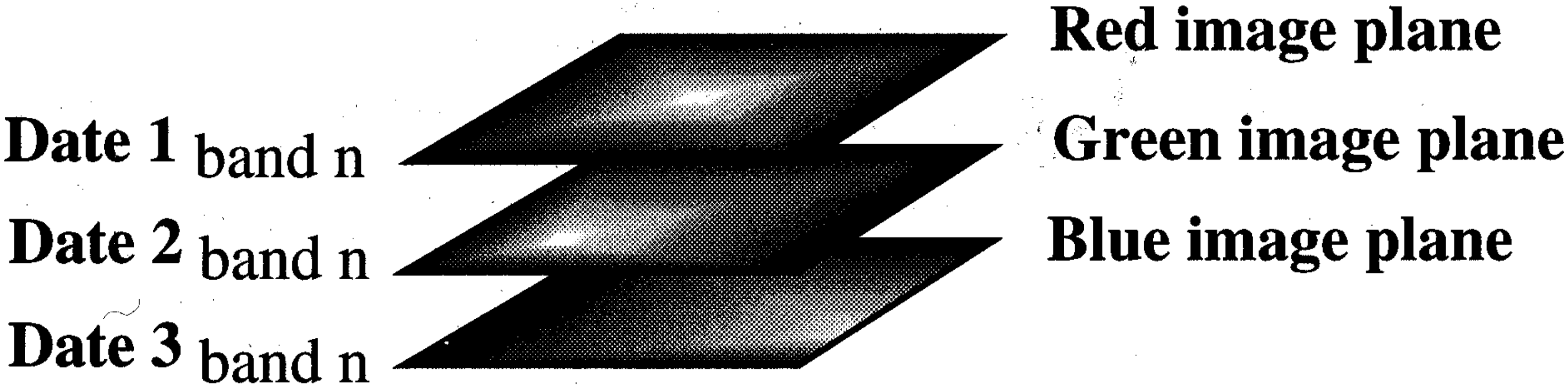


Figure 5-9 RGB color coordinate system based on additive color theory.

Multi-Date Visual Change Detection Using Write-Function Memory Insertion



Advantages:
- Visual examination of 2 or 3 years of nonspecific change

Disadvantages:
- Nonquantitative
- No 'from-to' change class information

Figure 9-6 Diagram of Multi-Date Visual Change Detection using Write Function Memory insertion.

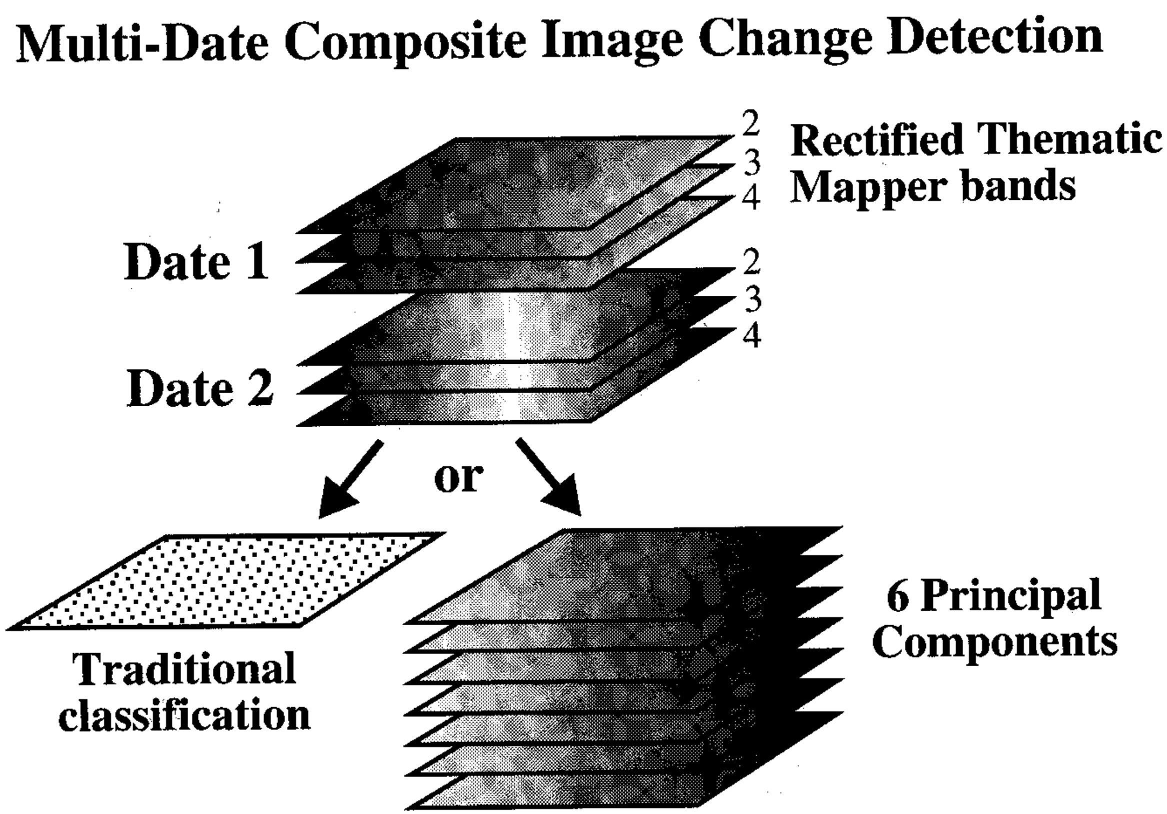
Multi-Date Composite Image

- Create a new dataset using multiple dates of co-registered imagery.

- You can analyze using:

  - Traditional classification – unsupervised classification will result in change and no-change clusters.

  - PCA – separation of uncorrelated (change) and correlated (unchanged) data components.



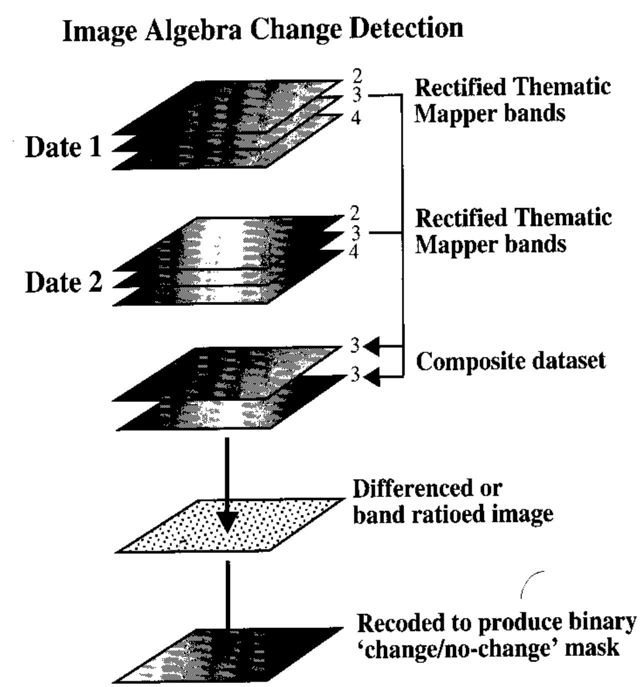
Advantages:
- Requires single classification

Disadvantages:
- Difficult to label change classes
- Little 'from-to' change class information available

Figure 9-9 Diagram of Multi-date Composite Image change detection.

Image Algebra

- Use of pixel point processes (band ratios, image differencing – Lab 8) to quantify change.



Advantages:	Disadvantages:
• Efficient method of identifying pixels that have changed in brightness value between dates	• No 'from-to' change classes available • Requires careful selection of the 'change/no-change' threshold

Figure 9-10 Diagram of Image Algebra change detection.

$$D_{ijk} = BV_{ijk}(1) - BV_{ijk}(2) + c \tag{9-1}$$

where

D_{ijk} = change pixel value

$BV_{ijk}(1)$ = brightness value at time 1

$BV_{ijk}(2)$ = brightness value at time 2

c = a constant (e.g., 127).

i = line number

j = column number

k = a single band (e.g. TM band 4)

0 DN in output image means no change. Positive values and negative values denote the magnitude and trend of temporal change.

For 8-bit input images, *D* will vary between -255 and 255 (if floating point output is chosen)

c is a constant used to transform the change DNs to positive values (optional).

Image Algebra

- Change image made using differencing has a DN histogram that is Gaussian.
  - 0 DN distributed around the mean
  - Change DNs are in the tails

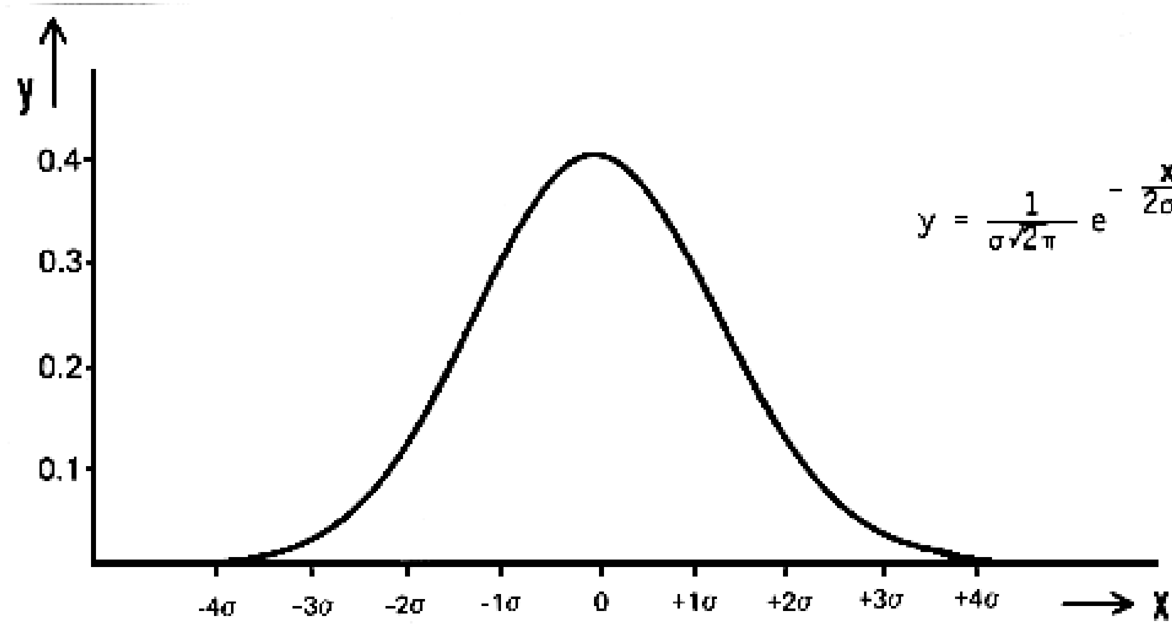
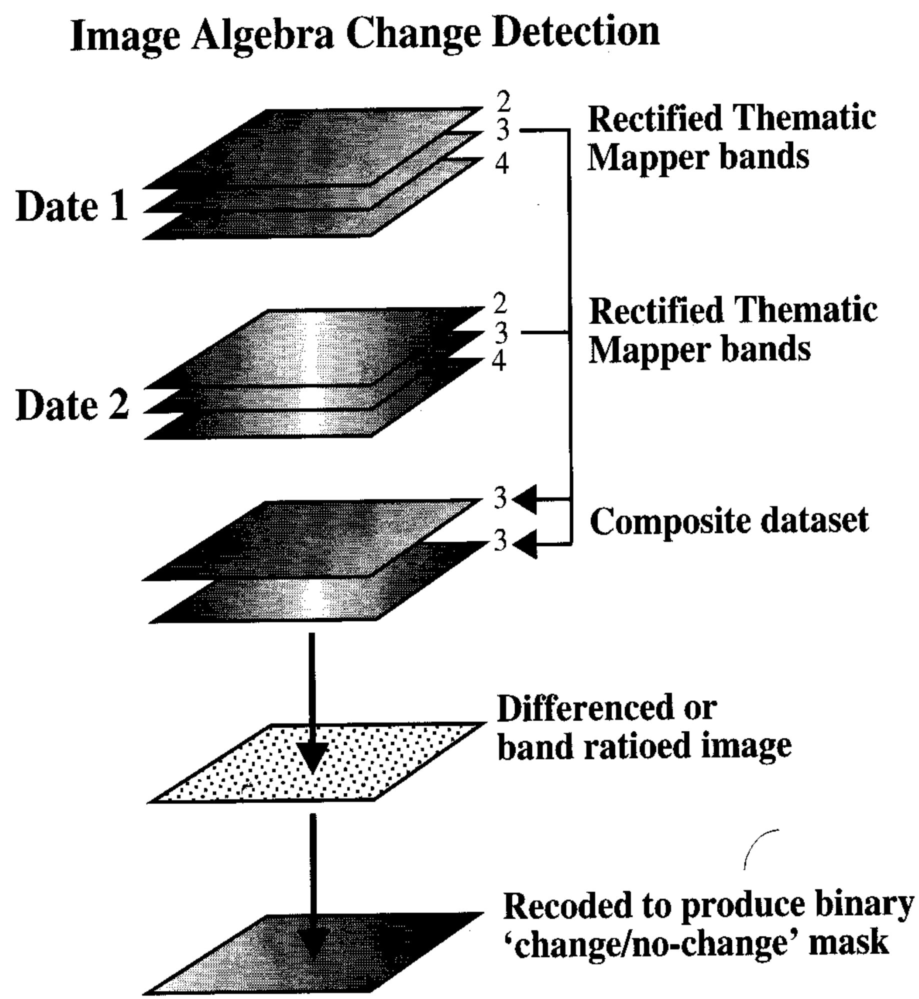


Image Algebra

- **Critical step is to choose a threshold value to decide between changed and no-change pixels.**

- **Once threshold is decided, use contrast stretching, threshold-to-ROI, density slicing, etc. to enhance the image.**

- **How decide threshold?**
  - **Trial and error.**
  - **Statistics – choose a particular standard deviation.**



Advantages:
- Efficient method of identifying pixels that have changed in brightness value between dates

Disadvantages:
- No 'from-to' change classes available
- Requires careful selection of the 'change/no-change' threshold

Figure 9-10 Diagram of Image Algebra change detection.

Post-Classification

- **Commonly-used technique.**

- **Requires accurate classification of two co-registered images.**

- **Classification maps are compared on a pixel-by-pixel basis using a change detection matrix.**

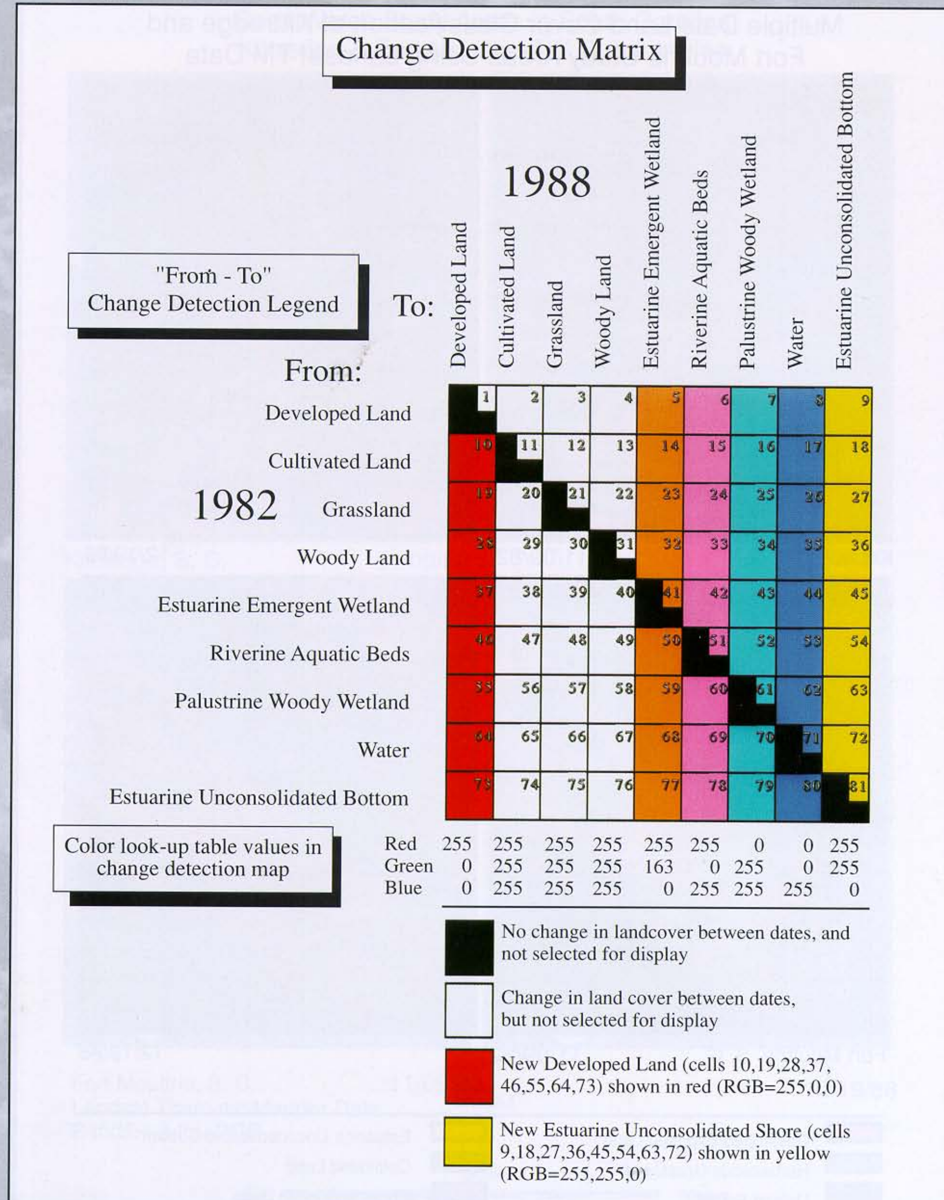


Figure 9-15 The basic elements of a change detection matrix may be used to select specific 'from-to' classes for display in a 'post-classification comparison' change detection map. There are $(n^2 - n)$ off-diagonal possible change classes which may be displayed in the change of detection map (72 in this example) although some may be highly unlikely. The colored off-diagonal cells in this diagram were used to produce the change maps in Figure 9-16. For example, any pixel in the 1982 map that changed to 'Developed Land' by 1988 is red (RGB = 255,0,0). Any pixel that changed into 'Estuarine Unconsolidated Shore' by 1988 is yellow (RGB = 255,255,0). Individual cells can be color coded in the change map to identify very specific 'from-to' changes. (Jensen et al., 1993a)

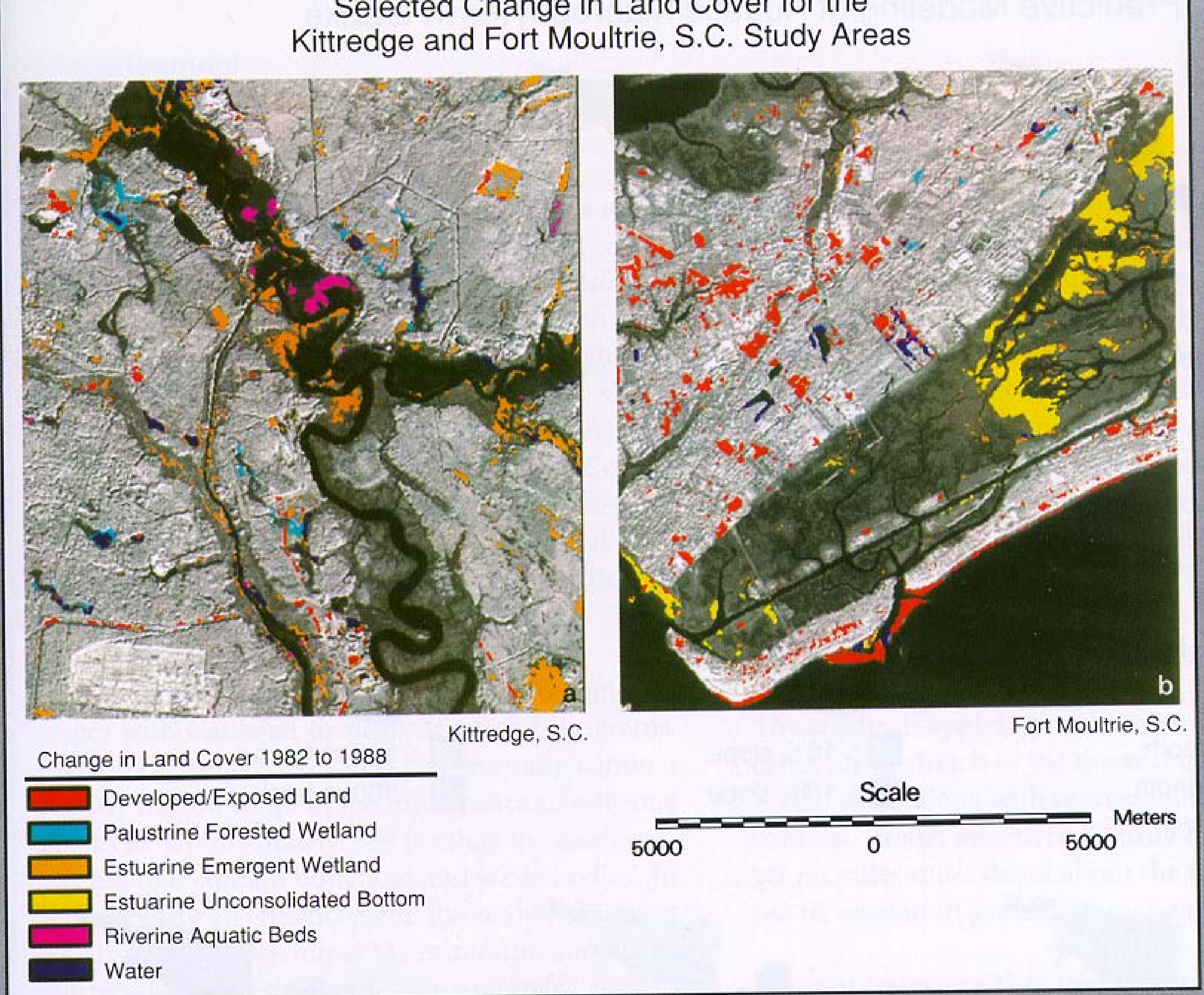


Figure 9-16 Change detection maps of the Kittredge and Fort Moultrie, South Carolina study areas derived from analysis of November 11, 1982 and December 19, 1988 Landsat TM data. The nature of the change classes selected for display are summarized in Figure 9-15. The change information is overlaid onto the Landsat TM band 4 image of each date for orientation purposes. (Jensen et al., 1993a)

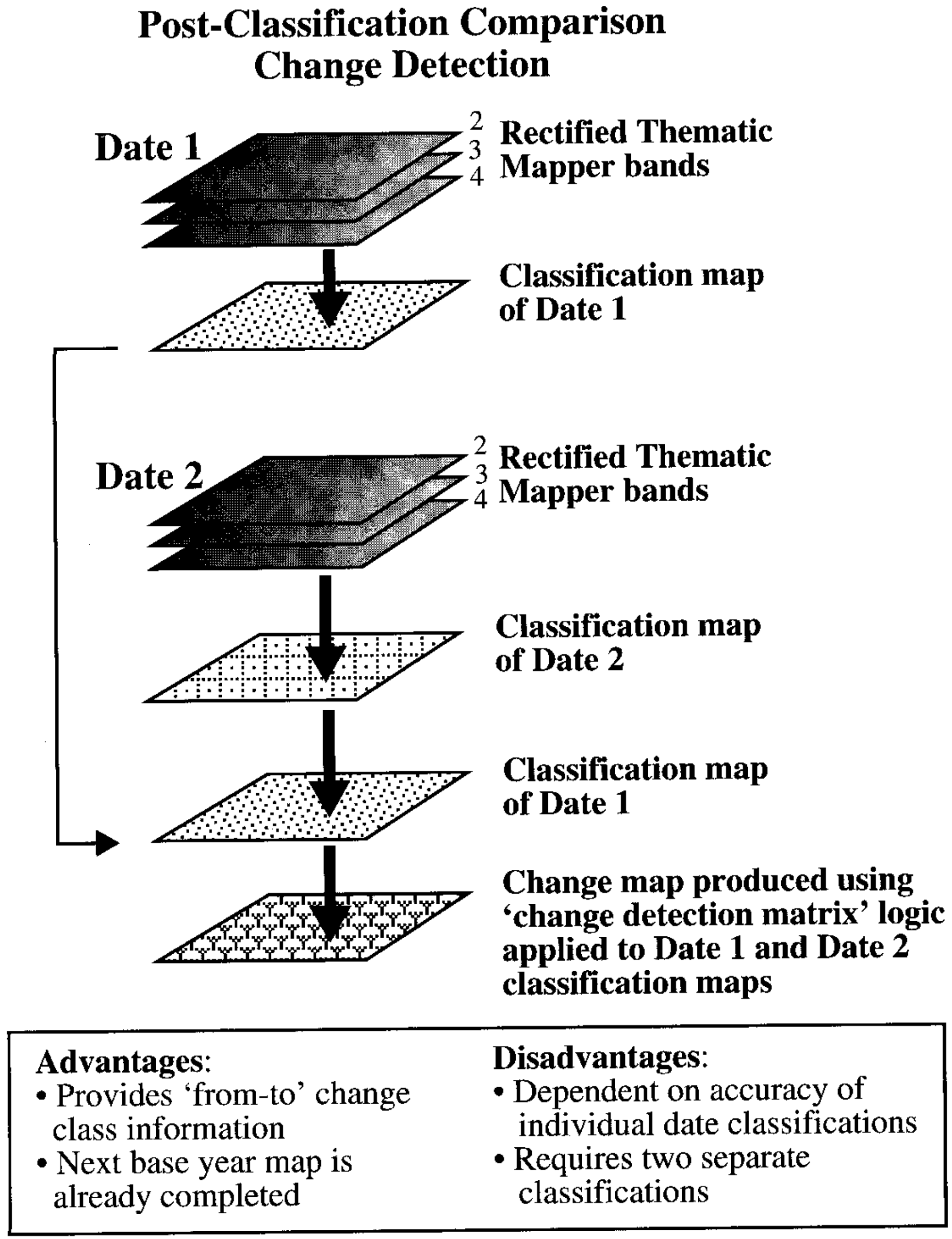


Figure 9-12 Diagram of Multi-Date Post-Classification Comparison change detection.

Binary Change Masking

1. Analyst selects base image (time1).

2. Analyst selects second image (time2, either earlier or later than time1).

3. Two image datasets co-registered.

4. Traditional classification of time1 performed.

Binary Change Masking

5. Analyst selects the same band from both time1 and time2 and creates a new, 2-band dataset.

6. New dataset analyzed using PCA, band-ratios, etc. → threshold to produce binary (change vs. no-change) image.

7. Use binary image as a mask

Binary Change Masking

8. **Overlay binary mask onto time2 image to select those pixels that changed.**

9. **Classification of time2 performed using only pixels that changed.**

10. **Get “To-From” information by comparing classification of time1 and masked-time2.**

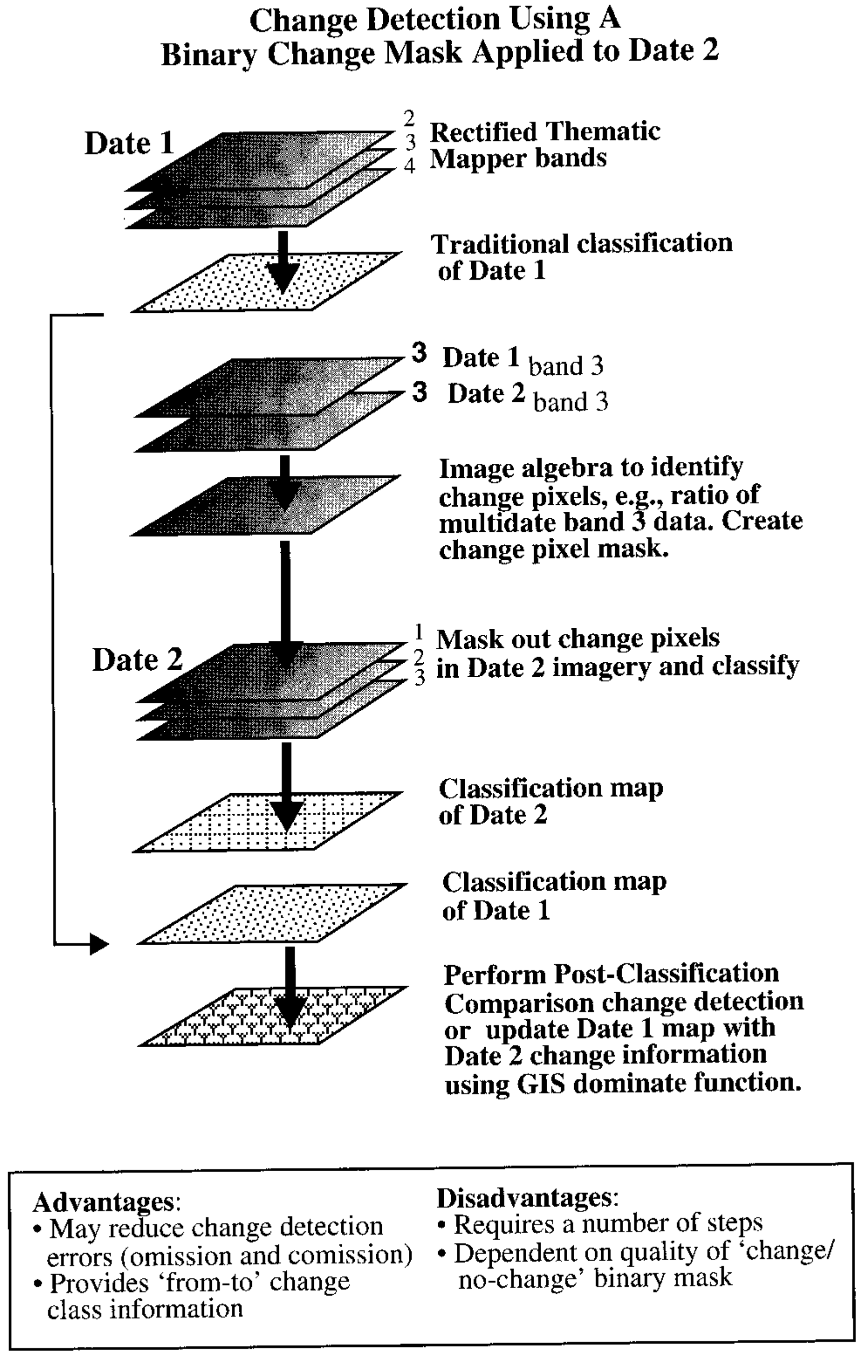


Figure 9-17 Diagram of Multi-Date Change Detection Using A Binary Change Mask Applied to Date 2.

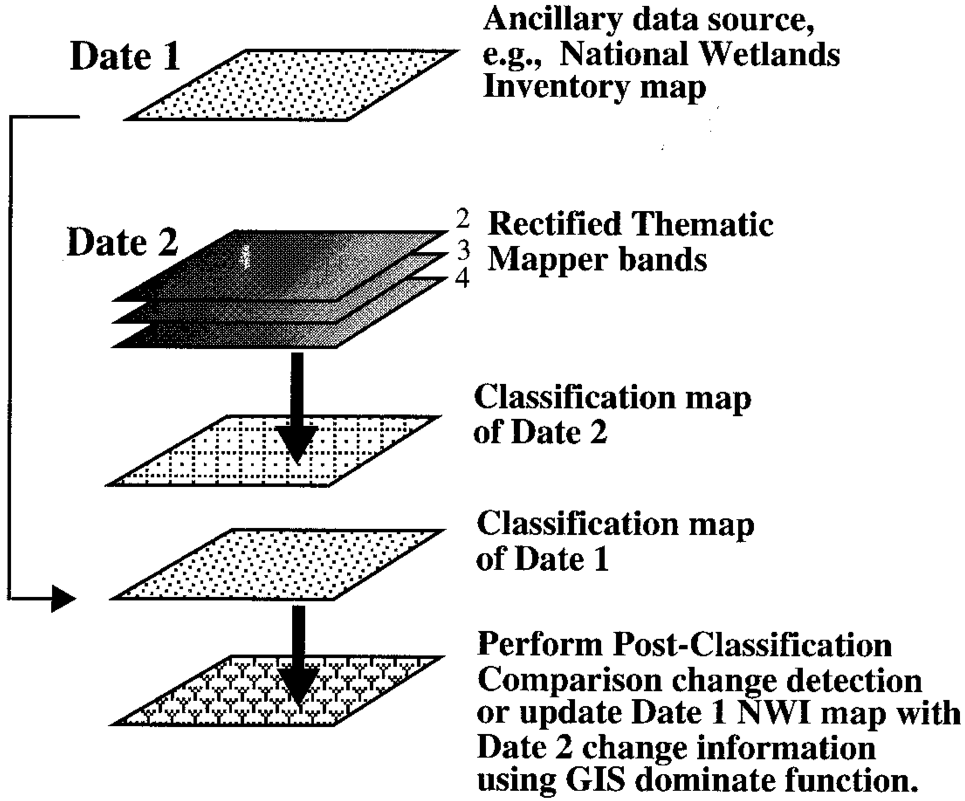
Use of Ancillary Data

1. Instead of using two remotely-sensed images, use digital map of ancillary data for the "before" dataset. Needs to be digitized, generalized, converted to raster of appropriate resolution (error may creep in).

2. For the "after" dataset, create a classification map using remotely sensed imagery that post-dates the data used to create the ancillary data.

3. Compare the two on a pixel-by-pixel basis using a change detection matrix.

Change Detection Using An Ancillary Data Source as Date 1



Advantages:
- May reduce change detection errors (omission and comission)
- Provides 'from-to' change class information
- Requires a single classification

Disadvantages:
- Dependent on quality of ancillary information

Figure 9-18 Diagram of Multi-date Change Detection Using Ancillary Data Source as Date 1.

Manual On-Screen Digitization

- Load two images side by side and compare them visually…
  - Image linking in ENVI
  - Image swiping
  - Polygon annotations

- Useful when the features being compared are small details (like linear features, etc.) in high-resolution images (as opposed to areas of pixels in lower resolution images).

Spectral Change Vector

- **Recall that we can visualize spectra as n-dimensional vectors.**

- **Change will presumably alter the spectral vectors of pixels in areas that underwent change.**

- **A new set of change vectors can be defined…**

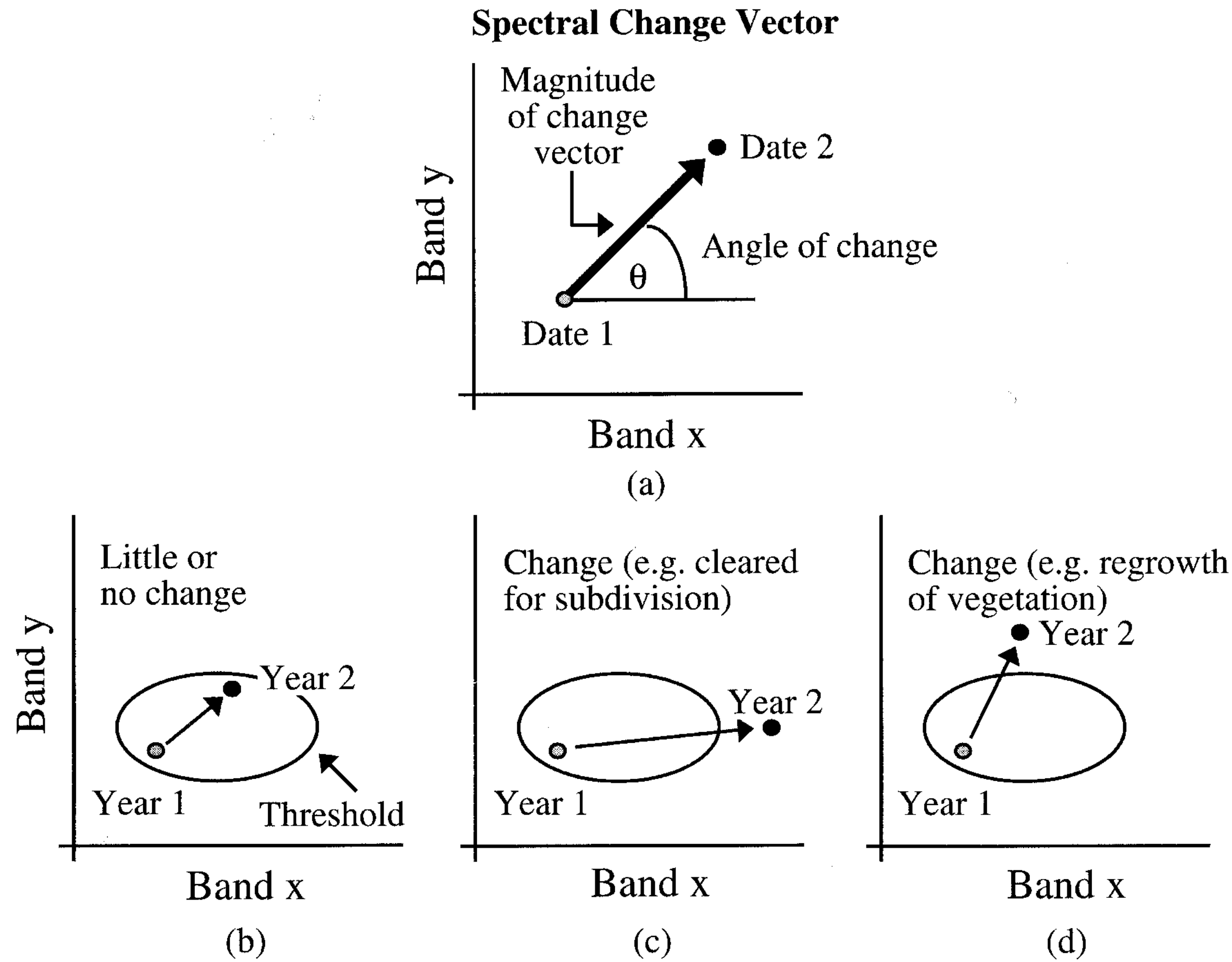


Figure 9-22 Schematic diagram of the spectral change detection method (after Malila, 1980).

Spectral Change Vector

- **Change vector describes the direction and magnitude of change between time1 and time2.**

- **Change magnitude (*CM*) computed as Euclidean distance between time1 and time2…**

$$\mathrm{CM}_{\mathrm{pixel}} = \sum_{k=1}^{n} \left[BV_{i,j,k(\mathrm{date2})} - BV_{i,j,k(\mathrm{date1})} \right]^2 \quad (9\text{-}2)$$

where $BV_{i,j,k(\mathrm{date2})}$ and $BV_{i,j,k(\mathrm{date1})}$ are the date 1 and date 2 pixel values in band k. A scale factor (e.g., 5) can be applied to each band to magnify small changes in the data if desired.

Spectral Change Vector

- **Change direction specified by whether the CM is positive or negative.**

- **For an *n*-band dataset, 2^n possible types of changes ("sector codes") can be determined for each pixel…**

$2^3 = 8$

possible
sector codes.

Table 9-1. Sector Code Definitions for Change Vector Analysis Processing Using Three Bands[a]

Sector Code	Change Detection[b] Band 1	Band 2	Band 3
1	–	–	–
2	–	–	+
3	–	+	–
4	–	+	+
5	+	–	–
6	+	–	+
7	+	+	–
8	+	+	+

[a] Source: after Michalek et al., 1993

Example: Band 1: time1 = 45, time2 = 38 ➔ change = +7

Band 2: time1 = 20, time2 = 10 ➔ change = +10

Band 3: time1 = 25, time2 = 30 ➔ change = -5

$CM = 7^2 + 5^2 + (-5)^2 = 174$

Sector code for this pixel: "+, +, -" ➔ 7 (from table)

Possible Change Sector Code Locations for A Pixel Measured in Three Bands on Two Dates

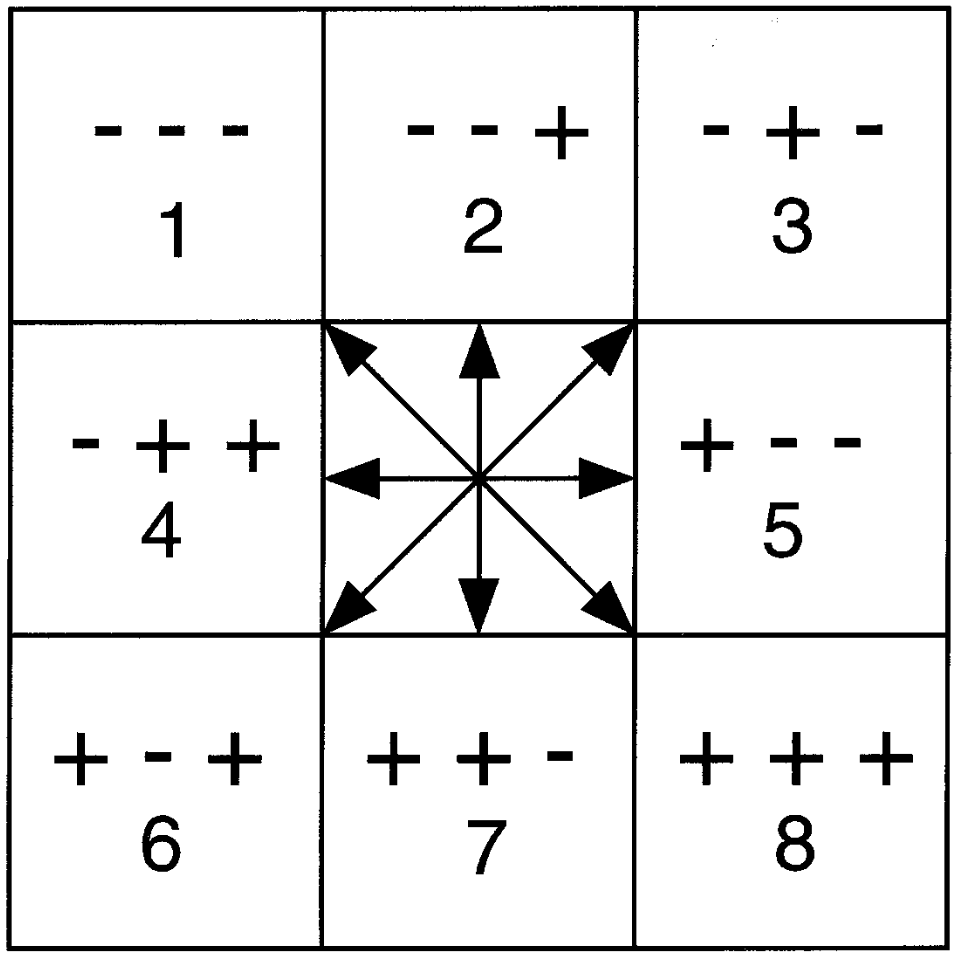


Figure 9-23 Possible change sector codes for a pixel measured in three bands on two dates.

Spectral Change Vector

- **This analysis will produce to co-registered files:**
  - **Sector codes**
  - **Vector magnitudes**
- **These can be superimposed on the original imagery, color-coded, etc. for visualization purposes.**