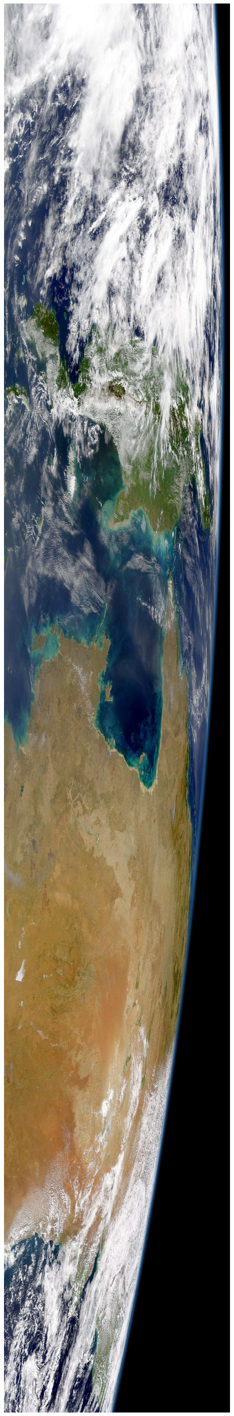
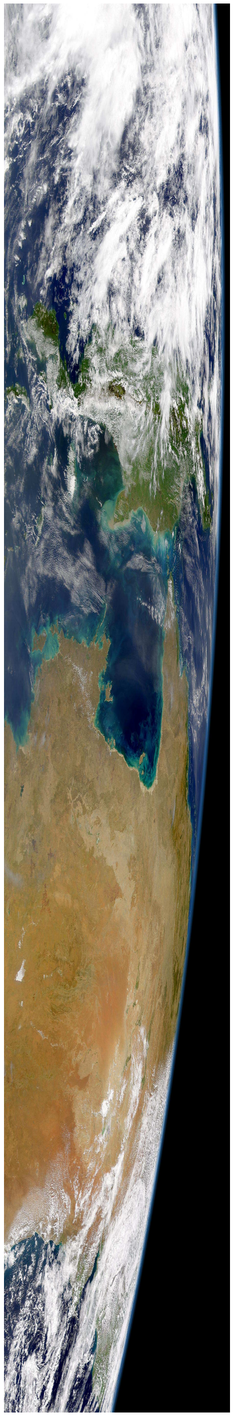


IMAGE RECTIFICATION

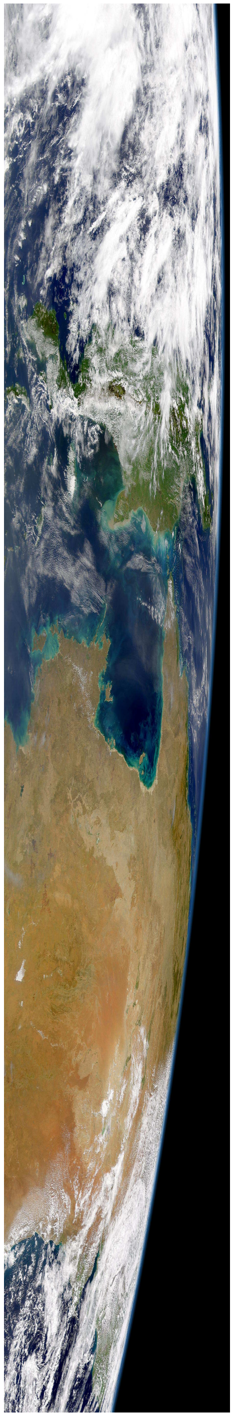


GEOMETRIC CORRECTION

It is usually necessary to *preprocess* remotely sensed data and remove geometric distortion so that individual picture elements (pixels) are in their proper planimetric (*x, y*) map locations.

This allows remote sensing–derived information to be related to other thematic information in GIS.

Geometrically corrected imagery can be used to extract accurate distance, polygon area, and direction (bearing) information.

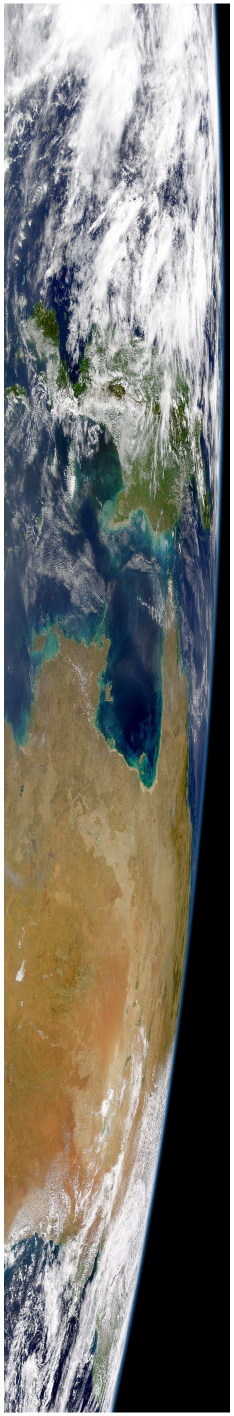


GEOMETRIC CORRECTION

Remotely sensed imagery typically exhibits *internal* and *external geometric errors.*

These can be
systematic (predictable)
or *nonsystematic* (random).

Systematic geometric error is generally easier to identify and correct than random geometric error.



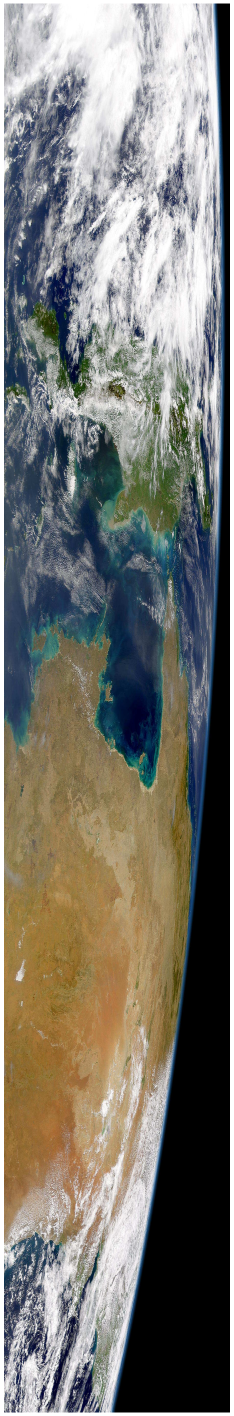
GEOMETRIC CORRECTION

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

These distortions are often *systematic* (predictable) and may be identified and corrected using pre-launch or in-flight platform ephemeris (i.e., information about the geometric characteristics of sensor and the Earth at 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, relief displacement, and tangential scale distortion.

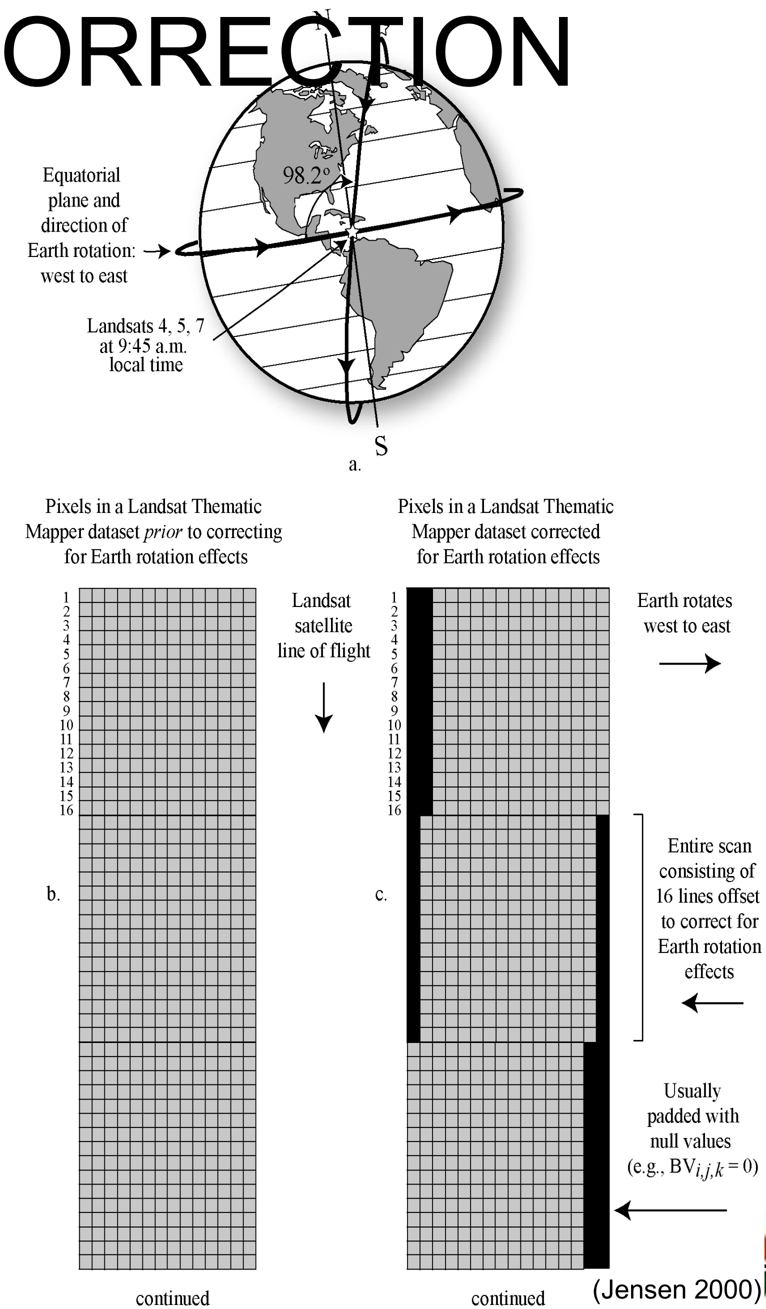


GEOMETRIC CORRECTION

a) Landsat satellites 4, 5, and 7 are in a Sun-synchronous orbit with an angle of inclination of 98.2°. The Earth rotates on its axis from west to east as imagery is collected.

b) Pixels in three hypothetical scans (consisting of 16 lines each) of Landsat TM data. While the matrix (raster) may look correct, it actually contains systematic geometric distortions caused by angular velocity of the satellite in its orbit in conjunction with the surface velocity of the Earth as it rotates on its axis while collecting a frame of imagery.

c) The result of adjusting (*deskewing*) the original Landsat TM data to the west to compensate for Earth rotation effects. Landsats 4, 5, and 7 use a bidirectional cross-track scanning mirror.



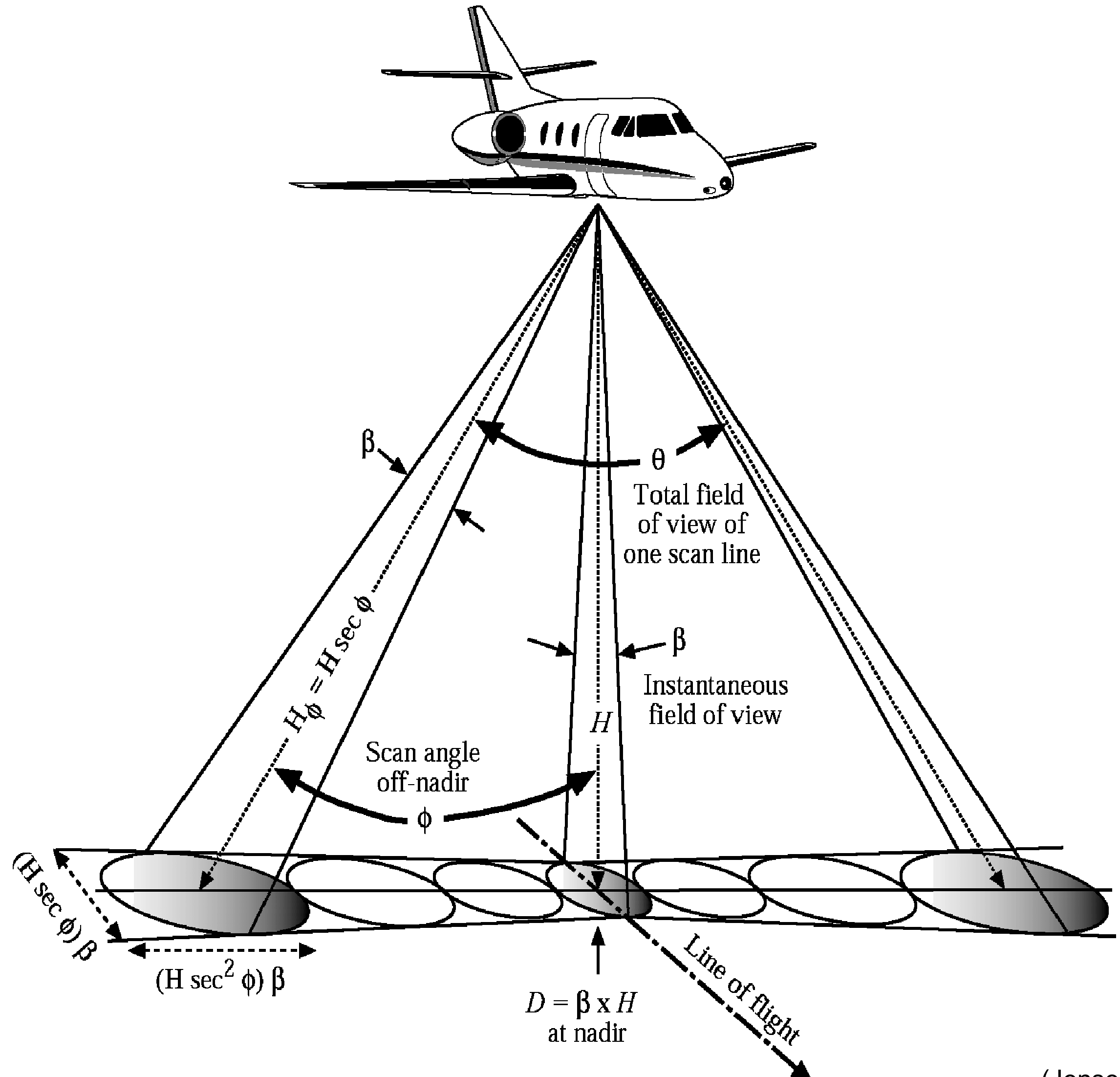
(Jensen 2000)

GEOMETRIC CORRECTION

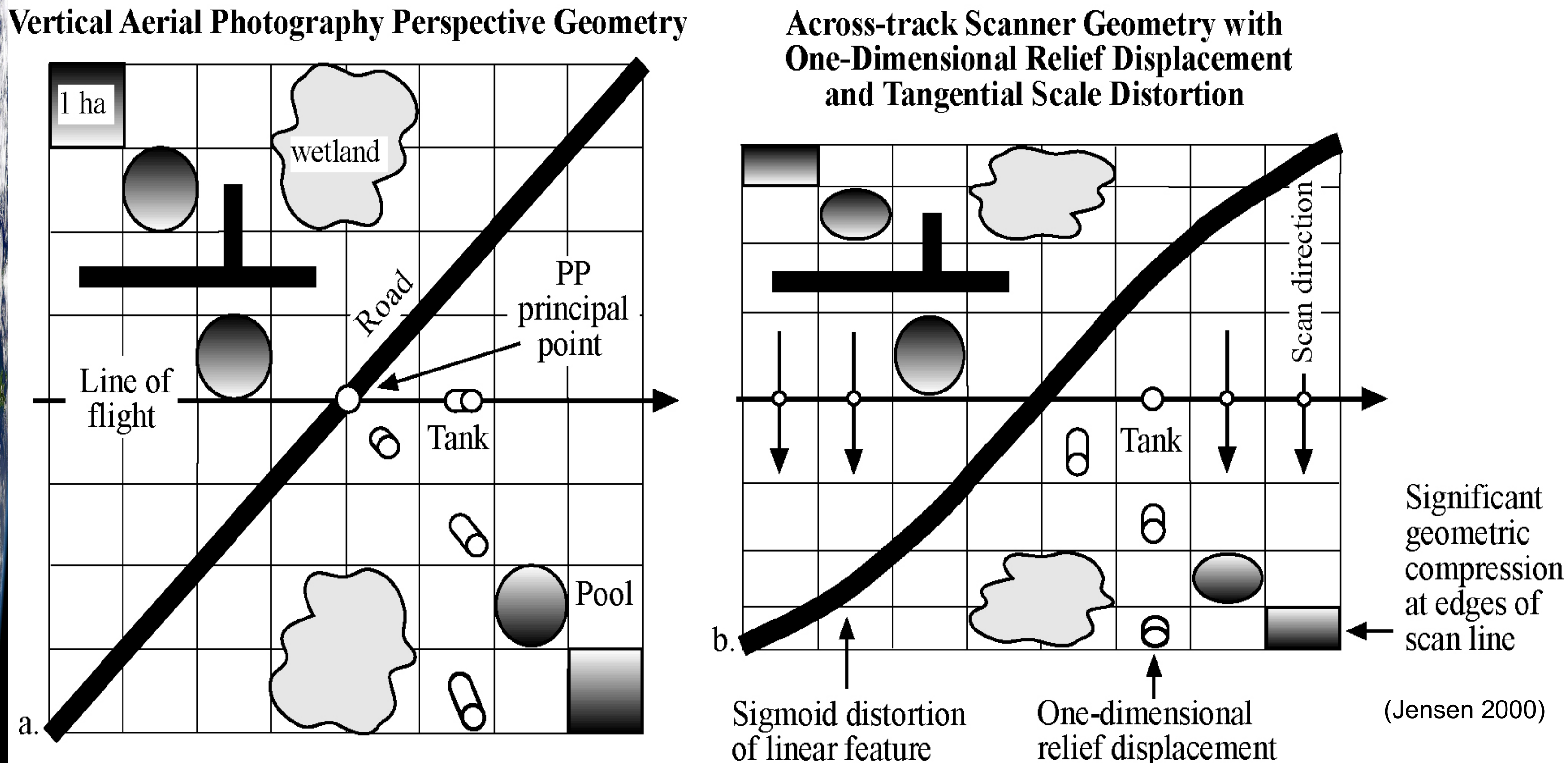
Scanning System-induced Variation in Ground Resolution Cell Size

- In low altitude scanning systems the amount of distortion introduced by the scanning system with large scan angles (up to 70°) can be significant.
- This introduces numerous types of geometric distortion that can be difficult to correct.

GEOMETRIC CORRECTION

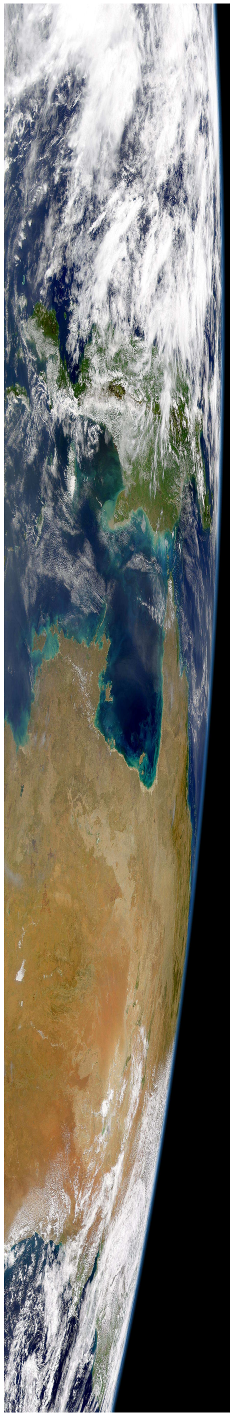


(Jensen 2000)



a) Hypothetical vertical aerial photograph obtained over level terrain. Four 50-ft-tall tanks are distributed throughout the landscape and experience varying degrees of radial relief displacement the farther they are from the principal point (PP).

b) b) 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.

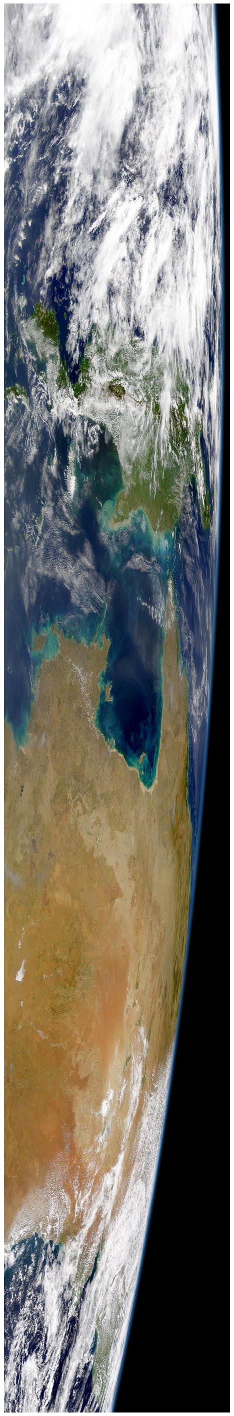


GEOMETRIC CORRECTION

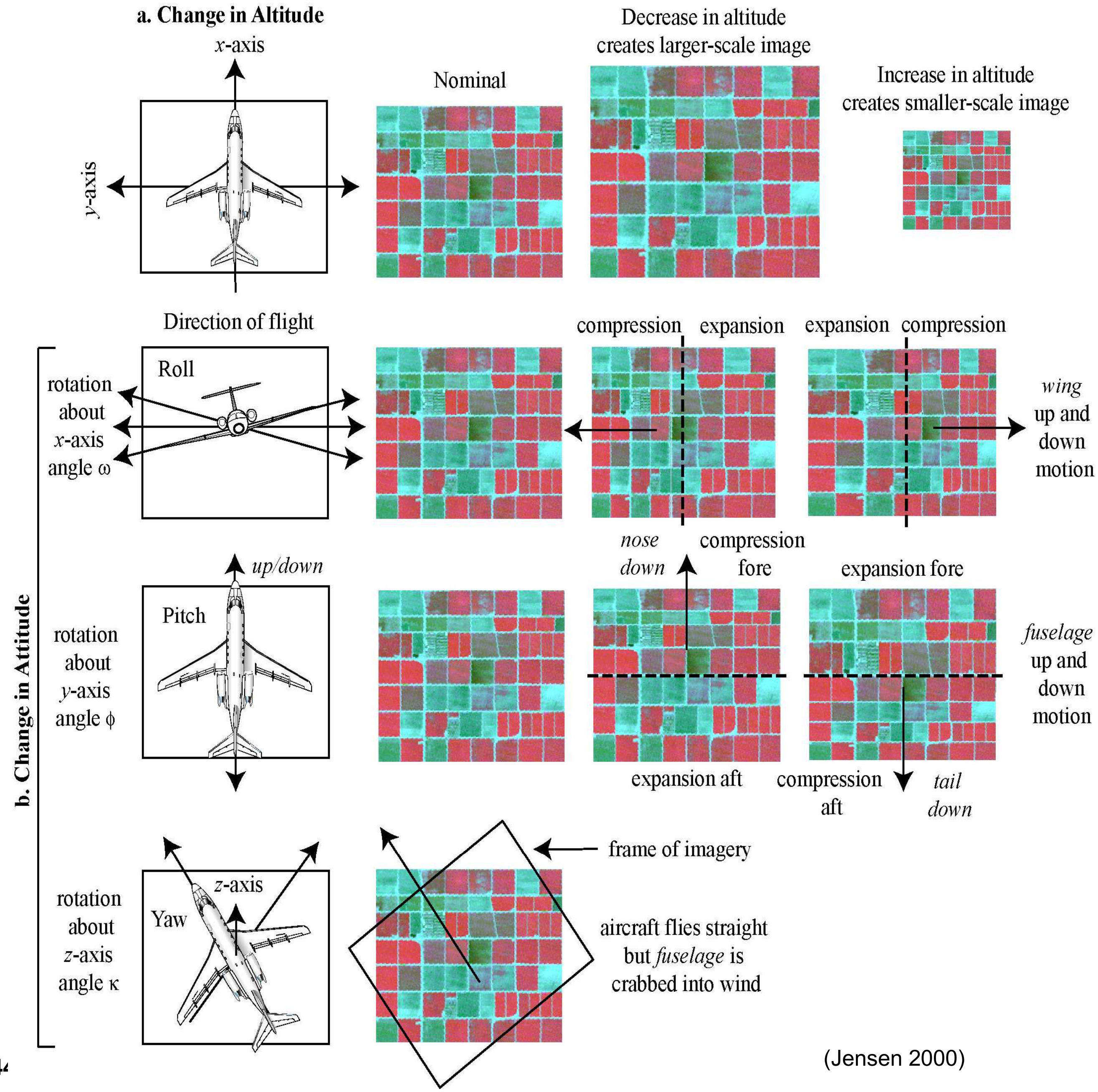
External geometric errors are usually introduced by phenomena that vary in nature through space and time.

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:

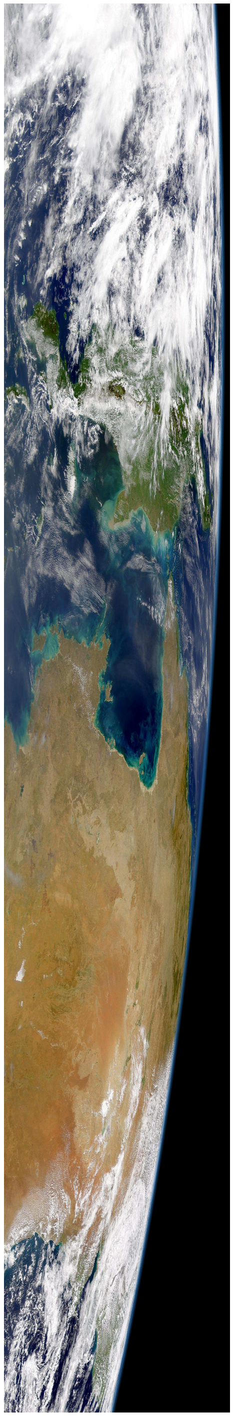
- *altitude* changes, and/or
- *attitude* changes (roll, pitch, and yaw).



Geometric Modification of Remotely Sensed Data Caused by Changes in Platform Altitude and Attitude



(Jensen 2000)



GEOMETRIC CORRECTION

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

1. Development of Mathematical Transformation between image and map

The geometric relationship between the input pixel coordinates (column and row) 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′*).

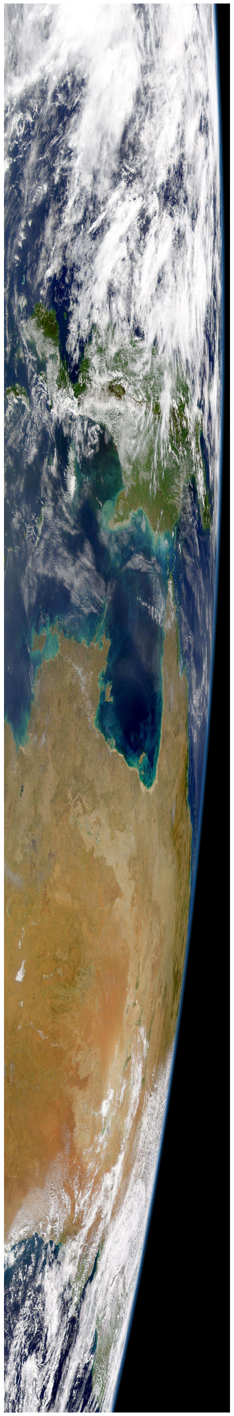
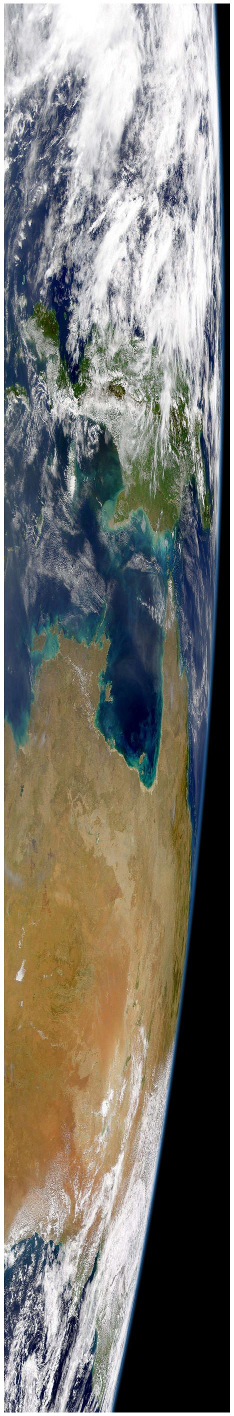


IMAGE TO MAP

Image-to-map rectification is the process by which the geometry of an image is made planimetric.

It may not, however, remove all the distortion caused by topographic relief displacement in images.

The *image-to-map rectification* process normally involves selecting GCP image pixel coordinates (row and column) with their map coordinate counterparts (e.g., meters northing and easting in a Universal Transverse Mercator map projection).



CORRECTION METHODS: GROUND CONTROL POINTS

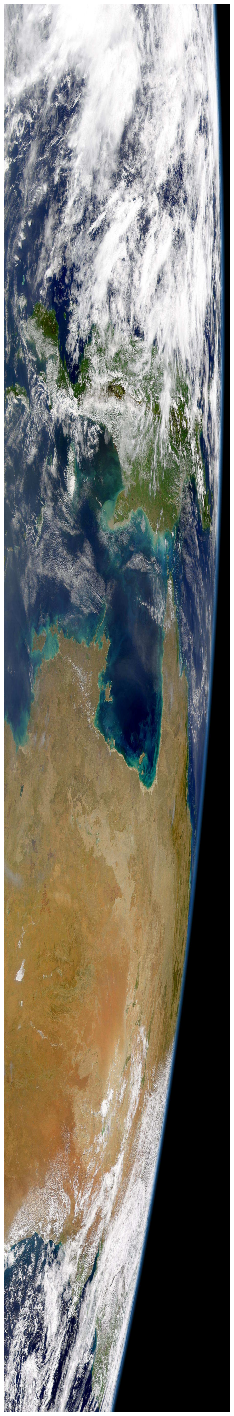
Geometric distortions introduced by distortions can be corrected using ground control points and appropriate mathematical models.

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.

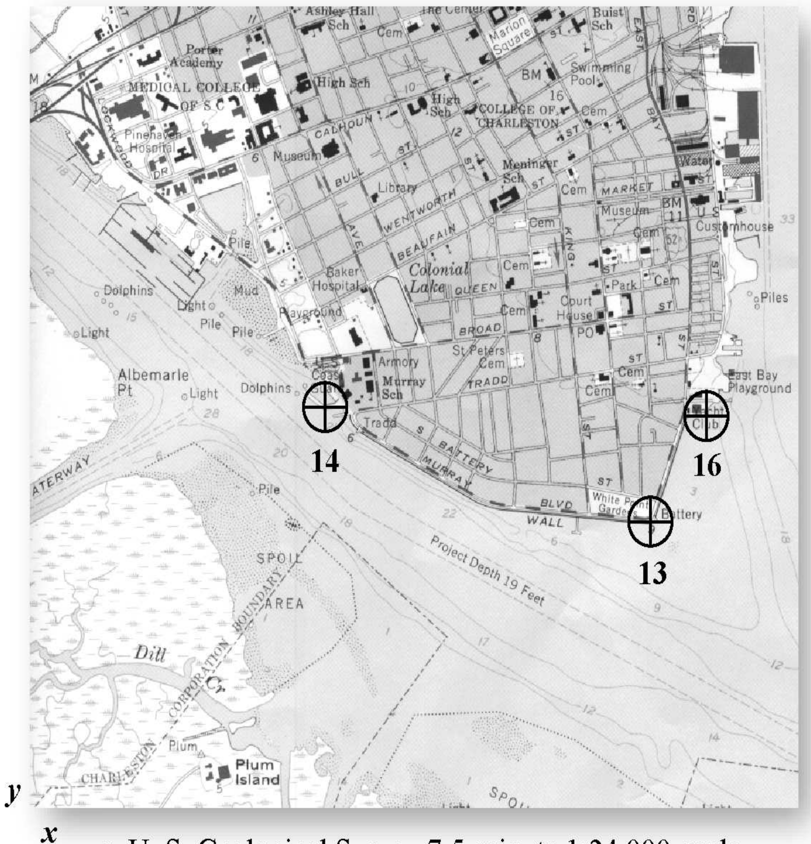
The image analyst must be able to obtain two distinct sets of coordinates associated with each GCP:

- *image coordinates* specified in *i* rows and *j* columns, and
- *map coordinates* (e.g., *x, y* measured in degrees of latitude and longitude, feet in a state plane coordinate system, or meters in a Universal Transverse Mercator projection).

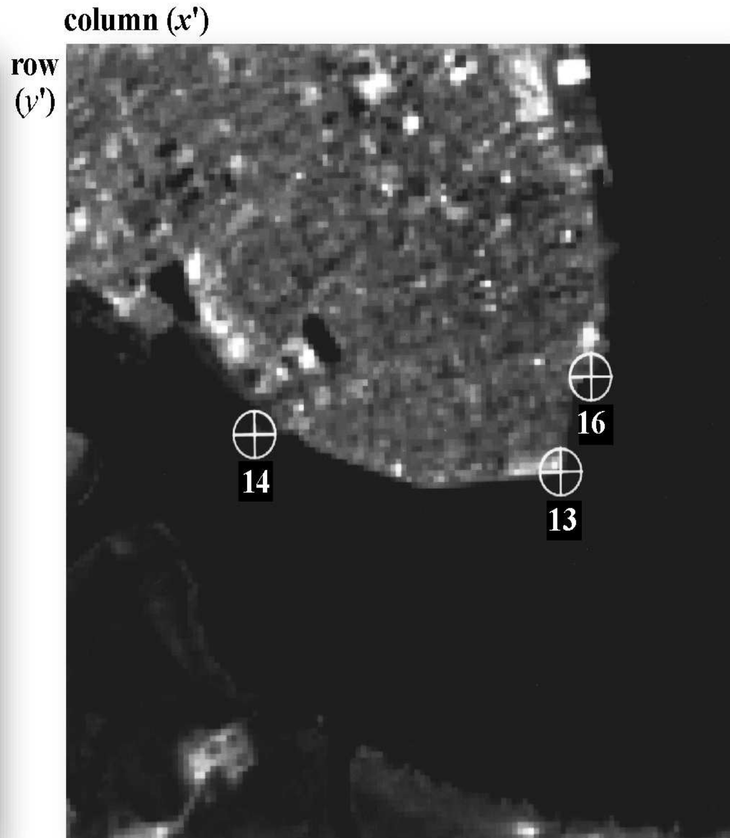
The paired coordinates from many GCPs (e.g., 20) can be modeled to derive *geometric transformation coefficients*. These coefficients may be used to geometrically rectify the remote sensor data to a standard datum and map projection.



Selecting Ground Control Points for Image-to-Map Rectification



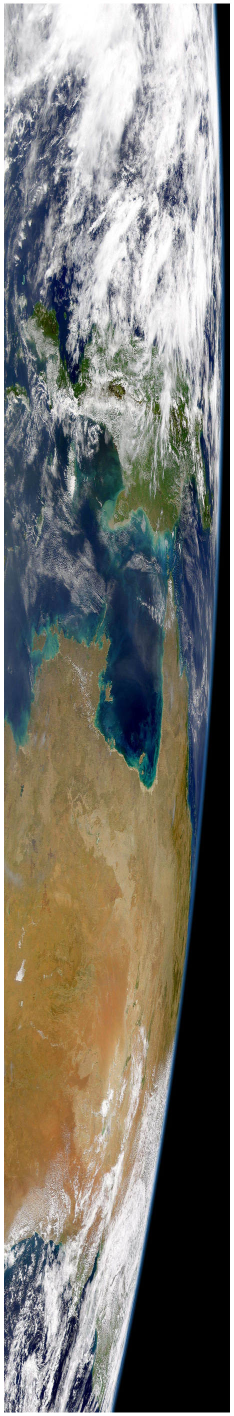
a. U. S. Geological Survey 7.5-minute 1:24,000-scale topographic map of Charleston, SC, with three ground control points identified.



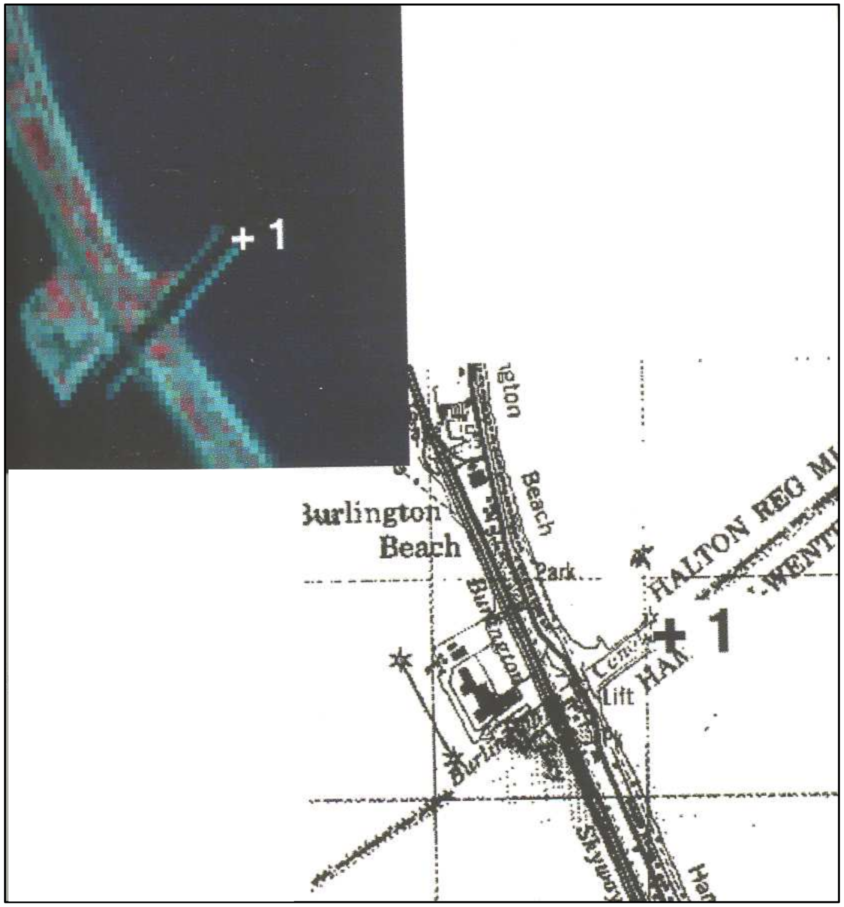
b. Unrectified Landsat Thematic Mapper band 4 image obtained on November 9, 1982.

(Jensen 2000)

a) USGS 1:24,000-scale map with three ground control points identified (13, 14, and 16). The GCP map coordinates are measured in meters easting (*x*) and northing (*y*) in a Universal Transverse Mercator projection. b) Unrectified TM image with the three ground control points identified. The image GCP coordinates are measured in rows and columns.



CORRECTION METHODS: GROUND CONTROL POINTS



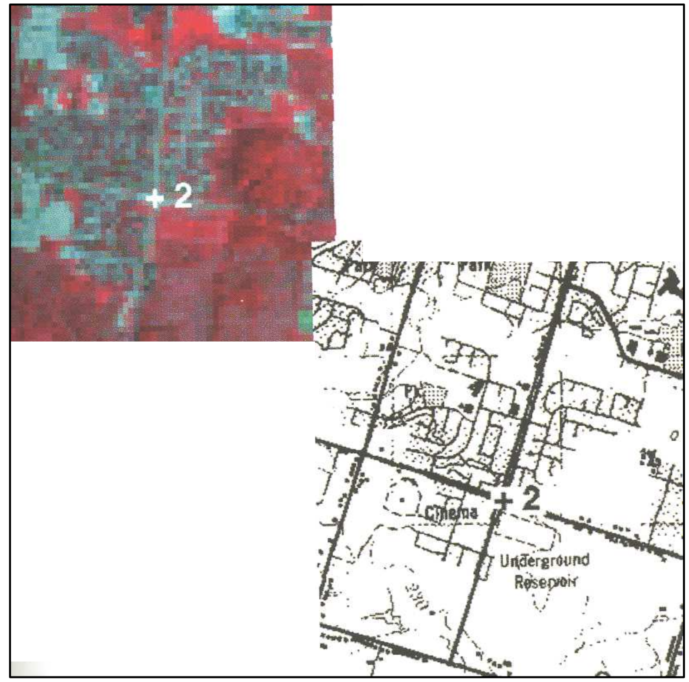
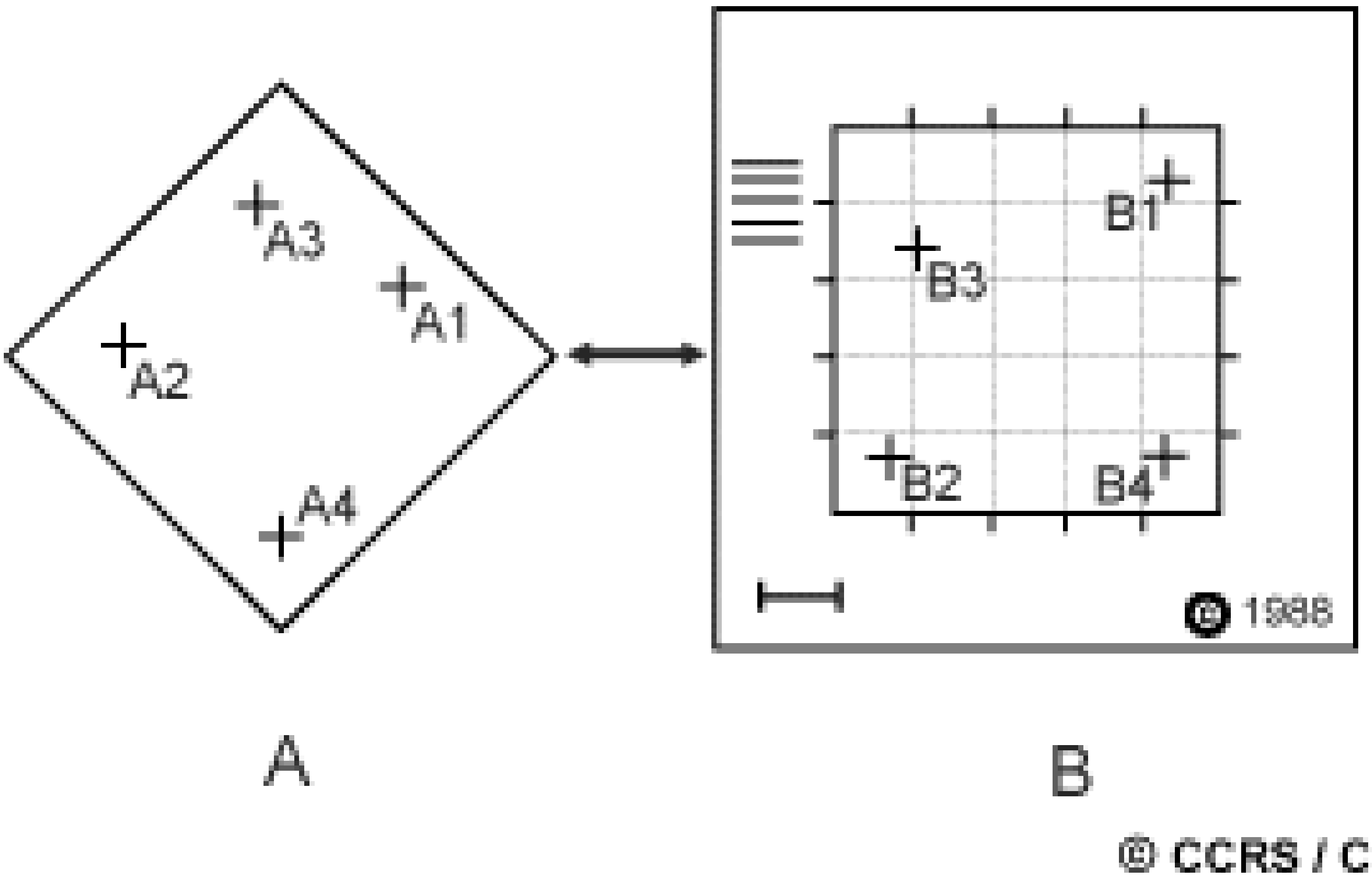
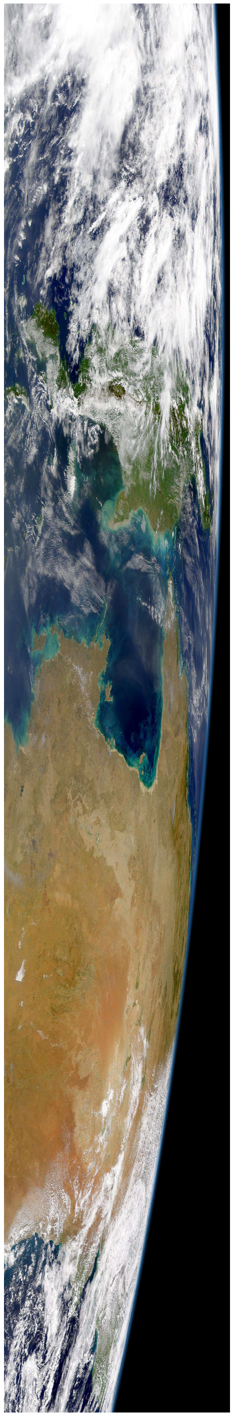


IMAGE TO MAP





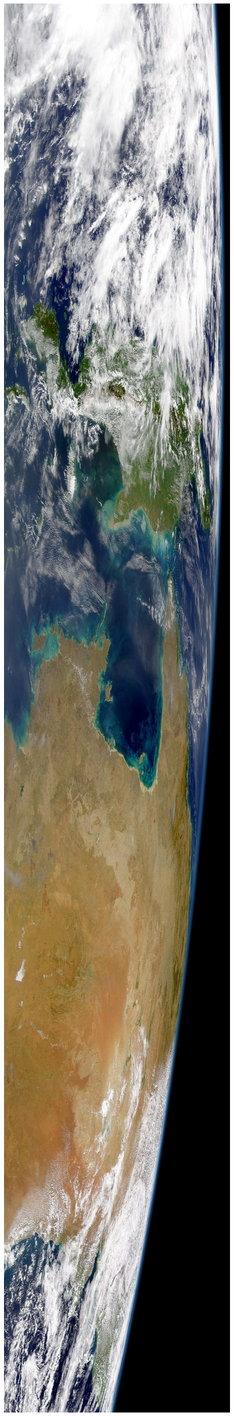


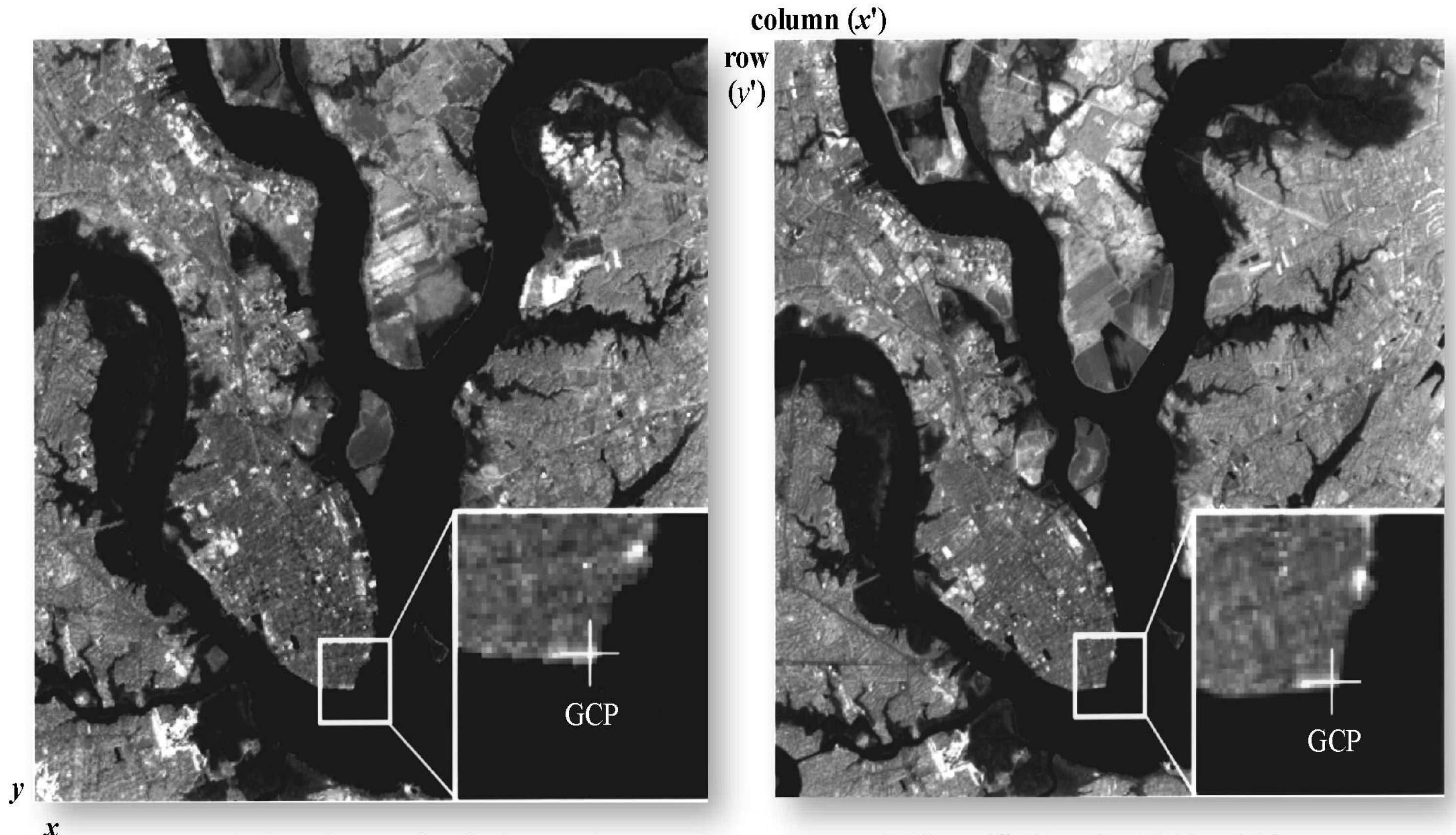
IMAGE TO IMAGE

Image-to-image registration is the matching of one image to another so the same geographic area is positioned coincident with respect to the other.

This type of geometric correction is used when it is *not* necessary to have each pixel assigned a unique *x, y* coordinate in a map projection.

For example, we might want to make a cursory examination of two images obtained on different dates to see if any change has taken place.

IMAGE TO IMAGE

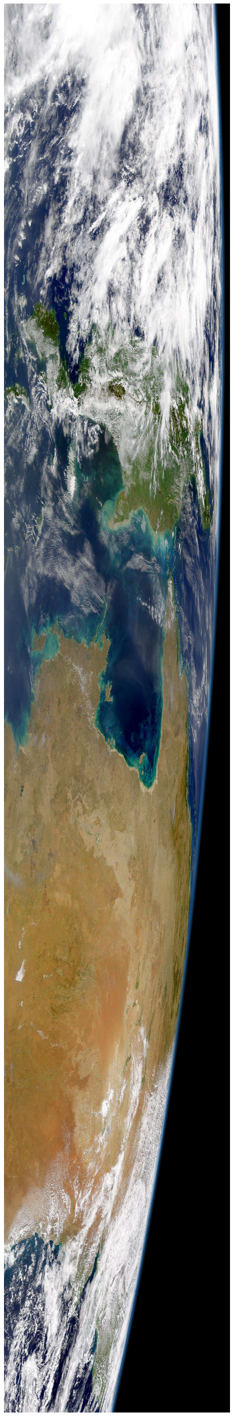


a. *Rectified* Landsat TM band 4 image of Charleston, SC, obtained on November 9, 1982.

b. Unrectified Landsat TM band 4 image obtained on October 14, 1987.

a) Previously rectified TM data with b) Unrectified TM data to be registered to the rectified 1982 Landsat scene.

(Jensen 2000)

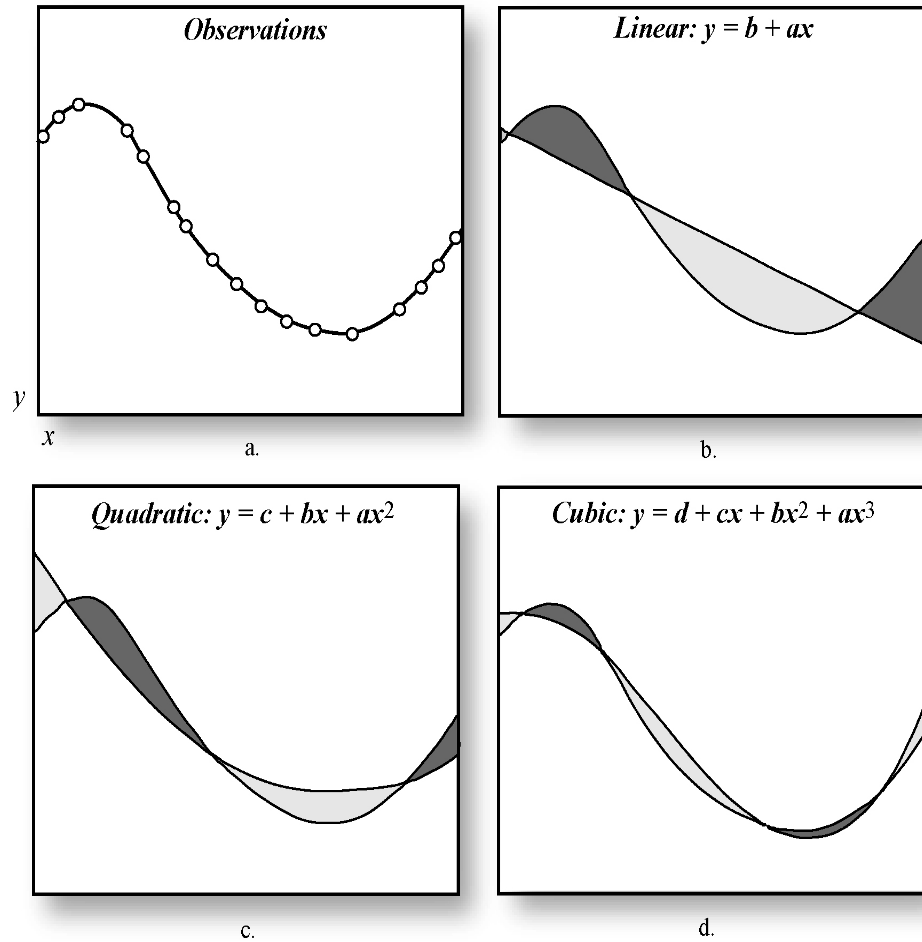


DEVELOPMENT OF MATHEMTICAL TRANSFORMATION

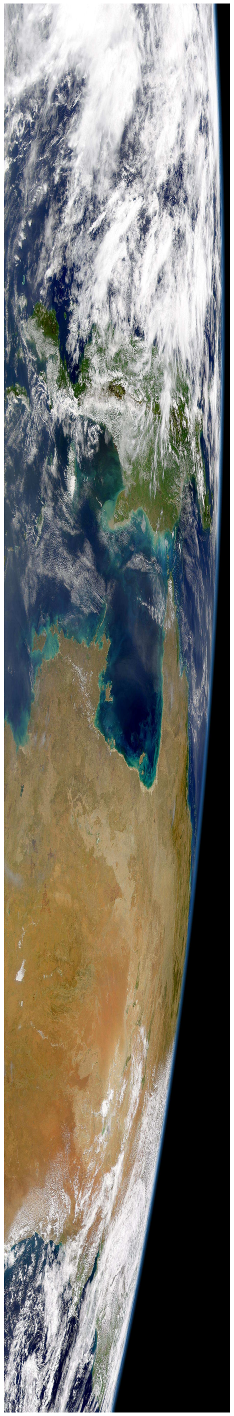
Equations need to be fitted to the GCP data using least-squares criteria to model the corrections.

Depending on the distortion in the imagery, the number of GCPs used, and the degree of topographic relief displacement in the area, *higher-order polynomial equations* may be required to geometrically correct the data.

The *order* of the rectification is simply the highest exponent used in the polynomial.



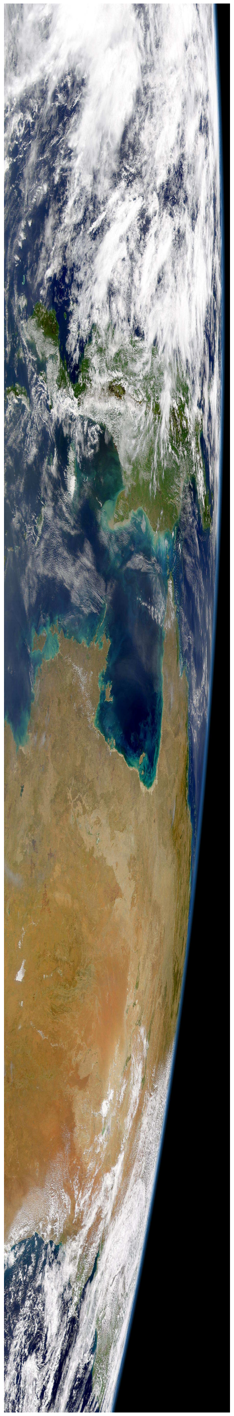
(Jensen 2000)



ROOT-MEAN-SQUARED ERROR

Before applying the coefficients to create the rectified output image, it is important to determine how well the transformation derived from the least-squares regression of the GCPs account for the geometric distortion in the input image.

The method used most often involves the computation of the **root-mean-square error** (RMS_{error}) for each of the ground control points.



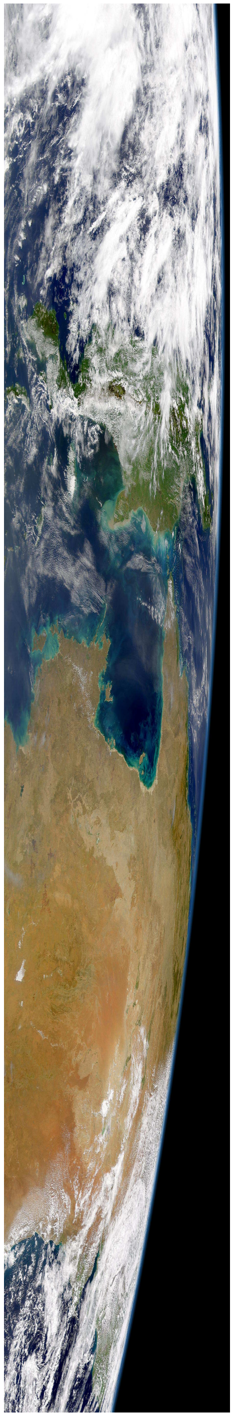
ROOT-MEAN-SQUARED ERROR

Selecting GCPs and deriving the transformation and RMS error is an iterative process.

- First, an initial set of GCPs (e.g., 20) are used to compute an initial set of coefficients and constants.
- The root mean squared error (RMSE) associated with each of these initial 20 GCPs is computed and summed.
- Then, the individual GCPs that contributed the greatest amount of error are determined and deleted.
- After the first iteration, this might only leave 16 of 20 GCPs.

A new set of coefficients is then computed using the16 GCPs. The process continues until the RMSE reaches a user-specified threshold (e.g., $\leq$1 pixel error in the x-direction and $\leq$1 pixel error in the y-direction).

The goal is to remove the GCPs that introduce the most error into the multiple-regression coefficient computation. When the acceptable threshold is reached, the final coefficients and constants are used to rectify the input image to an output image in a standard map projection as previously discussed.



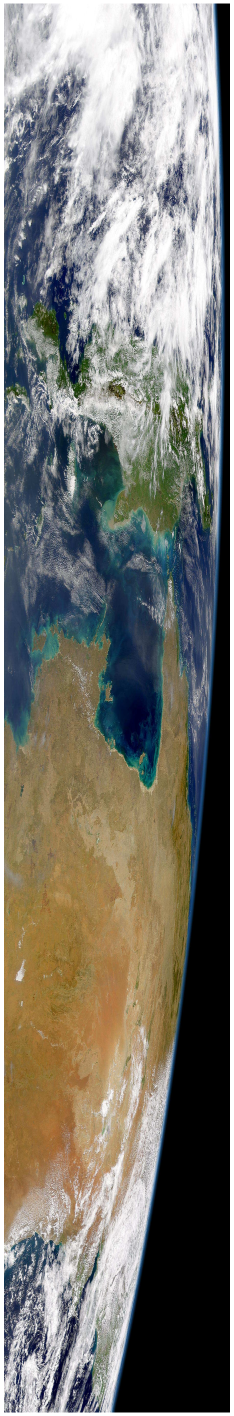
GEOMETRIC CORRECTION

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

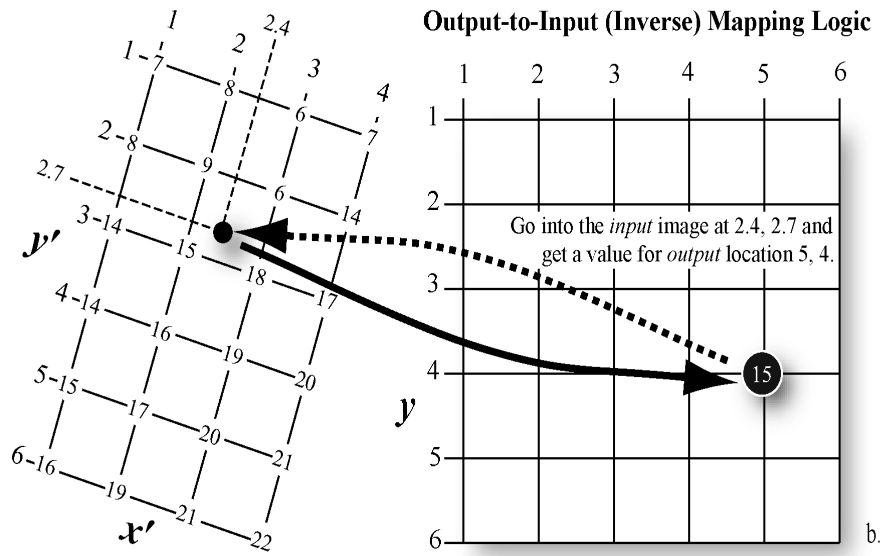
2. Intensity Interpolation

Pixel brightness values must then be determined. As there may be no direct one-to-one relationship between the movement of input pixel values to output pixel locations, the rectified output image often requires a value from the input pixel grid that does not fall neatly on a row-and-column coordinate.

When this occurs, there must be some mechanism for determining the brightness value (BV) to be assigned to the output rectified pixel. This process is called intensity interpolation.



SPATIAL INTERPOLATION



Original input image (x', y')

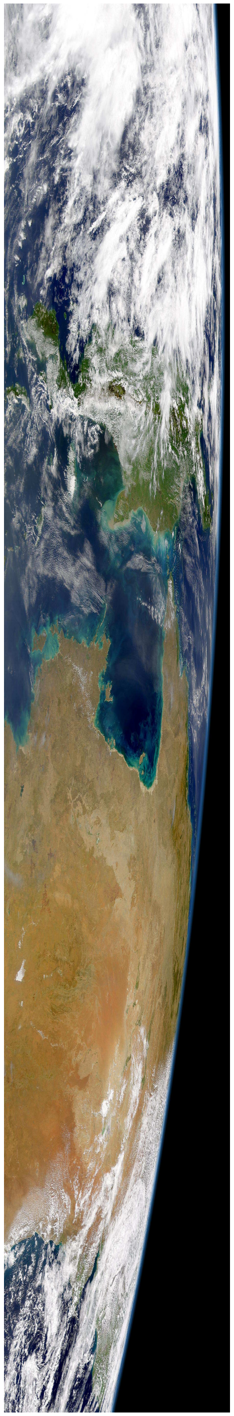
Rectified output image (x, y)

$$x' = a_0 + a_1 x + a_2 y$$
$$y' = b_0 + b_1 x + b_2 y$$

The logic is then to fill a rectified output matrix with values from an unrectified input image matrix using *output-to-input* (***inverse***) mapping logic.

Output-to-input inverse mapping logic is the preferred methodology because it results in a rectified output matrix with values at every pixel location.

(Jensen 2000)



SPATIAL INTERPOLATION LOGIC

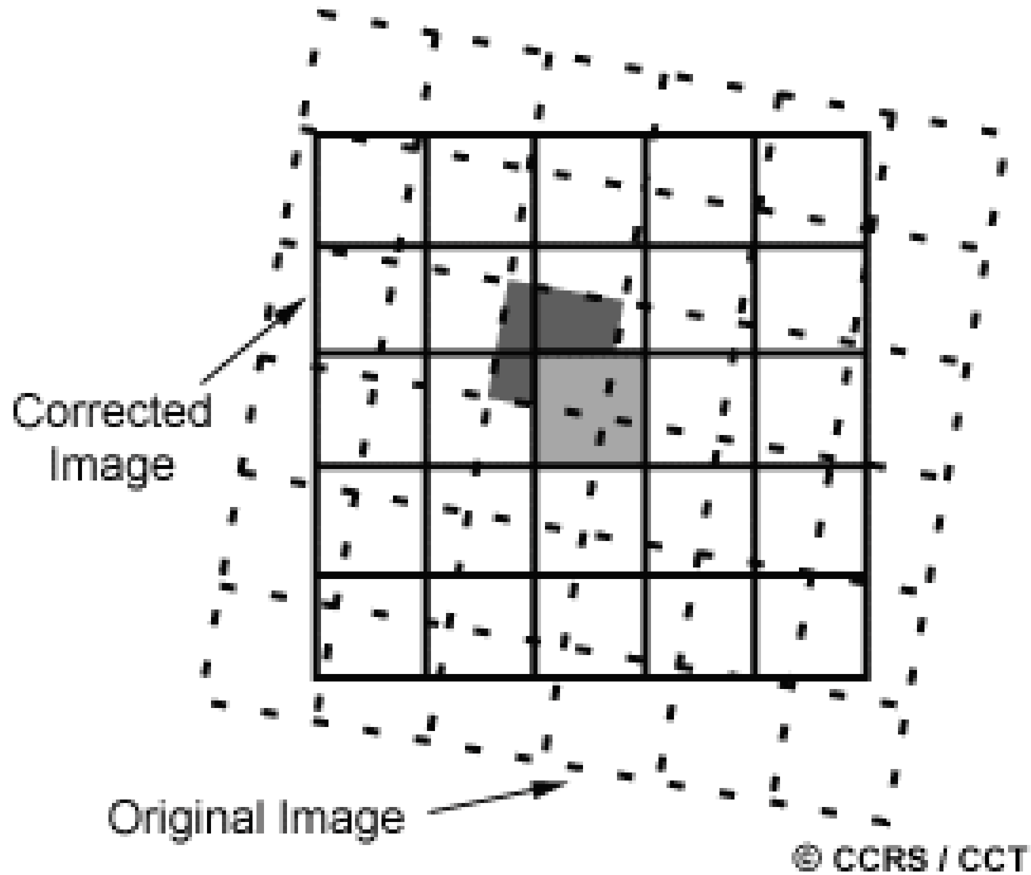
In order to actually geometrically correct the original distorted image, a procedure called resampling is used to determine the digital values to place in the new pixel locations of the corrected output image.

The resampling process calculates the new pixel values from the original digital pixel values in the uncorrected image.

There are three common methods for resampling:

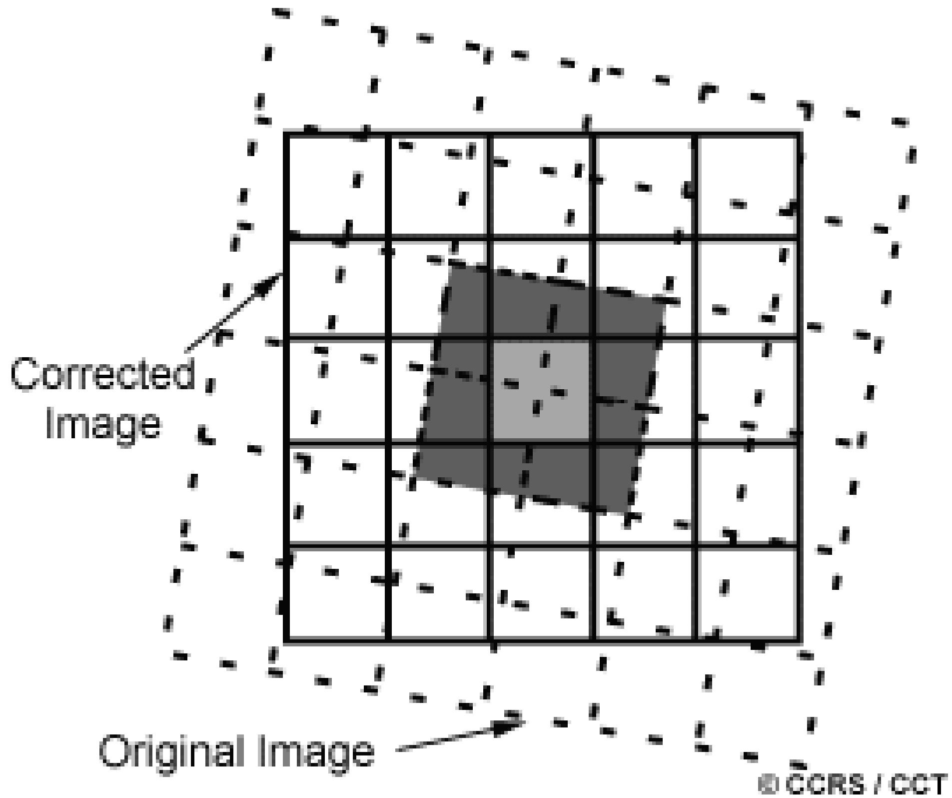
- nearest neighbour,
- bilinear interpolation,
- and cubic convolution.

NEAREST NEIGHBOUR

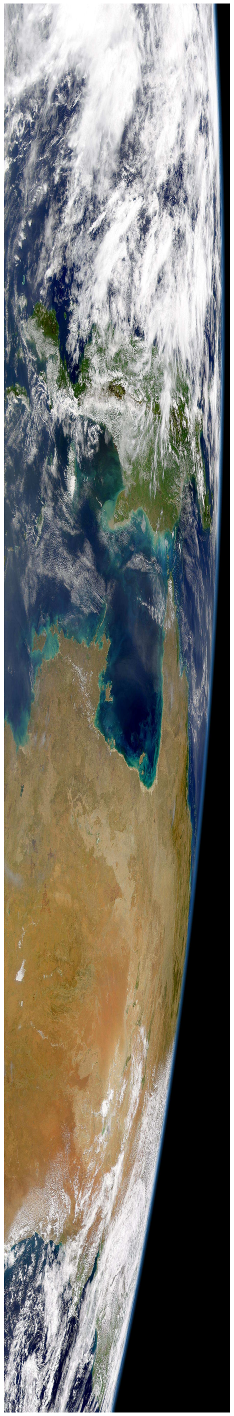


Nearest neighbour resampling uses the digital value from the pixel in the original image which is nearest to the new pixel location in the corrected image. This is the simplest method and does not alter the original values, but may result in some pixel values being duplicated while others are lost. This method also tends to result in a disjointed or blocky image appearance.

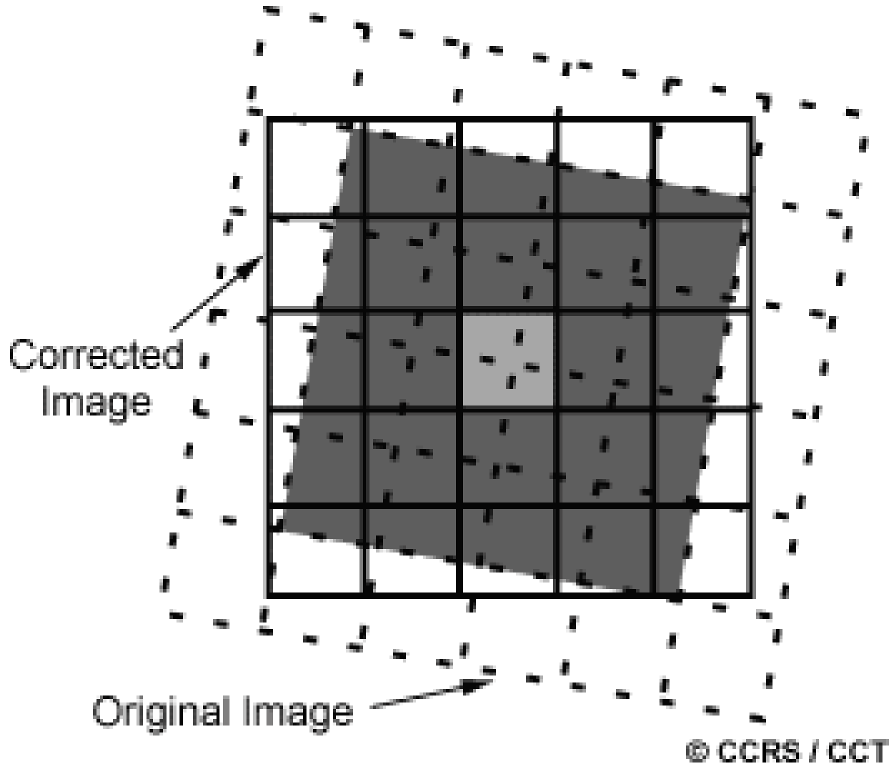
BILINEAR INTERPOLATION



Bilinear interpolation resampling takes a weighted average of 4 pixels in the original image nearest to the new pixel location. The averaging process alters the original pixel values and creates entirely new digital values in the output image. This may be undesirable if further processing and analysis, such as classification based on spectral response, is to be done. If this is the case, resampling may best be done after the classification process.



CUBIC CONVOLUTION



Cubic convolution resampling calculates a distance weighted average of a block of sixteen pixels from the original image which surround the new output pixel location.

As with bilinear interpolation, this method results in completely new pixel values. However, these two methods both produce images which have a much sharper appearance and avoid the blocky appearance of the nearest neighbour method

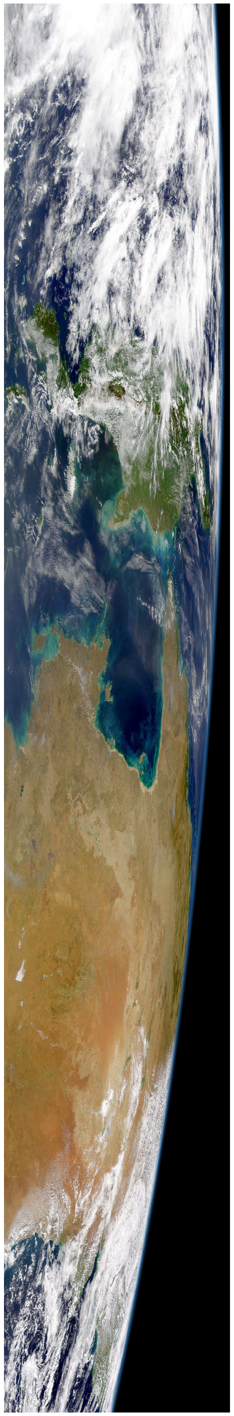


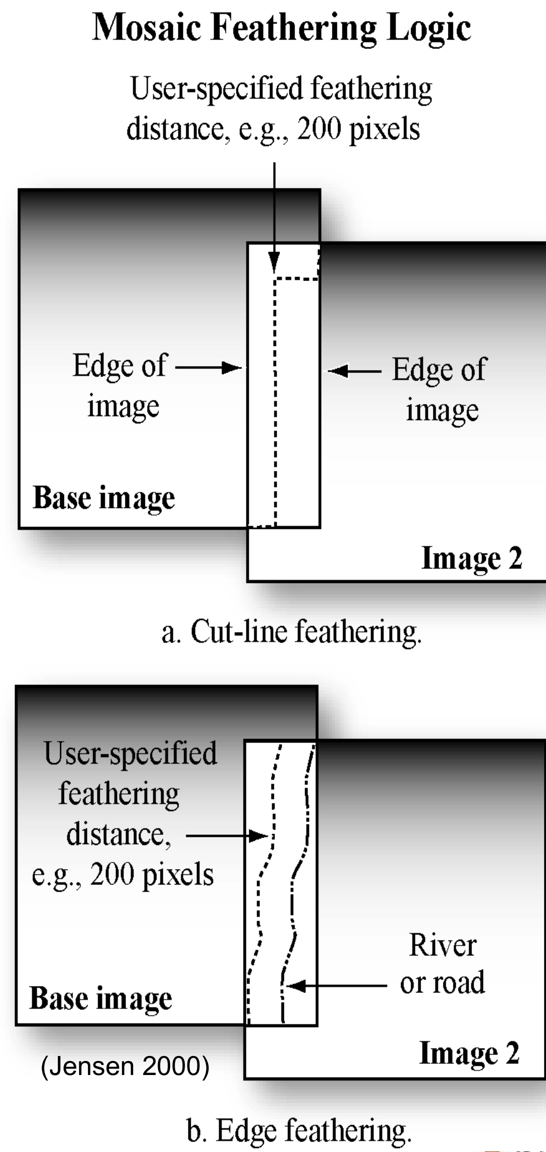
IMAGE MOSAICKING

In some cases it is necessary to mosaic a number of individual scenes. To do this the scenes should be rectified to the same map projection and datum.

Ideally, rectification of the *n* images is performed using the same intensity interpolation resampling logic and pixel size.

One of the images to be mosaicked is designated as the *base image*. The base image and *image 2* will normally overlap a certain amount (e.g., 20% to 30%).

A representative *geographic area in the overlap region* is identified and a histogram of the area in the base image is extracted. The histogram from the base image is then applied to image 2 using a *histogram-matching algorithm*. This causes the two images to have approximately the same grayscale characteristics.



(Jensen 2000)

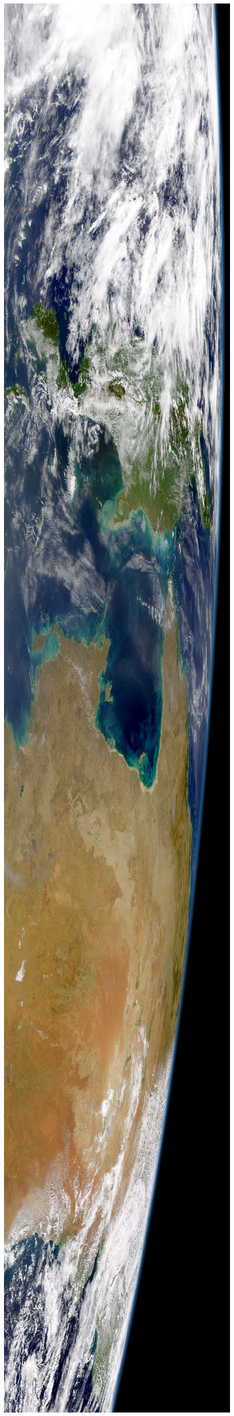
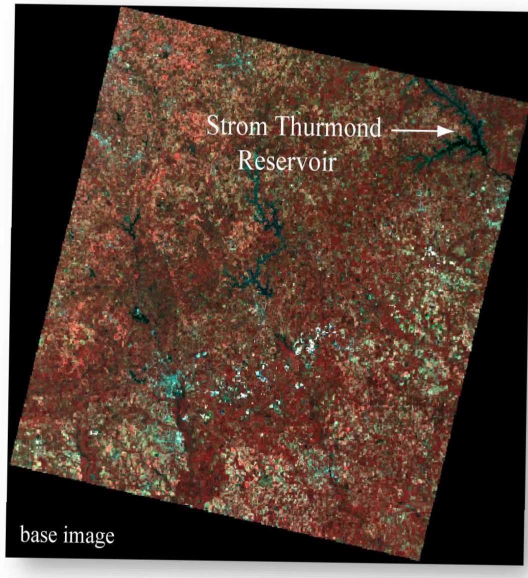
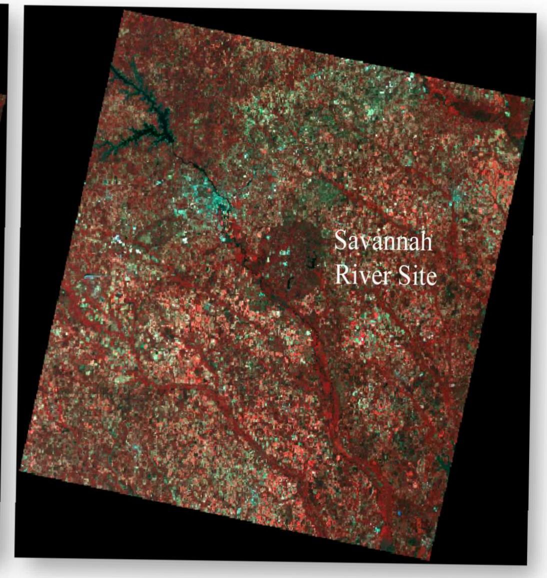


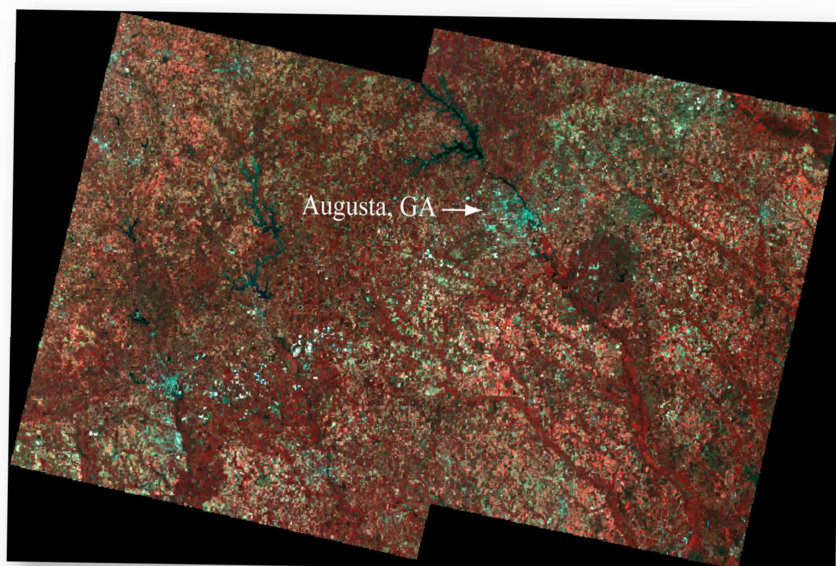
Image Mosaicking



a. Rectified Landsat ETM+ image of eastern Georgia obtained on October 3, 2001 (bands 4, 3, 2; Worldwide Reference System—Path 18, Row 37).

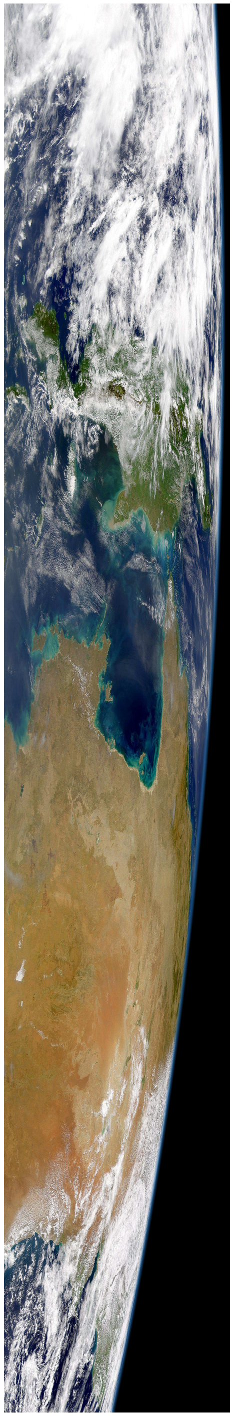


b. Rectified Landsat ETM+ image of western South Carolina obtained on October 26, 2001 (bands 4, 3, 2; Worldwide Reference System—Path 17, Row 37).



c. Feathered mosaic of rectified Landsat ETM+ imagery of eastern Georgia and western South Carolina.

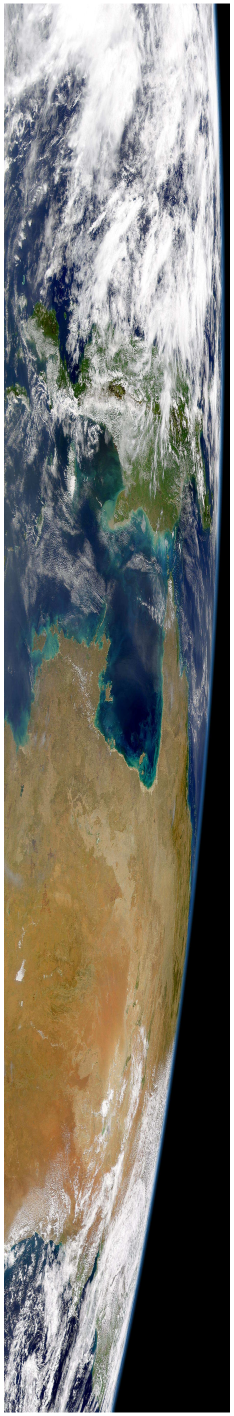
(Jensen 2000)



ORTHO-RECTIFICATION

- This approach of matching with ground control points does NOT take into account relief displacement—scale variations resulting from differences in terrain relief

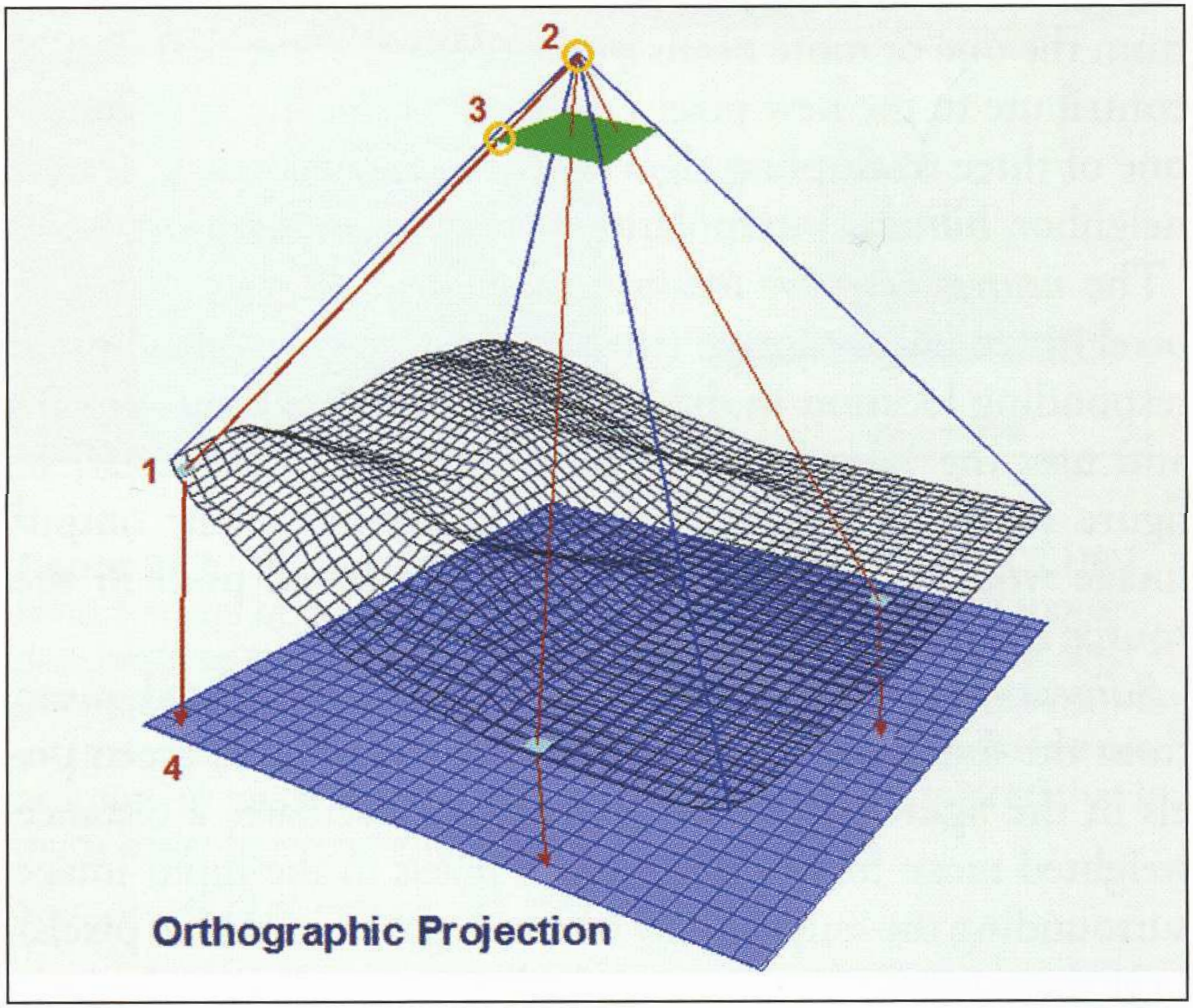
- Corrections for relief displacement can be added to either transformation method using digital elevation data for the scene.



ORTHO-RECTIFICATION

- The elevation data may be an existing dataset (topographic map), or a Digital Elevation Model (DEM).
- The magnitude and direction of relief displacement also depends on the sensor.
  - In a vertical aerial photograph, points closer to the sensor (or with higher elevation) are displaced radially outward from the center of the image;
  - In optical scanners they are displaced outward perpendicular to the flight path.

ORTHO-RECTIFICATION



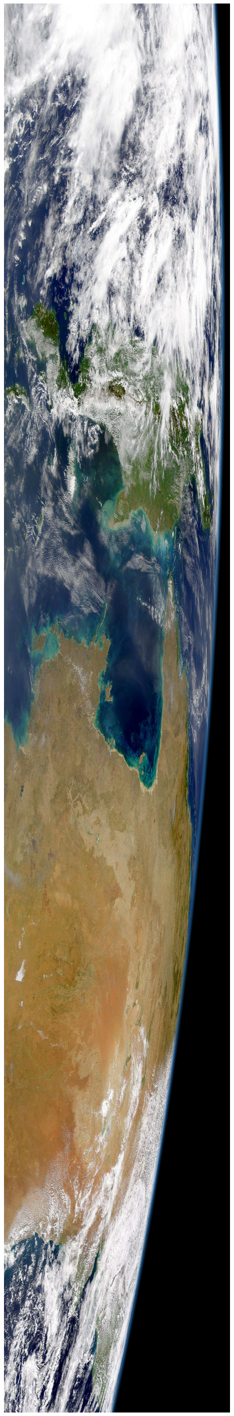


IMAGE RECTIFICATION

- Further Reading:
  - Lilliesand, Keifer and Chipman
    - 7.2,
    - 7.6-7.12