Geometric Errors and Corrections

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- It is concerned with placing remote sensing data in *their proper planimetric (map) location* so they can be associated with other *spatial information* in a geographic information system (GIS)
- The transformation of remotely sensed images so that it has a *scale* and *projections* of a map is called ***geometric correction***.
- It is usually necessary to preprocess remotely sensed data and remove geometric distortion so that individual pixels (i, j) are in their proper planimetric (x, y) map locations.
- Geometrically corrected imagery can be used to extract *accurate distance*, *polygon area*, and *direction (bearing) information*.
- 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

Types Of Geometric Errors

Internal Geometric Errors

External Geometric Errors

Internal Geometric Errors

- Internal geometric errors are introduced by the remote sensing system ***itself*** or in combination with ***Earth rotation*** or ***curvature*** characteristics.

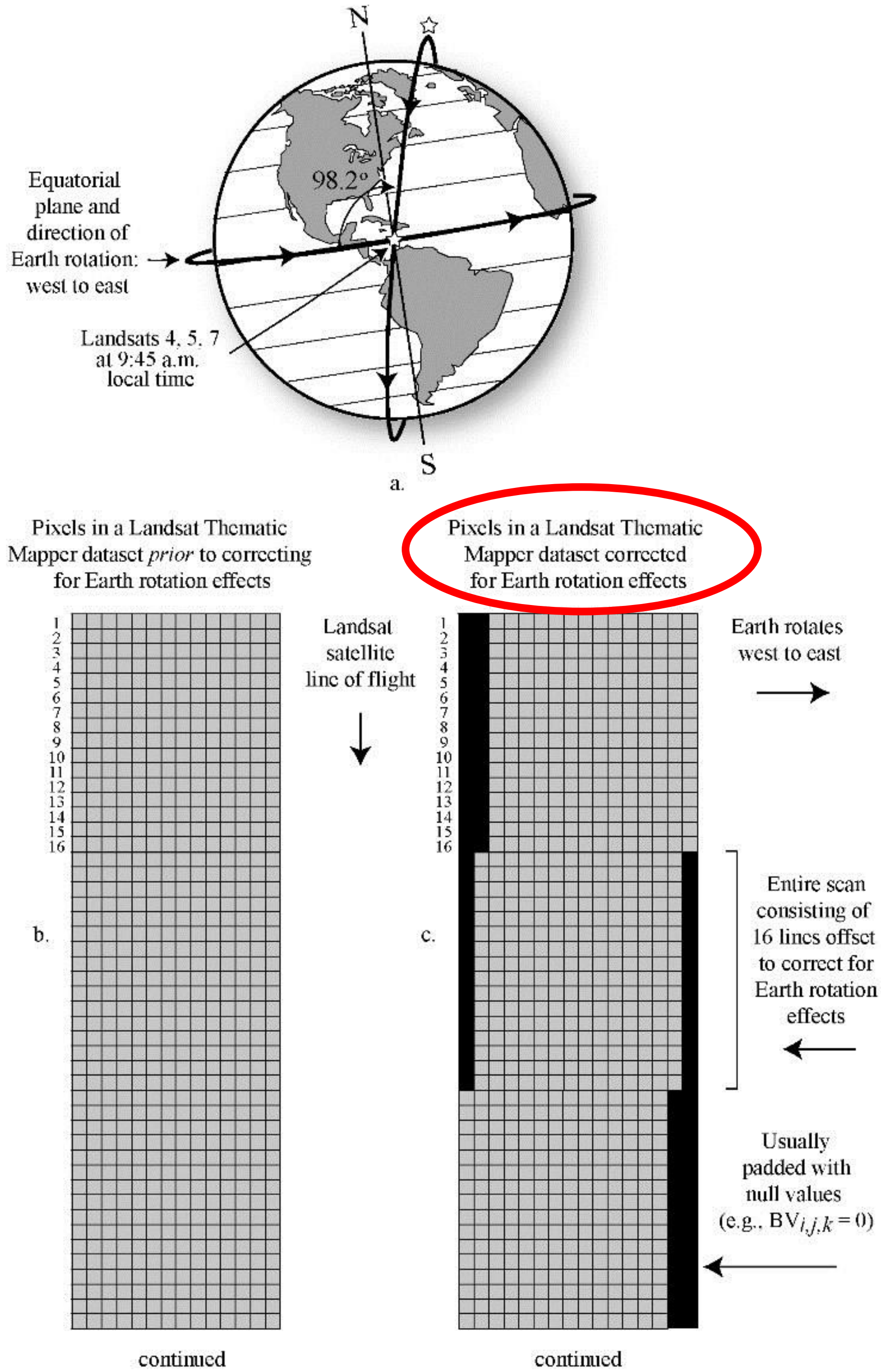
- **Systematic (predictable) errors:** may be identified and corrected using *pre-launch or in-flight* platform ephemeris (i.e., information about the geometric characteristics of the sensor system and the Earth at the time of data acquisition).

Geometric distortions in imagery that can sometimes be corrected through analysis of sensor characteristics and ephemeris data include:

- **Skew** caused by *earth rotation* effects,
- Scanning system–induced **variation in ground resolution cell size**,
- Scanning system **one-dimensional relief displacement**, and
- Scanning system **tangential scale distortion**.

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.
- This **skews the geometry of the imagery collected**

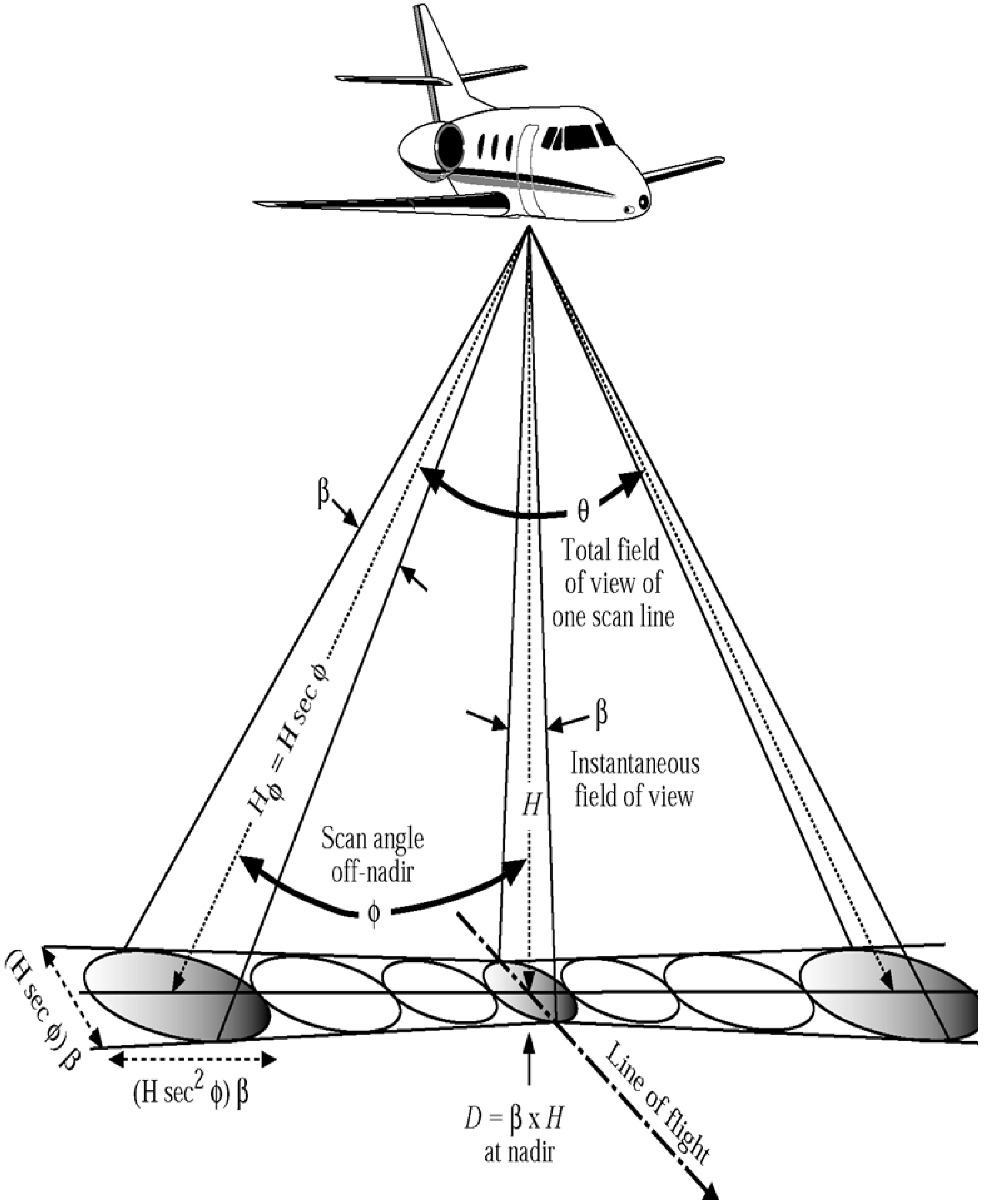


Variation in Ground Resolution Cell Size

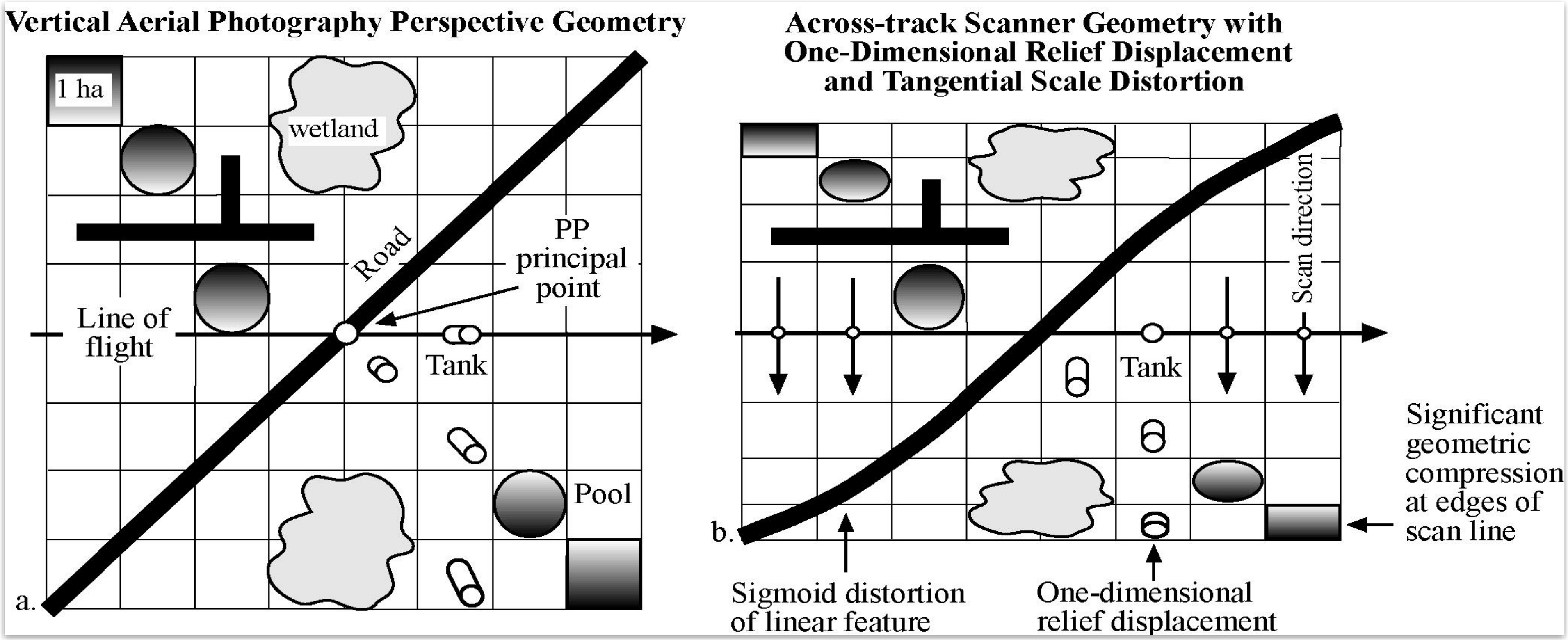
The **ground resolution cell** size along a single across-track scan is a function of:

1. The distance from the aircraft to the observation where **H is the altitude** of the aircraft above ground level (AGL) at nadir and H sec f off-nadir;
2. The **instantaneous-field-of-view (IFOV)** of the sensor, b, measured in radians; and
3. The **scan angle off-nadir**, f. Pixels off-nadir have semi-major and semi-minor axes (diameters) that define the resolution cell size.

The total field of view of one scan line is q.



Relief Displacement & Tangential scale distortion



1. Hypothetical perspective geometry of a vertical aerial photograph obtained over level terrain. Four 50-ft-tall water tanks are distributed throughout the landscape and experience varying degrees of radial relief displacement the farther they are from the principal point (PP).
2. Across-track scanning system introduces **one-dimensional relief displacement** *perpendicular to the line of flight* and **tangential scale distortion** and *compression the farther the object* is from nadir. Linear features trending across the terrain are often recorded with s-shaped or sigmoid curvature characteristics due to tangential scale distortion and image compression.

External Geometric Errors

- External geometric errors are usually introduced by **phenomena that vary in nature** through space and time.

- The *most important external variables* that can cause geometric error in remote sensor data are **random movements by the aircraft** (or spacecraft) at the exact time of data collection, which usually involve:

  - ✓ **Altitude** changes, and/or

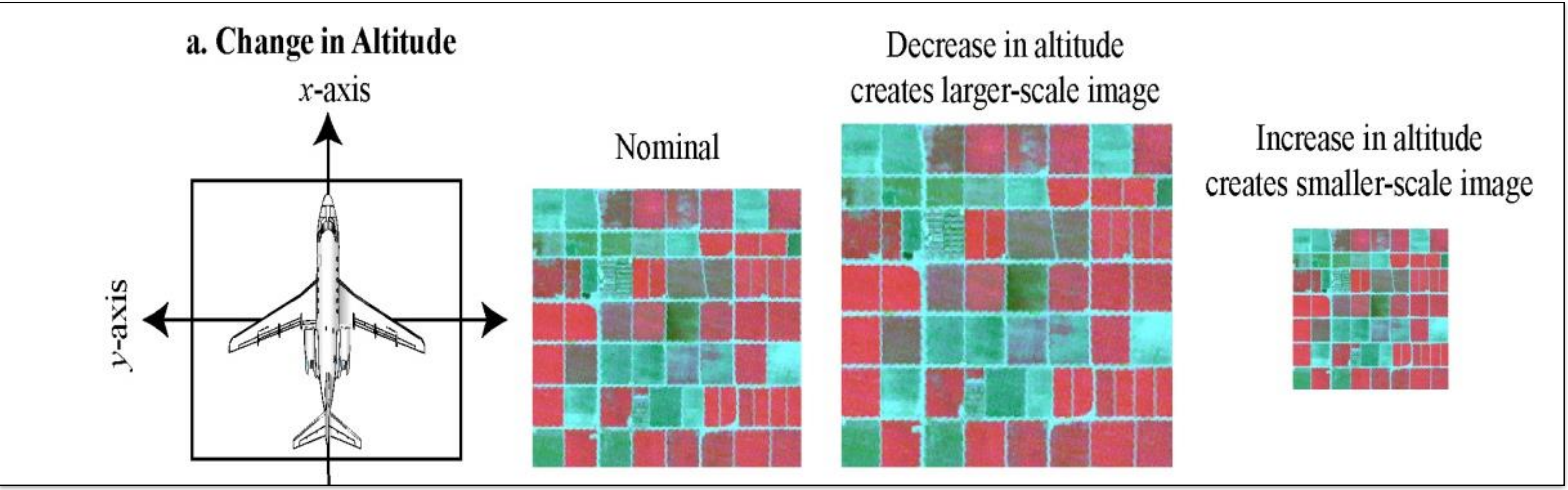
  - ✓ **Attitude** changes (Roll, Pitch, Yaw)

- The **diameter of the spot size on the ground** (D; the nominal spatial resolution) is a function of the instantaneous-field-of-view (ββ) and the altitude above ground level (H) of the sensor system, i.e.,

$$D = \beta \times H$$

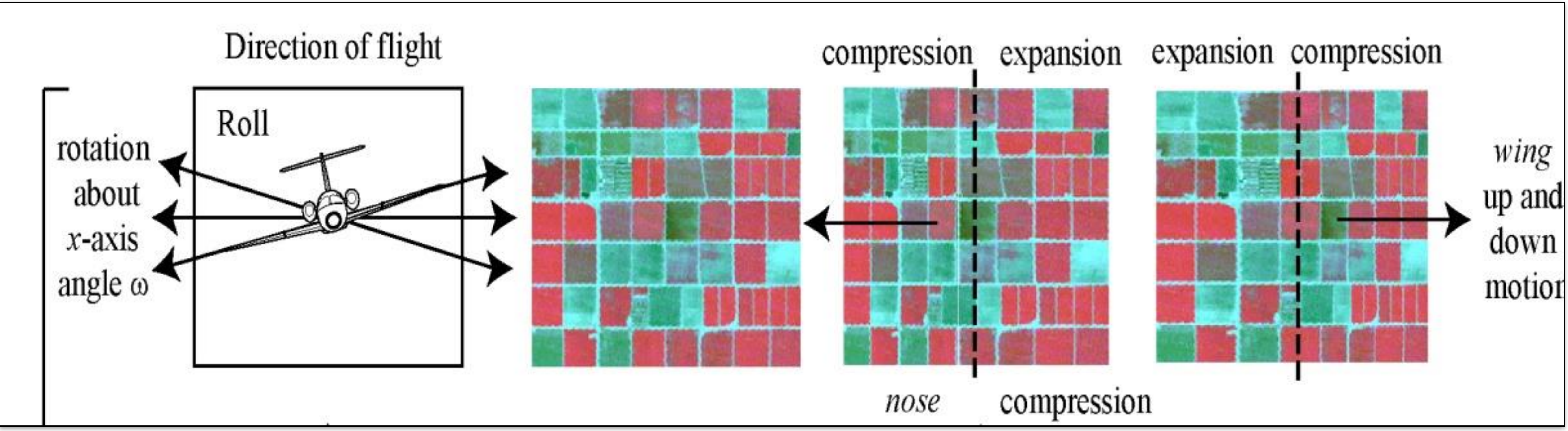
1. Variations due to ALTITUDE:

- Geometric modification in imagery may be introduced by changes in the aircraft or satellite platform *altitude* above ground level (AGL) at the time of data collection.
- *Increasing altitude* results in *smaller-scale imagery* while *decreasing altitude* results in *larger-scale imagery*.

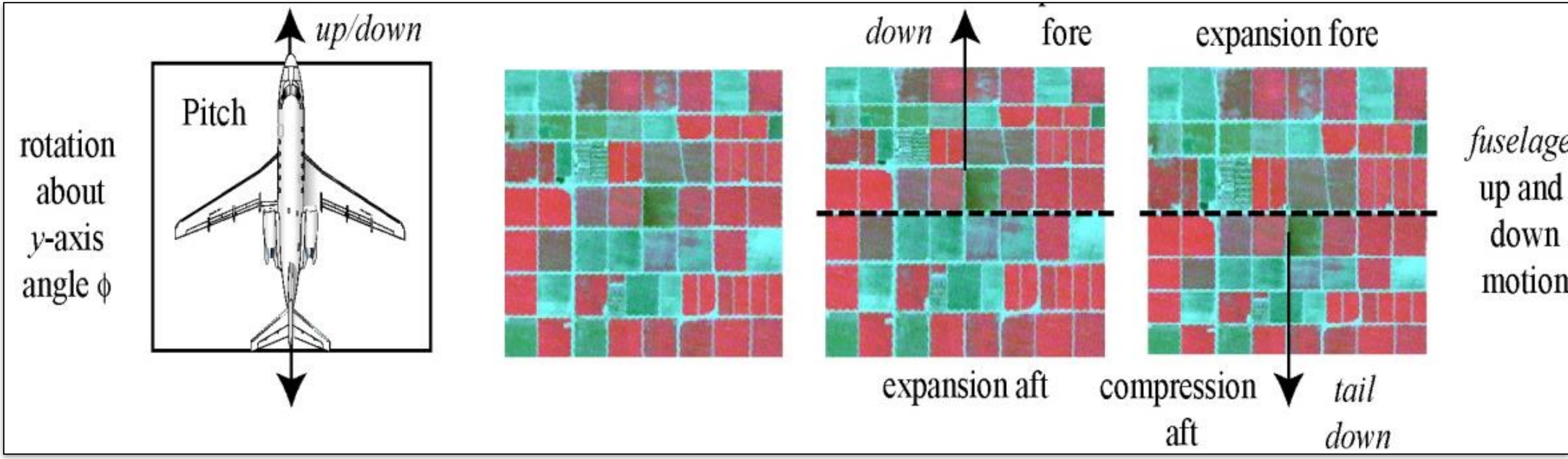


2. Variations due to **ALTITUDE:**

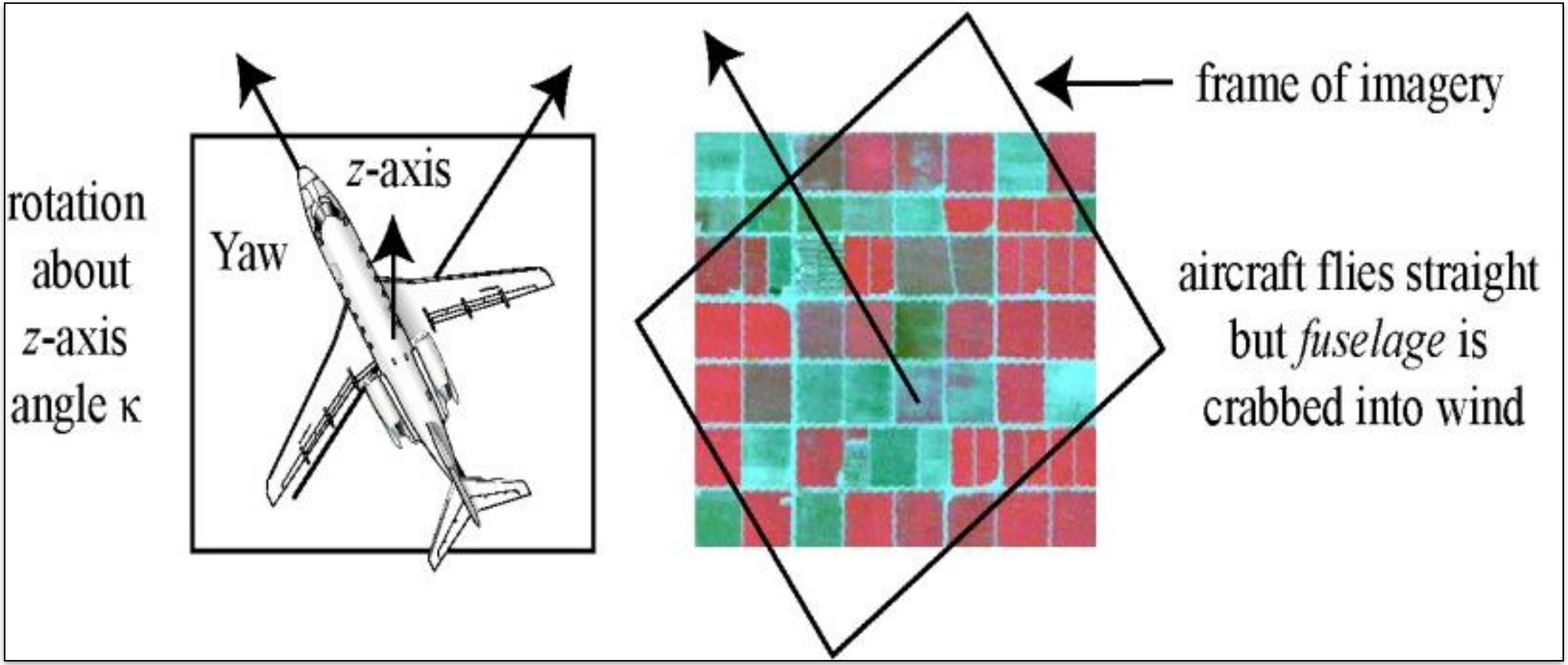
- Geometric modification may also be introduced by aircraft or spacecraft changes in *attitude*, including **roll, pitch, and yaw**.
- An aircraft flies in the *x*-direction.
- ***Roll*** occurs when the aircraft or *spacecraft fuselage maintains directional stability but the wings move up or down*, i.e. they rotate about the *x*-axis angle.



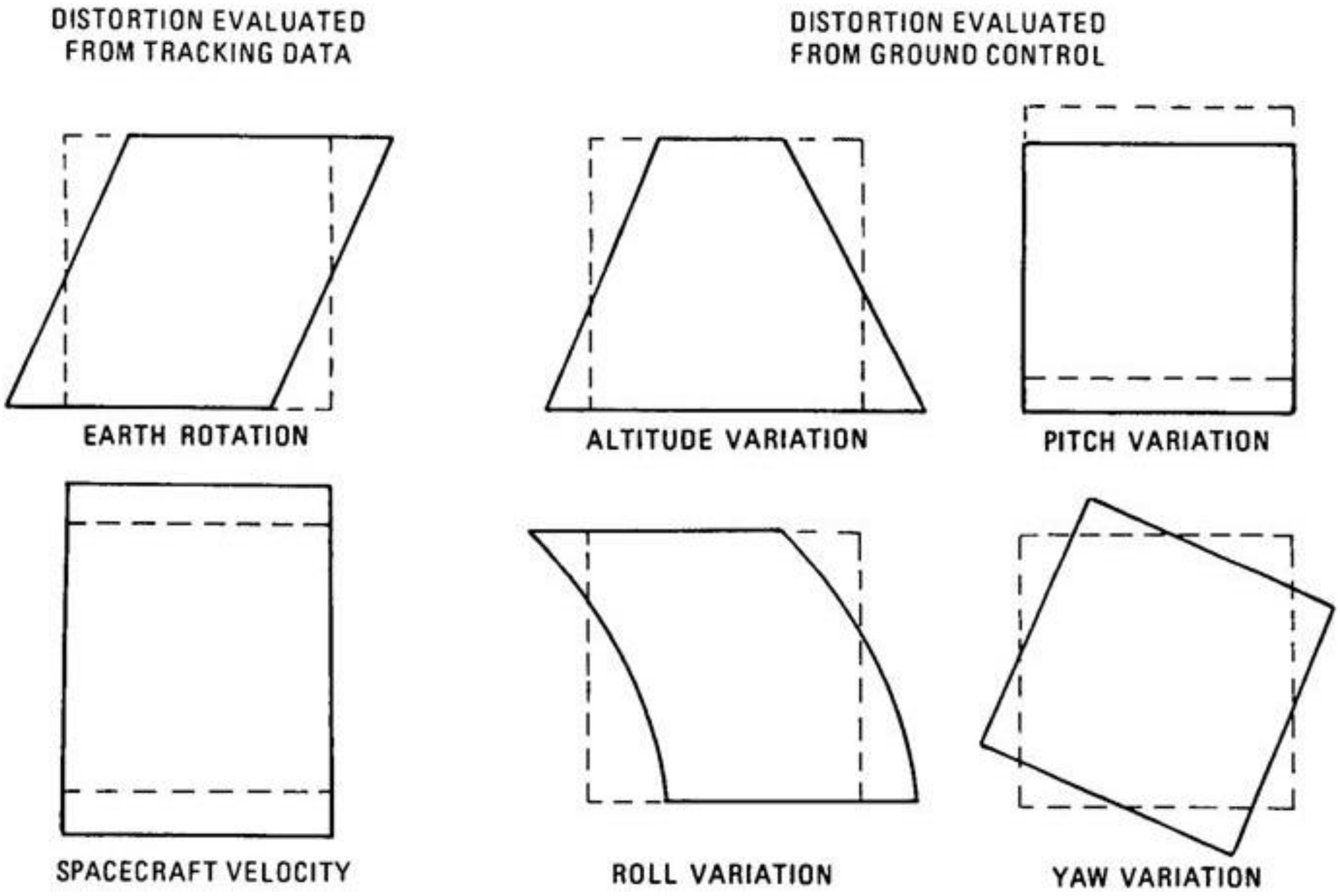
Pitch occurs when the **wings are stable but the fuselage nose or tail moves up or down**, i.e., they rotate about the *y*-axis angle.



- ***Yaw*** occurs when the *wings remain parallel but the fuselage is forced by wind to be oriented some angle to the left or right of the intended line of flight*, i.e., *it rotates about the z-axis angle*
- Thus, the plane flies straight but all remote sensor data are displaced by k. Remote sensing data often are distorted due to a combination of changes in *altitude* and *attitude* (roll, pitch, and yaw).



Geometric Distortion



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

Corrections

1. ***Image registration*** is the *translation* and *alignment* process by which **two images/maps** of like geometrics and of the same set of objects *are positioned co-incident* with respect to one another so that corresponding element of the same ground area appear in the same place on the registered images.

- **This is often called image to image registration.**

2. ***Rectification*** is the process by which the *geometry of an image area is made planimetric*.

- This process almost always involves relating *Ground Control Point (GCP), pixel coordinates with precise geometric correction* since each pixel can be referenced not only by the row or column in a digital image, but it is also rigorously referenced in degree, feet or meters in a standard map projection whenever accurate data, direction and distance measurements are acquired, geometric rectification is required.

- **This is often called as image to map rectification.**

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.
- 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.

Registration vs. Rectification

- Registration: reference one image to another of like geometry (i.e. same scale)
- Rectification: process by which the geometry of an image area is made planimetric by referencing to some standard map projection.
- Registration and rectification involve similar sets of procedures. Both registration and rectification require some form of coordinate transformation. Many references to rectification may also apply to image-to-image registration.

Image To Map Rectification Procedure

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

1. Geometric Transformation coefficient computation

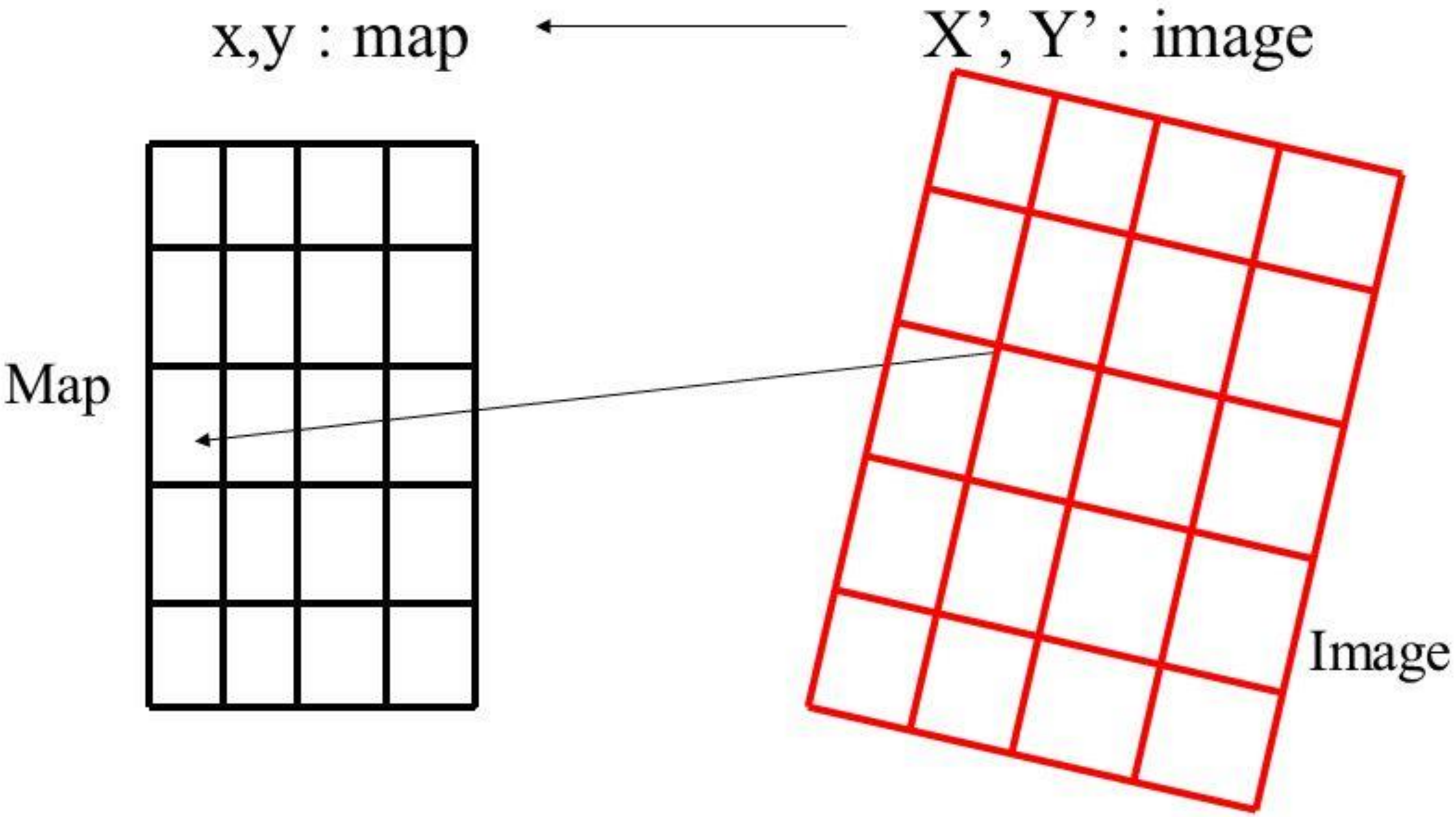
- The geometric relationship between input pixel location ('i' row & 'j' column) and associated map co-ordinates of the same point (x, y) are identified.
- Involves selecting Ground Control Points (GCPS) and fitting polynomial equations using least squares technique.

2. 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**.

Transforming from one Coordinate System to Another:

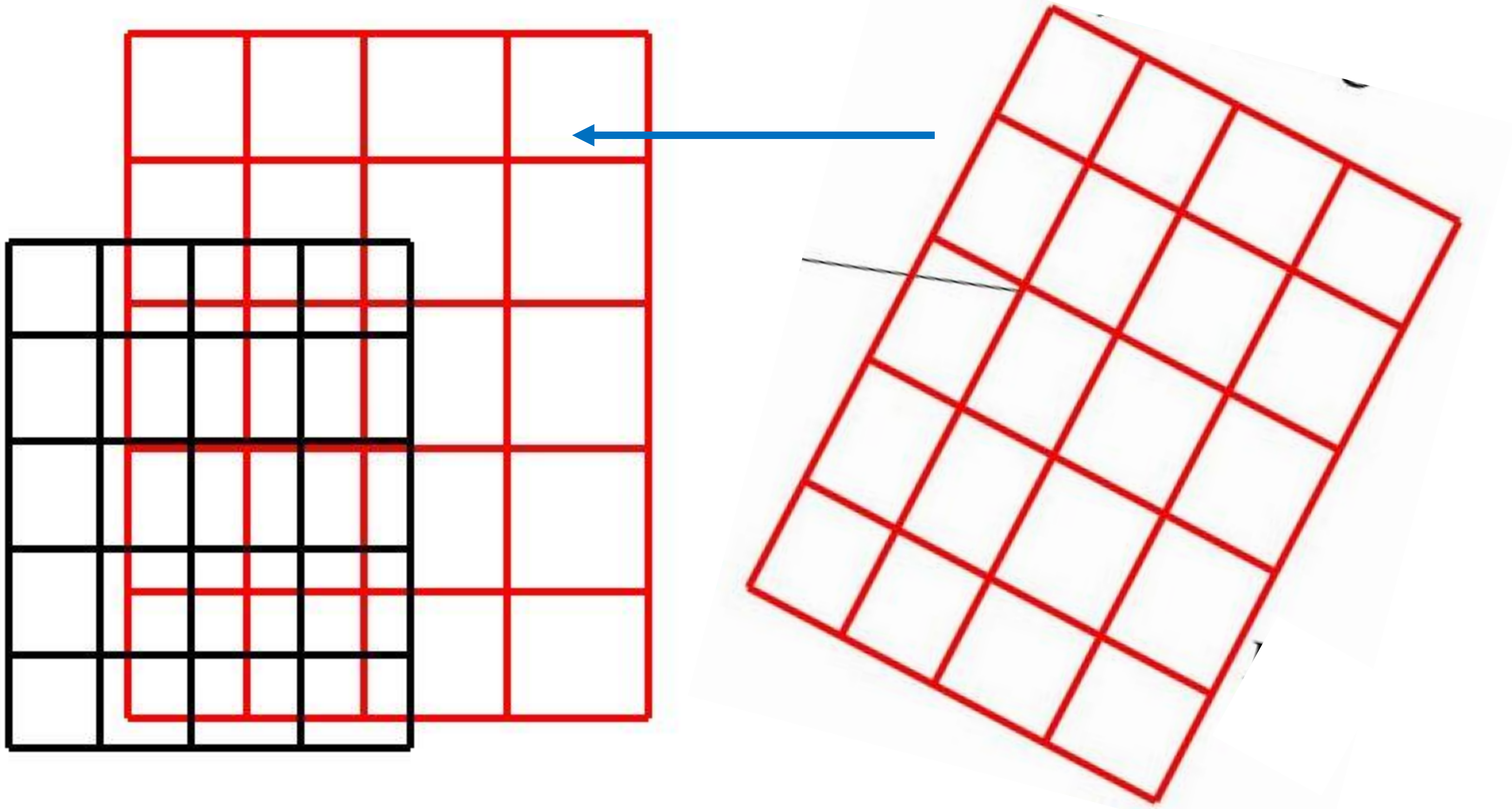
What transformations need to be accomplished?



What transformations need to be accomplished?

Rotate

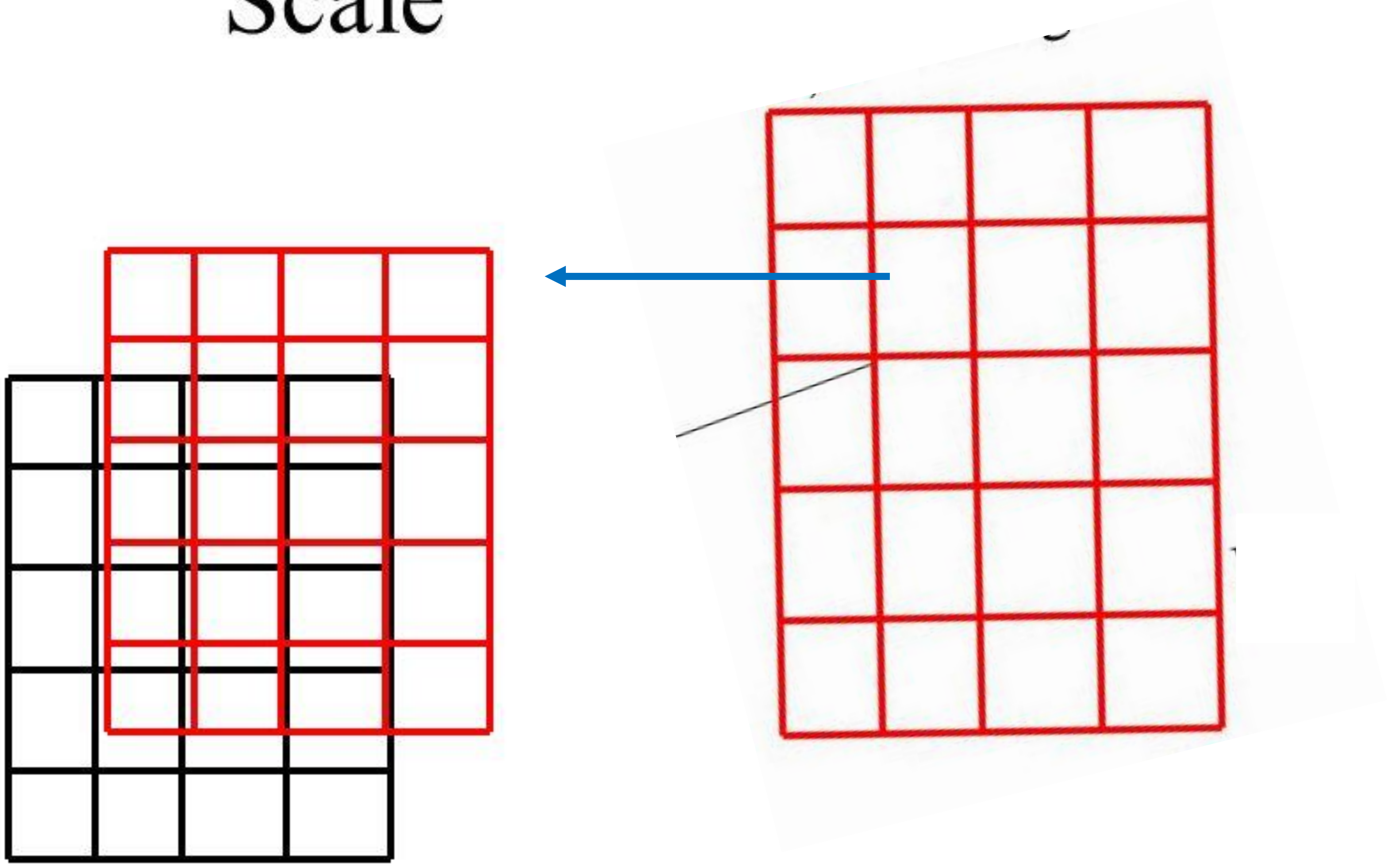
Map



What transformations need to be accomplished?

Scale

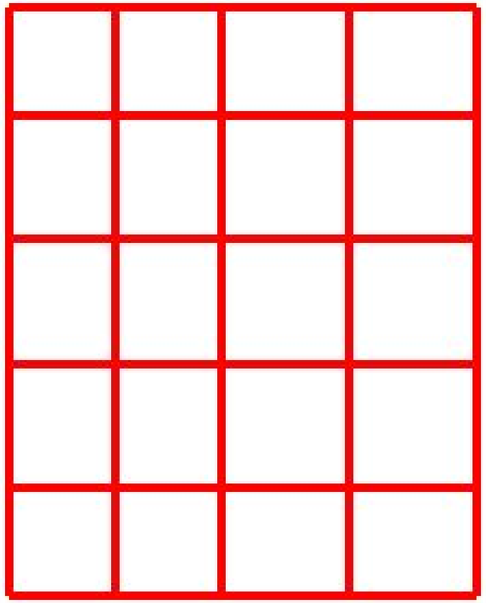
Map



What transformations need to be accomplished?

Translate

Map



Image

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 (*i*, *j*), and
  - Reference or map coordinates (*x*, *y*) (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. (Eg. 1^{st} order, 2^{nd} order….)
- The order is simply the *highest exponent **(power)***used in the polynomial

Mathematical Transformations

Linear Transformations/ Affine transformation/ 1st 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/ Transform*** **in x and/or y**
- ***Scale*** **in x and/or y**
- ***Skew*** **in x and/or y**
- ***Rotation***

1st order transformation

- Also referred to as an affine transformation
- $X' = a_o + a_1x + a_2y$ X', Y' = image
  $Y' = b_o + b_1x + b_2y$ x, y = map
- a_o, b_o: for translation
- a_1, b_1: for rotation and scaling in x direction
- a_2, b_2: for rotation and scaling in y direction
- 6 unknowns, need minimum of 3 GCP's
- difference in scale in X & Y, true shape not maintained but parallel lines remain parallel

Polynomial Coordinate Transformation

- If the *coefficients a0 ,a1,a2, b0, b1 and b2 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 6 coefficients are required for this transformation (3 for X and 3 for Y).
- So it requires **minimum 3 GCP's** for solving the above equation.
- However the error cannot be estimated with three GCP's alone. Hence one additional GCP is taken. ***(now total = 3+1 =4)***
- 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. (***Checking the accuracy of the GCPs)***

Accuracy of Transformation

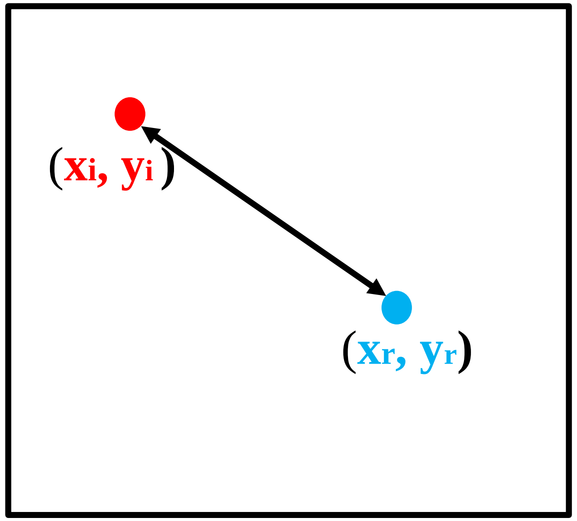
- In this method, we check **how good do selected points fit** between the *map* and the *Image*?
- To solve linear polynomials we first take 4 GCP's to compute the 6 coefficients.
- Its **source coordinates** in the **original input image** are say x_i and y_i.
- The position of the same points in reference *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
- Measured = x_i and y_i
- Computed = x_r and y_r values
- 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.

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



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)

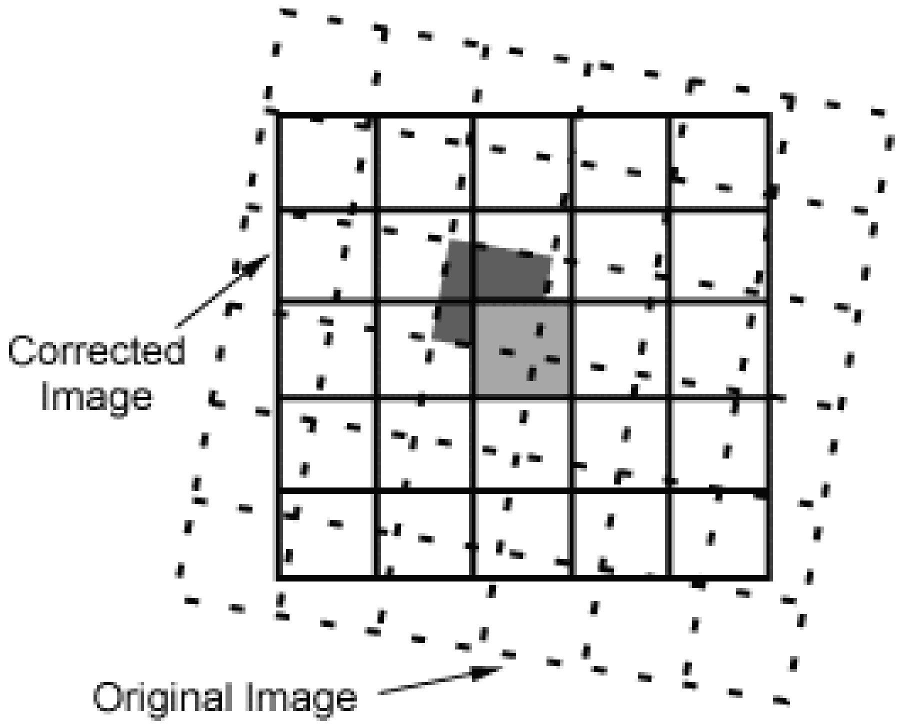
Corresponding latitude-longitude values in the toposheet (x',y')

Error

Intensity Interpolation (Resampling)

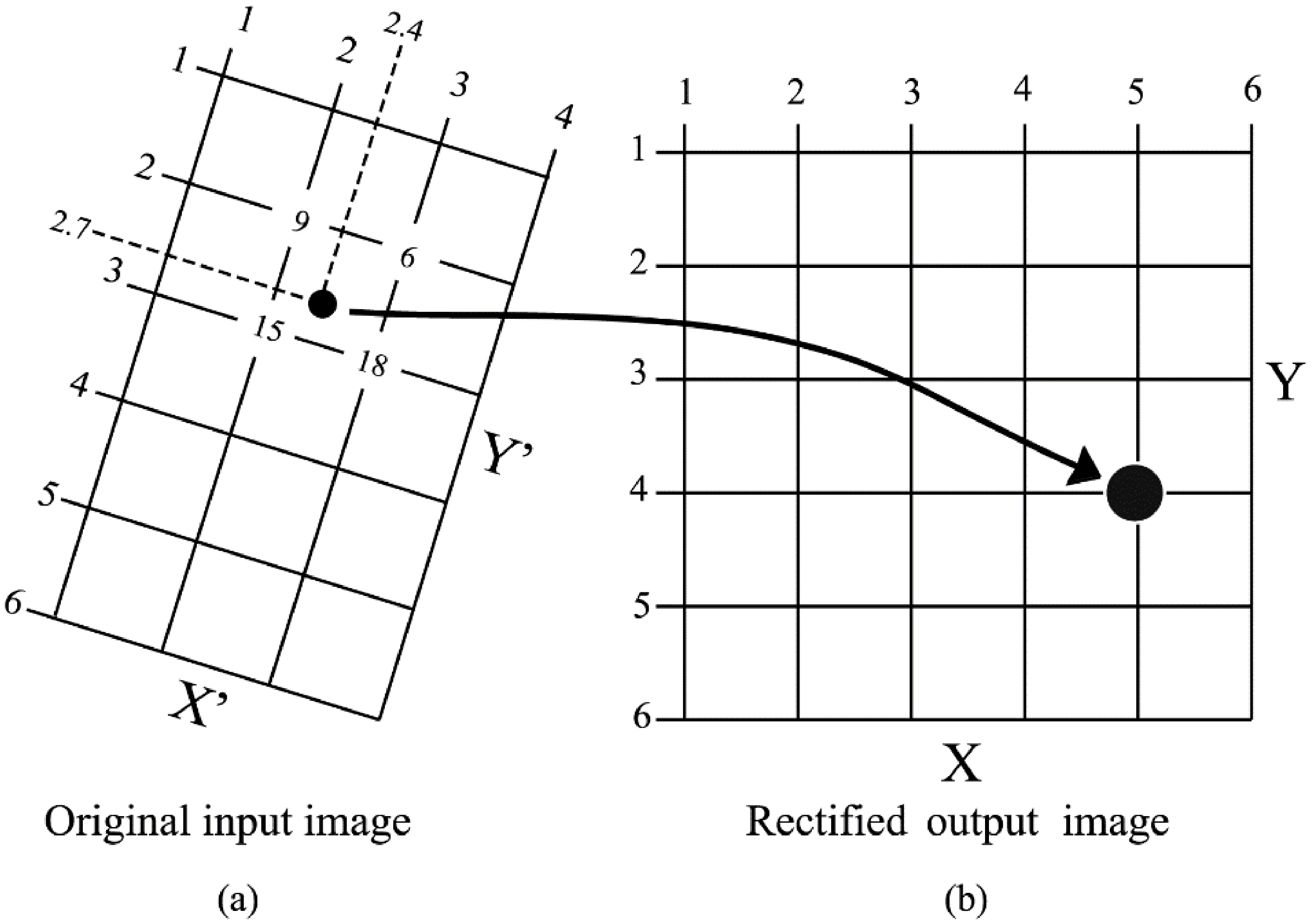
- Once an image is warped, how are **DNs assigned to the "new" pixels?**
- Since the *grid of pixels in the source image rarely matches the grid for the reference image*, the pixels are resampled so that new data file values for the output file can be calculated.
- This process involves ***filling the 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

1. **Nearest Neighbor**
2. **Bilinear**
3. **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.
- ✓ (Nearest pixel in this case = 15)



(2.7, 2.4)

(4, 5)

ADVANTAGES:

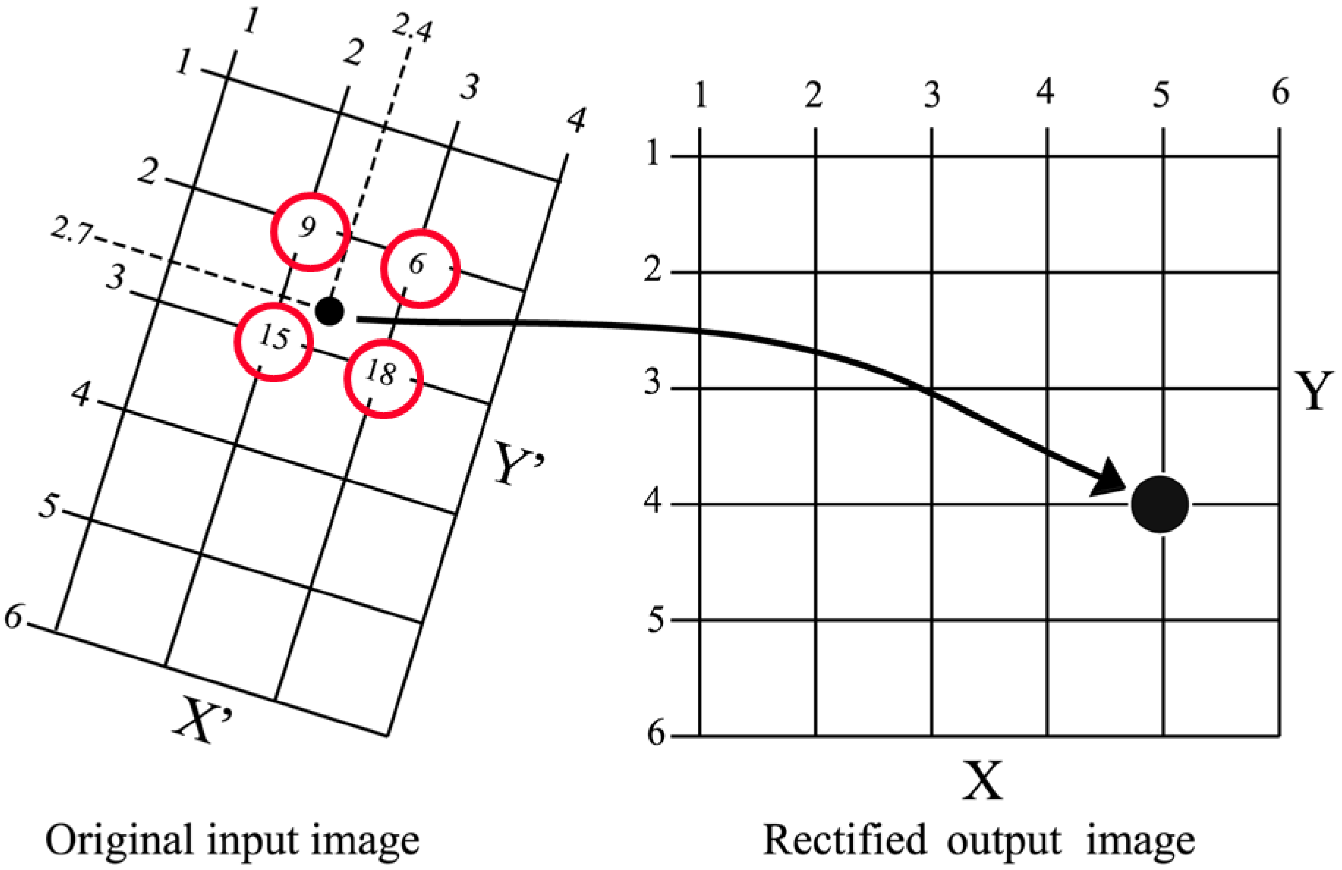
- Since **original data are retained**, this method is recommended before classification.
- Easy to compute and therefore fastest to use.

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

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



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

- The 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.