Introduction to Digital Image Processing of Remote Sensed Data

August 22, 2010

The Remote Sensing Process

Statement of the Problem → Data Collection → Data-to-Information Conversion → Information Presentation

Statement of the Problem

- **Formulate Hypothesis** (if appropriate)
- **Select Appropriate Logic**
  - Inductive and/or
  - Deductive
  - Technological
- **Select Appropriate Model**
  - Deterministic
    - Empirical
    - Knowledge-based
    - Process-based
  - Stochastic

Data Collection

- ***In Situ* Measurements**
  - Field (e.g., *x,y,z* from GPS, biomass, reflectance)
  - Laboratory (e.g., reflectance, leaf area index)
- **Collateral Data**
  - Digital elevation models
  - Soil maps
  - Surficial geology maps
  - Population density, etc.
- **Remote Sensing**
  - Passive analog
    - Frame camera
    - Videography
  - Passive digital
    - Frame camera
    - Scanners
      - Multispectral
      - Hyperspectral
    - Linear and area arrays
      - Multispectral
      - Hyperspectral
  - Active
    - Microwave (RADAR)
    - Laser (LIDAR)
    - Acoustic (SONAR)

Data-to-Information Conversion

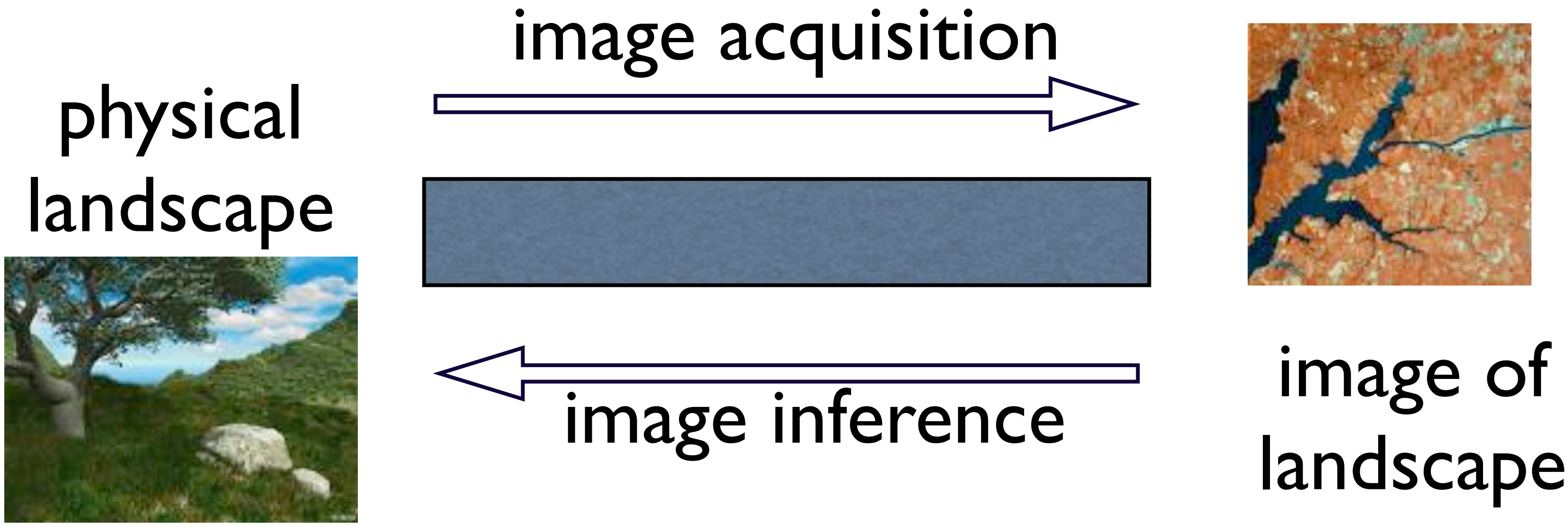
- **Analog (Visual) Image Processing**
  - Using the *Elements of Image Interpretation*
- **Digital Image Processing**
  - Preprocessing
    - Radiometric Correction
    - Geometric Correction
  - Enhancement
  - Photogrammetric analysis
  - Parametric, such as
    - Maximum likelihood
  - Nonparametric, such as
    - Artificial neural networks
  - Nonmetric, such as
    - Expert systems
    - Decision-tree classifiers
    - Machine learning
  - Hyperspectral analysis
  - Change detection
  - Modeling
    - Spatial modeling using GIS data
    - Scene modeling
  - Scientific geovisualization
    - 1, 2, 3, and *n* dimensions
- **Hypothesis Testing**
  - Accept or reject hypothesis

Information Presentation

- **Image Metadata**
  - Sources
  - Processing lineage
- **Accuracy Assessment**
  - Geometric
  - Radiometric
  - Thematic
  - Change detection
- **Analog and Digital**
  - Images
    - Unrectified
    - Orthoimages
  - Orthophotomaps
  - Thematic maps
  - GIS databases
  - Animations
  - Simulations
- **Statistics**
  - Univariate
  - Multivariate
- **Graphs**
  - 1, 2, and 3 dimensions

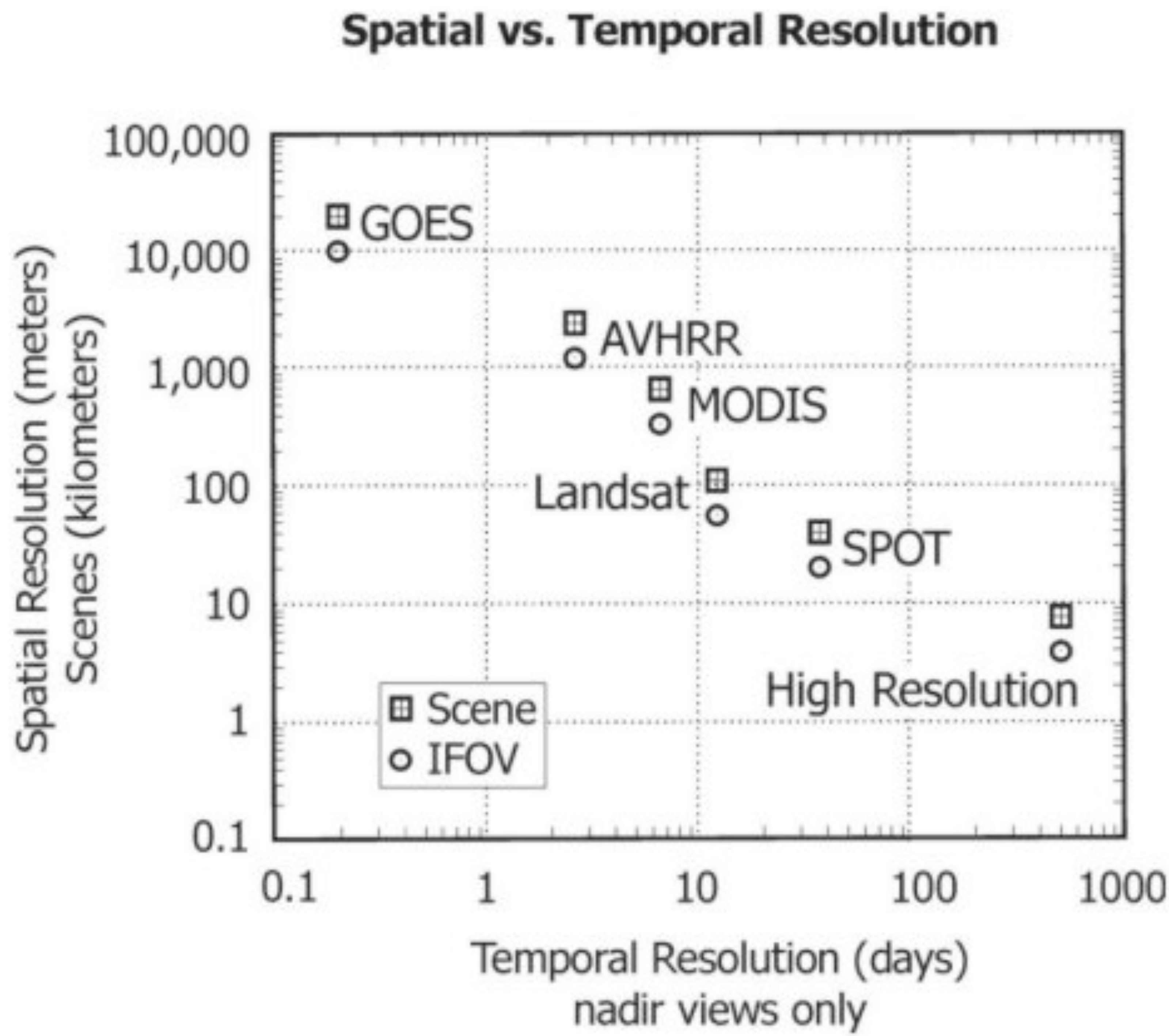
Jensen, 2007

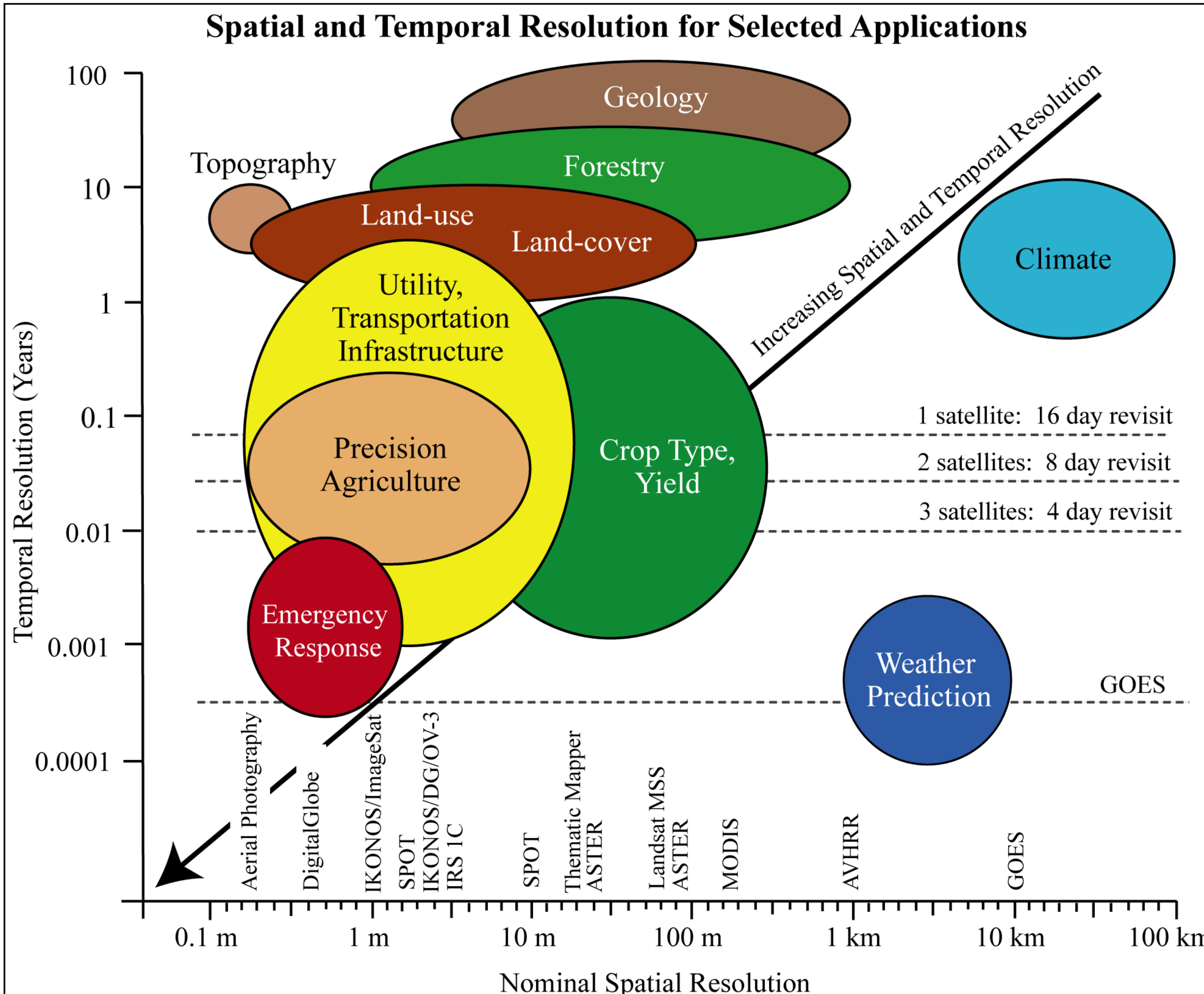
Dichotomy in Remote Sensing



Fundamental Question in Remote Sensing:

How to infer information about the landscape from a set of measurements that constitute an image?

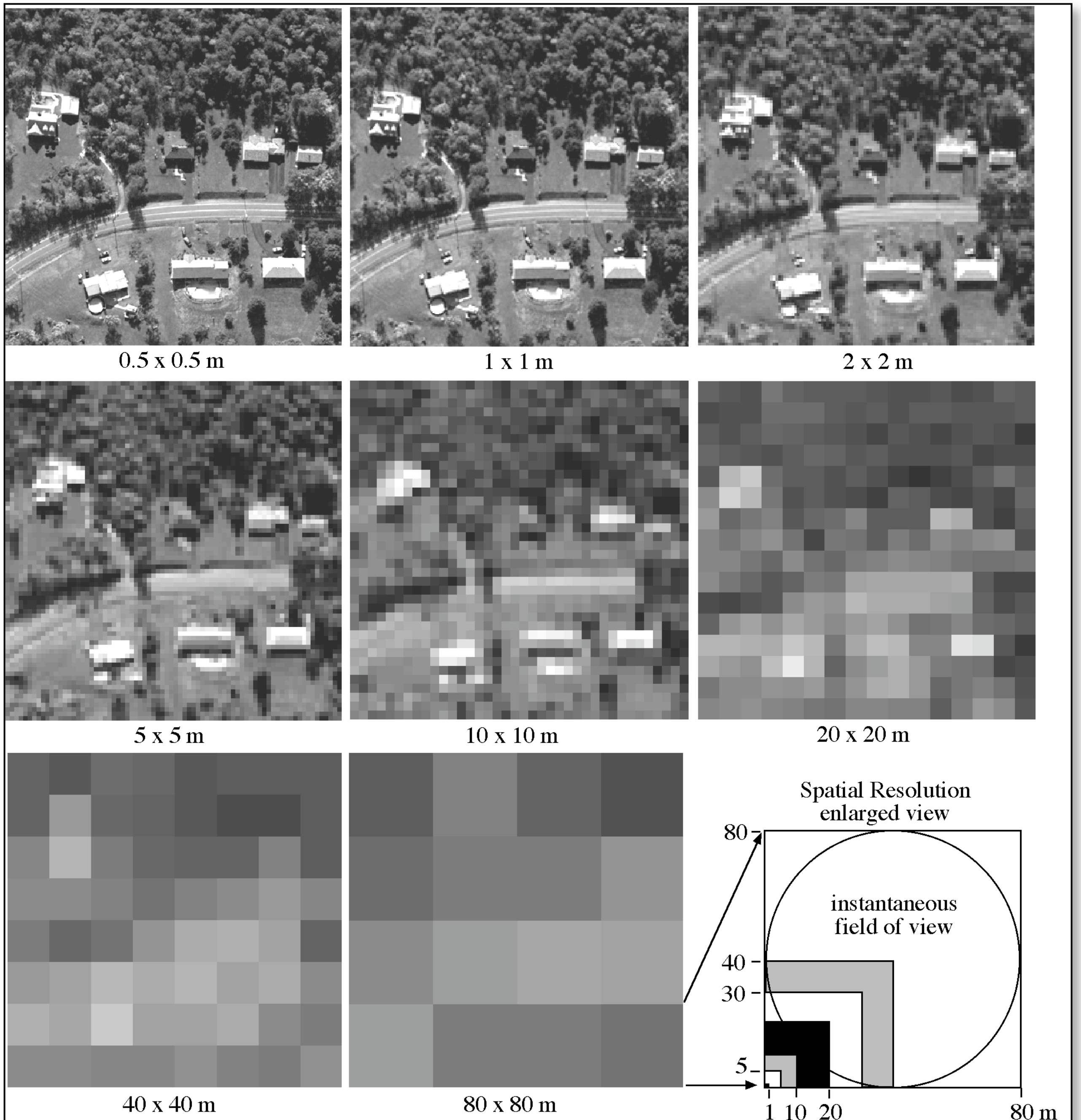

Spatial vs. Temporal Resolution
100,000
10,000
1,000
100
10
1
0.1
GOES
AVHRR
MODIS
Landsat
SPOT
High Resolution
Scene
IFOV
0.1
1
10
100
1000
Spatial Resolution (meters)
Scenes (kilometers)
Temporal Resolution (days)
nadir views only



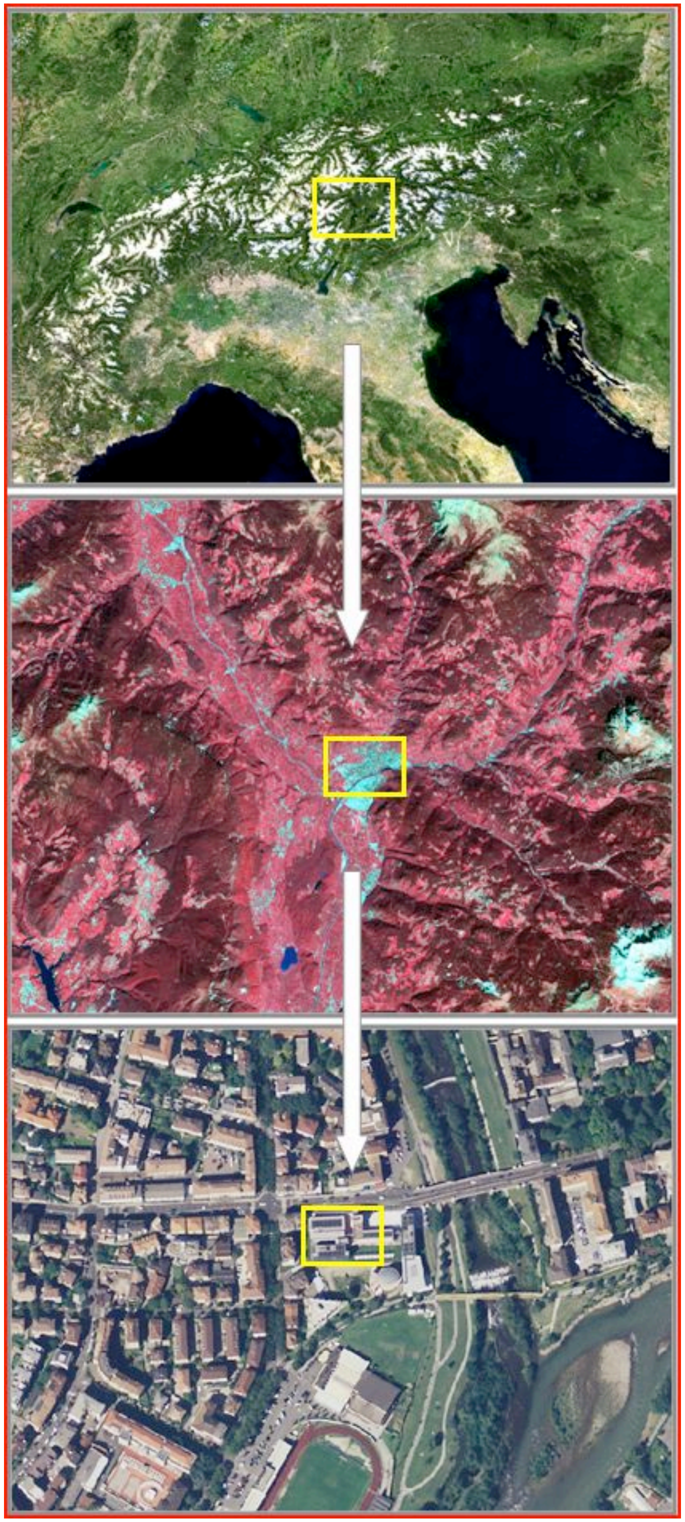
There are spatial and temporal resolution considerations that must be made for certain remote sensing applications.

Spatial Resolution

Imagery of residential housing in Mechanicsville, New York, obtained on June 1, 1998, at a nominal spatial resolution of 0.3 x 0.3 m (approximately 1 x 1 ft.) using a digital camera.



Jensen, 2007



Question of the day (1)

- What is a good spatial resolution?
- What is a good scale?

Resolution tradeoff

- High spatial resolution is associated with low spectral resolution
- High spectral resolution is associated with low spatial resolution
- So…
- Emphasize most important resolution - directly related to the application - and accept other resolutions as given or;
- Don’t emphasize any particular resolution and accept medium, spectral, spatial, temporal resolution.

Types of images
(with respect to spatial resolution)

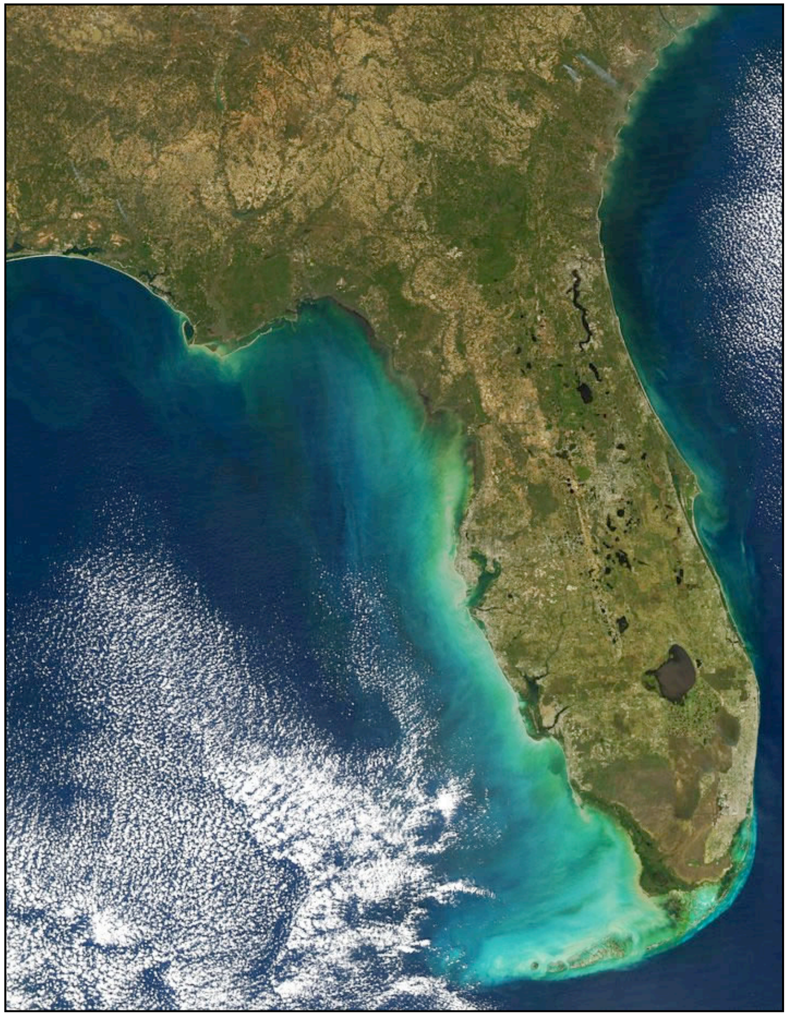
- H resolution image: where pixels are smaller than the objects in the image
- L resolution image: where pixels are greater than the objects in the image

Strahler, 1980

H image

1 meter spatial resolution

L image



500 meter spatial resolution

Why digital image processing?

The use of computer algorithms to perform signal processing on digital images

- To extract information
- To evaluate a sensor
- To evaluate images statistically
- To assess/improve quality
- To make base data sets (e.g. for GIS)
- To make art http://www.remotesensingart.com

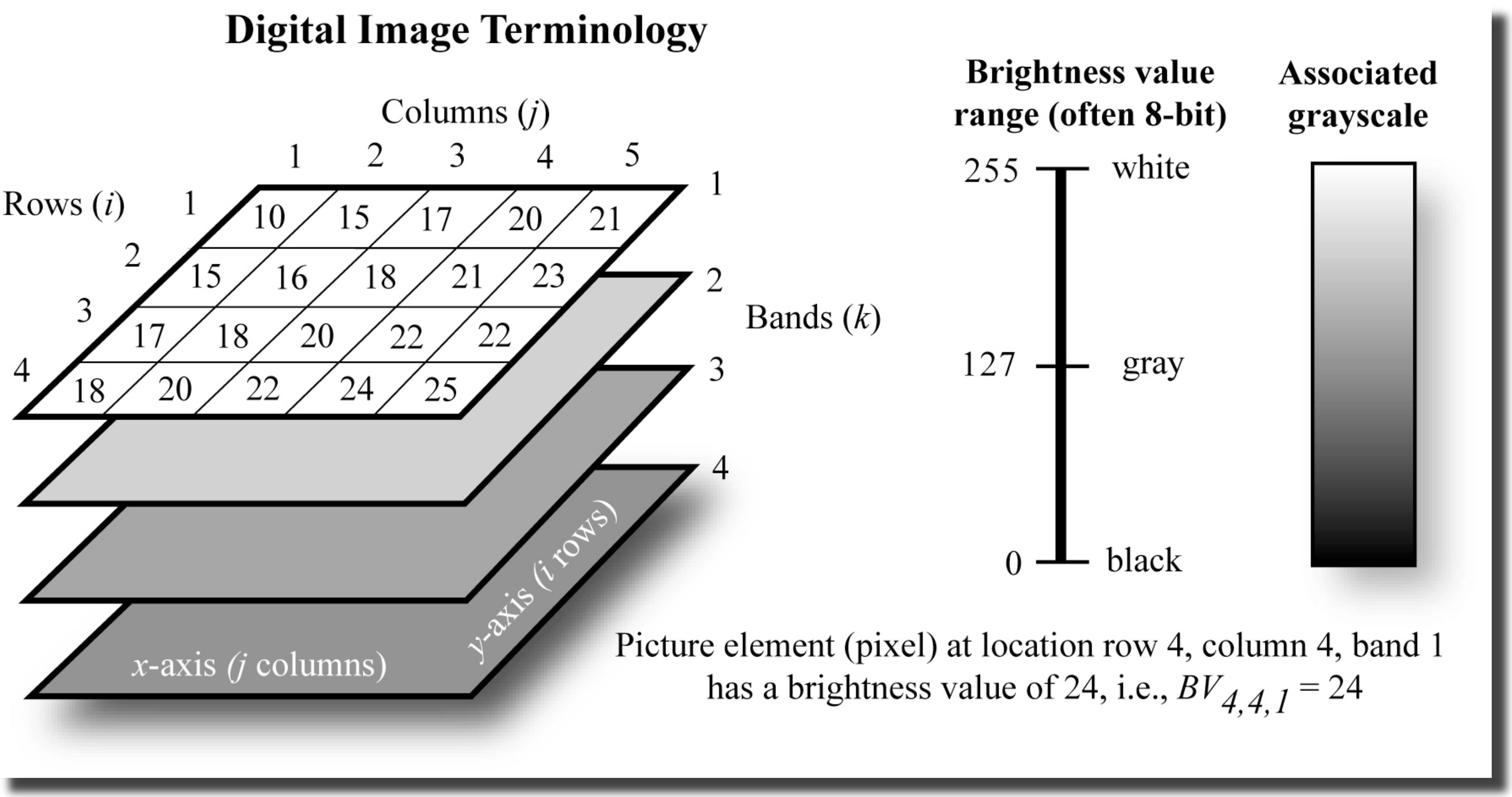
Digital image processing operations

- Geometric transformation
- Color correction
- Image editing
- Image registration
- Image projection
- Compositing
- Image differencing
- Image segmentation
- Pattern recognition

What is an image? (What's in an image?)

- An image is a two-dimensional picture that has the same appearance to a subject (a person)
- A digital image is a discreet representation of an image using ones and zeros (binary) as used in computing
- A raster image is same as a digital image made up of a finite number of pixels
- A pixel is the smallest individual element in a digital image holding quantized values of brightness
- A pixel has both a position and a value consisting of a quantile (sample)

Remote Sensing raster (matrix) data format



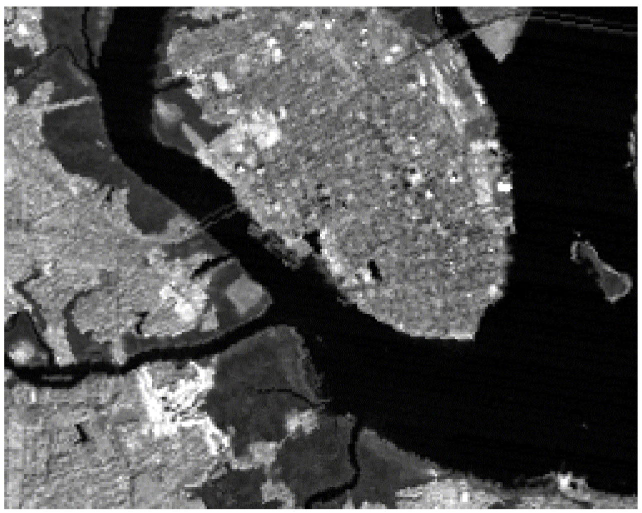
Jensen, 2004

Statistical description of images

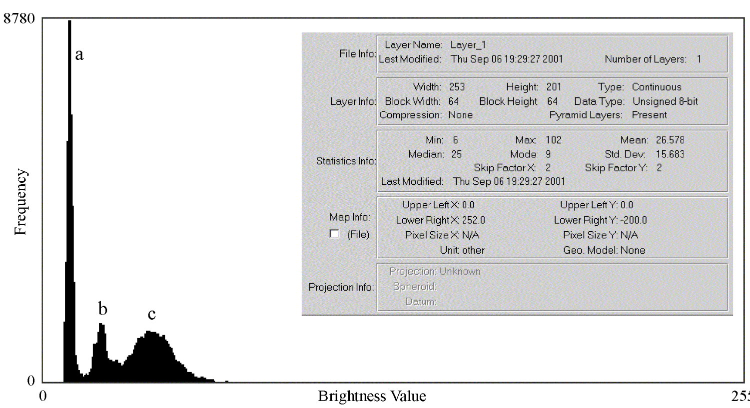
- image histogram
- individual pixel values
- univariate descriptive statistics
  statistics derived from a single variable
- multivariate statistics
  statistics derived from multiple variables

Image histogram

- The frequency of occurrence of individual or binned brightness values in an image

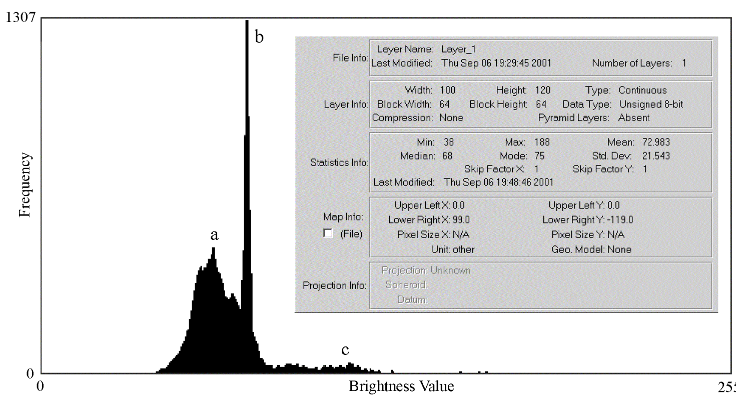


a. Landsat Thematic Mapper Band 4 Image of Charleston, South Carolina (contrast stretched).



a. Histogram of the original Landsat Thematic Mapper Band 4 imagery.

a. Nighttime thermal infrared image of the Savannah River on the South Carolina and Georgia border (contrast stretched).

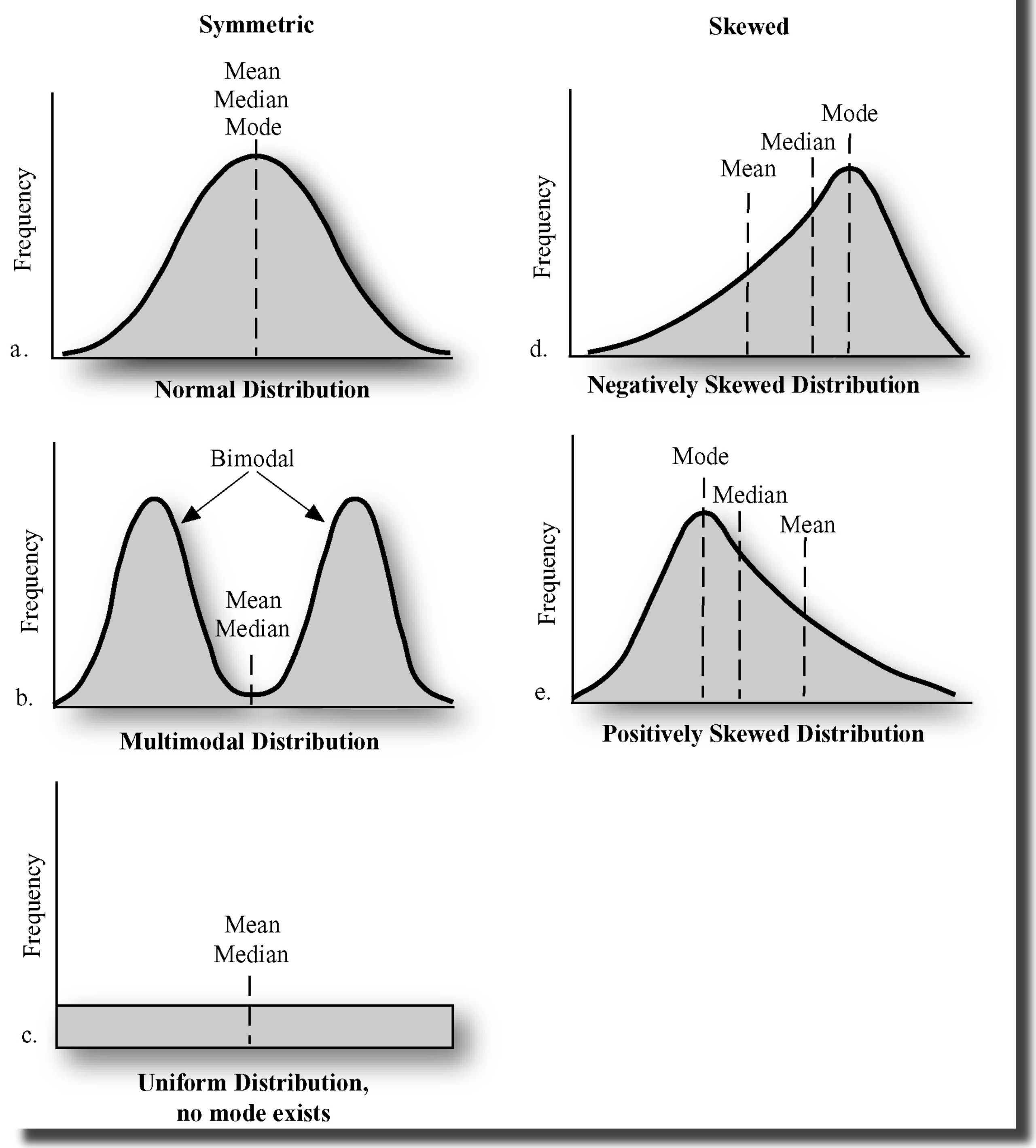


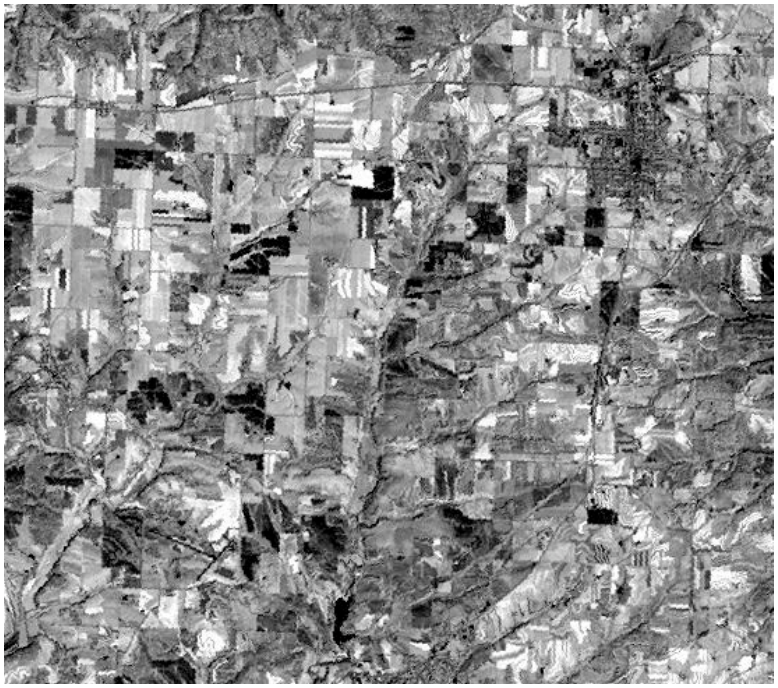
b. Histogram of the original thermal infrared data.

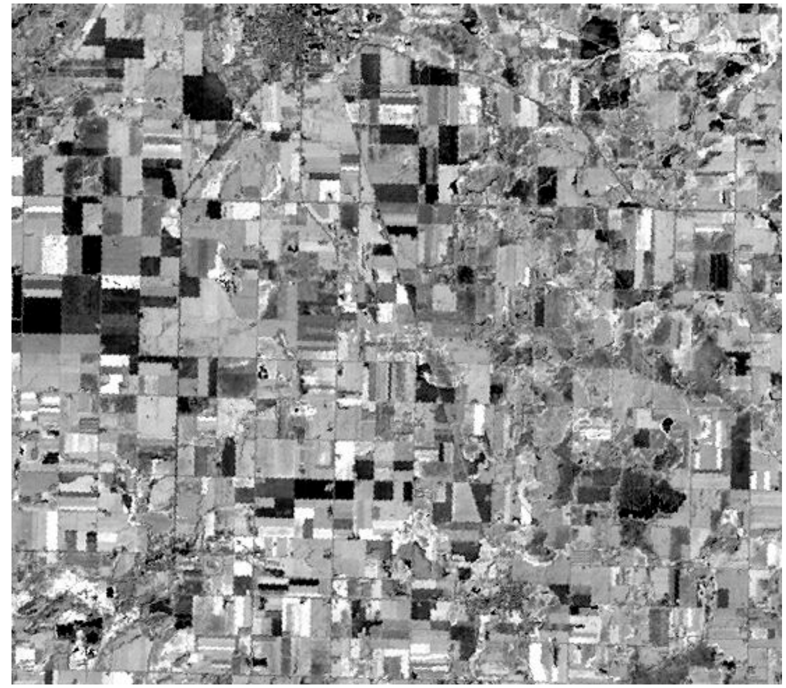
Why do we care about histograms?

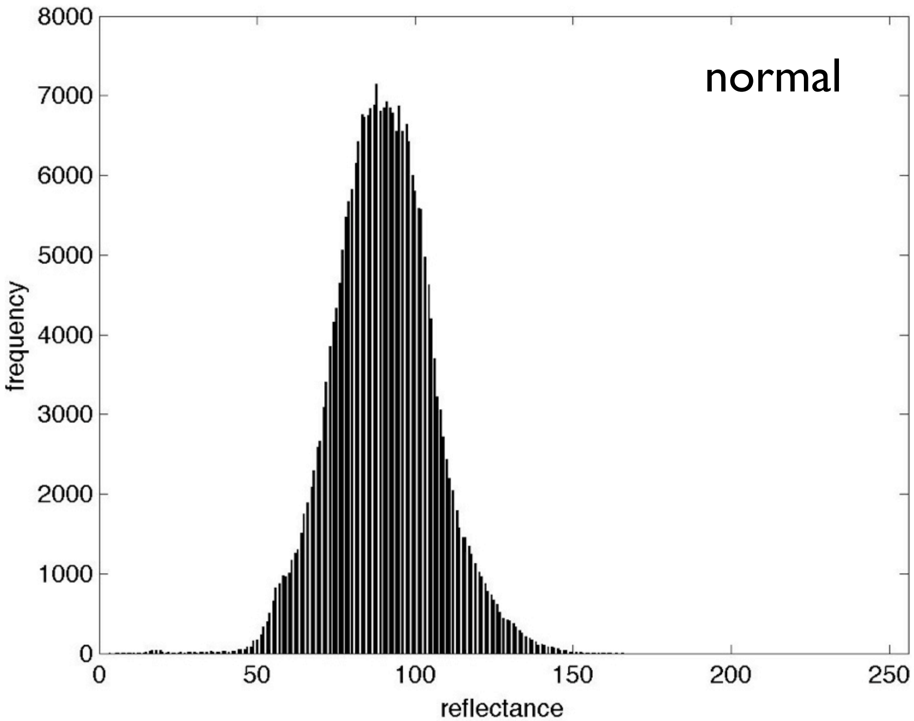
- Histograms provide a lot of information on images even without looking at the images themselves such as presence or absence of features, distribution etc.
- Histograms help evaluate images statistically e.g. normal, skewed, bimodal distribution
- Histograms are used in individual image enhancements
- Histograms are used in image classification
- Histograms are used in image segmentation
- Histograms help matching of images across time or space

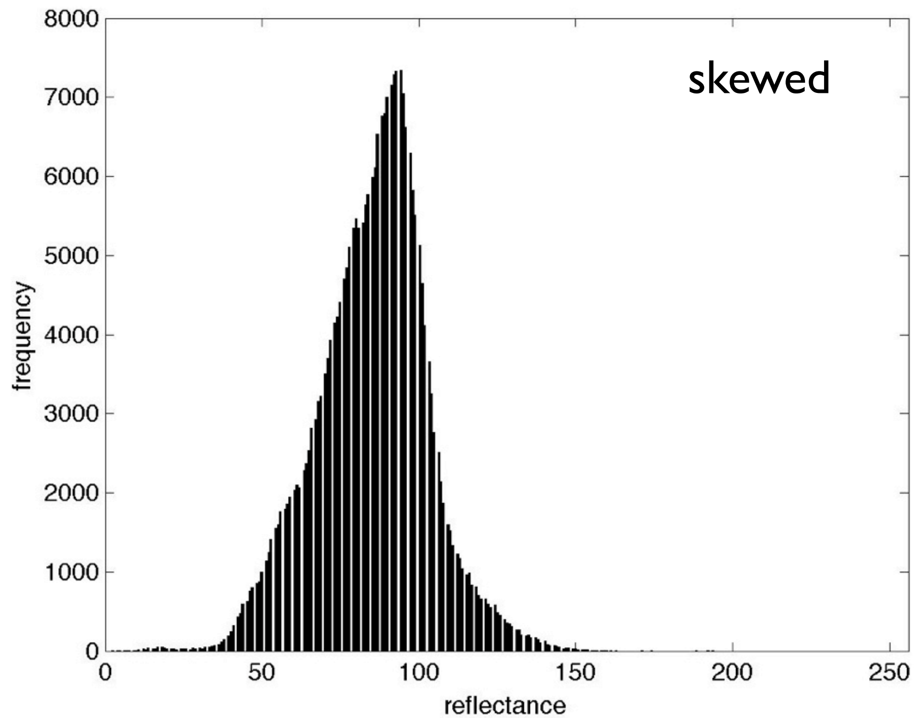
Histograms of Symmetric and Skewed Distributions

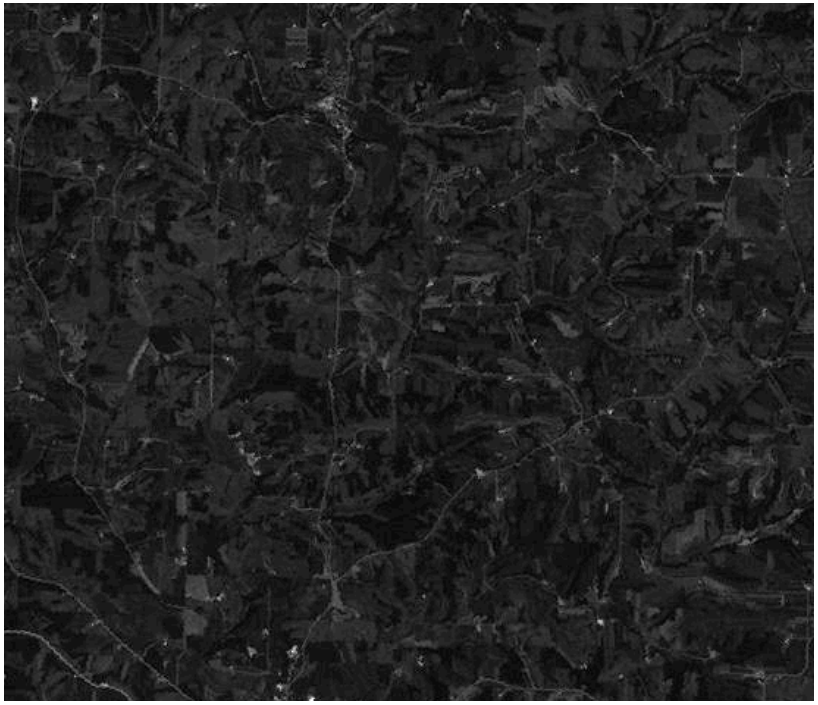


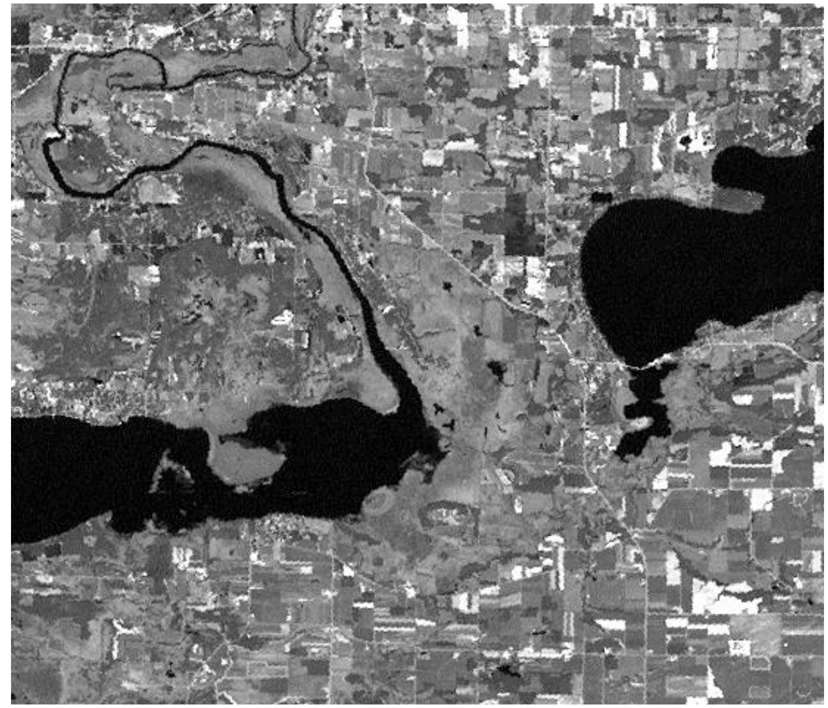


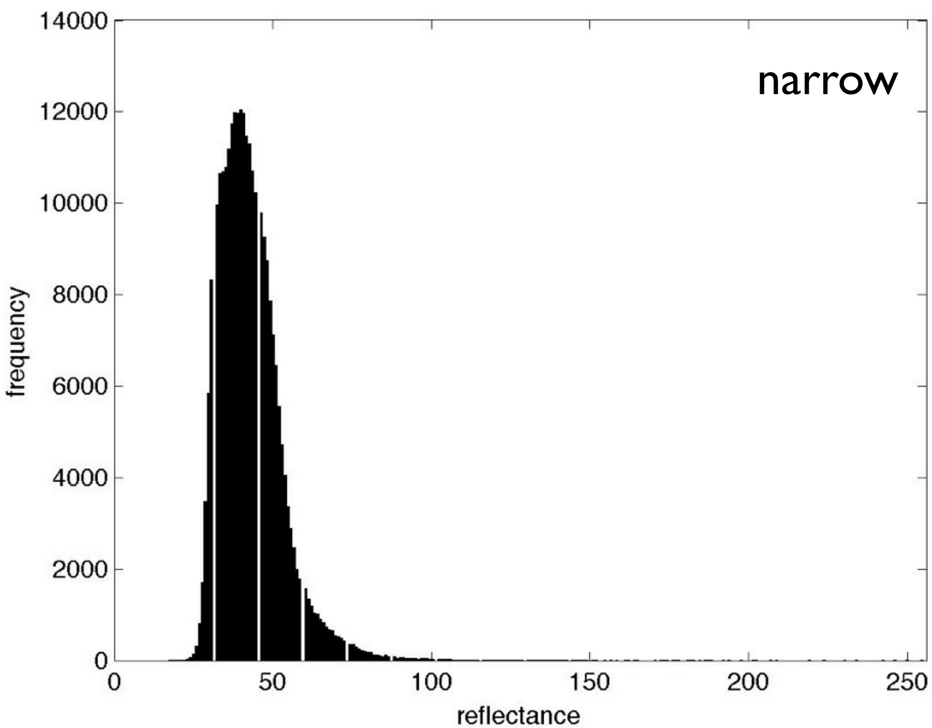


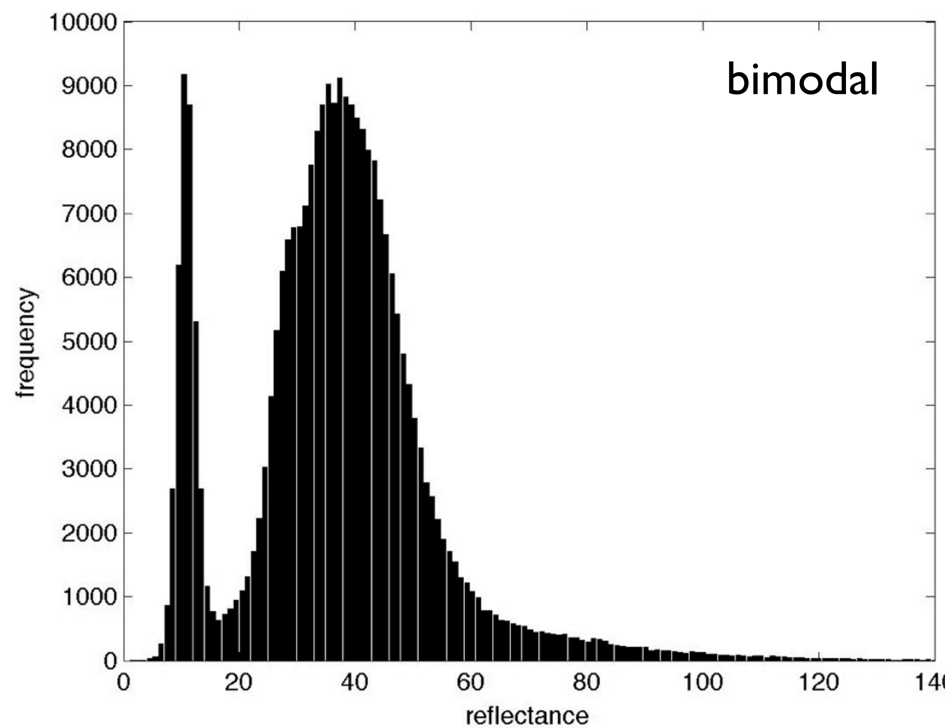

normal
frequency
reflectance
8000
7000
6000
5000
4000
3000
2000
1000
0
0
50
100
150
200
250


skewed
frequency
reflectance
8000
7000
6000
5000
4000
3000
2000
1000
0
0
50
100
150
200
250






narrow
frequency
reflectance
14000
12000
10000
8000
6000
4000
2000
0
0
50
100
150
200
250


bimodal
frequency
reflectance
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
0
20
40
60
80
100
120
140

Univariate descriptive statistics

- mode
- median
- min, max
- range
- mean
- variance
- standard deviation
- skewness
- kurtosis

Multivariate descriptive statistics

- covariance
- correlation
- regression basics
- coefficient of determination

A note on pixel position

- In addition to the values of pixels that make up an image, the spatial location and orientation of these pixels are also important
- For example, a stream of binary data has to be assembled into a two-dimensional array (matrix) in correct order for an image to display correctly.
- This is especially important for remotely sensed data as pixels are inherently spatial (geographic)
- However, the location of the pixels does not influence image statistics (unless they are spatial statistics)

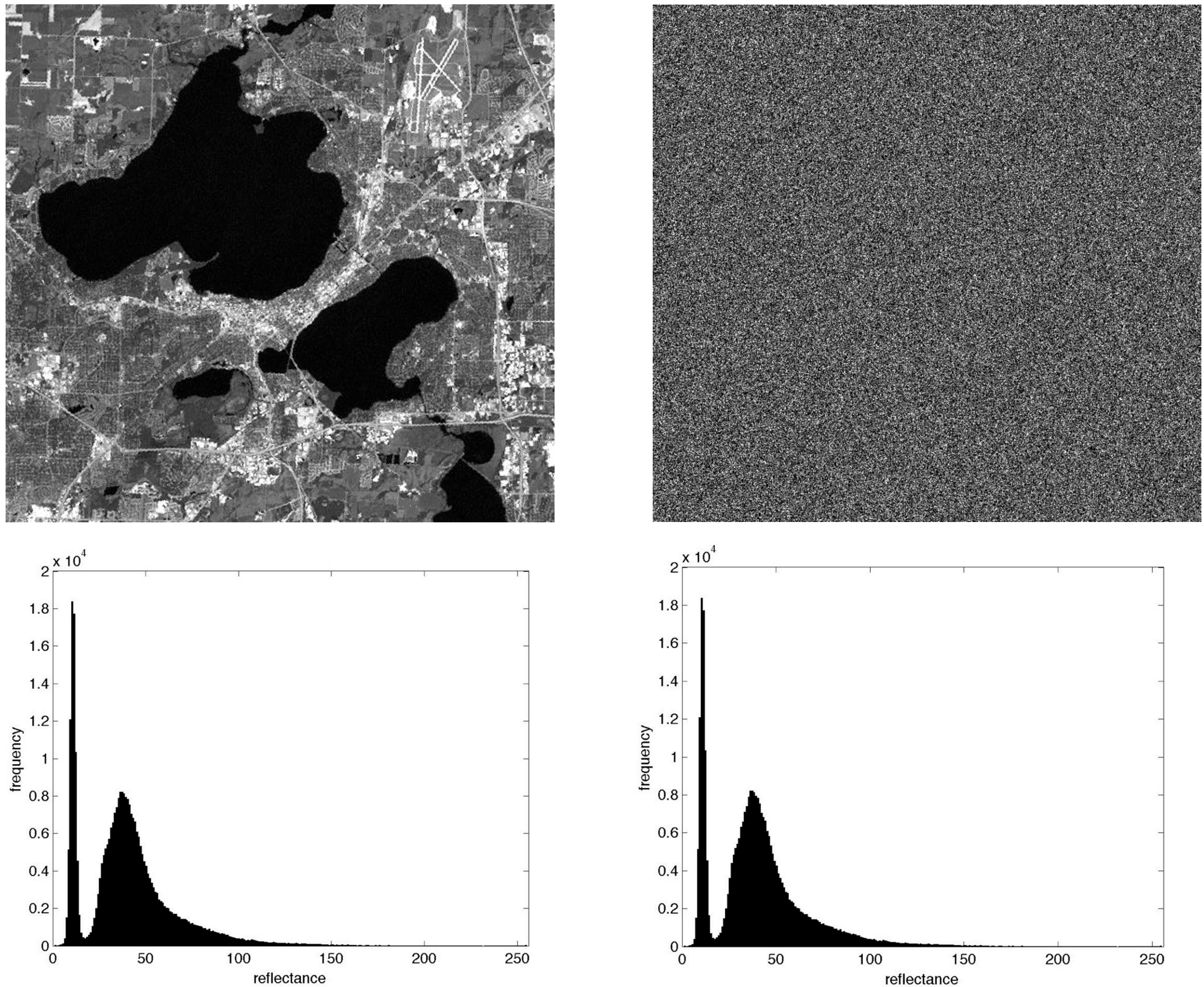

x 10^4
frequency
reflectance
0
50
100
150
200
250
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
x 10^4
frequency
reflectance
0
50
100
150
200
250
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2

Image enhancements

- Enhancement is the process of manipulating an image so that the result is more suitable than the original for a *specific* application
- The word *specific* is highlighted here because it establishes at the outset that enhancement techniques are problem specific
- For example, an enhancement method applied to X-Ray images may not be suitable for enhancing satellite images
- There is no specific theory of image enhancement
- The end user is the ultimate judge of how well a particular method works

Fundamentals

- The purpose of image enhancements:
  - visually appealing images
  - information extraction
  - noise removal
  - smoothing/sharpening
- Enhancements are generally in the form:

$$B = f(A)$$

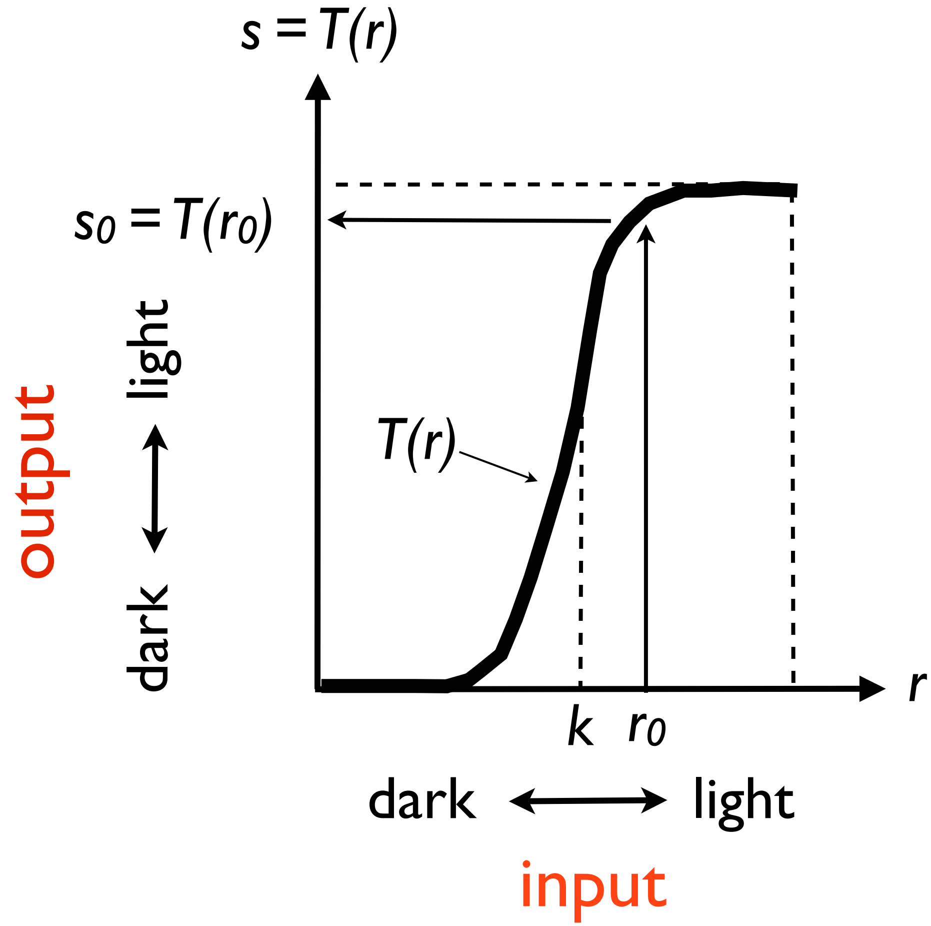
- All of the image processing techniques we will discuss today are in the *spatial domain* (i.e. in the image plain itself) as opposed to the transformed domain

Fundamentals

- Two major types of enhancements in the spatial domain:
  - intensity transformation
    - operates on a single point (pixel)
  - spatial filtering
    - operates on a group of points (pixels)
- Both are transformations (T) of the original input data into a new output data set i.e.

$$g(x,y) = T[f(x,y)]$$

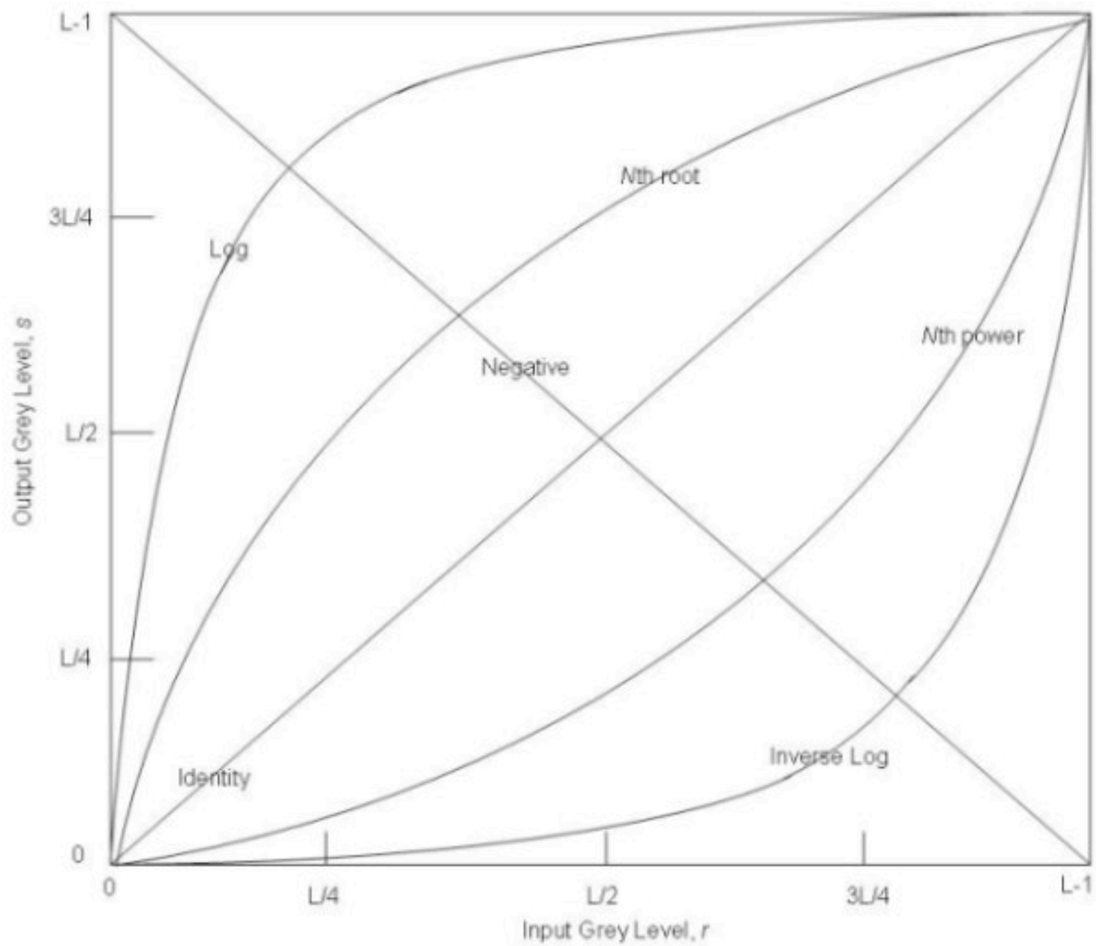
An intensity transformation example



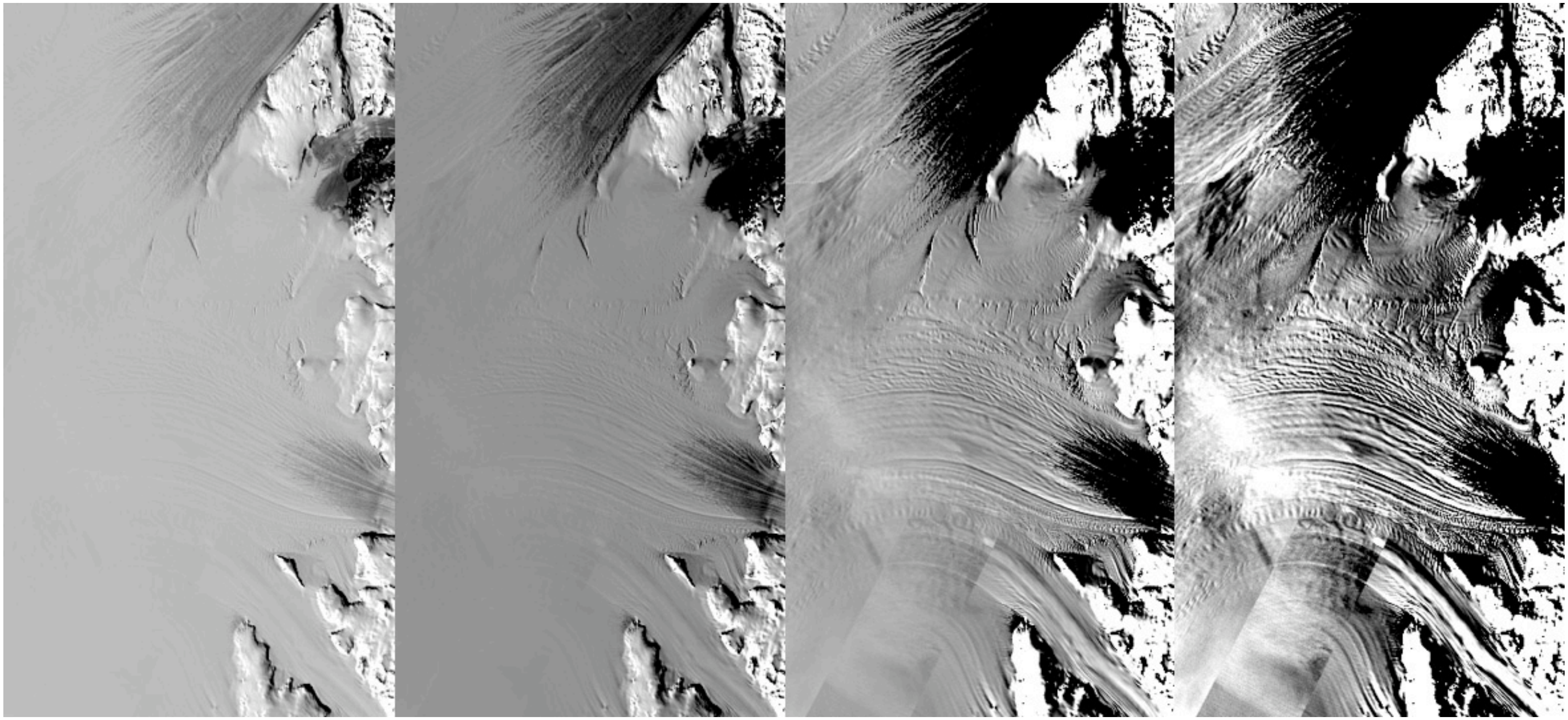
the effect of applying T would produce a higher contrast than the original by darkening the intensity levels below k and brightening the levels above k

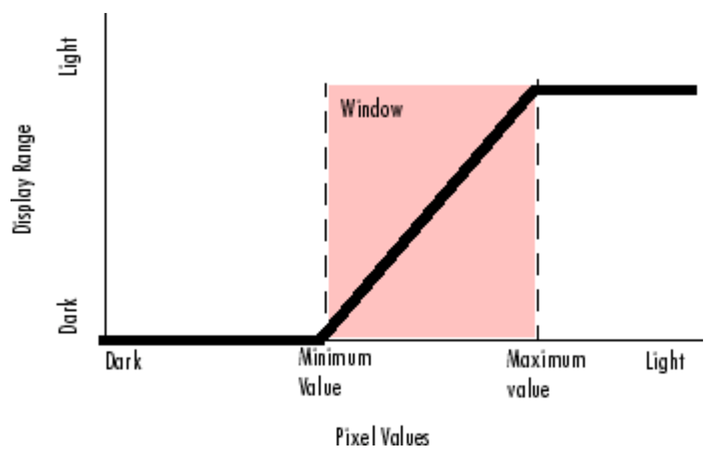
Some basic intensity transformation functions

- <u>log transformation</u> - the general form of the log transformation is $s = log(1 + r)$ and is used for *expanding values of dark pixels while compressing the higher values.* The opposite would be the inverse log transformation



contrast stretching example



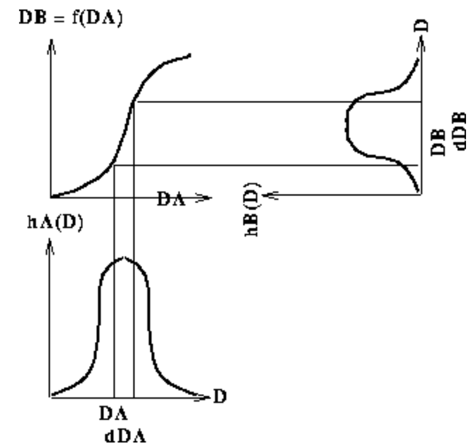


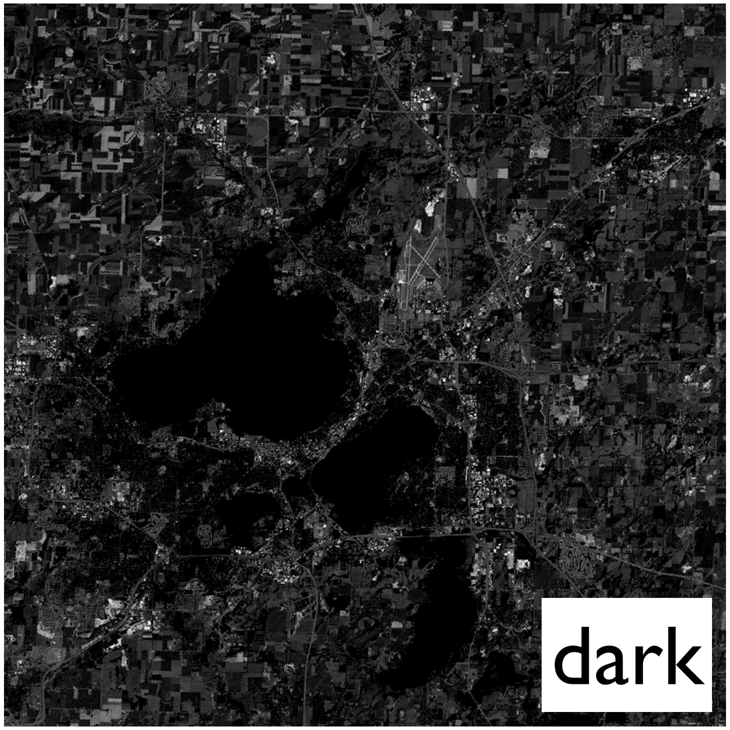
Histogram processing

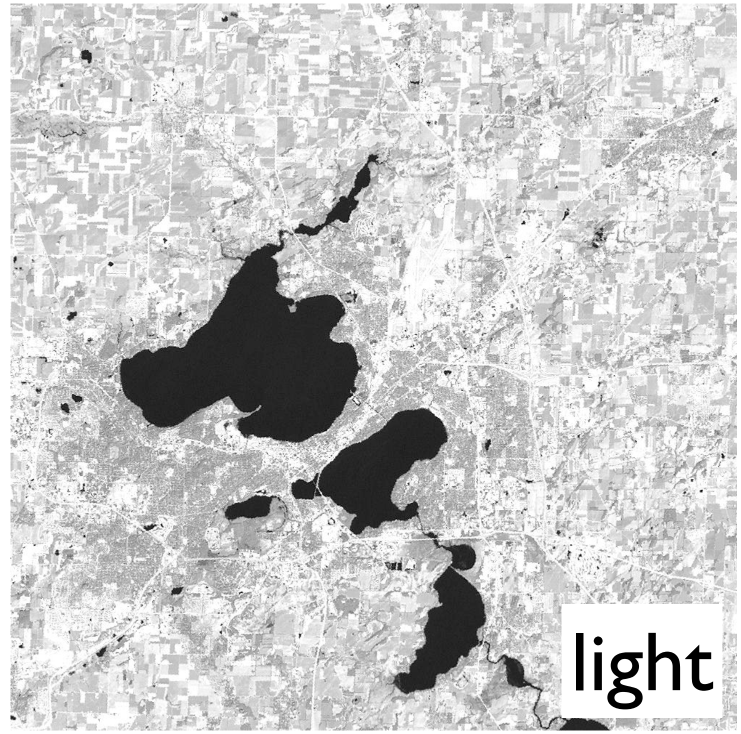
- histograms are the basis for numerous intensity domain processing techniques.
- in addition to providing useful image statistics, histogram manipulation can be used for image enhancement as well as image compression and segmentation
- histogram processing involves transformation of image values through transformation (manipulation) of the image histogram

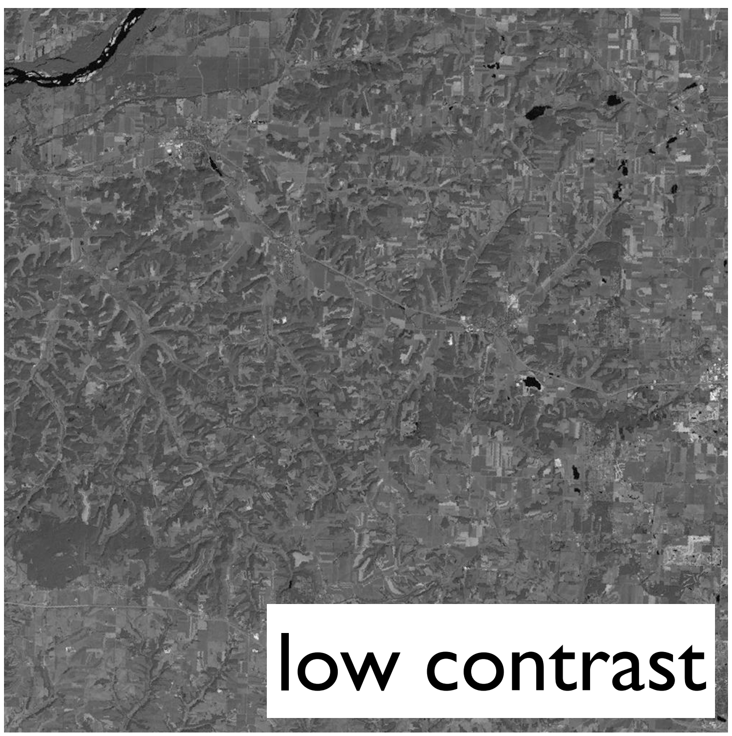
Histogram processing

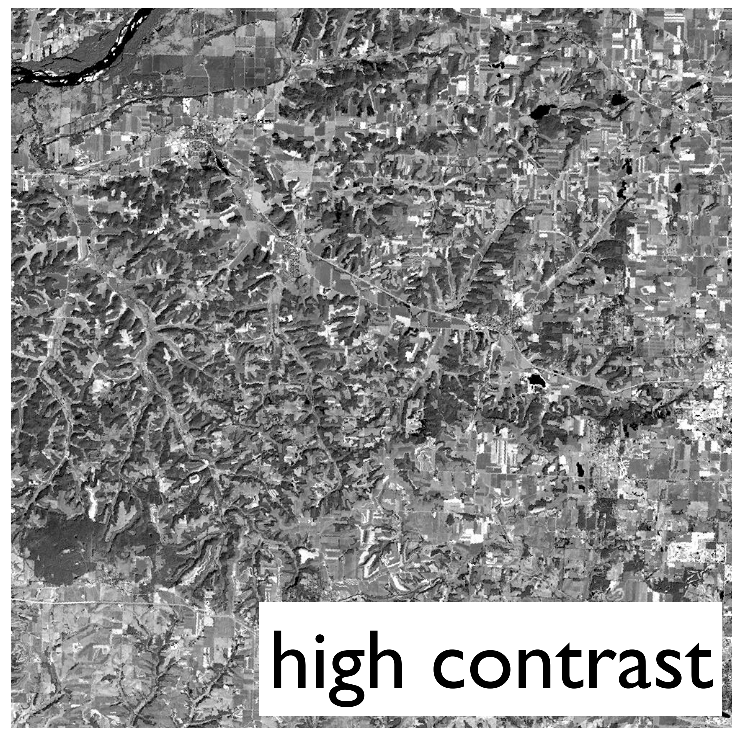
- basic stretch based on histogram shape
  - e.g. enhancing a low contrast image to have higher contrast
- matching image histogram to a pre-defined shape, statistical distribution, or to another histogram
  - e.g. histogram equalization, normal distribution, gamma distribution
- using histogram statistics
  - e.g. min/max, 2% saturation, 1 sigma




dark


light


low contrast


high contrast

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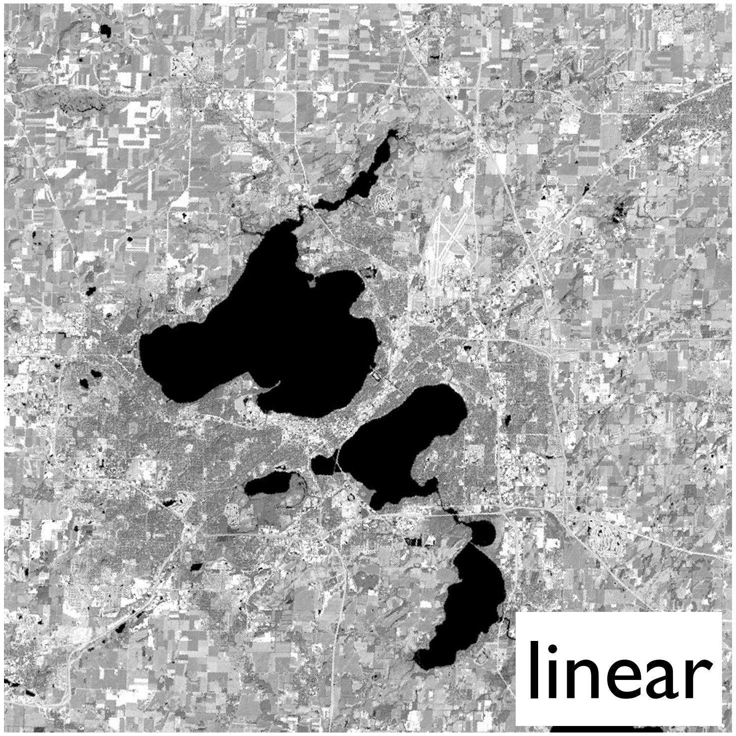
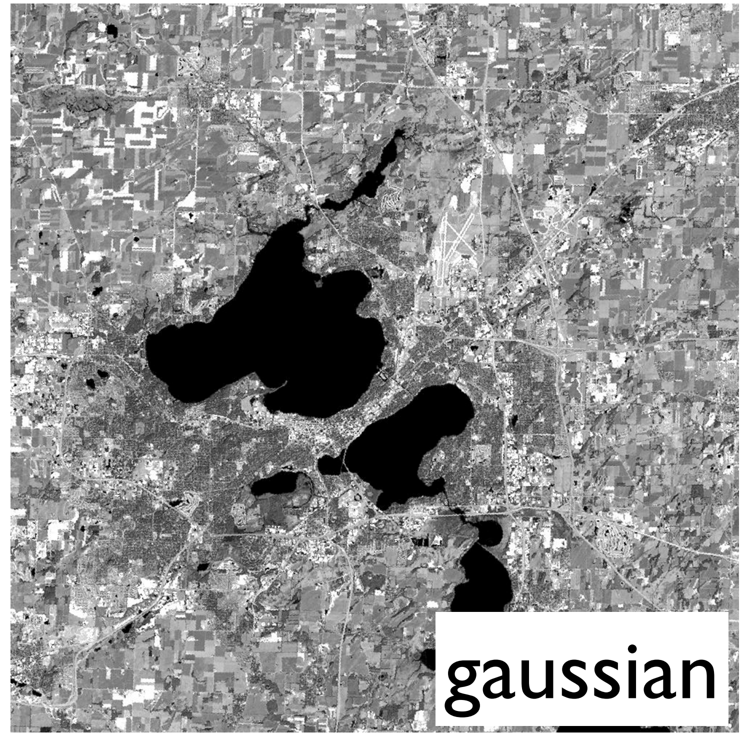
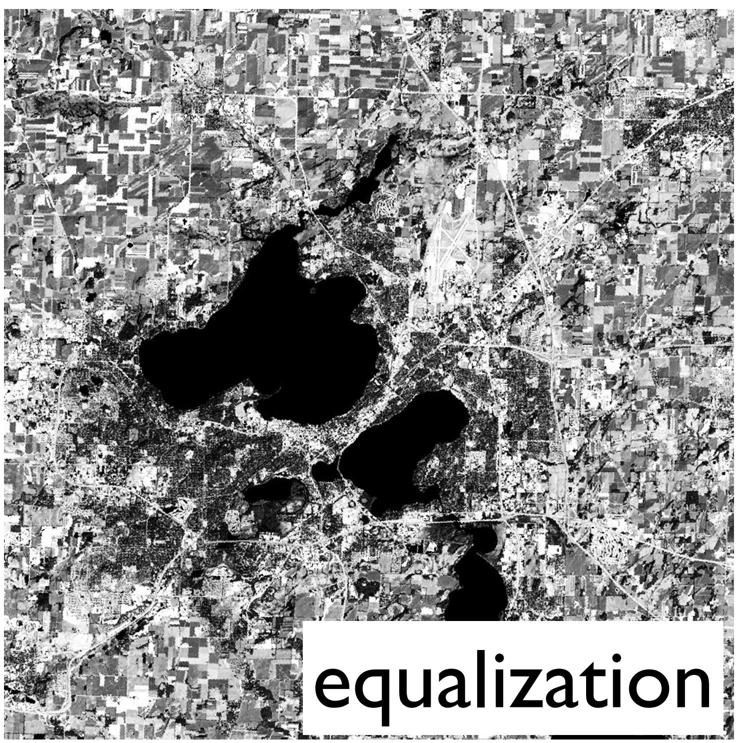
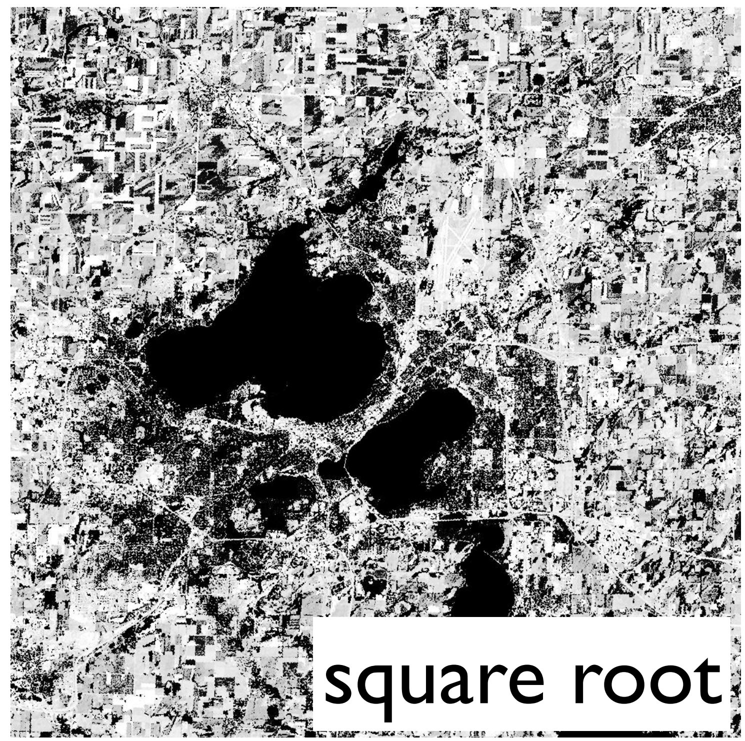

linear

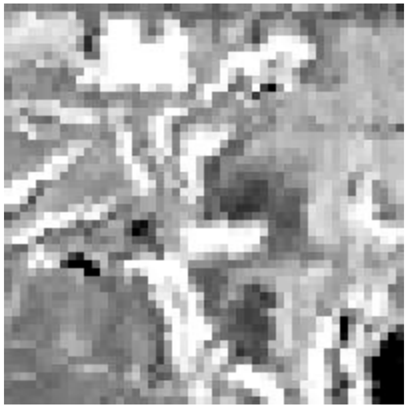

gaussian

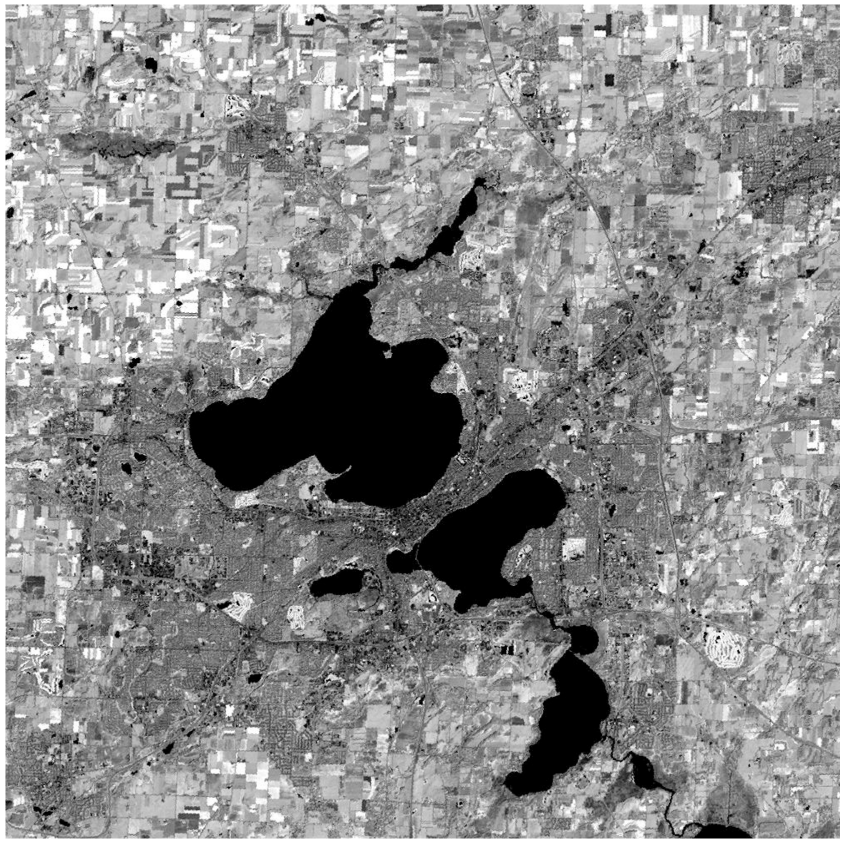
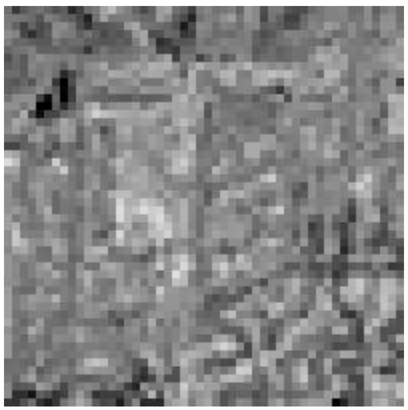
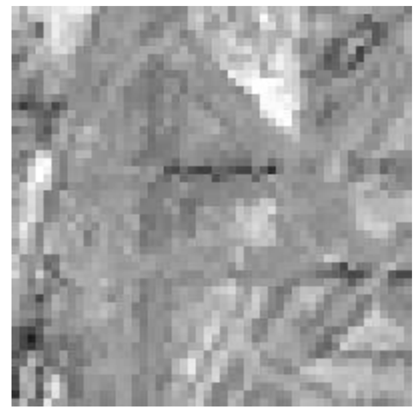

equalization


square root

Spatial enhancement (filtering)

- method of selectively emphasizing or suppressing information across different *spatial scales* is the subject of spatial enhancement
- enhancement of this type uses filters (or kernels) - a matrix of numbers - that are applied to the image over small spatial regions at a time
- so, the techniques operate *selectively* on the image data which contain *different* information at *different* spatial scales



Landsat TM Band 4

Spatial enhancement (filtering)

- noise removal/addition
- representation of spatial variability of a feature by region
- extract particular spatial scale component from an image
- smoothing
- edge detection
- frequency domain

What is a filter?

- by analogy with the procedure used in chemistry to separate components of a suspension, a digital filter is used to extract a particular feature (spatial-scale) component from a digital image

1/9	1/9	1/9
1/9	1/9	1/9
1/9	1/9	1/9

average

-1	-1	-1
-1	8	-1
-1	-1	-1

laplacian

0	-1	0
-1	4	-1
0	-1	0

laplacian

-1	-1	-1
0	0	0
1	1	1

horizontal

-1	0	1
-1	0	1
-1	0	1

vertical

-1	-1	0
-1	0	1
0	1	1

diagonal

What is a filter?

- low-pass (smoothes data)
  - moving-average
  - median
  - mode
  - adaptive filters
- high-pass (sharpening)
  - image subtraction method
  - derivate method (laplacian)
- edge detection

median filter with noise example

original image

3x3 filter

7x7 filter

9x9 filter

laplacian enhancement

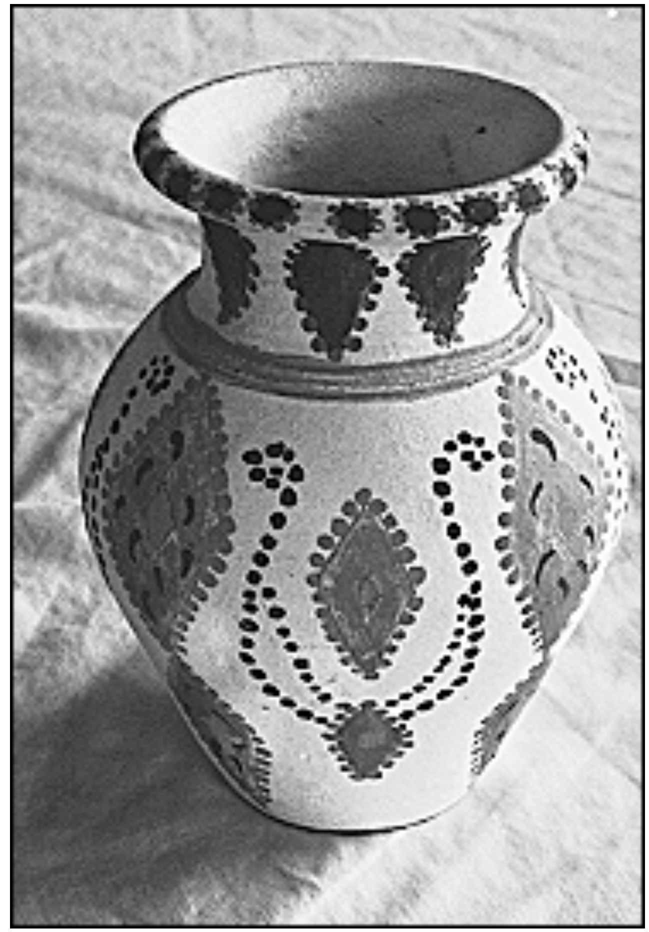


Image Geometric Correction

What is geometric correction?

- RS images are not maps
- Information extracted from RS data is often integrated with GIS for further analysis or to present to end-users
- Transformation of RS image data so that it has appropriate spatial scale and appropriate projection is called geometric correction
- Registration is the process of fitting the coordinate system of one image to another image of the same area

Why geometric correction?

- to transform an image to match a map projection
- to locate points of interest on a map or image
- to bring adjacent (or overlapping) images into a common registration
- to overlay temporal sequences of images of the same area (different times, different sensors)
- to overlay images and information products with other maps and GIS

Mather, 1999

Sources of geometric distortions in digital satellite data

- instrument error
  - distortion in the optical system
- panoramic distortion
  - sensor field of view
- Earth rotation
  - Earth rotation velocity changes with latitude
- platform instability
  - variation in platform altitude and attitude

Mather, 1999

Two forms of geometric correction

1. To match a distorted image to a map reference

   - Ground position is important, the correction information can come from a map, ground collected points, or another image with geographic coordinates

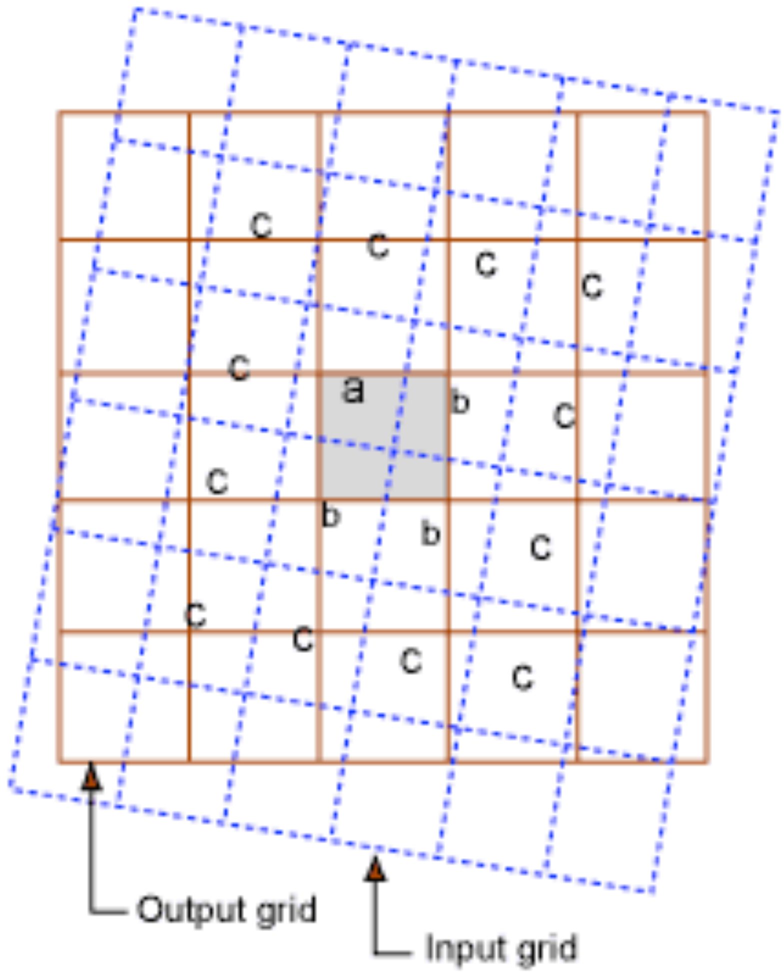
2. To match a distorted image to a "correct" image

   - Ground position is not important (unless you want it to be) but image-to-image match is the key

Common questions in image registration

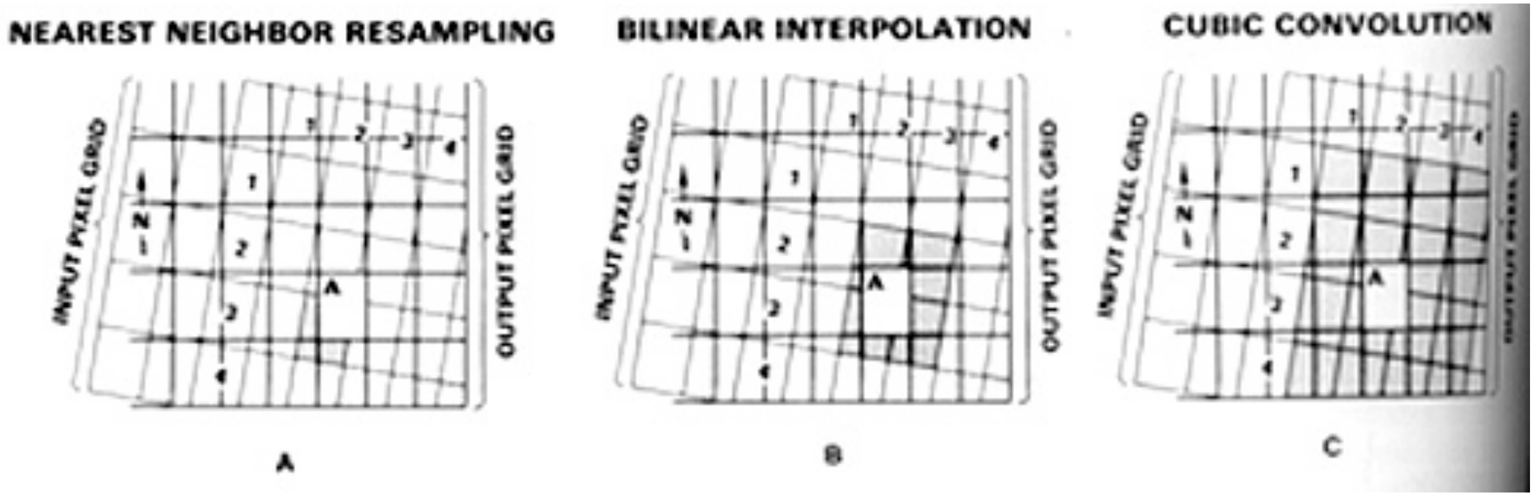
- How many points?
  - Depends on how difficult/easy the image pair is? 30-60 is often sufficient
- How should they be distributed?
  - evenly across the entire image
- Moving target problem!
  - be careful with lakes, reservoirs, agricultural fields
- What is the desired accuracy?
  - minimum 0.5 pixel or better (you'll never get 100%)

resampling



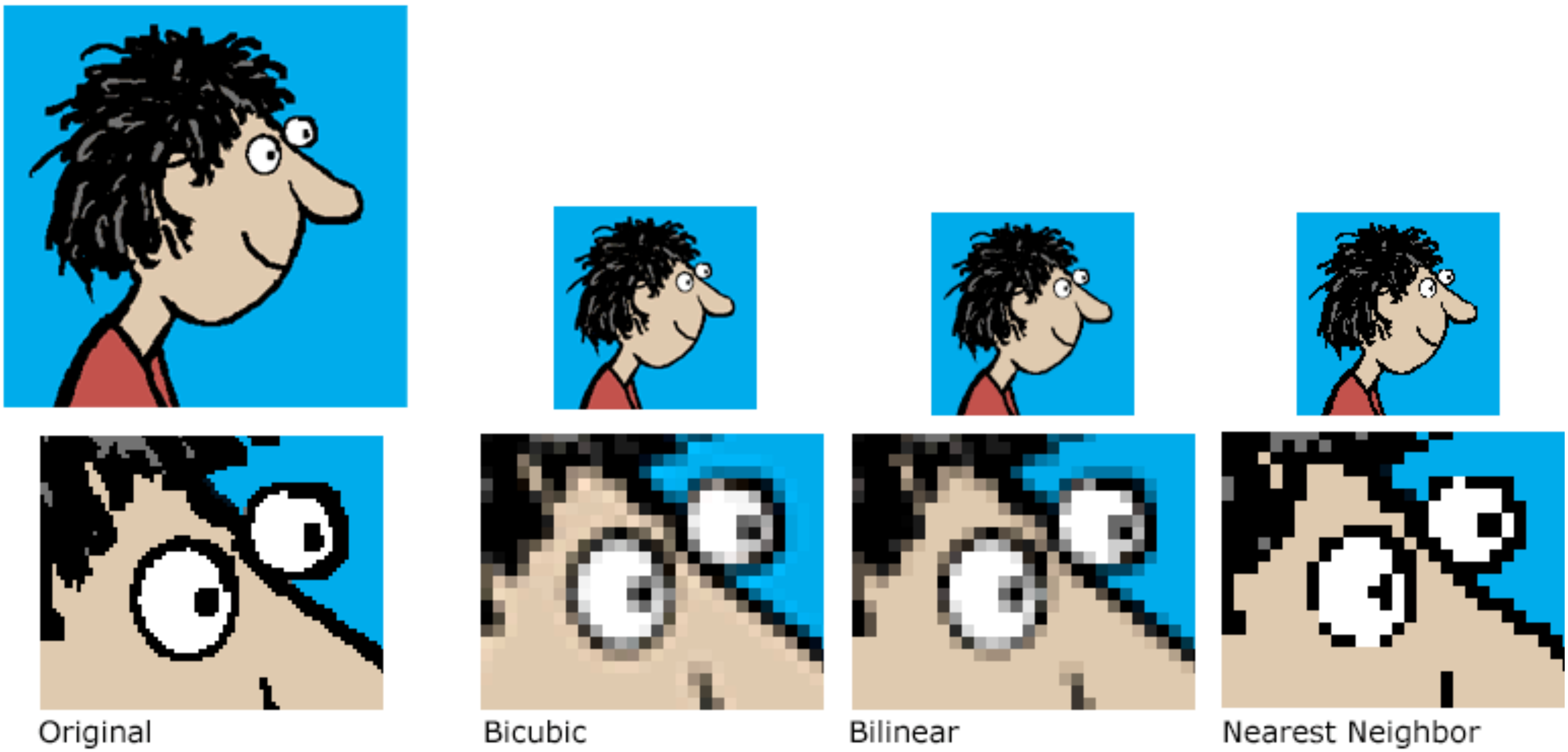
Grid of geometrically correct output pixels superimposed on the original, uncorrected input pixels

Resampling



- Nearest Neighbor - select the nearest neighbor of the target pixel whose location is computed from transformation
- Bilinear Interpolation - do two linear interpolations, first in one direction (X), and then again in the other direction (Y)
- Cubic Convolution - the brightness value of a pixel in a corrected image is interpolated from the brightness values of the 16 nearest pixels around the location of the corrected pixel

resampling



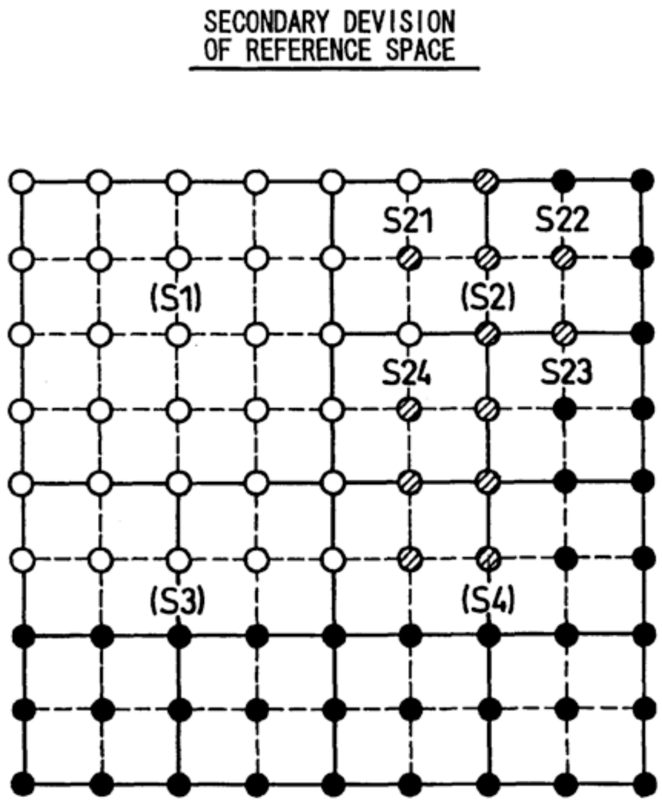
which resampling method?

- For analysis of remotely sensed data, prefer using Nearest Neighbor resampling to preserve original reflectance values
- Never perform interpolation-based resampling on categorical values
- You may be be able to use interpolation-based algorithms to smooth the data in places where this is needed
- Interpolation-based algorithms (especially Cubic Convolution) is slow!

What order?

- During registration and resampling, you will be asked to choose the order of the polynomial equation that will be used for the transformation
- Often, 1st order polynomials (linear equations) are sufficient for satellite data because satellite platforms are inherently stable and only rotational distortion occurs
- For image acquired with other devices (e.g. from aircrafts), use 2nd or 3rd order polynomials because of multiple distortions in the image

platform stability



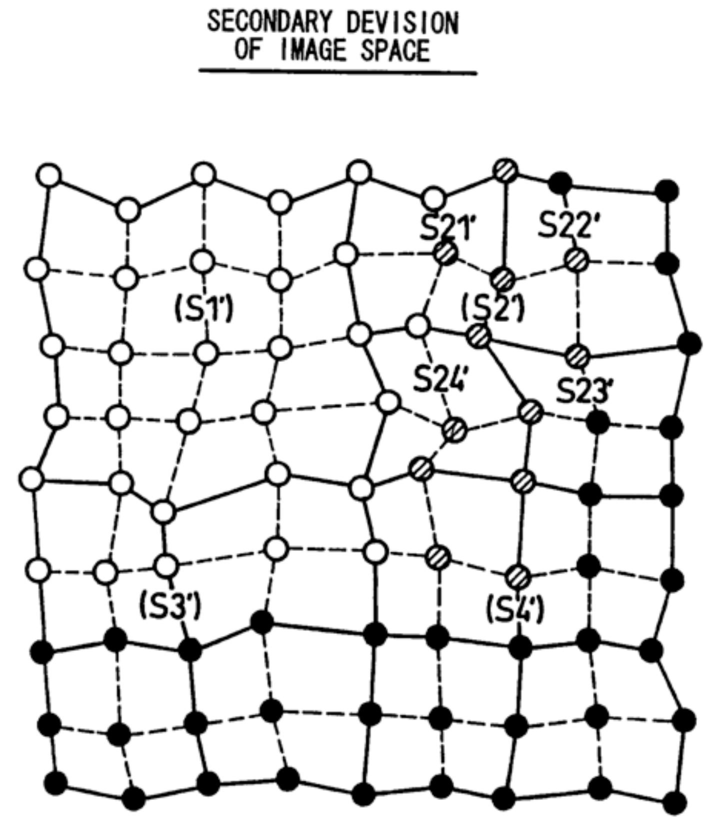


Image Radiometric Correction

What is radiometric correction?

- The radiance value recorded by an imaging sensor is not a true record of ground-leaving radiance (or reflectance) because the original signal is distorted by atmospheric absorption, scattering, as well as instrument errors
- <u>The purpose of radiometric correction</u> is to remove these effects so that an image of true surface properties can be obtained or compared
- The need for this correction and the chosen method depends on the remote sensing problem, available atmospheric information, satellite data, and detail and expertise available

Sources of radiometric errors

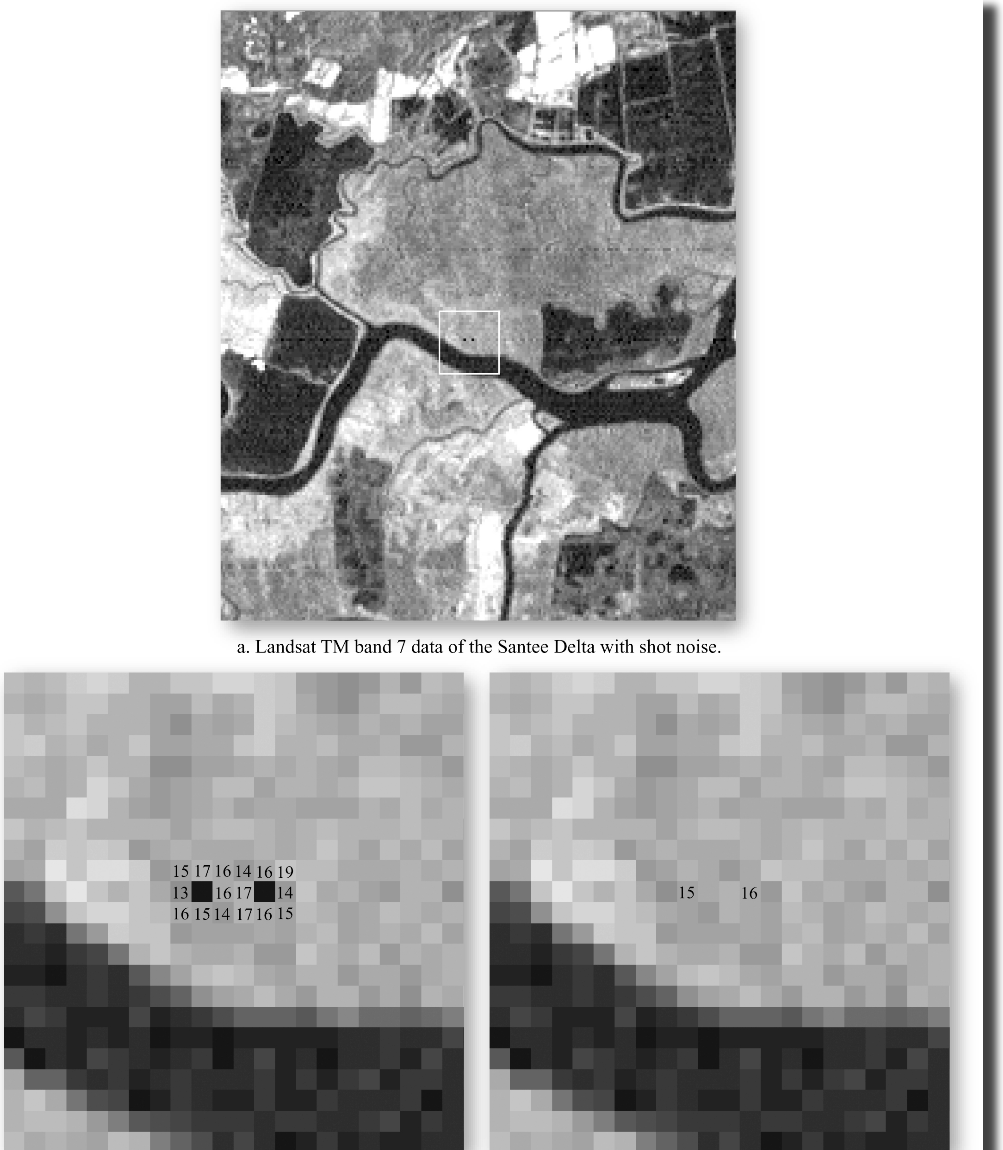
- Internal errors are introduced by the remote sensing system. They are generally systematic (predictable) and may be identified and then corrected based on prelaunch or in-flight calibration measurements. For example, in many instances, radiometric correction can adjust for detector mis-calibration
- External errors are introduced by phenomena that vary in nature through space and time. They include the atmosphere, terrain, slope, and aspect. Some external errors may be corrected by relating empirical ground observations (i.e., radiometric and geometric ground control points) to sensor measurements

Internal radiometric errors

- Ideally, the radiance recorded by a remote sensing system in various bands is an accurate representation of the radiance actually leaving the feature of interest (e.g., soil, vegetation, water, or urban land cover) on the Earth's surface. Unfortunately, *noise* (error) can enter the data-collection system at several points. Several of the more common remote sensing system–induced radiometric errors are:

random bad pixels (shot noise),
line-start/stop problems,
line or column drop-outs,
partial line or column drop-outs, and
line or column striping

Random bad pixels (shot noise)



a. Landsat TM band 7 data of the Santee Delta with shot noise.

b. Two pixels along a bad scan line with shot noise.

c. Shot noise removed.

a) Landsat Thematic Mapper band 7 (2.08 – 2.35 μm) image of the Santee Delta in South Carolina. One of the 16 detectors exhibits serious striping and the absence of brightness values at pixel locations along a scan line.
b) An enlarged view of the bad pixels with the brightness values of the eight surrounding pixels annotated.
c) The brightness values of the bad pixels after shot noise removal. This image was not destriped.

Jensen, 2004

N-line striping

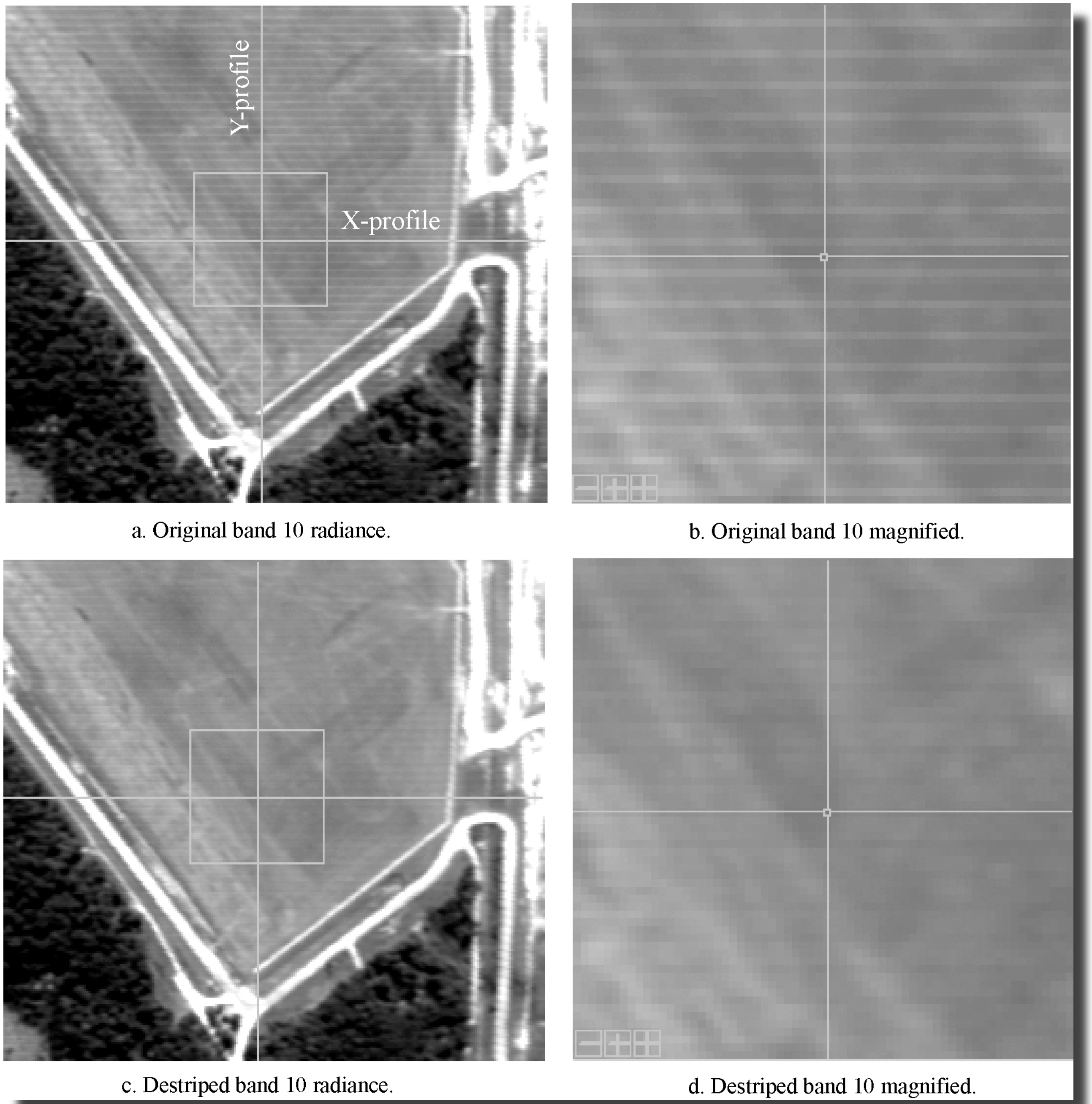
Striping

a. Landsat TM band 3 data of the Santee Delta.

b. Landsat TM band 3 data destriped.

Jensen, 2004

N-line striping



a. Original band 10 radiance.

b. Original band 10 magnified.

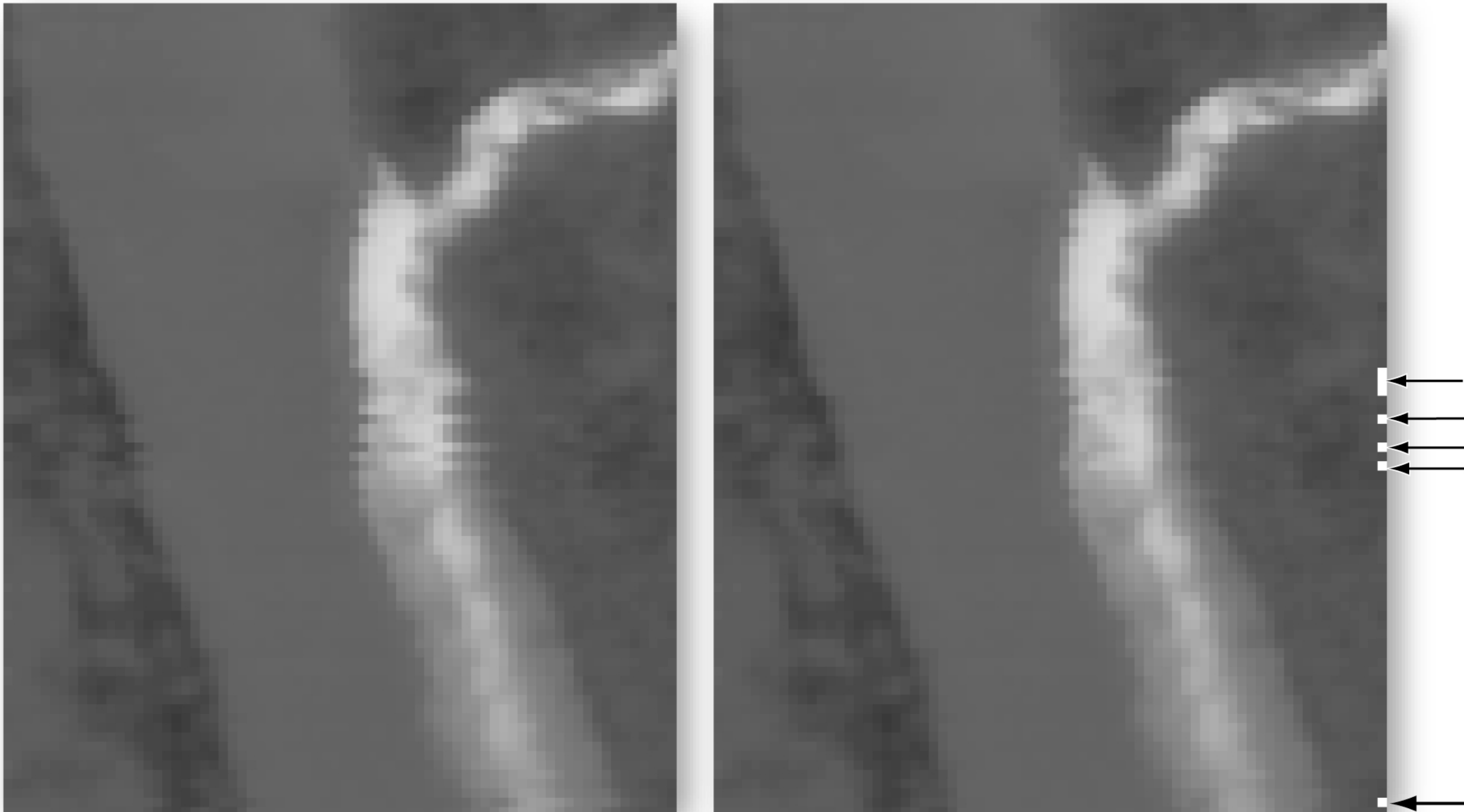
c. Destriped band 10 radiance.

d. Destriped band 10 magnified.

a) Original band 10 radiance (W m^{-2} sr^{-1}) data from a GER DAIS 3715 hyperspectral dataset of the Mixed Waste Management Facility on the Savannah River Site near Aiken, SC. The subset is focused on a clay-capped hazardous waste site covered with Bahia grass and Centipede grass. The 35-band dataset was obtained at 2 2 m spatial resolution. The radiance values along the horizontal (X) and vertical (Y) profiles are summarized in the next figure.
b) Enlargement of band 10 data.
c) Band 10 data after destriping.
d) An enlargement of the destriped data

Jensen, 2004

Line-start Problems



a. Predawn thermal infrared imagery of the Savannah River with line-start problems.

b. Seven line-start problem lines were translated one column to the left.

Jensen, 2004

External radiometric errors

- Even if the remote sensor is functioning properly, external radiometric errors can be introduced by phenomena that vary in nature through space and time. They are external to the remote sensing process but heavily influence the resulting image data.
- External errors are often non-systematic and include the atmosphere, terrain, slope, and aspect.
- Some external errors may be corrected by relating empirical ground observations (i.e., radiometric and geometric ground control points) to sensor measurements.
- Correcting for these external effects is often called "atmospheric correction" even though the correction may apply to both atmosphere and the terrain

Atmospheric Correction

Relative Correction

(Radiometric normalization)

Correction is performed relative to other (reference) images so that the corrected image is normalized as if it was acquired under same atmospheric, sensor, topographic conditions.

Absolute Correction

Requires (hard-to-obtain) information on atmospheric conditions at the time of image acquisition. The results are in absolute surface reflectance units.

- Image-based Methods
- RT-based methods

Unnecessary atmospheric correction

- Sometimes, it is possible to ignore atmospheric and terrain effects in remotely sensed data completely. For example, atmospheric correction is not necessary for certain types of classification and change detection.
- Research shows that only when training data from one place and one time must be extended through space and time is atmospheric correction necessary.
- For example, atmospheric correction is not necessary on a single date image data that will be classified, as long as the learning (training) data comes from the same image/date

Jensen, 2004

Unnecessary atmospheric correction

- The general principle is that atmospheric correction is not necessary as long as the training data are extracted from the image (or image composite) under investigation and are not imported from another image acquired at another time or place

Jensen, 2004

Atmospheric Correction

Relative Correction

(Radiometric normalization)

Correction is performed relative to other (reference) images so that the corrected image is normalized as if it was acquired under same atmospheric, sensor, topographic conditions.

Absolute Correction

Requires (hard-to-obtain) information on atmospheric conditions at the time of image acquisition. The results are in absolute surface reflectance units.

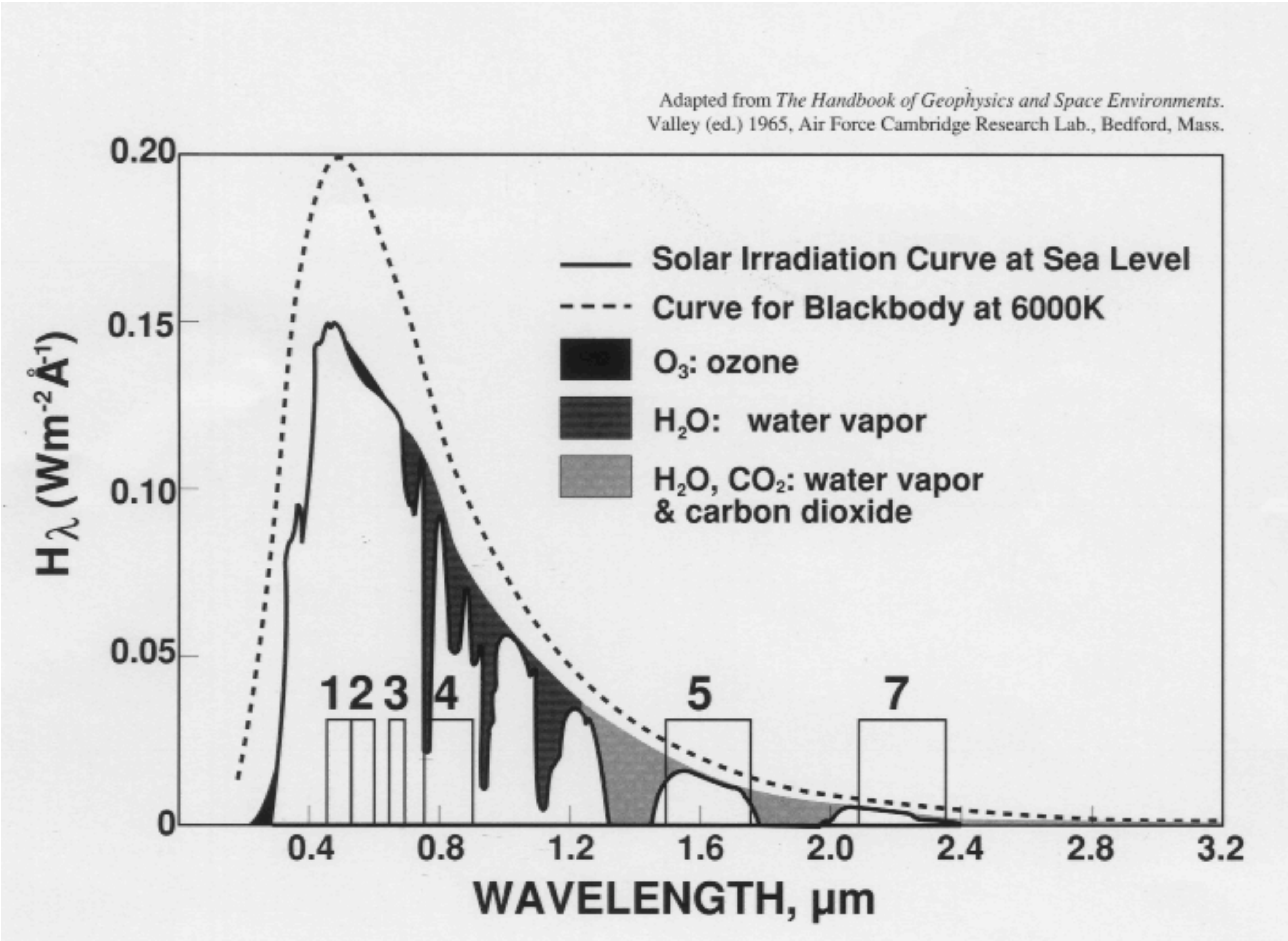
- Image-based Methods
- RT-based methods

Relative Radiometric correction methods

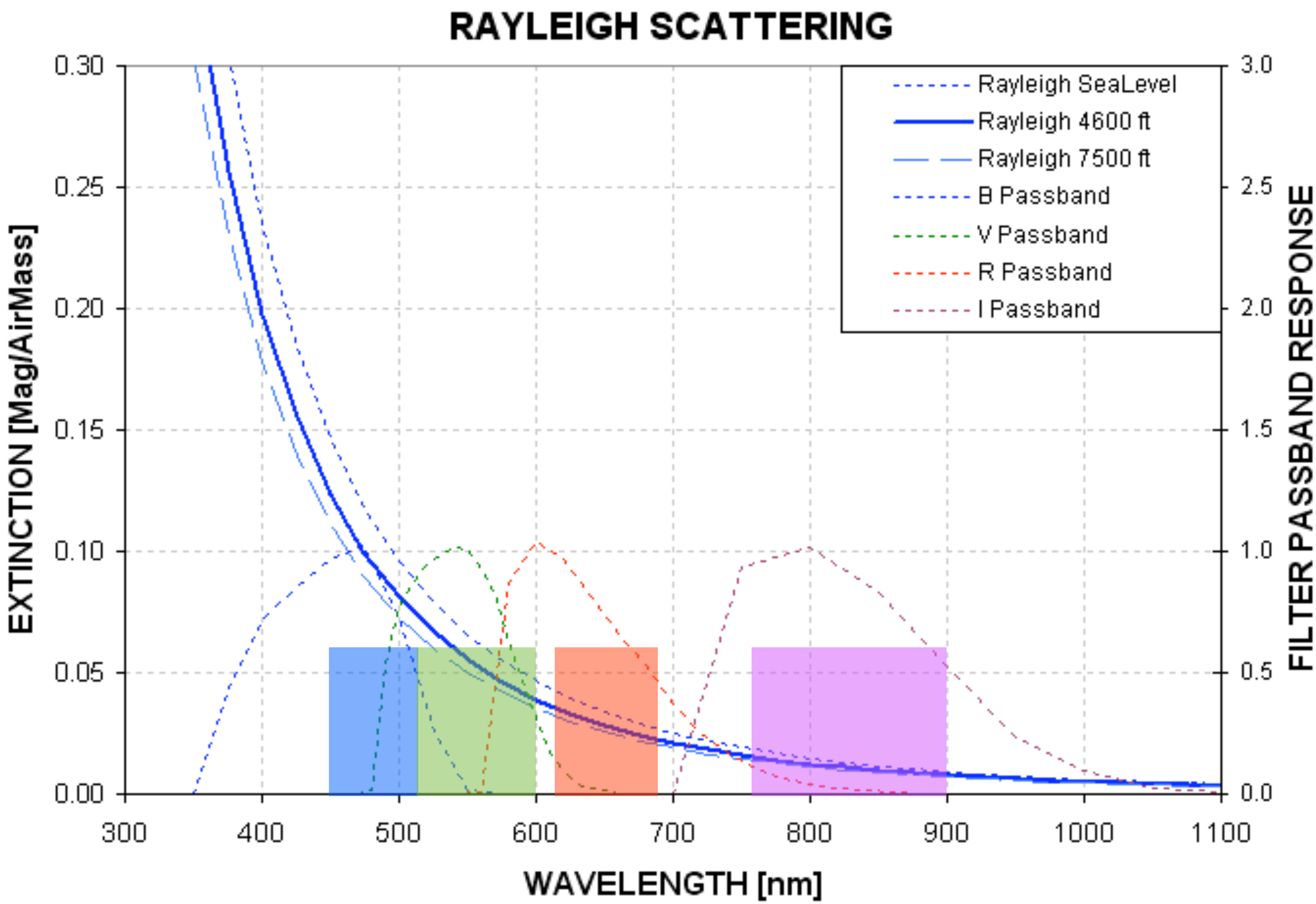
(three among many others)

- single image normalization using histogram adjustment
- multi-date image normalization using regression
- the ridge method

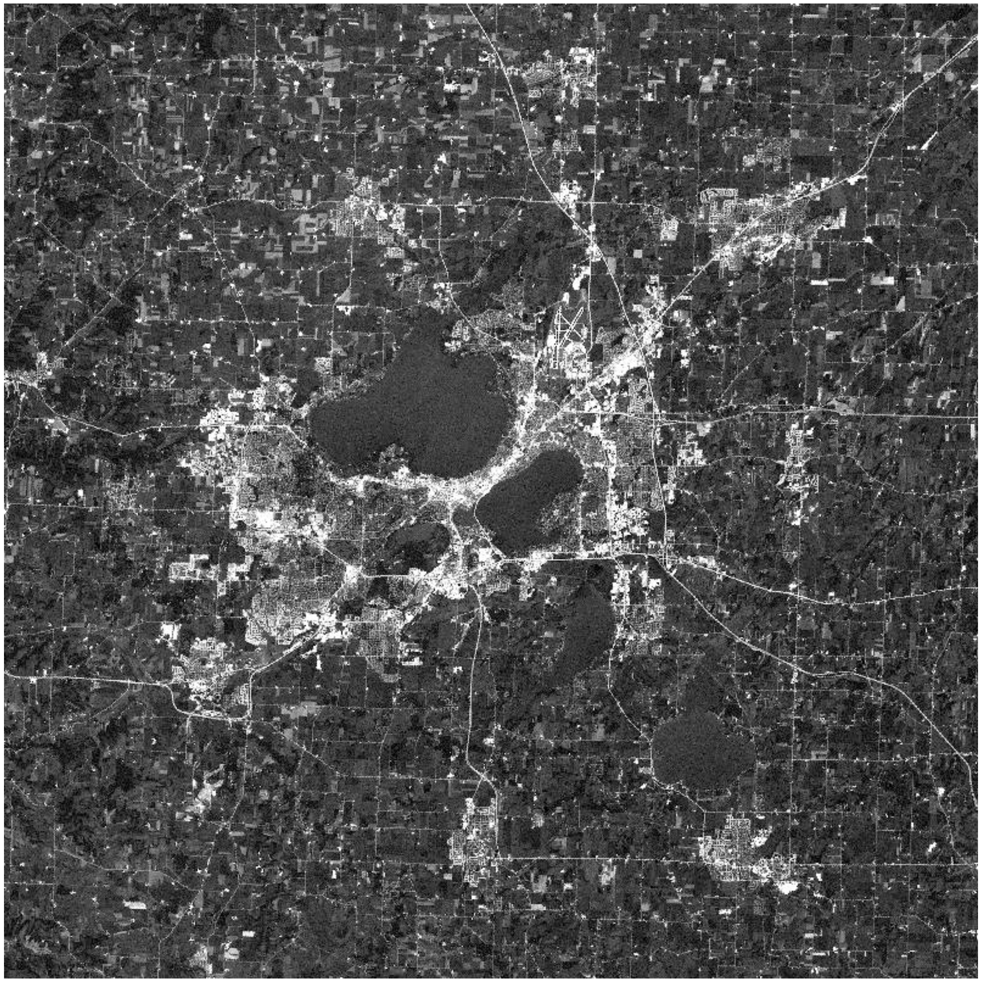
Atmospheric interaction with EMR



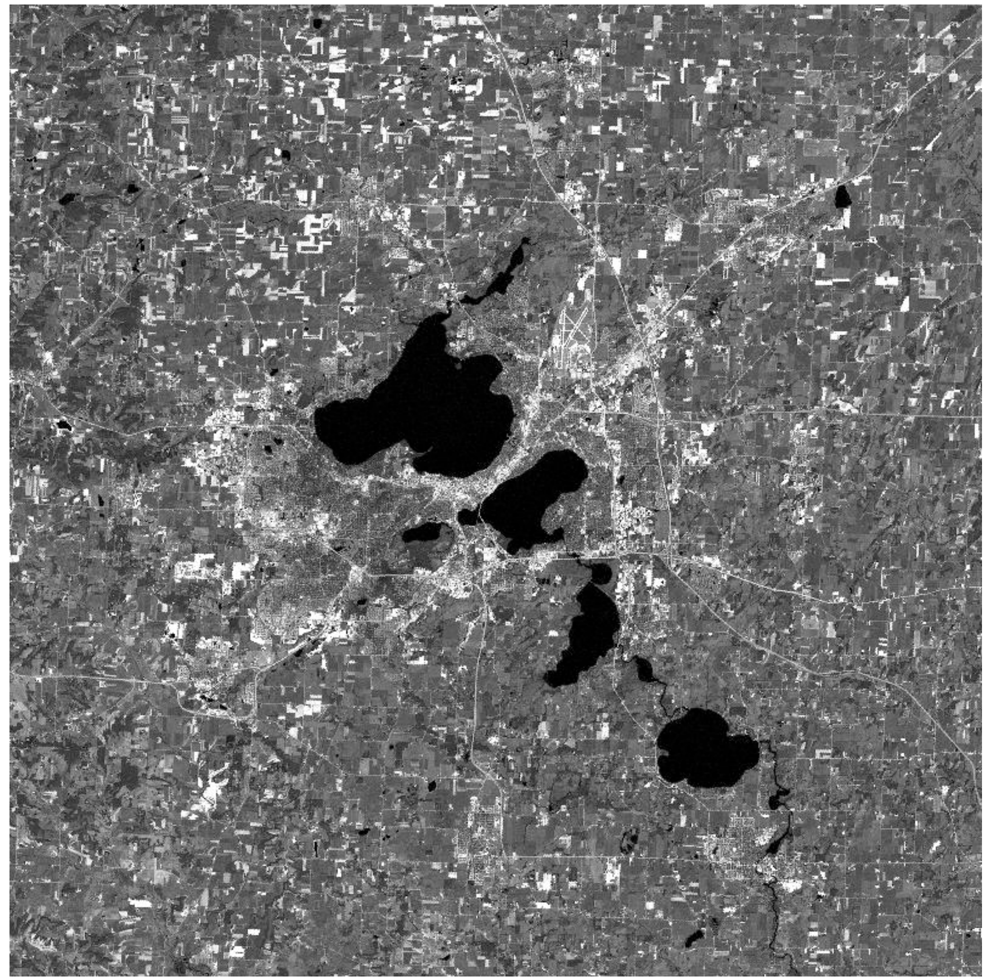
Atmospheric scattering in spectral regions



Atmospheric scattering in spectral regions



TM blue band



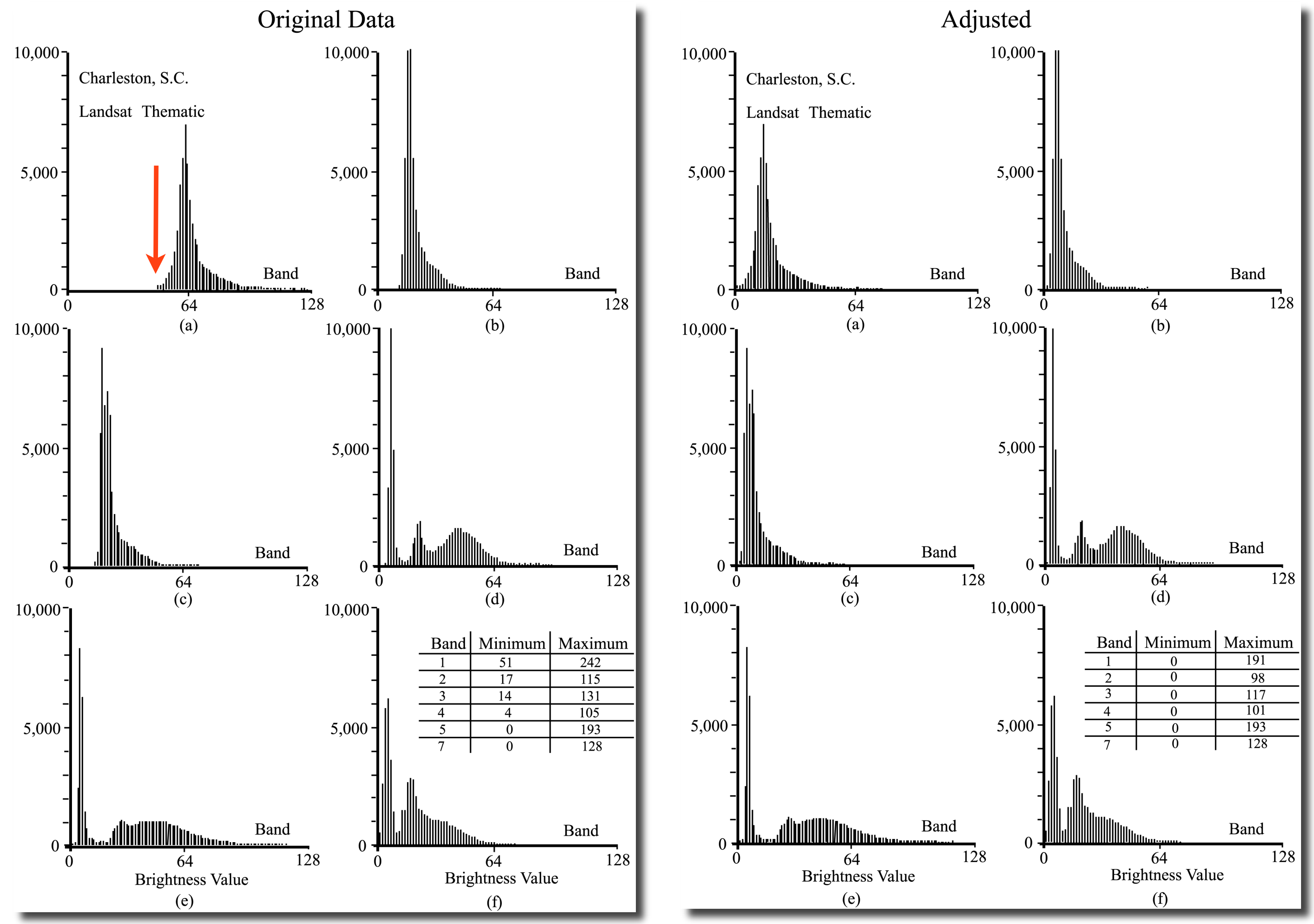
TM MIR band

Single image normalization using histogram adjustment

- The simplest method of relative atmospheric correction is based primarily based on the fact that infrared data (> 0.7 microns or 700 nm) are largely free of atmospheric scattering effects, whereas the visible range (0.4 - 0.7 microns) is strongly influenced by atmospheric scattering
- The method involves evaluating the histogram of various bands of remotely sensed data
- Normally, the data collected in visible region has a higher minimum value because of increased atmospheric scattering

Radiometric normalization

single image normalization using histogram adjustment



Original Data:

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

Adjusted:

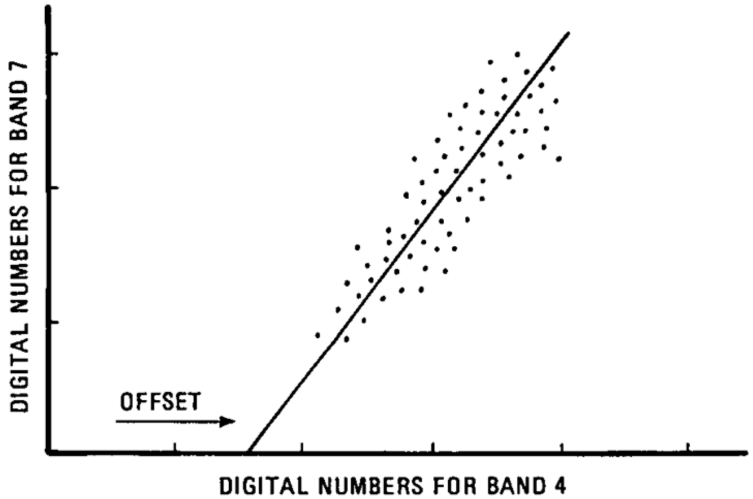
Band	Minimum	Maximum
1	0	191
2	0	98
3	0	117
4	0	101
5	0	193
7	0	128

Jensen, 2004

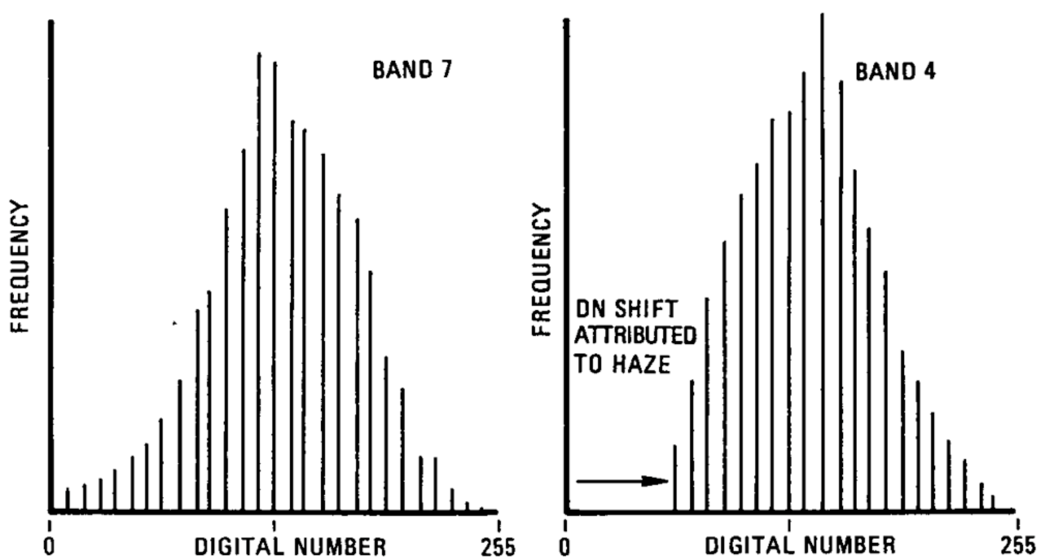
Single image normalization using histogram adjustment

- But in the NIR region, the atmospheric scattering is nearly zero, so the histogram minimums are close to zero (i.e. have true reflectance of zero)
- Of course this only applies to situations where a "dark object" exists with respect to NIR radiation (such as water)
- If the the visible band histograms are shifted to the left so that the values near zero appear in the data, the effects of atmospheric scattering will be somewhat minimized

single image normalization using histogram adjustment



A. PLOT OF BAND 7 VERSUS BAND 4 FOR AN AREA WITHIN THE IMAGE THAT HAS SHADOWS. OFFSET OF THE LINE OF LEAST–SQUARES FIT ALONG THE BAND 4 AXIS IS ATTRIBUTED TO ATMOSPHERIC SCATTERING IN THAT BAND.



B. HISTOGRAMS FOR BANDS 7 AND 4. THE LACK OF LOW DN'S ON BAND 4 IS CAUSED BY ILLUMINATION FROM LIGHT SCATTERED BY THE ATMOSPHERE (HAZE).

NOTE

Does not account for atmospheric absorption!!

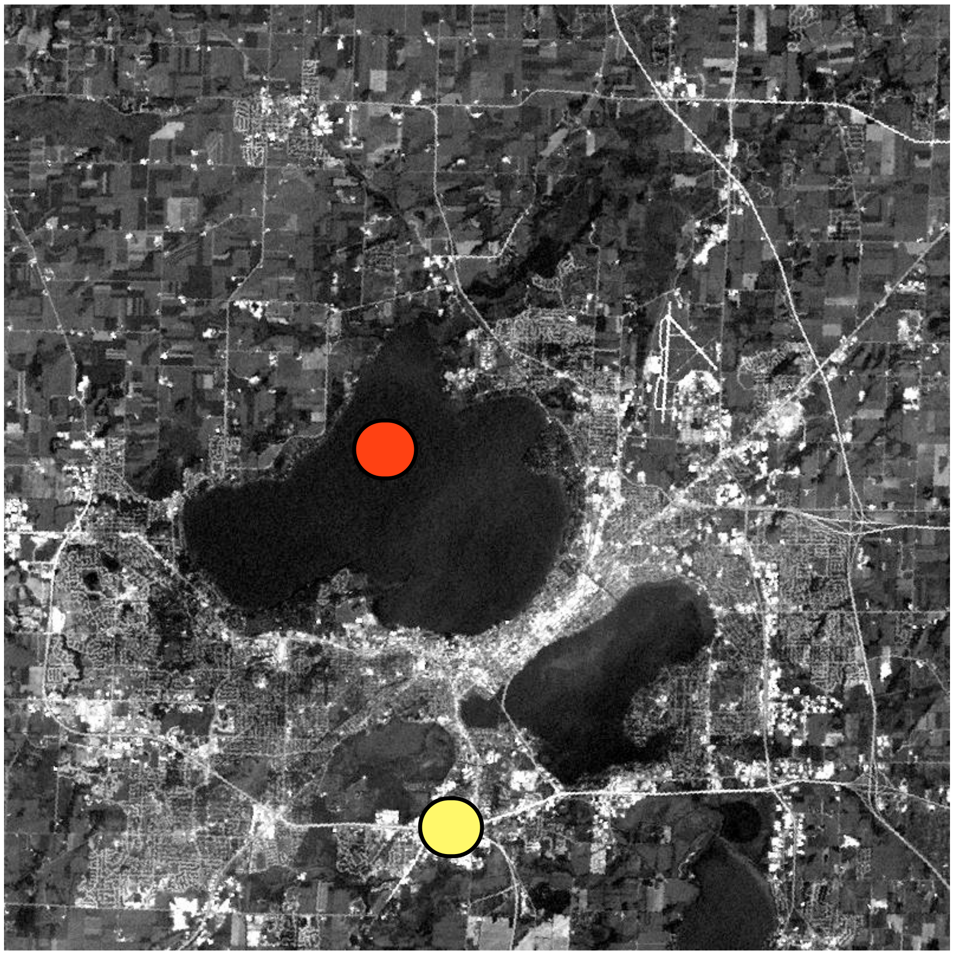
Radiometric correction using regression

- involves selecting a base (reference) image and then transforming the spectral characteristics of all other (subject) images obtained at different dates to have the approximately the same radiometric scale as this base (reference) image
- need to select pseudo-invariant features (PIFs) or radiometric ground control points
- obtain a regression equation using values from the PIFs and then apply it to the subject images

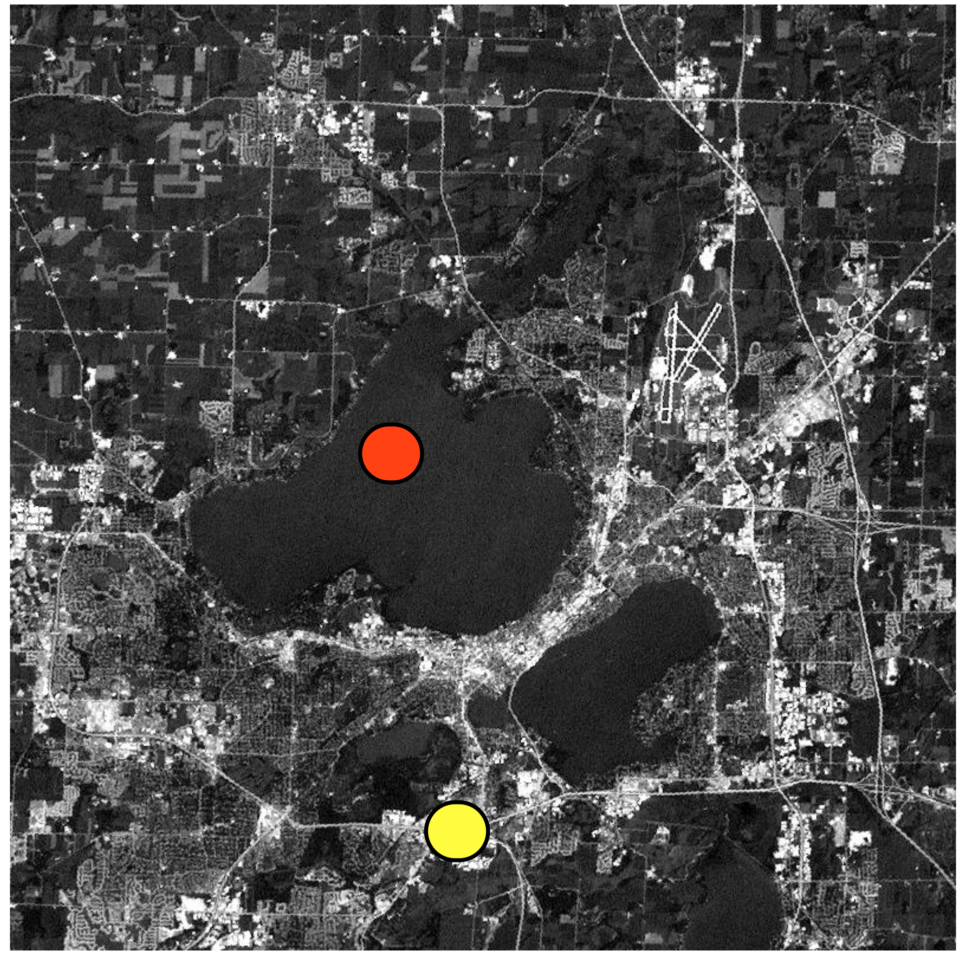
Characteristics of PIFs

- the PIFs should change very little across time, although some change is inevitable - deep non-turbid reservoirs (not coastal areas), bare soil, large rooftops, and other homogeneous areas are good candidates
- the PIFs should be obtained from the same elevation as other objects in the scene (image)
- the PIFs should contain minimal amounts of vegetation - vegetation spectral response changes over time - extremely stable homogeneous canopies are acceptable

Radiometric correction using regression



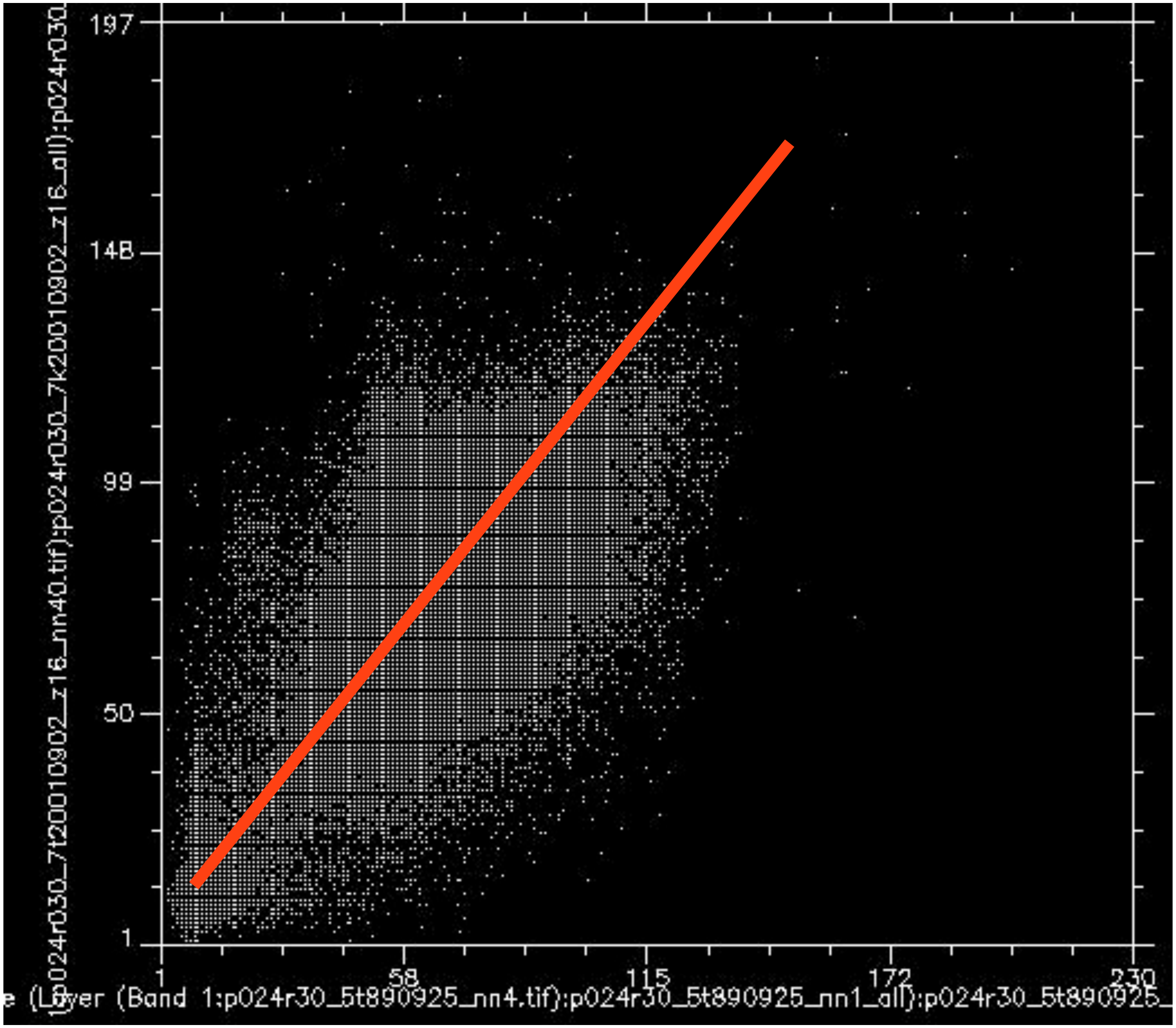
date 1 (red)



date 2 (red)

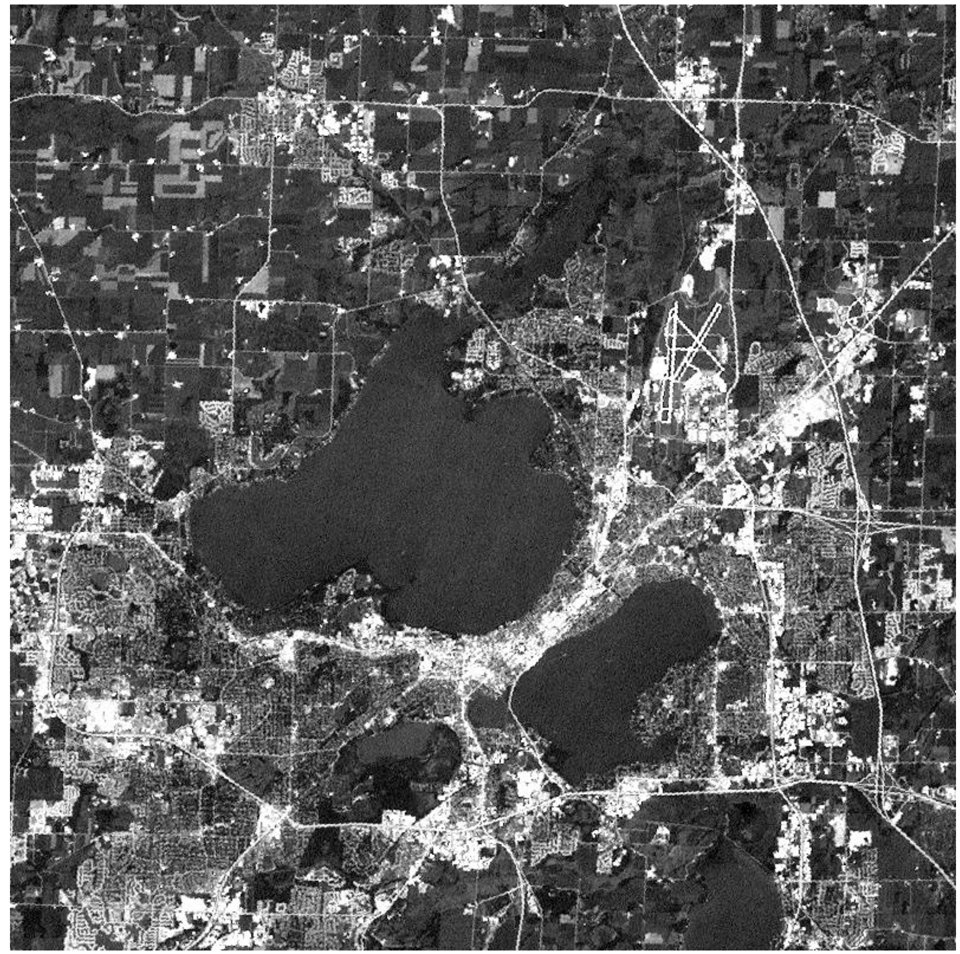
Radiometric correction using regression

date 2 (red)



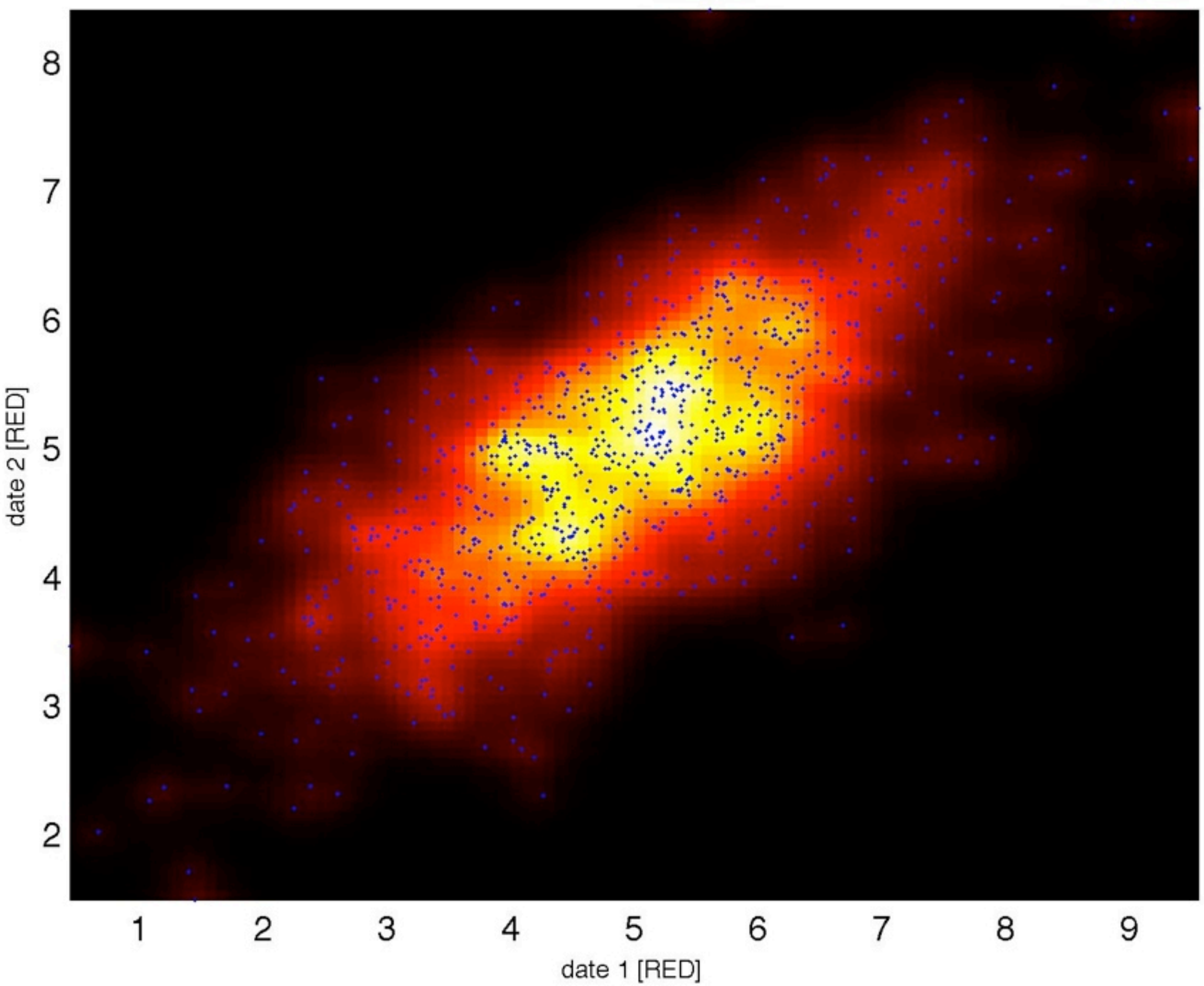
date 1 (red)

date 1 (red)



date 2 (red)-corrected

The ridge method



8
7
6
5
4
3
2
date 2 [RED]
1
2
3
4
5
6
7
8
9
date 1 [RED]

Atmospheric Correction

Relative Correction

(Radiometric normalization)

Correction is performed relative to other (reference) images so that the corrected image is normalized as if it was acquired under same atmospheric, sensor, topographic conditions.

Absolute Correction

Requires (hard-to-obtain) information on atmospheric conditions at the time of image acquisition. The results are in absolute surface reflectance units.

Image-based Methods

RT-based methods

Atmospheric correction

- Absolute atmospheric correction requires information on atmospheric properties and a method to remove those interactions using either simple (image based) or a complex radiometric transfer code.
- The choice of method depends on availability of data, resources, tools, and expertise
- The desired end result is application dependent
- More involved methods require detailed sensor spectral profile and information on atmospheric properties at the time of image acquisition but this information is rarely available

Absolute Atmospheric Correction

- Image based methods
  - Use the information available in the image itself to extract atmospheric parameters and then use this information to correct the image
- Radiative transfer based methods
  - Use the information about the atmosphere within a radiative transfer model which simulates solar radiation interaction with atmospheric particles
- Hybrid approaches
  - Use the combination of two approaches

Absolute atmospheric correction

- Image-based correction
  - Empirical line calibration
  - DOS (Dark Object Subtraction)
- Hybrid methods
  - DDV (Dark Dense Vegetation)
- Radiative Transfer Model based correction
  - 6S (Second Simulation of the Satellite Signal in the Solar Spectrum)
  - Lowtran (LOW resolution atmospheric TRANsmittence)
  - MODTRAN (MODerate resolution atmospheric TRANsmittence)
  - Streamer (UW-Madison!)

Image-based methods

- easy to implement - image (and some external data) is all you need
- the idea is that some or all of the atmospheric parameters can be obtained from the image itself
- simplified assumption about atmospheric absorption and transmittance of radiation
- often based on dark targets for haze correction - only scattering is corrected in a bulk approach
- successfully applied to many environments

Empirical line calibration

- It is a simple method based on regression (i.e. the empirical line) which forces to image data to match in situ or other atmospherically corrected image based spectral reflectance measurements
- the analyst selects two or more areas in the image with different albedos (bright sand, dark water)
- then, in-situ (or other image data) spectral reflectance measurements are made over the same targets and a regression line is computed from the two datasets
- If in-situ spectra is not available, it is possible to use established libraries of reflectance properties of different objects but these materials must exist in the image

Field crew taking a spectroradiometer measurement from a calibrated reflectance standard on the tripod. b) 8 x 8 m black and white calibration targets at the Savannah River Site

Jensen, 2004

DOS - Dark Object Subtraction

- It is perhaps the simplest yet most widely used image-based absolute atmospheric correction approach (Chavez, 1989).
- Based on the assumption that some pixels in the scene (image) are in complete shadow and their radiances received at the satellite are due to atmospheric scattering
- Also assumes that very few pixels (targets) are completely dark so 1% [0.01] reflectance is assumed instead of 0% [completely dark].

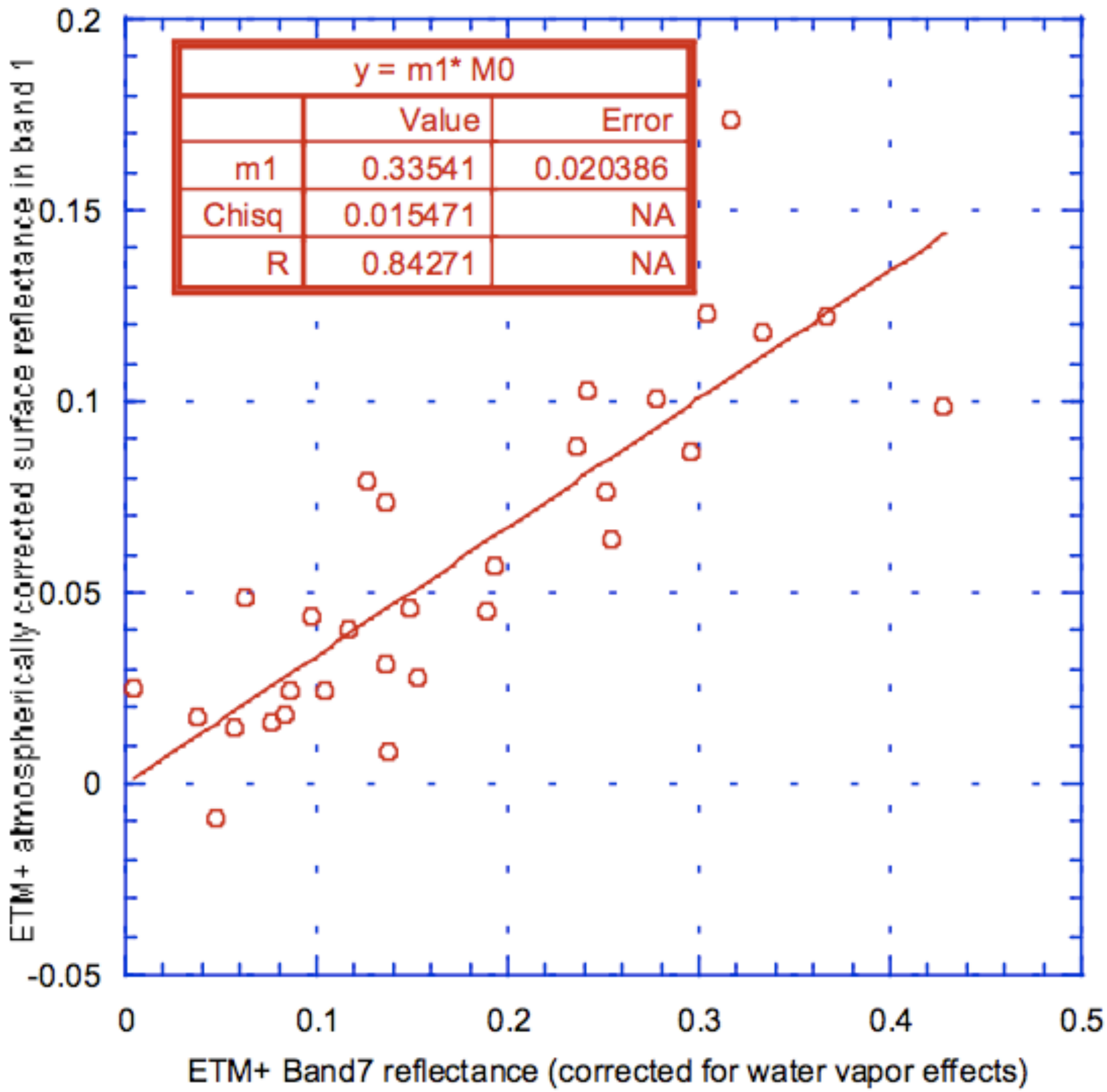
Radiative Transfer Models

- Models that calculate radiative transfer of electromagnetic radiation through the Earth's atmosphere and radiation interaction with atmospheric particles
- They are often used in numerical weather prediction and climate models
- They require information about atmospheric particles at the time of image acquisition and in absence of this information, they use standard profiles
- In remote sensing, they are used to estimate the contribution of atmospheric radiance to the radiance observed by the sensors using inversion and subtract this amount from the satellite signal

Hybrid methods

- DDV - Dark Dense Vegetation postulates a linear relationship between shortwave IR (2.2 microns) surface reflectance (unaffected by the atmosphere) and surface reflectance in the blue (0.4 microns) and red (0.6 microns) bands
- using this relation, surface reflectance for the visible bands are calculated and then compared to TOA reflectance to estimate Aerosol Optical Depth (AOD) using a radiative transfer code
- assumes dark vegetation exists in the scene and is identified by NDVI > 0.1 and SWIR(ref) < 0.05

DDV - Dark Dense Vegetation



MDDV - Dark Dense Vegetation (LEDAPS)

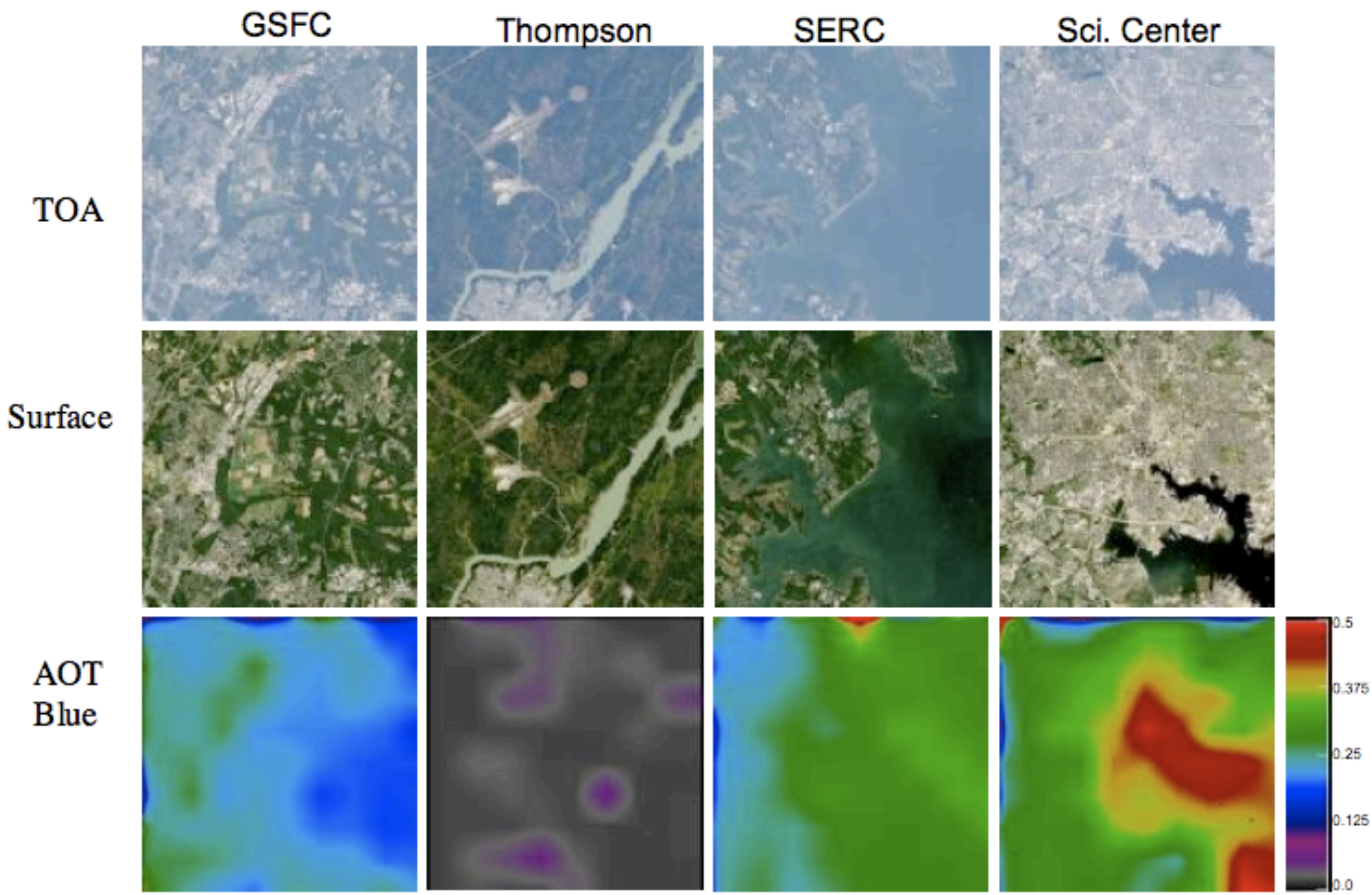


Figure 4: TOA reflectance, atmospherically corrected surface reflectance, and AOT (blue wavelengths) for the AERONET sites used in the study.

Image Classification

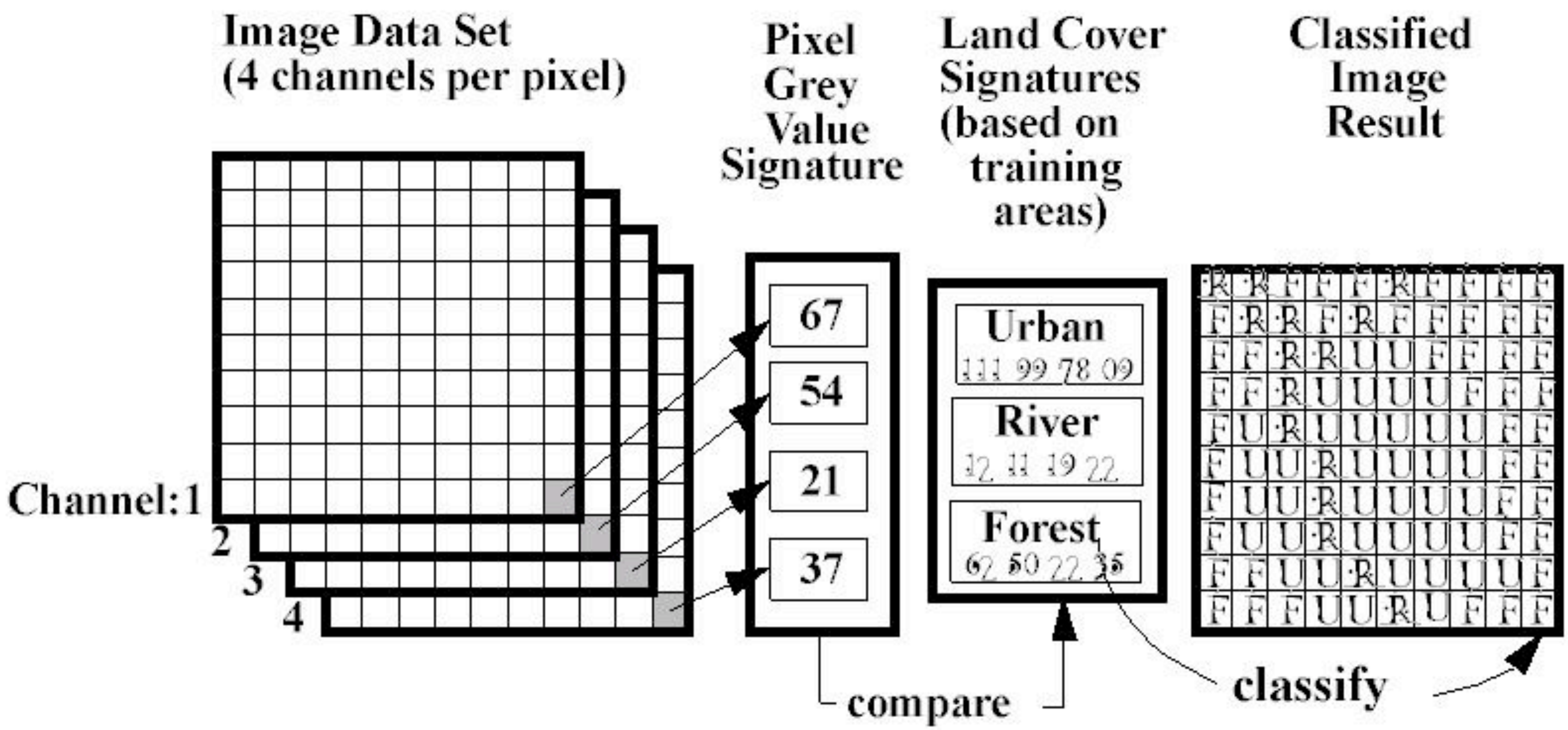
What is classification?

- thematic information extraction
- pattern recognition
- grouping of like-value measurements (pixels)
- image categorization

What is classification?

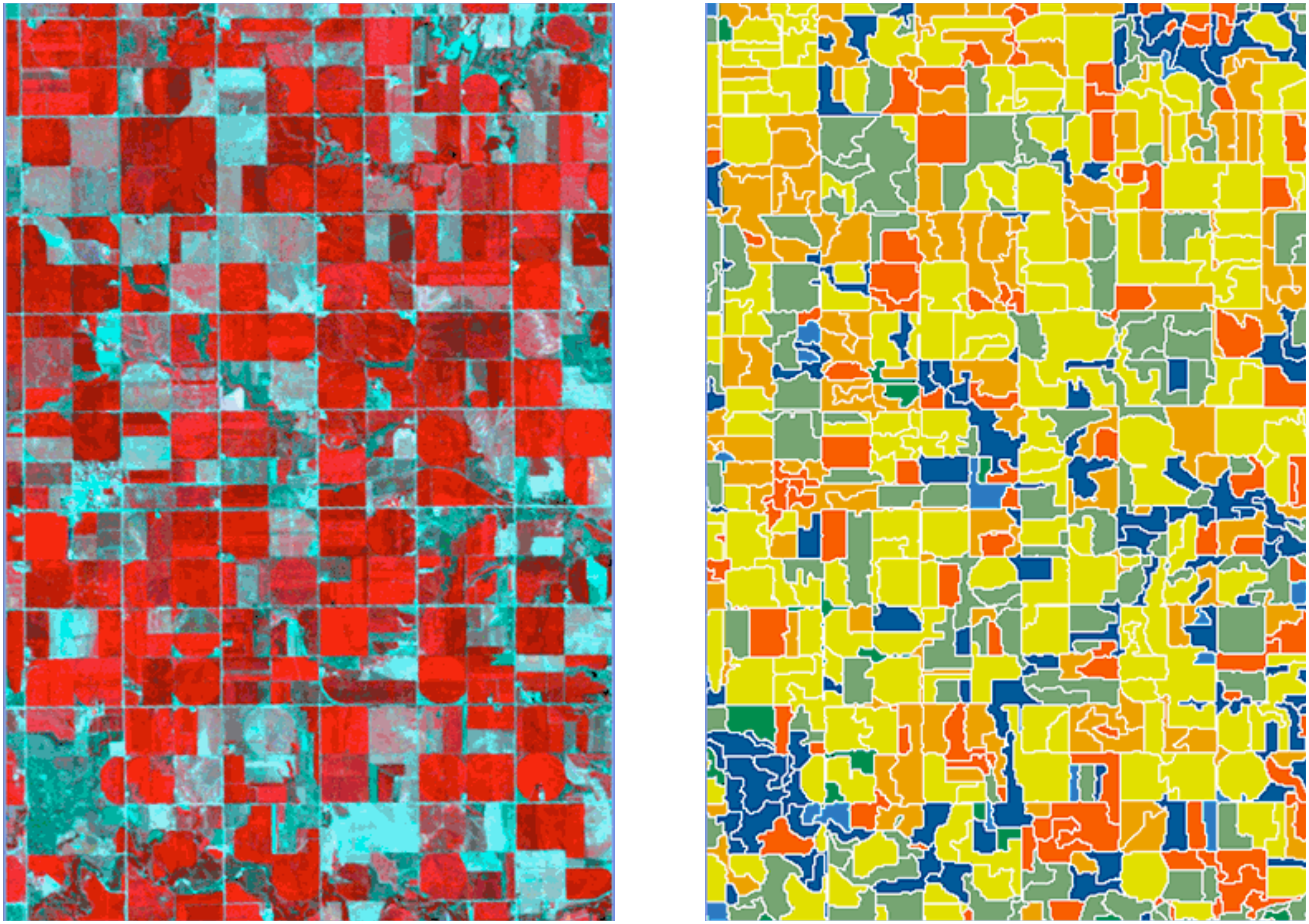
- The intent of the classification process is to categorize all pixels in a digital image into one of several land cover classes, or "themes".
- In remote sensing, multispectral (or multi-anything) data are used to perform the classification and it is this multi-variate pattern present within the data for each pixel is used as the numerical basis for categorization
- The objective of image classification is to identify and portray, as a unique gray level (or color), the features occurring in an image in terms of the object or type of land cover these features actually represent on the ground.

What is classification?



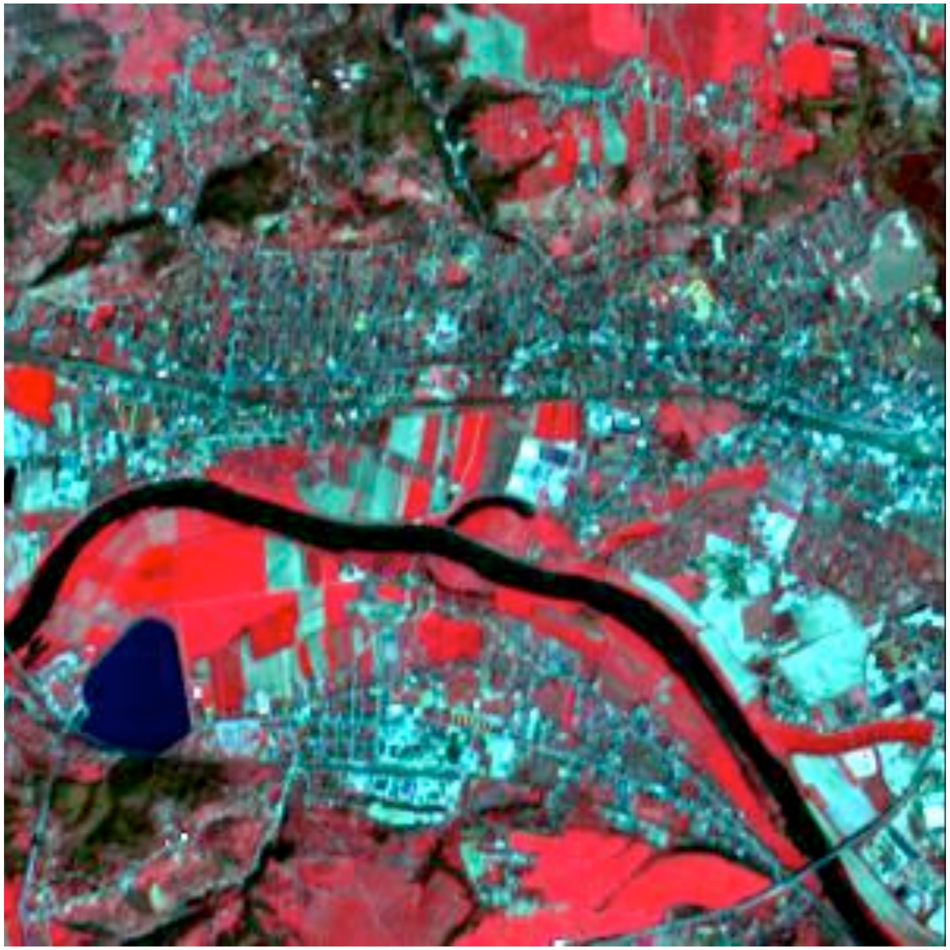
http://www.sc.chula.ac.th/courseware/2309507/Lecture/remote18.htm

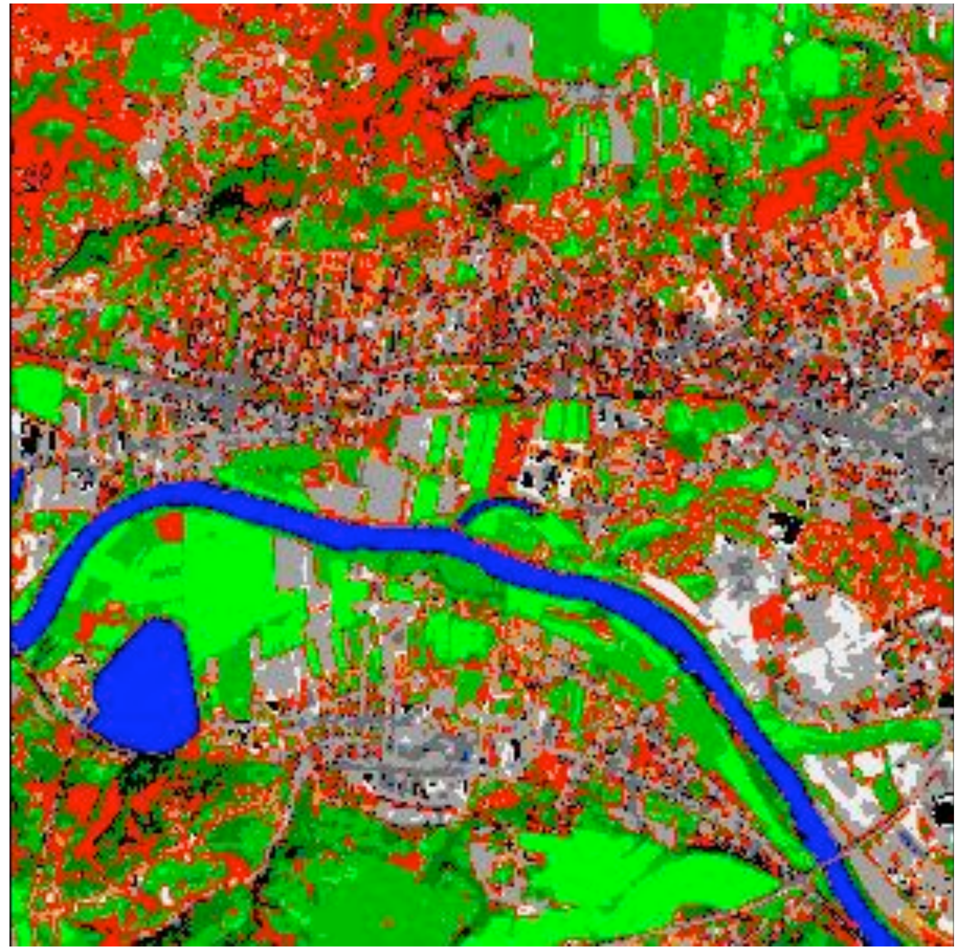
local scale



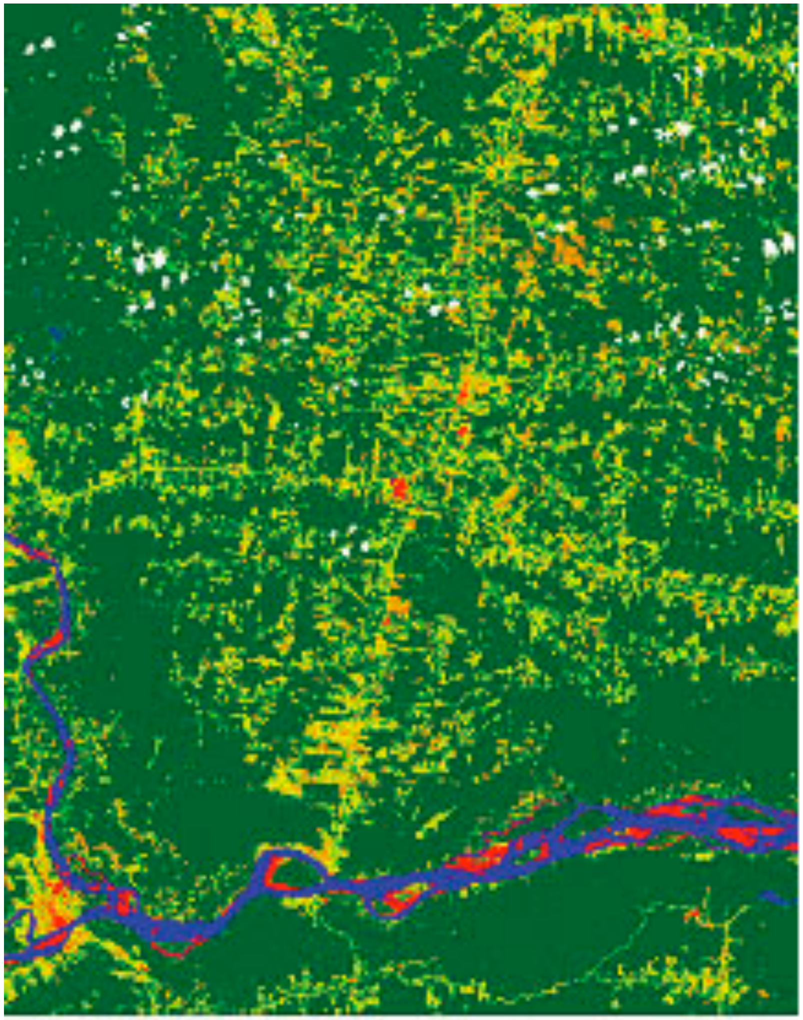
Iowa, 2006

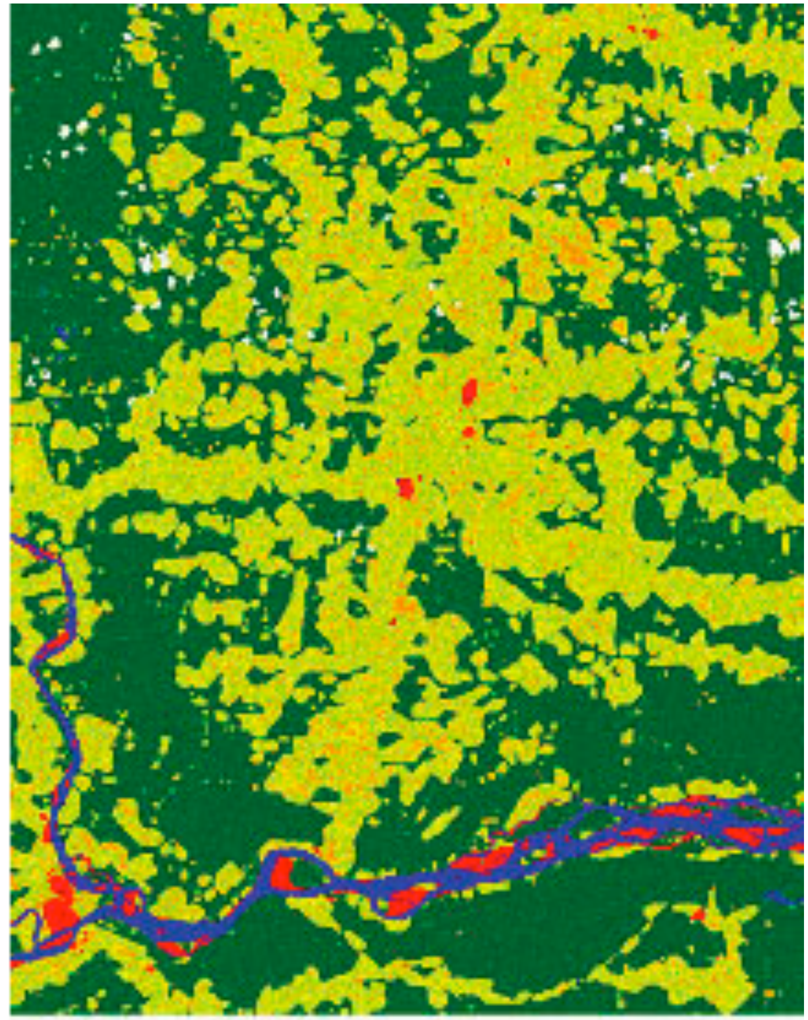
regional scale





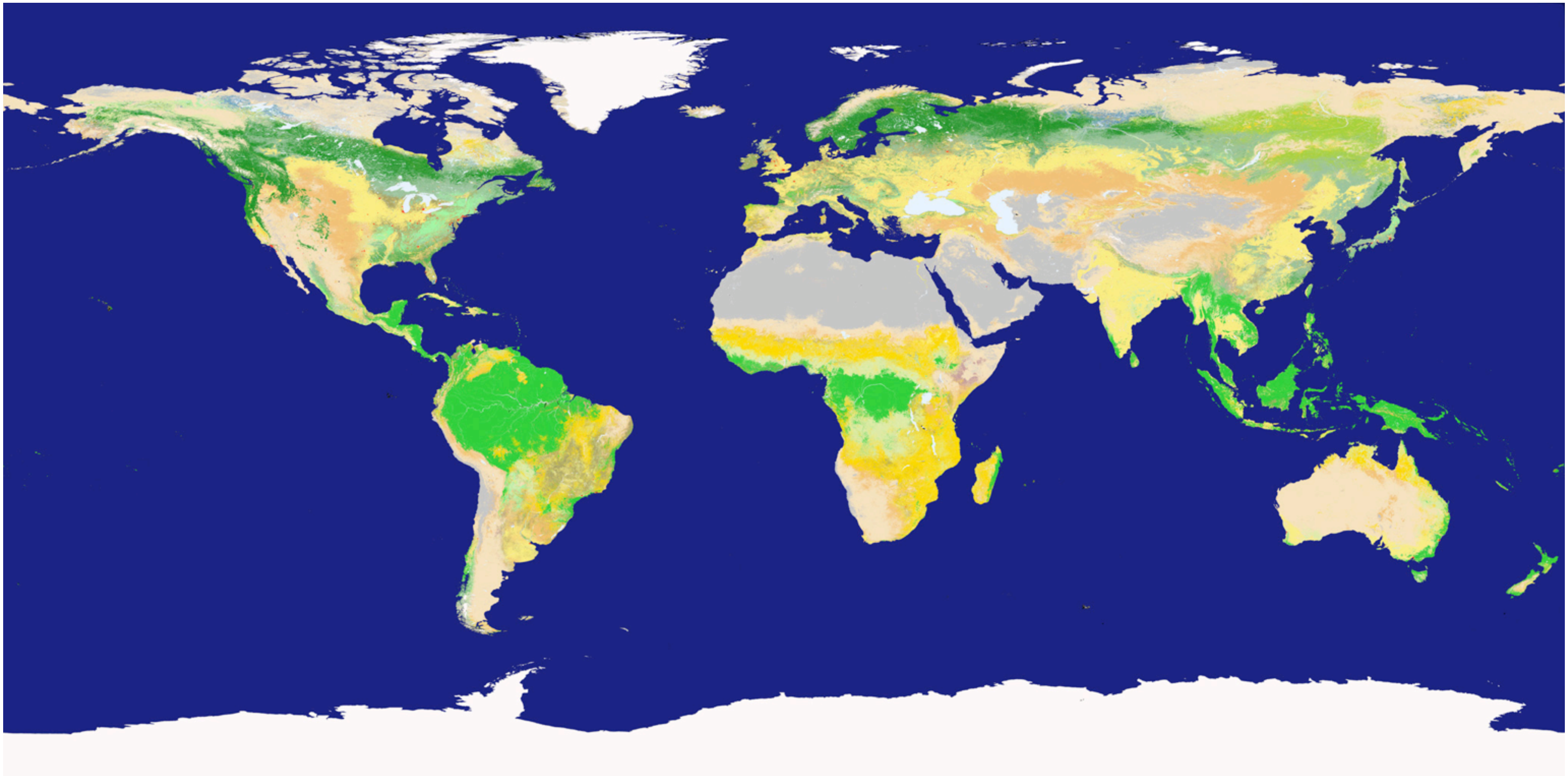
regional scale





Peruvian Amazon

global scale



MODIS land-cover map (2001)

Spatial scales and inputs

- Across these spatial scales, the methods are similar, exploiting the most useful information in an image (or a series of images)
- What is different however is the type of inputs that go into the classification algorithm
- At local scales, it is the spatial information that matters the most (and we have less spectral/ temporal information)
- At global scales, it is the temporal information most useful for accurate land-cover classifications

Categorization of classification methods

- Classification may be performed using the following methods:
  - algorithms based on supervised or unsupervised classification logic;
  - algorithms based on parametric or non-parametric statistics and non-metric methods;
  - the use of hard or soft (fuzzy) set classification logic to create hard or soft labels;
  - the use of per-pixel or object-oriented classification logic, and
  - hybrid approaches

unsupervised vs. supervised

- In a *supervised classification*, the identity and location of the land-cover types (e.g., urban, agriculture, or wetland) are known a priori and the analyst attempts to locate specific sites in the remotely sensed data that represent homogeneous examples of these known land-cover types known as *training sites* because they are used to train the classification algorithm for eventual land-cover mapping of the remainder of the image.

- In an *unsupervised classification*, the identities of land-cover types to be specified as classes within a scene are not generally known *a priori* and the computer is required to group pixels with similar spectral characteristics into unique clusters according to some statistically determined criteria. The analyst then re-labels and combines the spectral clusters into information classes.

parametric vs. non-parametric

- *Parametric* methods assume certain distributional properties in remote sensor data and knowledge about the forms of the underlying class density functions
- *Non-parametric* methods may be applied to remote sensor data with any histogram distribution without the assumption that the forms of the underlying densities are known.
- *Non-metric* methods such as rule-based decision tree classifiers can operate on both real-valued data (e.g., reflectance values from 0 to 100%) and nominal scaled data (e.g., class 1 = forest; class 2 = agriculture).

hard vs. soft (fuzzy)

- Supervised and unsupervised classification algorithms typically use *hard classification* logic to produce a classified map that consists of hard, discrete categories (e.g., forest, agriculture,water).

- Conversely, it is also possible to use *fuzzy set classification* logic, which takes into account the heterogeneous and imprecise nature of the real world. Here, the classes are more imprecise and can have a gradient of labels (e.g., 60% forest, 40% ag)

per-pixel vs. object oriented

- In the past, most digital image classification was based on processing the entire scene pixel by pixel. This is commonly referred to as *per-pixel classification*.
- *Object-oriented classification* techniques allow the analyst to decompose the scene into many relatively homogenous image objects (referred to as patches or segments) that are bigger than individual pixels using an image segmentation process. The various statistical characteristics of these homogeneous image objects in the scene are then subjected to traditional statistical or fuzzy logic classification. Object-oriented classification based on image segmentation is often used for the analysis of high-spatial-resolution imagery.

Image classification process

define the problem

select class labels

acquire data

process data to extract thematic information

perform accuracy assessment

distribute results

defining the problem

- What is thematic information you wish to extract?
- What are the categories you need?
- What is the desired extent and temporal frequency?
- What is the desired accuracy?
- What are your resources?

selecting class labels

- What are the categories you need?
- How detailed should they be?
- Do you have the information in satellite data to extract your desired labels?
- What scheme to use?
- What are your resources?

Classification schemes (i.e. class labels)

- All class labels of interest must be selected and defined carefully to classify remotely sensed data successfully into land-cover information.
- This requires the use of a *classification scheme* containing *taxonomically* correct definitions of classes of information that are organized according to logical criteria. If a hard classification is to be performed, then the classes in the classification system should normally be:
  - *mutually exclusive*
  - *exhaustive*, and
  - *hierarchical*.

Jensen, 2005

Existing classification schemes

- Certain hard classification schemes can readily incorporate land-use and/or land-cover data obtained by interpreting remotely sensed data, including the:

American Planning Association Land-Based Classification System which is oriented toward detailed land-use classification;

United States Geological Survey Land-Use/Land-Cover Classification System for Use with Remote Sensor Data and its adaptation for the U.S. National Land Cover

Dataset and the NOAA Coastal Change Analysis Program (C-CAP);

U.S. Department of the Interior Fish & Wildlife Service Classification of Wetlands and Deepwater Habitats of the United States;

U.S. National Vegetation and Classification System;

International Geosphere-Biosphere Program IGBP Land Cover Classification System modified for the creation of MODIS land-cover products

LCCS - Land Cover Classification System - UN FAO European effort

acquire data

- Is the data available? i.e. is it collected? Who collected it? Where is it?
- How do data sets relate to your problem - e.g. do you have the spatial/spectral/temporal/angular data requirements to extract the labels you require?
- What are the spatial/spectral/temporal/angular characteristics?
- How much does it cost?
- Do you have the tools to read/view/edit this data?

process data to extract thematic information

- Which methods to use?
- How much do you know about your study site - a lot (supervised) - not so much (unsupervised - or exploratory analysis)
- If supervised, where does your training data come from? You generate it. You get it from somewhere.
- If unsupervised, how many spectral classes? How much variability in the landscape?
- Any ancillary information?

accuracy assessment

- Which methods to use?
- Where will the “truth” data come from? From you on the ground, from an ancillary data, from other people, from another map?
- What is the expected accuracy?
- What is the desired accuracy?
- What are your resources?

distribute results

- Map vs. area estimates? (are they the same?)
- Who is the audience? Technical person - include most information; End-user - provide the most important information
- What format (data type, data size?)
- Is the map registered to Earth coordinates to be used within a GIS?
- What is the accuracy of the map (or the product) you are delivering? If your audience don't ask, you do!

unsupervised vs. supervised

- In a ***supervised classification***, the identity and location of the land-cover types (e.g., urban, agriculture, or wetland) are known a priori and the analyst attempts to locate specific sites in the remotely sensed data that represent homogeneous examples of these known land-cover types known as *training sites* because they are used to train the classification algorithm for eventual land-cover mapping of the remainder of the image.

- In an ***unsupervised classification***, the identities of land-cover types to be specified as classes within a scene are not generally known *a priori* and the computer is required to group pixels with similar spectral characteristics into unique clusters according to some statistically determined criteria. The analyst then re-labels and combines the spectral clusters into information classes.

Unsupervised classification

- Unsupervised classification (commonly referred to as *clustering*) is an effective method of partitioning remote sensor image data in multispectral feature space and extracting land-cover information. Compared to supervised classification, unsupervised classification normally requires only a minimal amount of initial input from the analyst. This is because clustering does not normally require training data.

Jensen, 2005

Common questions

- *How many spectral classes should I use?* The rule of thumb is to have 10 spectral classes per land-cover class of interest. This often captures enough variability in any given image
- *Which method should I use?* Tests show that many of the clustering algorithms function more or less the same way and the results are more dependent on available information in the image to separate land cover classes than the choice of the algorithm.
- *What would I do if spectral classes don't capture my land-cover classes?* Isolate those that worked, masked them out, then re-cluster, this time paying attention to more difficult classes.
- *Can I merge supervised classification results with unsupervised approaches?* Of course you can through masks

unsupervised vs. supervised

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Training site selection

- There are a number of ways to collect the *training site* data, including:

collection of *in situ* information such as tree type, height, percent canopy closure, and diameter-at-breast-height (dbh) measurements,

on-screen selection of polygonal training data, and/or

on-screen seeding of training data.

Jensen, 2004

Characteristics of training data

- All training data must be mutually exclusive i.e. must represent separate classes although a number of training sites may represent a single class.
- It is better to define more classes of interest than the required number of land-cover classes for the final map as merging of classes is much easier than disaggregating
- Often, homogeneous locations (easy examples) are chosen to define training sites but there is value in randomization as well
- The goal is to capture as much variability of a class within a training data set without overburdening the the classification algorithm

Jensen, 2004

loose ends

Classification and <u>spatial</u> scale

- There is a relationship between the level of detail in a classification scheme and the spatial resolution of remote sensor systems used to provide information.
- This suggests that the level of detail in the desired classification system dictates the spatial resolution of the remote sensor data that should be used.
- Of course, the spectral resolution of the remote sensing system is also an important consideration

Resolution effects on image classification

- In H type images, classification accuracy would be low due to <u>within class</u> variability

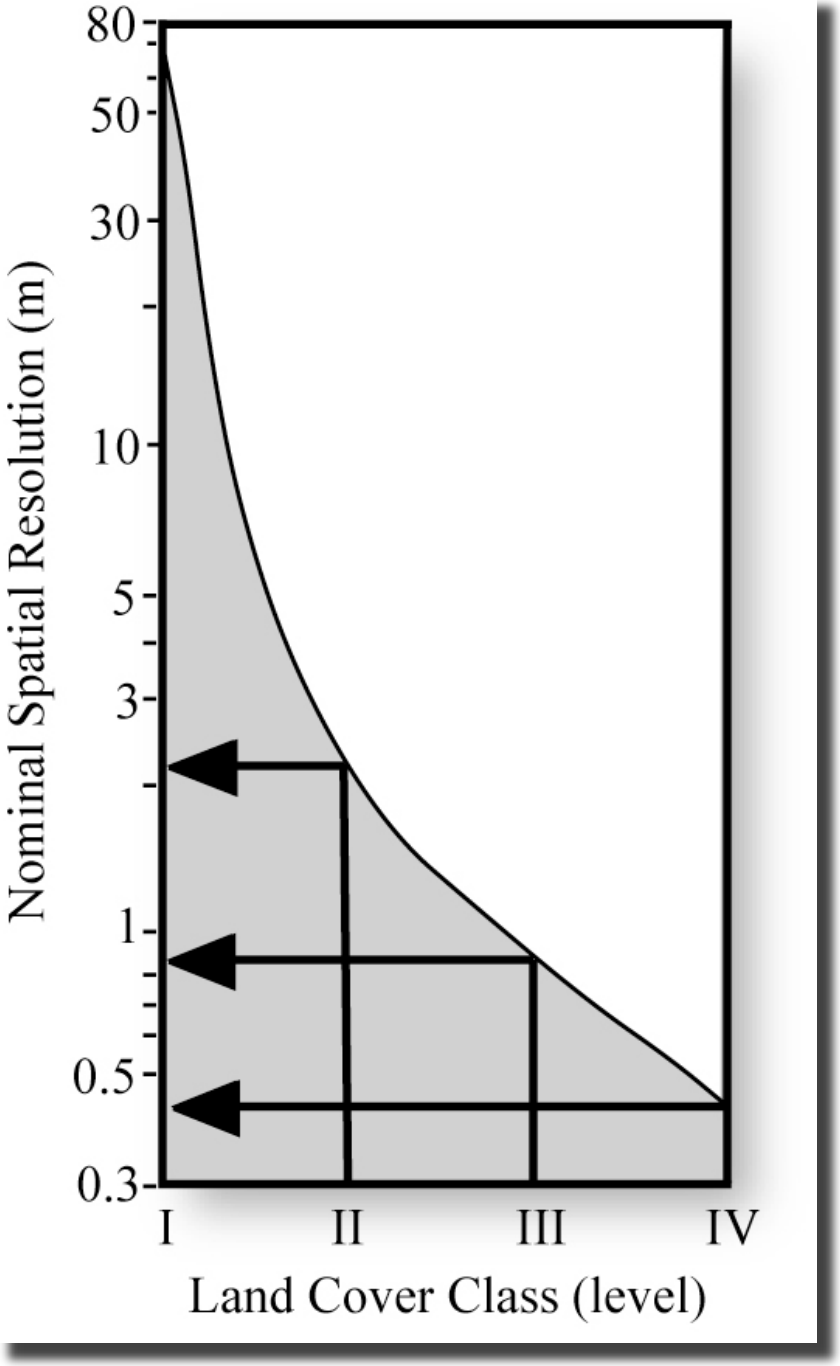
- In L type images, classification accuracy would be low due to <u>between class</u> variability

- There is always an <u>optimum</u> resolution for the map of interest

- But, you may not have data at that optimum resolution

Classification and categorical scale

- In contrast, there is an inverse relationship between the level of categorical detail and accuracy of the classification
- higher categorical detail (i.e. large number of classes) often leads to less accuracy to extract increased number of classes (categories) while lower categorical detail (i.e. fewer number of classes)
- e.g. a map with only deciduous vs. evergreen forest labels is generally more accurate (and is easier to make) than a map that attempts to distinguish evergreen tree species



Nominal spatial resolution requirements as a function of the mapping requirements for Levels I to IV land-cover classes in the United States (based on Anderson et al., 1976). Note the dramatic increase in spatial resolution required to map Level II classes.

Jensen, 2005

land-cover vs. land-use

- *Land cover* refers to the type of material present on the landscape (e.g., water, sand, crops, forest, wetland, human-made materials such as asphalt). Remote sensing image classification always produces a land-cover

- *Land use* refers to what people do on the land surface (e.g., agriculture, commerce, settlement). It is the use of land-cover and must be interpreted from land-cover made from remote sensing

Accuracy Assessment

Accuracy assessment

- Why?
  - We want to assess the accuracy and test our hypothesis
  - Create an objective means of map comparison
  - Correct area estimates
- How?
  - Extract known samples and test against predictions using a confusion a matrix

Accuracy assessment

- When a map is made from remotely sensed data using a classification algorithm, that map is considered to be only a hypothesis
- As with other hypothesis-based problems, the hypothesis has to be tested with data
- Testing is done by extracting samples from your map, compare these samples to a known reference and simply keep track of how many are correct
- Then accuracy can be reported using a variety of metrics based on a degree of confidence can be attached to classification results

How do you collect reference data?

- Back-classification of training data
- Cross-validation
- Independent non-random samples
- Independent random samples
- Independent stratified random samples

Which sampling design?

Common questions in accuracy assessment

- What is the sample?
- Which method to use to assess accuracy?
- What is my metric to measure accuracy?
- What is spatial autocorrelation?
- What is a good accuracy?

What is a sample?

- A sample is a subset of a population

- In general, the population is very large, making a census of all the values in the population impractical or impossible

- The sample represents a subset of manageable size. Samples are collected and statistics are calculated from the samples so that one can make inferences or extrapolations from the sample to the population

- This process of collecting information from a sample is referred to as sampling

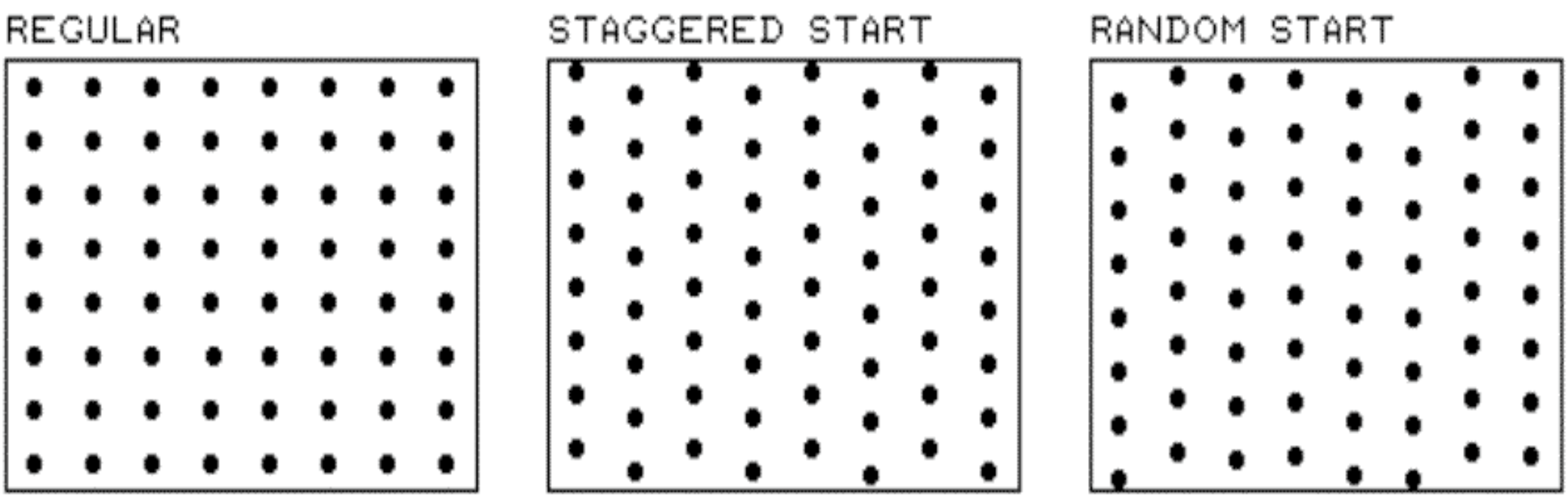
Wikipedia

Sampling Design

- systematic
- cluster
- simple random
- stratified random

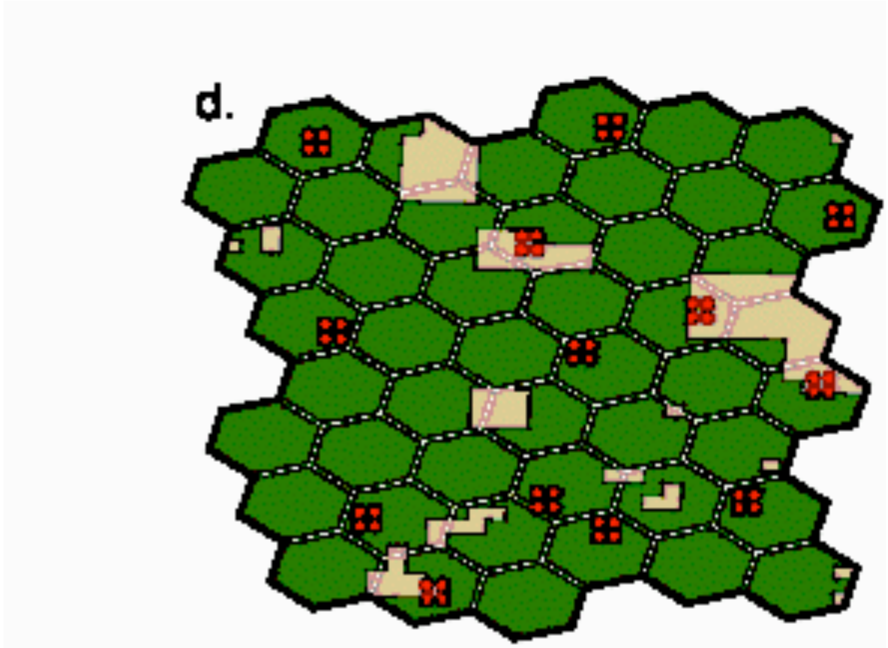
Systematic Sample

Systematic sampling is a statistical method involving the selection of elements from an ordered sampling frame. The most common form of systematic sampling is an equal-probability method, in which every kth element in the frame is selected



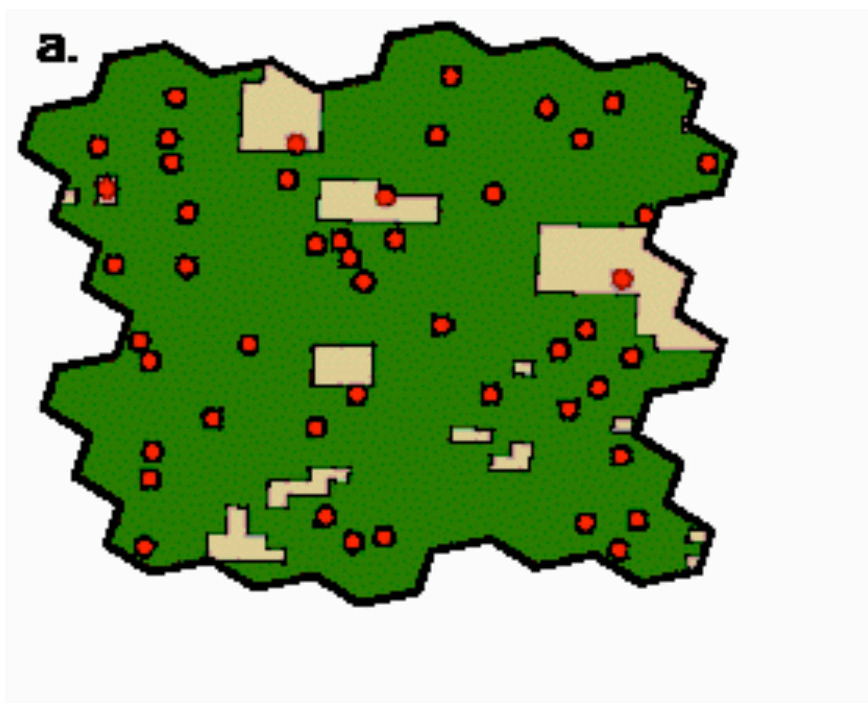
Cluster Sampling

Cluster sampling is a sampling technique used when "natural" groupings are evident in population. The total population is divided into these groups and a sample of the groups is selected. The method works best when most of the variation in the population is within the groups, not between them



Simple Random Sampling

Each sample is chosen randomly and entirely by chance, such that each individual in the sample has the same probability of being chosen at any stage during the sampling process.



Stratified Random Sampling

When sub-populations vary considerably, it is advantageous to sample each subpopulation (stratum) independently. Stratification is the process of grouping members of the population into relatively homogeneous subgroups before sampling. Then random or systematic sampling is applied within each stratum.

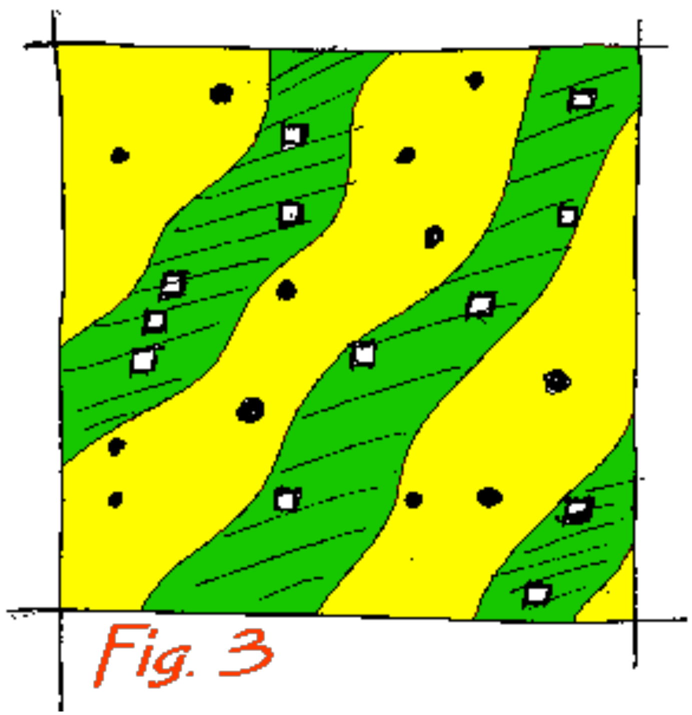


Fig. 3

Sample Size

Sample size ultimately depends on a number of factors including:

- Expected accuracy
- Desired accuracy
- Desired level of confidence interval
- ultimately resources available

Proportional Allocation

- Proportional Allocation: the sample size of each stratum is proportionate to the population size of the stratum. Strata sample sizes are determined by the following equation:
- ns = (Ns/Np)*np
- ns is stratum sample size
- Ns is stratum population size
- Np is total population size
- np = total sample population size

Sample Size

- a good rule of thumb:
- 50 samples per class
- if number of classes is high (>12), 75-100 samples per class
- homogeneous classes - fewer samples

Confusion Matrix
(Error matrix)

- Once a sample is selected from the population, and checked against a reference data set, the percentage of pixels from each class in the image labeled correctly by the classifier can be estimated
- Along with these percentages, the proportions of pixels from each class erroneously labeled into every other class can also be estimated
- The tool that expresses these results in a tabular form is called the confusion or error matrix

Accuracy assessment

calculating an error matrix:

truth data

classified map

	Corn	Soybeans	Forest	Other	
Corn	25	5	10	3	43
Soybeans	2	50	6	5	63
Forest	3	4	60	5	72
Other	2	2	2	100	106
Total	32	61	78	113	284

Accuracy assessment

truth data

classified map

	Corn	Soybeans	Forest	Other	
Corn	25	5	10	3	43
Soybeans	2	50	6	5	63
Forest	3	4	60	5	72
Other	2	2	2	100	106
Total	32	61	78	113	284

Add diagonals

235 correct

235/284 = 0.82 overall map accuracy

Which is better?

high **user's** or

high **producer's** accuracy?

- depends on your ultimate use

- example:

aerial tree

spraying program

option #1

- need to spray

only decidous trees

- **cannot damage coniferous!**

- higher **user's accuracy** is good –

if it says deciduous on the map, it *is* likely deciduous

Which is better?

high **user's** or

high **producer's** accuracy?

- depends on your ultimate use

- example:

aerial tree

spraying program

option #2

- need to spray deciduous trees and **must get all of them**
- no problem if other trees are sprayed as well
- a higher **producer's accuracy** is good –

we must correctly classify a lot of deciduous trees

Digital Change Detection

What is change detection?

- Extraction of temporal change information from remotely sensed imagery
- Remote sensing only provides the changes in measurements (reflectances) over time
- The purpose of digital change detection is to relate these changes in measurements to changes the nature and character of biophysical - environmental variables
- The main challange of digital change detection is then to separate changes of interest from changes of non-interest
- What are the examples of change detection?

What is change detection?

- The purpose of this list is to illustrate the kinds of changes (think variety) and then determine:
- which instrument (data) to use?
- which method to use?
- which scale of analysis?
    - coarse scale (1km and up)
    - medium scale (30-100 meters)
    - high resolution scale (10 m or less)

Ways to attack change detection problems

- spatial scales (spatial resolution):
  - H - high (1-10 m)
  - M - Medium (20-100 m)
  - C - Coarse (250 m and up)
- time periods over which change is monitored:
  - e - event driven (days to months)
  - a - one to several years
  - d - on the order of decades
- frequency of observations required:
  - d - daily to weekly
  - s - seasonal
  - e - end points

- geographic extent of area to be monitored:
    - l - local
    - r - regional
    - c - continental
    - g - global
- nature of desired information on environmental change:
    - space matters (map needed)? [yes] [no]
    - area estimates of change required? [yes] [no]
    - magnitude of change is important? [yes] [no]
    - categorical vs. continuous outcome? [yes] [no]
- eventual use of data:
    - l - local resource management/planning
    - n - national scale planning
    - g - monitoring global change
    - w - early warning

Examples

- Forest clearing I: studying forest change at local to regional scales (e.g. N. Wisconsin). map and area extent are both important
- Forest clearing II: studying global tropical deforestation for global change questions. No interest in map and location of change. Areal extent of changes are important although the areal estimates may be through map making

The Challenge in change detection is separating:

- the effects of changes unrelated to the surface
- from the effects of changes related to surface

unrelated (undesired) changes across time due to

- sun angle
- clouds/shadows
- snow cover
- phenology
- inter-annual variability (climate)
- atmospheric effects
- sensor calibration
- sensor view angle differences
- the problem of agriculture!

Remote Sensing system considerations

Successful remote sensing change detection requires careful attention to:

- remote sensor system considerations, and
- environmental characteristics.

Failure to understand the impact of the various parameters on the change detection process can lead to inaccurate results. Ideally, the remotely sensed data used to perform change detection is acquired by a remote sensor system that holds the following resolutions constant: temporal, spatial (and look angle), spectral, and radiometric.

Temporal resolution

- Two temporal resolutions should be held constant during change detection:
- First, use a sensor system that acquires data at approximately the same time of day. This eliminates diurnal Sun angle effects that can cause anomalous differences in the reflectance properties of the remote sensor data.
- Second, acquire remote sensor data on anniversary dates, e.g., Feb 1, 2004, and Feb 1, 2006. Anniversary date imagery minimizes the influence of seasonal Sun-angle and plant phenological differences that can negatively impact a change detection project.

Spatial resolution

- Accurate spatial registration of at least two images is essential for digital change detection.
- Ideally, the remotely sensed data are acquired by a sensor system that collects data with the same instantaneous field of view on each date.
- For example, Landsat TM data collected at 30 x 30 m spatial resolution on two dates are relatively easy to register to one another.

Spatial resolution

- Geometric rectification algorithms are used to register the images to a standard map projection
- Rectification should result in the two images having a root mean square error (RMSE) of < 0.5 pixel
- Mis-registration of the two images may result in the identification of spurious areas of change between the datasets.
- For example, just one pixel mis-registration may cause a stable road on the two dates to show up as a new road in the change image.

Spectral resolution

- Ideally, the same sensor system is used to acquire imagery on multiple dates.
- When this is not possible, the analyst should select bands that approximate one another.
- For example, Landsat MSS bands 4 (green), 5 (red), and 7 (near-infrared) and SPOT bands 1 (green), 2 (red), and 3 (near-infrared), can be used successfully with Landsat ETM+ bands 2 (green), 3 (red), and 4 (near-infrared).
- Many change detection algorithms do not function well when the bands in one image do not match those of the other image

Soil moisture

- Ideally, soil moisture conditions should be identical for the N dates of imagery used in a change detection project.
- Extremely wet or dry conditions on one of the dates can cause change detection problems.
- When soil moisture differences between dates are significant for only certain parts of the study area (perhaps due to a local thunderstorm), it may be necessary to stratify (cut out) those affected areas and perform a separate change detection analysis, which can be added back in the final stages of the project.

Phenological cycle of vegetation

- Natural ecosystems go through repeatable, predictable cycles of development. Humans also modify the landscape in predictable stages.
- Analysts use this information to identify when remotely sensed data should be collected. Therefore, analysts must be familiar with the biophysical characteristics of the vegetation, soils, and water constituents of ecosystems and their phenological cycles.
- Likewise, they must understand human-made development phenological cycles such as those associated with residential expansion at the urban/rural fringe.

Phenological cycle of vegetation

- Vegetation grows according to relatively predictable diurnal, seasonal, and annual phenological cycles.
- Obtaining near-anniversary images greatly minimizes the effects of seasonal phenological differences that may cause spurious change to be detected in the imagery.
- When attempting to identify change in agricultural crops, the analyst must be aware of when the crops were planted.
- A month lag in planting date between fields of the same crop can cause serious change detection error.

Steps required in digital change detection

- Define the problem
- Sensor and environmental considerations
- Perform digital change analysis
- Perform accuracy assessment
- Distribute results

Selection of change detection algorithm

- The selection of an appropriate change detection algorithm is very important.
- First, it will have a direct impact on the type of image classification to be performed (if any).
- Second, it will dictate whether important "from–to" change information can be extracted from the imagery.
- Many change detection projects require that "from–to" information be readily available in the form of maps and tabular summaries.

Change Detection Process

RAW MULTIDATE IMAGERY

RADIOMETRIC PREPROCESSING

scene matching
DOS
RT

TRANSFORMATION METHOD

image differencing
NDVI diff
multidate ratio
multidate regression
multidate K-T
change vector
GS
PCA

METHOD OF RELATING IMAGE CHANGE TO CHANGE OF INTEREST

density slicing
classification
regression
mixture analysis
neural networks
regression trees
decision trees

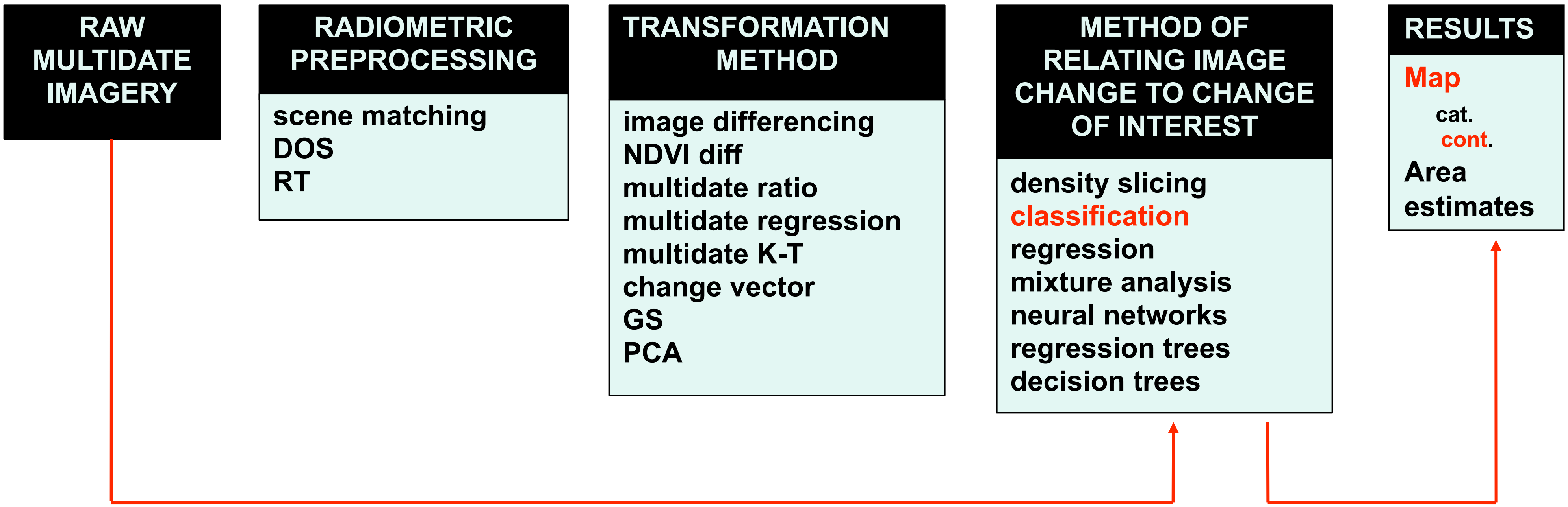
RESULTS

Map
- **cat.**
- **cont.**

Area estimates

DOS: Dark Object Subtraction; RT: Radiative Transfer; K-T: Kauth-Thomas transform; GS: Gramm-Schmidth; PCA: Principal Components Analysis; SMA: Spectral Mixture Analysis.

Change Detection Process



Machoney and Haack (1993)

Muchoney, D.M. and Haack, B.N., 1993, Change detection for monitoring forest defoliation, Photogrammetric Engineering and Remote Sensing, 60(10):1243-1251

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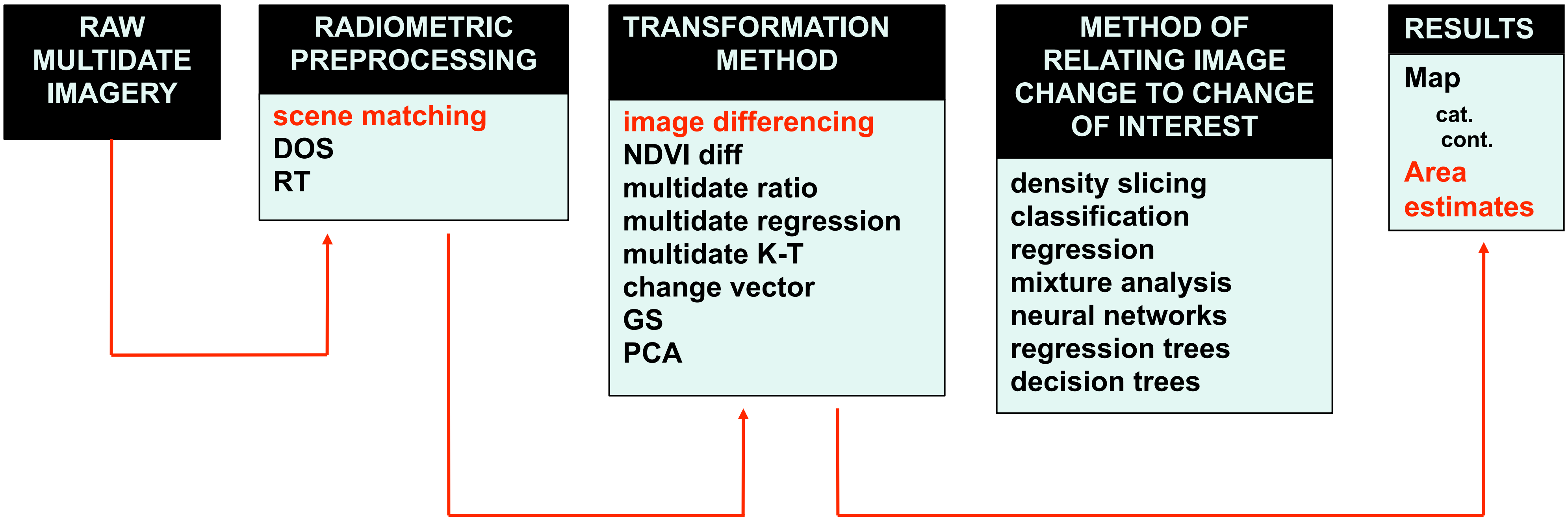

Vogelmann and Rock (1989)

Vogelmann, J.E. and Rock, B.N., 1989, Use of Thematic Mapper data for the detection of Forest damage caused by the pear thrips, Remote Sensing of Environment, 30:217-225

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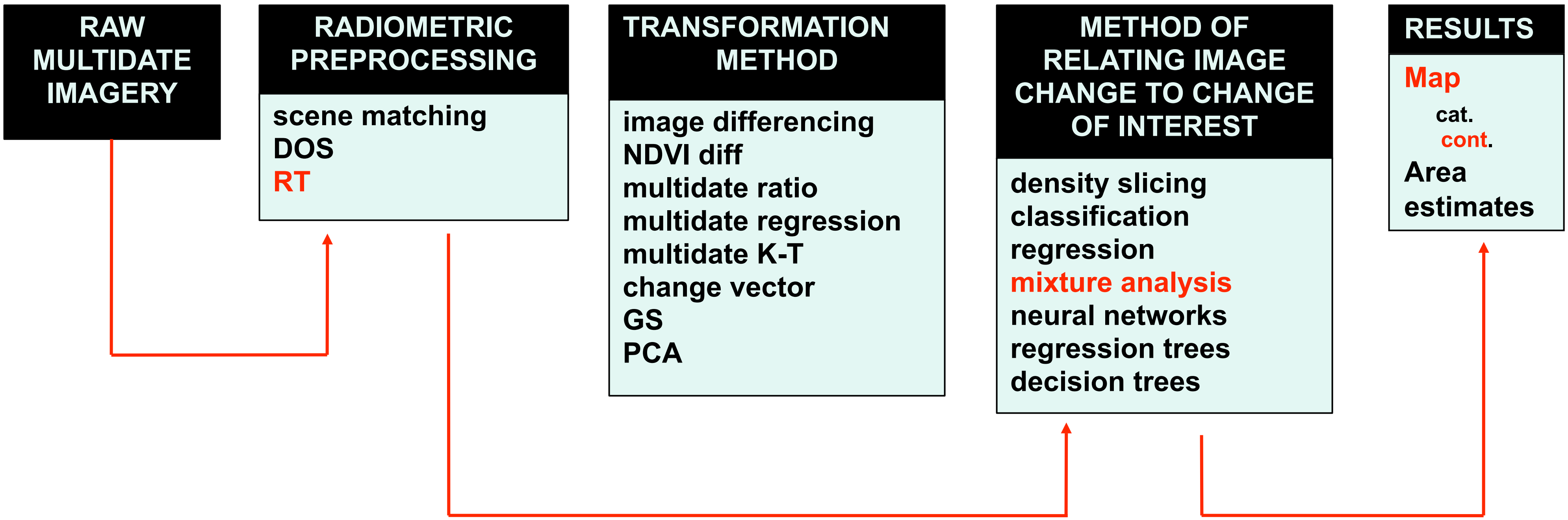

Radeloff et al. (1999)

Radeloff, V.C., Mladenoff, D.J., and Boyce, M.S., 1999, Detecting jack pine budworm Defoliation using spectral mixture analysis: separating effects from determinants, Remote Sensing of Environment, 69:156-169

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Methods

- write function memory insertion
- image arithmetic
- image regression
- multi-date compositing
- multi-date PCA
- post-classification comparison
- multi-date classification
- change vector analysis