Digital Image Processing
Basic Concepts

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Presentation Outline

- Digital Image
- Digital Image Processing
- Image Preprocessing
  - Radiometric Errors & Correction
    - Line /Column Dropout / Banding
    - Haze Correction
    - Sun angle Correction
  - Geometric Error & Correction
    - Rectification
    - Resampling

A Picture is worth a thousand words

- Complex and sometimes multiple ideas can be conveyed by a single still image conveying its meaning or essence more effectively than a mere verbal description.
- Pictures concisely convey information about positions, sizes and inter-relationships between objects.
- Human beings are good at deriving information from such images, because of our innate visual and mental abilities.
- About 75% of the information received by Human are in pictorial form.

In the present context, the analysis of pictures that employ an overhead perspective, including the radiation not visible to human eye are considered.

Pictorial Representation

Textual Description:

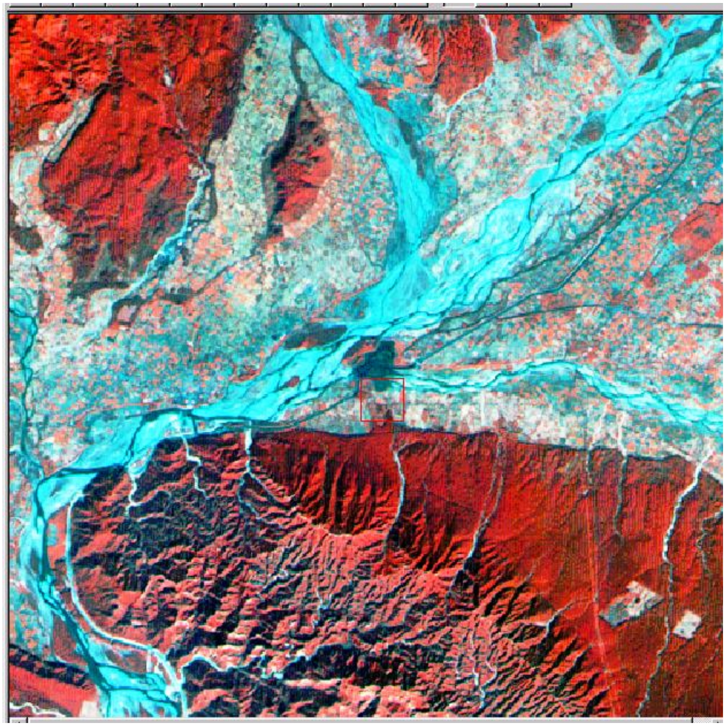
Ice cream is a sweetened frozen food typically eaten as a snack or dessert. It is usually made from dairy products, such as milk and cream, and often combined with fruits or other ingredients and flavours. It is typically sweetened with sucrose, corn syrup, cane sugar, beet sugar, and/or other sweeteners.

Typically, flavourings and colourings are added in addition to stabilizers. The mixture is stirred to incorporate air spaces and cooled below the freezing point of water to prevent detectable ice crystals from forming. The result is a smooth, semi-solid foam that is solid at very low temperatures (<35 °F / 2 °C). It becomes more malleable as its temperature increases.

https://en.wikipedia.org/wiki/Ice_cream

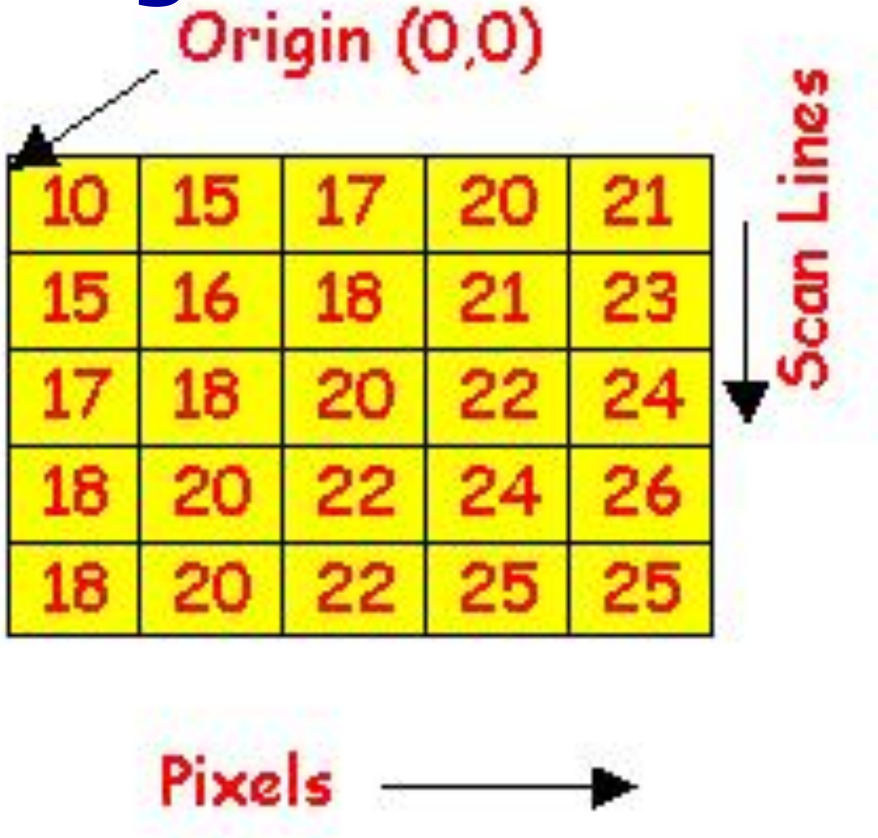
What is an Image ?

- **An IMAGE** is a Pictorial Representation of an object or a scene.
- Forms of Images
  - Analog
  - Digital



What is a Digital Image ?

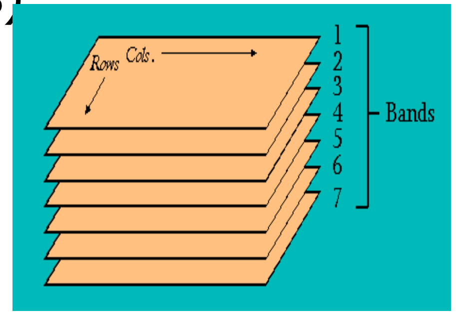
- Produced by Electro optical Sensors
- Composed of tiny equal areas, or picture elements abbreviated as <u>pixels</u> or pels arranged in a rectangular array
- With each pixel is associated a number known as Digital Number(DN) or Brightness value (BV) or gray level which is a record of variation in radiant energy in discrete form.
- An object reflecting more energy records a higher number for itself on the digital image and vice versa.

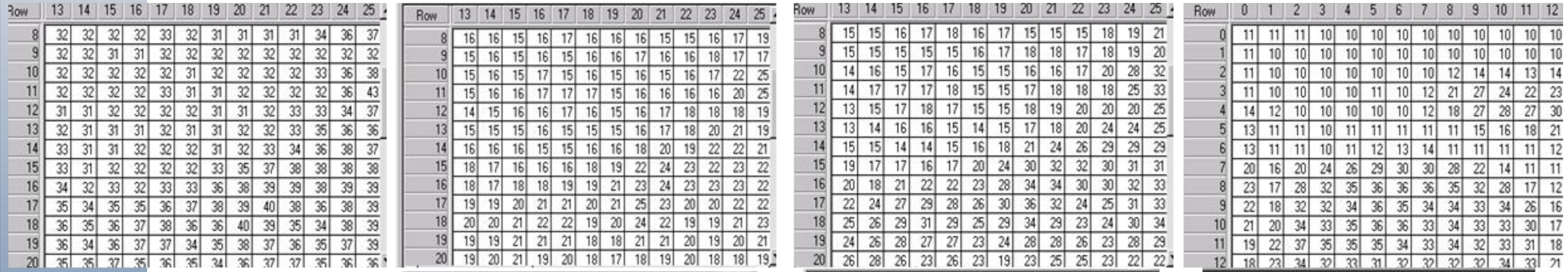


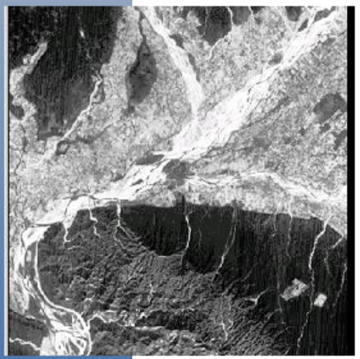
- Range of DN Values depend on Radiometric resolution
- 0 – Darkest, • 255 – Brightest (for 8 bit radiometric resolution)

Multi Spectral Remotely Sensed Image

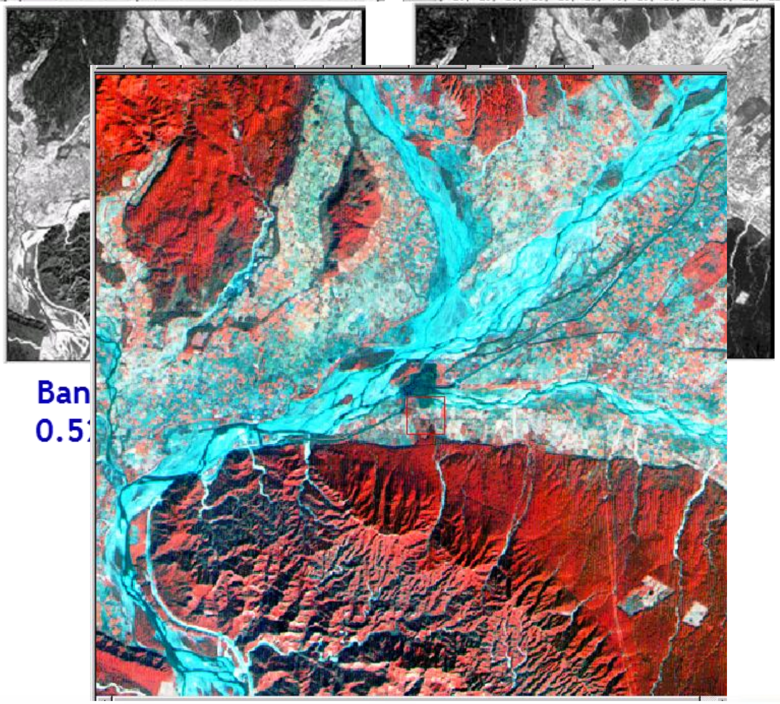
- Digital Images of an area captured in different spectral ranges (bands)
- A pixel is referred by its column, row, band number.





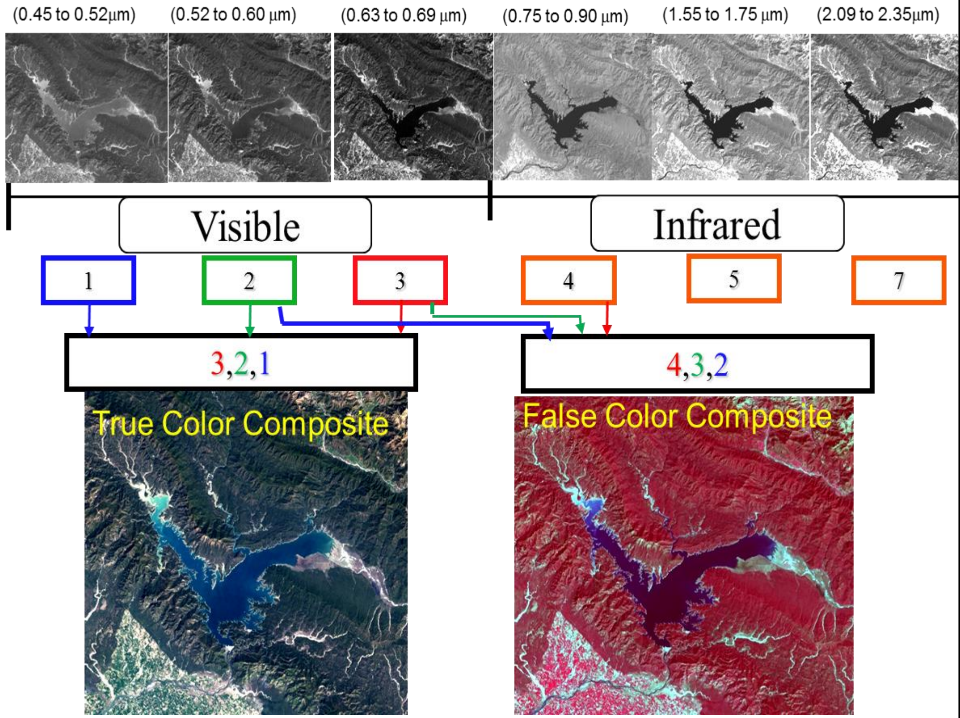


Band 1
0.45 - 0.52 µm



Ban
0.5

Band 4
0.77 - 0.86 µm



Digital Image Processing

Digital image processing can be defined as *the computer manipulation of digital values contained in an image for the purposes of image correction, image enhancement and feature extraction*.

A digital image processing system consists of computer Hardware (Personal Computer) and dedicated Image processing software necessary to analyze digital image data.

Image Processing Software Functionalities

- Data Acquisition/Restoration - Compensates for data errors, i.e Preprocessing (Radiometric and Geometric)
- Image Enhancement - Alters the visual impact of the image on the interpreter to improve the information content
- Information Extraction - Utilizes the decision making capability of computers to recognize and classify pixels on the basis of their signatures

Major Digital Image Processing Systems

Commercial

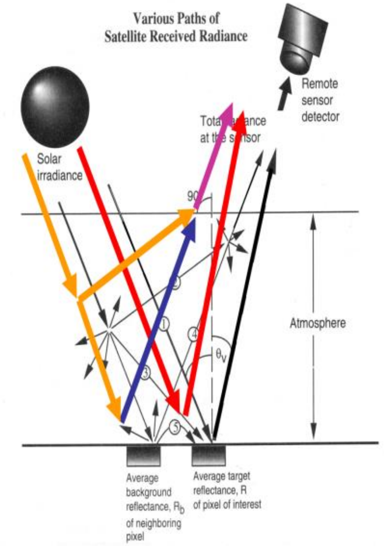
- ERDAS IMAGINE
- ENVI
- IDRISI
- ER Mapper
- PCI Geomatica
- *e*Cognition
- MATLAB
- Intergraph

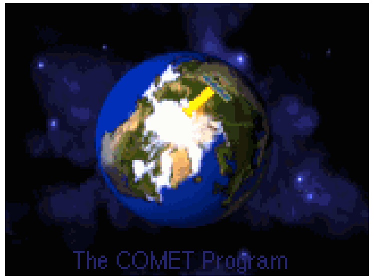
Open Source

- **ILWIS** (http://www.ilwis.org/index.htm)
- **Opticks** http://opticks.org/confluence/display/opticks/Welcome+To+Opticks
- **GRASS** (Geographic Resources Analysis Support System **http://grass.osgeo.org/**)
- **OSSIM** (Open Source Software Image Map www.ossim.org)
- **Multispec** https://engineering.purdue.edu/~biehl/MultiSpec/index.html
- **QGIS** (A Free and Open Source Geographic Information System http://www.qgis.org/en/site/)

Image Preprocessing

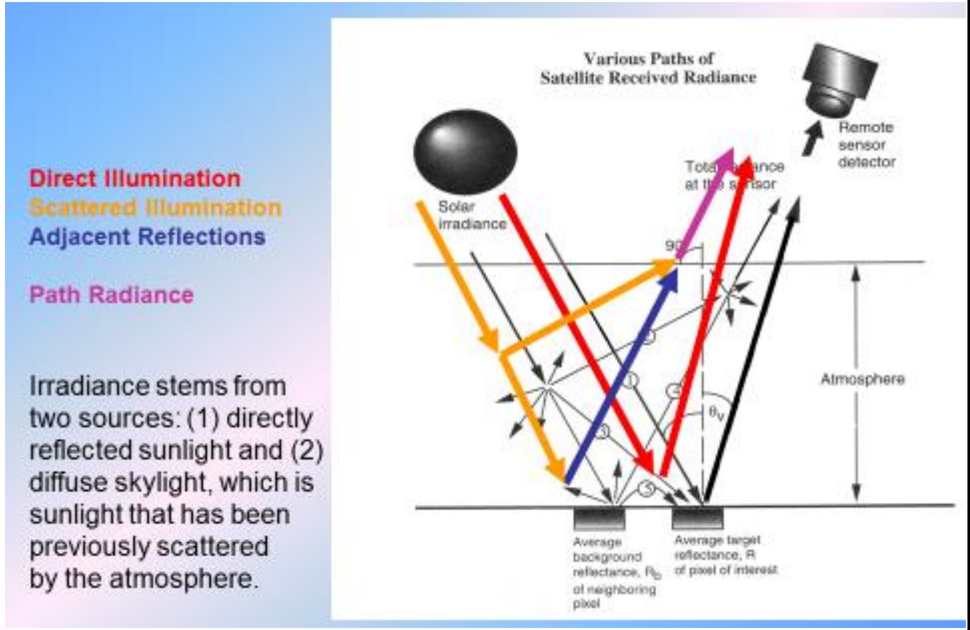
- *Remote sensing systems may not function perfectly all the time*.
- The Earth's atmosphere, land, and water are *complex* and do not lend themselves well to being recorded by remote sensing devices that have constraints such as spatial, spectral, temporal, and radiometric resolution.
- Consequently, error may creep into the data acquisition process and can degrade the quality of the remote sensor data collected.
- The two most common types of error encountered in remotely sensed data are ***radiometric*** and ***geometric***.
- Radiometric and geometric correction of remotely sensed data are normally referred to as ***preprocessing*** operations because they are performed prior to information extraction.





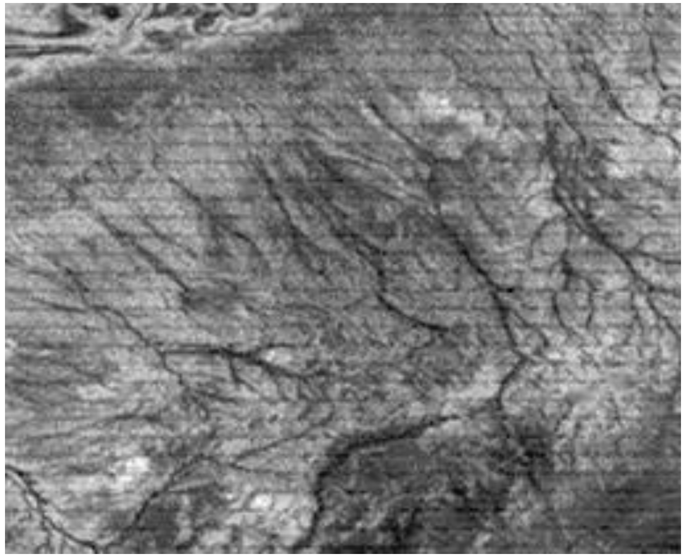
Radiometric errors- Causes

- Radiometric errors are caused by detector imbalance and atmospheric deficiencies.
- Radiometric corrections are also called as cosmetic corrections and are done to improve the visual appearance of the image.
- Common radiometric errors
    - Periodic line or column drop-outs,
    - Line or column striping.
    - Random bad pixels (shot noise),
    - Partial line or column drop-outs
    - Atmospheric errors

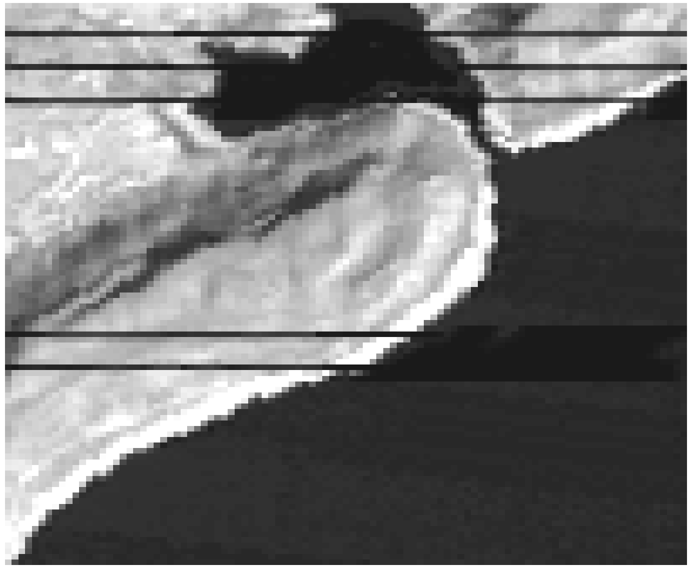


Line dropout

- If a detector fails to function this can result in an entire line or column of data with no spectral information.
- The bad line or column is commonly called a *line* or *column drop-out* and contains brightness values equal to zero



Periodic Line Dropout



Correction for Missing Lines /columns

- It is first necessary to locate each bad line in the dataset.
- A simple thresholding algorithm makes a pass through the dataset and flags any scan line having a mean brightness value at or near zero.
- Once identified, it is then possible to evaluate the output for a pixel in the preceding line ($BV_{i-1,j,k}$) and succeeding line ($BV_{i+1,j,k}$) and assign the output pixel ($BV_{i,j,k}$) in the drop-out line
- Replacement by either the preceding or the succeeding line

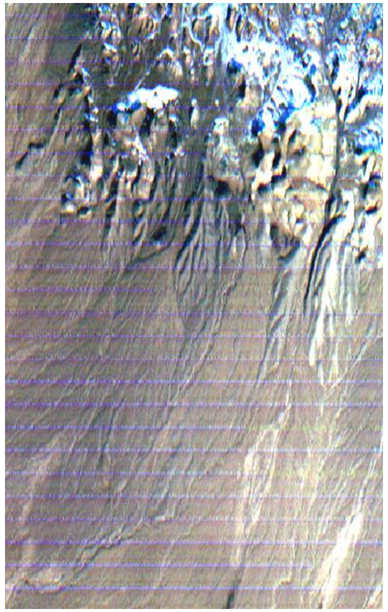
  $BV_{I,J}=BV_{I,J-1}$ OR $BV_{I,J}=BV_{I,J+1}$

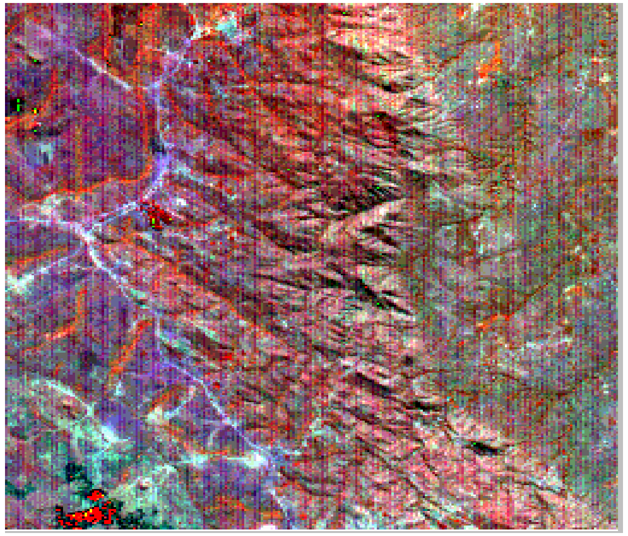
  $BV_{I,J}$ =missing pixel value of pixel I scan line J
- Averaging of the neighbouring pixel values

  $$BV_{I,J}=(BV_{I,J-1} + BV_{I,J+1})/2$$
- Replacing the line with other highly correlated band.

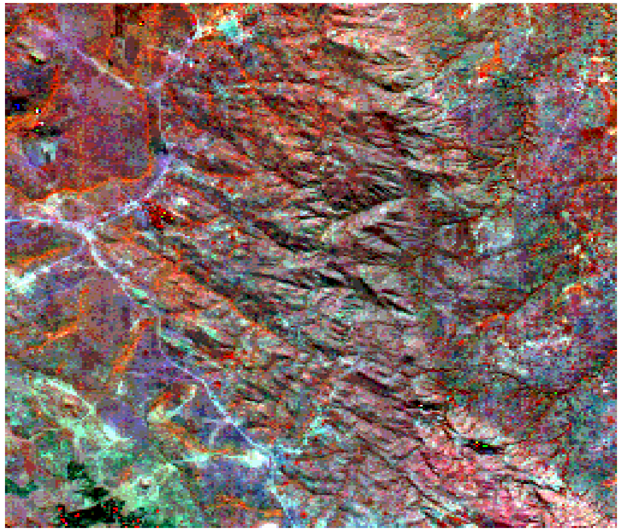
Line Striping (Banding)

- The response of some of the detectors may shift towards lower or higher end causing the presence of a systematic horizontal / vertical banding pattern
- Banding is an cosmetic defect and it interferes with the visual appreciation of the patterns and features on the image
- Variation in gain and offset of each sensor (linear sensor characteristic) as the sensor deteriorates in time





Striping



De-striped

Line striping correction

- A sensor is called ideal when there is a linear relationship between input and the output.
- Correction uses a linear expression to model the relationship between input & output values.
- Assumes that mean and standard deviation of data from each detector should be same.
- Linear sensor model :

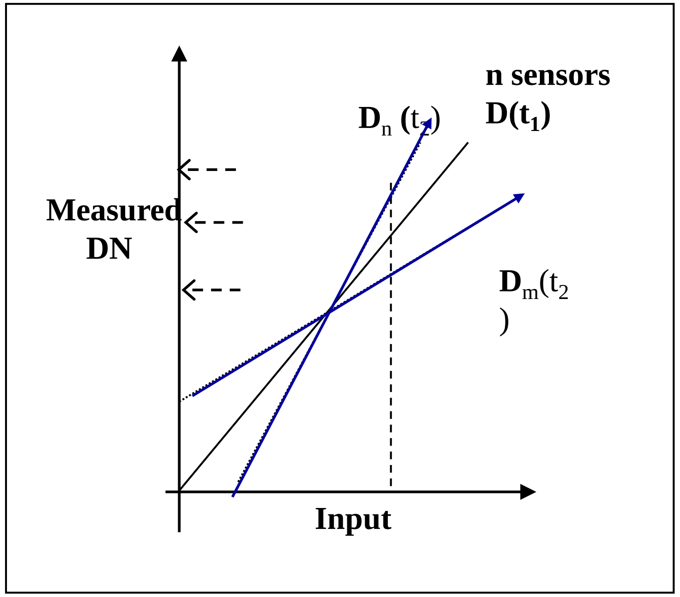
$y = a.x + b$

a = gain

b = offset

x = input

y = output



Atmosphere induced errors

HAZE

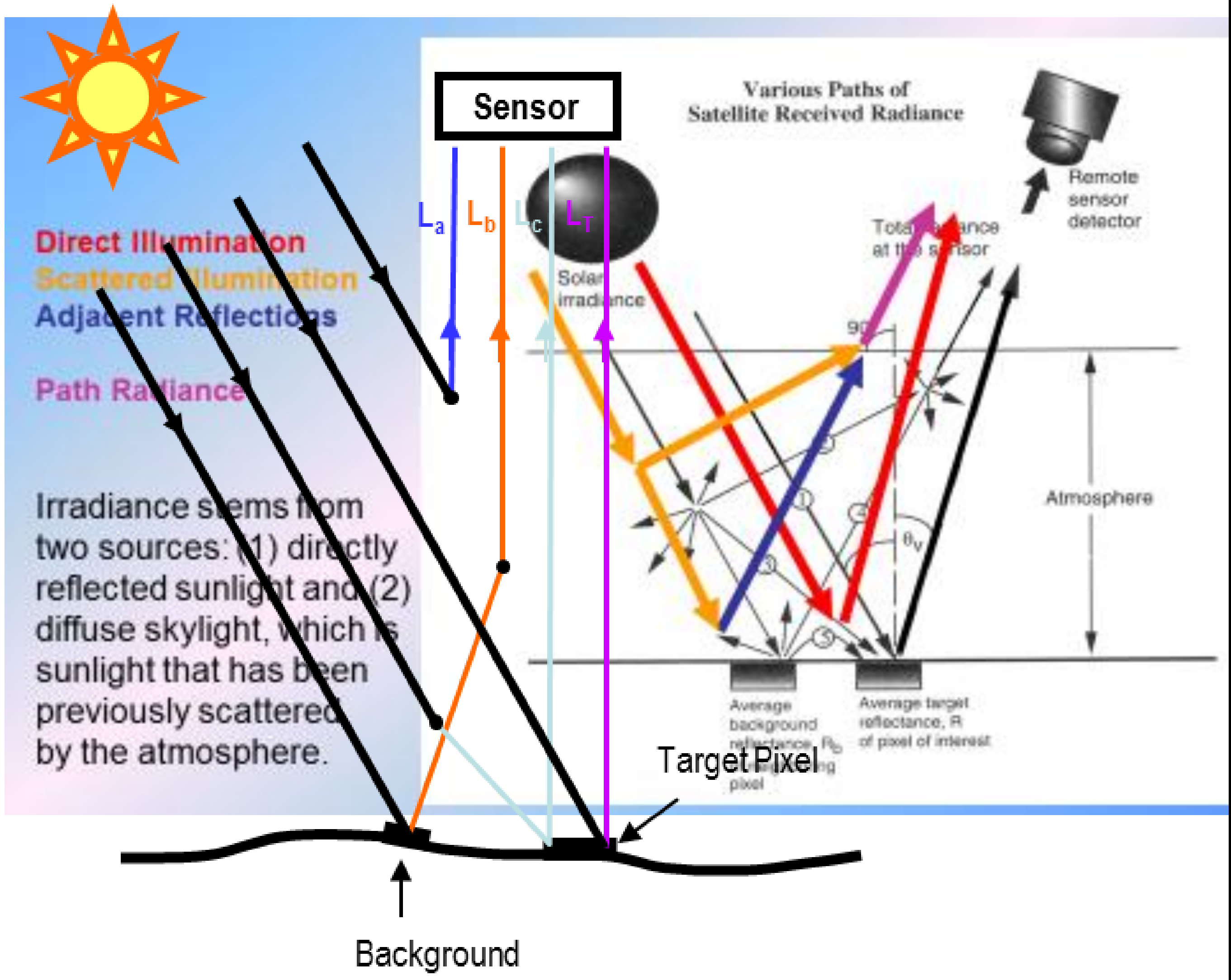
- Scattered light reaching the sensor from the atmosphere
- Additive effect, reducing CONTRAST

SKYLIGHT

- Scattered light reaching the sensor after being reflected from the Earth's surface
- Multiplicative effect

SUNANGLE

- Time/Seasonal effect changing the atmospheric path
- Multiplicative effect



Atmospheric Haze Effect

without haze

DN values of objects in a single band

Object1:	DN = 20	DN = 20 + 20
Object2:	DN = 40	DN = 40 + 20
Contrast:	40/20 = 2X	60/40 = 1.5 X

Haze Correction- Dark Object Subtraction

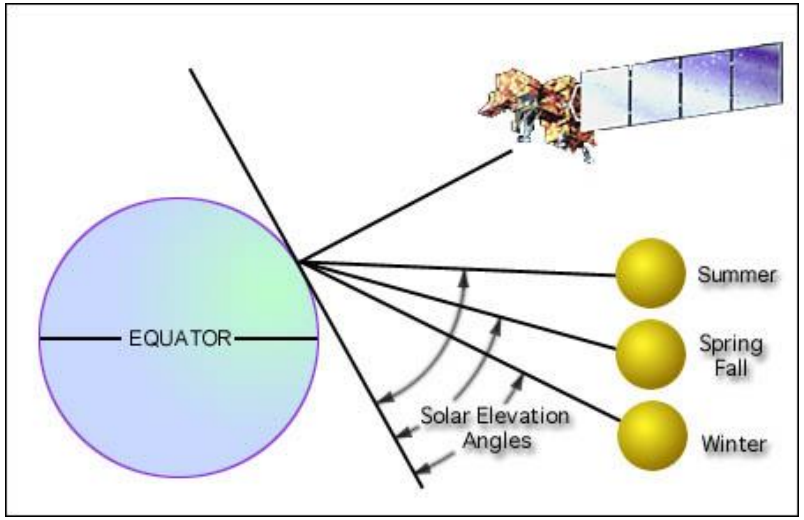
Histogram Minimum Method

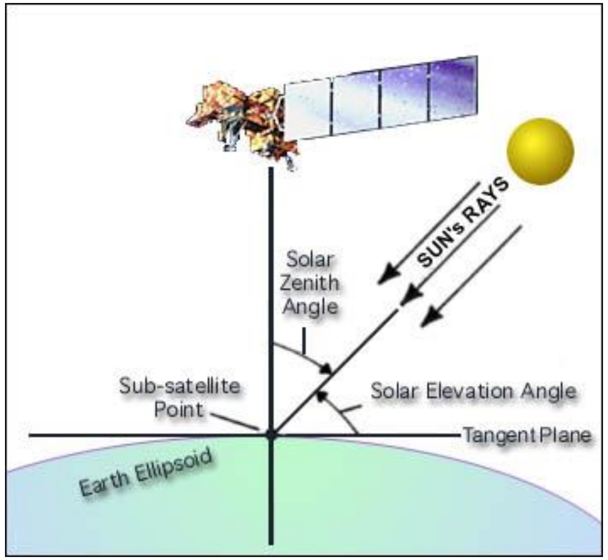
Assumption: infrared bands are not affected by Haze

- Identify black bodies: clear water and shadow zones with zero reflectance in the infrared bands
- Identify DN values at shorter wavelength bands of the same pixel positions. These DN are entirely due to haze
- Subtract the minimum of the DN values related to black bodies of a particular band from all the pixel values of that band

Sun Angle Correction

- The position of sun relative to earth changes depending on time of day and day of year.
- Solar elevation angle: Time- and location dependent
- *Sun elevation correction* accounts for the seasonal position of the sun relative to the earth
  - Image data acquired under different solar illumination angles need to be normalized to a constant solar position
- In the northern hemisphere the solar elevation angle is smaller in winter than in summer
- The solar zenith angle is equal to 90 degree minus the solar elevation angle
- Irradiance varies with the seasonal changes in solar elevation angle and the changing distance between the earth and sun
- Correction necessary for mosaicking and change detection





Sun Angle Correction

- Image data acquired under different solar illumination angles are normalized by calculating pixel brightness values assuming the sun was at the zenith on each date of sensing.
- The correction is usually applied by dividing each pixel value in a scene by the sine of the solar elevation angle for the particular time and location of imaging.

$$DN' = \frac{DN}{SIN(\alpha)}$$

Two Images with different Sun-angles

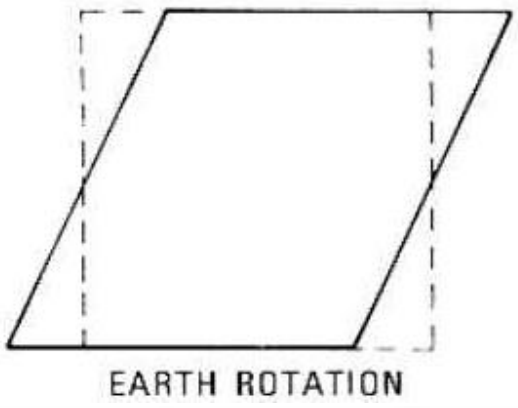
Corrected Mosaic

Geometric Errors and Corrections

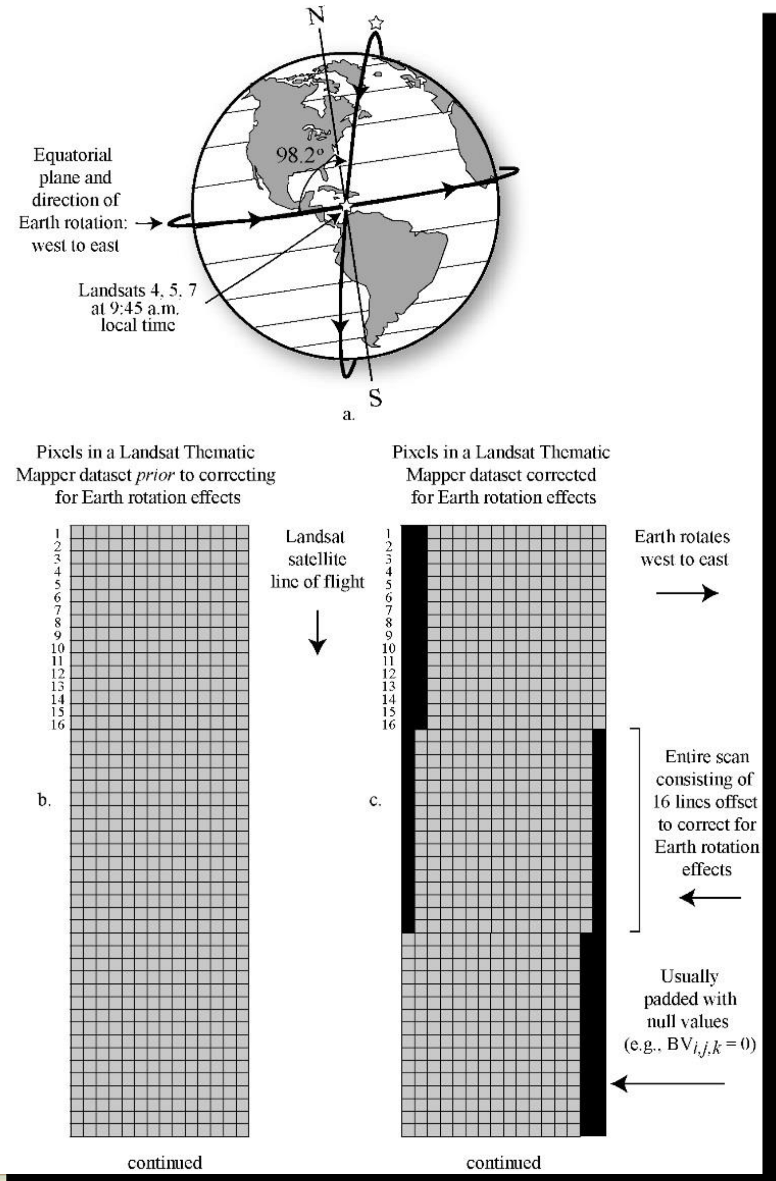
- The transformation of remotely sensed images so that it has a scale and projections of a map is called geometric correction.
- It is concerned with placing the reflected, emitted, or back-scattered measurements or derivative products in their proper planimetric (map) location so they can be associated with other spatial information in a geographic information system (GIS)
- Include correcting for geometric distortions due to sensor-Earth geometry variations, and conversion of the data to real world coordinates (e.g. latitude and longitude) on the Earth's surface

Earth Rotation Effect - Image Offset (skew)

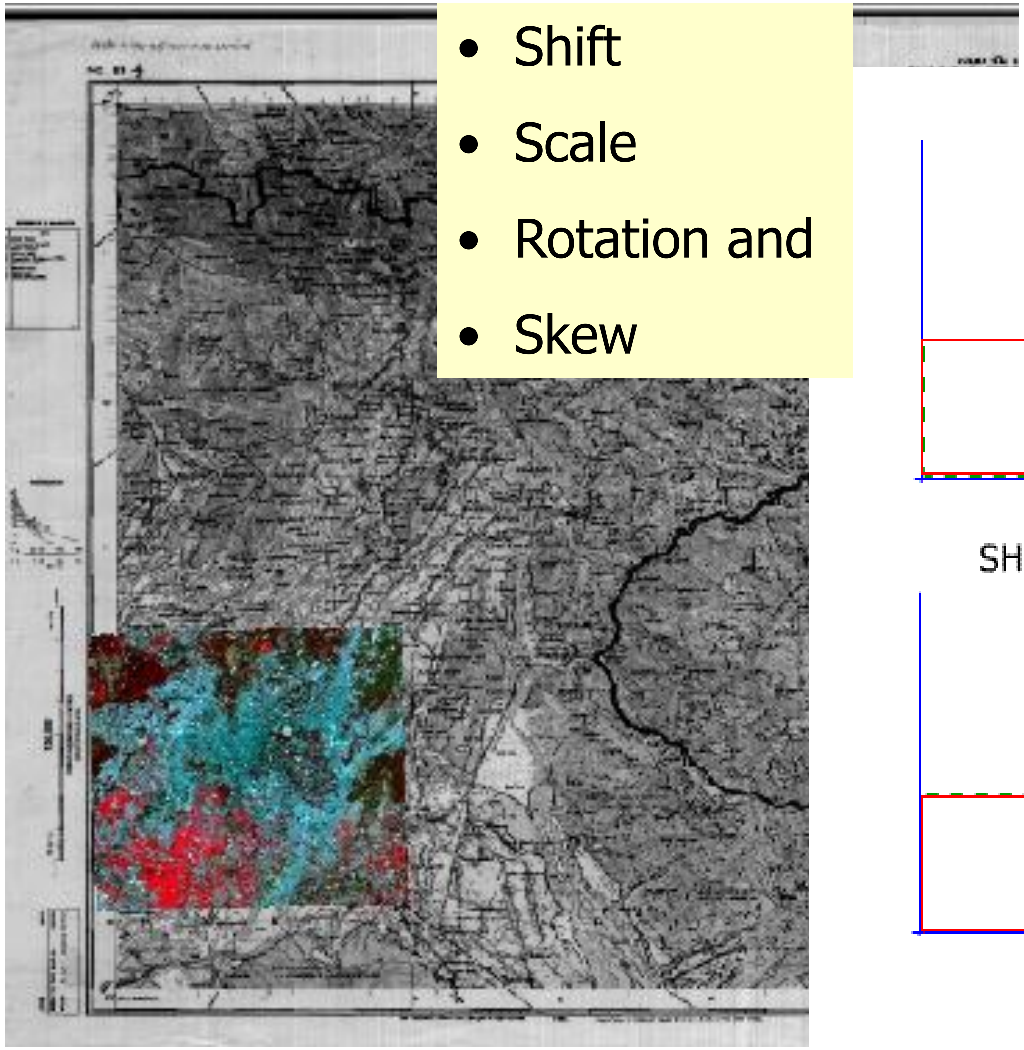
- Sun-synchronous satellites are normally in fixed orbits that collect a path (or swath) of imagery as the satellite makes its way from the north to the south in descending mode.
- Meanwhile, the Earth below rotates on its axis from west to east making one complete revolution every 24 hours. This *skews* the geometry of the imagery collected



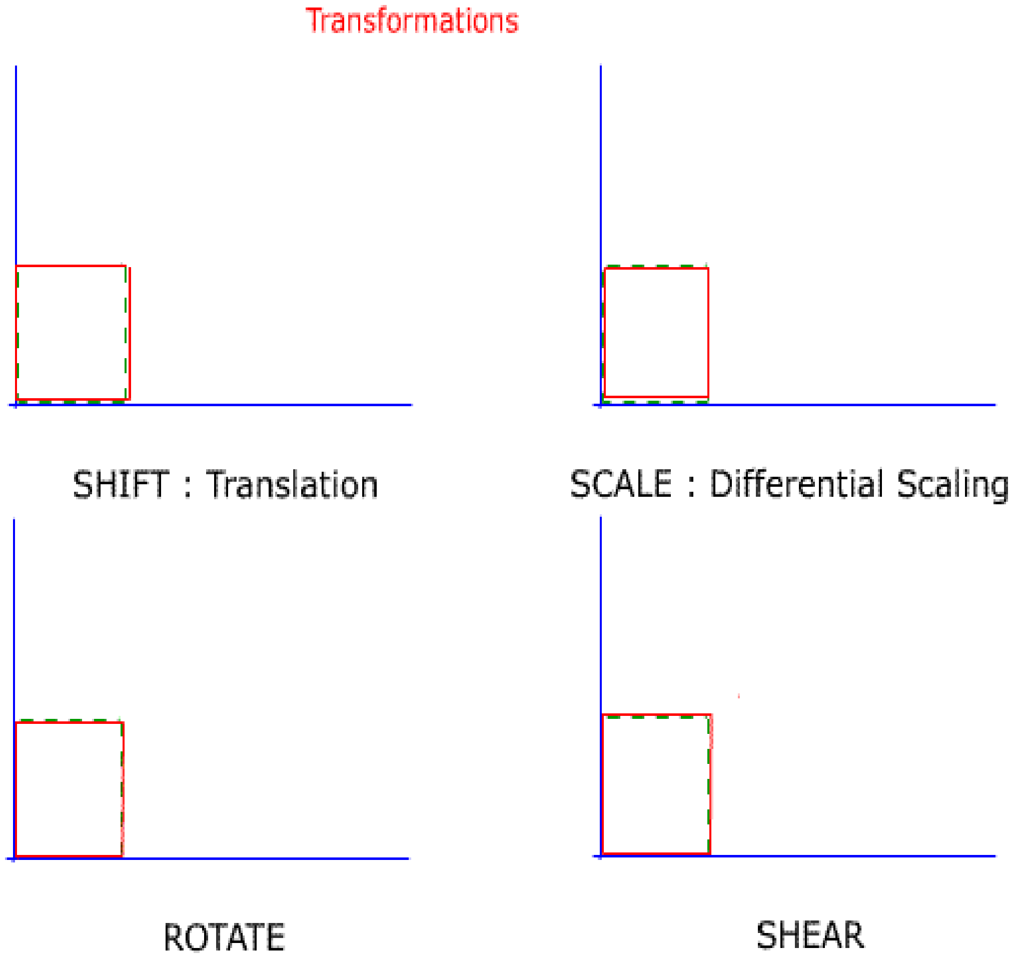
- Dashed line indicate shape of distorted image
- Solid line indicates restored image



Difference in Geometry



- Shift
- Scale
- Rotation and
- Skew



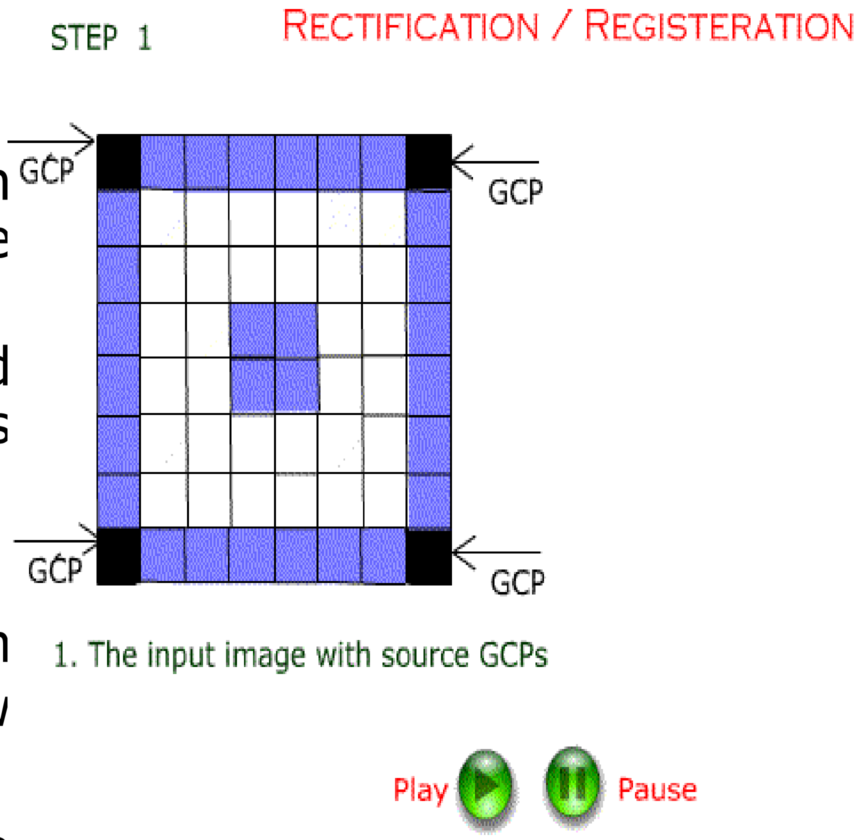
Rectification

- Is a process of geometrically correcting an image so that it can be represented on a planar surface , conform to other images or conform to a map.
- That is it is the process by which geometry of an image is made planimetric.
- It is necessary when accurate area , distance and direction measurements are required to be made from the imagery.
- It is achieved by transforming the data from one grid system into another grid system using a geometric transformation
- Grid transformation is achieved by establishing mathematical relationship between the addresses of pixels in an image with corresponding coordinates of those pixels on another image or map or ground.

Image to Map Rectification Procedure

Two basic operations must be performed to geometrically rectify a remotely sensed image to a map coordinate system:

- Geometric Transformation coefficient computation
  - The geometric relationship between input pixel location (row & column) and associated map co-ordinates of the same point (x,y) are identified.
  - Involves selecting Ground Control Points (GCPS) and fitting polynomial equations using least squares technique.
- Intensity Interpolation (Resampling)
  - A pixel in the rectified image often requires a value from the input pixel grid that does not fall neatly on a row and column co-ordinate.
  - For this reason resampling mechanism is used to determine pixel brightness value.



Ground Control Points (GCPs)

- A ***ground control point*** (GCP) is a location on the surface of the Earth (e.g., a road intersection) that can be identified on the imagery and located accurately on a map.
- There are two distinct sets of coordinates associated with each GCP:
  - *source or image coordinates* specified in *i* rows and *j* columns, and
  - *Reference or map coordinates* (e.g., *x, y* measured in degrees of latitude and longitude, or meters in a Universal Transverse Mercator projection).

Ground Control Points (GCPs)

- Accurate GCPs are essential for accurate rectification
- Well dispersed GCPs result in more reliable rectification
- GCPs for Large Scale Imagery
  - Road intersections, airport runways, towers buildings etc.
- for small scale imagery
  - larger features like Urban area or Geological features can be used
- NOTE : landmarks that can vary (like lakes, other water bodies, vegetation etc) should not be used.
- Sufficiently large number of GCPs should be selected
- Requires a minimum number depending on the type of transformation

Polynomial Coordinate transformation

- Polynomial equations are used to convert the source file coordinates to rectified map coordinates.
- Depending upon the distortions in the imagery, the number of GCPs used, their location relative to one other, complex polynomial equations are used.
- The degree of complexity of the polynomial is expressed as ORDER of the polynomial.
- The order is simply the highest exponent used in the polynomial

Mathematical Transformations

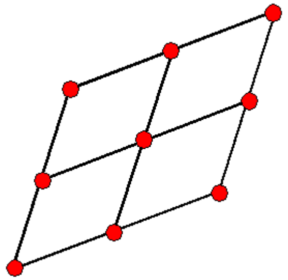
Linear Transformations/ Affine transformation/ first order transformation

$X = a_0 + a_1 x + a_2 y$

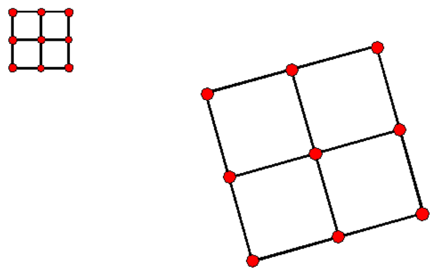
$Y = b_0 + b_1 x + b_2 y$

where

- X , Y are the Rectified coordinates (output)
- x, y are the source coordinates (input)



- A first order transformation can change
  - Location in x and/or y
  - Scale in x and/or y
  - Skew in x and/or y
  - Rotation



Polynomial transformation

- If the coefficients a_0 ,a_1,a_2, b_0, b_1 and b_2 are known then, the above polynomial can be used to relate and point on map to its corresponding point on image and vice versa. Hence six coefficients are required for this transformation (three for X and three for Y).
- So it requires Minimum THREE GCP's for solving the above equation.
- However the error cannot be estimated with three GCP's alone. Hence one additional GCP is taken
- Before applying rectification to the entire set of the data, it is important to determine how well the six coefficients derived from the least square regression of the initial GCPs account for the geometric distortion in the input image.

Accuracy of transformation

- In this method, we check how good do selected points fit between the map and the Image?
- To solve linear polynomials we first take four GCP's to compute the six coefficients. Its source coordinates in the original input image are say x_i and y_i. The position of the same points in reference map in degrees, feet or meters are say x,y
- Now, if we input the map x,y values for the first GCP back into the linear polynomial equation with all the coefficients in the place, we would get the computed or retransformed x_r and y_r values , which are supposed to be location of this point in input image
- Ideally measured and computed values should be equal.
- In reality this does not happen.

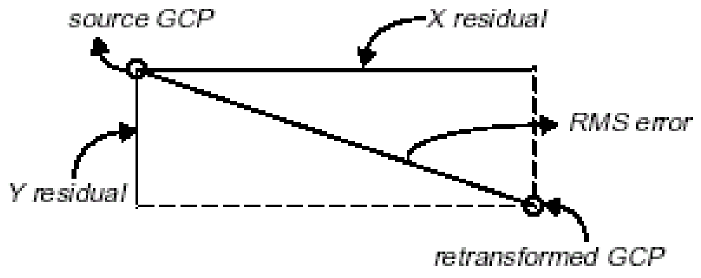
Root Mean Square (RMS) error

- Accuracy is measured by computing Root Mean Square Error (RMS error) for each of the ground control point
- RMS error is the distance between the input (source or measured) location of a GCP and the retransformed (or computed) location for the same GCP.
- RMS error is computed with a Euclidean Distance Equation.

$$\text{RMS error} = \sqrt{(x_r - x_i)^2 + (y_r - y_i)^2}$$

Where

- x_i and y_i are the input source coordinates and
- x_r and y_r are the retransformed coordinates



Acceptable RMS error

- The amount of RMS error that is tolerated can be thought of as a window around each source coordinate, inside which a retransformed coordinate is considered to be correct.
- Acceptable RMS error depends upon the
  - End use of the data
  - The type of data being used, and
  - The accuracy of the GCP and the ancillary data.
- Normally an RMS error of less than 1 per GCP and a total RMS error of less than half a pixel (0.5) is acceptable

TABLE

Name	On	Edit	Cell X	Cell Y	Northing	Easting	Height	RMS
1	On	Edit	453.98	405.95	30.38N	77.73E	0.00	0.03
2	On	Edit	279.03	245.14	30.44N	77.68E	0.00	0.58
3	On	Edit	377.85	190.91	30.45N	77.72E	0.00	0.53
4	On	Edit	281.32	245.00	30.44N	77.68E	0.00	0.01

Co-ordiantes of the pixel in the satellite image (x,y)

Corresponding latitude-longitude values in the toposheet (x',y')

Error

Actual to image co-ordinates:

$x' = 29.4266 + 0.0325488x - 0.0061536y$

$y' = 77.8772 - 0.006085x - 0.0323303y$

Image to actual co-ordinates:

$x = -250 + 29.6671x' - 5.64673y'$

$y = 2950 - 5.584x' - 29.8676y'$

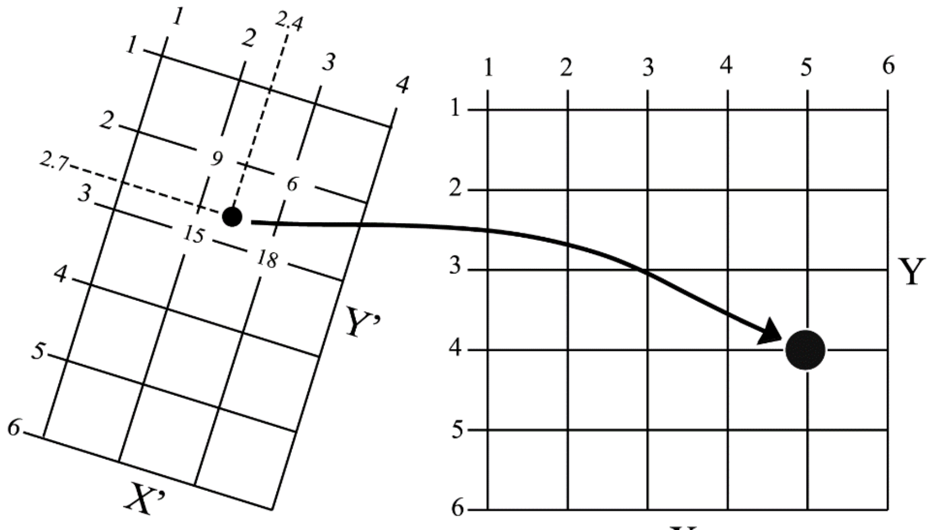
The last coloumn refers to the RMS error in the selection of GCP's. For better and high accuracy the RMS error should be less than unity.

Intensity Interpolation (Resampling)

- Once an image is warped, DNs are to be assigned to the “new” pixels?
- Since the grid of pixels in the source image rarely matches the grid for the reference image, the pixels are resampled so that new data file values for the output file can be calculated.
- This process involves filling the rectified output grid with brightness values extracted from a location in the input image and its reallocation in the appropriate coordinate location in the rectified output image.
- This results in input line and columns numbers as real numbers (and not integers)
- When this occurs, methods of assigning Brightness values are
  - Nearest Neighbour
  - Bilinear
  - Cubic

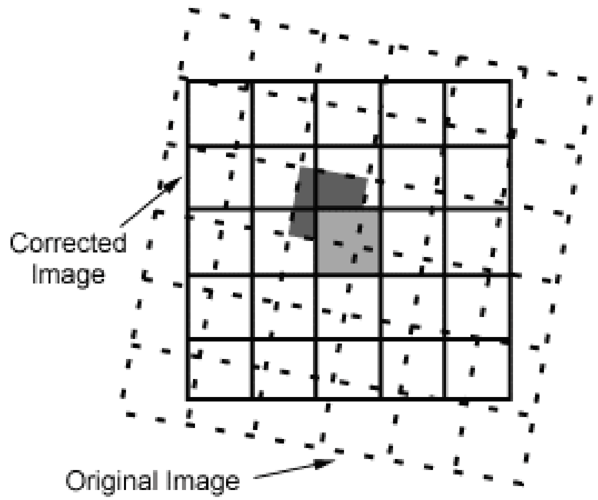
Nearest Neighbor

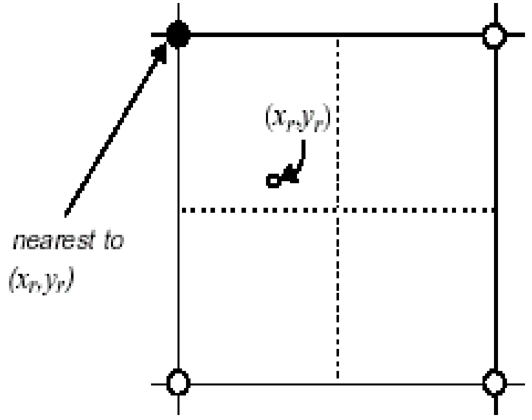
- The nearest neighbor approach uses the value of the closest input pixel for the output pixel value.
- The pixel value occupying the closest image file coordinate to the estimated coordinate will be used for the output pixel value in the georeferenced image.



Original input image
(a)

Rectified output image
(b)





Nearest Neighbor

ADVANTAGES:

- Output values are the original input values. Other methods of resampling tend to average surrounding values. This may be an important consideration when discriminating between vegetation types or locating boundaries.
- Since original data are retained, this method is recommended before classification.
- Easy to compute and therefore fastest to use.

DISADVANTAGES:

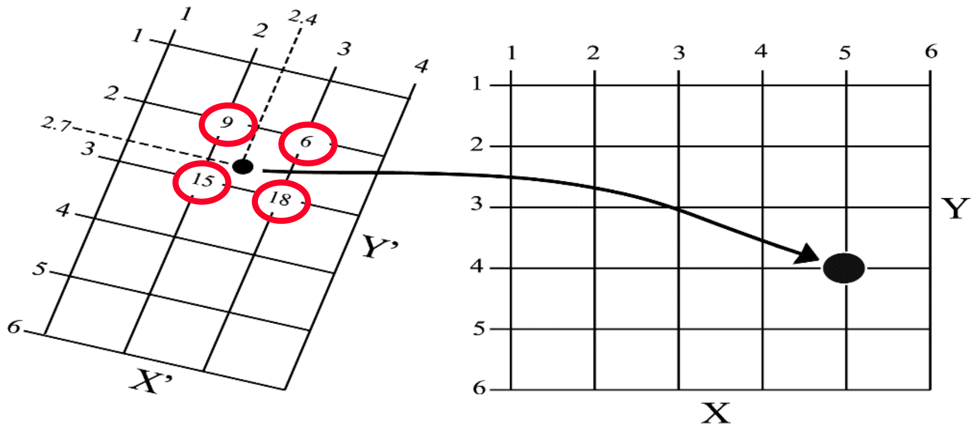
- Produces a choppy, "stair-stepped" effect. The image has a rough appearance relative to the original unrectified data.
- Data values may be lost, while other values may be duplicated.

Bilinear Interpolation

- **T**he bilinear interpolation approach uses the weighted average of the nearest four pixels to the output pixel.

$$BV_{wt} = \frac{\sum_{k=1}^{4} \frac{Z_k}{D_k^2}}{\sum_{k=1}^{4} \frac{1}{D_k^2}}$$

where Z_k are the surrounding four data point values, and D^2_k are the distances squared from the point in question (***x′, y′***) to the these data points.



Original input image
(a)

Rectified output image
(b)

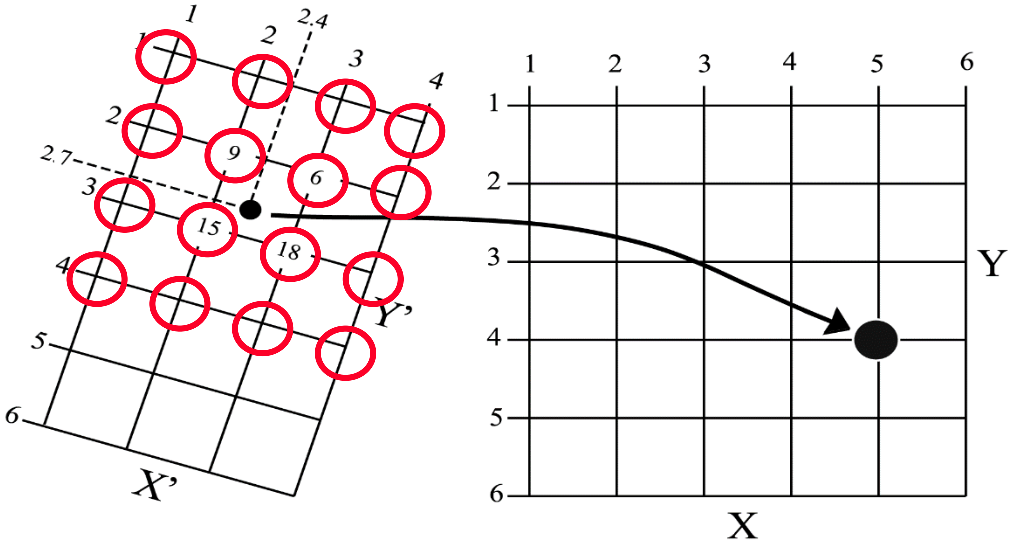
- **ADVANTAGES:**
  - Stair-step effect caused by the nearest neighbor approach is reduced. Image looks smooth.
- **DISADVANTAGES:**
  - Alters original data and reduces contrast by averaging neighboring values together.
  - Is computationally more extensive than nearest neighbor.

Cubic Convolution

- **T**he cubic convolution approach uses the weighted average of the nearest sixteen pixels to the output pixel. The output is similar to bilinear interpolation, but the smoothing effect caused by the averaging of surrounding input pixel values is more dramatic.

$$BV_{wt} = \frac{\sum_{k=1}^{16} \frac{Z_k}{D_k^2}}{\sum_{k=1}^{16} \frac{1}{D_k^2}}$$

where Z_k are the surrounding four data point values, and $D^2{}_k$ are the distances squared from the point in question (***x'***, ***y'***) to the these data points.



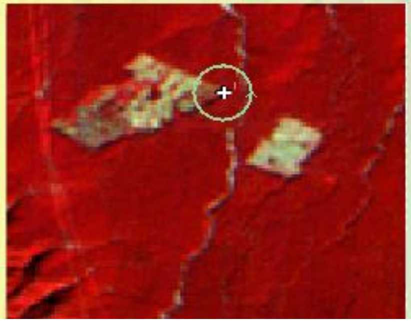
Original input image
(a)

Rectified output image
(b)

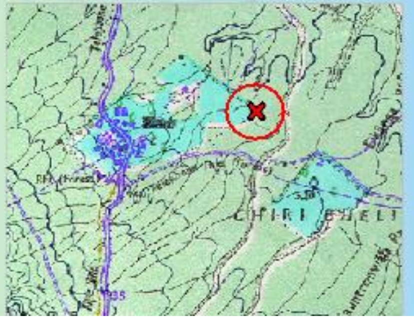
- **ADVANTAGES:**
  - Stair-step effect caused by the nearest neighbor approach is reduced. Image looks smooth.
- **DISADVANTAGES:**
  - Alters original data and reduces contrast by averaging neighboring values together.
  - Is computationally more expensive than nearest neighbor or bilinear interpolation.

First some GCP's(Ground Control Points) are selected. These are certain reference points, that are bright enough and can be easily located. We take the satellite image as well as a reference data of the same area that can be either a toposheet or a reference image using GPS. Shown below is an example of that.....

SATELLITE IMAGE



GCP 1

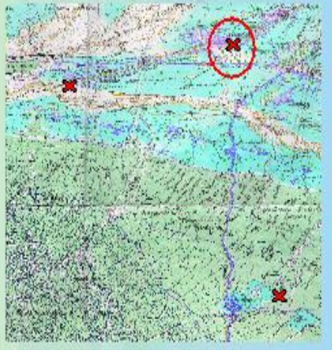


TOPOSHEET

For solving the first order transformation equations, we need a minimum of three GCP's. For more accuracy and root mean square adjustment, a fourth GCP is also selected. We can even choose more GCP's according to the requirements.

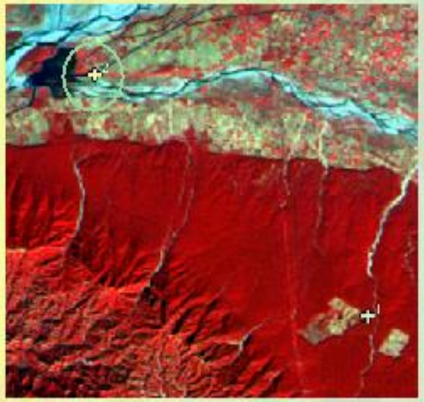
SATELLITE IMAGE

GCP 3



TOPOSHEET

SATELLITE IMAGE



GCP 2

TOPOSHEET

These are the first order transformation equations:

1. $x' = a + bx + cy$
2. $y' = d + ex + fy$

Now, we have the following RMS table :

TABLE

Name	On	Edit	Cell X	Cell Y	Northing	Easting	Height	RMS
1	On	Edit	453.98	405.95	30.38N	77.73E	0.00	0.03
2	On	Edit	279.03	245.14	30.44N	77.68E	0.00	0.58
3	On	Edit	377.85	190.91	30.45N	77.72E	0.00	0.53
4	On	Edit	281.32	245.00	30.44N	77.68E	0.00	0.01

Co-ordiantes of the pixel in the satellite image (x,y)

Corresponding latitude-longitude values in the toposheet (x',y')

Error

Actual to image co-ordinates:

$x' = 29.4266 + 0.0325488x - 0.0061536y$

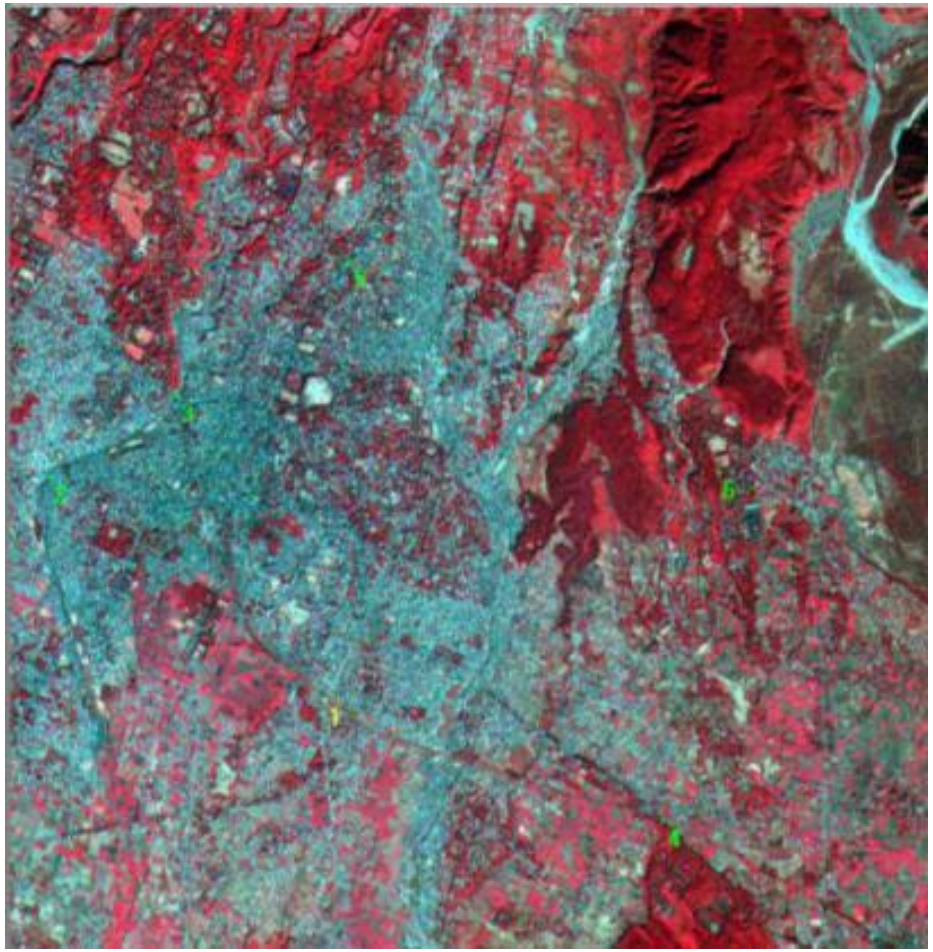
$y' = 77.8772 - 0.006085x - 0.0323303y$

Image to actual co-ordinates:

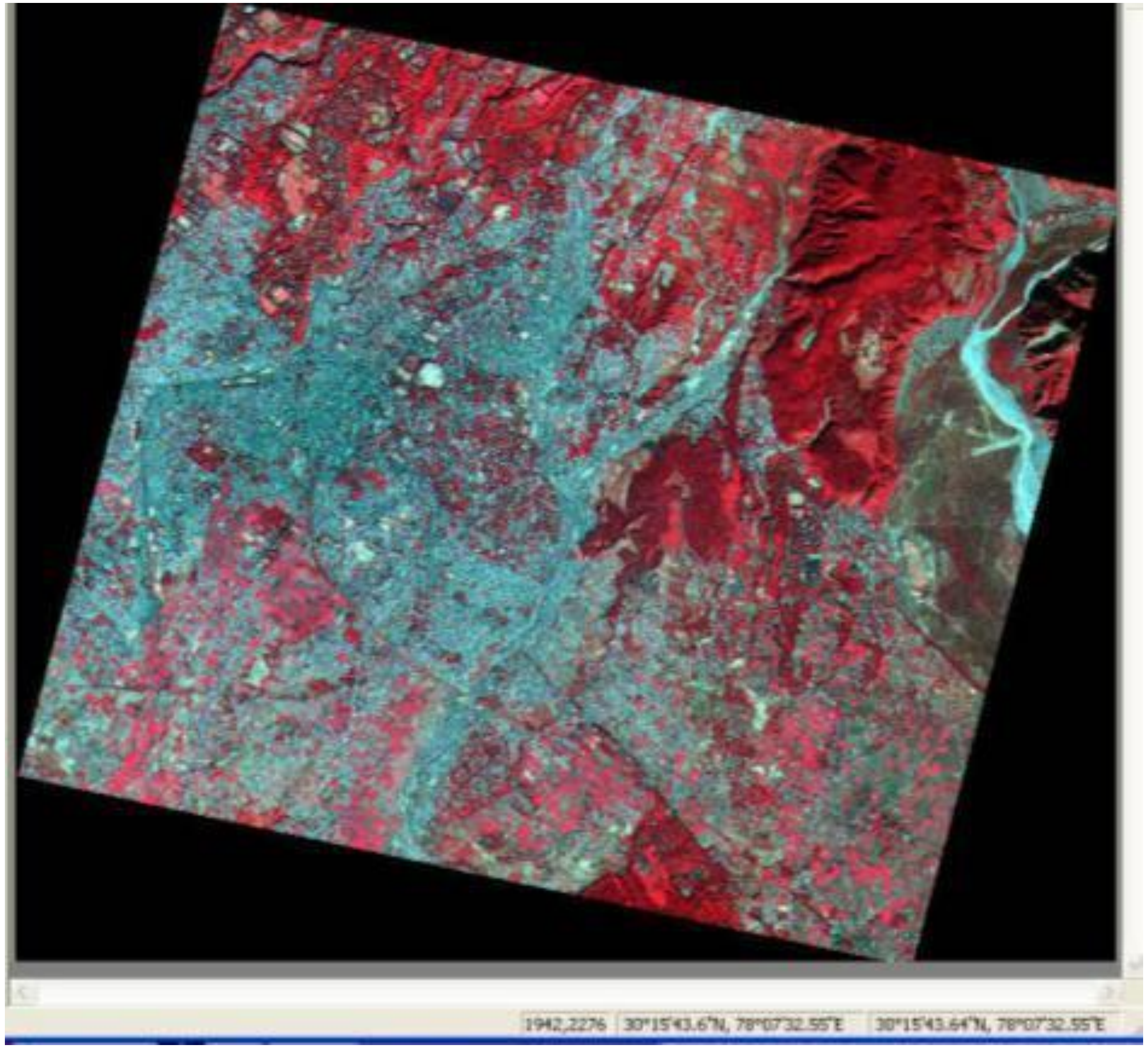
$x = -250 + 29.6671x' - 5.64673y'$

$y = 2950 - 5.584x' - 29.8676y'$

The last coloumn refers to the RMS error in the selection of GCP's. For better and high accuracy the RMS error should be less than unity.



Input Image



Rectified Image

Discussion / Query

Thank You