Image Pre-Processing

Consists of processes aimed at the geometric and radiometric correction, enhancement or standardization of imagery to improve our ability to interpret qualitatively and quantitatively image components.

- **Radiometric Enhancement:**
  - **Image Restoration**
  - **Atmospheric Correction**
  - **Contrast Enhancement**
  - **Solar Angle Adjustment**
  - **Conv. to Exo-Atmos. Reflectance**
- **Spectral Enhancement:**
  - **Spectral Indices**
  - **PCA, IHS, Color Transforms**
  - **T-Cap, BGW**
- **Spatial Enhancement:**
  - **Focal Analysis**
  - **Edge-Detection**
  - **High/Low Pass Filters**
  - **Resolution Merges**
  - **Statistical Filtering**
  - **Adaptive Filtering**
  - **Texture Filters**
- **Geometric Correction**
  - **Polynomial Transformation**
  - **Ground Control Points**
  - **Reprojections**

Radiometric Enhancement

Radiometric correction of remotely sensed data normally involves the processing of digital images to improve the fidelity of the brightness value magnitudes.

The main purpose for applying radiometric corrections is to reduce the influence of errors or inconsistencies in image brightness values that may limit one's ability to interpret or quantitatively process and analyze digital remotely sensed images.

Radiometric errors and inconsistencies are referred to as "noise", which could be considered any undesirable spatial or temporal variations in image brightness not associated with variations in the imaged surface.

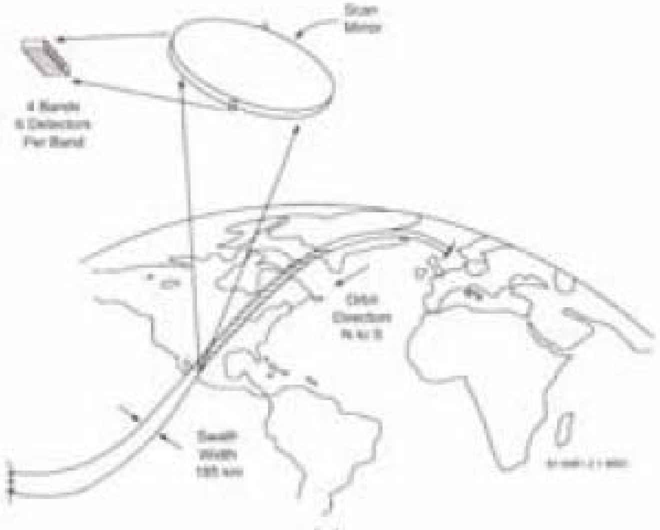
System Errors:

created by failure and or miss-calibration of the sensors

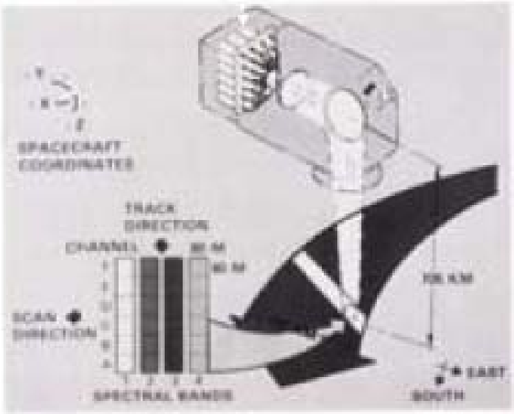
- **Line Drop-outs** – Caused by the failure of one of n detectors.
- **N-line striping -** Caused by the miss-calibration of one of n detectors
- **Banding -** Caused by variations of neighboring forward and backward scans of the Landsat Thematic Mapper
- **Line-start -**Failure of one or more detectors to start collecting data along a line, or failure during mid-line.

Line Drop-outs

Line Drop-outs caused by the failure of any of the detectors



(a)



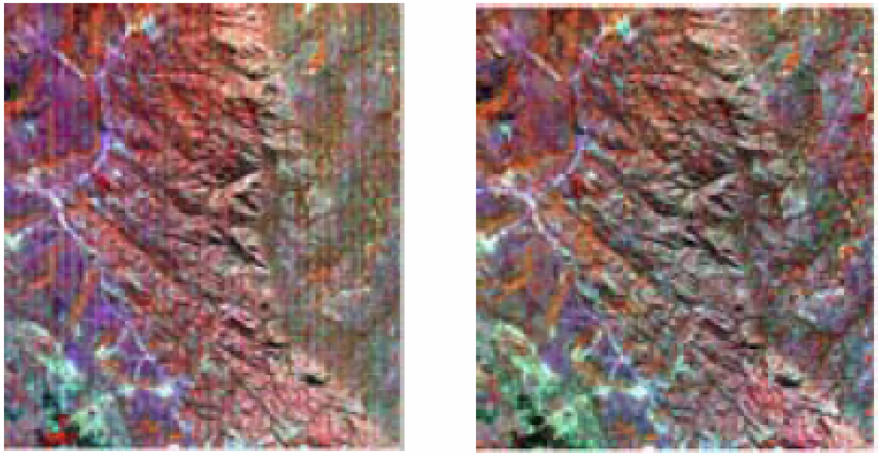
(b)

Figure 1. MSS scanning approach. (a) Object-space scan mirror scans image west-to-east across track while orbital motion provides north-south scan. (b) Fiber-Optic array relays scanned image from focal plane to 24 discrete detectors. Active imaging only takes place in one scan direction.

Mika, A.M. 1997. Three Decades of Landsat Instruments. PE&RS (63)7:839-852

System detector error is dependent on the system itself. In this case, the pushbroom arrangement of the SPOT sensor creates vertical striping in an image due to the miss-calibration of one or more of the linearly arrayed detectors

Mika, A.M. 1997. Three Decades of Landsat Instruments. PE&RS (63)7:839-852



- The output from each detector is scaled to match the mean and standard deviation of the entire image. In this case the value of each pixel in the image is altered.

- The output from the problem detector is scaled to resemble the mean and standard deviation of the other detectors. In this case the values of the pixels in normal data lines are not altered.

Correction of Line Drop and Striping

Simple average of adjacent rows (i-1 and i+1) to replace line dropout or line striping. Row 'i' is replaced with the average of rows i-1 and i+1. k refers to the band or channel number

$$BV_{ijk} = \mathrm{Int}\left(\left(\frac{BV_{i-1,j,k} + BV_{i+1,j,k}}{2}\right) + .5\right)$$

Simple average of adjacent columns (j-1 and j+1) to replace column oriented dropout or line striping. Row 'j' is replaced with the average of rows j-1 and j+1. k refers to the band or channel number

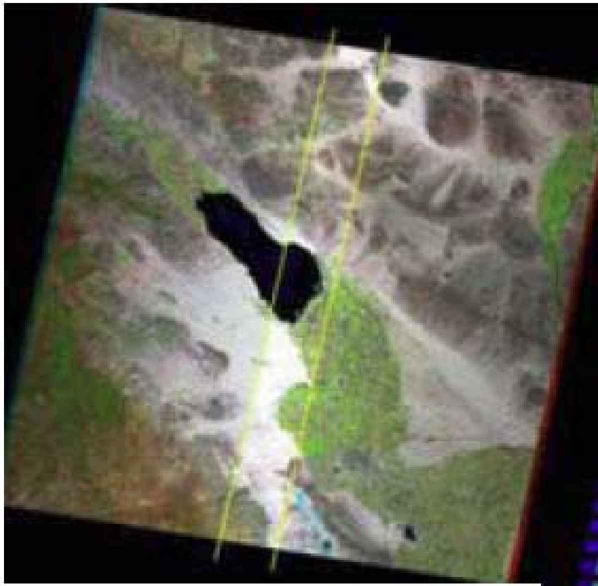
$$BV_{ijk} = \mathrm{Int}\left(\left(\frac{BV_{i,j-1,k} + BV_{i,j+1,k}}{2}\right) + .5\right)$$

Banding caused by forward/backward scan miss-calibration is evident in this image section of the Great Salt Lake.

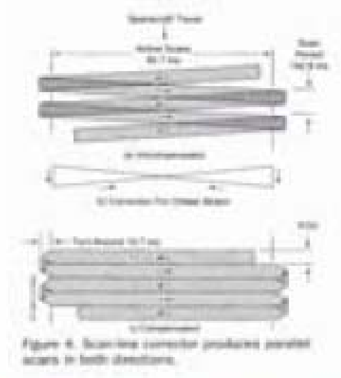
Banding is most evident in bodies of water or other areas of low variability. Banding is present scene-wide, but local ground variance makes it less evident.

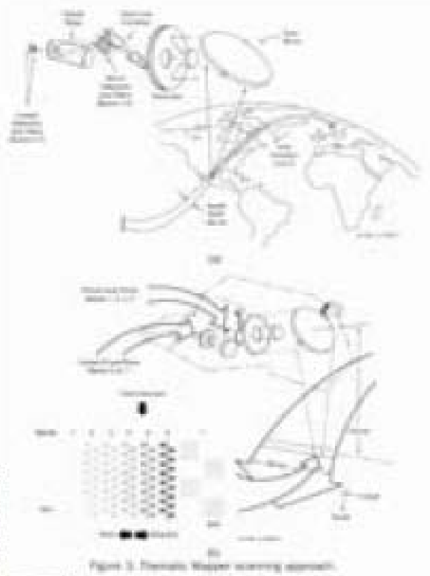
Correction of this type of error consists of a bias adjustment of alternate 16-line groups, or the use of Fourier Transforms to isolate and eliminate noise.

Landsat 7 Scan Line Compensator Error



SLC-Off Data





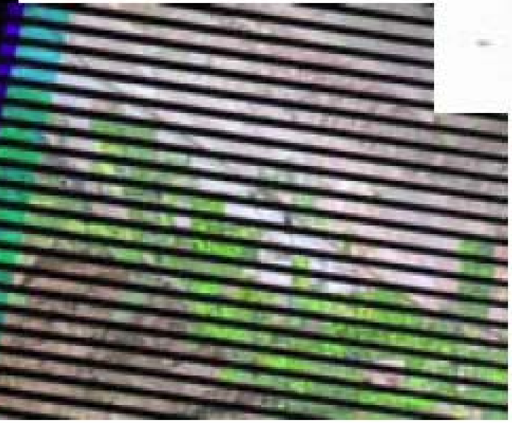


Image Edge

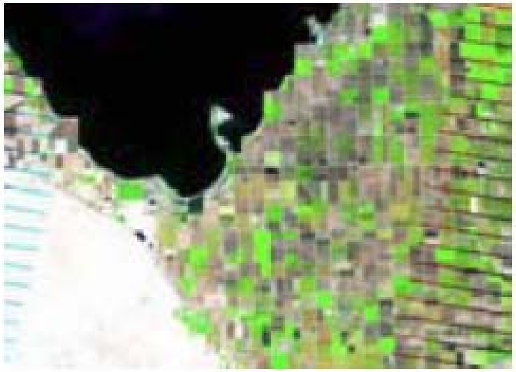


Image Center

http://landsat.usgs.gov/slc_off.html

Non-System Errors:

Radiometric attenuation from influences outside the sensor.

- Atmospheric Attenuation

  Caused by scattering/diffraction of light by natural and introduced components of the atmosphere. The goal of Atmospheric correction is to properly estimate biophysical variables on the surface and to standardize images within a temporal dataset for the purpose of change detection and monitoring

- Topographic Attenuation

  Correction of terrain influences to account for variable reflectance between similar cover types caused by topographic slope and aspect.

Strategies for the Correction of Atmospheric Attenuation

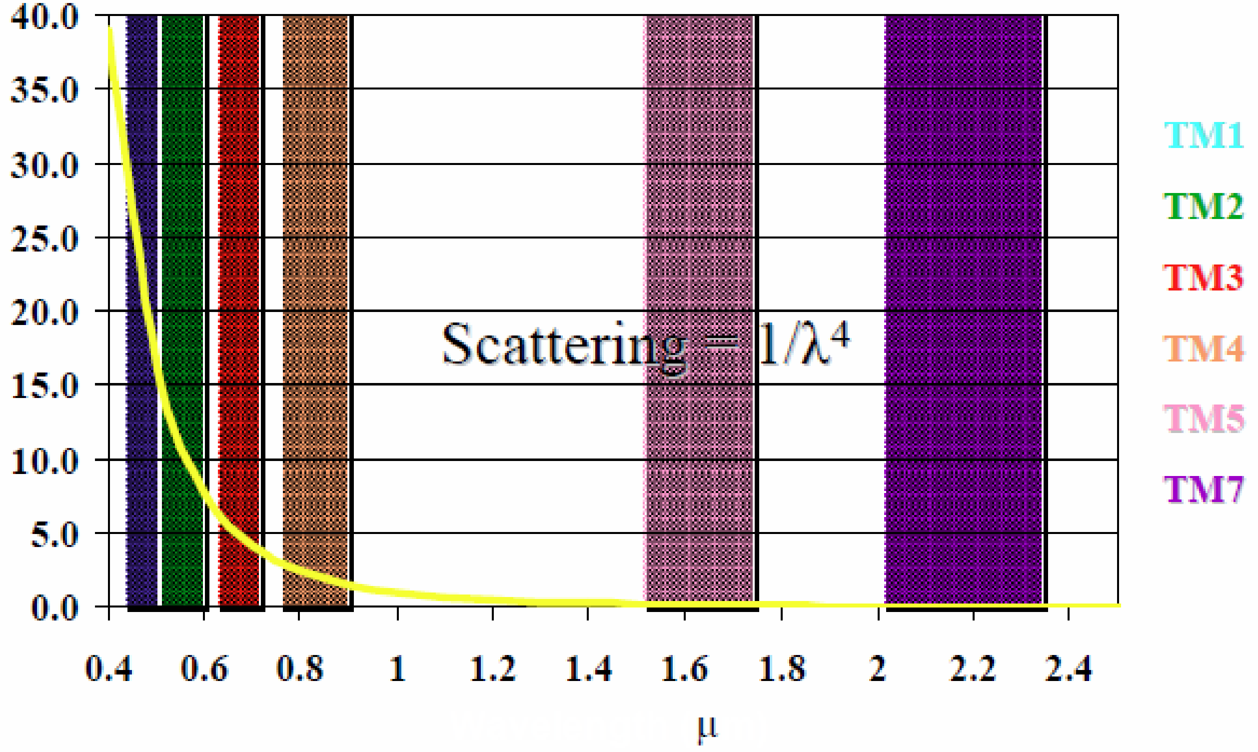
Depending on the nature of the problem, the type of remote sensing data available, the amount of in-situ atmospheric information available, and how accurate the biophysical information to be extracted from the imagery must be, there are different strategies available to correct atmospheric attenuation

The science of absolute correction of imagery for atmospheric attenuation is relatively complete in comparison to the data available to carry out such activities.

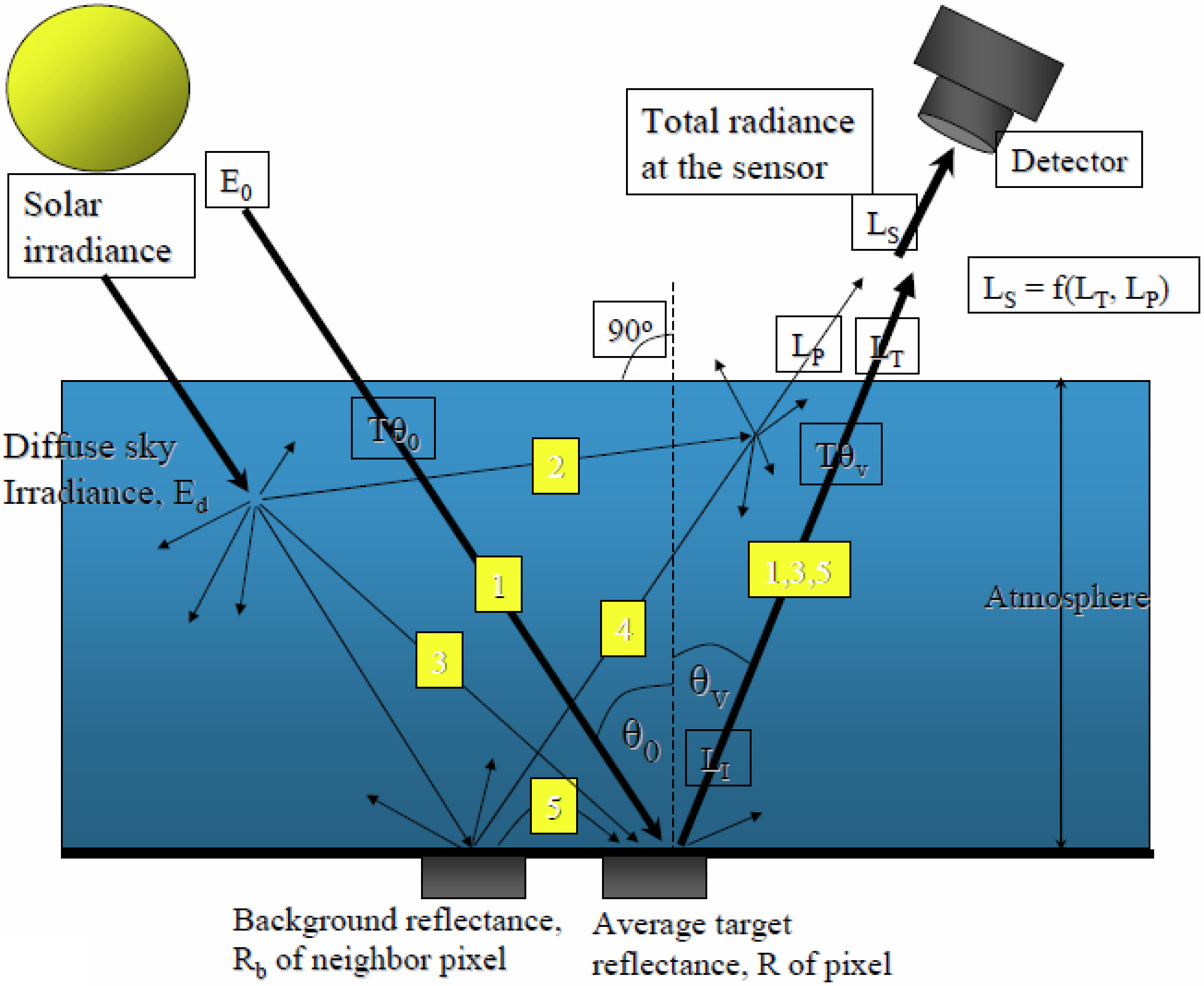
The purpose of a number of sensors currently in orbit or in preparation is to properly estimate atmospheric conditions at or near the time of the acquisition of “land surface” data. These data can be used to correct land surface images for atmospheric conditions on a pixel-by-pixel basis. – Ref EO-1 (Adv. Land Imgr, Atmos. Corr., Hyperion)

- **Do Nothing -** Due to the lack of in-situ information and if the signal is strong and the information required has sufficient contrast, this may be a viable option.
- **Absolute (in-situ) Correction -** If the problem requires the extraction of biophysical features whose relative contrast is small or must be calibrated with other models or measurement techniques, this option is required if the in-situ atmospheric information is available. In-situ measurements must be made at the time of image collection and cannot be accurately extrapolated through time or space.
- **Atmospheric Modeling** – Viable alternative if in-situ data is not available. This uses geographic position to account for path radiance and the general nature of the atmosphere at that location. This can be extrapolated through time, but does not account for "stochastic" variation in atmospheric clarity.
- **Atmospheric Modeling + In-situ Data -** A preferred alternative if in-situ data is available at the time of image collection. This accounts for path radiance and reflectance characteristics caused by geographic location and sun angle, and corrects for "stochastic" atmospheric variation.
- **Relative Correction -** Also called image normalization, this procedure uses a standard image (possibly corrected as above) to normalize other, temporally adjacent images.

Rayleigh Scattering as a Function of Wavelength



Upper atmosphere scattering is caused when the diameter of gas molecules are less than the incident wavelength


Solar irradiance
E_0
Total radiance at the sensor
Detector
L_S
$L_S = f(L_T, L_P)$
90º
L_P
L_T
$T\theta_0$
$T\theta_V$
Diffuse sky Irradiance, E_d
2
1
1,3,5
4
3
Atmosphere
θ_V
θ_0
L_I
5
Background reflectance, R_b of neighbor pixel
Average target reflectance, R of pixel

E_0 - Solar irradiance at top of atmosphere.

$T\theta_0$ - Downward atmos. transmittance at angle θ.

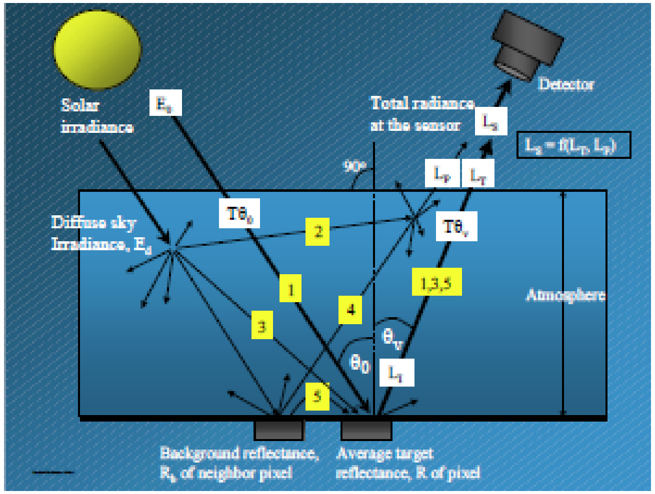
L_I - Intrinsic radiance of the target ($Wm^{-2}\ sr^{-1}$).

$T\theta_v$ - Atmospheric transmittance from the target at angle θ.

L_P - Path radiance resulting from multiple scattering.

L_t - Total radiance transmitted by the atmosphere toward the sensor.

L_s - Total radiance at the sensor.



1. Radiation directly from the sun to the target
2. Radiation from the sun that was scattered into the IFOV of the sensor
3. Radiation scattered from the sun into an adjacent target (skylight)
4. Diffuse sky irradiance striking an adjacent target and reflected back into the IFOV of the sensor.
5. Energy reflected from an adjacent target onto the principal target.

Conversion to Radiance

$$\mathbf{L_k = Gain_k * BV_{ijk} + Bias_k}$$

Where:

L_k = Radiance ($W / m^2 / ster / \mu m$)

$Gain_k = (LMAX_k - LMIN_k)/255$

$Bias_k = LMIN_k$

Where:

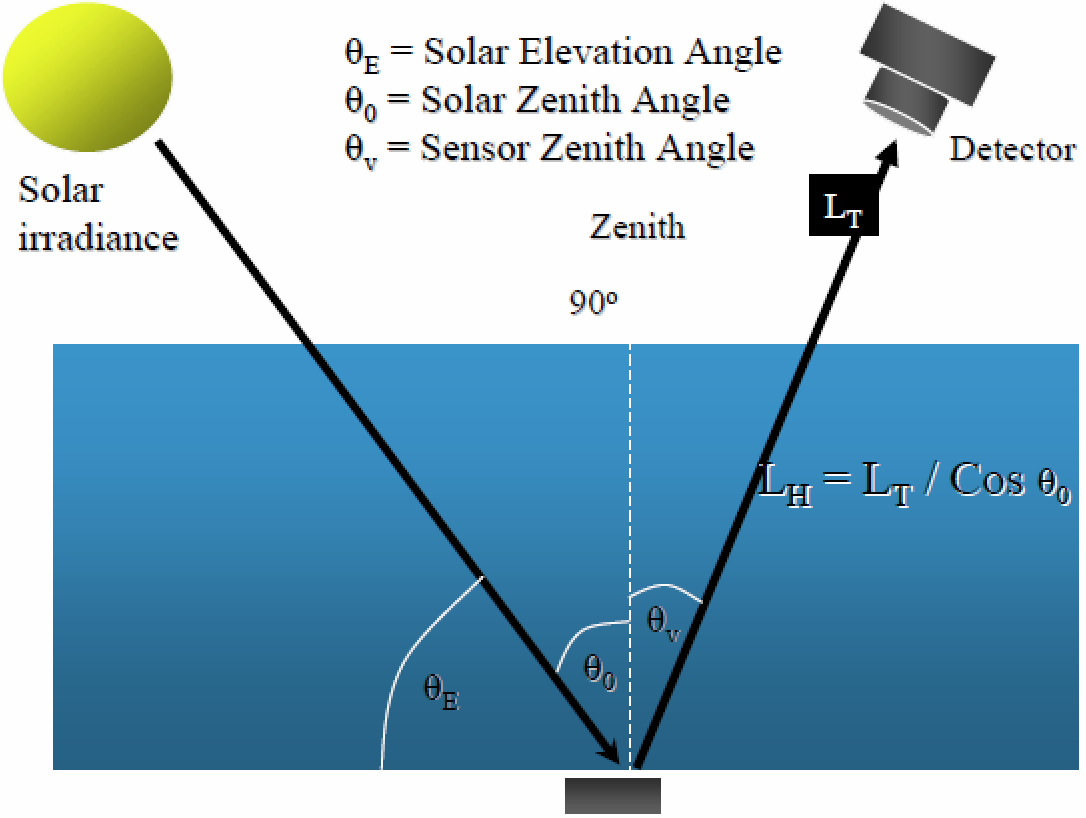
$LMAX_k$ = Maximum Radiance for Band k.

$LMIN_k$ = Minimum Radiance for Band k.

Therefore:

$$\mathbf{L = (Lmax-Lmin)/255*DN + Lmin}$$

Solar Angle Correction



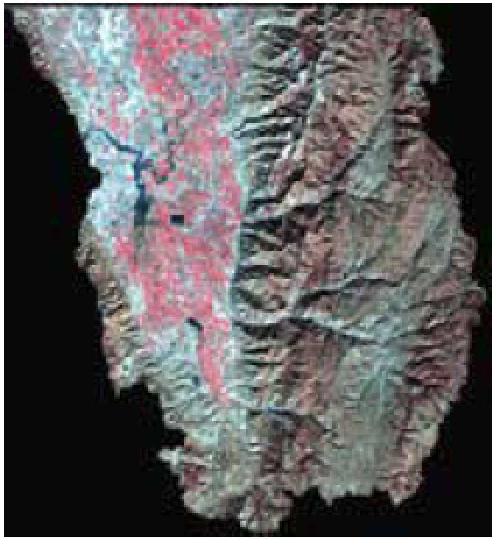
θ_E = Solar Elevation Angle
θ_0 = Solar Zenith Angle
θ_v = Sensor Zenith Angle

$$L_H = L_T / \text{Cos } \theta_0$$

Atmospheric Standardization Methods

Dark Object Subtraction (DOS)

Based on the concept that clear, deep water and deep shadow should have no reflective properties and any response by the sensor is a result of atmospheric scattering.



Min. Dark Obj. Val.

Blu = 31

Grn = 20

Red = 10

NIR = 5

MIR = 0

MIR = 0

Operator identifies a dark object pixel in the image – usually a clear, deep water body and samples pixel values to determine minimum value

Output = input - Bias

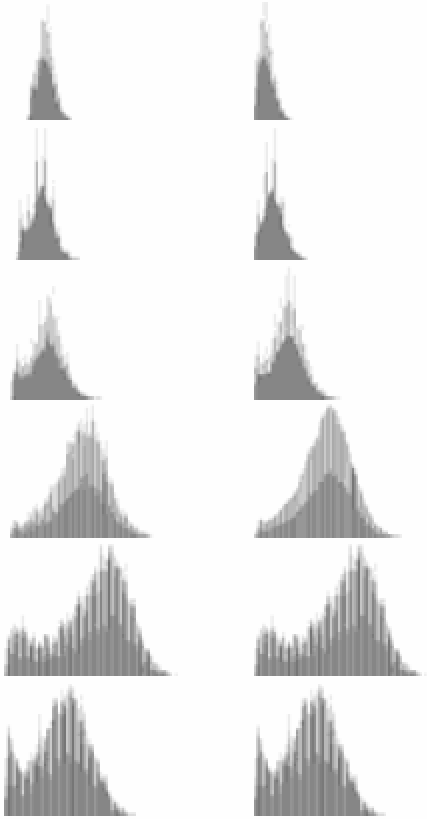


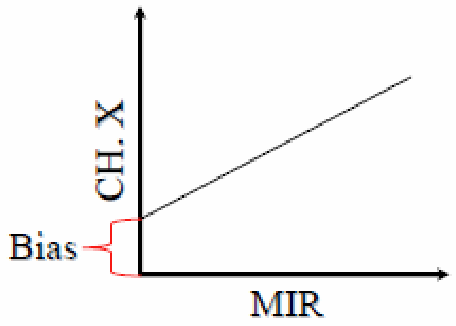
Image Subtraction

Atmospheric Standardization Methods (cont.)

Regression Method

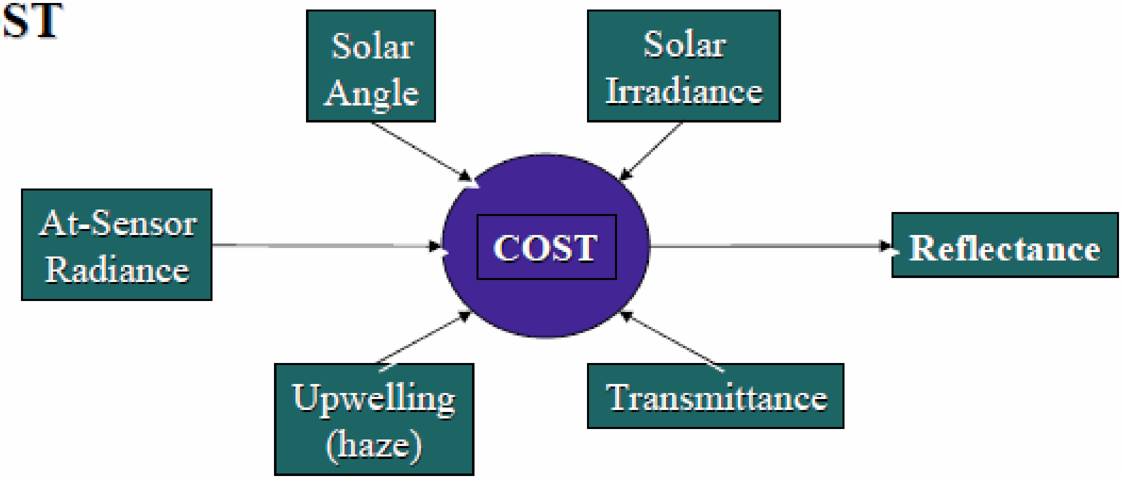
This technique is similar in execution to the DOS method mentioned in the preceding slide. However, the bias value is calculated by plotting pixel values of each spectral band against the response of a MIR band.

The assumption here is that MIR energy is not significantly affected by normal atmospheric scattering.



Atmospheric Standardization Methods (cont.)

COST



$L_{SATn} = (DN_{x,y,z} * Gain_n) + Bias_n$ — At Sensor Radiance

$L_{HAZEn} = (DN_{hazex,y,z} - Bias_n) / Gain_n$ — At Sensor Scattering

$R_{SATn} = \&(L_{SATn} - L_{HAZEn}) / E_n(COS\ \theta_z) * (TAU_z)$ — COST Correction

E_n – Exoatmospheric solar irradiance for band n
TAU_z - Approximate atmospheric transmittance

Image Pre-Processing:

Contrast Enhancement

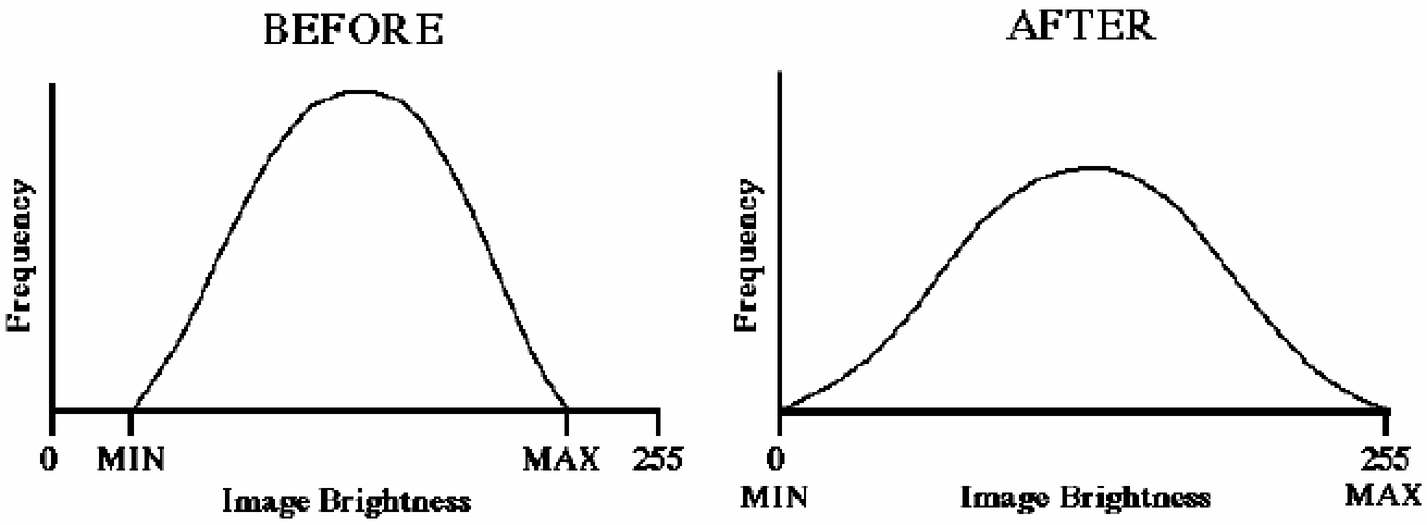
Min-Max Linear Contrast Stretch

Percent Linear Contrast Stretch

Piecewise Linear Contrast Stretch

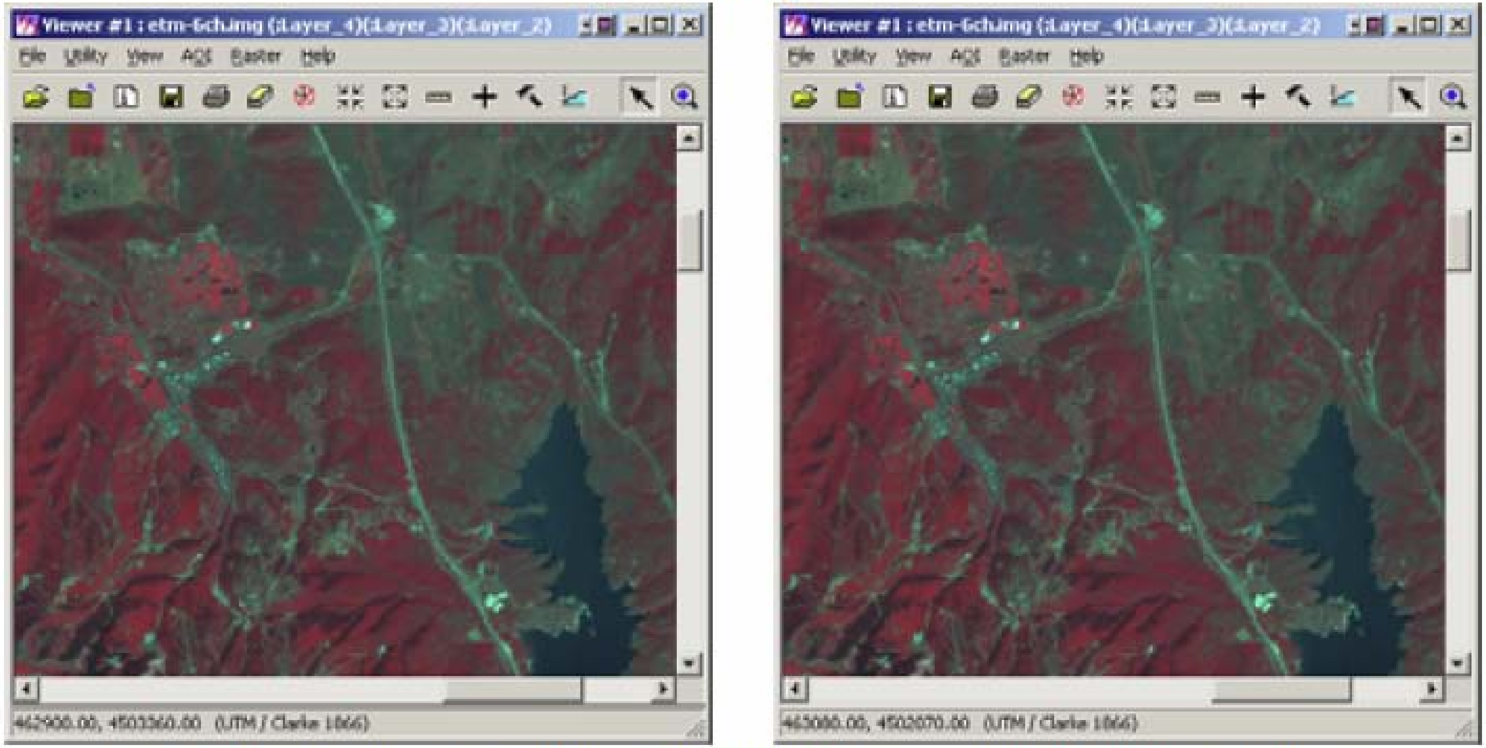
Histogram Equalization

Min-Max Linear Contrast Stretch



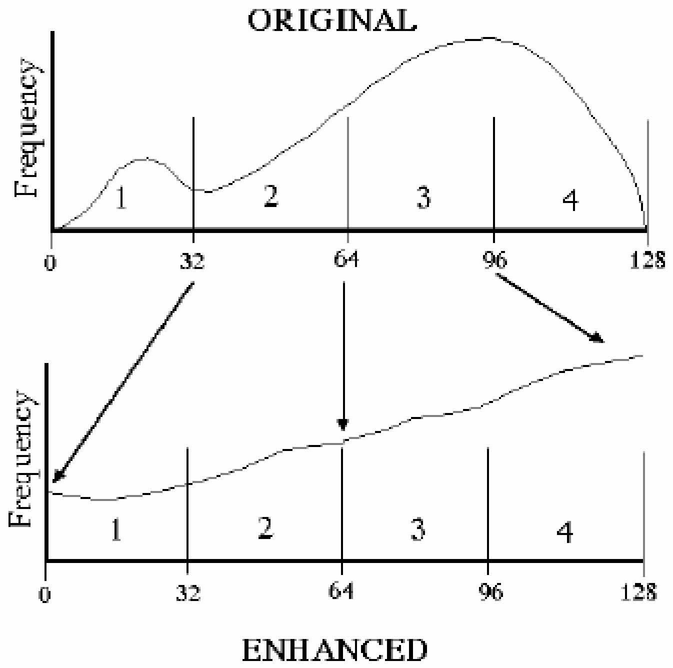
Minimum-maximum linear contrast enhancement. The minimum and maximum values of the original image are stretched to produce a range of brightness values that uses the full capabilities of the image display (Campbell, 1987).

Min-Max Linear Contrast Stretch Example



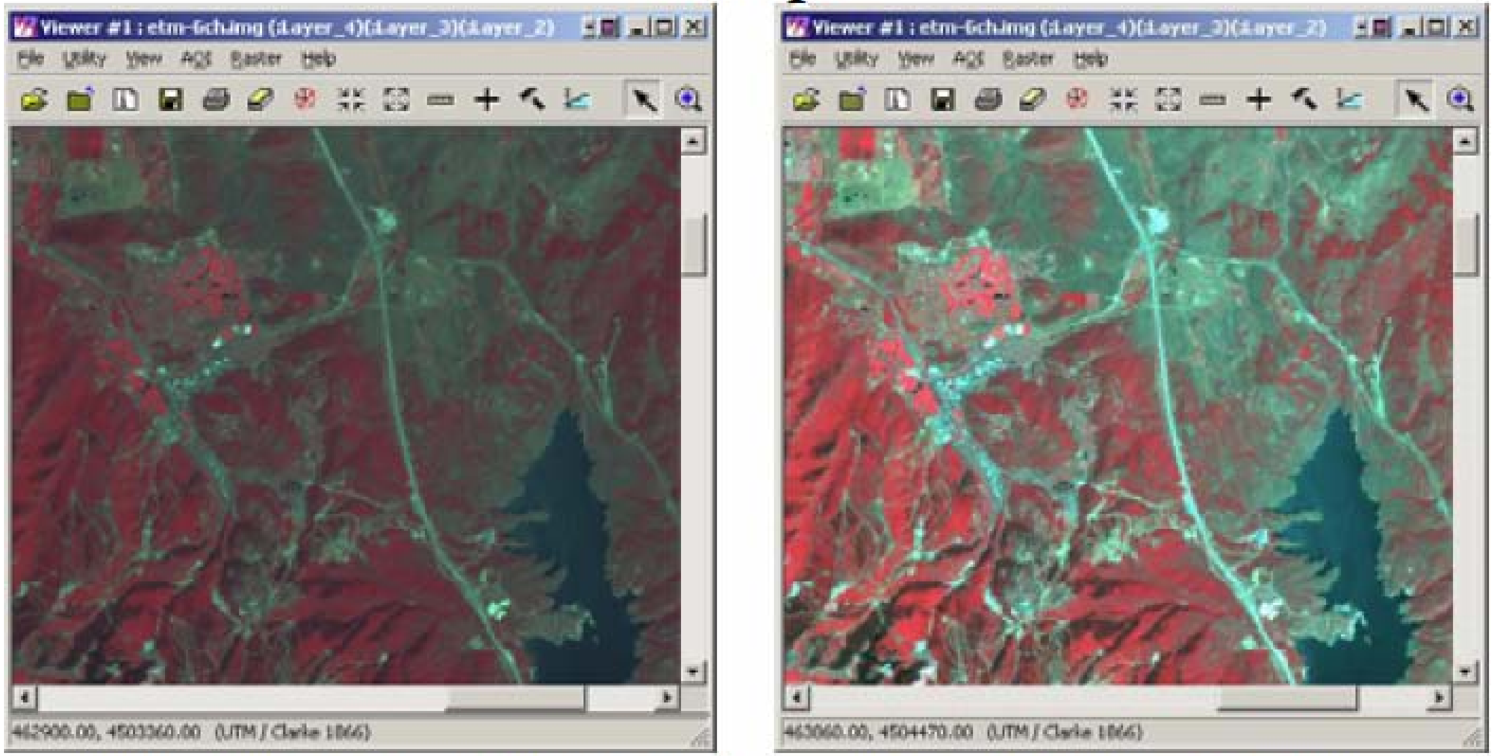
This portion of a Landsat 7 Thematic Mapper image of Park City, Utah shows the original brightness values on the left and the result of a linear contrast stretch on the right. This stretch resulted in little or no enhancement of the image since the min and max values approach the dynamic range of the display screen.

Percent Linear Contrast Stretch



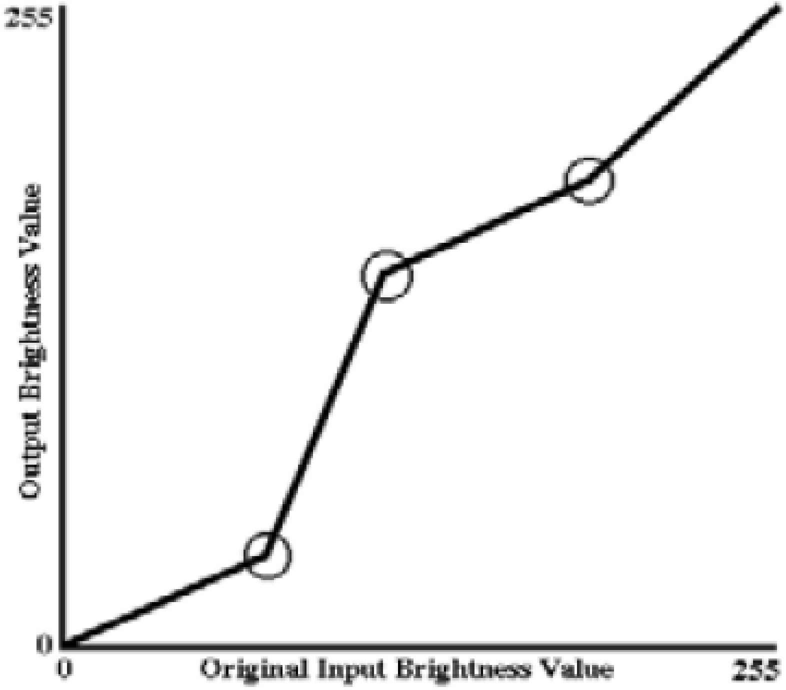
Percentage Linear Contrast Stretch is also called a "*Standard Deviation Stretch*". In this case values between 32 and 96 are stretched to the full display range to reveal subtle variations within the central part of the histogram. Values below 32 and above 96 are pushed to the minimum and maximum of the display scale respectively.

Percent Linear Contrast Stretch Example



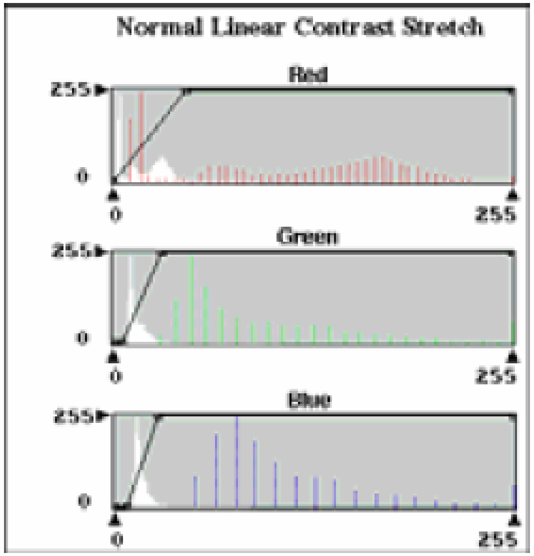
This portion of a Landsat 7 Thematic Mapper image of Park City, Utah shows the original brightness values on the left and the result of a percent linear contrast stretch on the right using a 2-standard deviation from the mean rule to determine the percent of the histogram to stretch.

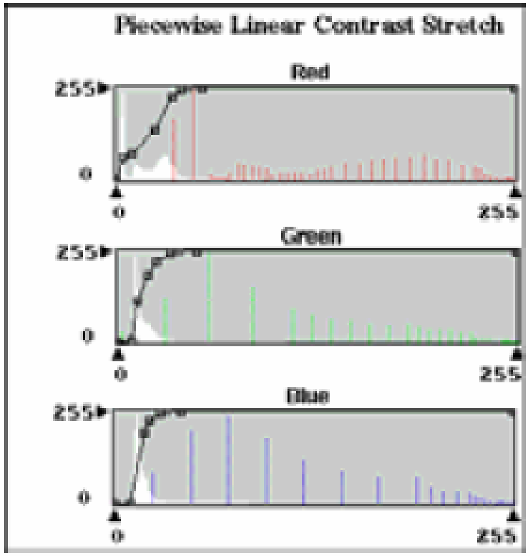
Piecewise Linear Contrast Stretch



The piecewise linear contrast stretch uses a series of min-max stretches within a single histogram. This enhancement method creates a series of linear stretches that display data at different levels of intensities.

Normal Linear Contrast vs. Piecewise Linear Contrast



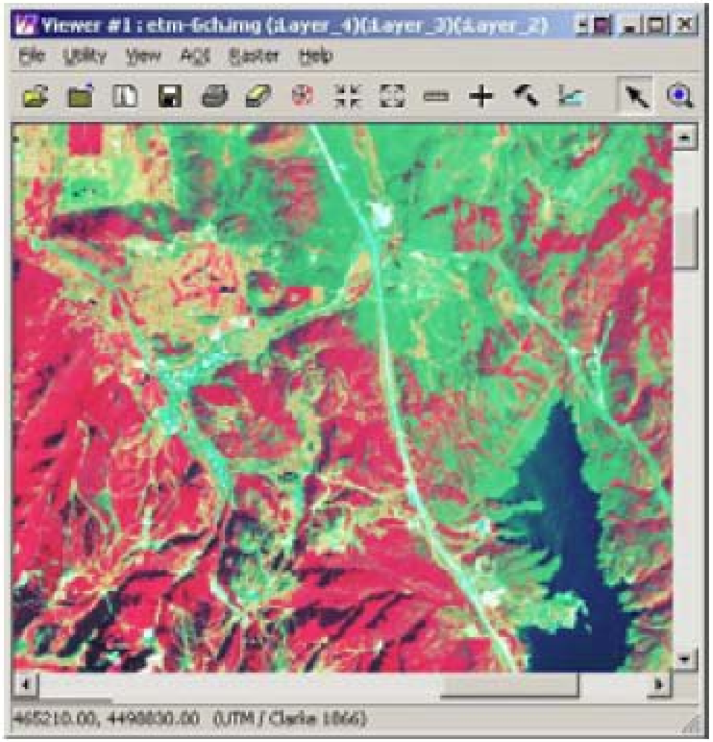


The white histogram in each graphic represents the raw data values before enhancement. The red, green, and blue plots are the histograms of the displayed image after the linear stretch is applied.

In a normal linear contrast stretch (Left), the minimum and maximum values are stretched to the values of 0 and 255 at a constant level of intensity (defined by the black line).

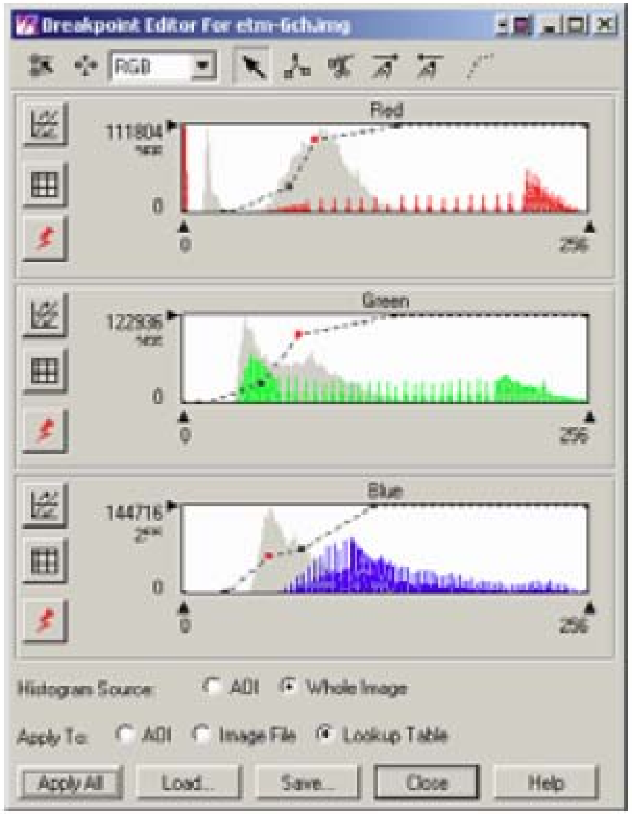
In the piecewise linear contrast stretch (right), several breakpoints are defined that increase or decrease the contrast of the image for a given range of values. The higher the slope, the narrower the range of input values (x-axis) and the wider the output spread (y-axis). This increases the contrast for that range of values.

Piecewise Linear Contrast Stretch Example



465210.00, 4498830.00 (UTM / Clarke 1866)

Piecewise contrast allows the user to enhance selected portions of the image to separate features of interest

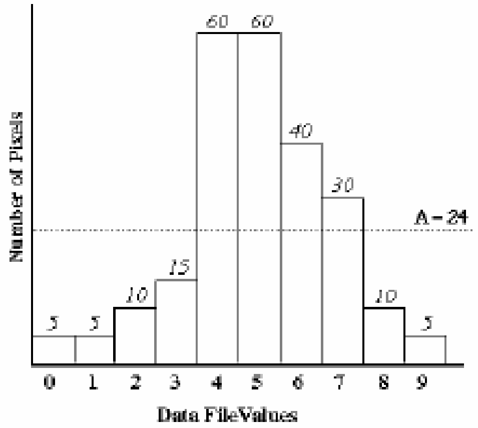


Histogram Source: ○ AOI ● Whole Image

Apply To: ○ AOI ○ Image File ● Lookup Table

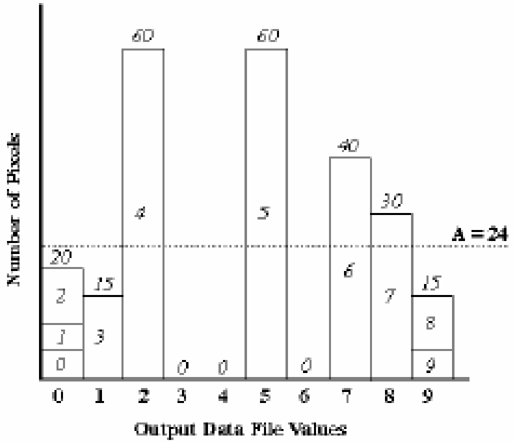
Histogram Equalization

Before Equalization



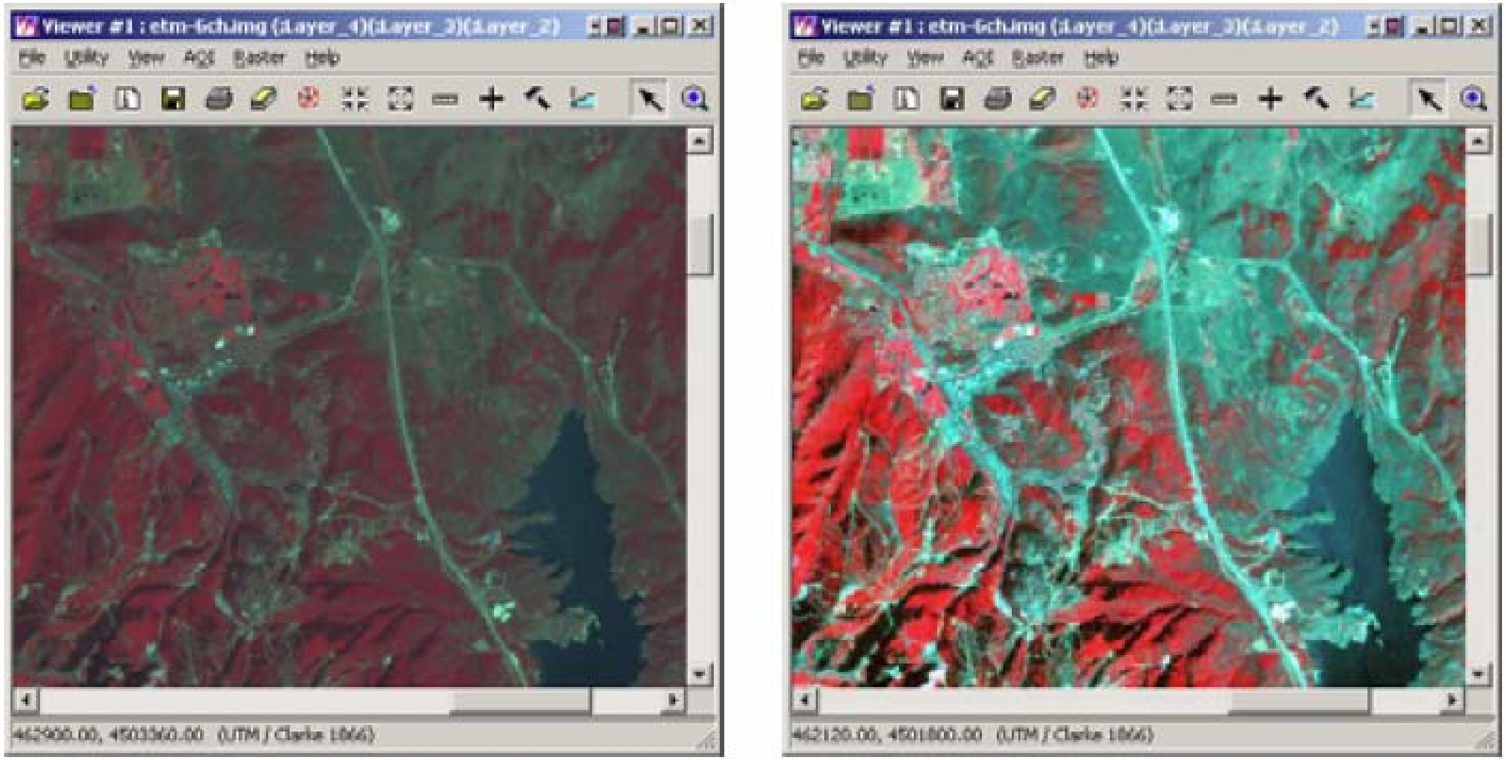
After Equalization

* Numbers inside bars are input data values



With Histogram equalization, the enhanced image gains contrast in the most populated areas of the original histogram. In this example, the input range of 3 to 7 is stretched to the range of 1 to 8. However, the data values at the tails of the original histogram are grouped together. Input values 0 through 2 all have the output values of 0. This results in the loss of the dark and bright characteristics usually associated with the tail pixels (ERDAS Inc. 1995)

Histogram Equalization Example



This portion of a Landsat 7 Thematic Mapper image of Park City, Utah shows the original brightness values on the left and the result of a histogram equalization on the right. Detail in the mid range values is increased, while the extremes are saturated.

Image Pre-Processing

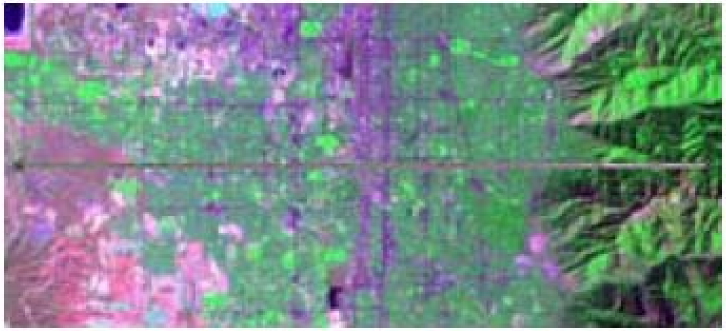
Spatial Enhancement

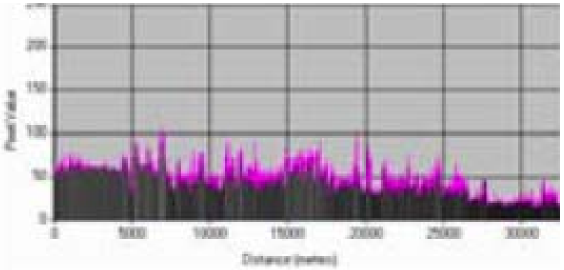
Spatial enhancement of digital images seeks to take advantage of the spatial frequency and improve the visual quality, analytical properties, and extract biophysical/landscape parameters.

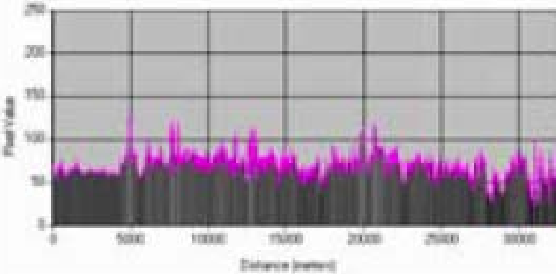
The spatial frequency of an image is defined as the number of changes in brightness value per unit distance of any particular part of an image.

- **Focal Analysis – Statistical analysis of thematic layers**
- **Edge-Detection – Location of areas of high spatial frequency**
- **High/Low Pass Filters – Increases/Decreases areas of high frequency**
- **Resolution Merges – Increases resolution by combining two data sources**
- **Statistical Filtering – Uses local variance to suppress spurious data points**
- **Adaptive Filtering – Adapts output to local input contrast**
- **Texture Filters – Generates local variability images.**

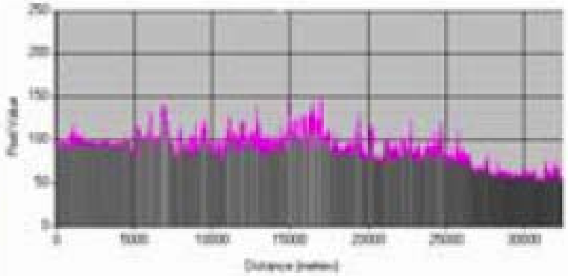
Spatial Frequency

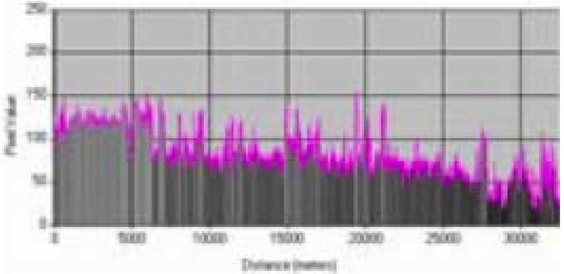


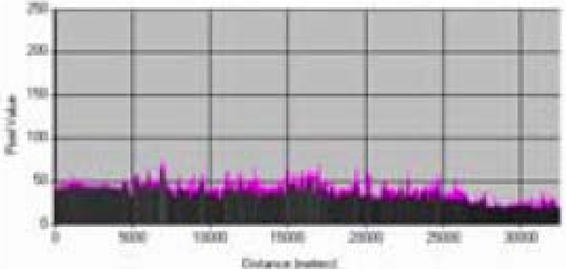


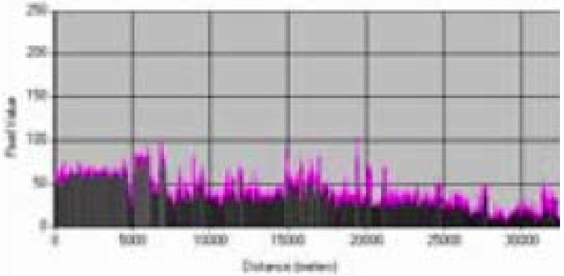


This spectral transect depicts the changes in spatial frequency as one moves from the left edge of the image above to the right. Spatial frequency is dependent on surface conditions and wavelength









Convolution Filtering

Used to change the spatial frequency characteristics of an image

C1	C2	C3
C4	C5	C6
C7	C8	C9

Convolution filtering uses a mask of nrows x ncols size (always odd numbers) to systematically modify input pixel values based on the weighted average of the surrounding pixels identified by the mask size.

$$\frac{\sum \begin{pmatrix} C1 \times BV1 & C2 \times BV2 & C3 \times BV3 \\ C4 \times BV4 & C5 \times BV5 & C6 \times BV6 \\ C7 \times BV7 & C8 \times BV8 & C9 \times BV9 \end{pmatrix}}{\mathbf{N}}$$

Where ‘N’ = nrows x ncols

3 x 3

C	C	C
C	C	C
C	C	C

5 x 5

C	C	C	C	C
C	C	C	C	C
C	C	C	C	C
C	C	C	C	C
C	C	C	C	C

7 x 7

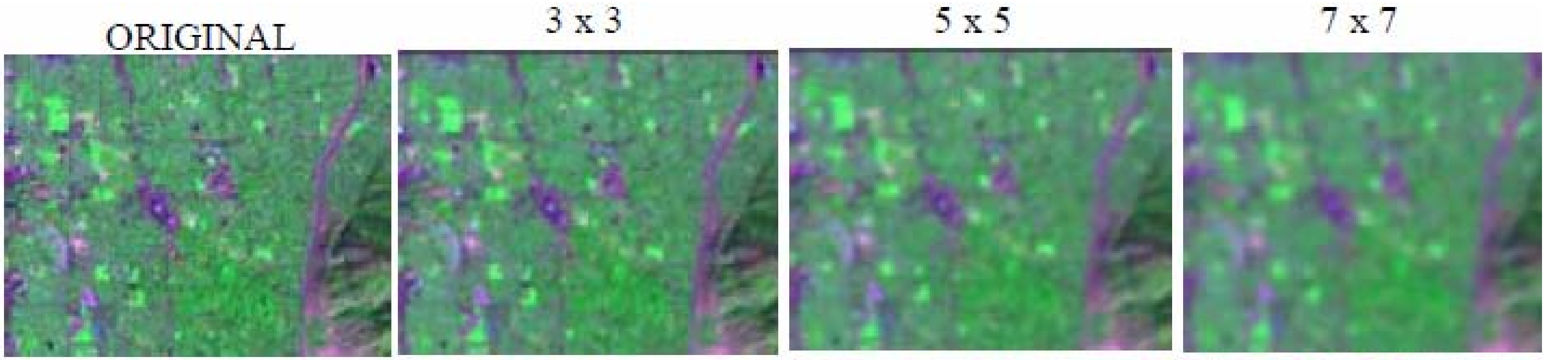
C	C	C	C	C	C	C
C	C	C	C	C	C	C
C	C	C	C	C	C	C
C	C	C	C	C	C	C
C	C	C	C	C	C	C
C	C	C	C	C	C	C
C	C	C	C	C	C	C

7 x 7 Round

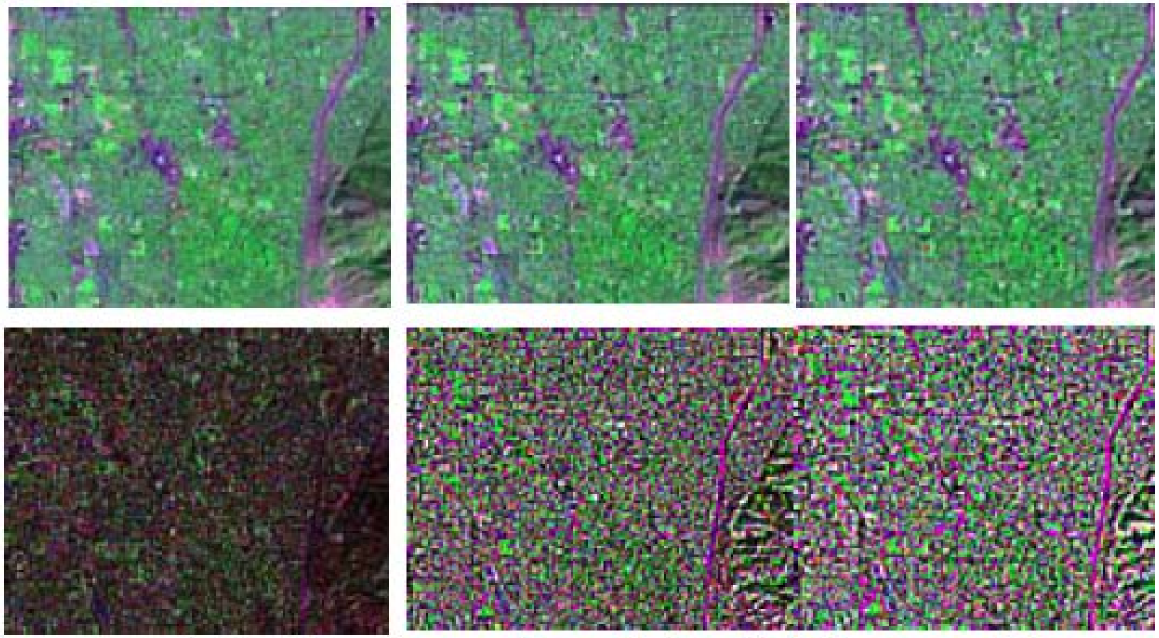
0	0	C	C	C	0	0
0	C	C	C	C	C	0
C	C	C	C	C	C	C
C	C	C	C	C	C	C
C	C	C	C	C	C	C
0	C	C	C	C	C	0
0	0	C	C	C	0	0

7 x 7 Donut

0	0	C	C	C	0	0
0	C	C	C	C	C	0
C	C	0	0	0	C	C
C	C	0	0	0	C	C
C	C	0	0	0	C	C
0	C	C	C	C	C	0
0	0	C	C	C	0	0



Different effects are the result of variations in the weights applied to each kernel.



There are many different convolution filters that can be applied to digital imagery. The mathematical function remains the same weighted average of all cells within the kernel. The only thing that changes is the kernel size and weights applied to each cell.

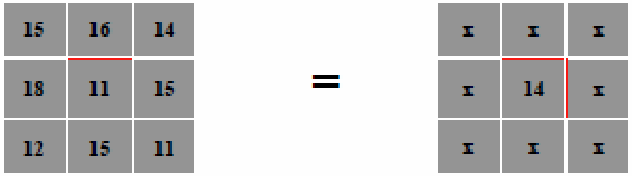
Image Texture

Humans interpret imagery based on color, context, edges, texture, and tonal variations. Most classification algorithms commonly use only spectral (color) and tonal variations in an image. The incorporation of texture into classification algorithms allow us to extract yet another image component (local variation) to assist in feature identification.

Texture calculation is based on the extraction of local variance using a convolution filter approach.

Calculating Image Texture

$$\textbf{AVE} = \frac{\sum_{i=1}^{n=j} BV_i}{j}$$

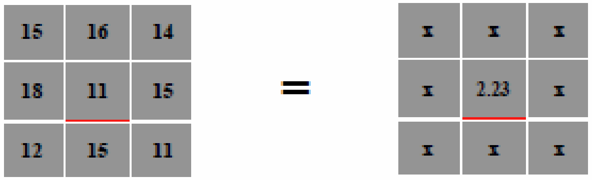


15	16	14
18	11	15
12	15	11

=

x	x	x
x	14	x
x	x	x

$$\textbf{STD} = \sqrt{\frac{\sum_{i=1}^{n=j} (i - AVE)^2}{j}}$$



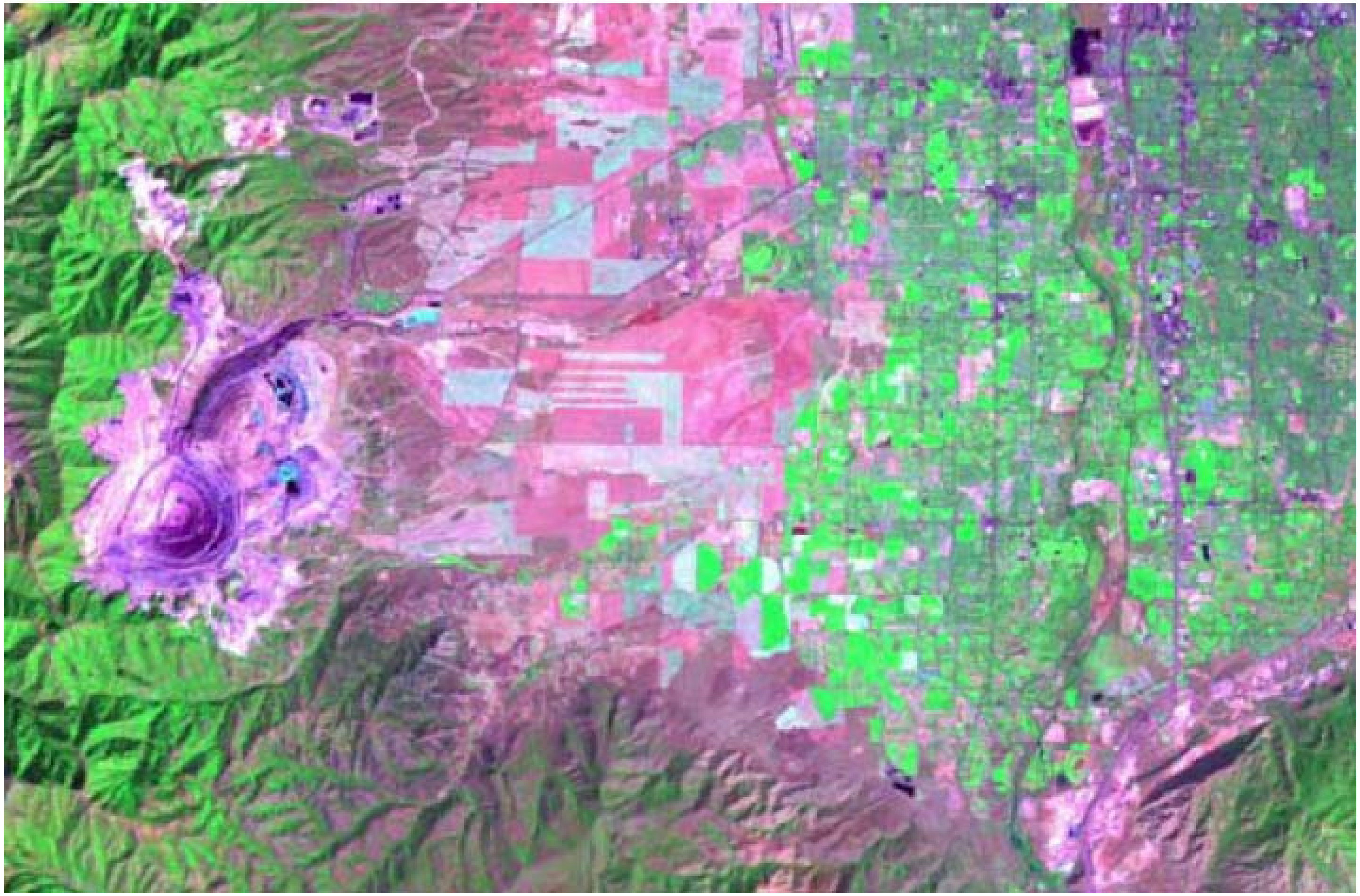
15	16	14
18	11	15
12	15	11

=

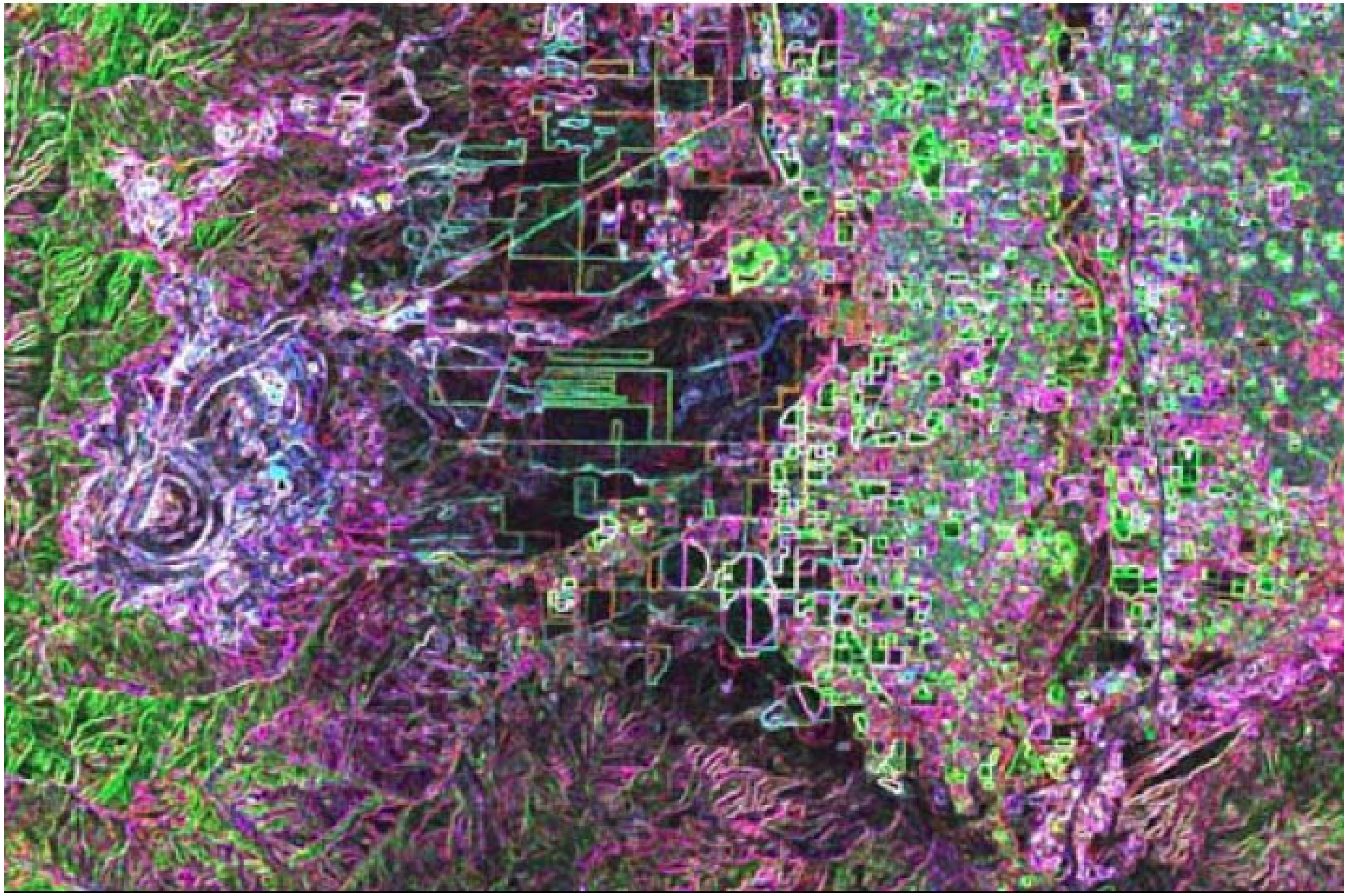
x	x	x
x	2.23	x
x	x	x

X = output value of cell when it is the center cell of the convolution matrix.

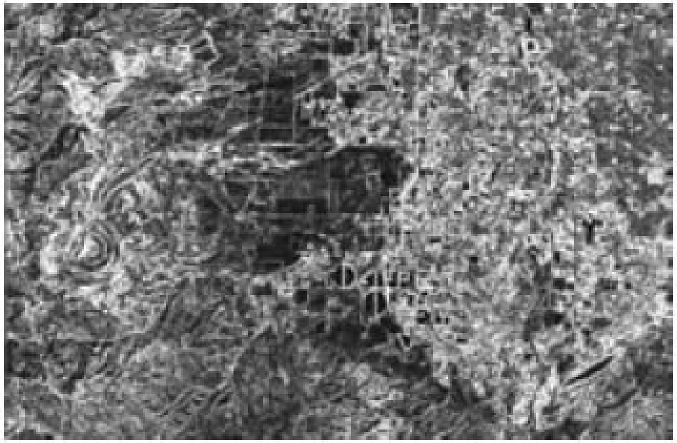
Landsat TM 7,4,2 (RGB)



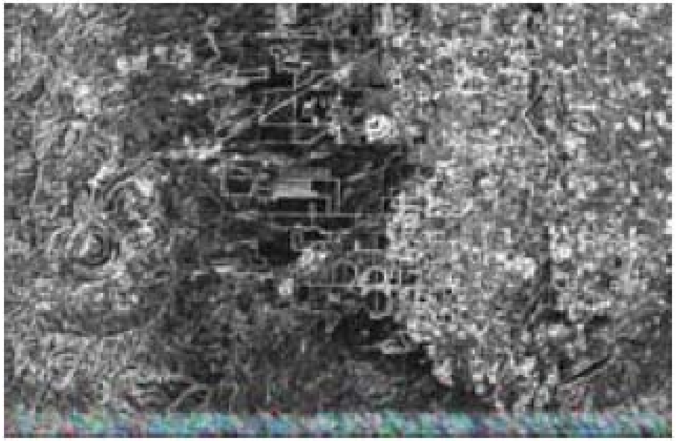
Landsat TM 7,4,2 (RGB) Texture



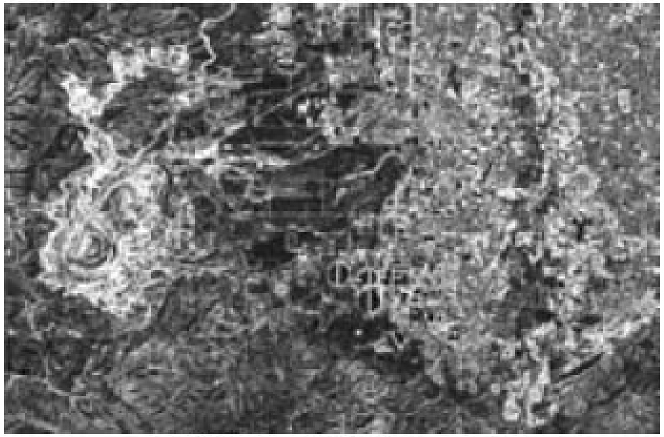
Individual Band Texture Results



TM Band 7 Texture



TM Band 4 Texture



TM Band 2 Texture

Variable spectral reflectance properties of landscapes provide different texture results that further allow users to extract features.