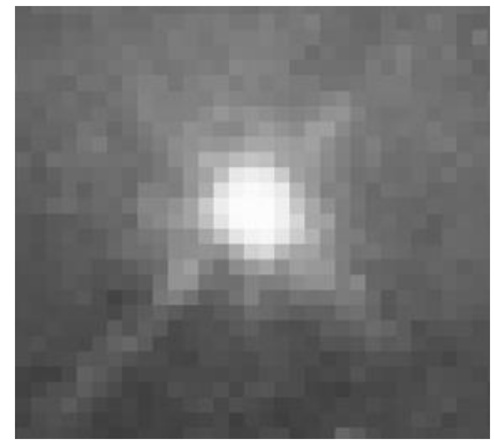
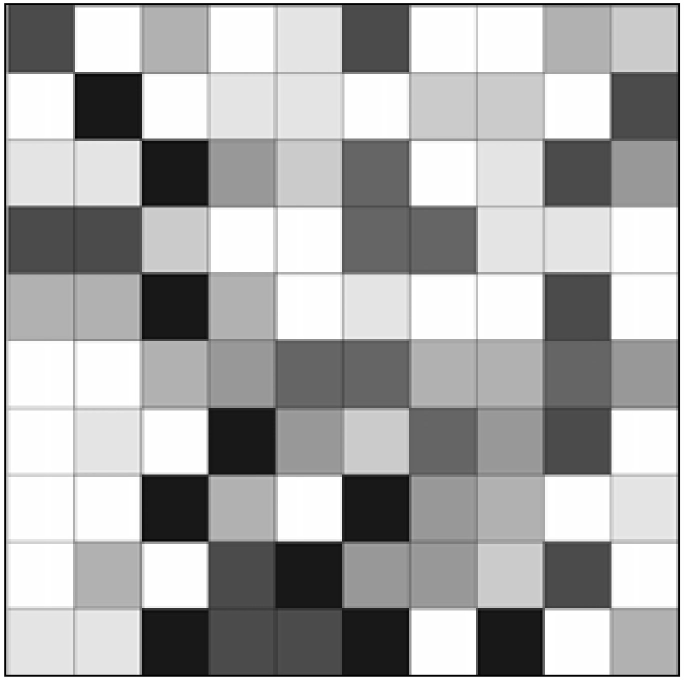
IMAGE ENHANCEMENT

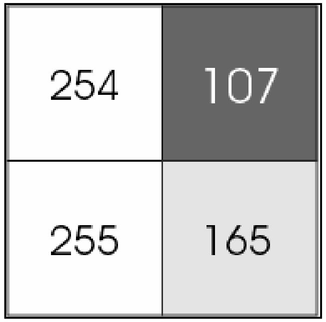
- An image is an array, or a matrix, of square pixels (picture elements) arranged in columns and rows.
- In a (8-bit) image each picture element has an assigned intensity that ranges from 0 to 255.
- A grey scale image (black and white image), will also include many shades of grey.



8-Bit GreyStyle Image

- *Each pixel has a value from 0 (black) to 255 (white).*
- *The possible range of the pixel values depend on the colour depth of the image,*
- *here 8 bit = 256 tones or grey scales.*





PIXEL VALUES

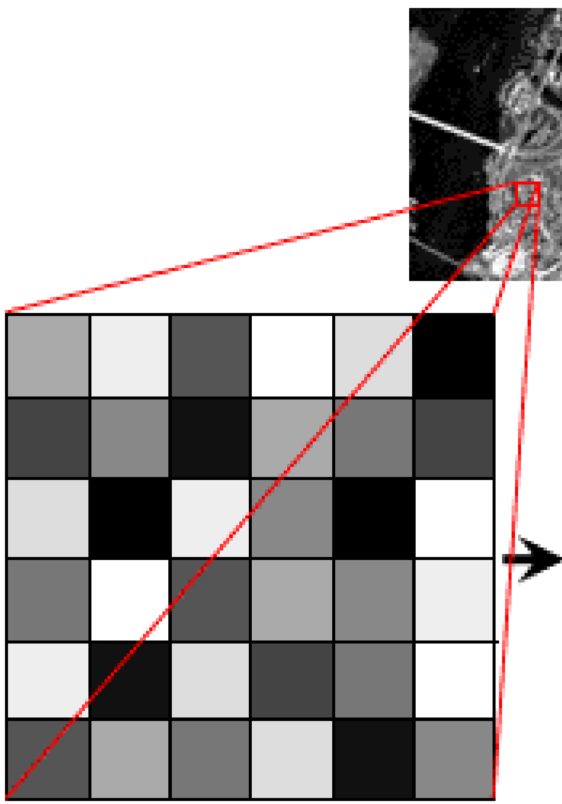
- *Pixel Values:* The magnitude of the electromagnetic energy (or, intensity) captured in a digital image is represented by positive digital numbers.

- The *digital numbers* are in the form of *binary digits (or 'bits')* which vary from 0 to a selected power of 2

Image Type	Pixel Value	Color Levels
8-bit image	$2^8 = 256$	0-255
16-bit image	$2^{16} = 65536$	0-65535
24-bit image	$2^{24} = 16777216$	0-16777215

16 million colors!!!

DIGITAL NUMBER



170	238	85	255	221	0
68	136	17	170	119	68
221	0	238	136	0	255
119	255	85	170	136	238
238	17	221	68	119	255
85	170	119	221	17	136

TRUE COLOUR IMAGE

- *A true-colour image assembled from three greyscale images coloured red, green and blue.*
- *Such an image may contain up to 16 million different colors.*

IMAGE RESOLUTION

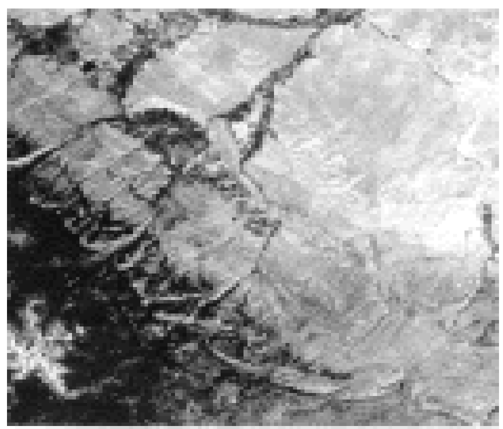
- **Image Resolution:** the (radiometric) resolution of a digital image is dependant on the range in magnitude (i.e. range in brightness) of the pixel value.
- With a 2-bit image the maximum range in brightness is $2^2 = 4$ values ranging from 0 to 3, resulting in a low resolution image.
- In an 8-bit image the maximum range in brightness is $2^8 = 256$ values ranging from 0 to 255, which is a higher resolution image

2-bit Image (4 grey levels)

8-bit Image (256 grey levels)

IMAGE ENHANCEMENT

- *<u>Image Histogram:</u>* For every digital image the pixel value represents the magnitude of an observed characteristic (brightness level)
- An image histogram is a *graphical representation* of the brightness values that comprise an image.
- The *brightness values (i.e. 0-255)* are displayed along the *x-axis* of the graph. The *frequency of occurrence* of each of these values in the image is shown on the *y-axis*.



8-bit image
(0 - 255 brightness levels)

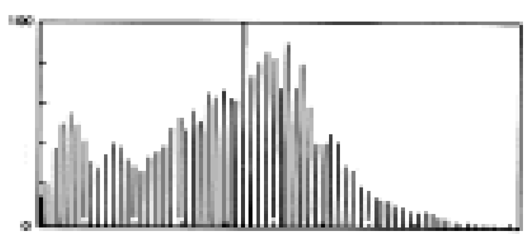


Image Histogram
x-axis = 0 to 255
y-axis = number of pixels

IMAGE ENHANCEMENT

- *Contrast Stretching*: Quite often the useful data in a digital image populates only a small portion of the available range of digital values (commonly 8 bits or 256 levels).
- Contrast enhancement involves changing the original values so that more of the available range is used, this then increases the contrast between features and their backgrounds.
- There are several types of *contrast enhancements* which can be subdivided into *Linear* and *Non-Linear procedures*.

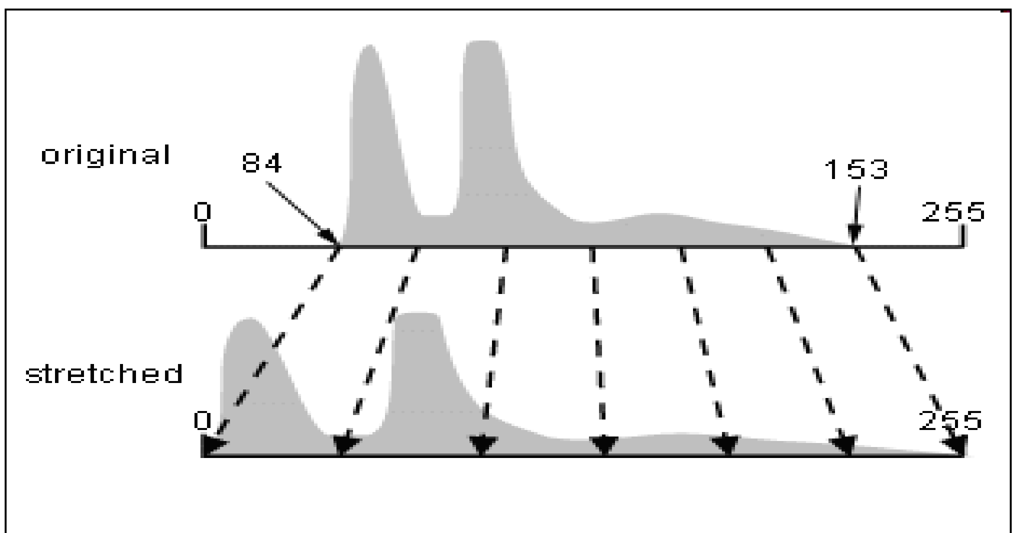
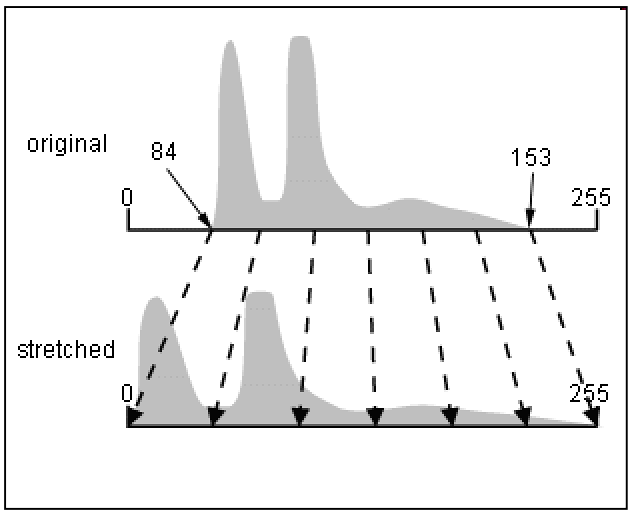
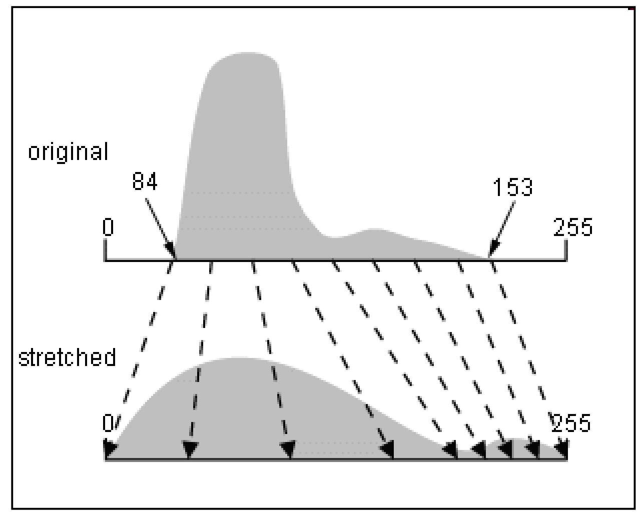


IMAGE ENHANCEMENT

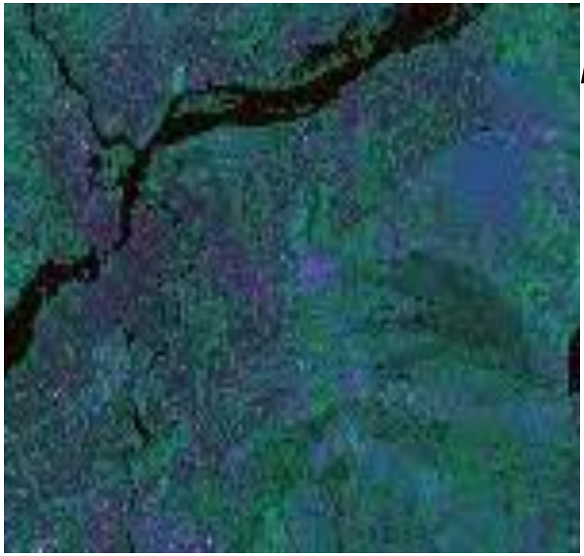
- *Linear Contrast Stretch:* This involves identifying lower and upper bounds from the histogram (usually the minimum and maximum brightness values in the image) and applying a transformation to stretch this range to fill the full range.





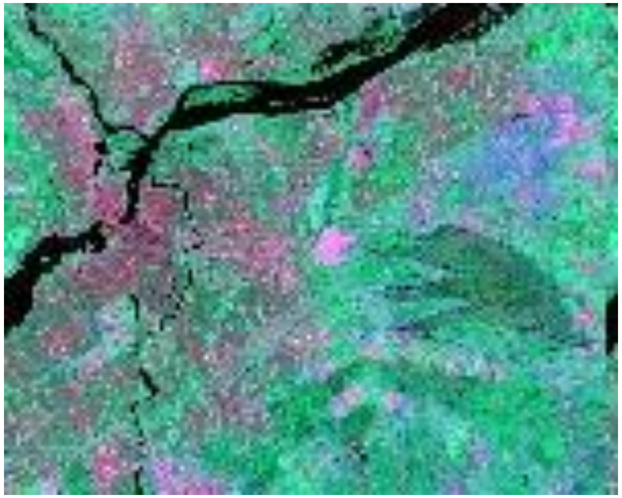
- *Equalized Contrast Stretch*: This stretch assigns more display values (range) to the frequently occurring portions of the histogram. In this way, the detail in these areas will be better enhanced relative to those areas of the original histogram where values occur less frequently.

LINEAR STRETCH



Before Linear Stretch

After Linear Stretch



The linear contrast stretch enhances the contrast in the image with ***light toned areas appearing lighte***r and ***dark areas appearing darker***, making visual interpretation much easier.

SPATIAL FILTERING

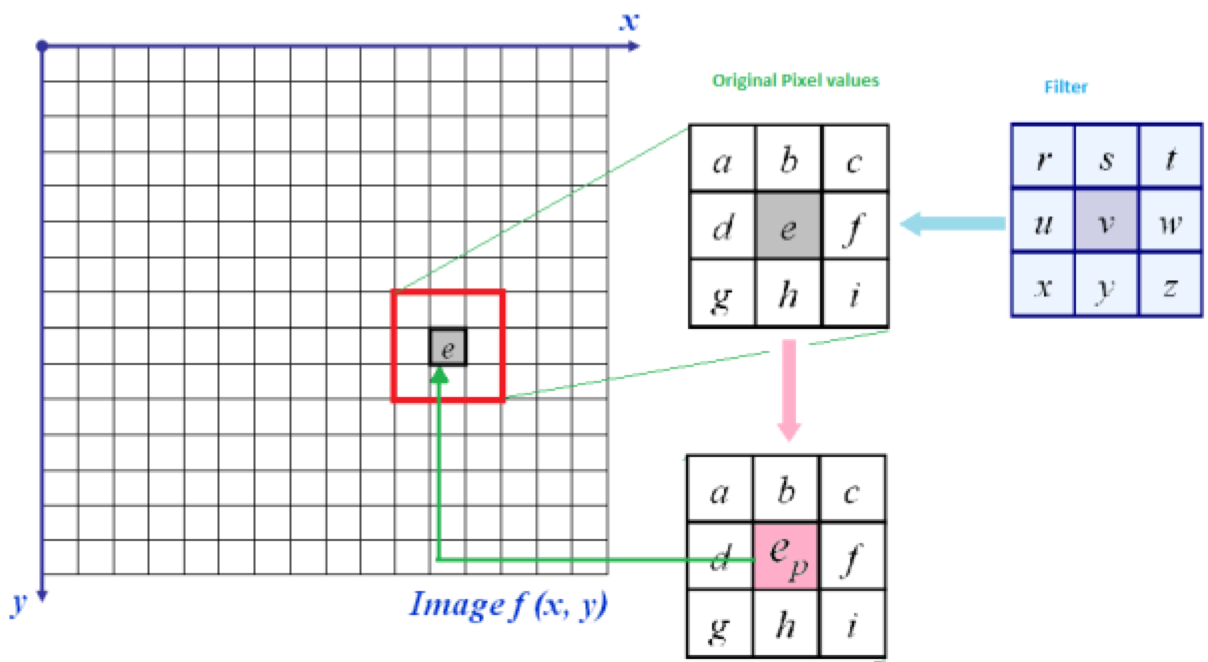
- Filtering is the process by which the tonal variations in an image, in selected ranges or frequencies of the pixel values, are enhanced or suppressed
- Spatial filters are designed to *highlight or suppress features* in an image based on their *spatial frequency*.
- The spatial frequency refers to the *textural characteristics* of an image.
- Rapid variations in brightness levels (*'roughness'*) reflect a *high spatial frequency*; *'smooth' areas* with little variation in brightness level or tone are characterized by a *low spatial frequency*.
- Spatial filters are used to suppress 'noise' in an image, or to highlight specific image characteristics.

Examples:

- *Low-pass Filters*
- *High-pass Filters*
- *Directional Filters*

SPATIAL FILTERING

- A filter is a regular array or matrix of numbers which, using simple arithmetic operations, allows the formation of a new image by assigning new pixel values depending on the results of the arithmetic operations



$$e_p = (e.v + a.r + b.s + c.t + d.u + f.w + g.x + h.y + i.z)/9$$

LOW PASS FILTERS

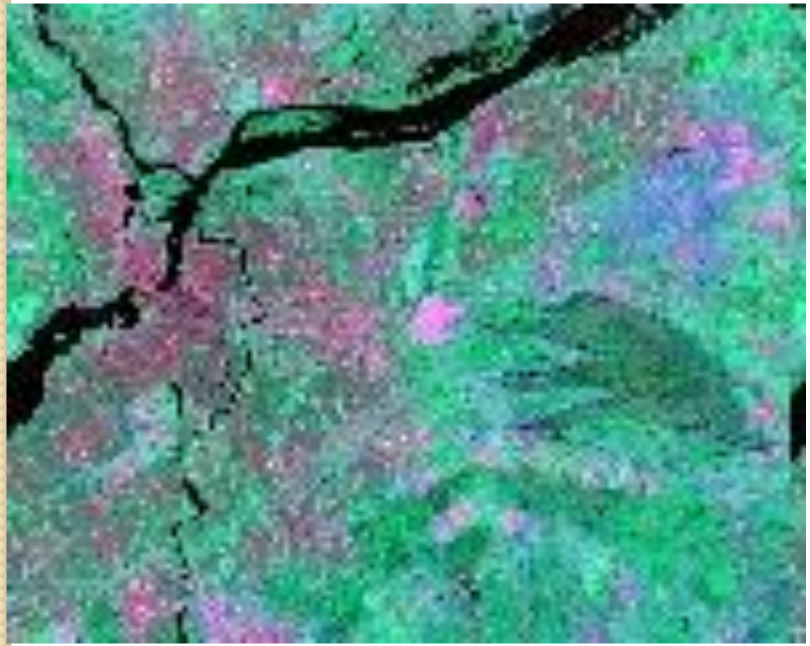
- Convolution kernels used in filtering are square in shape and are generally of odd number of pixels in size viz., 3x3, 5x5, 7x7
- Low pass filters are also called averaging filters (filter output is the average pixel value of all the pixels in the neighborhood)
- When low pass filter is applied on an image, it will replace every pixel with the average of the surrounding pixel values. Thus, the low frequency values in the image are highlighted after filtering.
- Low pass filter reduces the effects of noise component of an image.

1	1	1
1	1	1
1	1	1

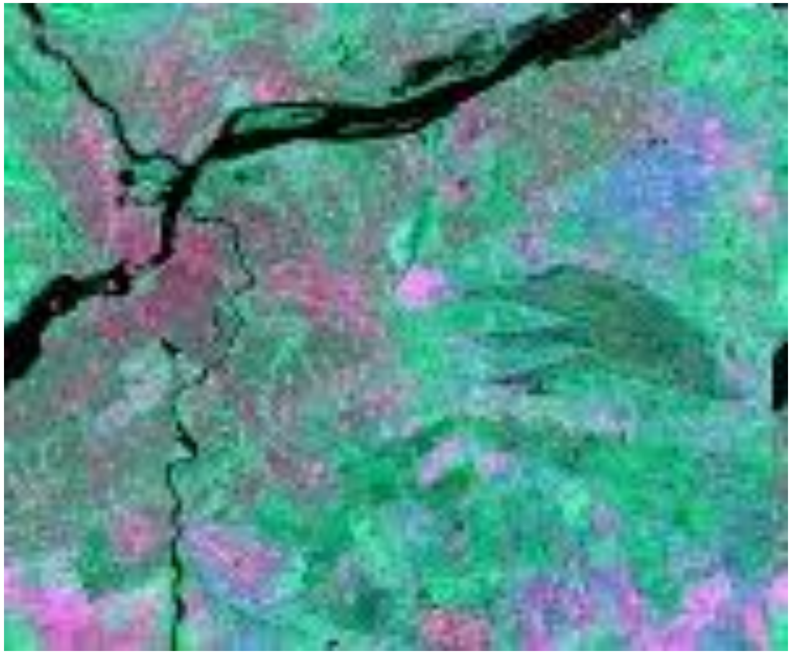
SPATIAL FILTERING

- *__Low-pass Filters:__* These are used to emphasize large homogenous areas of similar tone and reduce the smaller detail. Low frequency areas are retained in the image resulting in a smoother appearance to the image.

Linear Stretched Image



Low-pass Filter Image



HIGH PASS FILTERS

- High pass filters enhances the high frequency values in an image.
- Accordingly, in the resulting image, low frequency values are de-emphasized

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

SPATIAL FILTERING

- ***High-pass Filters:*** allow high frequency areas to pass with the resulting image having greater detail resulting in a sharpened image

Linear Contrast Stretch

Hi-pass Filter

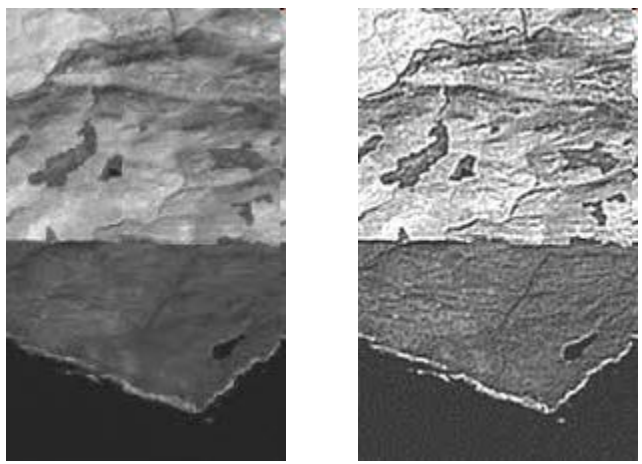
DIRECTIONAL FILTERS

- Directional filters help to highlight the features oriented in any specific direction. For example: N – S highlighted
- They are particularly useful in detecting and enhancing linear features with a specific orientation.

1	0	-1
2	0	-2
1	0	-1

SPATIAL FILTERING

- *Directional Filters*: Designed to *enhance linear features* such as roads, streams, faults, etc.
- The filters can be designed to enhance features which are *oriented in specific directions*, making these useful for r*adar imagery* and for *geological applications*.
- Directional filters are also known as edge detection filters.



Edge Detection
Lakes & Streams

Edge Detection
Fractures & Shoreline

EMBOSS FILTERS

- Emboss filter when applied to an image, highlights the features that are having gradient in the specified direction
- Filter embossed in NW direction is given below

0	0	1
0	0	0
-1	0	0

SPATIAL FILTERS

1	1	1
1	1	1
1	1	1

Low pass

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

High pass

1	0	-1
2	0	-2
1	0	-1

Directional gradient filter - N/S features highlighted

0	0	1
0	0	0
-1	0	0

Emboss NW

SPATIAL FILTERS

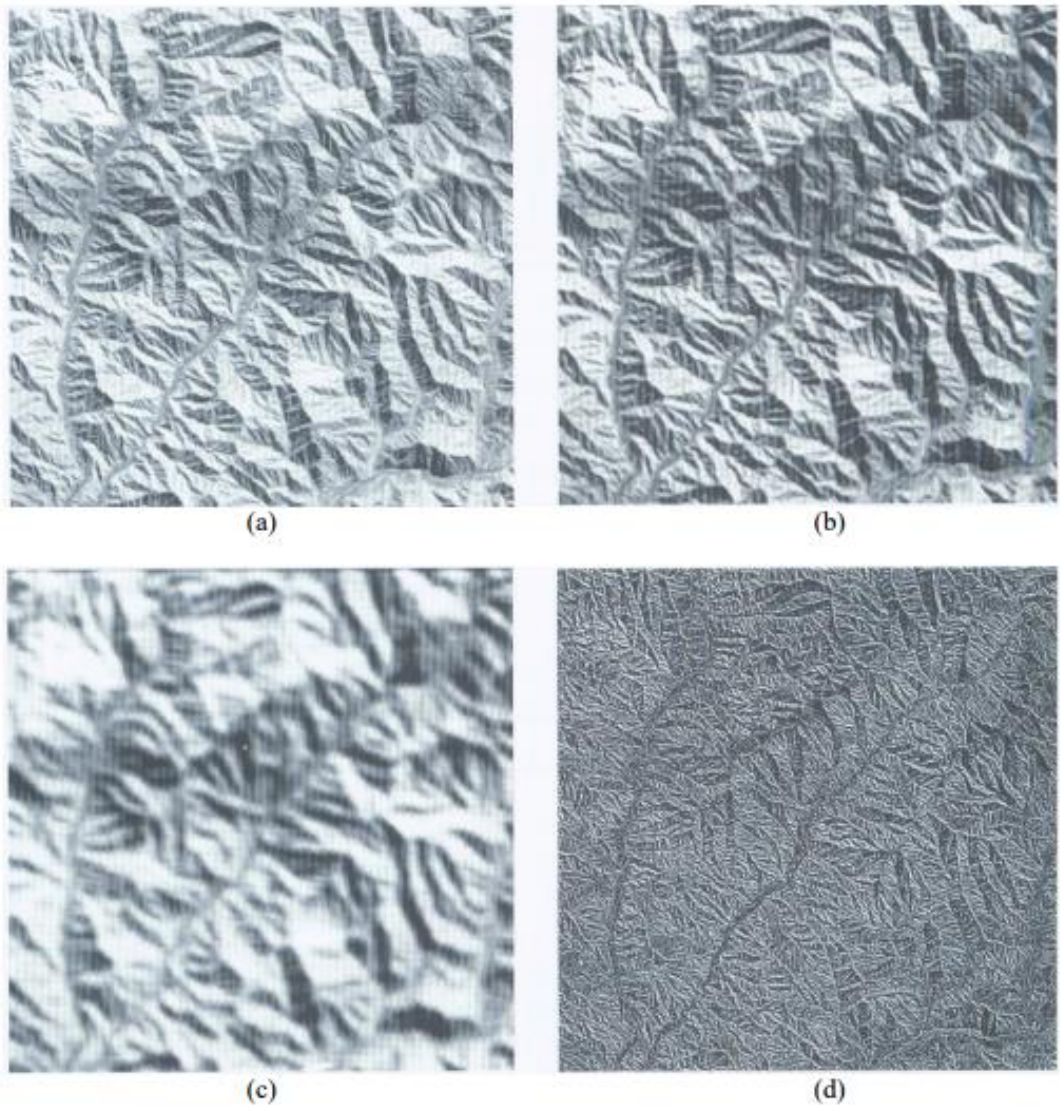


Fig. 3 (a) Input image : ASTER GDEM (b) 3x3 low pass filtered image (c) 11x11 low pass filtered image and (d) 3x3 high pass filtered image

SPATIAL FILTERS

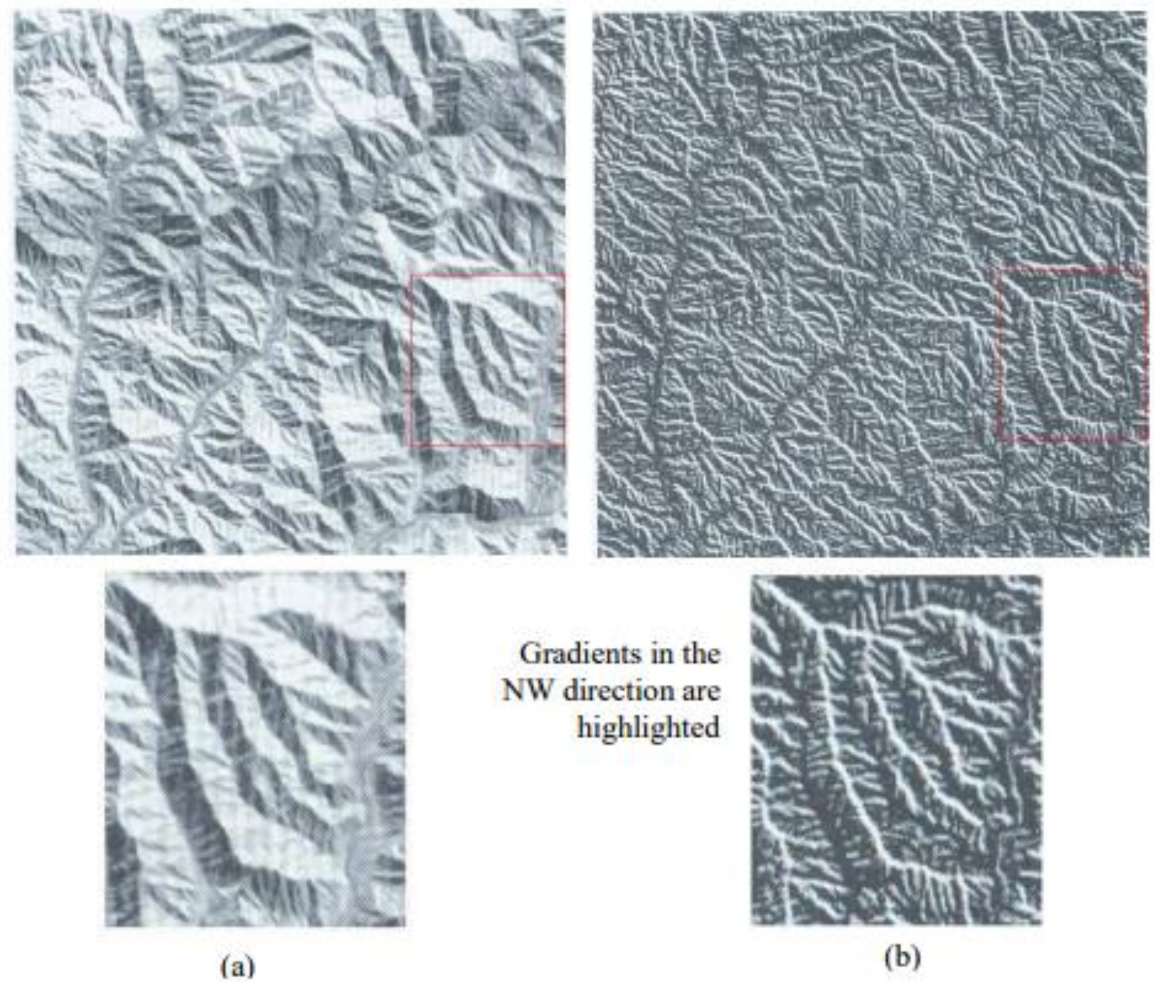


Fig. 4 (a) Original image: ASTER GDEM (b) Image filtered using NW emboss filter

IMAGE RATIOS

- It is possible to *divide the digital numbers* of one image band by those of another image band to create a third image.
- Ratio images may be used to remove the influence of light and shadow on a ridge due to the sun angle.
- It is also possible to *calculate certain indices* which can enhance vegetation or geology

Sensor	Image Ratio	EM Spectrum	Application
Landsat TM	**Bands 3/2**	**red/green**	**Soils**
Landsat TM	**Bands 4/3**	**PhotoIR/red**	**Biomass**
Landsat TM	**Bands 7/5**	**SWIR/NIR**	**Clay Minerals/Rock Alteration**

Normalized Difference Vegetation Index (NDVI), a commonly used vegetation index which uses the red and infrared bands of the EM spectrum.

SPECTRAL INDICES

- Spectral indices → Combinations of surface reflectance at two or more wavelengths that indicate relative abundance of features of interest
- Indices can be based on ‘difference’ or ‘ratio’ or ‘a combination’ of reflectance in various bands
- Spectral indices are mainly used in vegetation, and geological applications

SPECTRAL INDICES

Common Vegetation Indices

1) Normalized Difference Vegetation Index (NDVI) →

$$NDVI = \frac{(\rho_{NIR} - \rho_{RED})}{(\rho_{NIR} + \rho_{RED})}$$

- Range -1 to + 1
- This index is a measure of healthy, green vegetation
- Uses the combinations of highest absorption and reflectance regions of Chlorophyll
- It can saturate in dense vegetation conditions when LAI becomes high

2) Green-NDVI → $GNDVI = \frac{(\rho_{NIR} - \rho_{GREEN})}{(\rho_{NIR} + \rho_{GREEN})}$

- This index is more sensitive to chlorophyll concentration than NDVI

SPECTRAL INDICES

Common Vegetation Indices ..

3) Difference Vegetation Index (DVI) → $DVI = \rho_{NIR} - \rho_{RED}$

- This index can distinguish between soil and vegetation, but it does not account for the difference between reflectance and radiance caused by atmospheric effects or shadow

4) Enhanced Vegetation Index (EVI) →

$$EVI = 2.5\ x\ \frac{(\rho_{NIR} - \rho_{RED})}{(\rho_{NIR} + 6\rho_{RED} - 7.5\rho_{BLUE} + 1)}$$

- Used in optimizing the vegetation signal in areas of high LAI
- Useful in high LAI regions where NDVI may saturate
- Uses the blue reflectance region to correct for soil background signals and to reduce atmospheric influences, including aerosol scattering

SPECTRAL INDICES

Common Vegetation Indices ..

5) Leaf Area Index (LAI) → $LAI = (3.618 * EVI - 0.118)$

- This index is used to estimate foliage cover and to forecast crop gowth and yield

6) Soil Adjusted Vegetation Index (SAVI) →

$$SAVI = \frac{1.5\, x\, (\rho_{NIR} - \rho_{RED})}{(\rho_{NIR} + \rho_{RED} + L)}$$

- This index is similar to NDVI, but it suppresses the effects of soil pixels
- Uses a canopy background adjustment factor, *L*, (~ 0.5) which is a function of vegetation density
- This index is best used in areas with relatively sparse vegetation where soil is visible through the canopy

SPECTRAL INDICES

Common Vegetation Indices ..

7) Simple Ratio (SR) → $SR = \frac{\rho_{NIR}}{\rho_{RED}}$

- This index is used to estimate foliage cover and to forecast crop gowth and yield

SPECTRAL INDICES

For a detailed list of spectral indices used in RS, refer to

http://www.harrisgeospatial.com/docs/SpectralIndices.html

IMAGE PRE PROCESSING

- Pre processing refers to those operations which are preliminary (basis) for the principal analysis
- Pre-processing mainly deals with
  - Image restoration – Obtaining a clean/correct image from a noisy/corrupt image
  - Image rectification -- transformation process to project two-or-more images onto a common image plane
- Pre processing Operations:

  1) Radiometric Pre processing

  -- To adjust digital values (DNs) for effects of hazy atmosphere

  2) Geometric Pre processing

  -- To bring an image into registration with a map or another image
- Once Pre processing (corrections) is done, the data (image) can be subjected to primary analysis including:

1) Image Classification ; 2) Change Detection ; 3) Land Use Land Cover

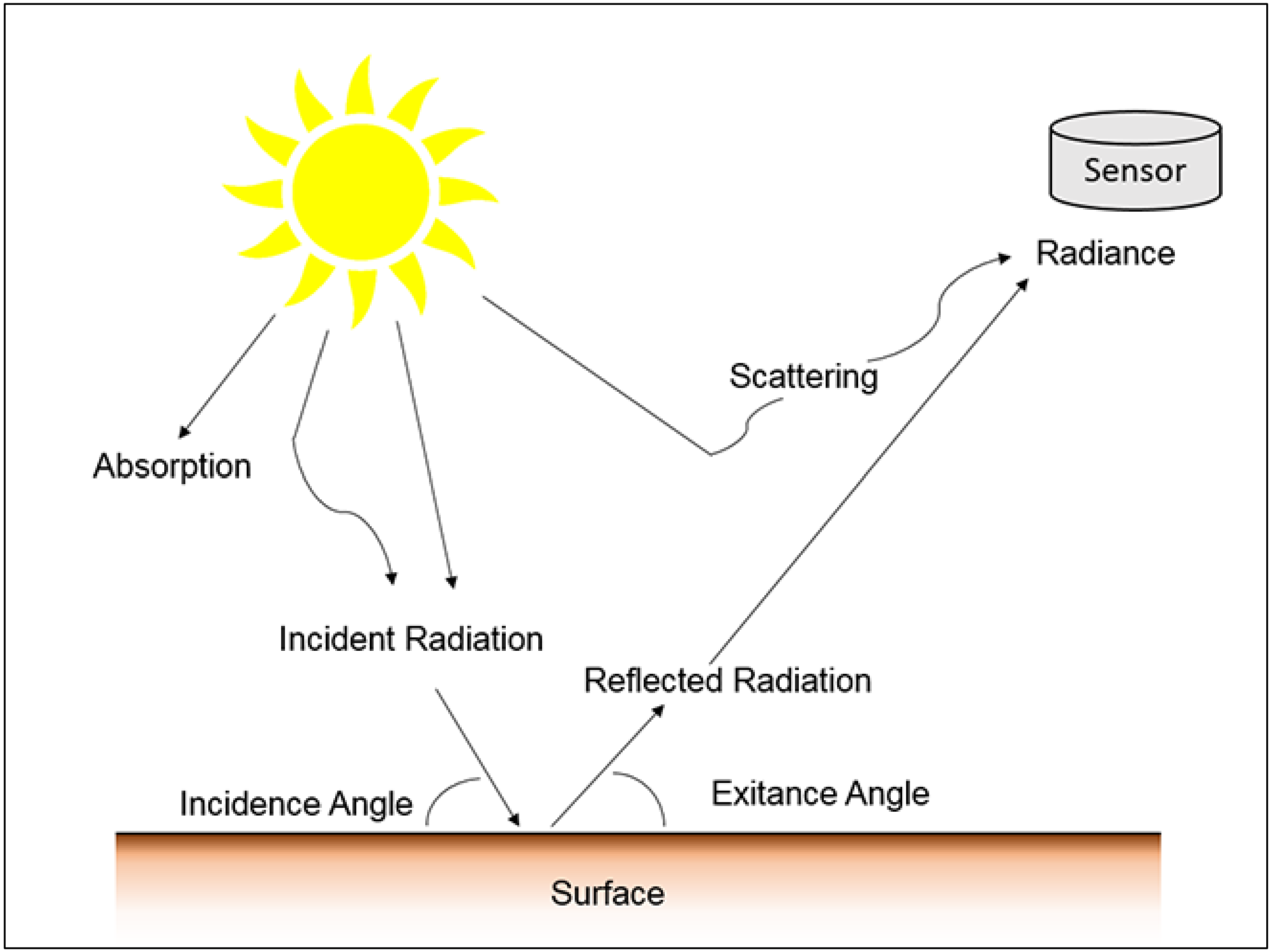
IMAGE PRE PROCESSING

- Preprocessing of satellite images prior to image classification and change detection is essential.
- Preprocessing commonly comprises a series of sequential operations, including atmospheric correction or normalization, image registration, geometric correction, and masking (e.g., for clouds, water, irrelevant features)
- Preprocessing is intended to correct for sensor- and platform-specific radiometric and geometric distortions of data
- Although the effects of the atmosphere upon remotely sensed data are not considered errors, since they are part of the signal received by the sensing device, consideration of these effects is important
- Geometric rectification of the imagery resamples or changes the pixel grid to fit that of a map projection or another reference image
- This becomes especially important when scene to scene comparisons of individual pixels in applications such as change detection are being sought

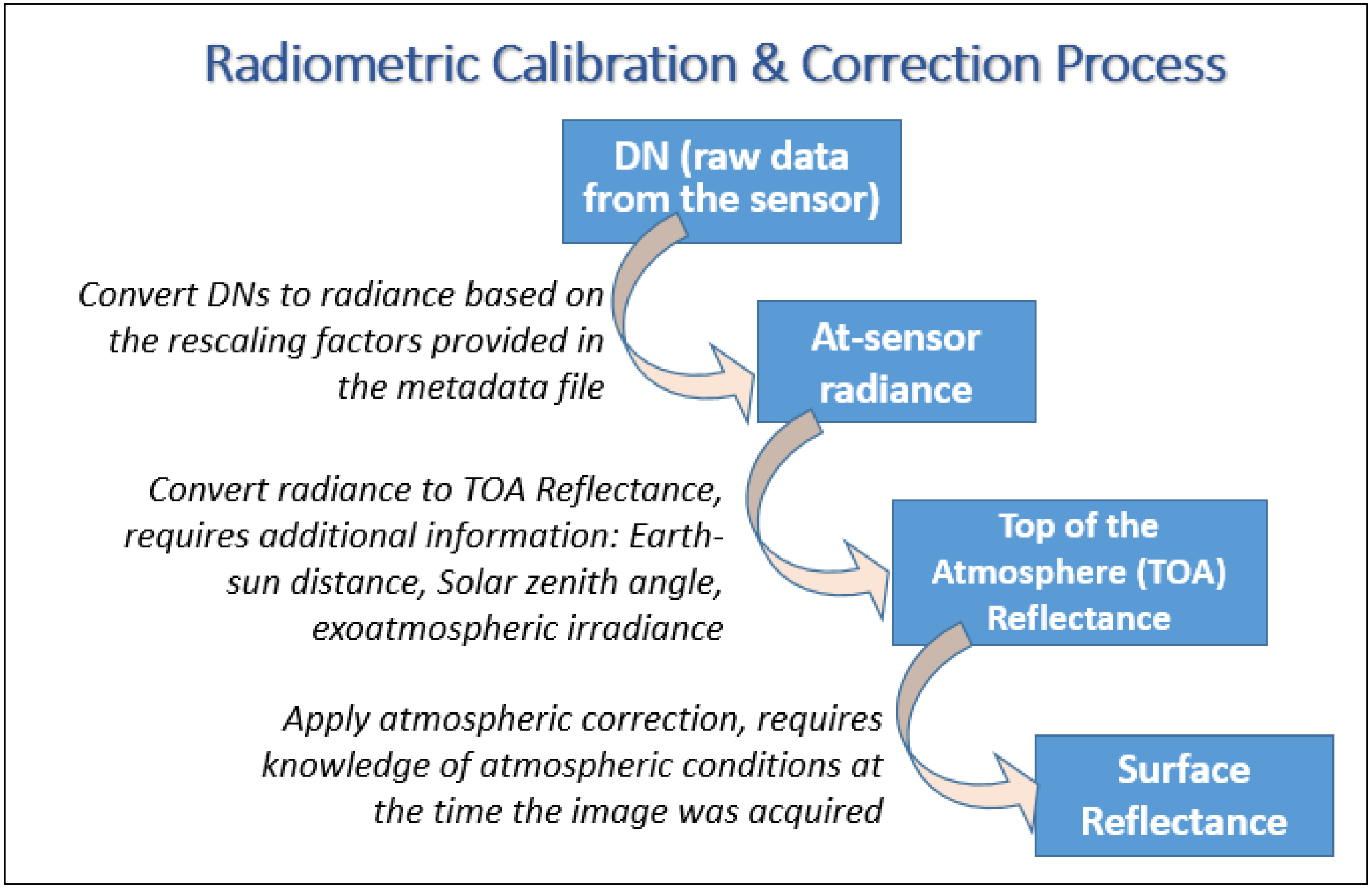
RADIOMETRIC PRE PROCESSING

- Radiometric correction is done to reduce or correct errors in the digital numbers of images
- This process improves the interpretability and quality of remote sensed data
- Radiometric calibration and correction are particularly important when comparing data sets over a multiple time periods
- Error in energy sensed by the sensor onboard can be due to:
  - Sun's azimuth and elevation
  - Atmospheric conditions

RADIOMETRIC PRE PROCESSING



RADIOMETRIC PRE PROCESSING



SOME COMMON DEFINITIONS

Image Registration

The process of transforming different sets of data (multiple photographs, data from different sensors, times, depths, or viewpoints) into one coordinate system.

Image Restoration

The operation of taking a corrupt/noisy image (motion blur, noise) and estimating the clean, original image

Image Rectification

Transformation process used to project images onto a common image plane

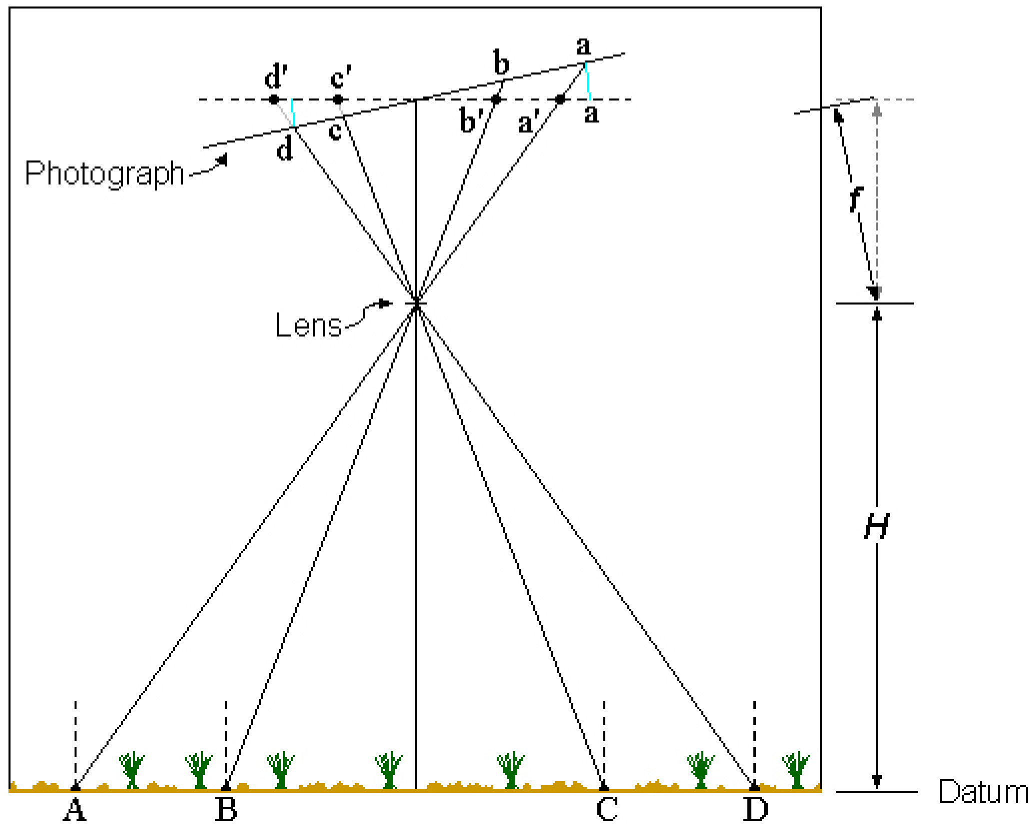
Orthorectification

process of removing the effects of image perspective (tilt)
and relief (terrain) effects for the purpose of creating a planimetrically correct image

Image Mosaicing

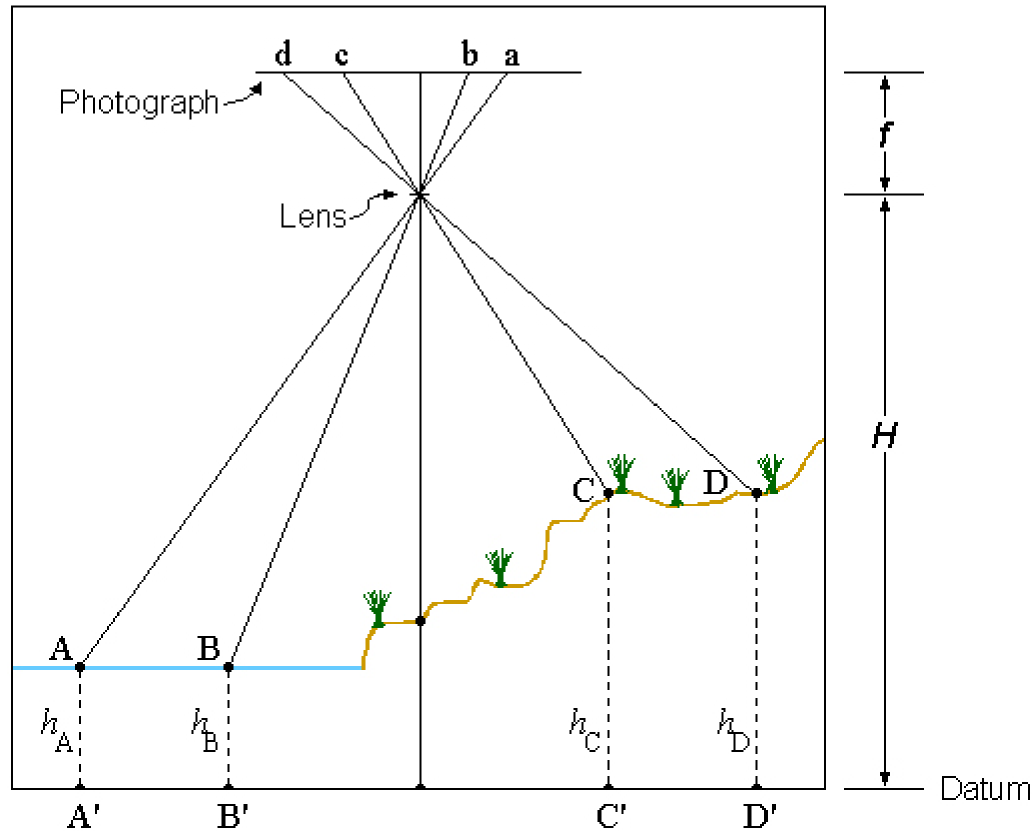
The process of assembling a series of images and joining them together to form a continuous seamless photographic representation

TILT DISPLACEMET



Tilt displacement is the shift in an object's image position on a tilted photo from its theoretical position on a truly vertical photo

RELIEF DISPLACEMET



Relief displacement is the shift in an object's image position caused by its elevation above a particular datum

DATA PRODUCTS – BASED ON PROCESSING

1) **Level 0** imagery is raw instrument data, just as they were collected at the sensor. Most agencies will not distribute Level 0 imagery

2) **Level 1A** data have been corrected for detector variations within the sensor. Number of detectors depends on the instrument design (Landsat TM: 16). Satellite operators try to equalize the detector responses through a series of data calibrations involving pre-launch values and in-flight measurements. Level 1A processing involves applying inter-detector equalizations (*radiometric correction)*

DATA PRODUCTS – BASED ON PROCESSING

3) **Level 1B** involves the geometry of the image product. Used to rectify distortions in the geometry of the imagery such as mis-aligned scan lines and non-uniform pixel sizes. All of these distortions are predictable and measurable systematic corrections can be applied to the imagery to improve its geometric qualities
4) **Level 2A** images have been systematically mapped into a standard cartographic map projection based on a prediction of where the satellite was when the image was acquired. However, these images still have expected location errors of more than 100 m (can be used with GIS)

DATA PRODUCTS – BASED ON PROCESSING

5) **Level 2B** In this, image analyst "registers" the image to an existing base map by selecting pairs of well-defined points (known as *ground control points*) from both the image and the map. The position accuracy of Level 2B images generally matches the spatial resolution of the original data

6) **Level 3A** In addition to manually locating ground control points (as in Level 2B), a digital elevation model (DEM) must be supplied to the procedure so that the relief displacement at differing elevations can be accounted for. This process is known as **Ortho-rectification.** Used for mountainous terrains

7) **Level 3B** Mosaic Level 3A products to cover larger area

RADIANCES FROM DN VALUES

- Satellite imagery pixel information is stored as DN values (integer values for convenience with computation, transmittance, scaling, display)
- DN values donot store brightness values in physical units (Watts per square meter per micrometer per steradian)
- When image brightness is expressed in DNs
    1) Each image becomes individual entity
    2) There will not be defined relationship between the images, or to features on the ground
    3) comparison, Matching, and Mosaics of images is NOT possible
    4) DNs can not serve as input for models of physical process in agriculture; hydrology; forestry
- Conversion of DNs to radiances is an important transformation to prepare remotely sensed images for further analysis

RADIANCES FROM DN VALUES

➢Satellite onboard calibration targets can be viewed , or, take an image of a flat uniform landscape such as carefully selected desert terrain

➢ For a given sensor, given spectral channel, and a given DN (of a pixel), the corresponding radiance value (L) can be calculated as

$$L_\lambda = ((LMAX_\lambda - LMIN_\lambda)/(QCALMAX-QCALMIN)) * (QCAL-QCALMIN) + LMIN_\lambda$$

Where:

L_λ → Spectral radiance at the sensor's aperture (W/m^{2})

Q_{CAL} → Quantized calibrated pixel value (DN)

Q_{CALMIN} → Minimum quantized calibrated pixel value (DN) correspond to L_{min}

Q_{CALMAX} → Maximum quantized calibrated pixel value (DN) correspond to L_{max}

$LMIN_\lambda$ → Lowest possible spectral radiance (measured)

$LMAX_\lambda$ → Highest possible spectral radiance (measured)

RADIANCES FROM DN VALUES

$$L_\lambda = ((LMAX_\lambda - LMIN_\lambda)/(QCALMAX-QCALMIN)) * (QCAL-QCALMIN) + LMIN_\lambda$$

CALIBRATION INFORMATION FOR SPECIFIC SATELLITE (LANDSAT MSS / TM) WILL BE PRESENTED IN THE SYSTEM SPECIFIC REVIEW ARTICLES

DN to Reflectance Conversion (LandSAT-8)

- The raw digital numbers (DN) in the images can be converted to top-of-atmosphere (TOA) radiance or reflectance
- Sensor specific information is needed to carry out this calibration (available in metadata file)
- For Landsat-8, the conversion is given by:

$$\rho\lambda = \frac{M_\rho Q_{cal} + A_\rho}{\cos(\theta_{SZ})}$$

$\rho\lambda$ = TOA reflectance
θ_{SE} = Local sun elevation angle provided in the metadata
θ_{SZ} = Local solar zenith angle; $\theta_{SZ} = 90° - \theta_{SE}$
M_ρ = Band-specific multiplicative rescaling factor from the metadata
A_ρ = Band-specific additive rescaling factor from the metadata
Q_{cal} = Quantized and calibrated standard product pixel values (DN)

Equation provided by the USGS to convert Landsat 8 OLI raw DNs to TOA Reflectance

ERROR SOURCES

Error Sources are of TWO types

1) Internal Sources
   - Introduced by the remote sensing system
   - Generally systematic (predictable) and may be identified and then corrected based on prelaunch or in-flight calibration measurements

2) External Sources
   - Introduced by phenomena that vary in nature through space and time
   - Due to atmosphere, terrain elevation, slope, and aspect
   - corrected by relating empirical ground observations

RADIOMETRIC PRE PROCESSING

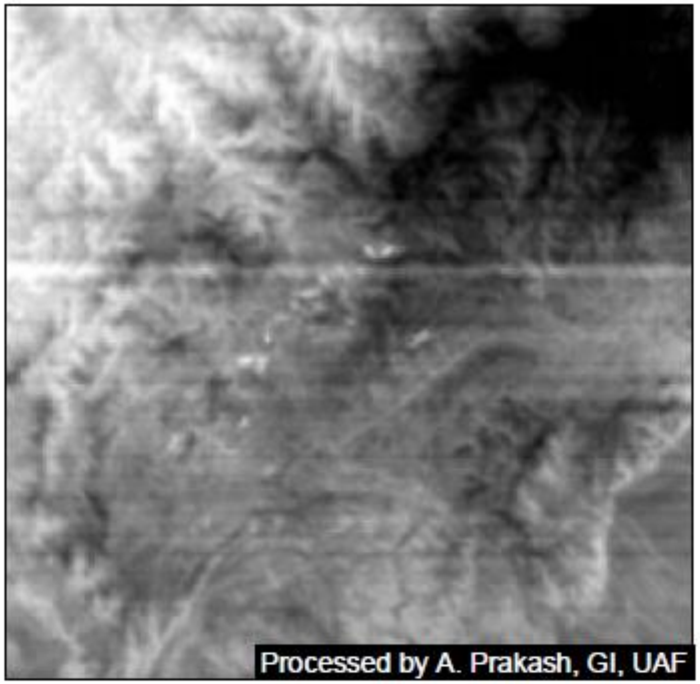
Types of Radiometric Correction

- Striping
- (partially) missing lines
- Illumination and view angle effects
- Sensor calibration
- Terrain effects
- Atmospheric correction

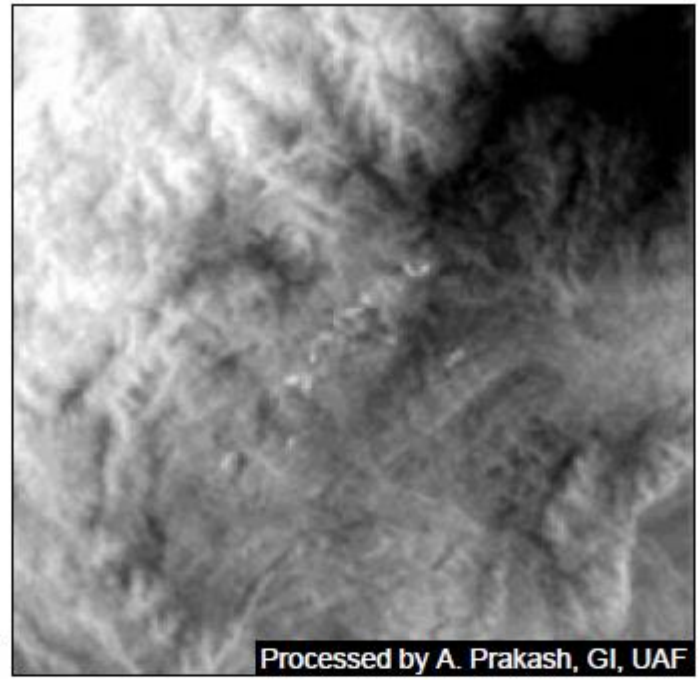
RADIOMETRIC PRE PROCESSING

Line or Column Striping

- Sometimes a detector does not fail completely, but simply goes out of radiometric adjustment
- The result would be an image with systematic, noticeable lines that are brighter than adjacent lines
- This is referred to as n-line striping
- To repair systematic n-line striping, it is first necessary to identify the mis-calibrated scan lines in the scene.
- Every line and pixel in the scene recorded by the mal-adjusted detector may require a bias (additive or subtractive) correction or a more severe gain (multiplicative) correction



Striping



De-striped

RADIOMETRIC PRE PROCESSING

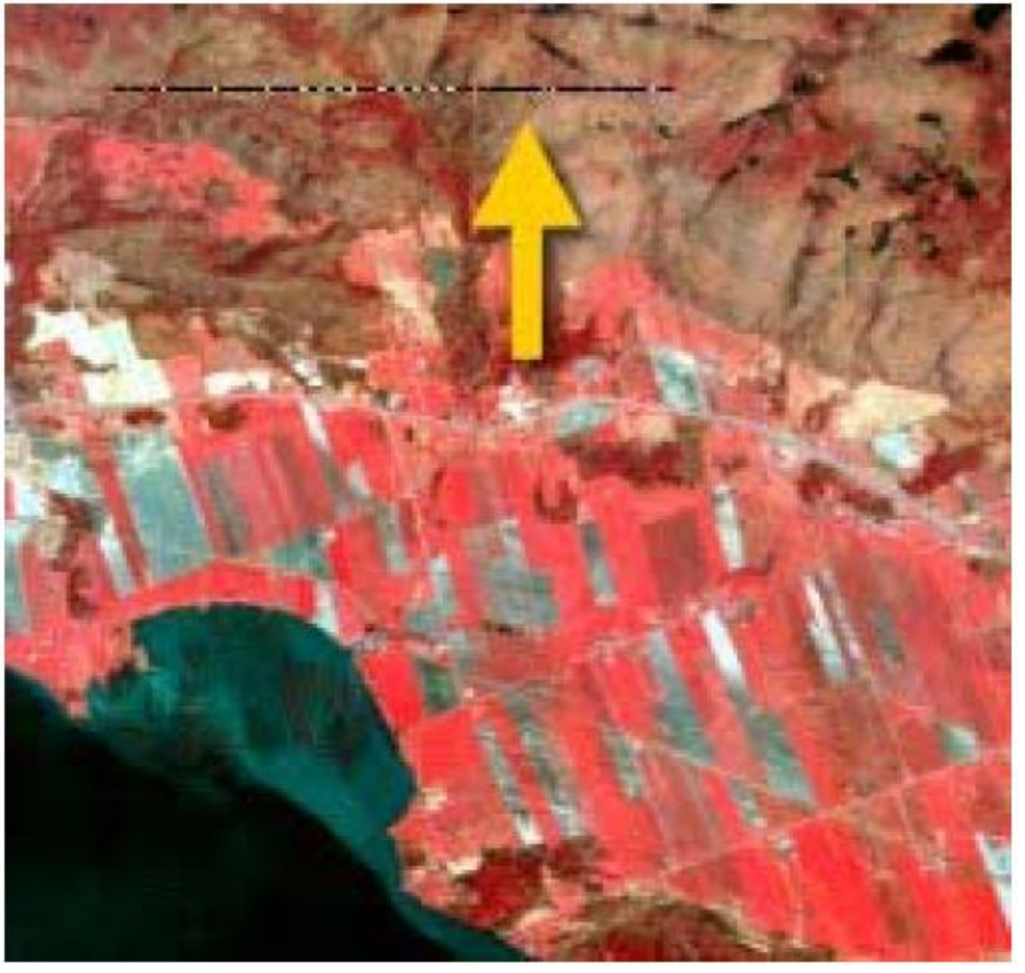
(Partially) missing lines

Due to Errors in

- ☐ sampling or scanning equipment
- ☐ transmission or recording of image data
- ☐ reproduction of the media containing the data

Methods of Correction

- ☐ interpolation using data from adjacent scan lines
- ☐ interpolation data at the same scan line from different spectral bands

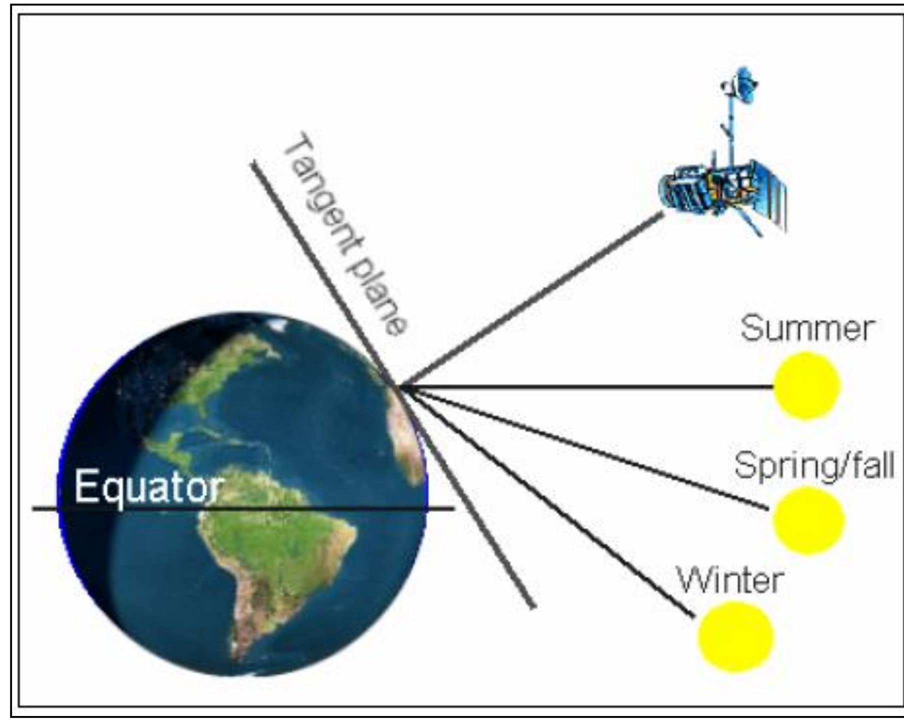


RADIOMETRIC PRE PROCESSING

Sun Angle Correction

❖ position of the sun relative to the earth changes depending on time of the day and the day of the year

❖ In the northern hemisphere the solar elevation angle is smaller in winter than in summer



- An absolute correction involves dividing the DN-value in the image data by the sine of the solar elevation angle
- Size of the angle is given in the header of the image data

$$DN_{Corr} = \frac{DN}{Sin\alpha}$$

RADIOMETRIC PRE PROCESSING

Sensor Calibration

necessary to generate absolute data on

physical properties such as

- ☐ reflectance
- ☐ temperature
- ☐ emissivity
- ☐ backscatter

☐ values provided by data provider / agency

RADIOMETRIC PRE PROCESSING

- Influences the brightness values (DNs) of an image to correct for sensor malfunctions or to adjust for atmospheric degradation
- Any sensor, reading a DN (in near IR or VIS bands) is a mixture (sum) of

  DN derived from the earth surface

  DN of the atmosphere
- A Pre processing operation to correct for atmospheric degradation fall into THREE categories

  1) Radiative Transfer Code (RTC) computer models

  2) Image Based Atmospheric Correction

  3) Covariance Matrix Method

1. RTC COMPUTER MODELS

- Model the physical behaviour of solar radiation as the EM wave passes through the atmosphere (*calculates radiative transfer of EM radiation through a planetary atmosphere*)
- Application of these models permits observed brightness to be adjusted to approximate true values that might be observed under a clear atmosphere, there by
  1) Improves image quality
  2) Provide accurate analysis
- RTC models the physical process of scattering at the level of individual particles and molecules
- Advantages:
  1) Rigorous 2) Accurate
  3) Applicable to wide variety of circumstances

1. RTC COMPUTER MODELS

- Dis-Advantages:
    1) Complex models
    2) Requires detailed in-situ data acquired simultaneously with the image
- Mateorological satellites can collect atmospheric data that can contribute to atmospheric corrections of imagery

2. IMAGE BASED ATMOSPHERIC CORRECTION

- Based on examination of spectra of objects of known (or, assumed) brightness recorded by multi spectral image
- Atmospheric scattering is related to:

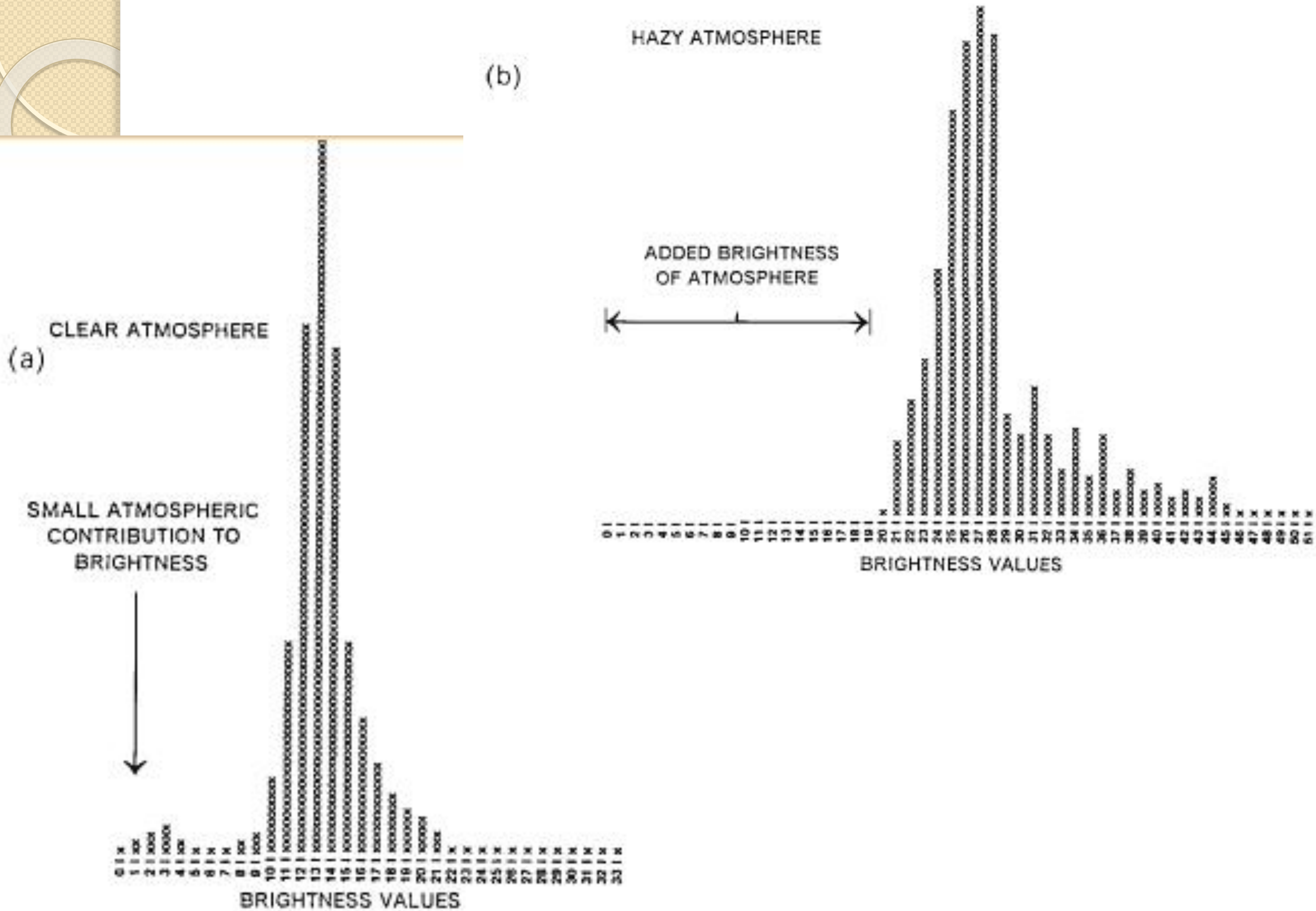
  Wavelength; Size of particles; Abundance of Particles
- This method is based on establishing the relationships in spectral values in separate bands (of a multi spectral image)
- This method is also known as "image based atmospheric correction"
- Adjustment to atmospheric effects is solely done from the evidence that is available in image itself
- Ideally, the target consists of natural (or, man made) features that can be observed with airborne (or, ground based) instruments at the time of image acquisation

- Target feature : Objects of known brightness – very dark object (such as water body, shadows cast by clouds, shadows cast by large topographic features)
- The lowest value for dark object in each band will be set to zero
- The dark black colour is assumed to be the correct tone for a dark object in the absence of atmospheric scattering
- This method of adjusting digital values or atmospheric degredation is known as:

  Histogram Minimum Method (HMM)

  Dark Object Subtraction Method (DOS)
- This method is simple to use
- Dis-advantges:

  Application of a single correction to all the pixels is a rough approximation


(a)
CLEAR ATMOSPHERE
SMALL ATMOSPHERIC CONTRIBUTION TO BRIGHTNESS
BRIGHTNESS VALUES
(b)
HAZY ATMOSPHERE
ADDED BRIGHTNESS OF ATMOSPHERE
BRIGHTNESS VALUES

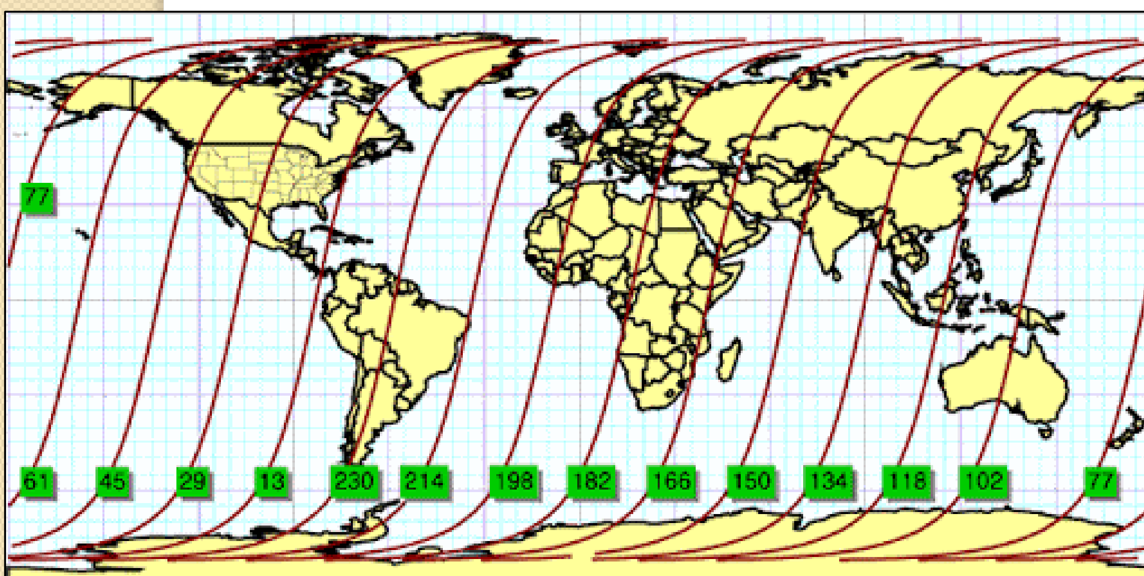
3. COVARIANCE MATRIX METHOD

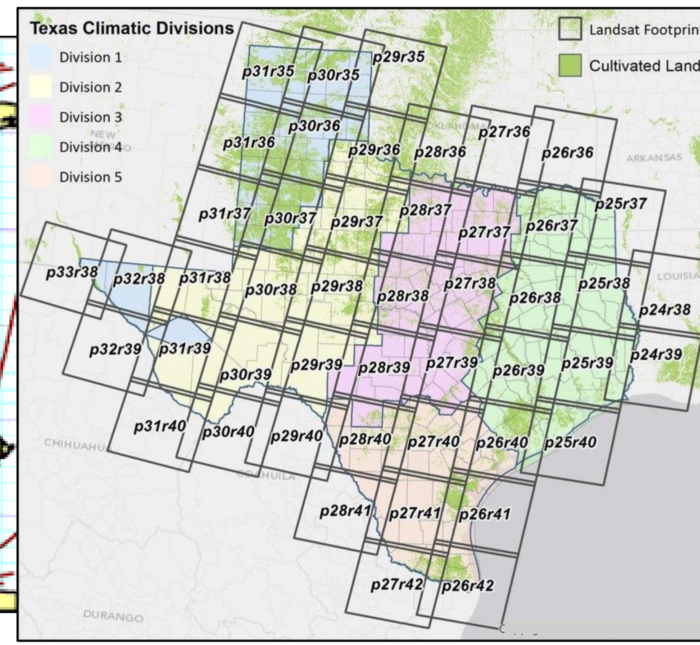
- Examines brightness of objects within each scene but attempts to exploit knowledge of interrelationships between separate spectral bands
- Uses paired values within each band with values from a near infra red spectral channel
- The Y-intercept of the regression line is taken as the correction value for the specific band in question
- This method can be applicable to local areas (100 to 500 pixels)
- Adjustment (Correction) is tailored to conditions important within specific regions
- The variance – covariance matrix is examined to denote the variability between all band pairs on the data
- This method is applied with care and knowledge of local geographic setting will yield satisfactory results

IMAGE SCENE REPRESENTATION

LANDSAT

- Orbit paths are numbered westward
- Path 001 -- > Through eastern Greenland and south America
- Row refers to the latitudinal center line of a frame of imagery
- Rows are numbered southward beginning at 80 deg, N latitude
- Latitude with row 60 is closest to the equator
- Combination of path and row numbers identifies the scene center





GEOMETRIC CORRECTIONS

- Remotely sensed images are distorted by both the curvatures of the Earth and the sensor being used
- The process of shifting pixel locations to remove distortion is known as rectification or georectification
- The process of assigning geographic coordinates to an image is known as georeferencing
- Georeferencing is followed by map projection (by representing the surface of the sphere on a plane)
- Geometric correction is necessary to preprocess remotely sensed data and remove geometric distortion so that individual pixels are in their proper plani metric (x, y) map locations
- Geometrically corrected imagery can be used to extract accurate distance, polygon area, and direction information

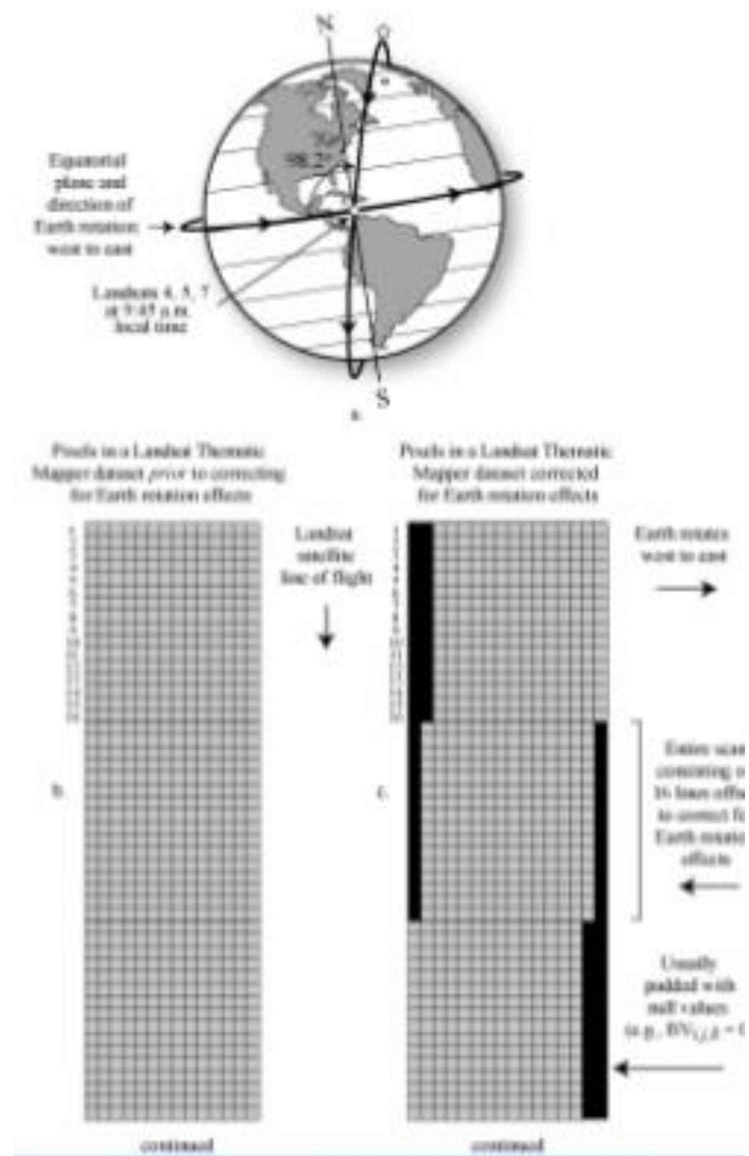
GEOMETRIC ERRORS IN RS

- Introduced by the remote sensing system itself or in combination with earth rotation and curvature effects (internal errors) OR by random movements of space craft (external errors)
- **Internal errors** are systematic (predictable) and can be easily corrected, as below

1) Skew caused by earth rotation effects
2) Scanning system induced variation in ground resolution cell size
3) Scanning system one-dimensional relief system
4) Scanning system tangential scale distortion

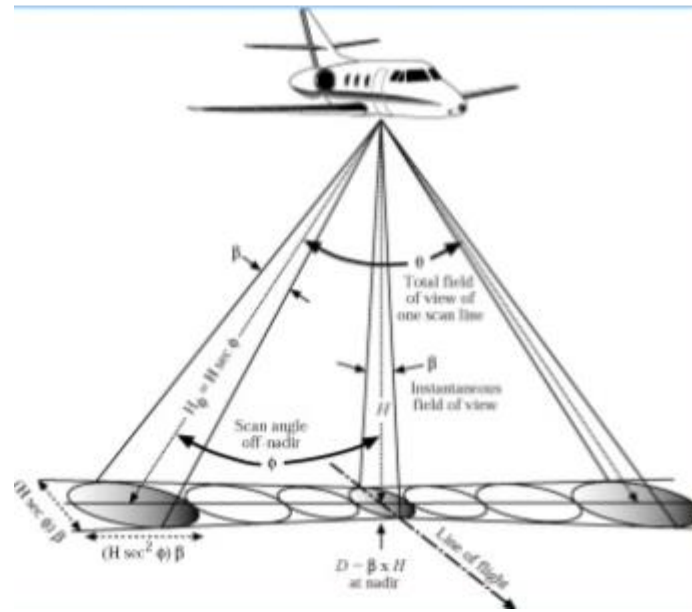
1. Earth Rotation Effects

- Land observation (sun synchronous) satellites have fixed orbits – North to south, where as earth rotation is west to east
- The interaction of these two skews the geometry of the image collected
- While the matrix (raster) may look correct, it actually contains systematic geometric distortion caused by the angular velocity of the satellite in its descending orbital path in conjunction with the surface velocity of the Earth as it rotates on its axis while collecting a frame of imagery
- Adjusting the image to the west to compensate earth rotation is called de-skewing



2. Variation in Ground cell resolution

- Happens along a single across-track scanning
- Instantaneous FoV define the image size
- Pixels off-nadir have semi major and semi minor axis that defines cell resolution

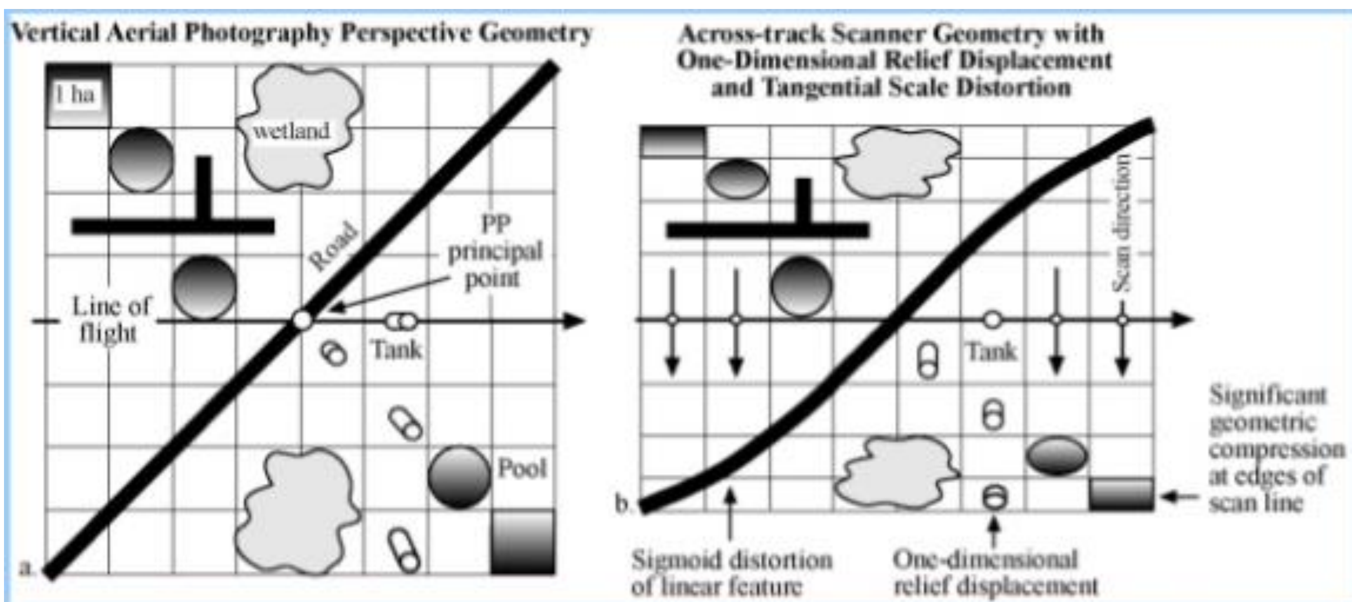


GROUND SWATH

- The width of the terrain strip remotely sensed by the system during one complete across-track sweep of the scanning mirror
- It is a function of angular field of view of the system (θ) and altitude of the sensor above ground level (H)
  - Ground swath width = tan(θ/2) * H * 2

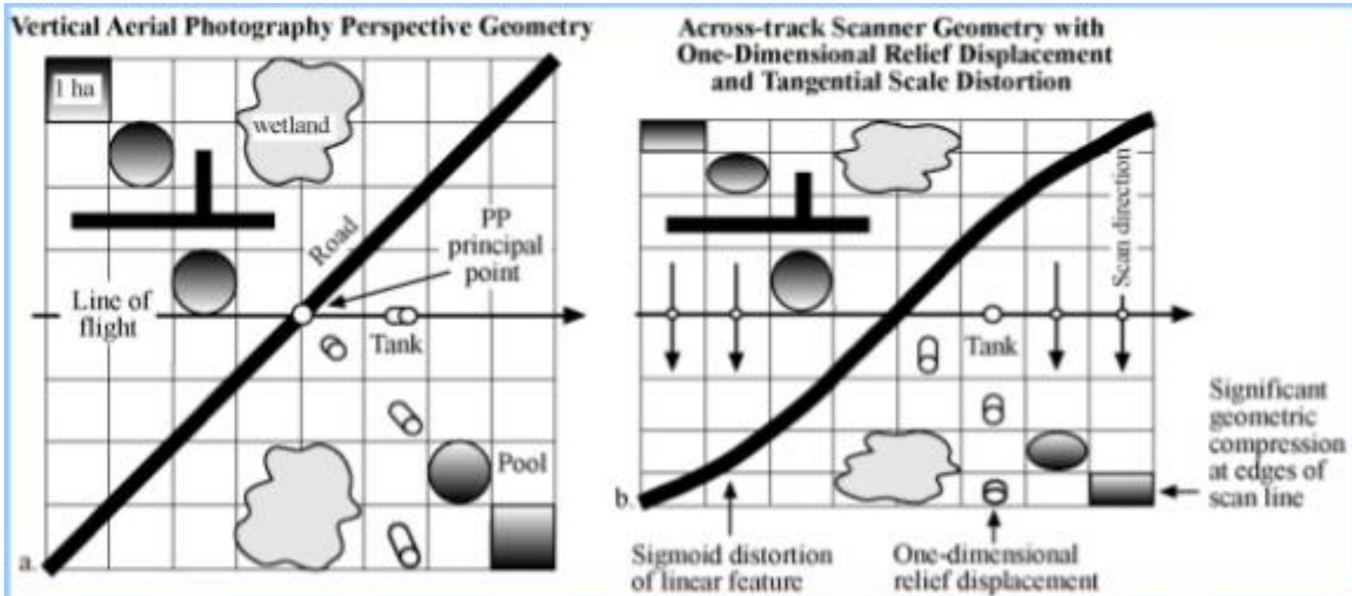
3. Variation in Relief displacement

- Relief displacement is the shift in an object's image position caused by its elevation above a particular datum
- Tangential scale distortion is the compression of image features at points away from the nadir
- Greater the height of object above local terrain, and greater is the distance from nadir (flight path), greater is relief displacement



4. Scale distortion

- Resulting from the mirror rotation at a constant rate
- Sensor scans shorter distance at nadir than at edge
- Objects near the nadir exhibit a proper shape and scale
- Greater the distance of ground-resolution cell from nadir, greater is the image scale compression – tangential scale distortion
- Linear features take S-shaped, sigmoid function

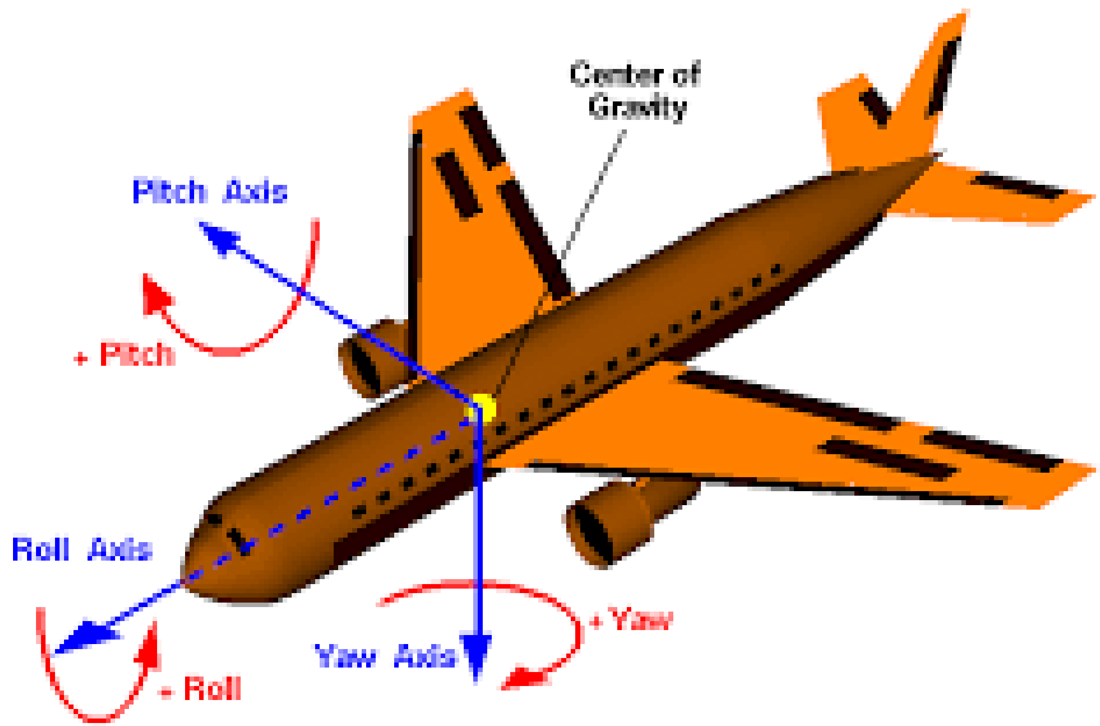


SATELLITE MOVEMENT AXIS

Rotation around the front-to-back axis is called **roll**

Rotation around the side-to-side axis is called **pitch**.

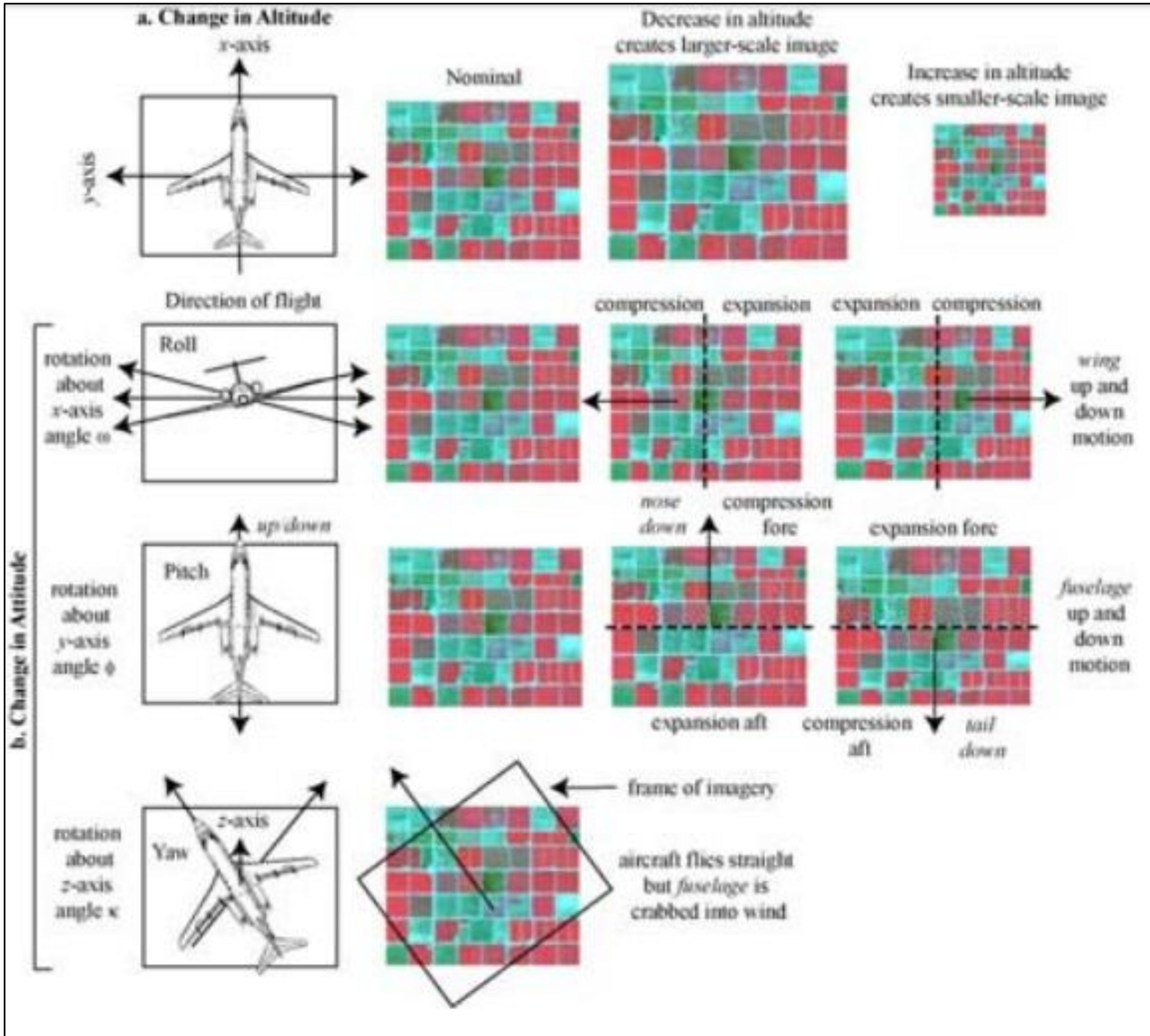
Rotation around the vertical axis is called **yaw**



EXTERNAL ERRORS

- External geometric errors are usually introduced by phenomena that vary in nature through space and time
- Resulting from random movements by the aircraft (or spacecraft) at the exact time of data collection
- *altitude changes, and/or*
- *attitude changes (roll, pitch, and yaw)*
- Geometric distortions introduced by sensor system attitude (roll, pitch, and yaw) and/or altitude changes can be corrected using ground control points and appropriate mathematical models
- The image analyst must be able to obtain two distinct sets of coordinates associated with each GCP:
- image coordinates specified in i rows and j columns, and
- • map coordinates (e.g., x, y measured in lat and long)

EXTERNAL ERRORS



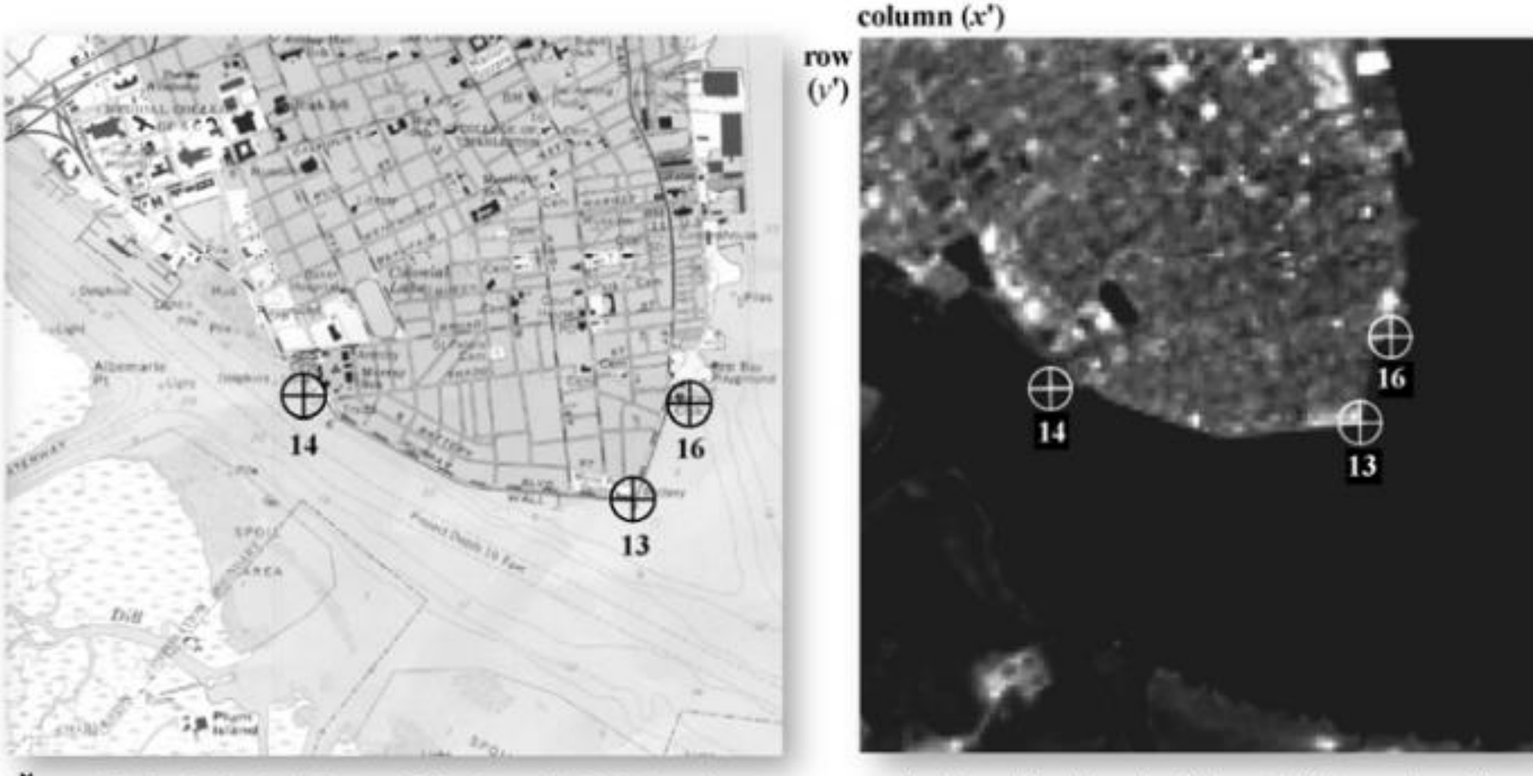
GROUND CONTROL POINTS

- Geometric distortions introduced by the sensor system can be corrected using ground control points (GCPs) and appropriate mathematical models
- The paired coordinates (i, j and x, y) from many GCPs (e.g., 20) can be modeled to derive geometric transformation coefficients.
- GCP → Location on the surface of earth that can be identified on imagery and located accurately on the map
- Geometrical rectification of an image ensure a standard datum and projection
- Can be done using:
  - Image to Map rectification
  - Image to Image registration

GROUND CONTROL POINTS

Image to Map Registration

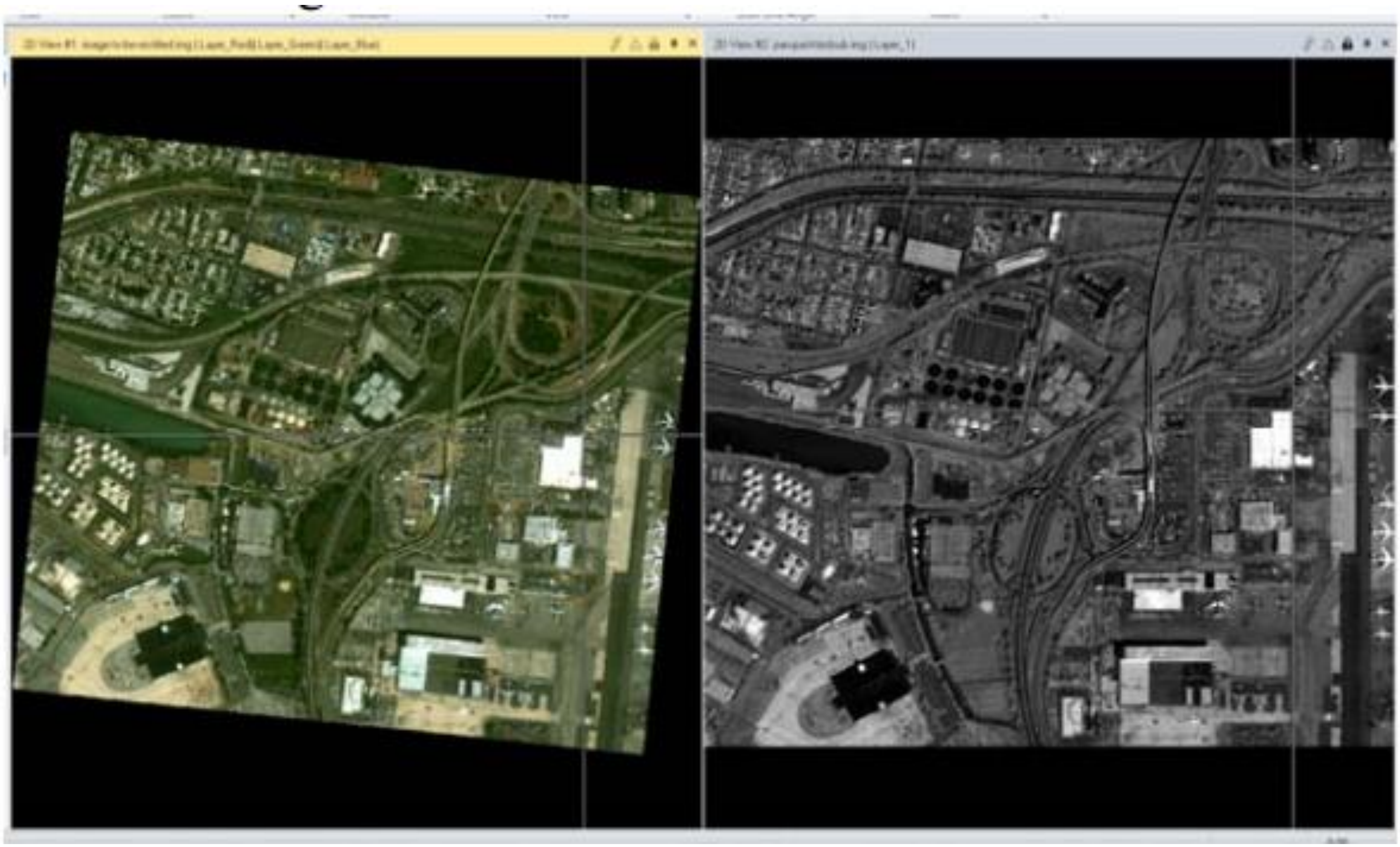
Selecting Ground Control Points for Image-to-Map Rectification



a. U. S. Geological Survey 7.5-minute 1:24,000-scale topographic map of Charleston, SC, with three ground control points identified.

b. Unrectified Landsat Thematic Mapper band 4 image obtained on November 9, 1982.

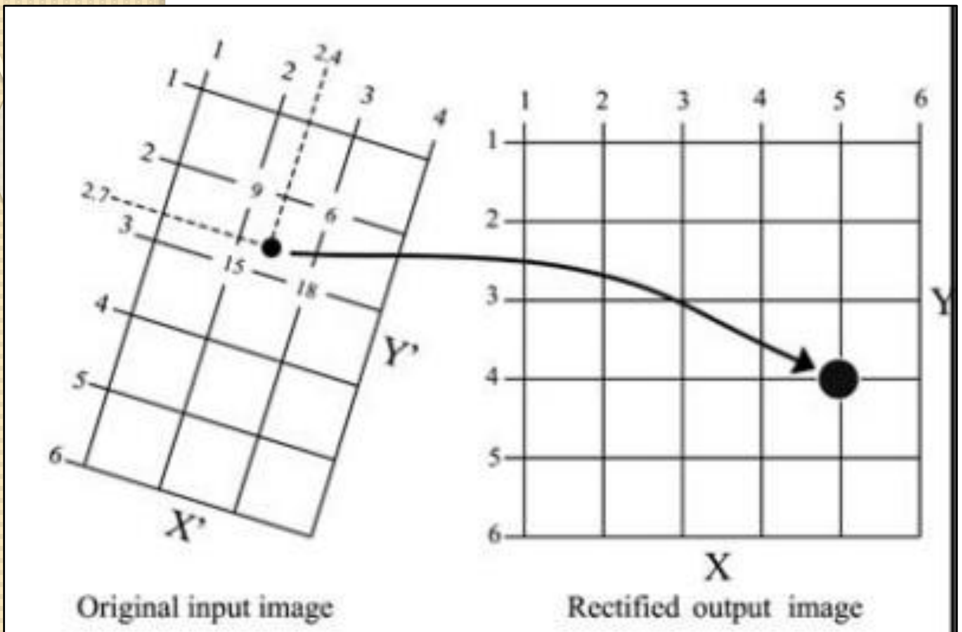
GROUND CONTROL POINTS

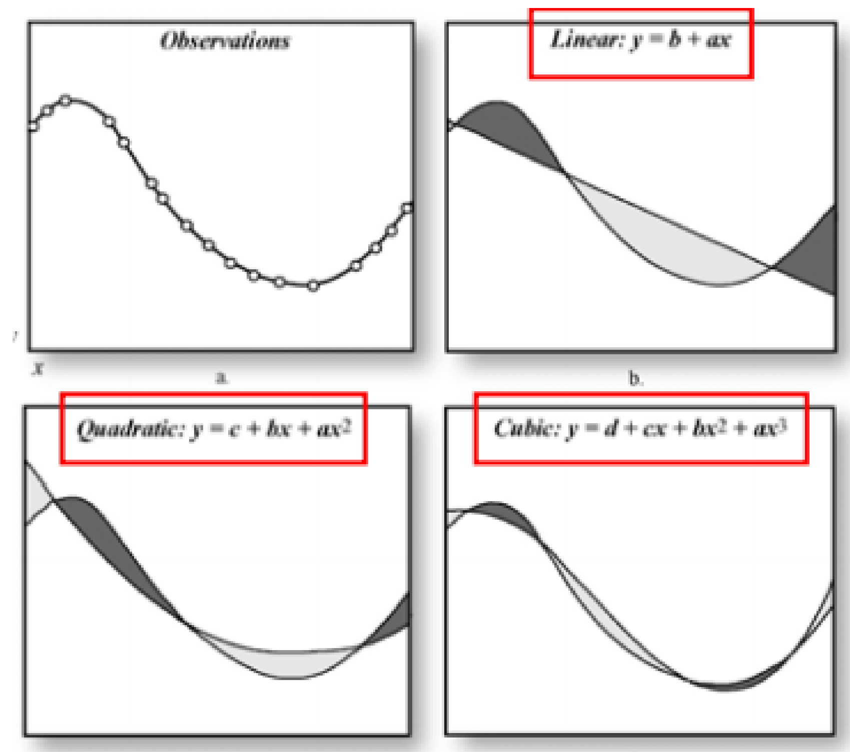


SPATIAL INTERPOLATION

- The geometric relationship between the input pixel coordinates (column and row; referred to as x', y') and the associated map coordinates of this same point (X,Y) must be identified
- A number of GCP pairs are used to establish the nature of the geometric coordinate transformation that must be applied to rectify or fill every pixel in the output image (x, y) with a value from a pixel in the unrectified input image (x' y')
- Polynomial equations are used to convert source file coordinates into the referencing map coordinates
- Depending upon the distortion in an image, the number of GCPs used, and their locations relative to one another vaies

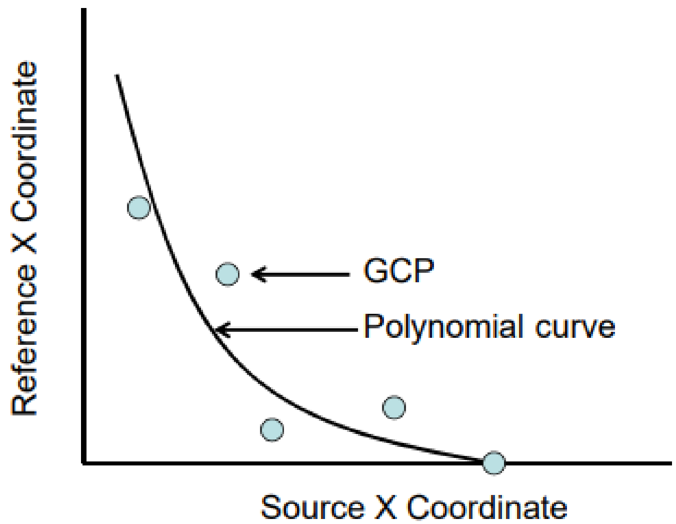
SPATIAL INTERPOLATION



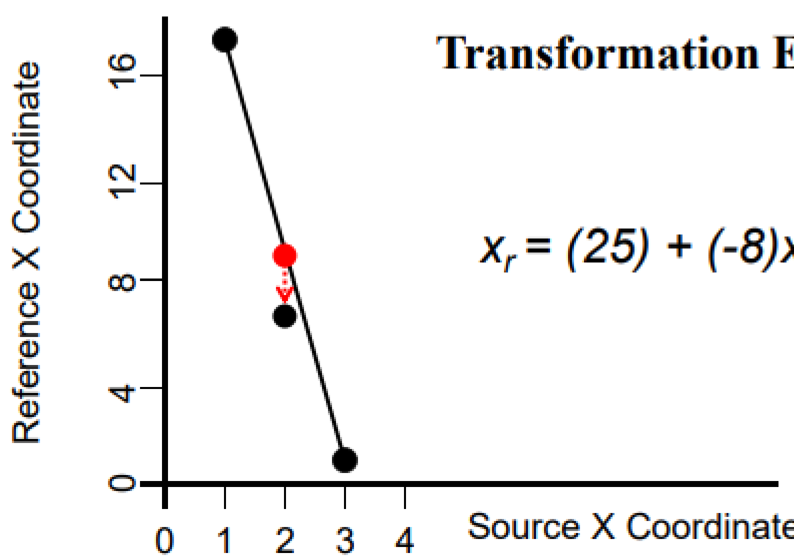


- A transformation matrix is computed from the GCPs.
- The matrix consists of coefficients which are used in polynomial equations to convert the coordinates
- It is almost impossible to derive coefficients that produce no error.
- Every GCP influence the coefficients

SPATIAL INTERPOLATION

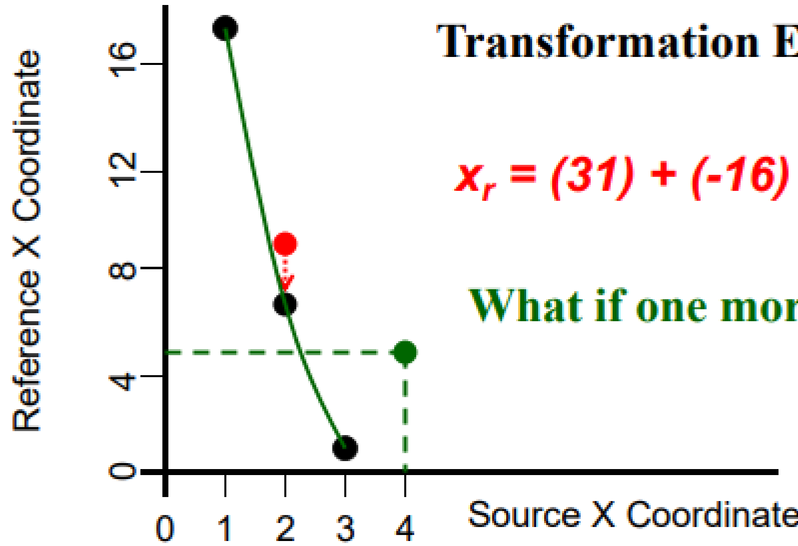


Transformation Example: 1st order



$$x_r = (25) + (-8)x_i$$

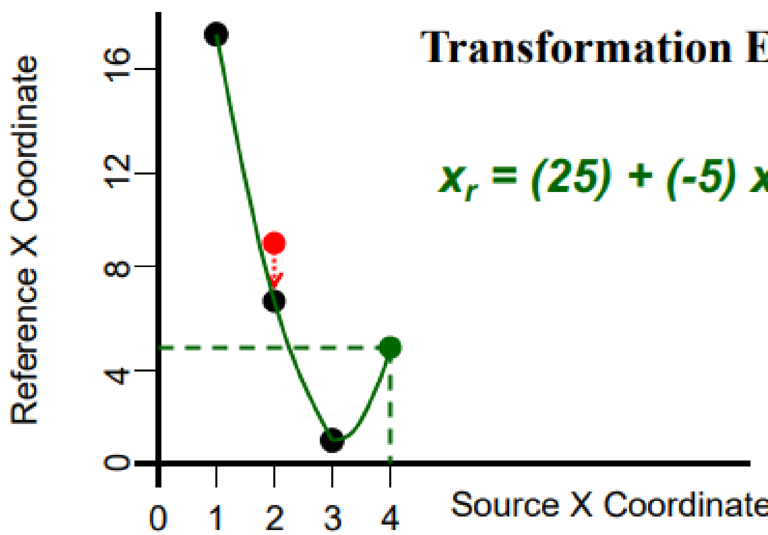
SPATIAL INTERPOLATION



Transformation Example: 2nd order

$$x_r = (31) + (-16)\,x_i + (2)\,x_i^2$$

What if one more GCP is added?



Transformation Example: 3rd order

$$x_r = (25) + (-5)\,x_i + (-4)\,x_i^2 + (1)\,x_i^3$$

SPATIAL INTERPOLATION

- Higher orders of transformation can be used to correct more complicated types of distortion.
- However, to use a higher order of transformation, more GCP's are needed.
- The minimum number of points required to perform a transformation of order t equals

$$\frac{((t+1)(t+2))}{2}$$

Order of Transformation	Minimum GCPs Required
1	3
2	6
3	10
4	15
5	21
6	28
7	36

GEOMETRIC CORRECTION

- Needed in preparation of planimetrically correct versions of aerial and satellite images
- Requires removal of positional effects of topographic relief to produce a positional accurate image
- Image registration is done using sampling techniques such as:

    a) Nearest Neighbourhood

    b) Bilenier Interpolation

    c) Cubic Convolution

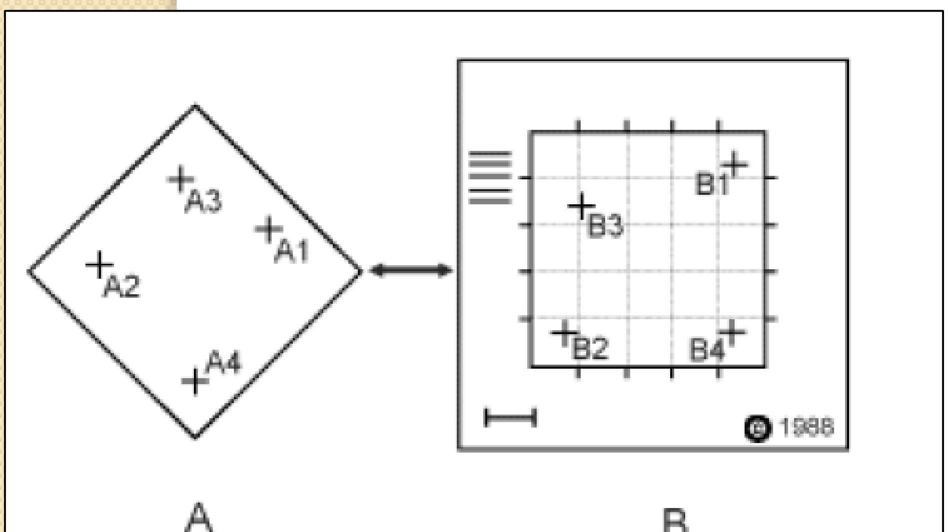
- Resampling scales; rotates; translates; and performs related manipulations as necessary to bring the geometry of an image to match a particular reference image of desired properties
- Georeferencing is a resampling technique, where in matching is done not only to a reference image but also to reference points that corresponds to specific (known) locations on ground

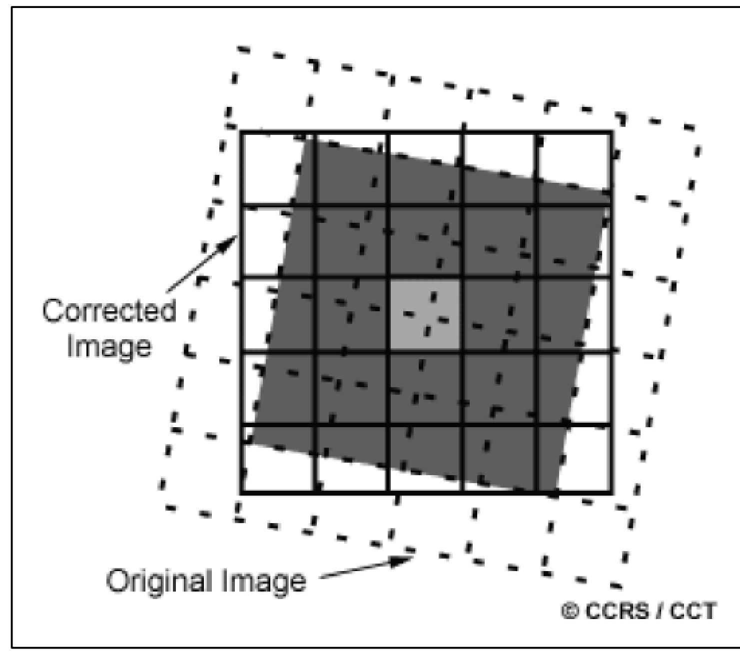
GEOMETRIC CORRECTION

- Intensity interpolation involves the extraction of a brightness value from an x', y' location in the original (distorted) input image and its relocation to the appropriate x, y coordinate location in the rectified output image
- There are several methods of brightness value (BV) intensity interpolation that can be applied
    1. nearest neighbor,
    2. bilinear interpolation, and
    3. cubic convolution.
- The practice is commonly referred to as resampling

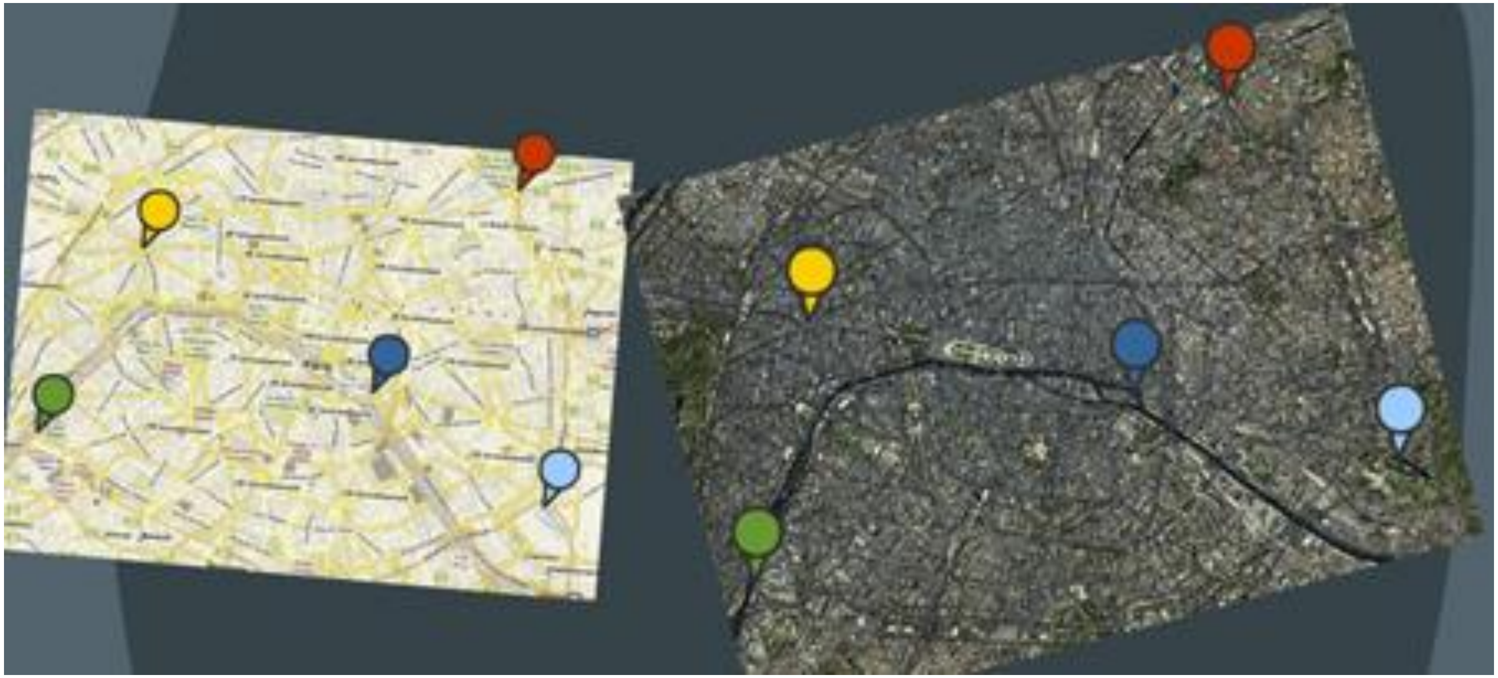
GEOMETRIC CORRECTION

Geometric registration process involves identifying the image coordinates of several clearly discernible points, called ground control points (or GCPs), in the distorted image, and matching them to their true positions in ground coordinates (e.g. latitude, longitude)





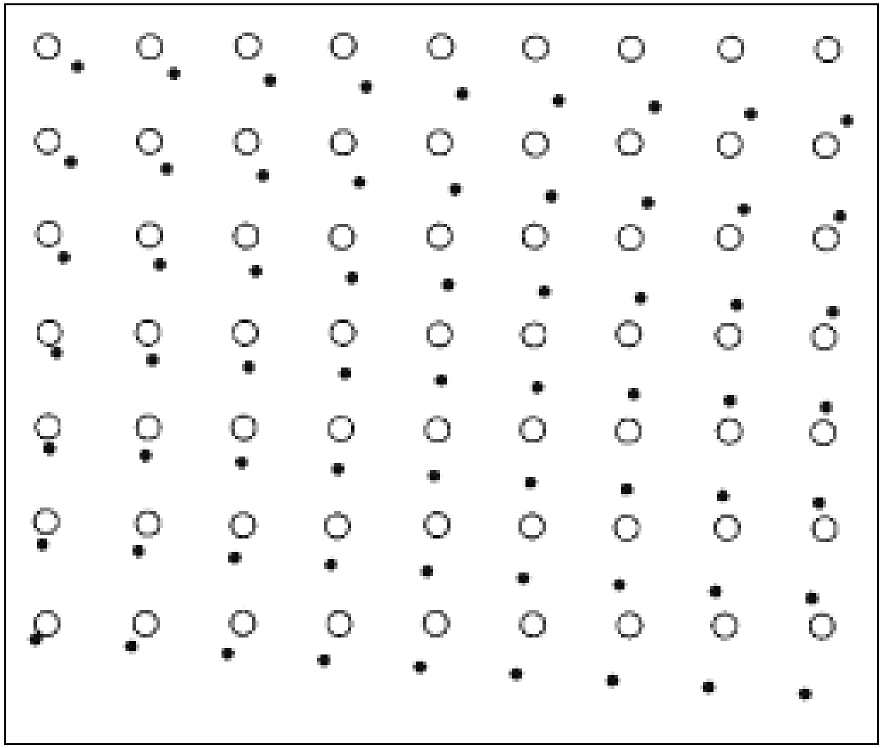
GEOMETRIC CORRECTION



GEOMETRIC CORRECTION

Resampling

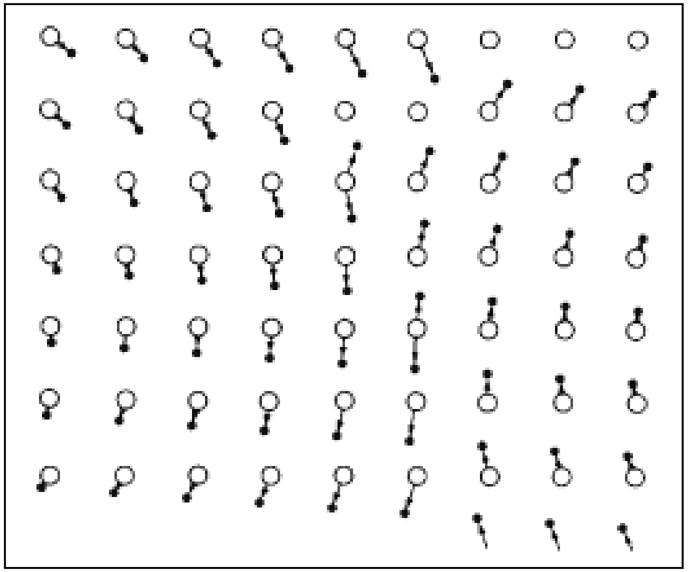
- Input Image → Array of open dots (Uncorrected Image)
- Output Image → Array of solid dots
- Locations of output pixels are derived from information provided by Ground Control Points (GCPs)
- Aim is to convert the input image for position and resample



GEOMETRIC CORRECTION

Nearest Neighbour

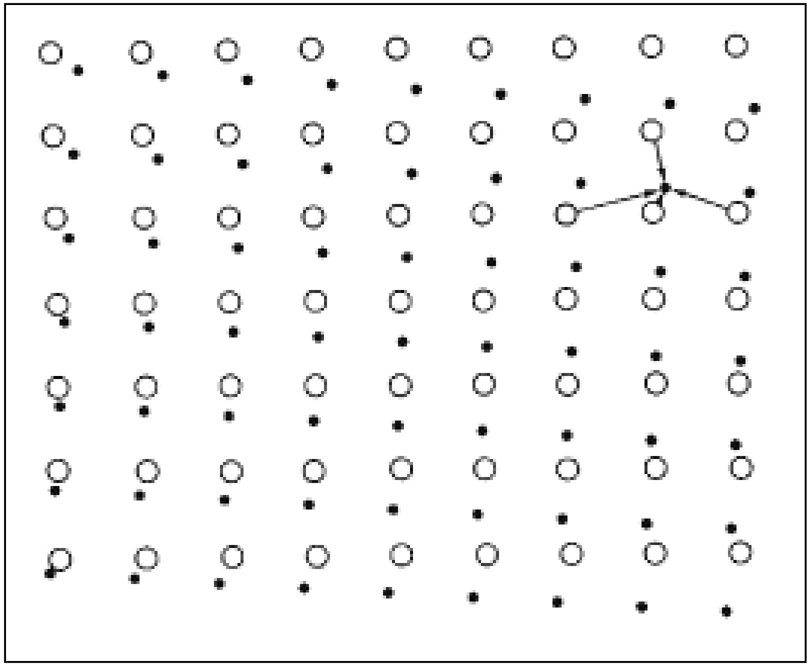
- Assign each "corrected" pixel the value from the nearest "uncorrected" pixel
- Simple to use
- Has the ability to preserve the original values of image
- May create noticeable positional errors
- The brightness value closest to the predicted x', y' coordinate is assigned to the output x, y coordinate



GEOMETRIC CORRECTION

Bilinear Interpolation

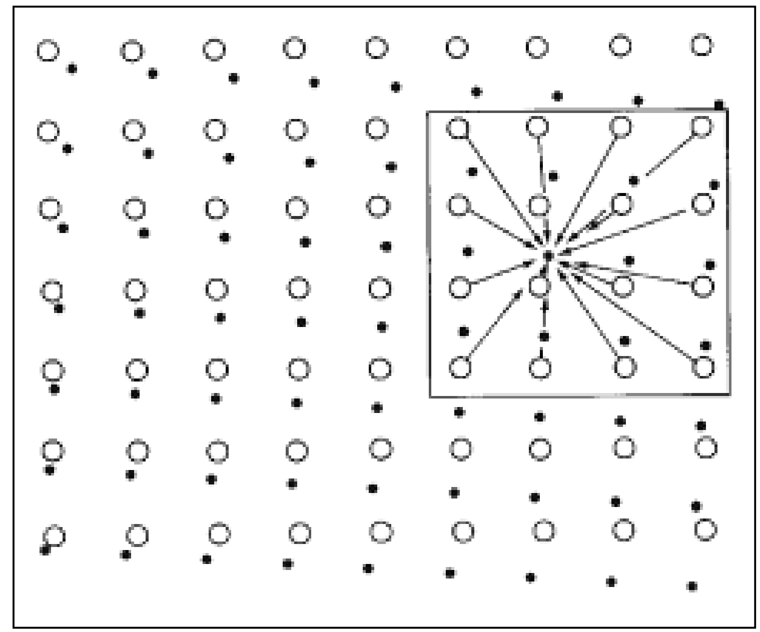
- Calculates a value for each output pixel based on a weighted average of the four nearest input pixels
- Nearer pixel values are given greater influence in calculating output pixel values
- Output image will not have the unnaturally blocky appearance of nearest neighbours
- Creates new pixel values. Brightness values in the input image are lost
- Since resampling is done on blocks of pixels, spatial resolution is lost

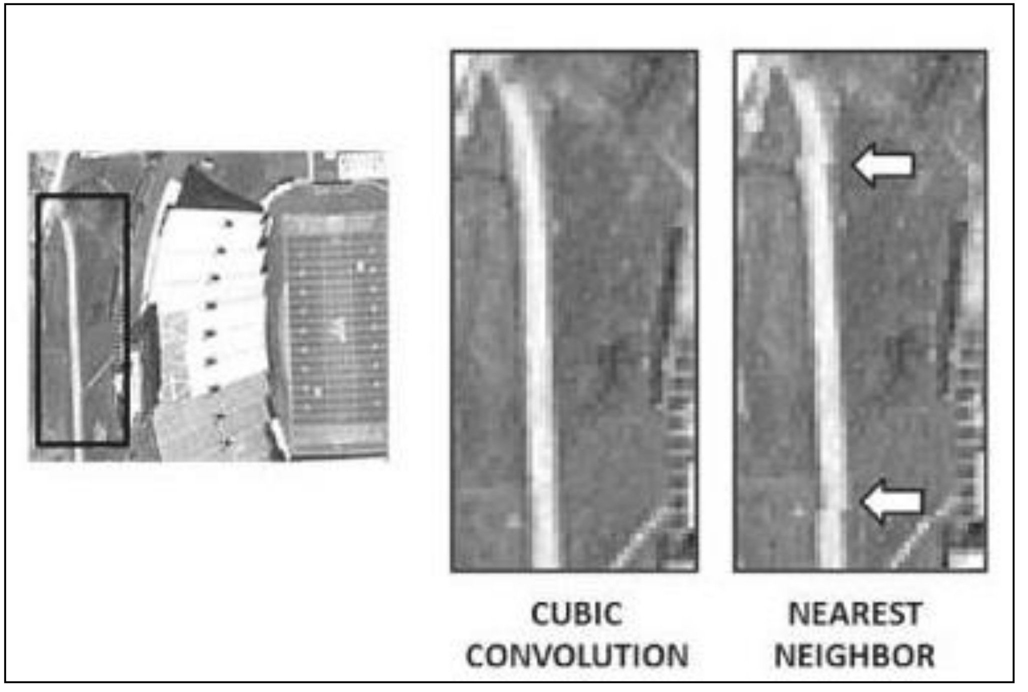


GEOMETRIC CORRECTION

Cubic Convolution

- Most sophisticated, most complex, most widely used method
- Uses a weighted average of values within a neighbourhood that extends 2 pixels in each direction (a total of 16 pixels)
- Data is altered more that are those of other methods
- Minimum number of GCPs needed is more
- Has natural appearance




CUBIC
CONVOLUTION
NEAREST
NEIGHBOR


QUESTIONS ?