Digital Image Processing
Image Rectification and Restoration

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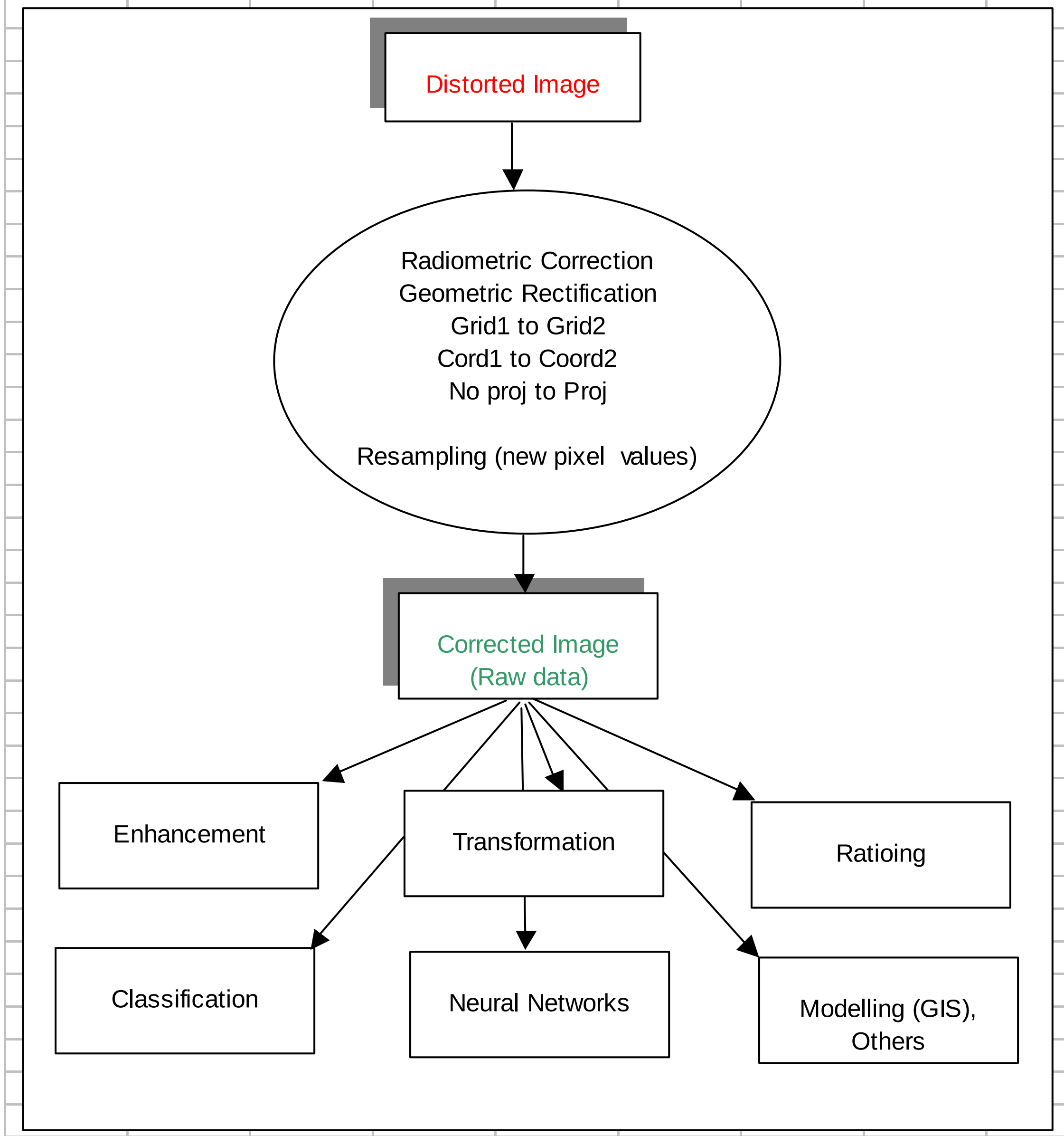


Overview of DIP

Introduction

The common image processing functions available in image analysis systems can be categorized as follows:

- Preprocessing (on distorted images)
- Processing (on corrected images)

  * Image Enhancement

  * Image Transformation

  * Image Classification and Analysis

Pre-processing

- Operations that are normally required prior to the main data analysis and extraction of information
  - Radiometric corrections.
  - Geometric corrections.
- Radiometric corrections
  - correcting the data for sensor irregularities and unwanted sensor or atmospheric noise, and converting the data so they accurately represent the reflected or emitted radiation measured by the sensor.
- Geometric corrections
  - 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.

Radiometric Distortion

- **What is a radiometric distortion?**
- It's an error that influences the radiance or radiometric value of a scene element (pixel).

Why?

- Signal traveling through atmosphere; atmosphere affects the signal
- Sun illumination influences radiometric values
- Seasonal changes affect radiometric values
- Sensor failures or system noise affects values
- Terrain influences radiance

Radiometric Distortion

Radiometric distortions are due to:

- Sensor noise and failures
- Seasonal variations
- Atmospheric effects
- Terrain

Radiometric Correction

- Radiometric correction is used to modify DN values in order to account for noise, i.e. contributions to the DN that are a function NOT of the feature being sensed but of the atmosphere or the sensor itself.
  - The purpose is to ensure accuracy in the relationship between radiant flux leaving a surface and radiant flux recorded by a sensor (DN).
  - Internal radiometric errors include sensor malfunction and improper calibration.
  - External radiometric errors include atmospheric effects ("fixed" with atmospheric correction).

Sensor Failure & Calibration

- Sensor Malfunction ⇒
  - Sensors sometimes simply do not operate correctly, resulting in radiometric error.
- Common forms of this type of error include:
  - line drops,
  - striping (banding),
  - line-start error
  - random noise or spikes

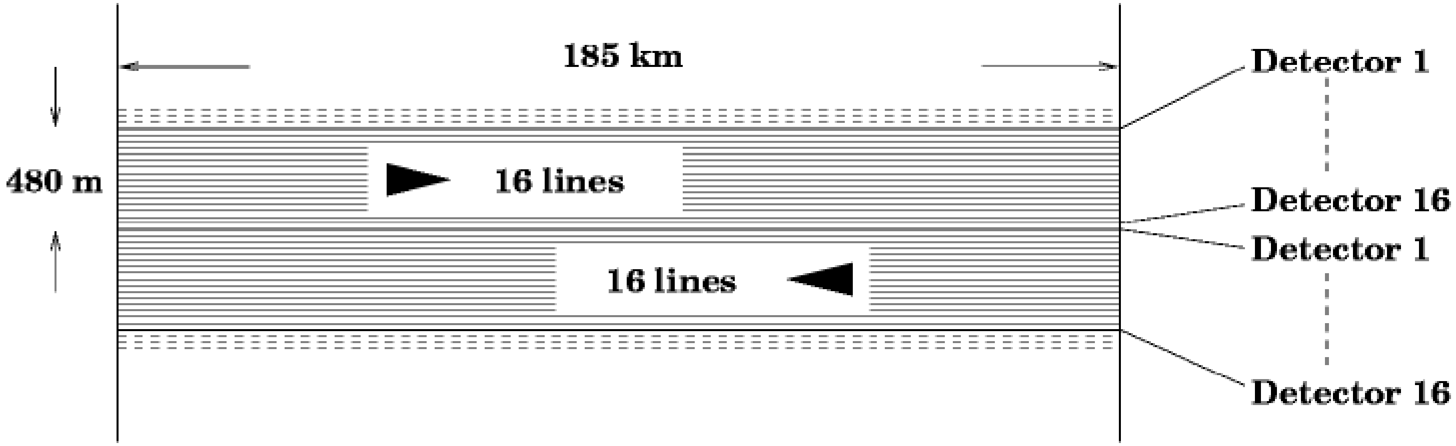
Missing data due to sensor failure results in a line of 0 values every 16th line for TM data (or 6th line for MSS) .. since there are 16 sensors for each band, scanning 16 lines at a time.

- Data can also show excessive speckle 'salt and pepper' effect (high and low values); this can be corrected using a box filter (3 x 3, 5 x 5): mean, median or modal.

Sensor Noise and Failure

Multi-spectral scanner patterns: example of a *whiskbroom* scanner, Landsat-TM

16 detectors scan the scene alternating from left to right and back by use of an oscillating mirror



At any time 100 detectors are operating simultaneously

(6x16 VNIR plus 1x4 TIR).

Line drop out

Line drops are caused by a detector failing to operate during a scan

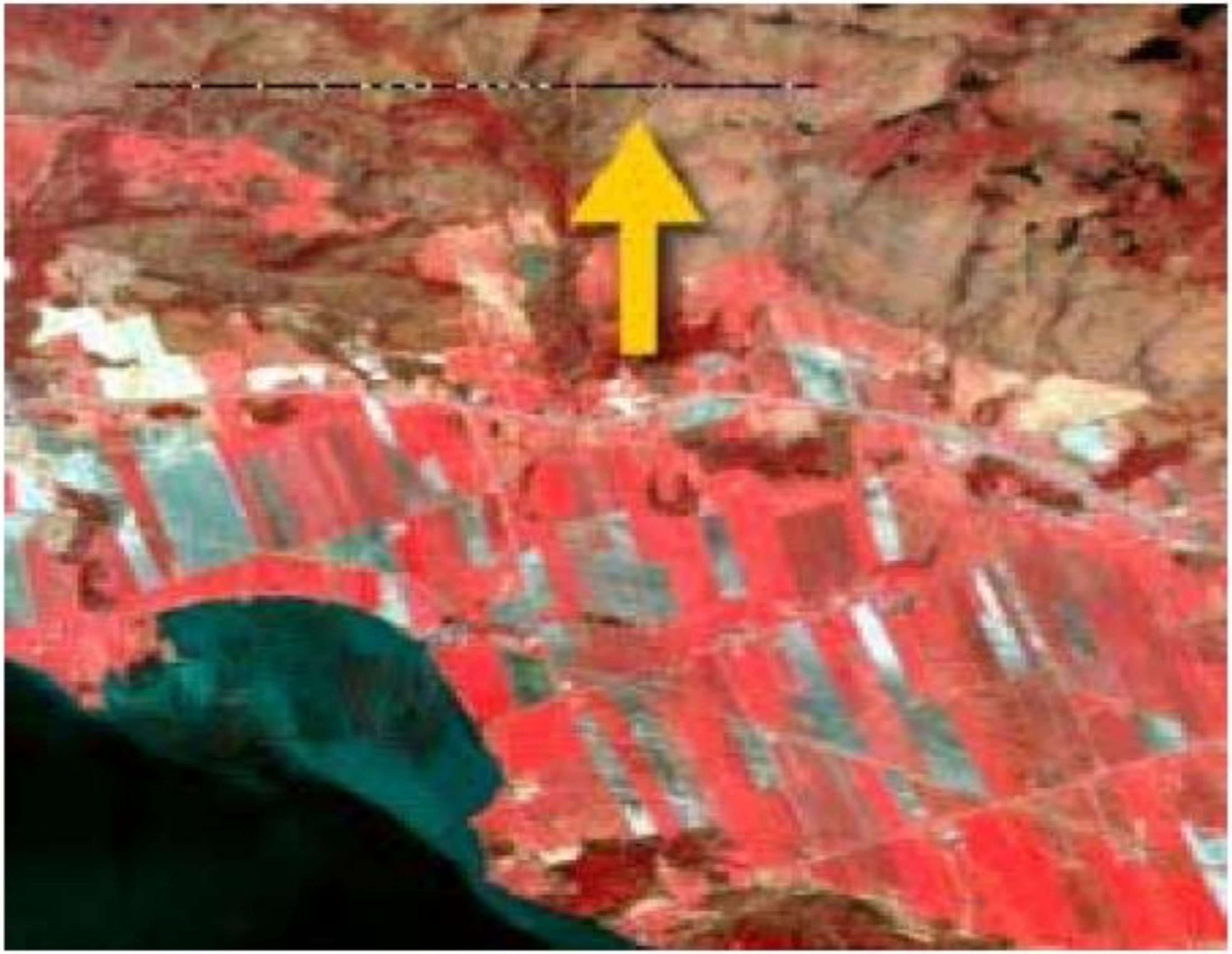
A serious problem, because data never collected cannot be restored.

However, we can improve our ability to interpret the data by estimating DNs for each pixel on the bad line.

Correction method:

1. Identify defective scan lines by comparing scene average DN to average DN of each scan line
2. Replace pixel in defective scan lines by the average of the two pixels directly above and beneath the pixel of the defected scan line

Line drop out



(CCRS Remote Sensing Tutorial)

Correcting Sensor Errors

- Line drops can be corrected using the formula:

$$DN_{ijk} = \mathrm{Int}\left(\frac{DN_{i-1,\, j,\, k} + DN_{i+1,\, j,\, k}}{2}\right)$$

  - where DN_{ijk} = output DN;
  - $DN_{i\text{-}1,j,k}$ = preceding line pixel DN; and
  - $DN_{i+1,j,k}$ = succeeding line pixel DN.

Line dropout

Original

11	11	11	11	11	11	12	15	22	23
10	11	11	11	11	12	16	20	28	31
10	11	11	11	13	16	22	28	36	39
10	11	11	13	17	23	30	36	42	45
10	11	13	17	25	33	40	45	47	48

Line drop-out

11	11	11	11	11	11	12	15	22	23
10	11	11	11	11	12	16	20	28	31
0	0	0	0	0	0	0	0	0	0
10	11	11	13	17	23	30	36	42	45
10	11	13	17	25	33	40	45	47	48

11	11	11	11	11	11	12	15	22	23
10	11	11	11	11	12	16	20	28	31
10	11	11	12	14	17	23	28	35	38
10	11	11	13	17	23	30	36	42	45
10	11	13	17	25	33	40	45	47	48

Corrected

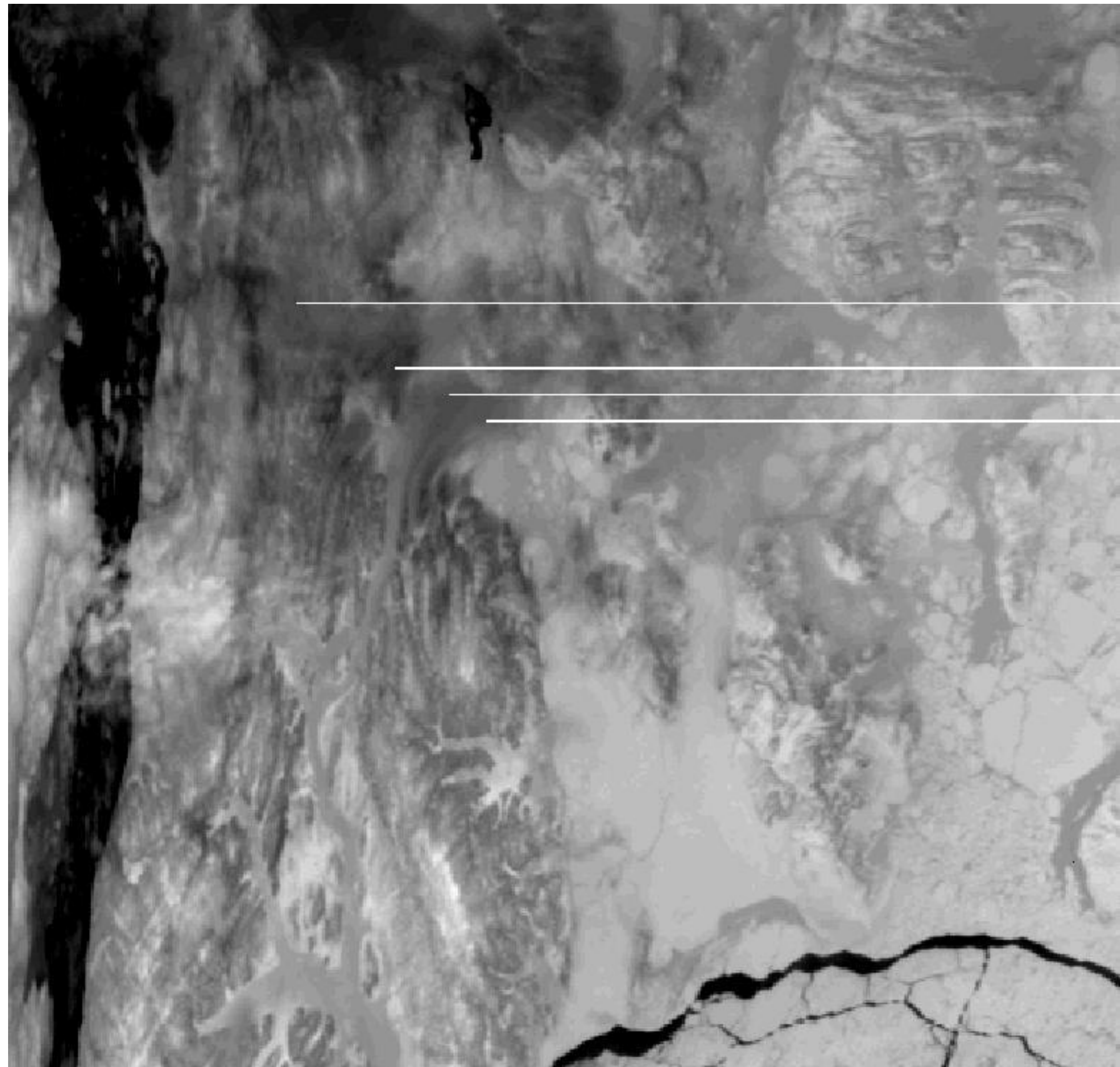
ITC

Line Start errors are caused by a detector failing to operate during a scan.
Similar to line drop.

Data never collected cannot be restored.

However, DNs for each pixel on the bad line can be estimated, as was done to correct line drop out.

If you do not want to calculate values for the entire affected line, you must intervene more directly.



B. Rundquist

Striping is caused by a detector that is out of adjustment

That is, one sensor is not responding like the others.

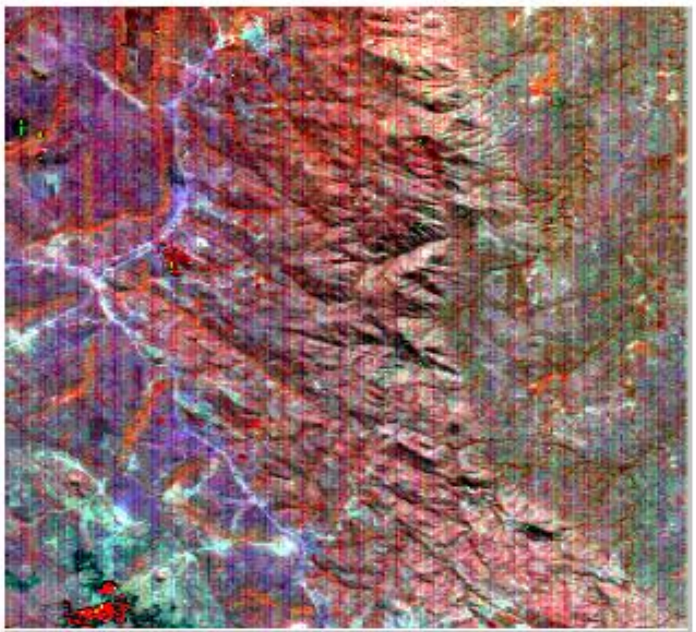
Does not represent a complete loss of data.

The computer first calculates which lines are striped by calculating a mean for each 6th line (detector).

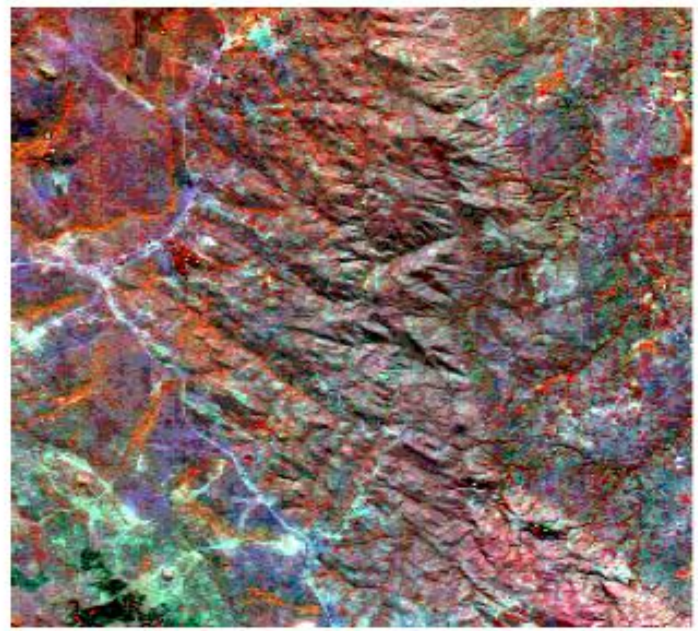
The means should match closely. If there is significant differences, the detector is striping the image.
The mean for that detector can then be adjusted to match the others.

Striping

Example SPOT



Striping



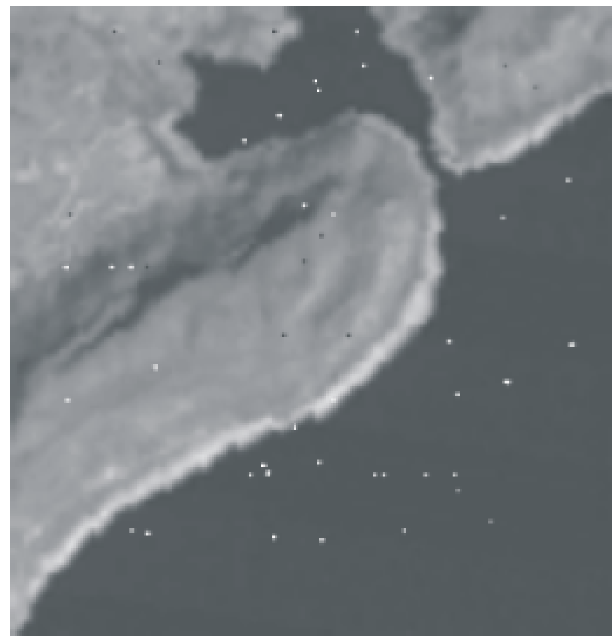
De-striped

Random Noise or Spikes

- Cause: Transmission errors or temporary disturbances
- Correction method:
  - 1. Detect spikey by comparing DN with DN of its surrounding pixels (neighbors')
  - 2. Replace DN with DN value interpolated from the surrounding pixels

Example of Spikes in Landsat MSS

7	14	14	15	16	15	15	17	16	13	12	14	1
4	13	12	13	12	11	12	14	13	11	12	17	2
2	12	11	11	11	10	12	16	15	13	16	23	3
1	11	11	11	11	12	15	22	23	21	24	31	3
1	180	11	11	12	16	20	28	31	29	32	39	4
1	11	11	13	16	22	28	36	39	39	42	47	5
1	11	13	17	23	30	36	42	45	45	48	51	5
1	13	17	25	33	40	45	47	48	48	50	53	5
3	21	26	33	40	47	50	50	50	50	51	54	5
1	36	40	42	46	49	50	50	50	50	51	54	5
0	45	47	48	49	51	51	50	50	8	52	54	5
4	47	49	50	51	53	53	51	50	50	52	54	5
7	49	50	51	52	54	54	52	51	51	51	53	5
3	50	51	53	54	55	54	52	51	51	51	53	5
0	52	53	55	0	56	55	53	51	50	50	52	5
2	120	55	57	58	58	56	54	51	50	50	52	5
3	55	57	58	59	59	57	55	52	49	49	51	5



Example of correcting for 'spikes'

21	26	33	40	47	50	50
36	40	42	46	49	50	50
45	47	48	49	51	51	50
47	49	50	51	53	53	51
49	50	51	52	54	54	52
50	51	53	54	55	54	52
52	53	55	0	56	55	53
20	55	57	58	58	56	54
55	57	58	59	59	57	55
56	58	58	59	59	57	55

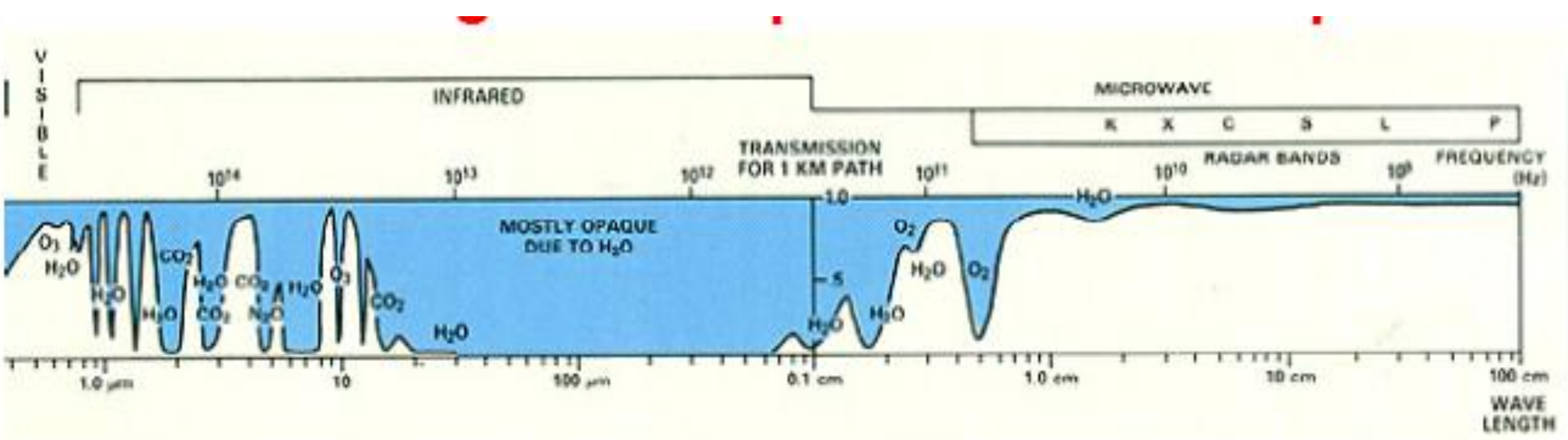
Image with spike

21	26	33	40	47	50	50
36	40	42	46	49	50	50
45	47	48	49	51	51	50
47	49	50	51	53	53	51
49	50	51	52	54	54	52
50	51	53	54	55	54	52
52	53	55	56	56	55	53
20	55	57	58	58	56	54
55	57	58	59	59	57	55
56	58	58	59	59	57	55

De-spiked image

Atmospheric Effects

- Absorption
  - Water vapour
  - Carbon dioxide
  - Ozone

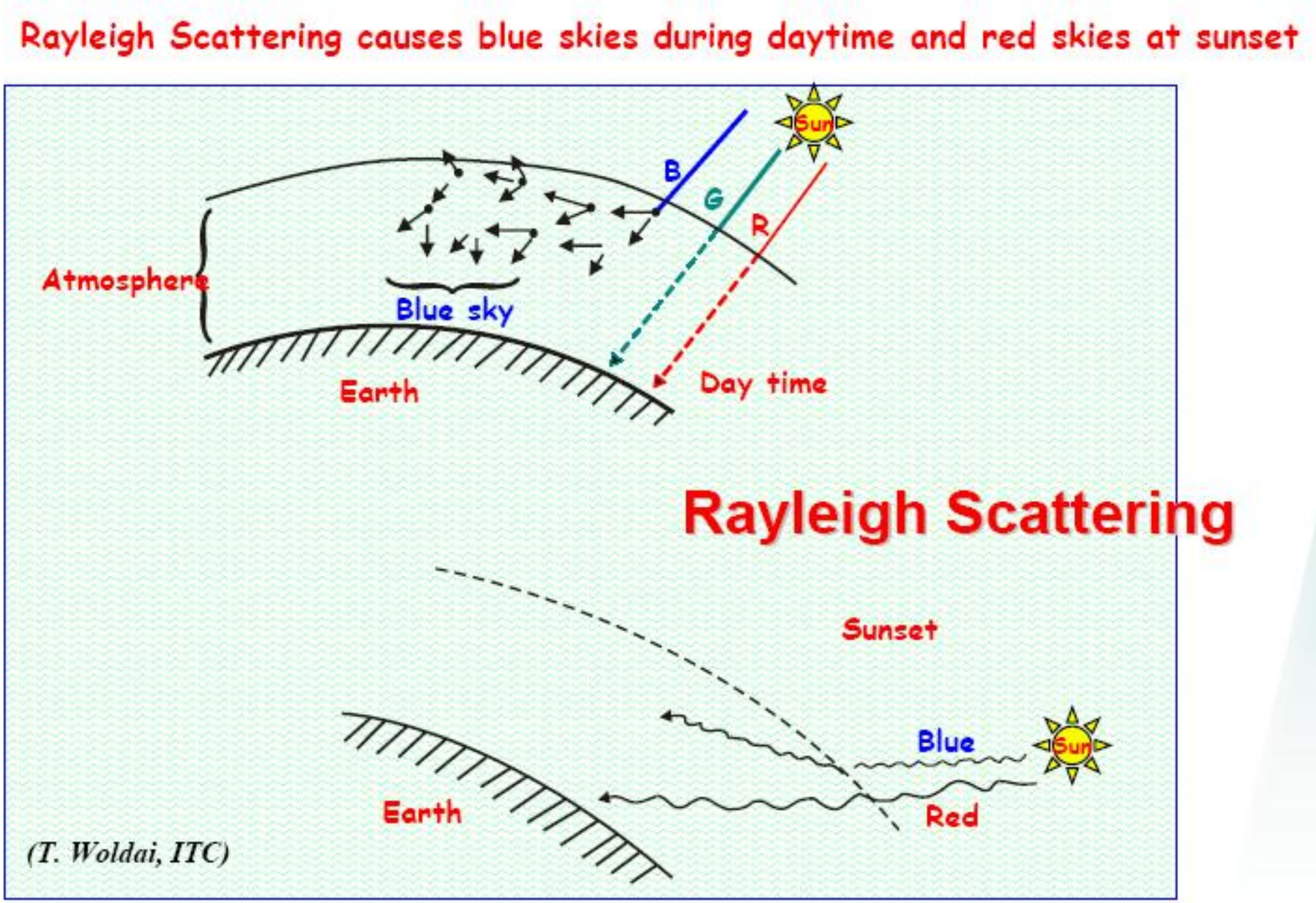


Atmospheric Interference

HAZE

- Lower wavelength bands are increasingly subject to **haze**, which falsely increases the DN value.
- This needs correction in some cases, for example to mosaic scenes with different amounts of haze, or to generate band ratios, where the resultant values may be affected.
- The effect of haze diminishes with increasing wavelength, but clouds affect all visible and IR bands, hiding features twice: once with the cloud, once with its shadow. Only in the microwave, can energy penetrate through clouds.

Atmospheric Effects



Haze – Example (Indonesia)

without haze (haze-corrected) **with haze**

DN values of objects in a single band

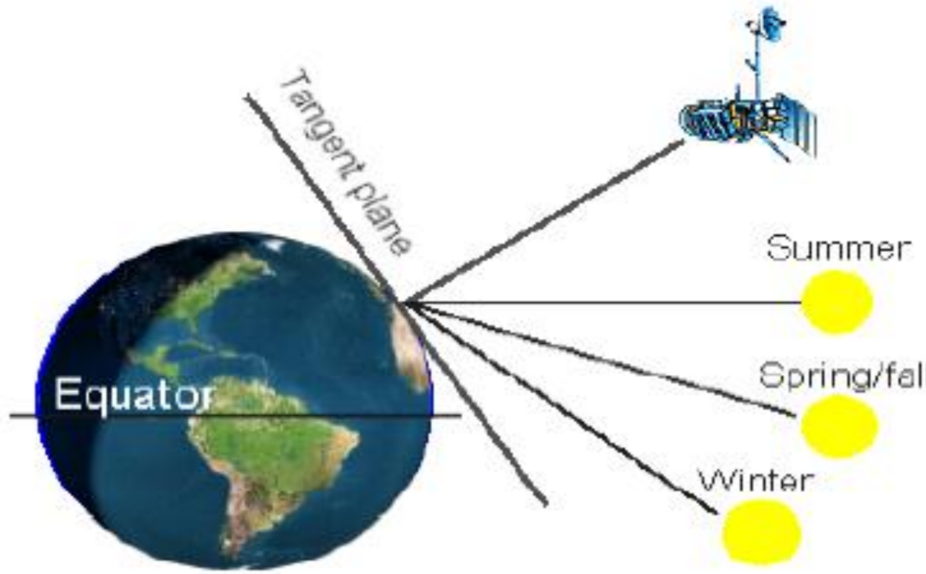
Object1:	DN = 20	DN = 20 + 20
Object2:	DN = 40	DN = 40 + 20
Contrast:	40/20 = 2X	60/40 = 1.5 X

Haze Correction

- The simplest method is known as dark object subtraction
- 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

Effects of Sun Illumination

- **Position of sun**
  - Sun elevation (sun-angle)
  - Sun - earth distance
- **Correction elevation**
  - Division of each pixel value by the sine of solar elevation angle for particular time and location per spectral band
- **Correction distance**
  - Sun irradiance decreases with square of distance



- Corrections are needed to compensate for sun illumination variations resulting from different scene acquisition dates
- Applications
  - Change detection studies
  - Mosaics

Correction for seasonal variations in Sun illumination

- **Sun angle correction**

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

- **Earth-Sun distance correction**

$$DN' = DN\left(1 + 0.00167\sin\left[\frac{2\pi(d - 93.5)}{365}\right]\right)^2$$

Where *d* is the day number in a year

Summary

- We need to correct for atmospheric effects, variations in sun illumination and system defects
- Atmospheric correction is the most complex correction
- In many cases only **haze** correction is applied (dark object subtraction)
- If we want to relate RS data with field spectrometric measurements we need to apply full atmospheric corrections, taking into account wavelength dependent factors, such as diffuse sky irradiance, transmission coefficients, path radiance and sensor calibration coefficients

Geometric Distortions & Restoration

- Any remotely sensing image, regardless of whether it is acquired by a multispectral scanner on board a satellite, a photographic system in an aircraft, or any other platform/sensor combination, will have various geometric distortions.
- This problem is inherent in remote sensing, as we attempt to accurately represent the three-dimensional surface of the Earth as a two-dimensional image.
- All remote sensing images are subject to some form of geometric distortions, depending on the manner in which the data are acquired.

Sources of Distortion

- the perspective of the sensor optics,
- the motion of the scanning system,
- the motion and (in)stability of the platform,
- the platform altitude, attitude, and velocity- causes changes in pixel recording- roll, pitch, yaw
- the terrain relief, and
- the curvature and rotation of the Earth.
- Tilt- a slight tilt of a satellite can have enormous distortions since it is positioned 100’s of km from the earth

Exterior Orientation

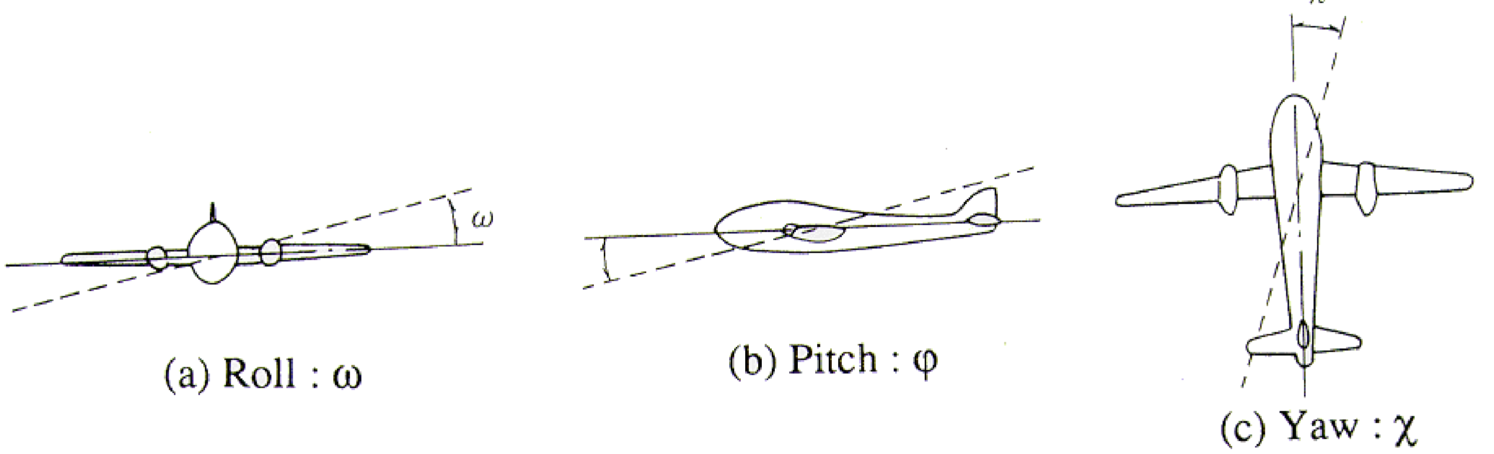
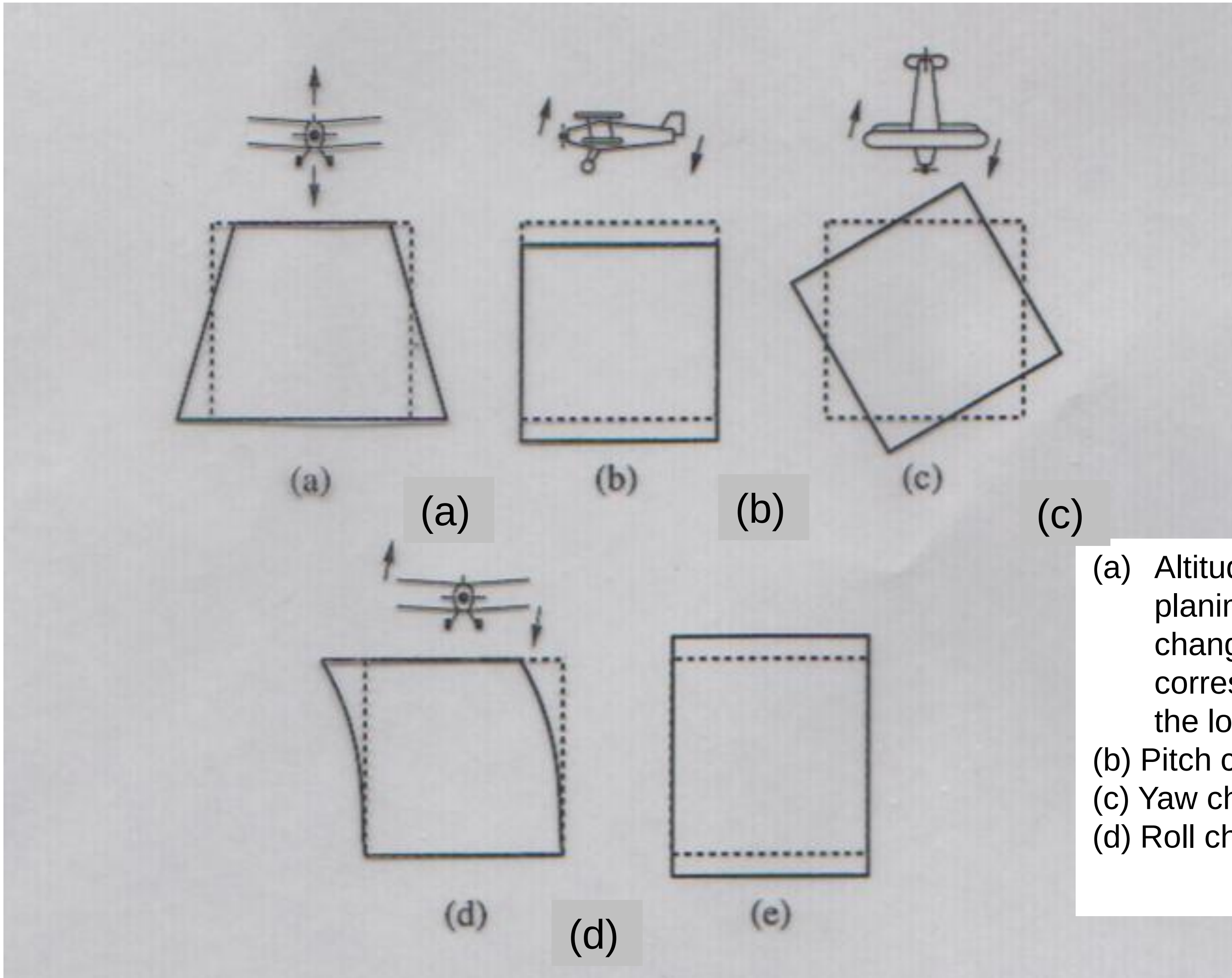


Figure 5.3.1 Aeroplane attitude change

- attitude (**roll, pitch, yaw**)
- three dimensional position (**x, y, z**)

Geometric Distortion (Pushbroom Sensor)

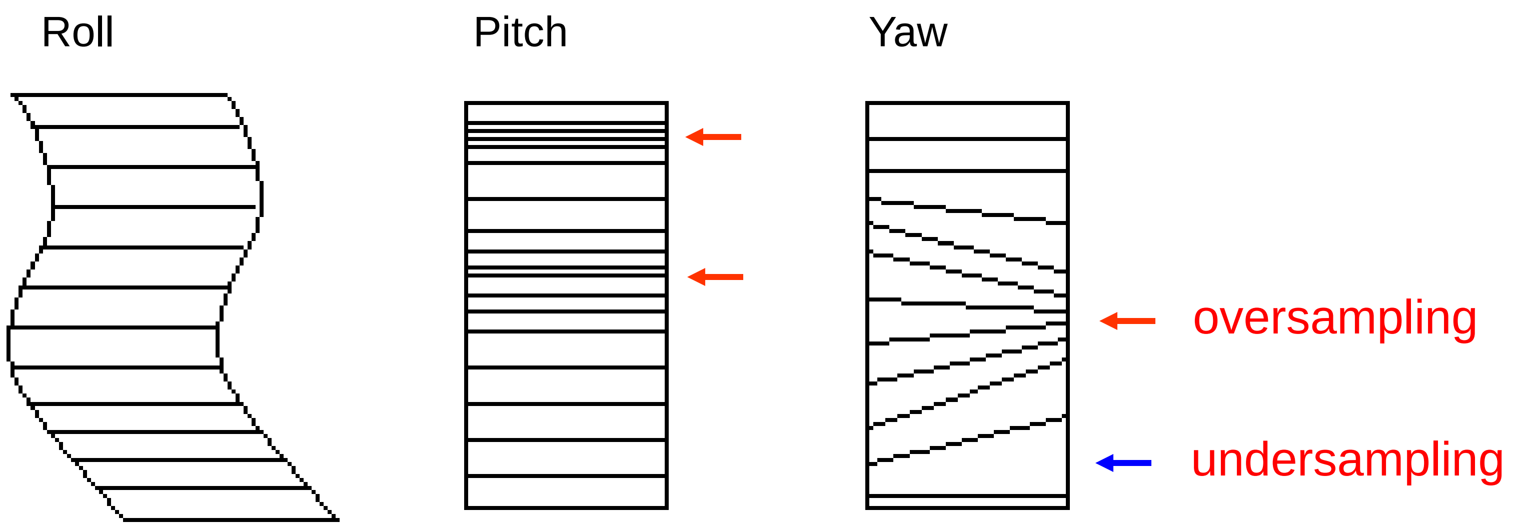
due to platform exterior orientation changes



(a) Altitude change [planimetric position (x,y) changes cause directly corresponding changes in the location of sensed data]
(b) Pitch change
(c) Yaw change
(d) Roll change

Geometric Distortion

due to platform velocity changes



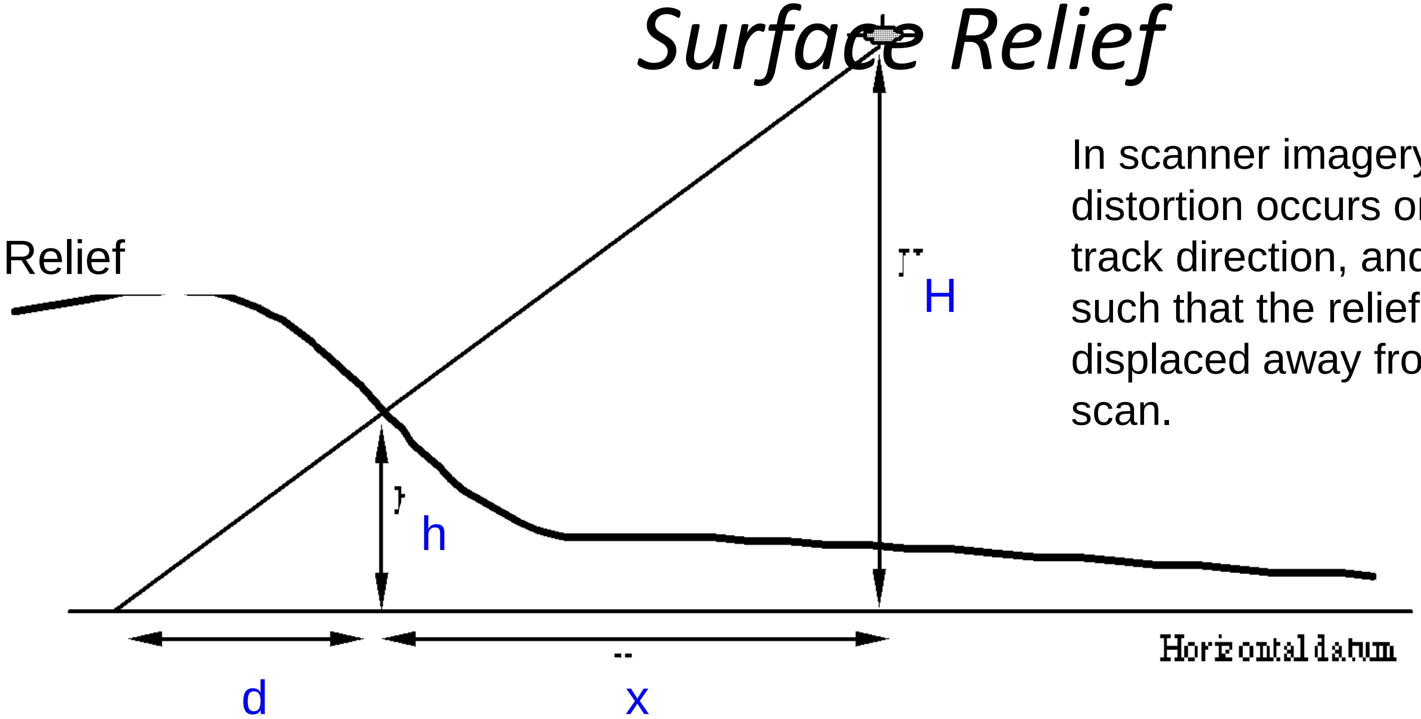
- forward platform velocity decreases (higher orbit) -> spacing between scan lines in the along track direction decreases, i.e. oversampling (redundancy of image data).

- forward platform velocity increases (lower orbit) -> spacing between the scan lines in the along track direction increases, i.e. undersampling (gaps).

Sources of Distortion

- Relief displacement on aerial photographs - objects that are directly below the lens will have only their top part imaged where as other objects will lean away from the centre of the photographs and their sides appear.
- Images from across-track scanning systems are distorted due to the rotation of the scanning optics. As the sensor scans across each line, the distance from the sensor to the ground increases further away from the centre of the swath.
- Skew distortion - caused by the eastward rotation of the earth which causes a sweep of scanning systems to cover an area slightly to the west of each previous scan

Surface Relief



In scanner imagery the relief distortion occurs only in the across track direction, and its visual effect is such that the relief appears to be displaced away from nadir along scan.

d = relief distortion (m)

$$d = h\,x / H - h$$

H = Sensing altitude relative to horizontal datum (m)
h = Relief height relative to horizontal datum (m)
X = Distance of relief from nadir (m)

Example: MODIS over Mount Everest (8.84km high). The mountain top may be located 0 - 1170km (edge of scanline) from nadir. The corresponding relief distortion is 0 - 14.8 km.

Image Rectification & Restoration

- Distortions can be classified into systematic and non-systematic /random distortions
- Systematic distortions are
    - Scan skew due to forward movement of the platform
    - Changes in velocity of scanner
    - Scanning at an angle
  - These distortions are removed during pre-processing by applying formulas derived by modeling the sources of distortion mathematically.

- **Non-systematic distortions**
  - Variation in platform altitude, relief displacement, tilt, velocity, earth rotation
- Distortions vary from area to area
- Corrections are done using ground control points distributed on the image e.g. Highway intersections, river confluences
- GCPs are located both in terms of their two image coordinates (column, row numbers) on the distorted image and in terms of their ground coordinates.
- The values are submitted to a regression to determine coefficients for two coordinate transformation equations, which are then used to precisely estimate the coordinates of the distorted image for any map position.
- Transformation techniques such as Affine or conformal are used to correct for the distorted images

Problems with GCPs

1) Availability not guaranteed

- over repetitive/unstructured surfaces e.g., dense forest, desert, ocean
- because of occlusion by clouds, fog, cloud/relief shadows

2) Sampling ?

- the number and spatial distribution of GCPs that should be collected is poorly defined
- this usually leads to locally redundant (i.e. excessive effort) or insufficient (i.e. inaccurate) use of GCPs

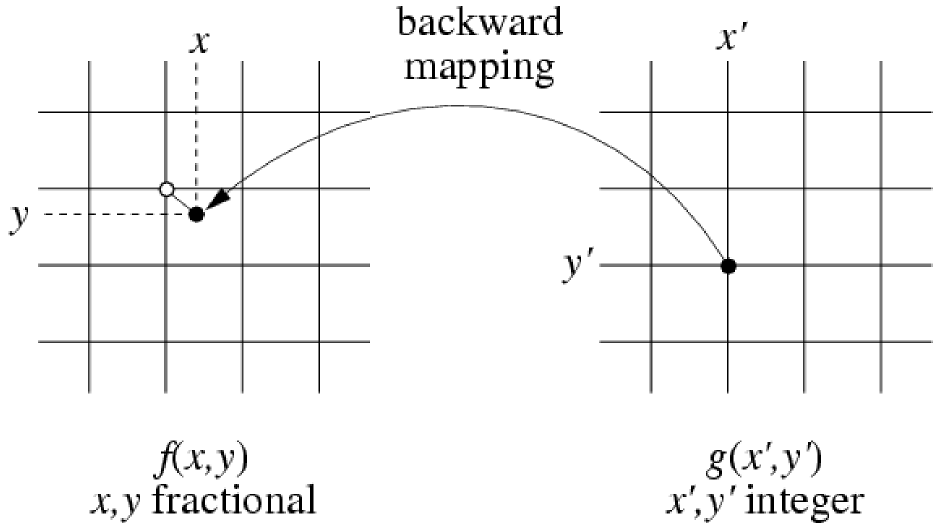
3) Accuracy

- GCP positional accuracies vary as a function of numerous variables - particularly if they are collected manually

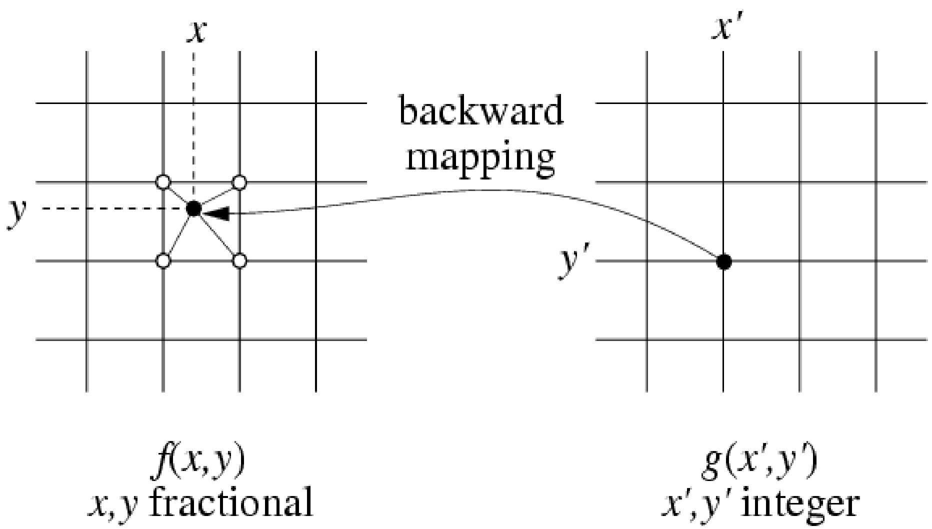
- After transformation, the original arrangement of pixels is distorted
- Grid centers from the map-registered pixels grid will not usually project to exact pixel centre locations in the image
- Resampling is therefore necessary in order to produce a regular grid size of pixels

Interpolation Techniques

- *Nearest neighbour* – simply chooses the actual pixel that has its centre nearest the point located in the image. This pixel is then transferred to the corresponding display grid location.
  - Advantage – computationally simple to implement and original values of the image are not altered thus ideal when image is used for classification
  - Disadvantage – Features in the output matrix maybe offset by up to one half pixel

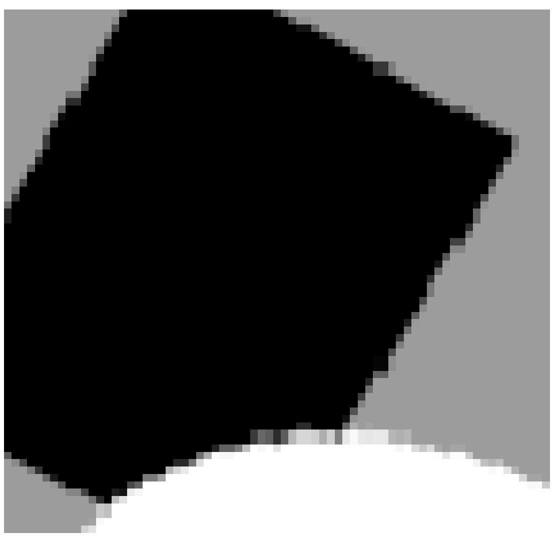


Nearest Neighbour



Bilinear

Nearest Neighbour



Bilinear

- *Bilinear Interpolation* – Output value is calculated by finding the weighted average value from the 4 surrounding pixels in the original image. Resulting image is smooth without offsets. But the process alters the gray levels of the original image.
- *Cubic convolution* – Takes into consideration all 16 surrounding pixels for computing the output value
  - Adv – it avoids the disjointed appearance of the nearest neighbour method & provides a sharper image than the bilinear method.
  - But the technique also alters the original image gray levels.