Digital Image Processing
Image Enhancement

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Image Enhancement

- Modification of an image to alter its impact on viewer
- Enhancements are used to make it easier for visual interpretation and understanding of imagery.
- Process of making an image more interpretable for a particular application to accentuate certain image features for subsequent analysis or for image display
- Useful since many satellite images give inadequate information for image interpretation.
- Attempted after image is corrected for distortions.
- May be performed temporarily or permanently.

In raw imagery, the useful data often populates only a small portion of the available range of digital values (commonly 8 bits or 256 levels).

Enhancement Types:

- RADIOMETRIC ENHANCEMENT

  Modification of brightness values of each pixel in an image data set independently (**Point operations**).

- SPECTRAL ENHANCEMENT

  Enhancing images by transforming the values of each pixel on a multiband basis.

- SPATIAL ENHANCEMENT

  Modification of pixel values based on the values of surrounding pixels. (**Local operations**)

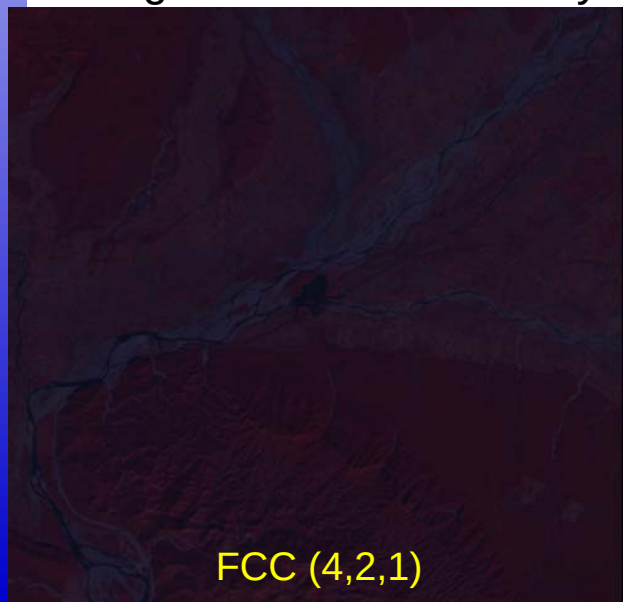
Radiometric Enhancement

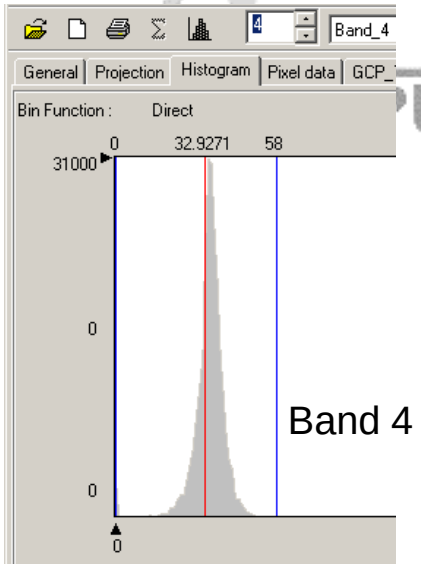
- Modification of brightness values of each pixel in an image data set independently (Point operations).
- Brings out contrast in the image
- Applied separately to each band of data.
- Enhancement applied to one band may not be appropriate to other bands.
    - Contrast Enhancement falls under Radiometric enhancement

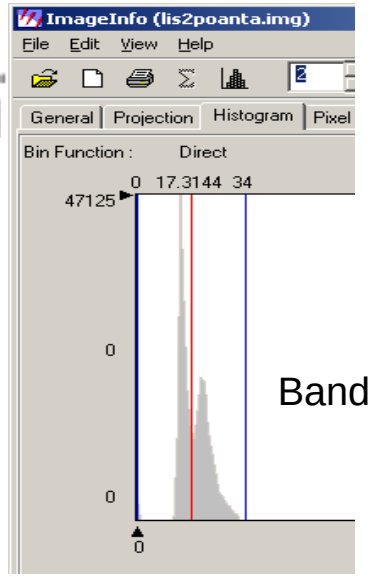
CONTRAST

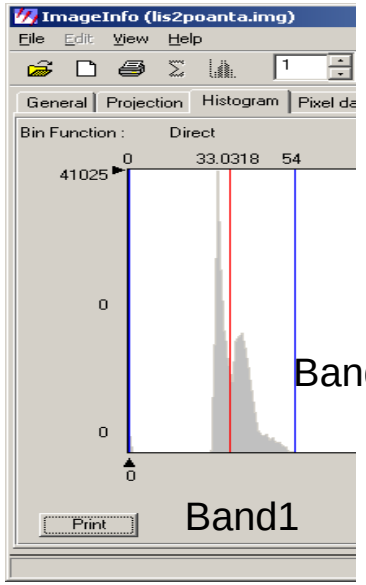
- Amount of difference between average gray level of an object and that of surroundings
- Difference in illumination or grey level values in an image or Intuitively, how vivid or washed-out an image appears
- Ratio of Maximum Intensity to Minimum Intensity
- Larger the ratio more easy it is to interpret the image

CONTRAST = Max . Grey Value / Min. Grey Value



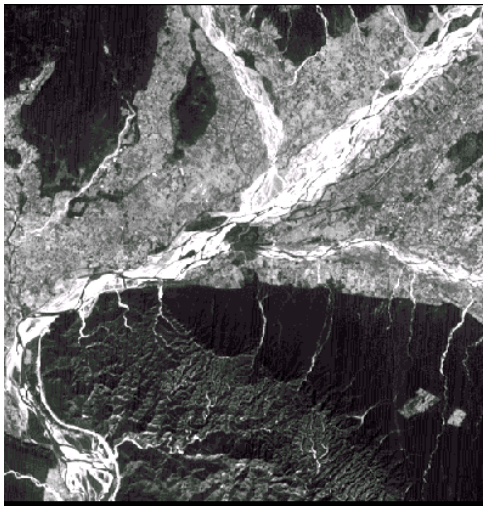




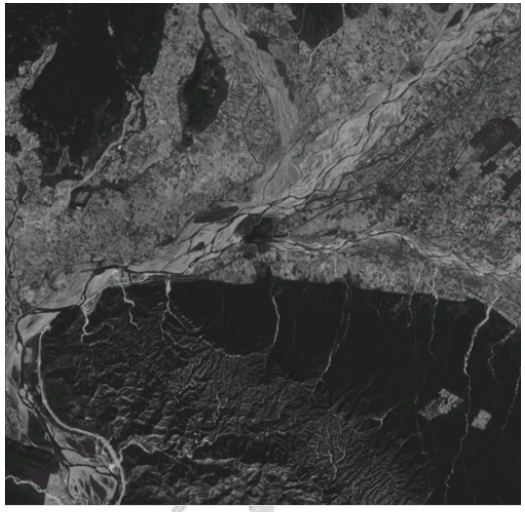


Reasons for Low Contrast

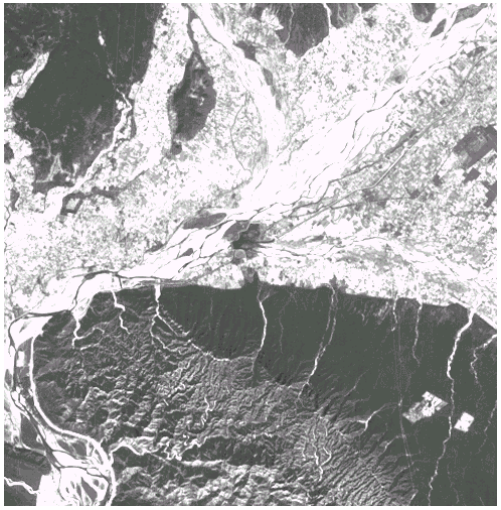
- Scene itself has low contrast ratio
- The individual objects and background that make up the terrain may have a nearly uniform electromagnetic response at the wavelength band of energy that is recorded by the remote sensing system
- Different materials often reflect similar amounts of radiant flux through out the Visible, NIR and MIR portion of EM Spectrum.
- Cultural Factors e.g. People in developing countries use natural building material (wood, soil) in construction of urban areas
- Sensitivity of Detector
- Atmospheric Factors



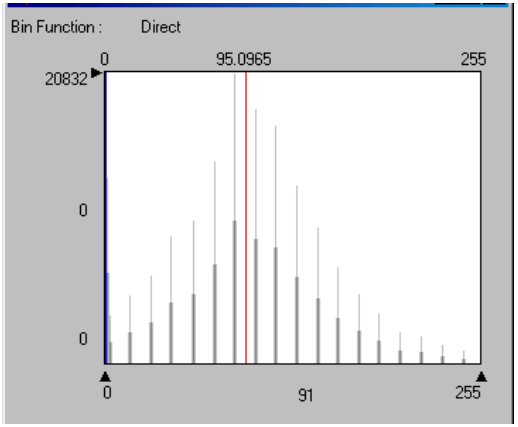
Original

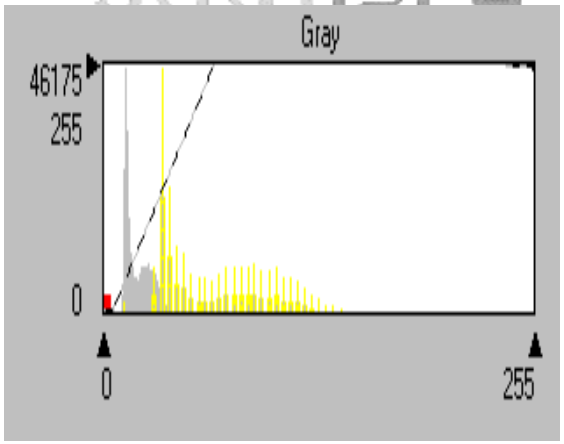


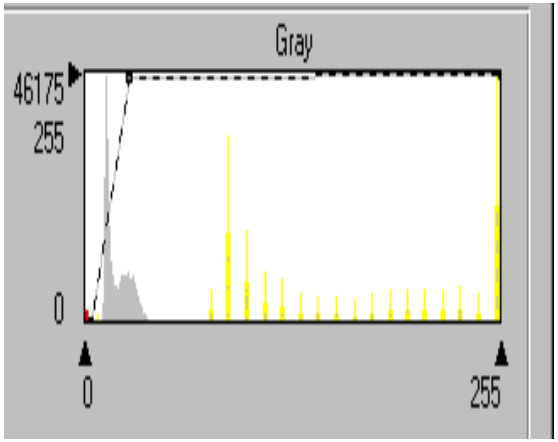
Low Contrast



Saturated







Radiometric Enhancement: Contrast (Min - Max) Enhancement

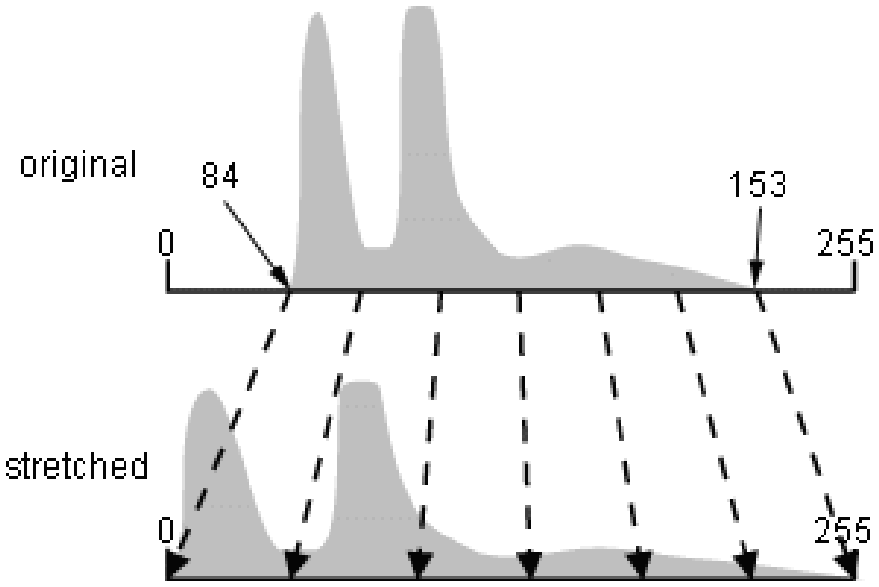
- Linear Contrast Stretch
  - Input and Output Data Values follow a linear relationship
    - Min – Max Stretch
    - % stretch
    - Std. deviation Stretch
    - Piecewise Linear Stretch
    - Saw tooth Stretch

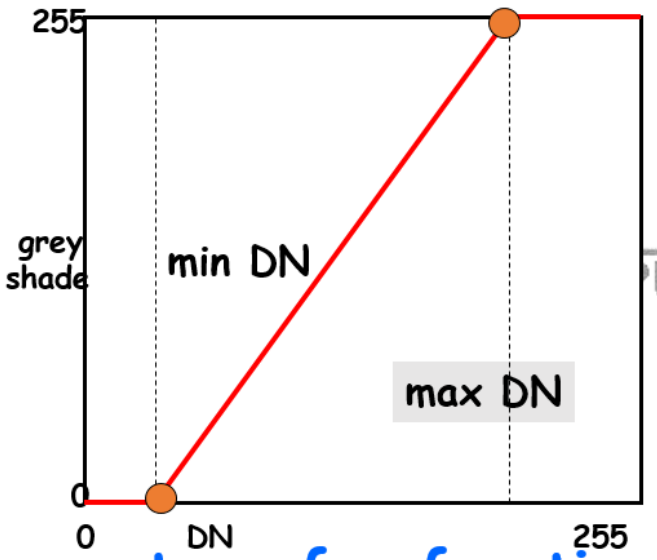
- Non Linear Contrast Stretch
  - Input and Output Data Values do not follow a linear relationship
    - Logarithmic
    - Inverse Log
    - Exponential
    - Square
    - Square root etc ....

Minimum Maximum Stretch

Expands the original input values to make use of the total range of the sensitivity of the display device.

- The density values in a scene are literally pulled farther apart, that is, expanded over a greater range.
- The effect is to increase the visual contrast between two areas of different uniform densities.
- This enables the analyst to discriminate easily between areas initially having a small difference in density.
- A DN in the low range of the original histogram is assigned to extreme black, and a value at the high end is assigned to extreme white.
- The remaining pixel values are distributed linearly between these two extremes



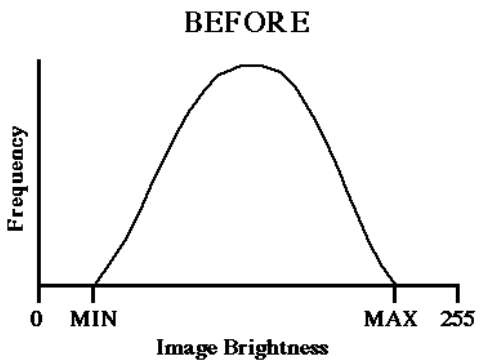


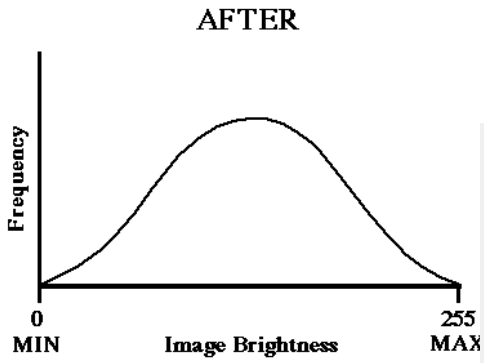
transfer function

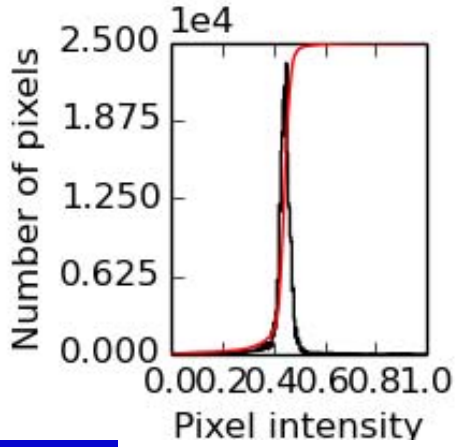
Y = ax + b

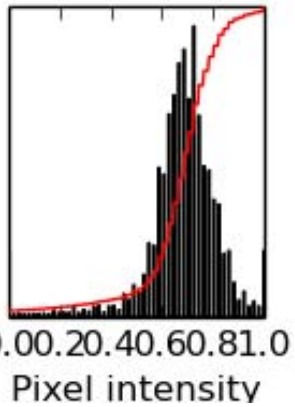
- By expanding the original input values of the image, the total range of sensitivity of the display device can be utilized.
- Linear contrast enhancement also makes subtle variations within the data more obvious.
- These types of enhancements are best applied to remotely sensed images with Gaussian or near-Gaussian histograms.

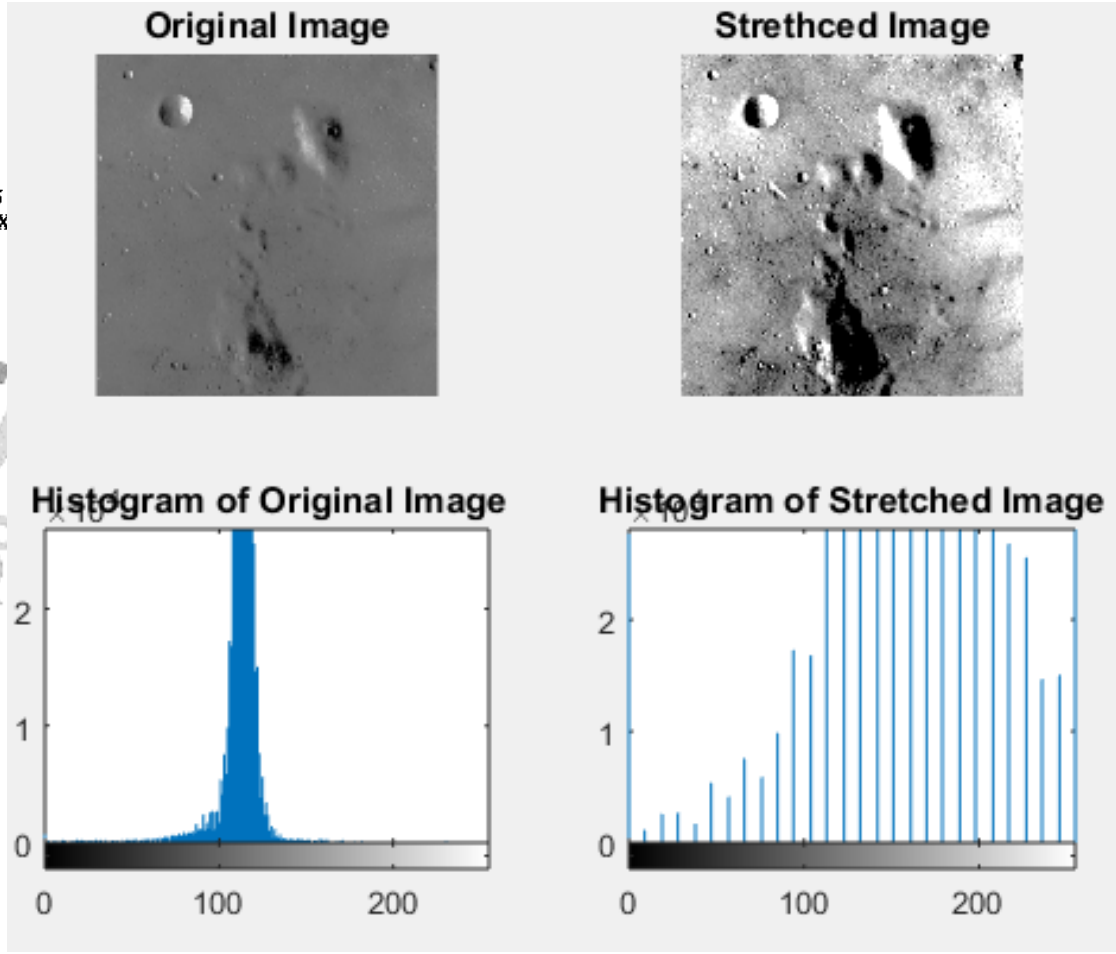
$$Y = \frac{X - X_{min}}{X_{max} - X_{min}} \cdot 255$$



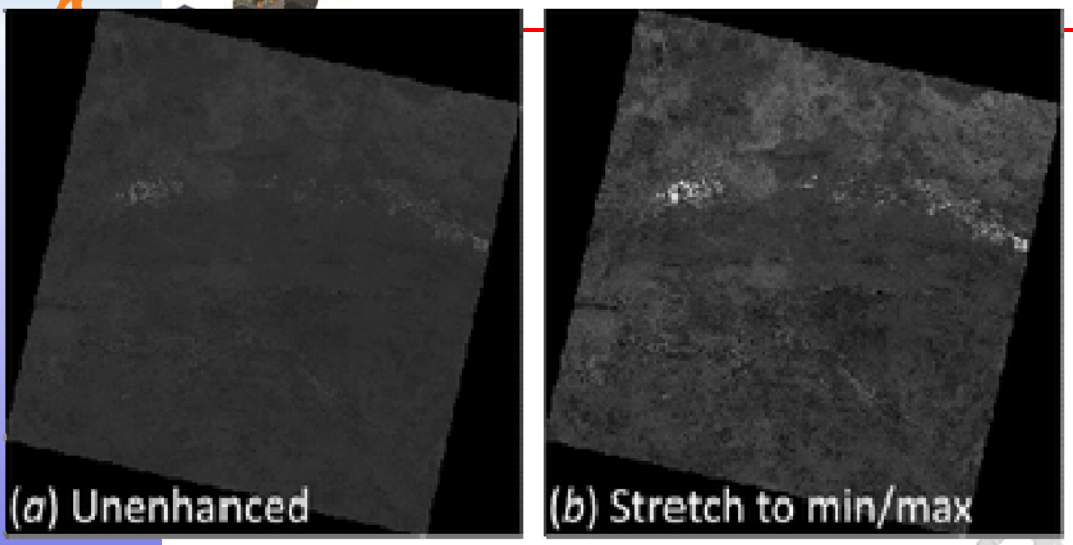


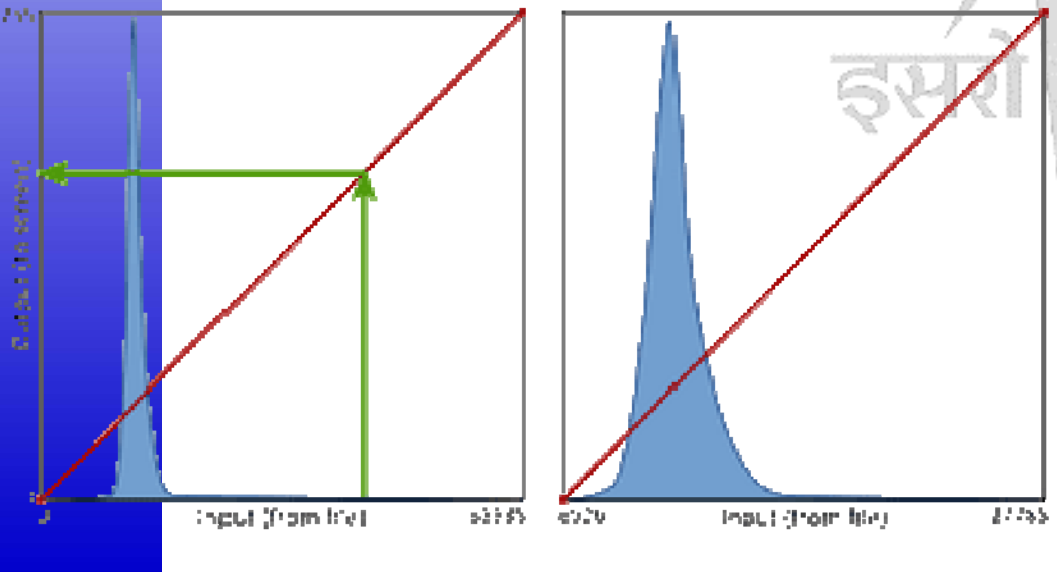


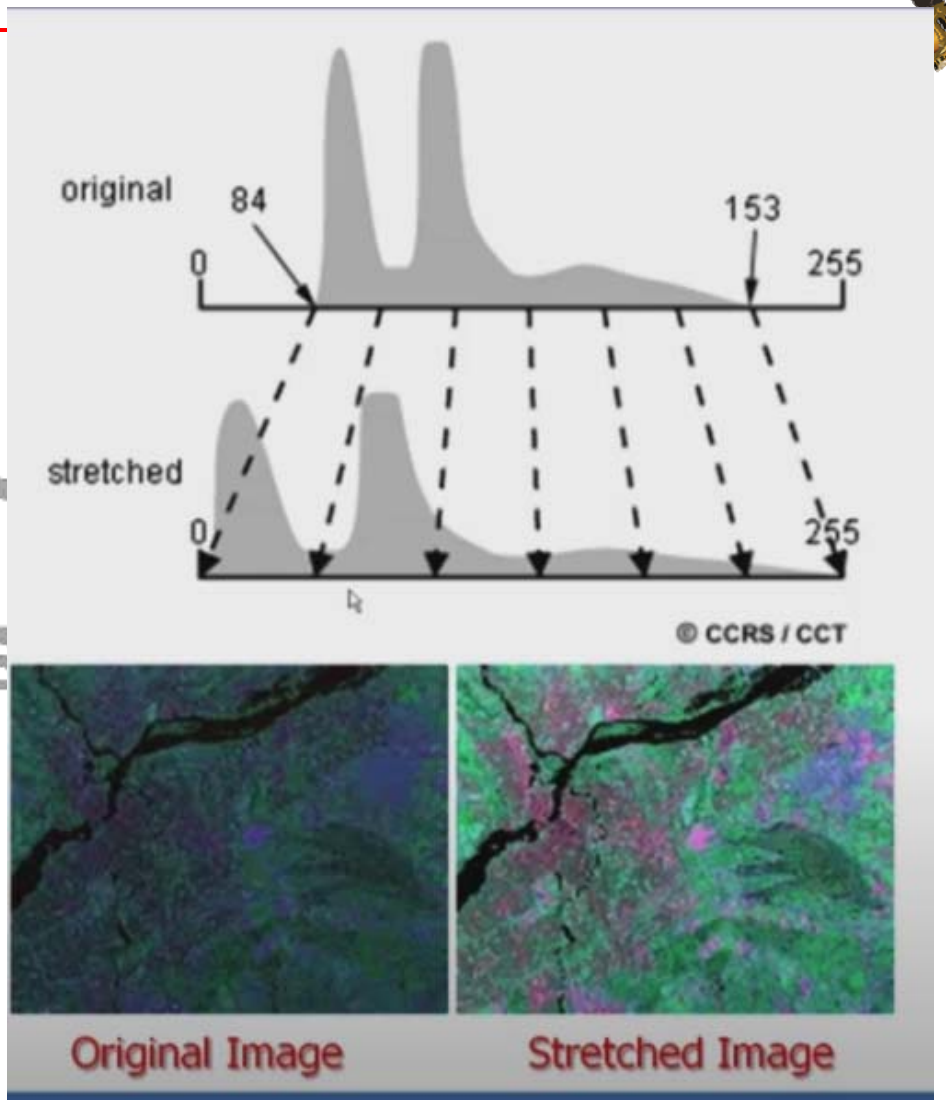


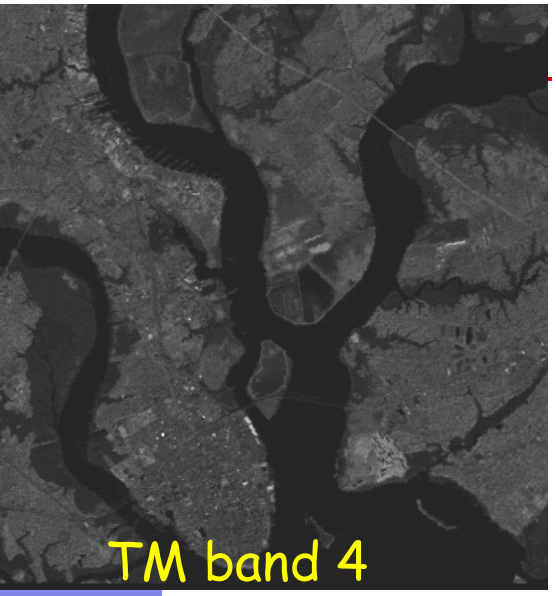


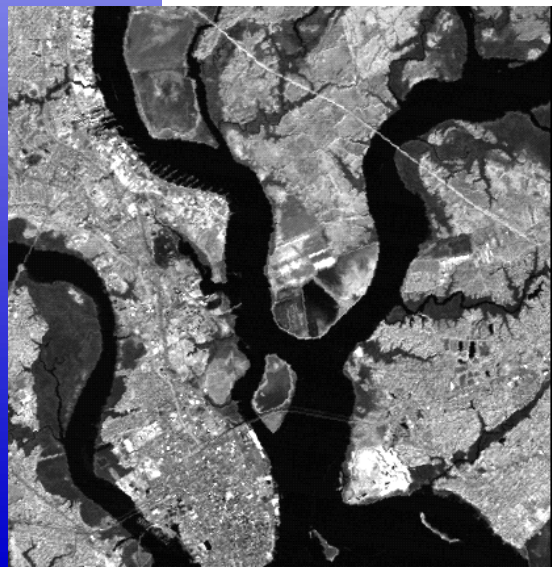
Linear Stretch Min Max

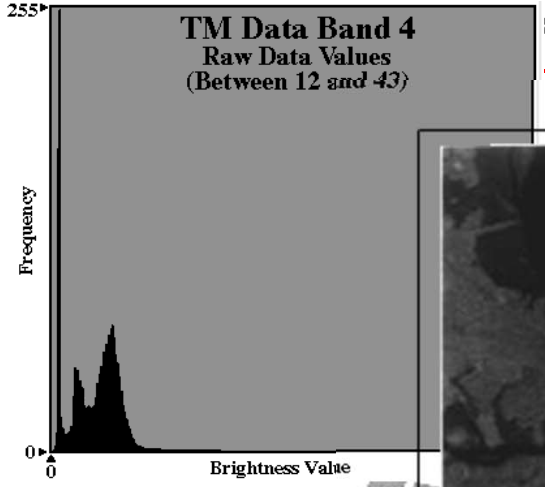

(a) Unenhanced
(b) Stretch to min/max

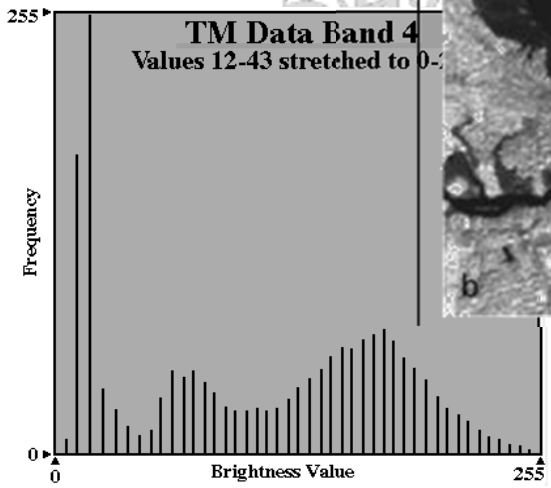


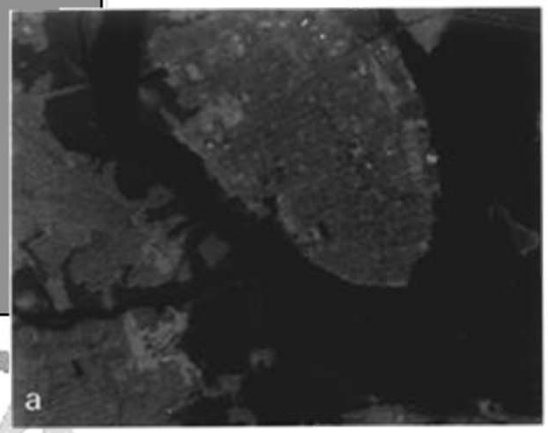

original
84
153
0
255
stretched
0
255
© CCRS / CCT
Original Image
Stretched Image


TM band 4

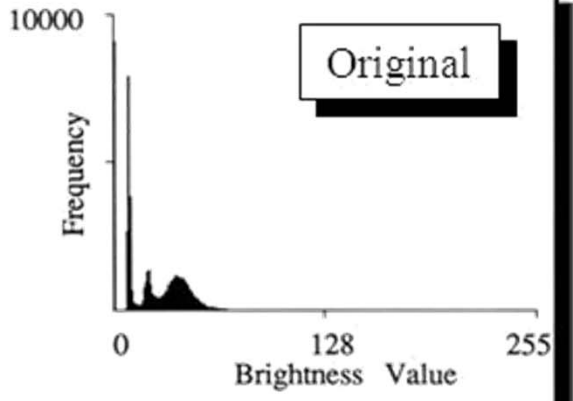


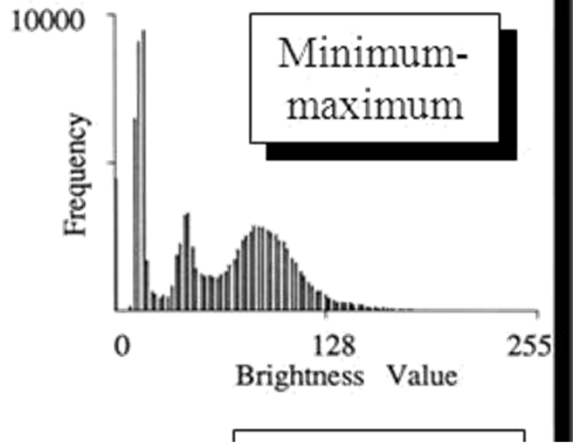

TM Data Band 4
Raw Data Values
(Between 12 and 43)
255
0
Frequency
0
Brightness Value

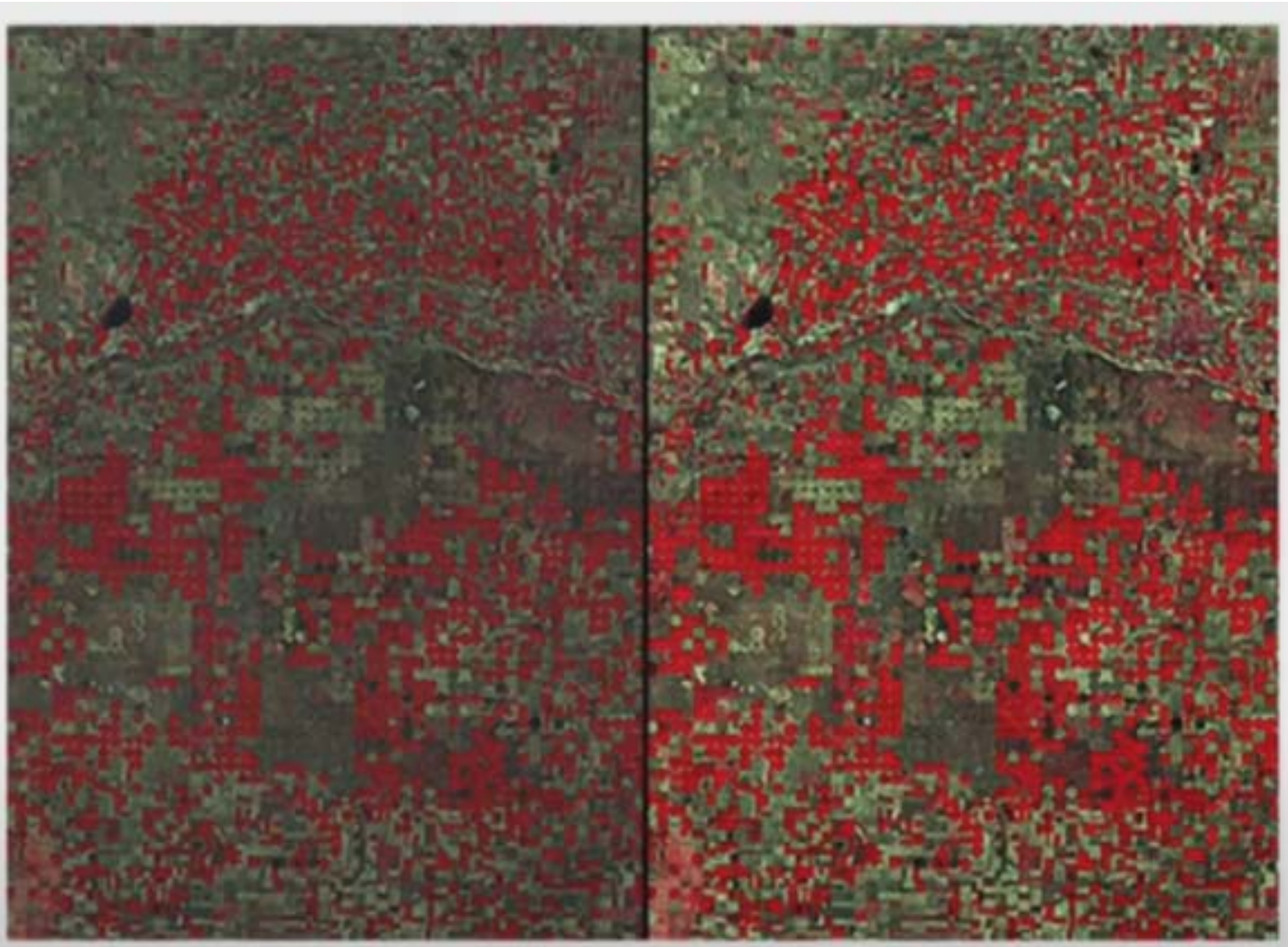

TM Data Band 4
Values 12-43 stretched to 0-
255
0
Frequency
0
Brightness Value
255


a


b


10000
Original
Frequency
0
128
255
Brightness Value


10000
Minimum-
maximum
Frequency
0
128
255
Brightness Value



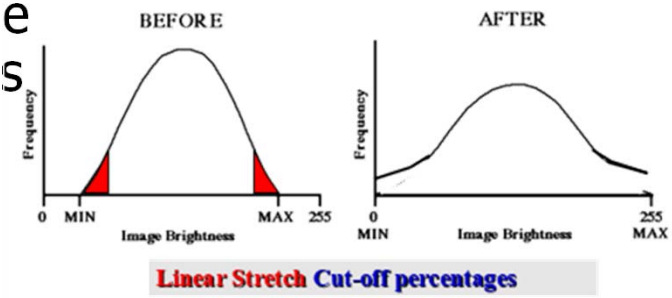
Before and after effects of contrast stretching

Image A

Image B

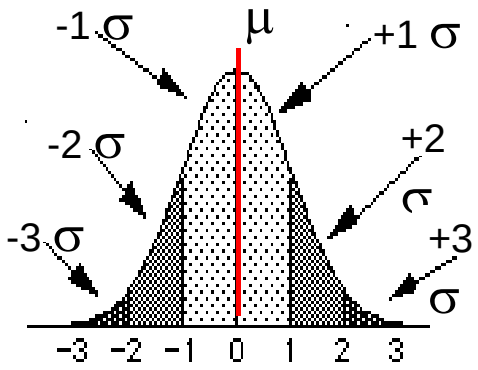
Percentage Cutoff Stretch

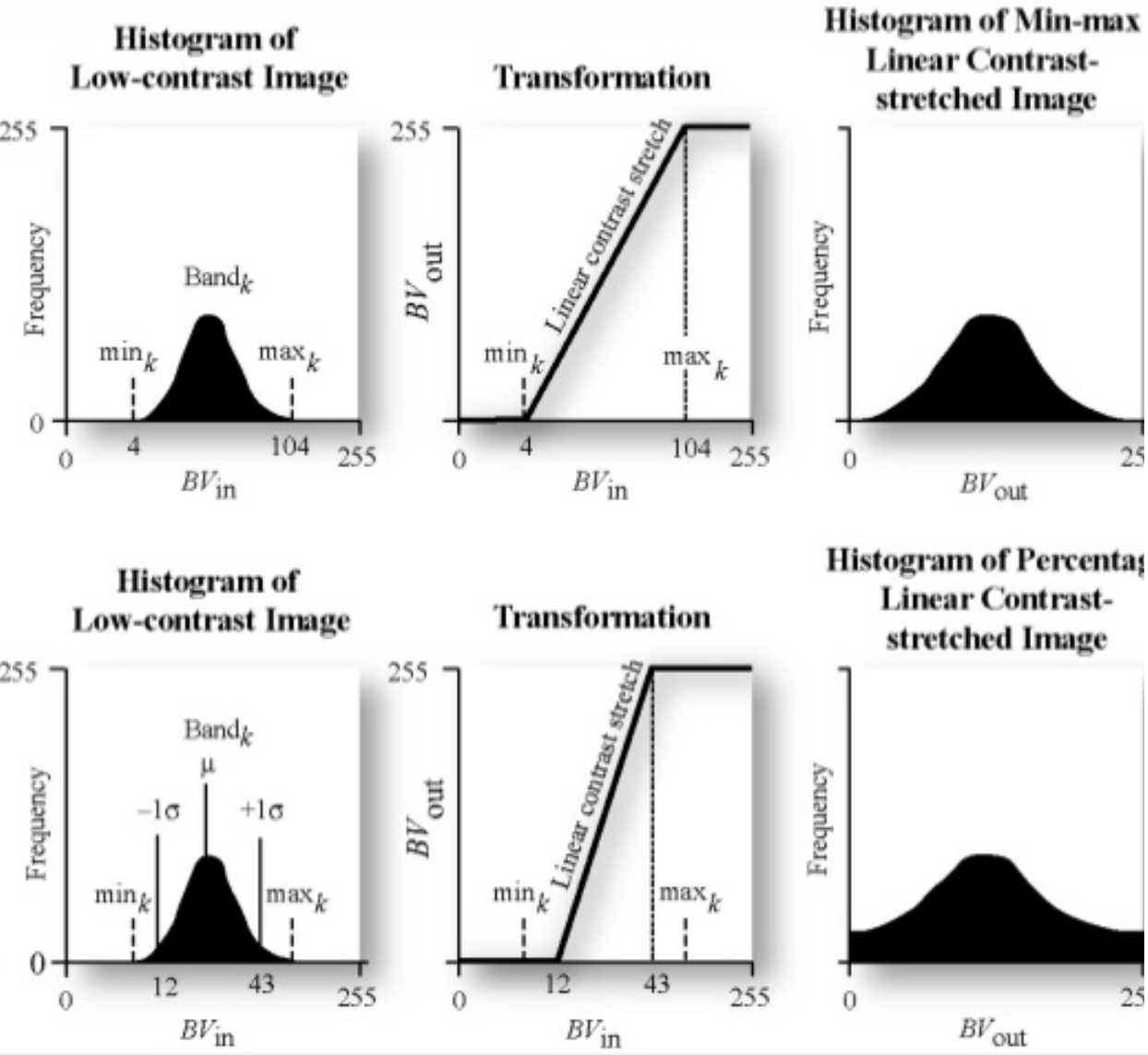
- The *percentage linear contrast stretch* is similar to the minimum-maximum linear contrast stretch except this method uses a specified minimum and maximum values that lie in a certain percentage of pixels from the mean of the histogram

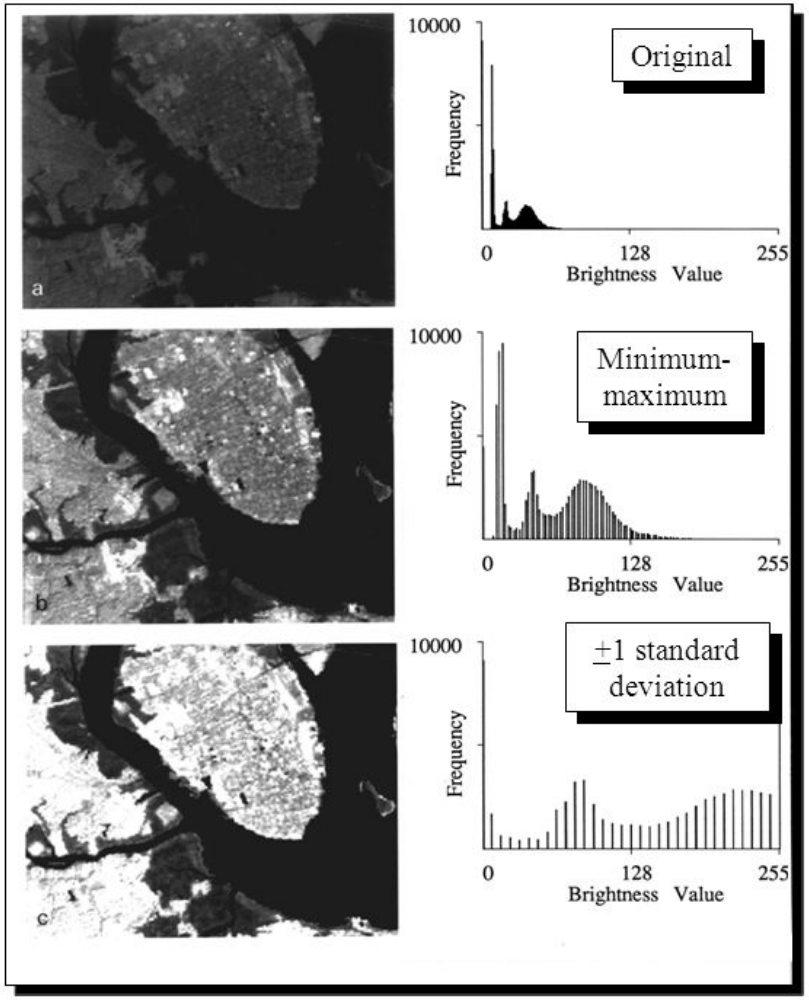


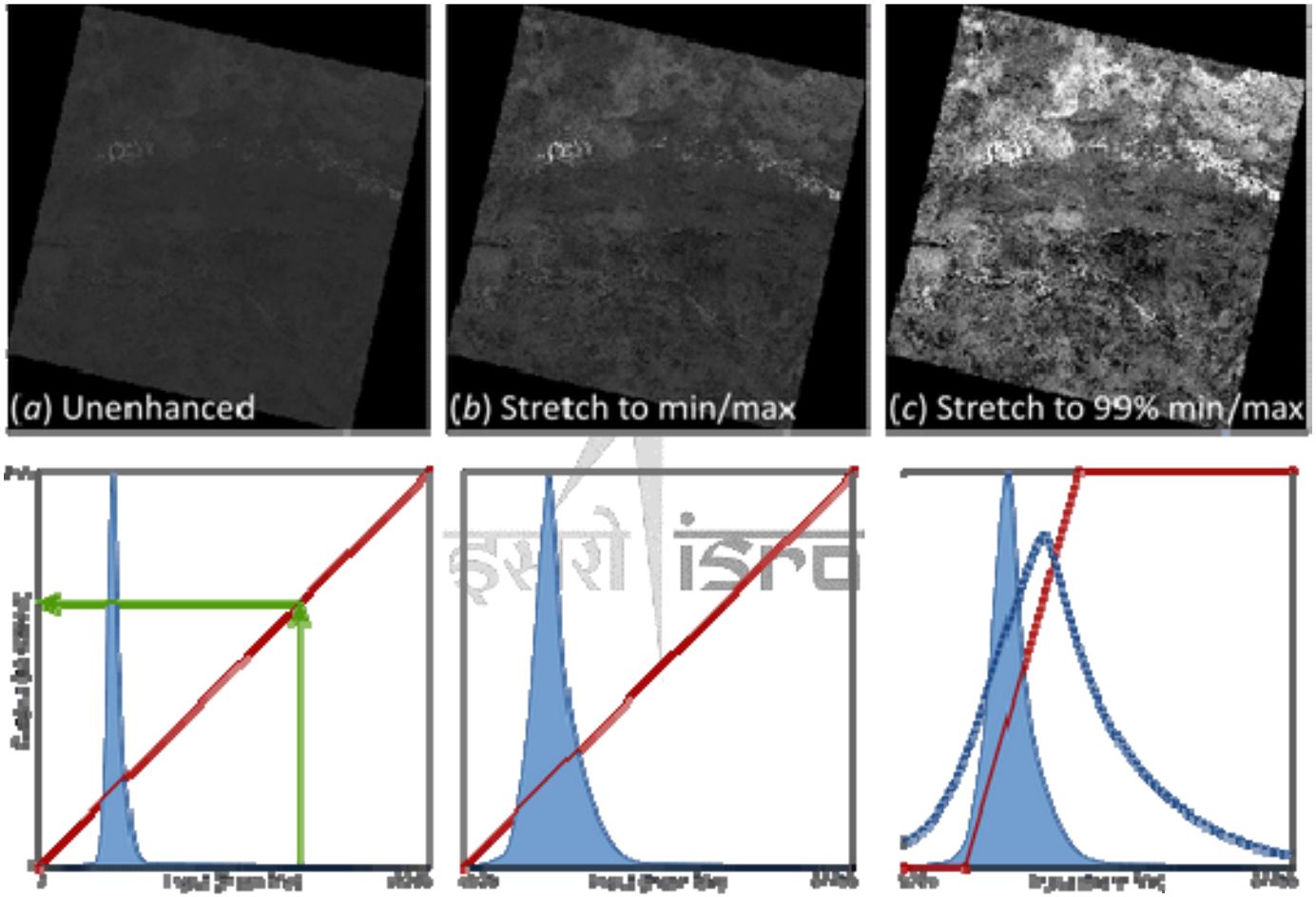
Standard Deviation Linear stretch

- Similar to the minimum-maximum linear contrast stretch except this method uses a specified minimum ar maximum values that lie outside a certain standa Deviation of pixels from the mean of the histogram.
- A standard deviation from the mean is often used to pu the tails of the histogram beyond the original minimu and maximum values



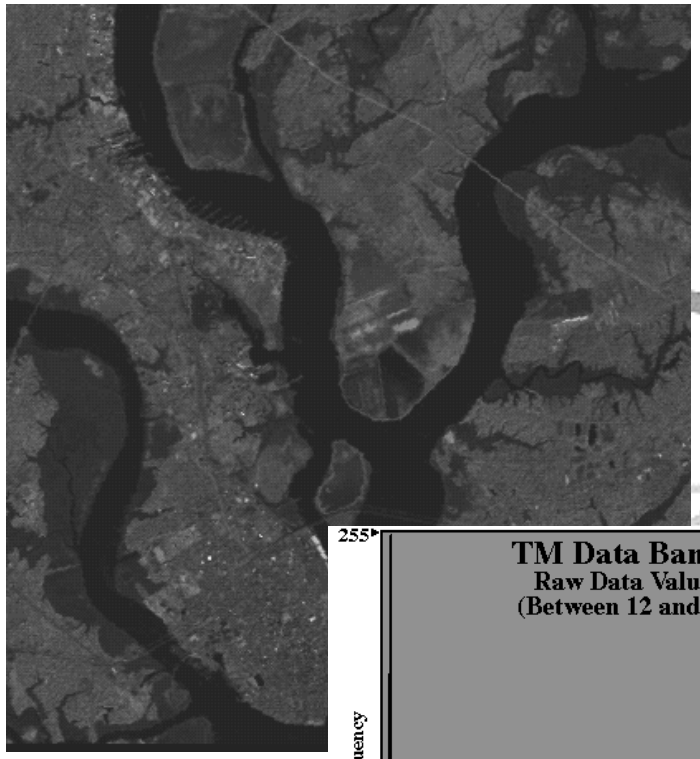

Histogram of Low-contrast Image
Transformation
Histogram of Min-max Linear Contrast-stretched Image
255
Frequency
Band$_k$
min$_k$
max$_k$
0
4
104
255
BV_{in}
BV_{out}
Linear contrast stretch
Histogram of Low-contrast Image
Transformation
Histogram of Percentag Linear Contrast-stretched Image
μ
−1σ
+1σ
12
43

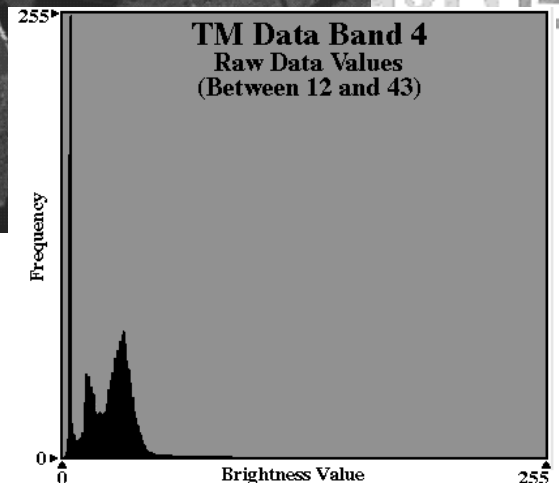

a
b
c
10000
Frequency
Original
Minimum-maximum
±1 standard deviation
0
128
255
Brightness Value

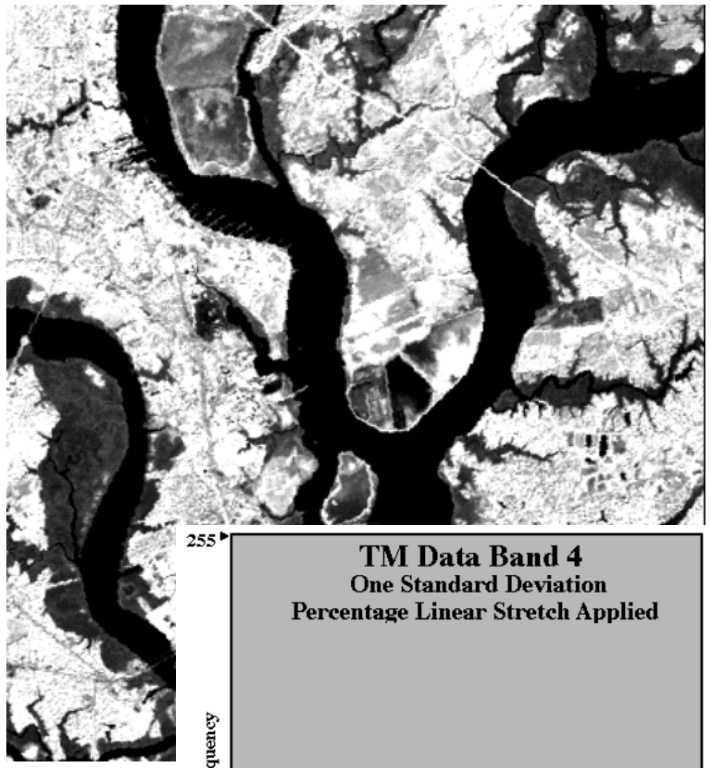

(a) Unenhanced
(b) Stretch to min/max
(c) Stretch to 99% min/max

Standard Deviation Percentage Cutoff Linear Stretch

TM band 4

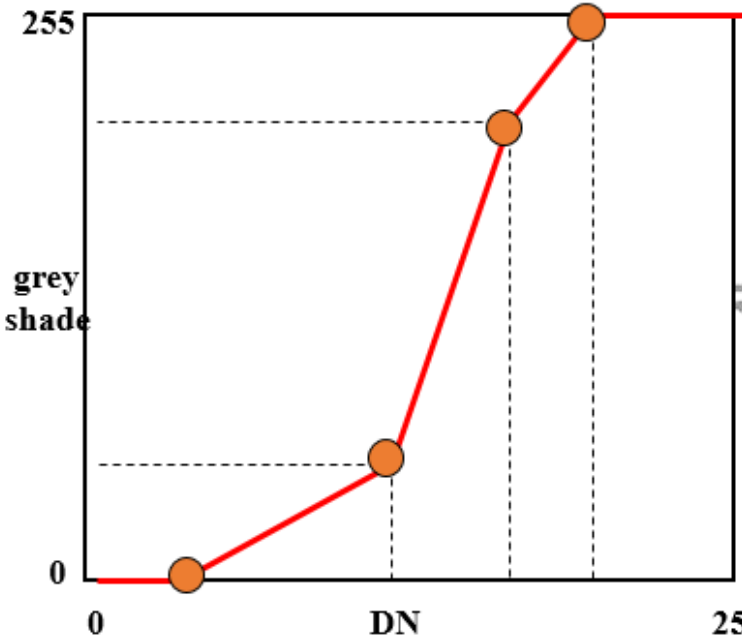




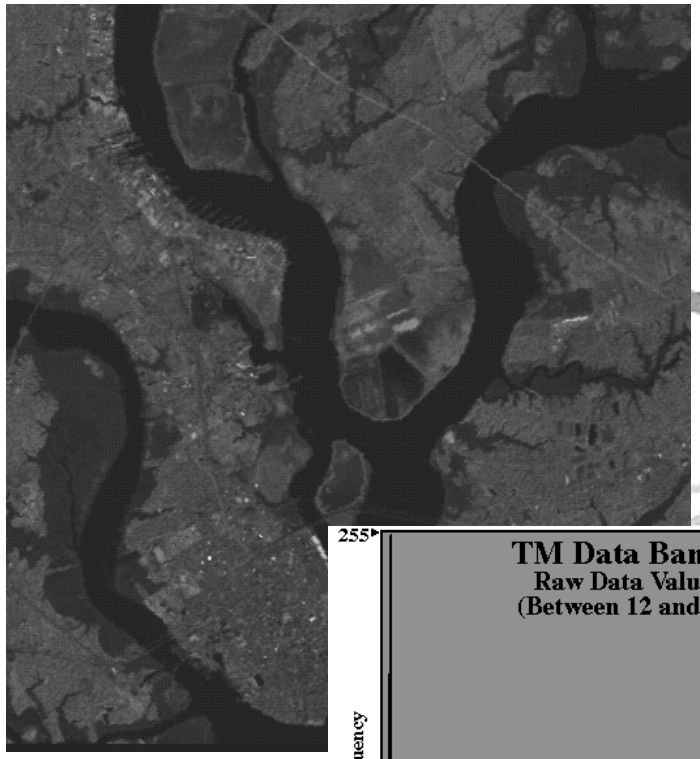


Piecewise linear Stretch

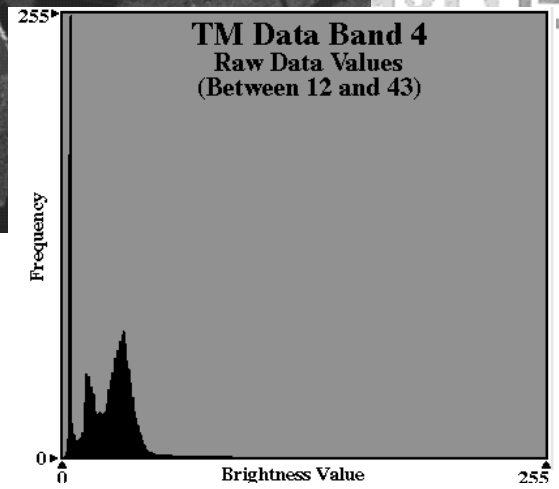
- When the distribution of a histogram in an image is bi or tri-modal, an analyst may stretch certain values of the histogram for increased enhancement in selected areas.
- A piecewise linear contrast enhancement involves the identification of a number of linear enhancement steps that expands the brightness ranges in the modes of the histogram.
- In the piecewise stretch, a series of small min-max stretches are set up within a single histogram.

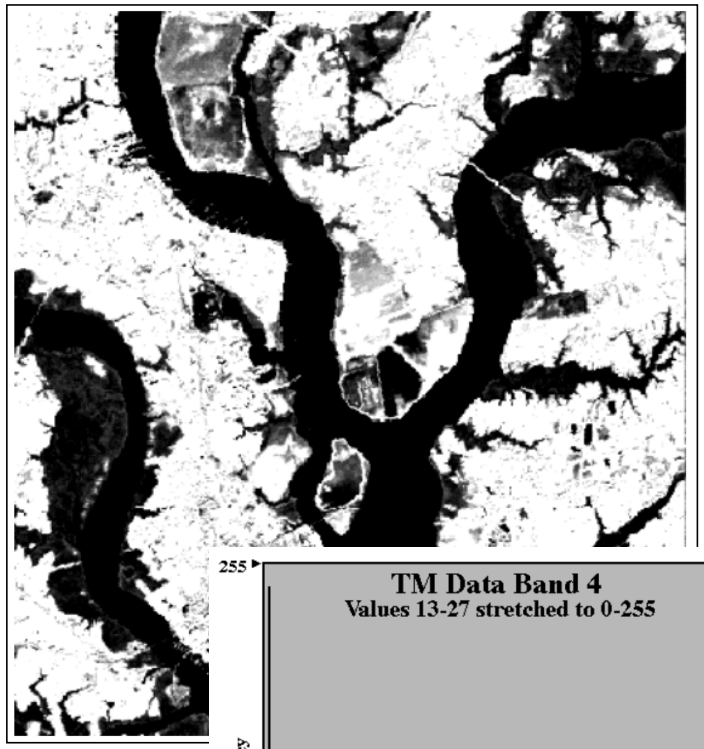


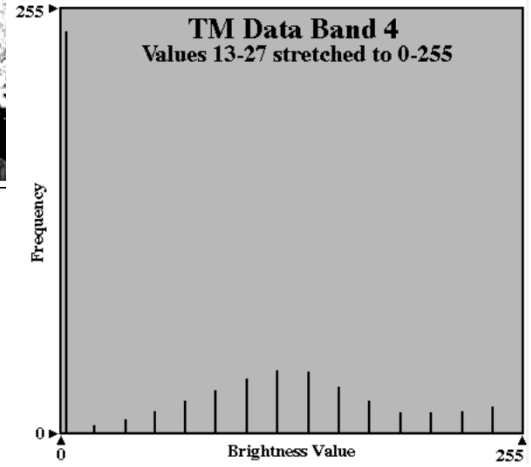
Piecewise linear stretch



TM band 4







Non-Linear Contrast Enhancement

- **Input and Output Data Values do not follow linear relationships**
- **Input and output are related via a transformation function**

  $Y = f(x)$
- **Increases or decreases contrast in different regions of histogram**

Transfer Function Types:

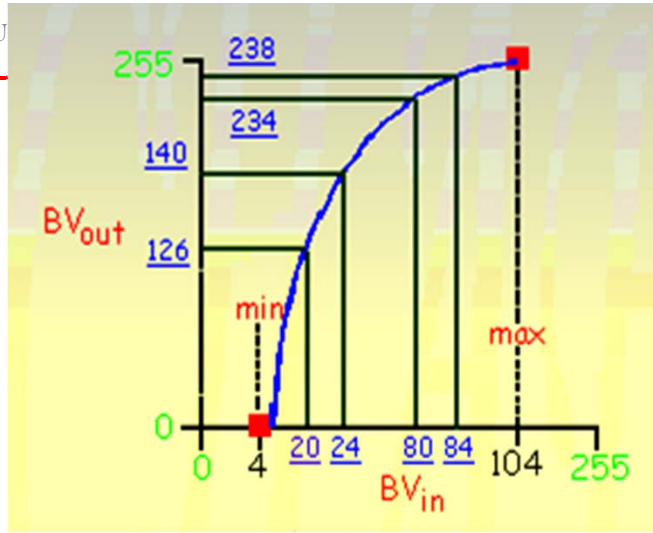
Mathematical
* Logarithmic
* Inverse Log
* Exponential
* Square
* Square root
* Cube
* Cube Root

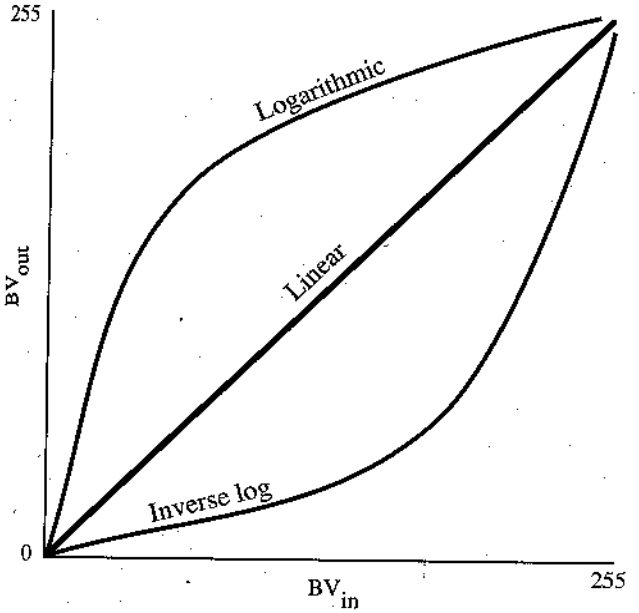
Statistical
* Histogram Equalization
* Gaussian Stretch

Trigonometrical
* Arc tangent ($\tan^{-1}$)

Logarithmic Contrast Stretch

- In this process the logarithmic values of the input data are linearly stretched to get the desired output values.
- It is a two step process. In the first step we find out the log values of the input DN values.
- In the second step the log values are linearly stretched to fill the complete range of DN no. (0-255).
- Logarithmic stretch has greatest impact on the brightness values found in the darker part of the histogram or on the low DN values.

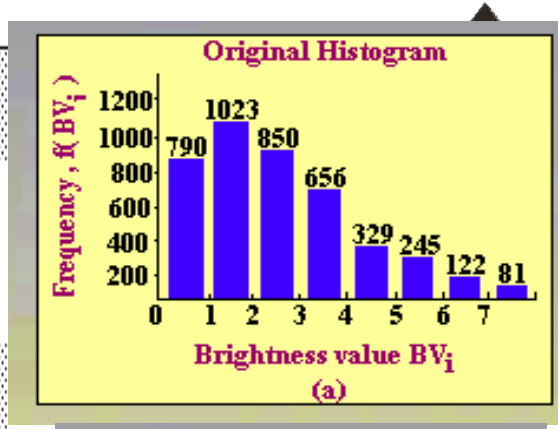


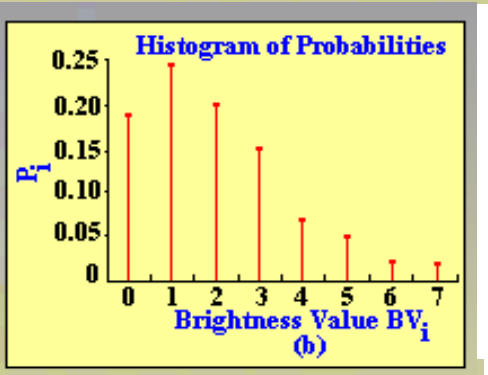


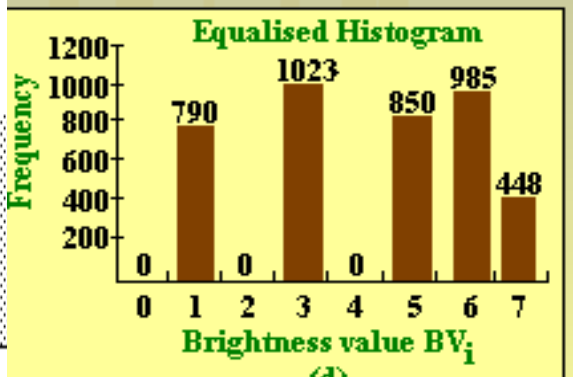
Histogram Equalisation

- In this technique, histogram of the original image is redistributed to produce a uniform population density.
- This is obtained by grouping certain adjacent gray values.
- Thus the number of gray levels in the enhance image is less than the number of gray levels in the original image.
- Contrast is increased at the most populated range of brightness values of the histogram (or "peaks").
- It automatically reduces the contrast in very light or dark parts of the image associated with the tails of a normally distributed histogram
- This technique groups pixels that are very dark or very bright into very few gray scales.
- If one is trying to bring out information about data in terrain shadows, or there are clouds in your data, histogram equalization may not be appropriate.

Frequency, $f(BV_i)$	790	1023	850	656	329	245	122	81
Original brightness value, BV_i	0	1	2	3	4	5	6	7
$L_i = \frac{\text{brightness value}}{n}$	0	0.14	0.28	0.42	0.57	0.71	0.85	1.0
Cumulative frequency	$\frac{790}{4096}$	$\frac{1813}{4096}$	$\frac{2663}{4096}$	$\frac{3319}{4096}$	$\frac{3648}{4096}$	$\frac{3893}{4096}$	$\frac{4015}{4096}$	$\frac{4096}{4096}$
transformation: $k_i = \sum_{j=0}^{\text{quant}_k} \frac{f(BV_i)}{n}$	=0.19	= 0.44	= 0.65	= 0.81	= 0.89	= 0.95	= 0.98	= 1.0
Assign original BV_i class to the new class it is closest to in value	1	3	5	6	6	7	7	7







Colaba Mumbai original Image

Colaba Mumbai equalized & filtered image.

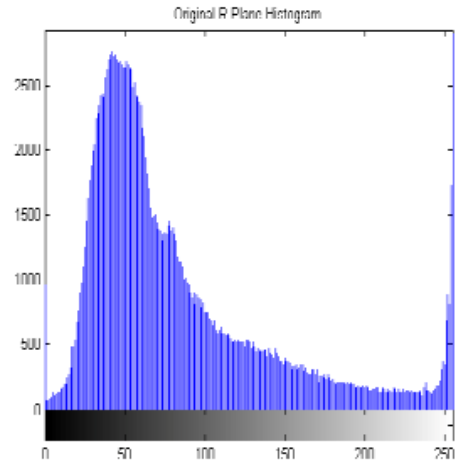


Fig.2(A)R- component of original Image of

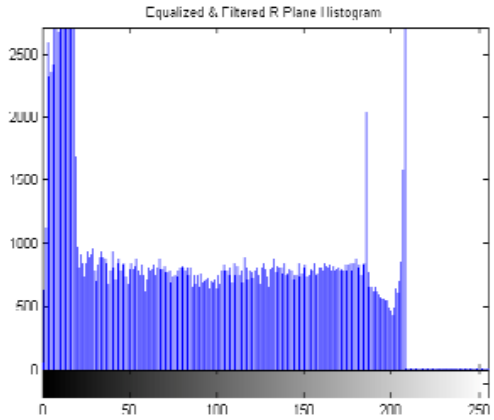
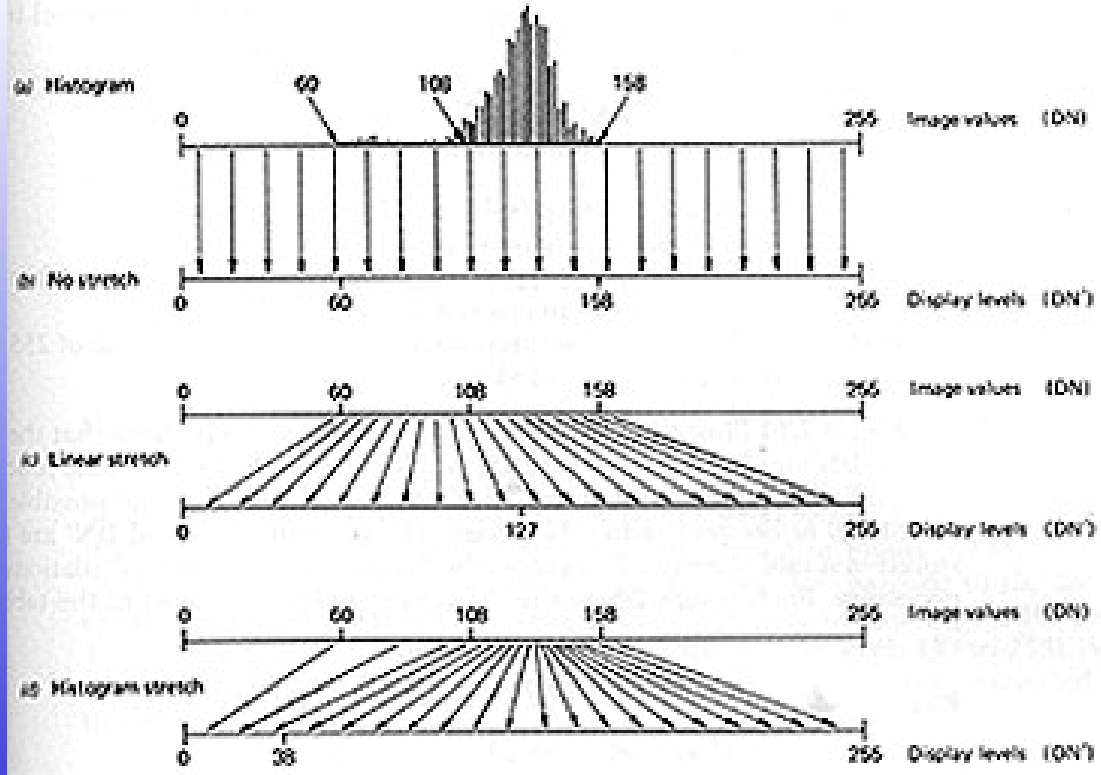
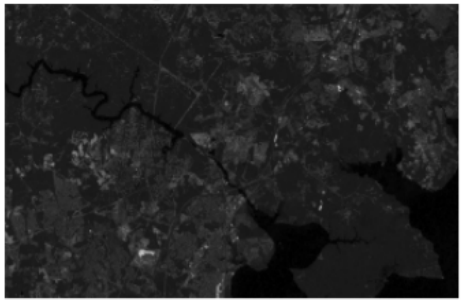
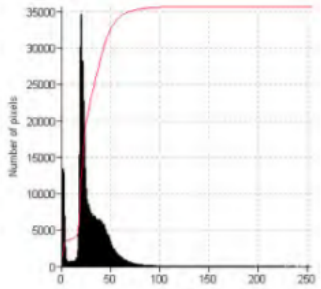


Fig.3(B)R- component equalized & filtered Image of colaba.

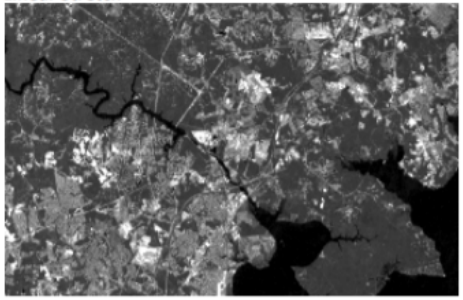


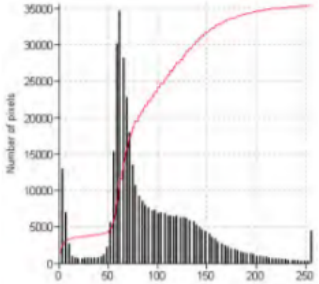
Un-stretched Image



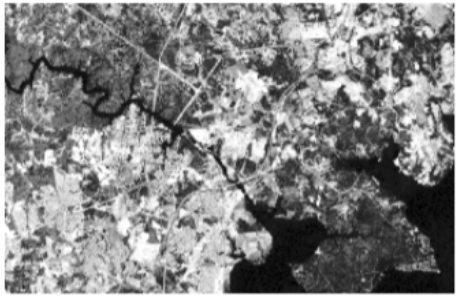


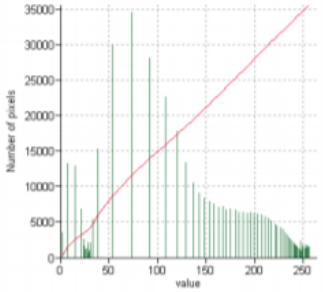
Linear Stretch





Histogram Equalization Stretch

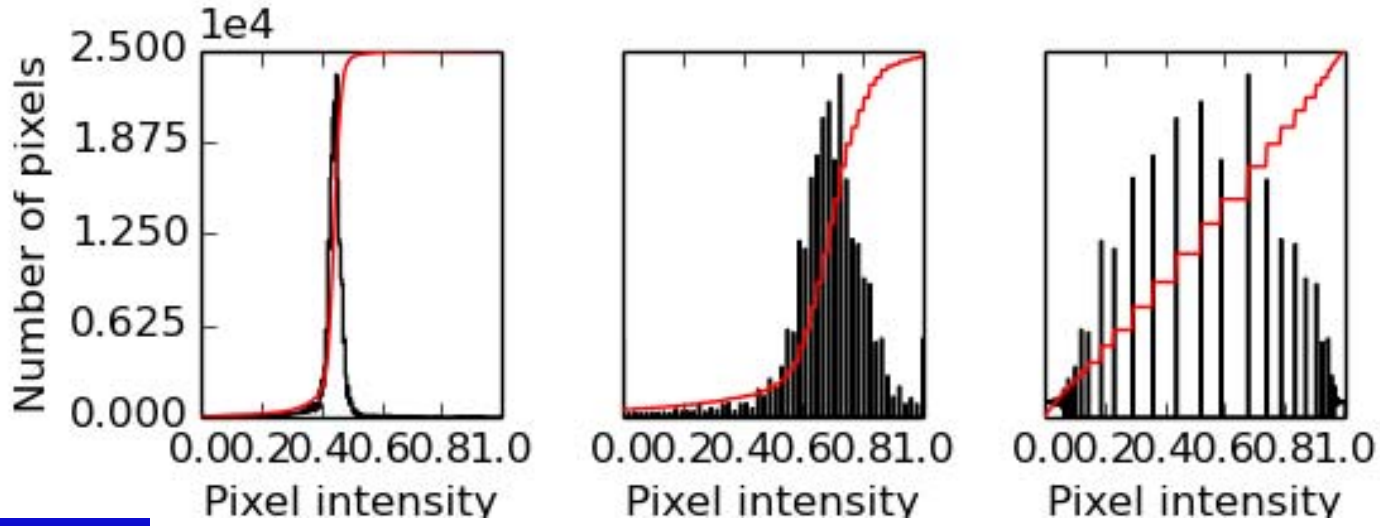


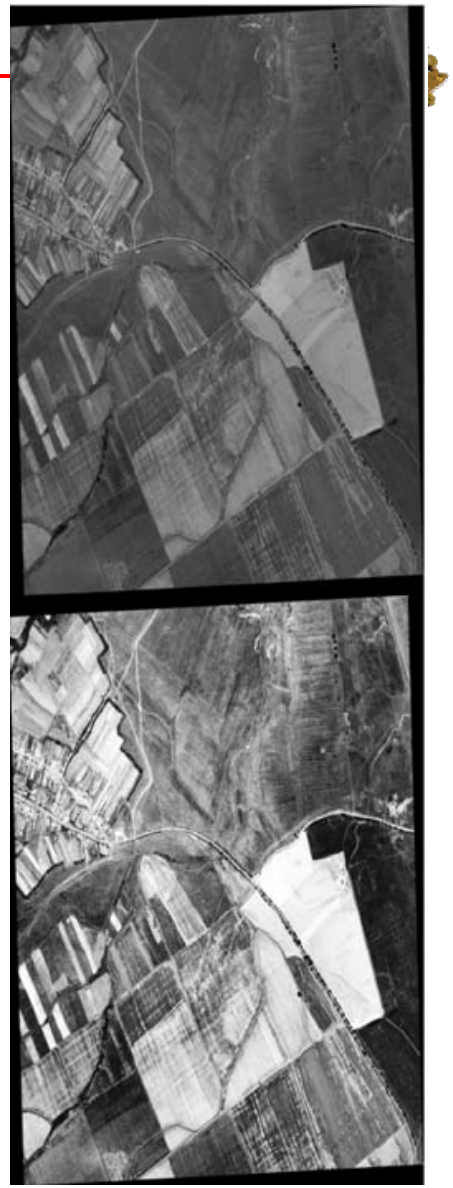


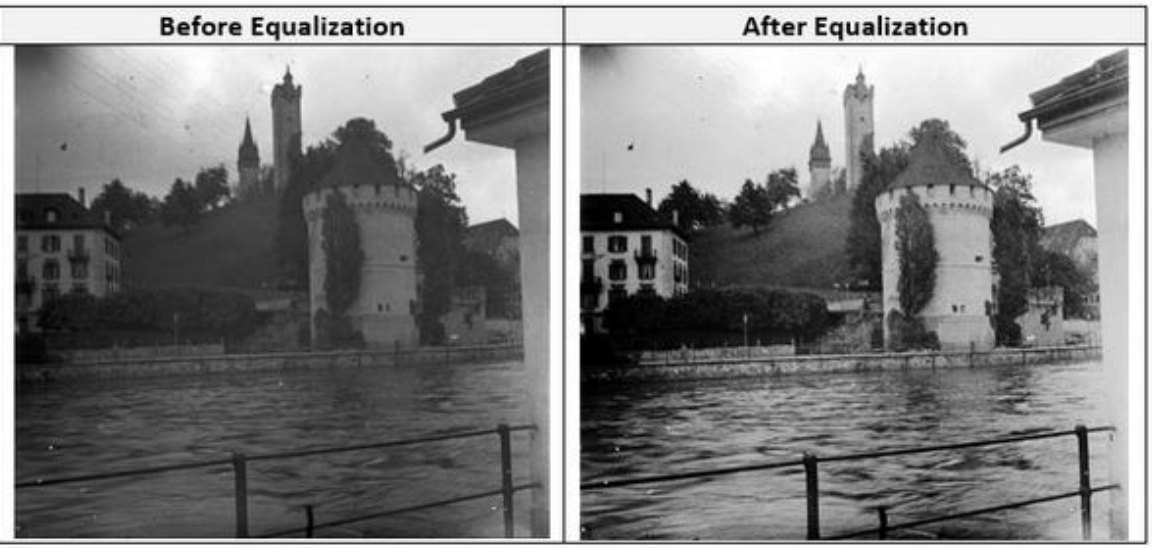
Low Contrast Image

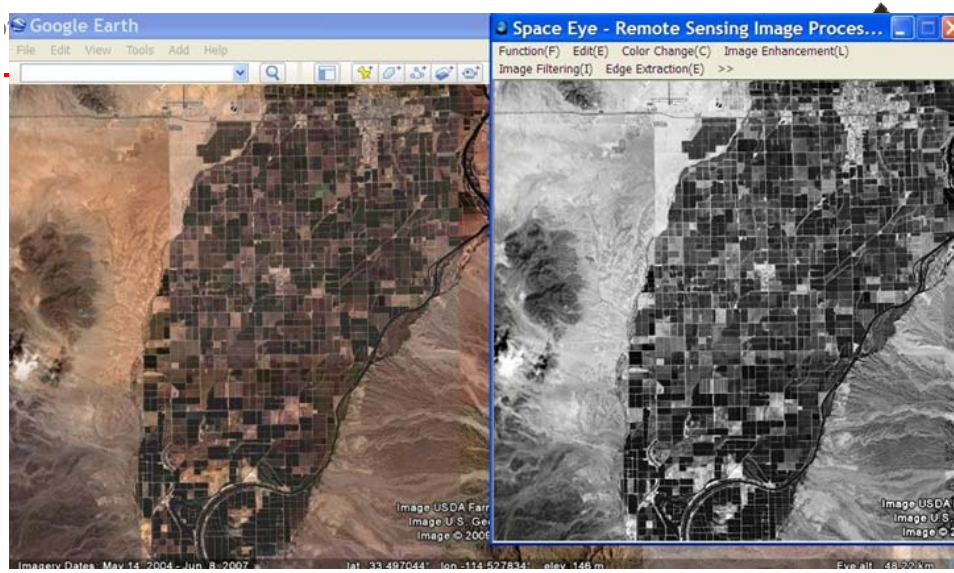
Contrast Stretching

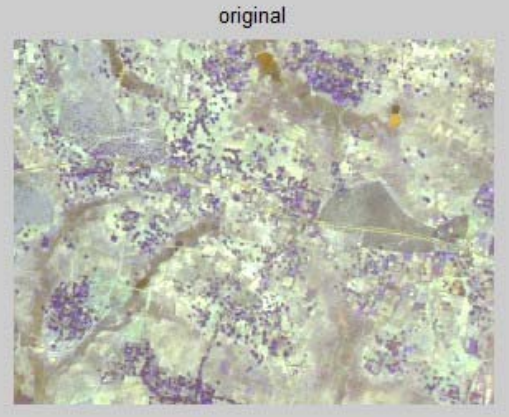
Histogram Equalization

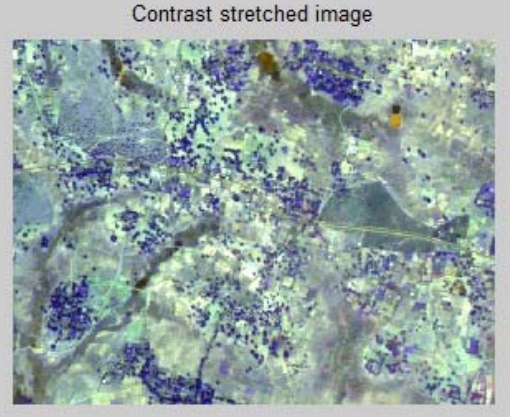




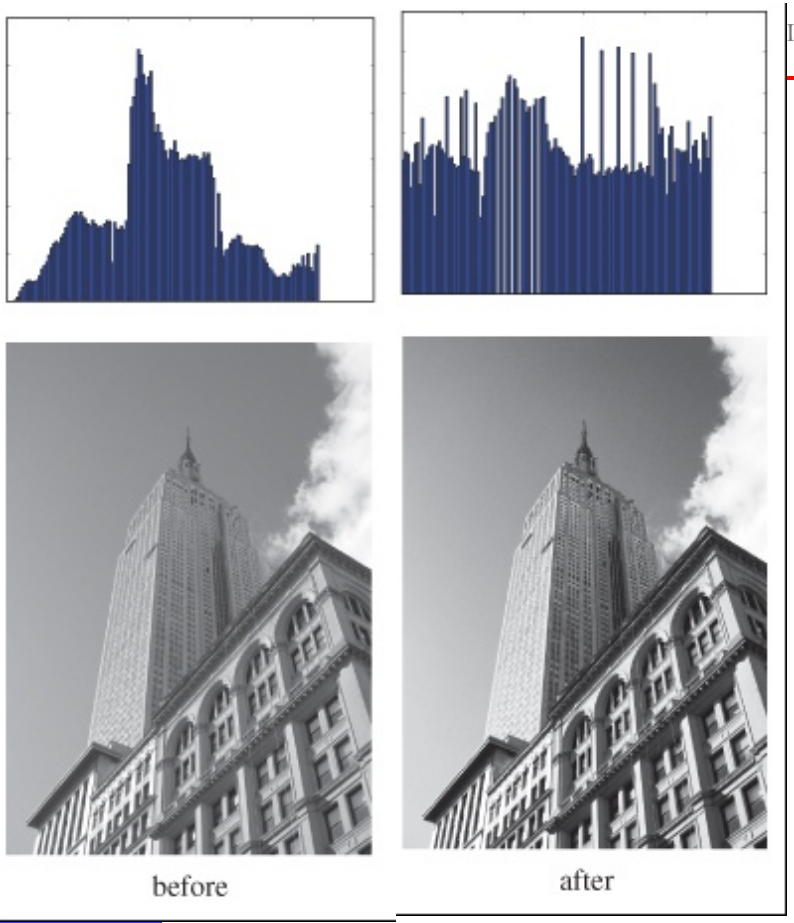

Before Equalization
After Equalization

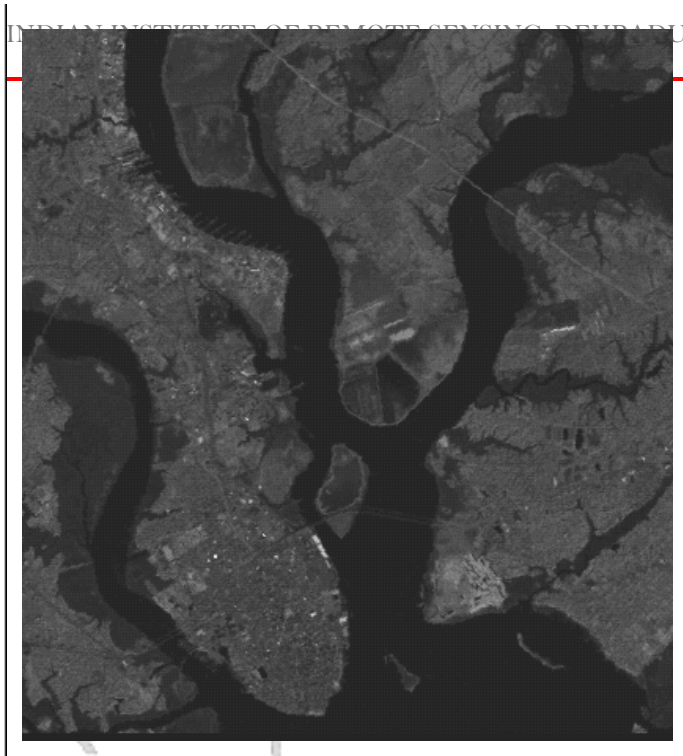

Google Earth
Space Eye - Remote Sensing Image Proces...
Function(F) Edit(E) Color Change(C) Image Enhancement(L)
Image Filtering(I) Edge Extraction(E) >>

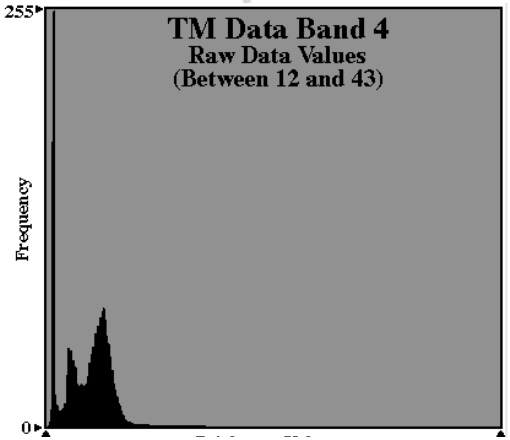

original

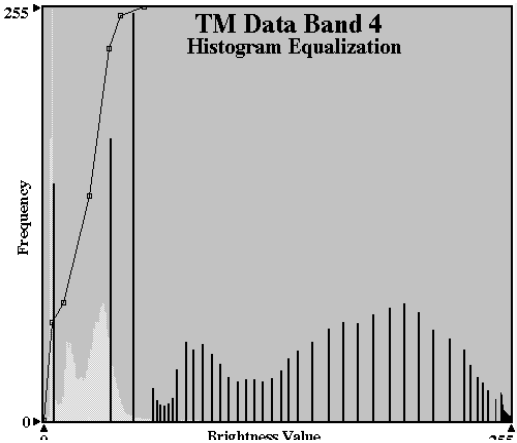

Contrast stretched image


sharpened image

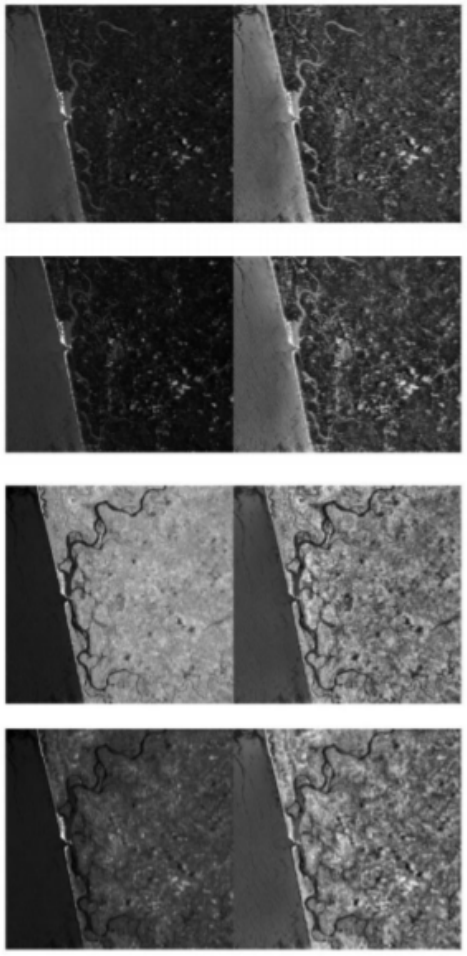

before
after



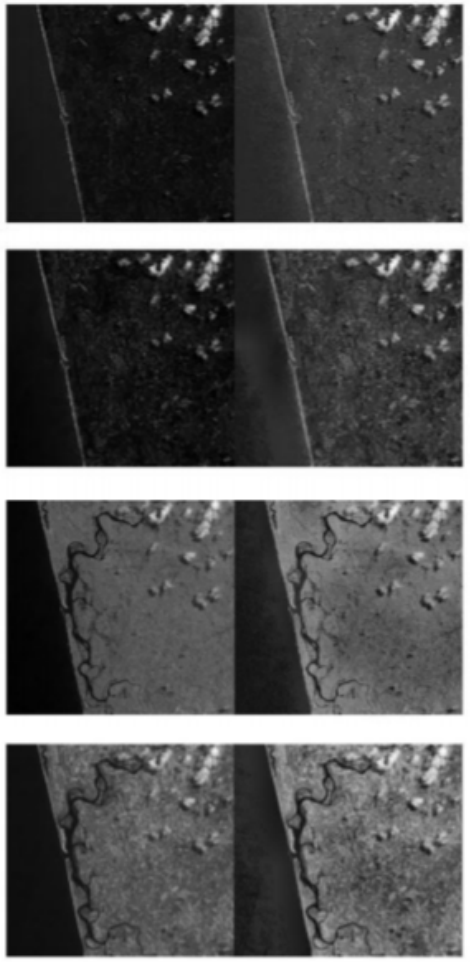

TM Data Band 4
Raw Data Values
(Between 12 and 43)
255
0
Frequency


TM Data Band 4
Histogram Equalization
255
0
Frequency
Brightness Value

Original and enhanced images of the study area in Landsat 8 OLI in (a) Green, (b)Red, (c) NIR, and (d) SWIR bands



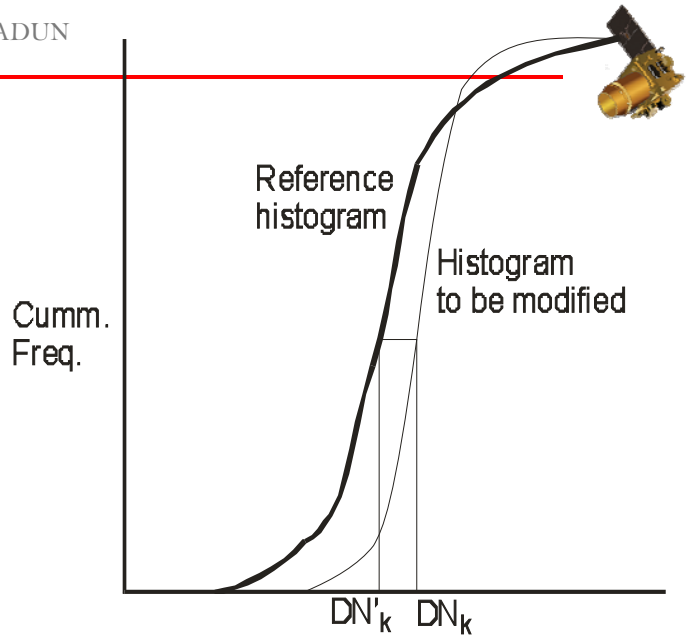
Original and enhanced images of the study area in Sentinel 2A MSI in (a) Green, (b)Red, (c) NIR, and (d) SWIR bands



Vidhya, G. R., & Ramesh, H. (2017)

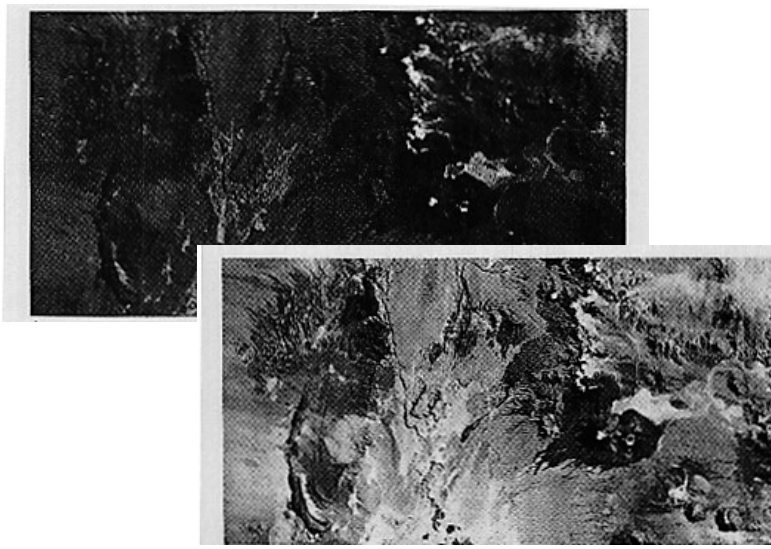
Histogram Matching

- In histogram matching we are trying to manipulate the pixel values of one image into the same pixel distribution as another image.
- The method requires that both images have the same number of pixels.
- Cumulative frequency histogram of the image and reference image is computed.
- Look Up table of (DN_k,DN'_K) is created and is applied on the input image



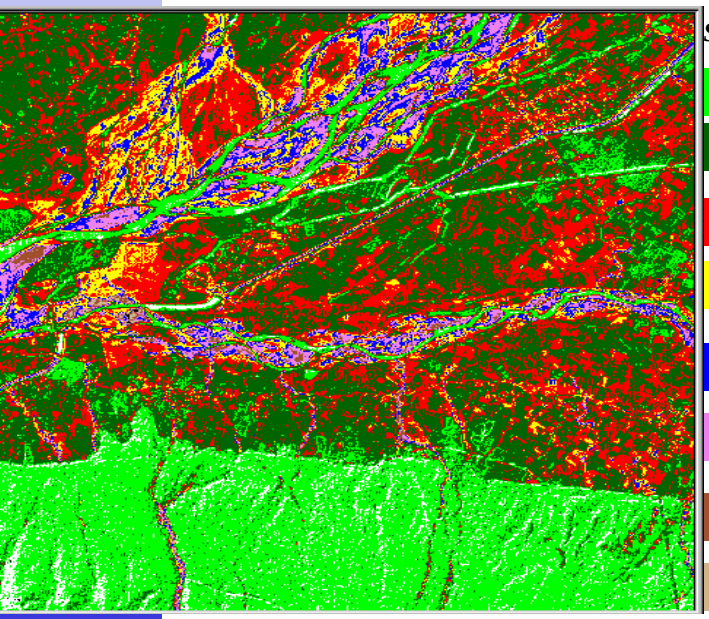
Gaussian Stretch

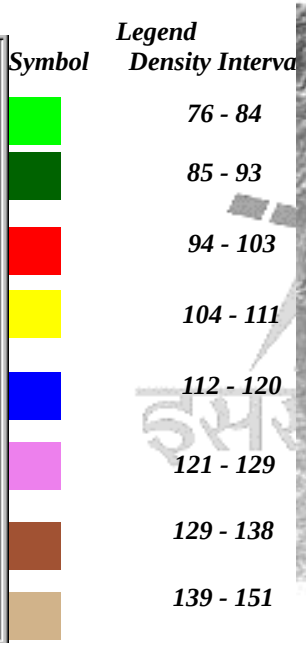
- Stretching based on histogram of pixel values
- involves fitting of observed histogram to a norma or Gaussian histogram
- highlight the tail parts of the histogram



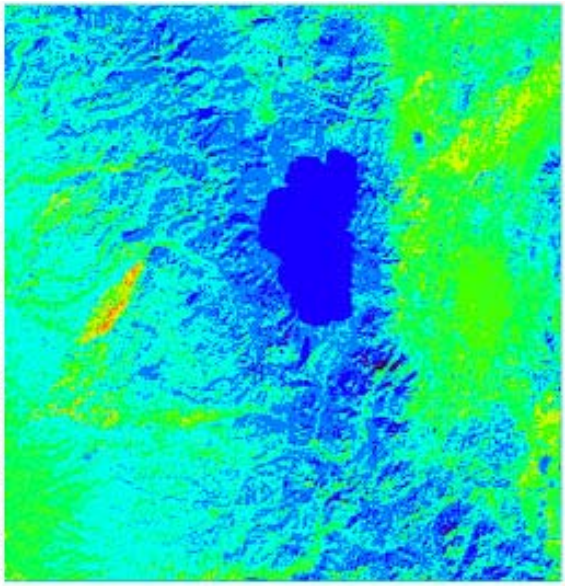
Density Slicing

Density slicing is a technique that converts the continuous gray tone of an image into a series of density intervals, or slices, each corresponding to a specified digital range. Each slice is displayed in a separate colour.

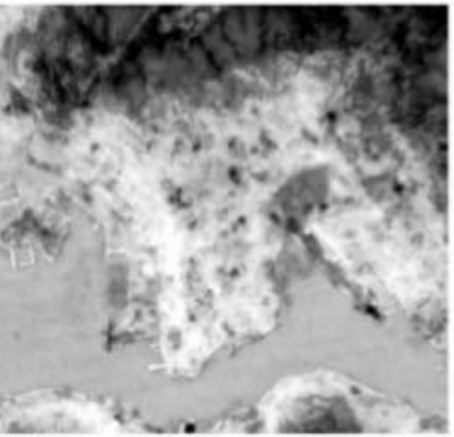


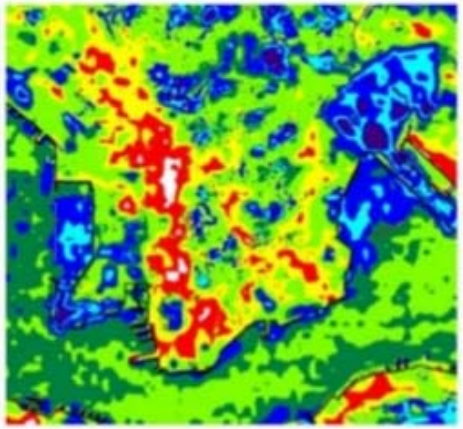


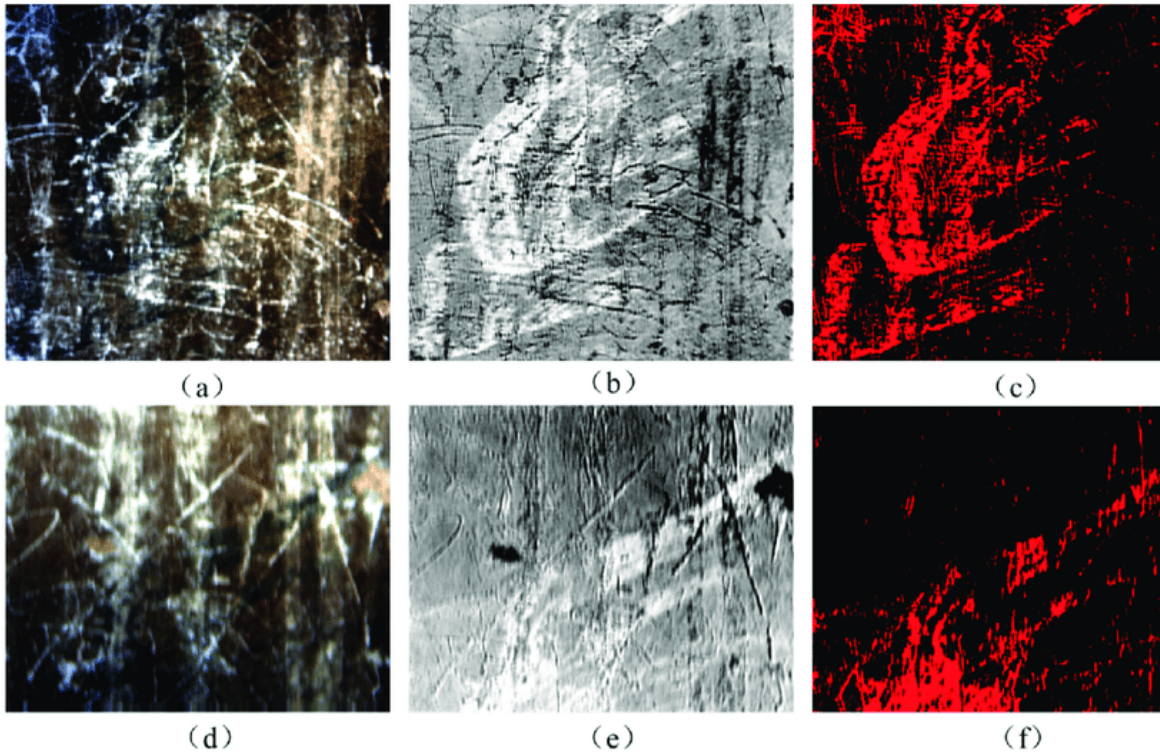
Original Greyscale Thermal Image



Thermal Imagewith Denisty Slice Applied





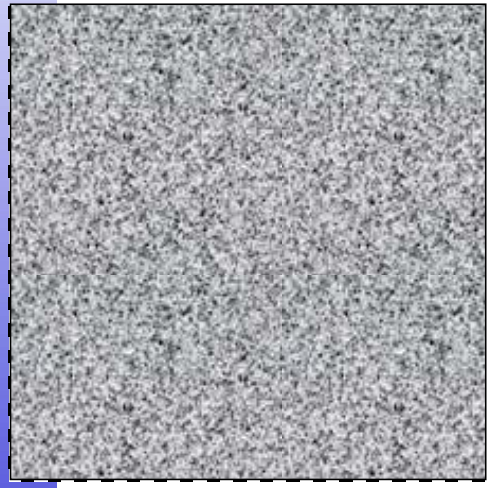


Density Slice for surface Temperature Visualization

The extraction of the hidden information using density slicing: (a) Color image of area 1 (synthesized from original hyperspectral images); (b) the DN value of area 1 is transformed to start from 0 and the pattern is highlighted in white; (c) the pattern of area 1 is extracted by density slicing with threshold of 7.95; (d) color image of area 2; (e) the DN value of area 2 is transformed to start from 0 and the pattern is highlighted in white; (f) the pattern of area 2 is extracted by density slicing, with a threshold of 6.55.
Source publication

Spatial frequencies

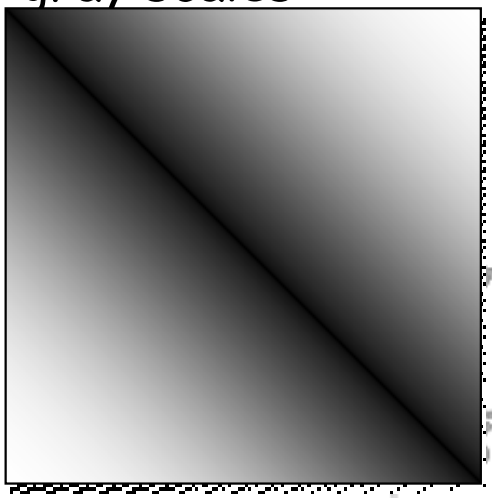
Radical variation in gray scale



"Rough" textured areas of an image, where the changes in tone are abrupt over a small area, have high spatial frequencies,

High Spatial Frequency

Slowly varying changes in gray scales



"smooth" areas with little variation in tone over several pixels, have low spatial frequencies

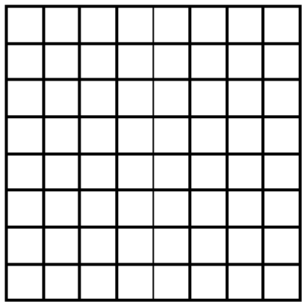
Low Spatial Frequency

Numbers of changes in the brightness values per unit distance for any particular part of the image

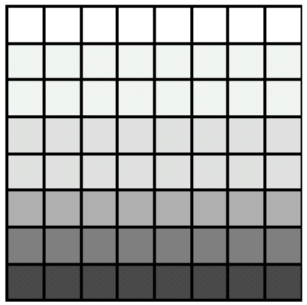
Image Composed of

Low Frequency Details: Few changes in brightness value over a given area

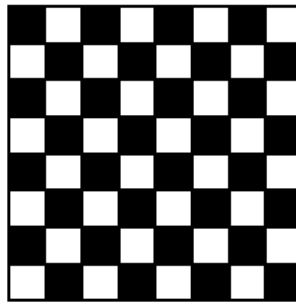
High Frequency Details: Brightness values change dramatically over short distances



zero spatial frequency

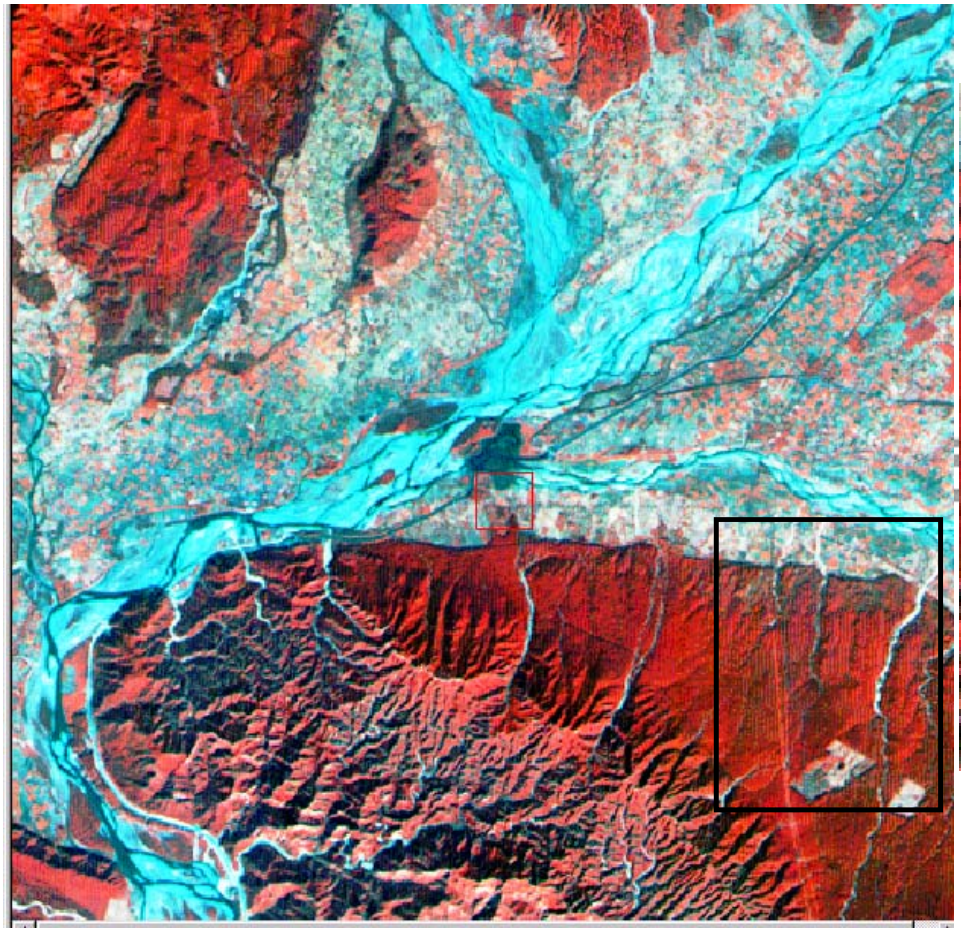


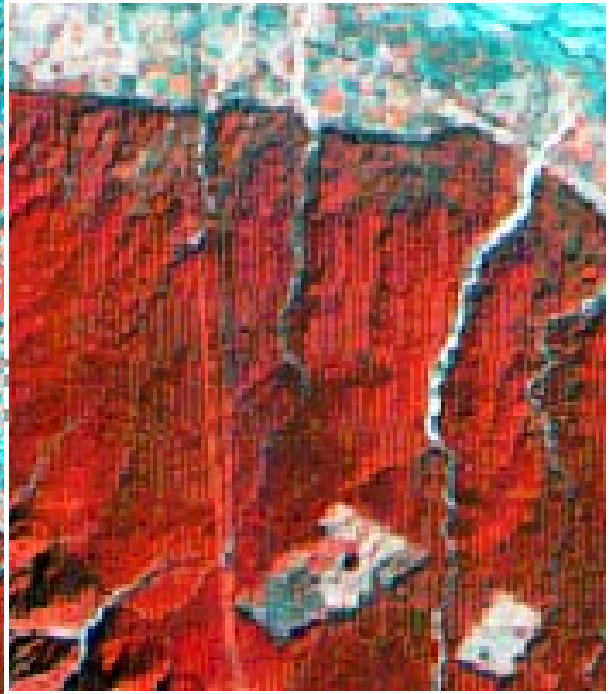
low spatial frequency



high spatial frequency

Where are the low and high frequencies ?





Spatial Filtering

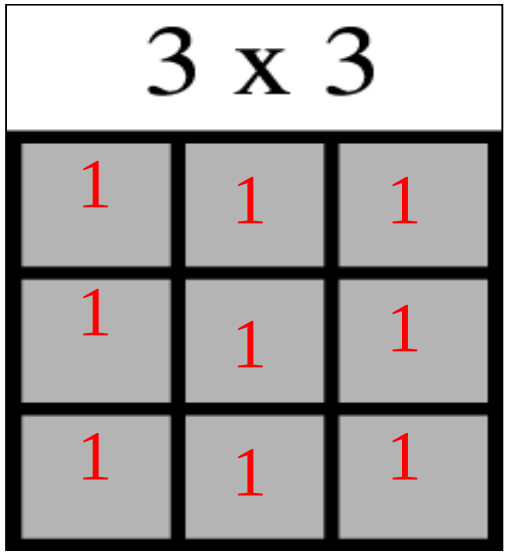
- Spatial Filtering is the process of dividing the image into its constituent spatial frequencies, and selectively altering certain spatial frequencies to emphasize some image features.
- Process of suppressing (de-emphasizing) certain frequencies & passing (emphasizing) others. Increases the analyst's ability to discriminate detail.
- Local operation i.e. pixel value is modified based on the values surrounding it.
- used for enhancing certain features, removal of noise and Smoothening of image

Filters

- are Algorithms for filtering
- Composed of
  - Window mask /Kernal / Convolution mask and
  - Constants (Weights given to mask)
- Mask size 3x3, 5x5, 7x7, 9x9.....

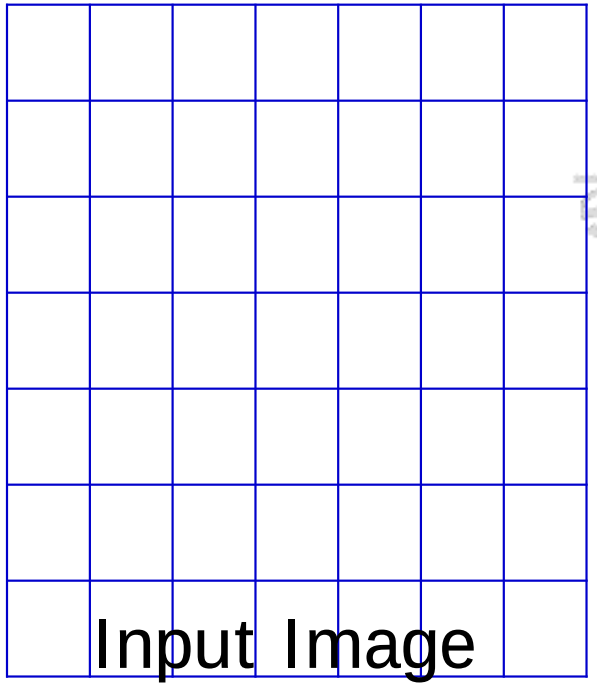
ex. Square mask

1	1	1
1	1	1
1	1	1



Convolution (Filtering)

- Brightness value (*BVi,j,out*) at location *i,j* in the output image is a function of some weighted average of brightness values located in a particular spatial pattern around the *i,j* location in the input image.
- Process of evaluating the weighted neighbouring pixel values located in a particular spatial pattern around the i,j, location in input image.

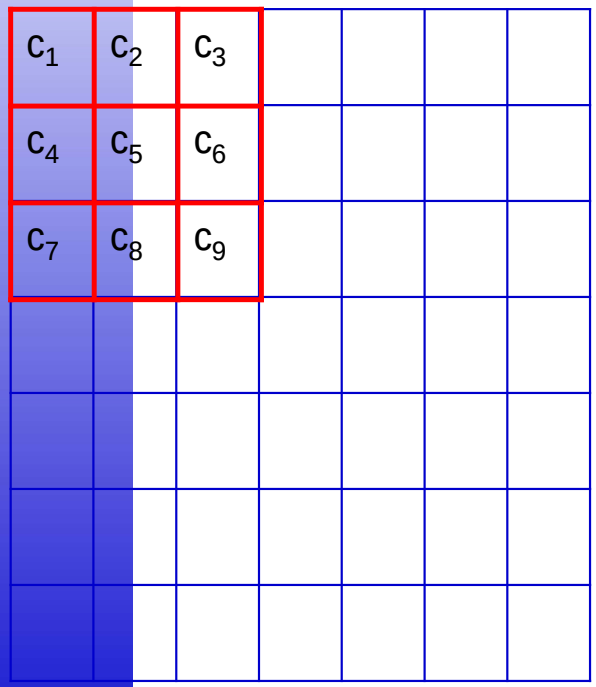


c_1	c_2	c_3
c_4	c_5	c_6
c_7	c_8	c_9

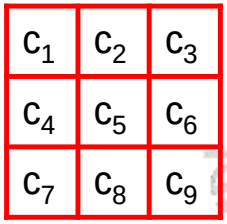
Filter

Convolution Process

Step 1 : Window mask is placed over part of Image

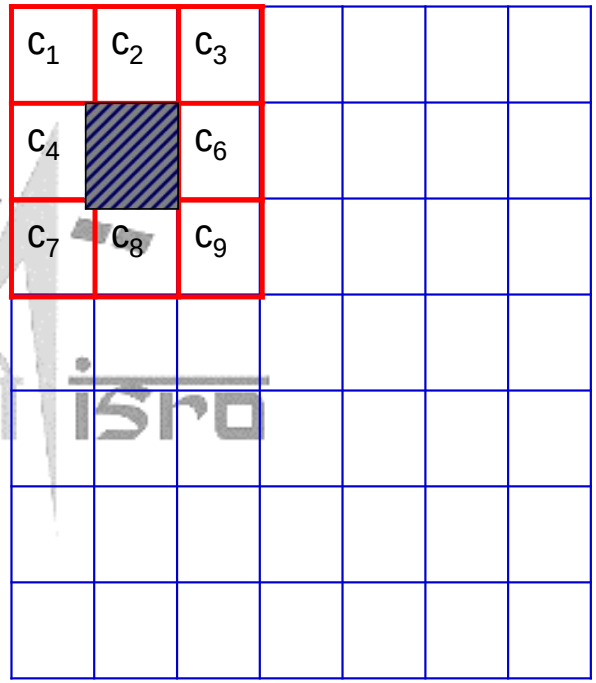


Input Image



Filter

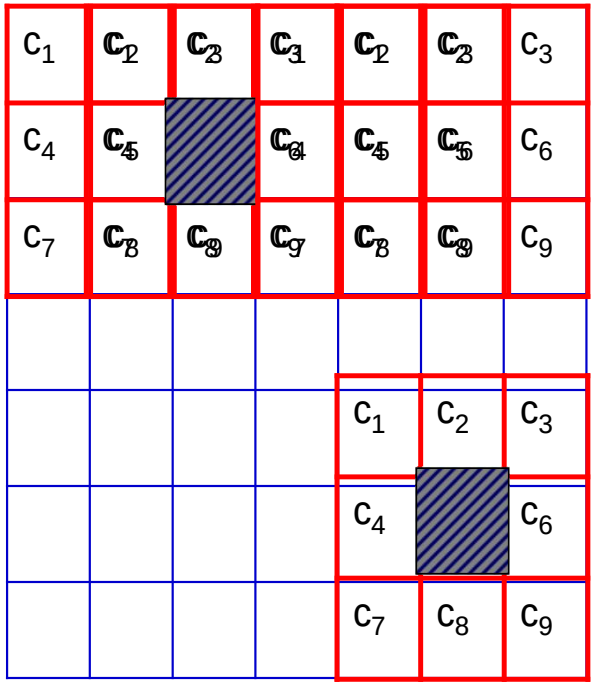
Step 2 : Central Pixel values is calculated based on its neighbouring values



C_1 BV_1	C_2 BV_2	C_3 BV_3
C_4 BV_4	C_5 BV_5	C_6 BV_6
C_7 BV_7	C_8 BV_8	C_9 BV_9

$$BV_{5,\,out} = (C_1 * BV_1 + C_2 * BV_2 + C_3 * BV_3 + C4 * BV_4 + C_5 * BV_5 + C_6 * BV_6 + C_7 * BV_7 + C_8 * BV_8 + C_1 * BV_9)$$

Convolution Process



Input Image

Step 3: Central Pixel Value is replaced by the new value and window is shifted by one pixel to the right and the entire process is repeated

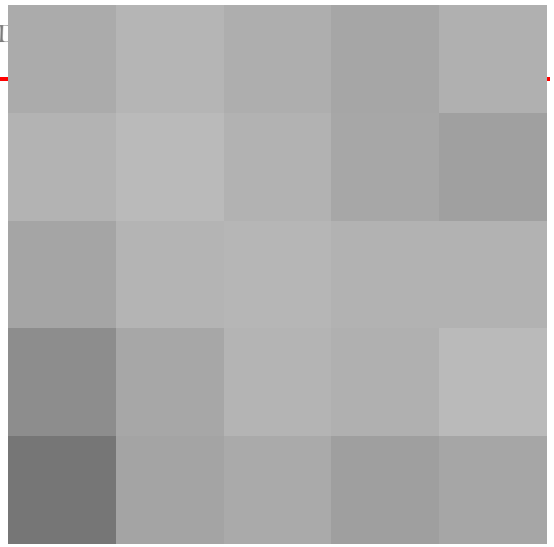
The coefficients, c_1, in the mask are multiplied by the following individual brightness values (BV_i) in the input image:

Mask template =

$$\begin{matrix} c_1 x\, BV_1 & c_2 x\, BV_2 & c_3 x\, BV_3 \\ c_4 x\, BV_4 & c_5 x\, BV_5 & c_6 x\, BV_6 \\ c_7 x\, BV_7 & c_8 x\, BV_8 & c_9 x\, BV_9 \end{matrix}$$

The primary input pixel under investigation at any one time is $BV_5 = BV_{i,j}$

164	188	164	161	195
178	201	197	150	137
174	168	181	190	184
131	179	176	185	198
92	185	179	133	167



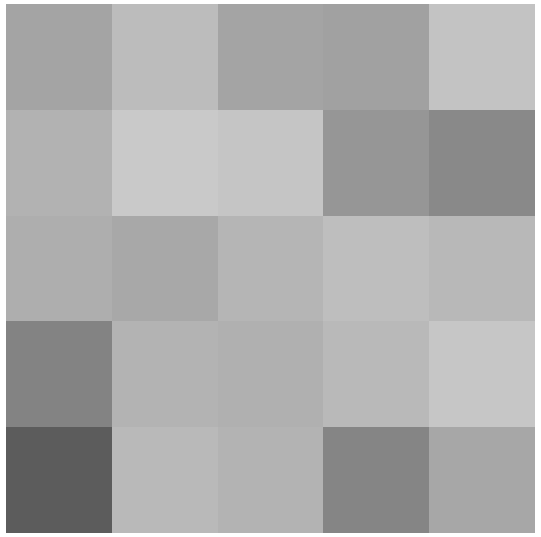
Before Filtering

Window mask

0 1 0
1 1 1
0 1 0

0*164	1*188	0*164	161	195
1*178	1*201	1*197	150	137
0*174	1*168	0*181	190	184
131	179	176	185	198
92	185	179	133	167

$BV_{5, out}$ = 932 / 5 = 186



After filtering

Filter Types

- Low Pass Filters
  - block high frequency details
  - has a smoothening effect on images.
  - Used for removal of noise
  - Removal of “salt & pepper” noise
  - Blurring of image especially at edges.

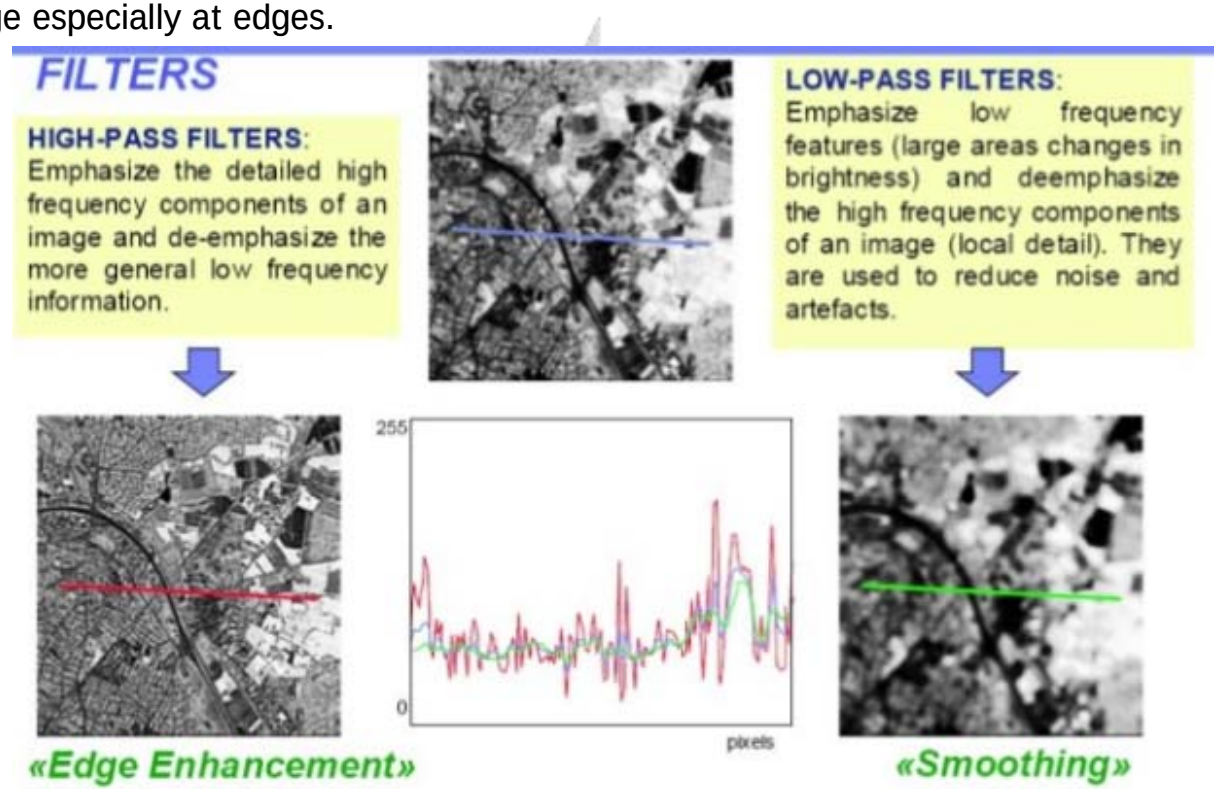
High Pass Filters

Preserves high frequencies and Removes slowly varying components

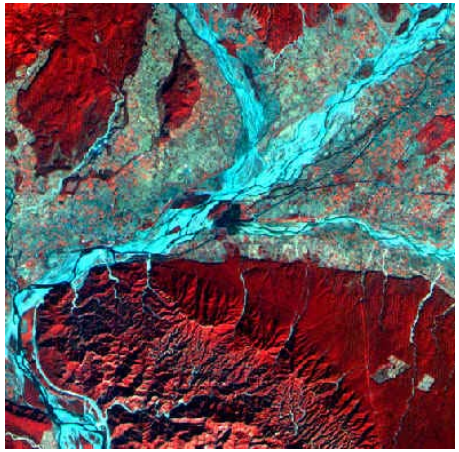
Emphasizes fine details

Used for edge detection and enhancement

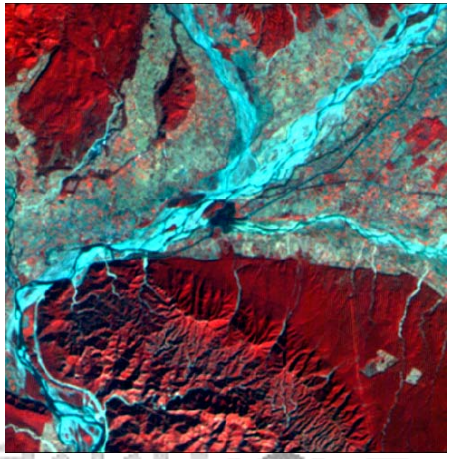
Edges - Locations where transition from one category to other occurs



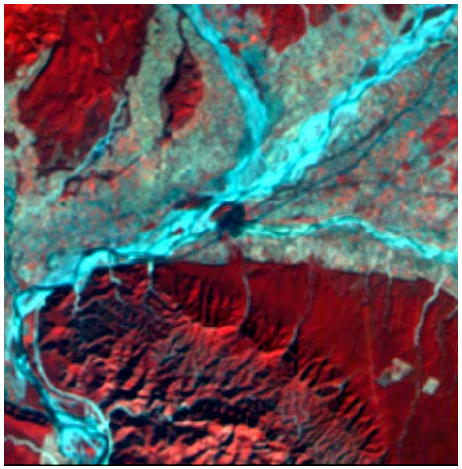
Low Pass Filters- Mean filter



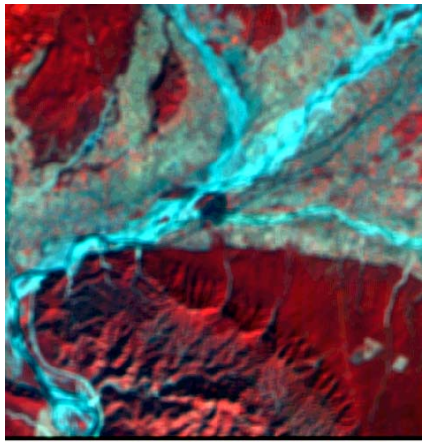
FCC



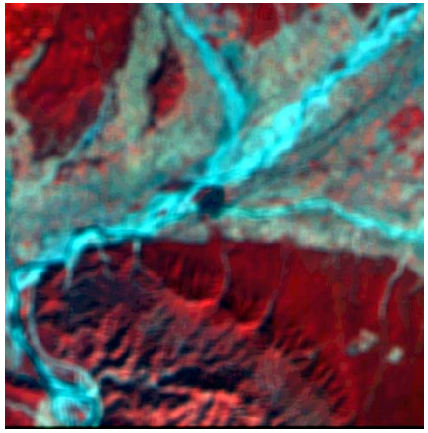
3 x 3



5x5

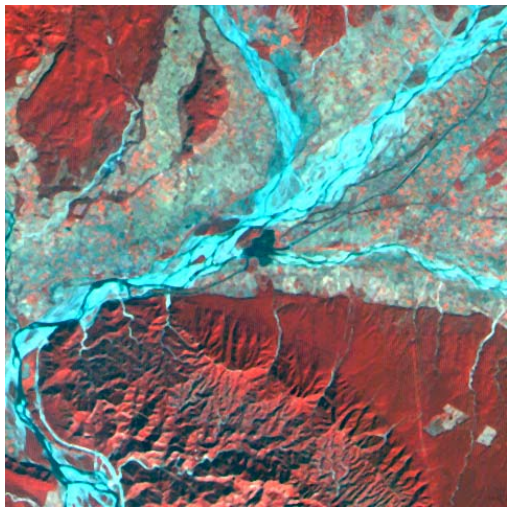


7x7

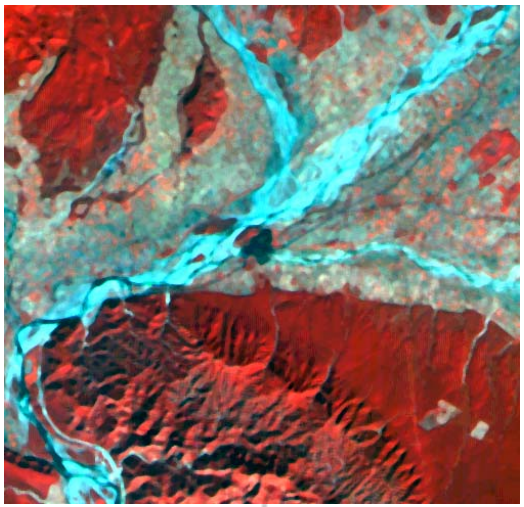


9x9

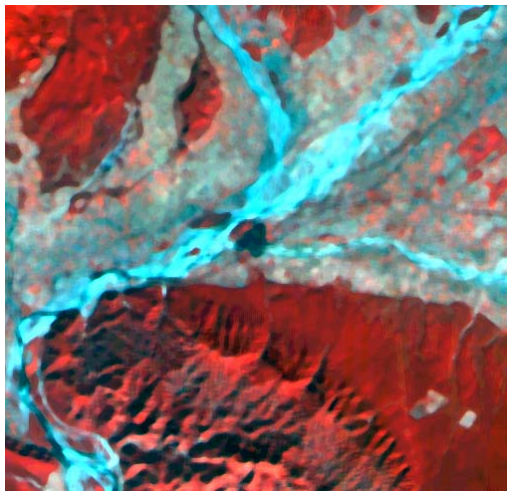
Low Pass – Median Filter



3x3

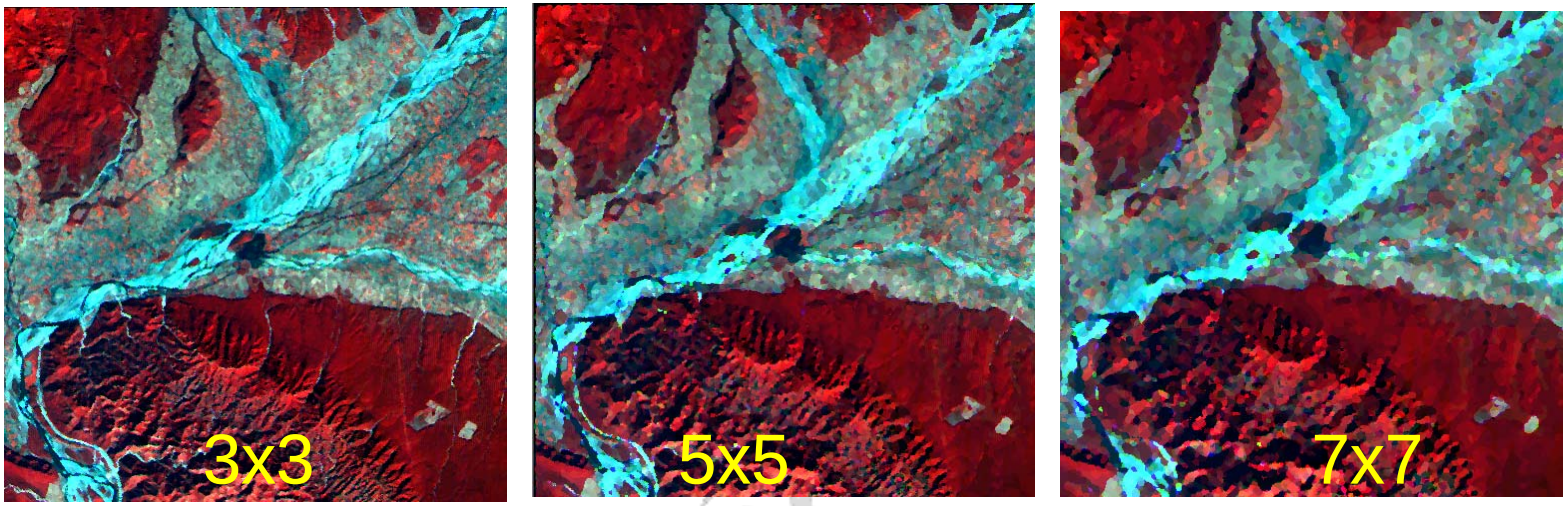


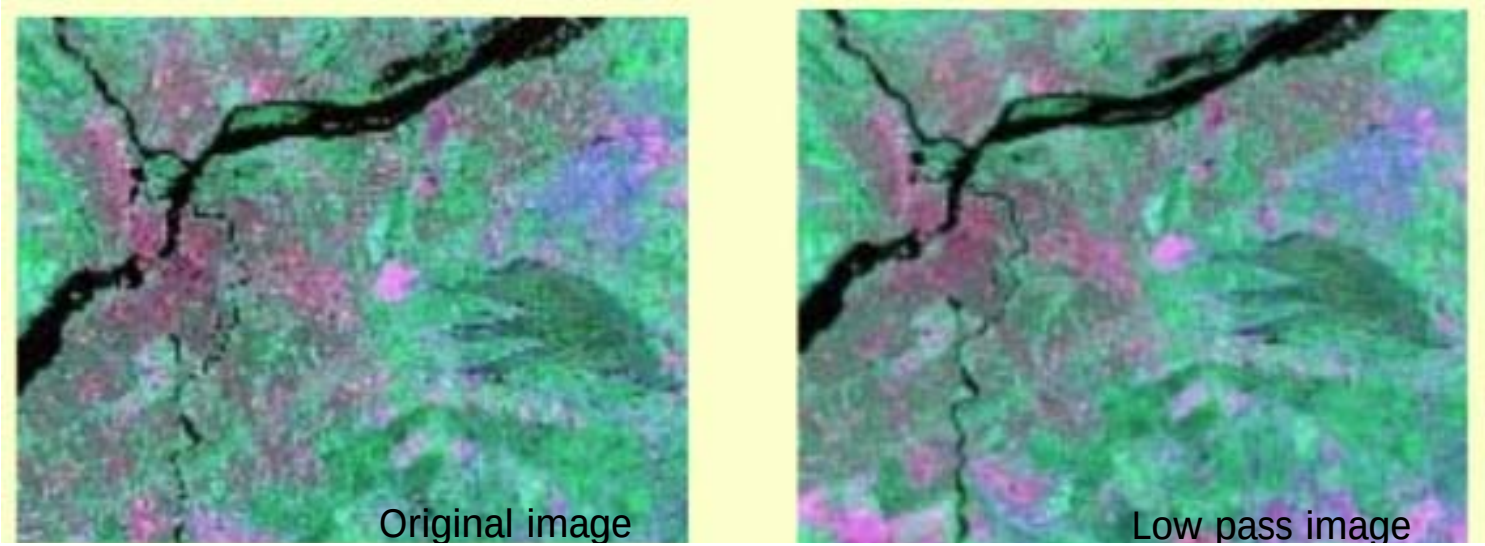
5x5

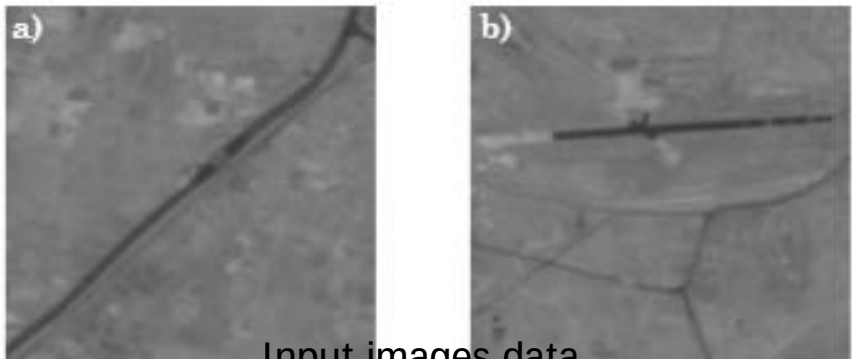


7x7

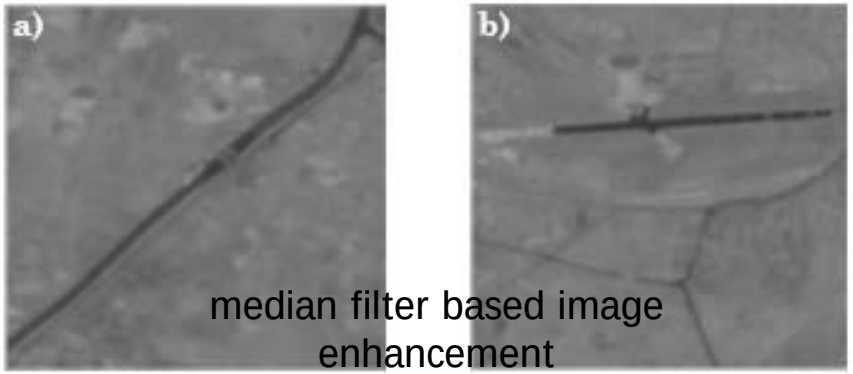
Low Pass Filters - Mode





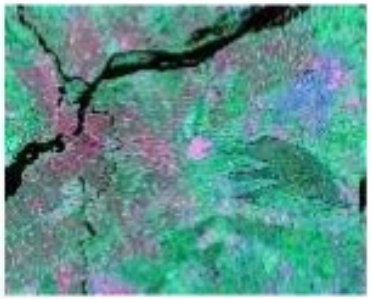


Input images data

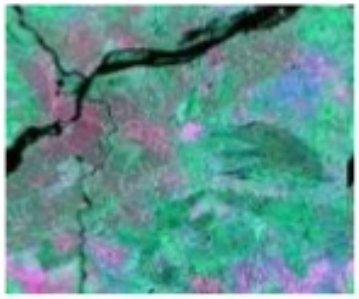


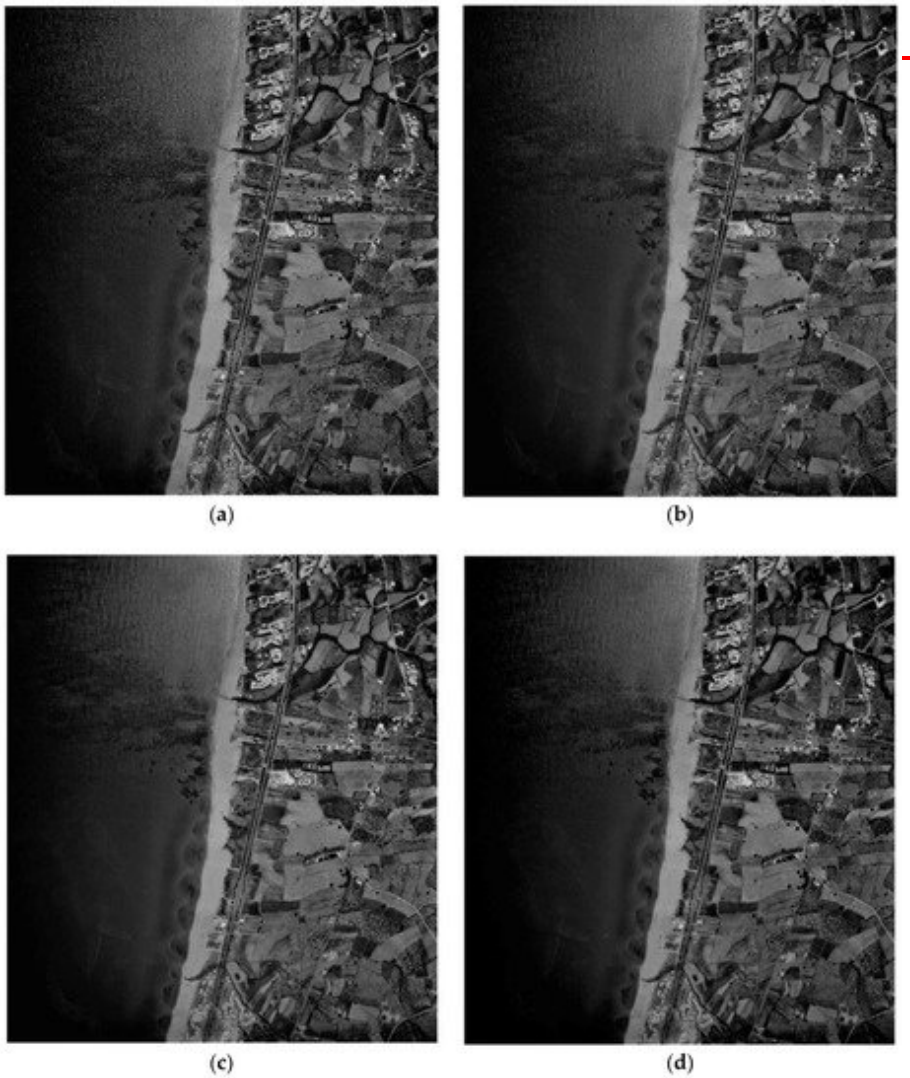
median filter based image enhancement

Linear Stretched Image



Low-pass Filter Image





Filtering effect: (**a**) Initial image, (**b**–**d**) image after applying the Gaussian, Median, and Mean filters, respectively.

High Pass Filtering

Types

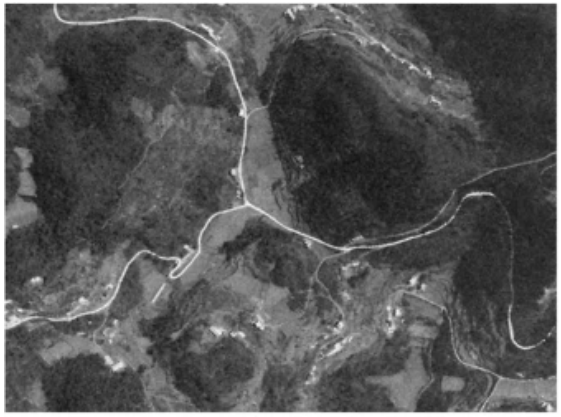
- Linear
  - output brightness value is a function of linear combination of BV's located in a particular spatial pattern around the i,j location in the input image
- Non Linear
  - use non linear combinations of pixels
- Edge Detection -Background is lost
- Edge Enhancement
  - Delineates Edges and makes the shapes and details more prominent
  - background is not lost.

Automated coastline extraction from aerial imagery. (**a**) Initial image, (**b**) filtered and enhanced image.

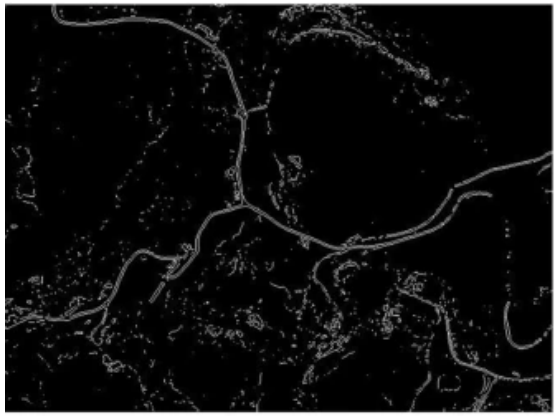
Edge Detection: Zero-Sum Kernels

- The sum of all coefficients in the kernel equals zero.
- This generally causes the output values to be:
  - zero in areas where all input values are equal (no edges)
  - low in areas of low spatial frequency
  - extreme in areas of high spatial frequency (high values become much higher, low values become much lower)
- an edge detector,
  - smoothes out or zeros out areas of low spatial frequency
  - creates a sharp contrast where spatial frequency is high
  - The resulting image often consists of only edges and zeros.
- Zero-sum kernels can be biased to detect edges in a particular direction.

-1	-1	-1
1	-2	1
1	1	1

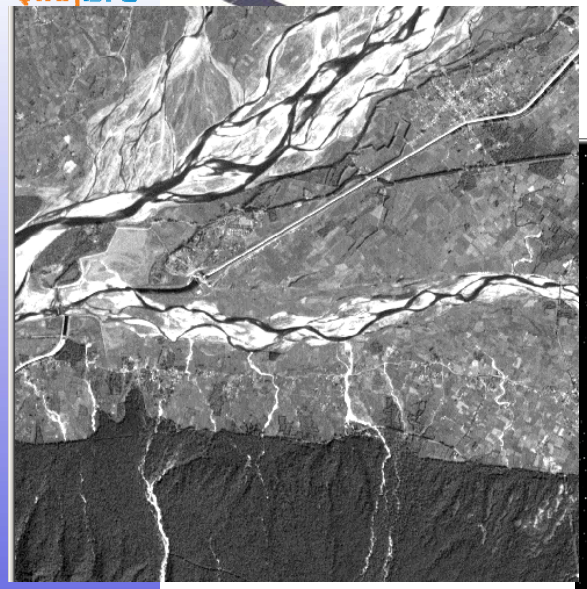


(a) Before edge detection

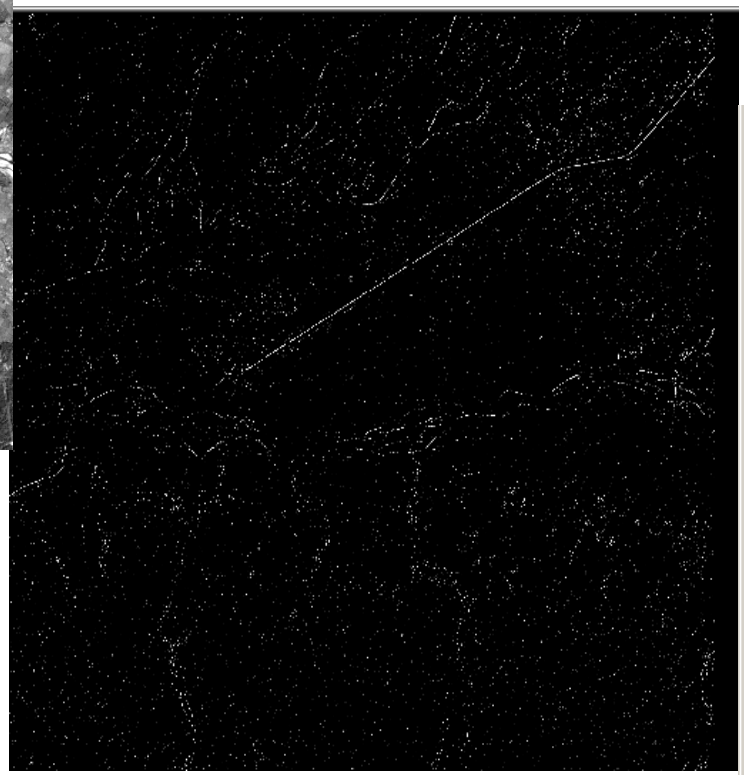


(b) After edge detection

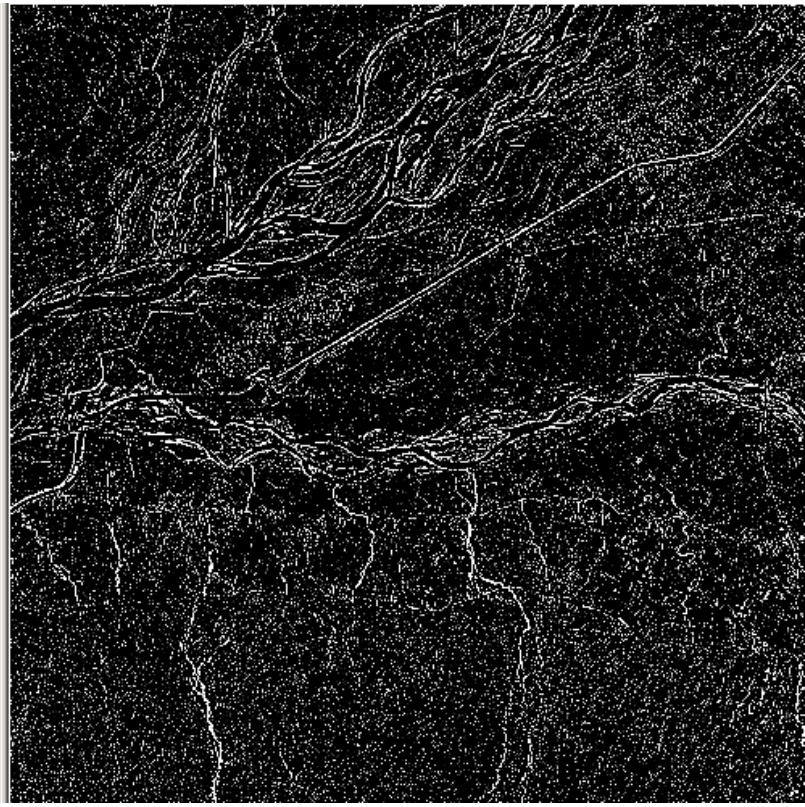
Edge Detection



Original image



3 x 3 Edge Detection



5x5 Edge Detection

Edge Enhancement

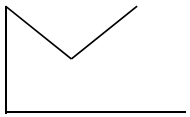
They highlight edges and do not necessarily eliminate other features. (The sum of coefficients of kernel is not zero)

-1	-1	-1
-1	16	-1
-1	-1	–1

When this kernel is used on a set of pixels in which a relatively low value is surrounded by higher values, like this…

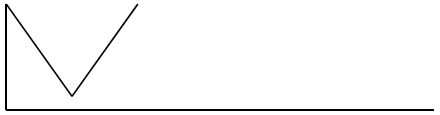
BEFORE

204	200	197
201	106	209
198	200	210



AFTER

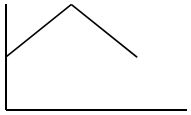
204	200	197
201	9	209
198	200	210



…**the low value gets lower. Inversely, when the kernel is used on a set of pixels in which a relatively high value is surrounded by lower values…**

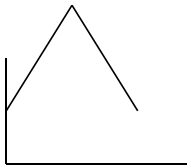
BEFORE

64	60	57
61	125	69
58	60	70



AFTER

64	60	57
61	187	69
58	60	70



…the high value becomes higher. In either case, spatial frequency is increased by this kernel.

Laplace Filter (Non Directional)

The *Laplacian* operator highlights point, line, and edges in the image and suppresses uniform and smoothly varying regions.

Laplace Edge Detectors

-1	-1	-1
-1	8	-1
-1	-1	-1

0	-1	0
-1	4	-1
0	-1	0

Laplace Edge Enhancement filter

-1	-1	-1
-1	16	-1
-1	-1	-1

0	-1	0
-1	5	-1
0	-1	0

Additional Edge Detector Masks

-1	-1	-1
2	2	2
-1	-1	-1

Horizontal

-1	-1	2
-1	2	-1
2	-1	-1

diagonal

-1	2	-1
-1	2	-1
-1	2	-1

vertical

- Designed to highlight linear features, such as roads or field boundaries.
- can enhance features are oriented in specific directions.

Non-linear Edge Enhancement : Sobel Operator

$$Sobel_{5,out} = \sqrt{X^2 + Y^2}$$

where

$$X = (BV_3 + 2BV_6 + BV_9) - (BV_1 + 2BV_4 + BV_7)$$

$$Y = (BV_1 + 2BV_2 + BV_3) - (BV_7 + 2BV_8 + BV_9)$$

3 x 3

1	2	3
4		6
7	8	9

X =

3 x 3

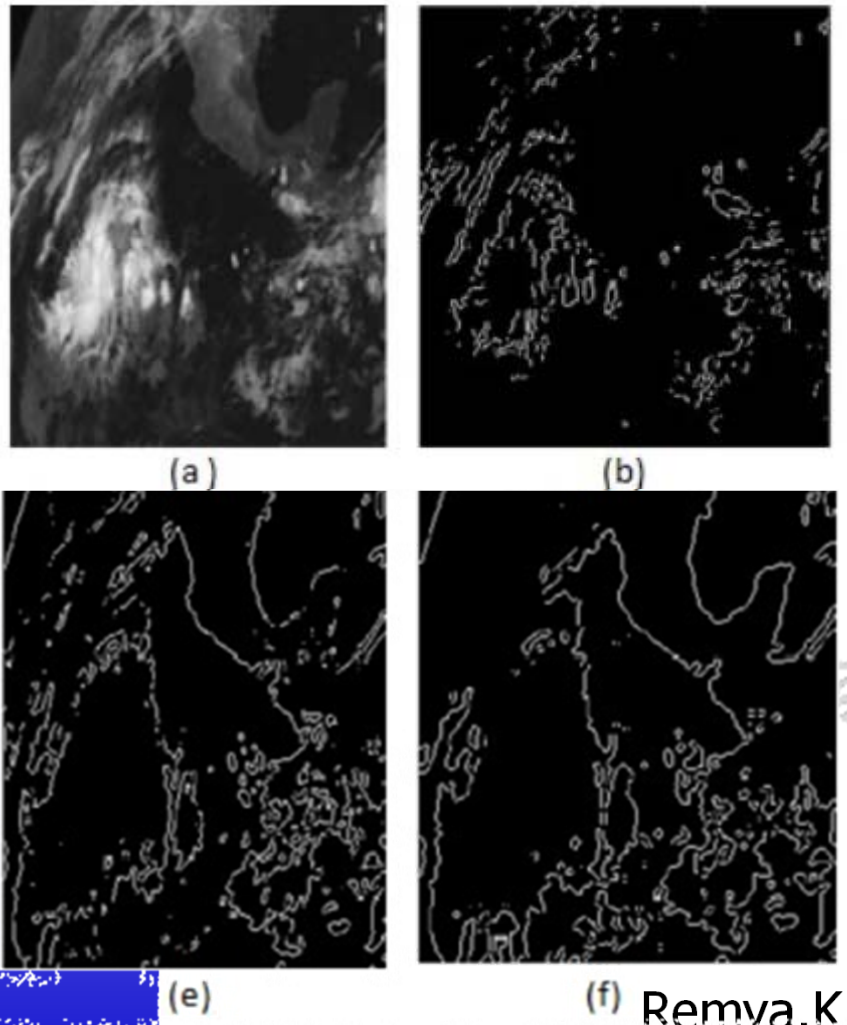
-1	0	1
-2	0	2
-1	0	1

Y =

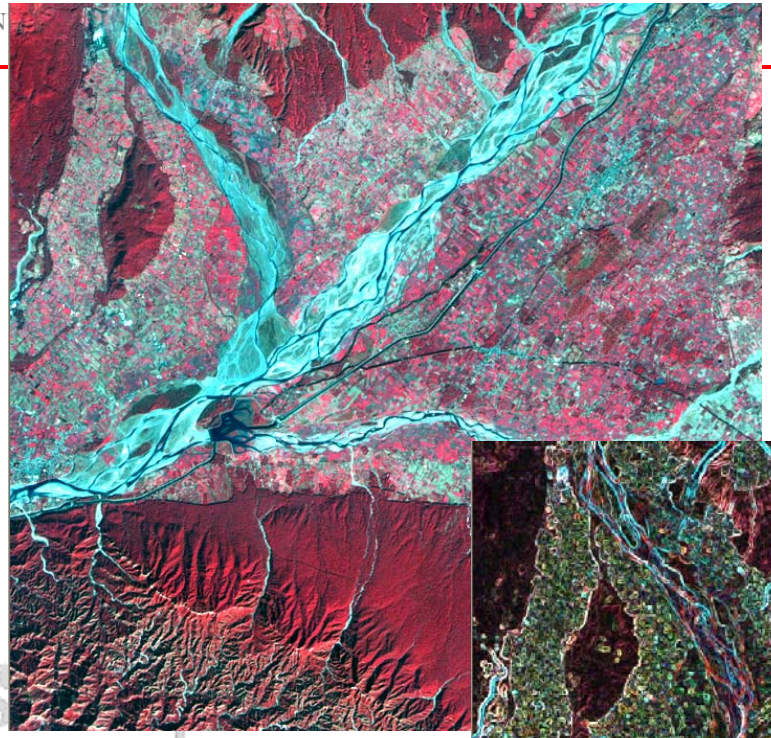
3 x 3

1	2	1
0	0	0
-1	-2	-1

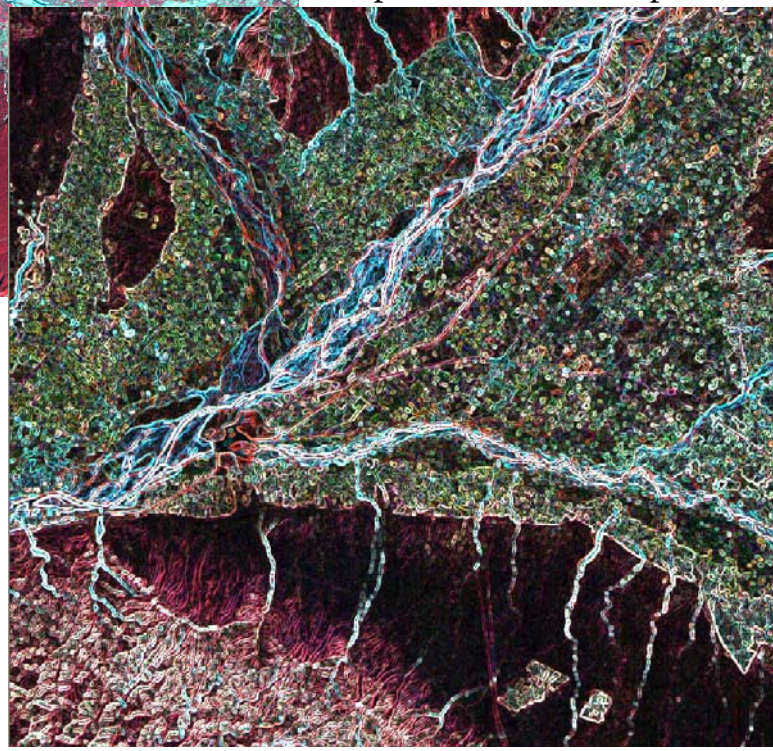
The *Sobel* operator may also be computed by simultaneously applying the following 3 x 3 templates across the image:



Original Image



Output from Sobel Operator



Remya.K.R et.al. (2013)

a)Low contrast remote sensed image, edges detected using sobel operator in (b) low contrast image e) contrast enhanced image using DW T based PCA, (f)contrast enhanced image using **Sobel** method.

Non-linear Edge Enhancement : Robert's Edge Detector

The Robert's edge detector is based on the use of only four elements of a 3 x 3 mask.

$$Roberts_{5,out} = X + Y$$

$$X = \left|BV_5 - BV_9\right|, Y = \left|BV_6 - BV_8\right|$$

The *Robert's Edge* operator may also be computed by simultaneously applying the following 3 x 3 templates across the image:

3 x 3

1	2	3
4	5	6
7	8	9

X =

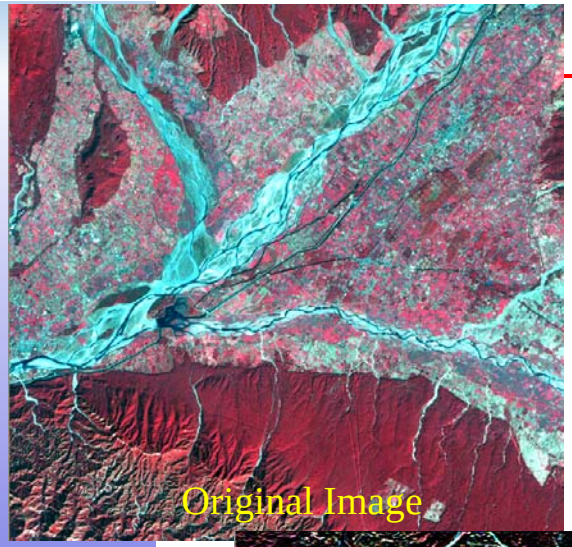
3 x 3

0	0	0
0	1	0
0	0	-1

Y =

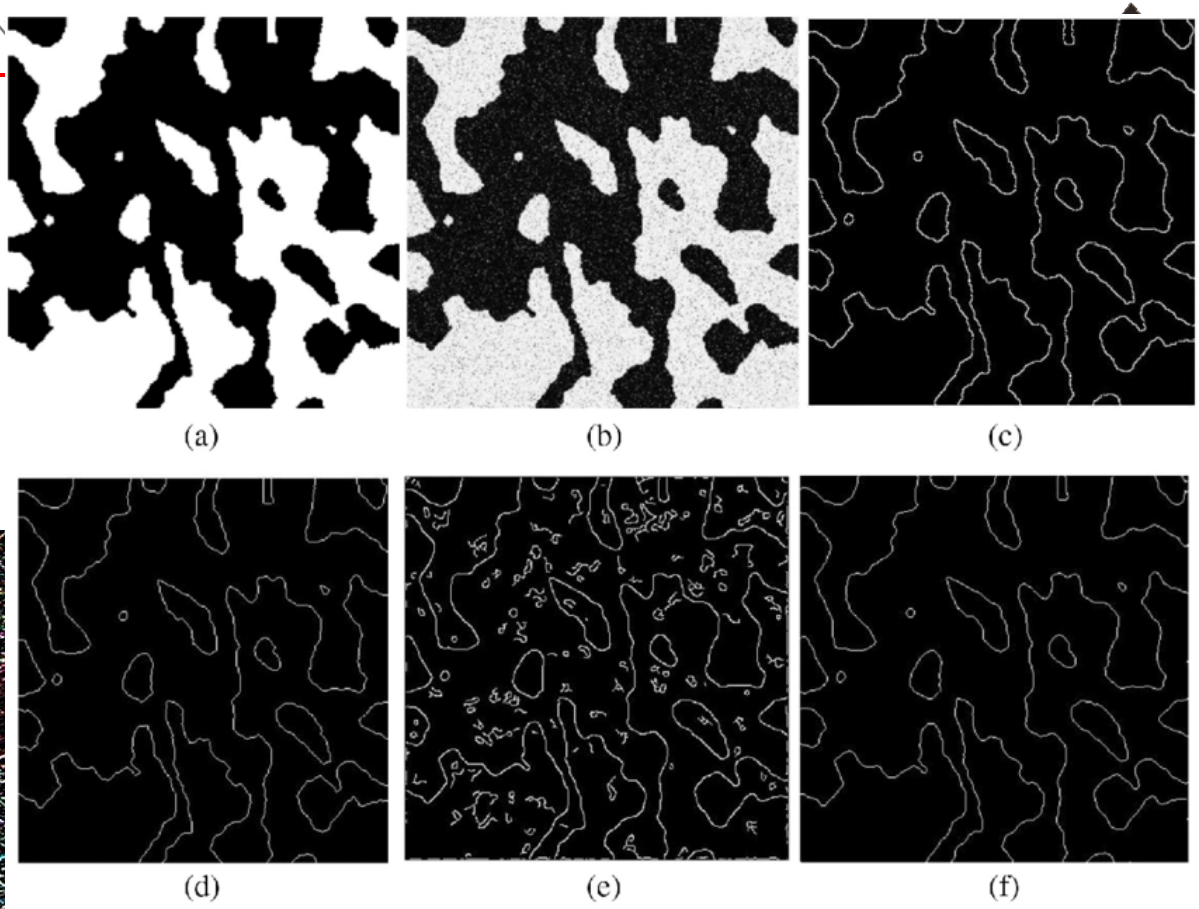
3 x 3

0	0	0
0	0	1
0	-1	0



Original Image

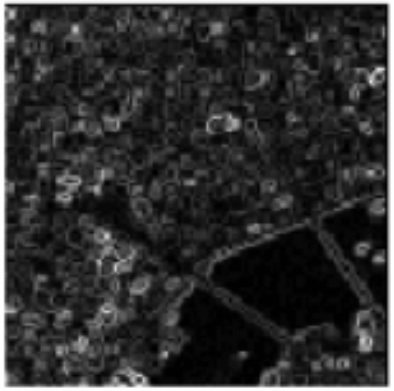
Output from Robert's Filter



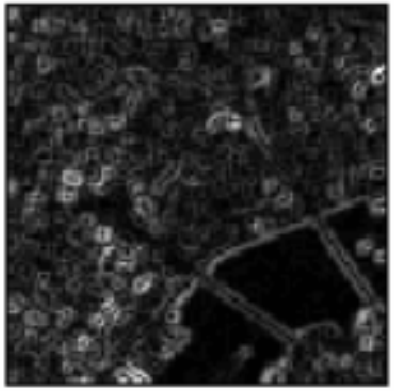
Simulated SAR image: (a) noiseless image, (b) noisy image, (c) Sobel edge detection, (d) Roberts edge detection, (e) Canny edge detection, (f) Prewitt edge detection

Original

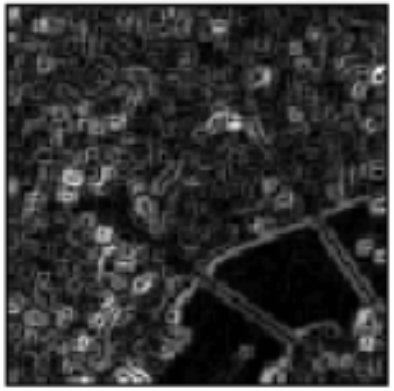
Roberts Filter



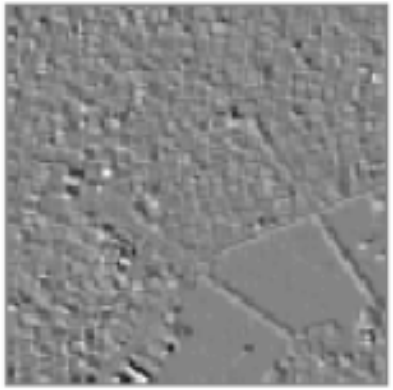
Sobel Filter



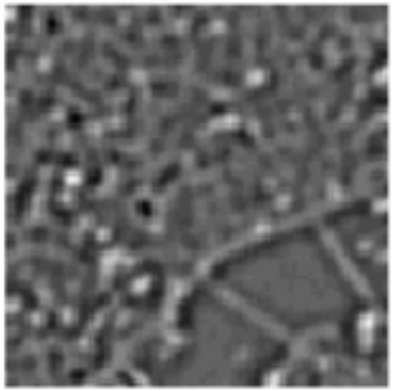
Prewitt Filter



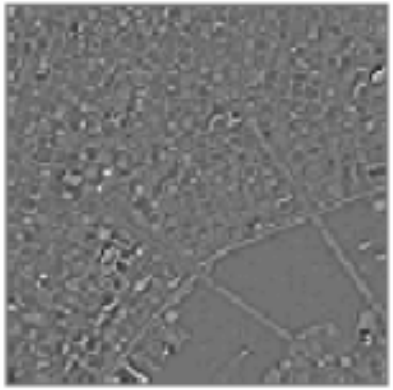
SHIFT_DIFF Filter



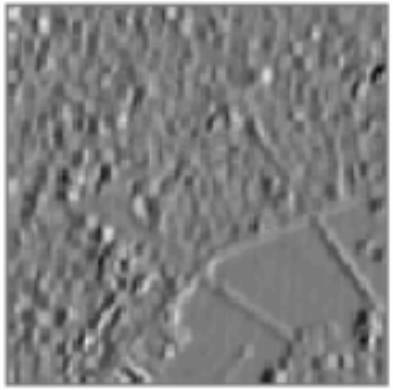
EDGE_DOG Filter



Laplacian Filter



EMBOSS Filter



Non-linear Edge Enhancement : Kirsch Edge Detector

The *Kirsch* nonlinear edge enhancement calculates the gradient at pixel location $BV_{i,j}$. To apply this operator, however, it is first necessary to designate a different 3 x 3 window numbering scheme.

$$\textit{Kirsh window} = \begin{matrix} BV_0 & BV_1 & BV_2 \\ BV_7 & BV_{i,j} & BV_3 \\ BV_6 & BV_5 & BV_4 \end{matrix}$$

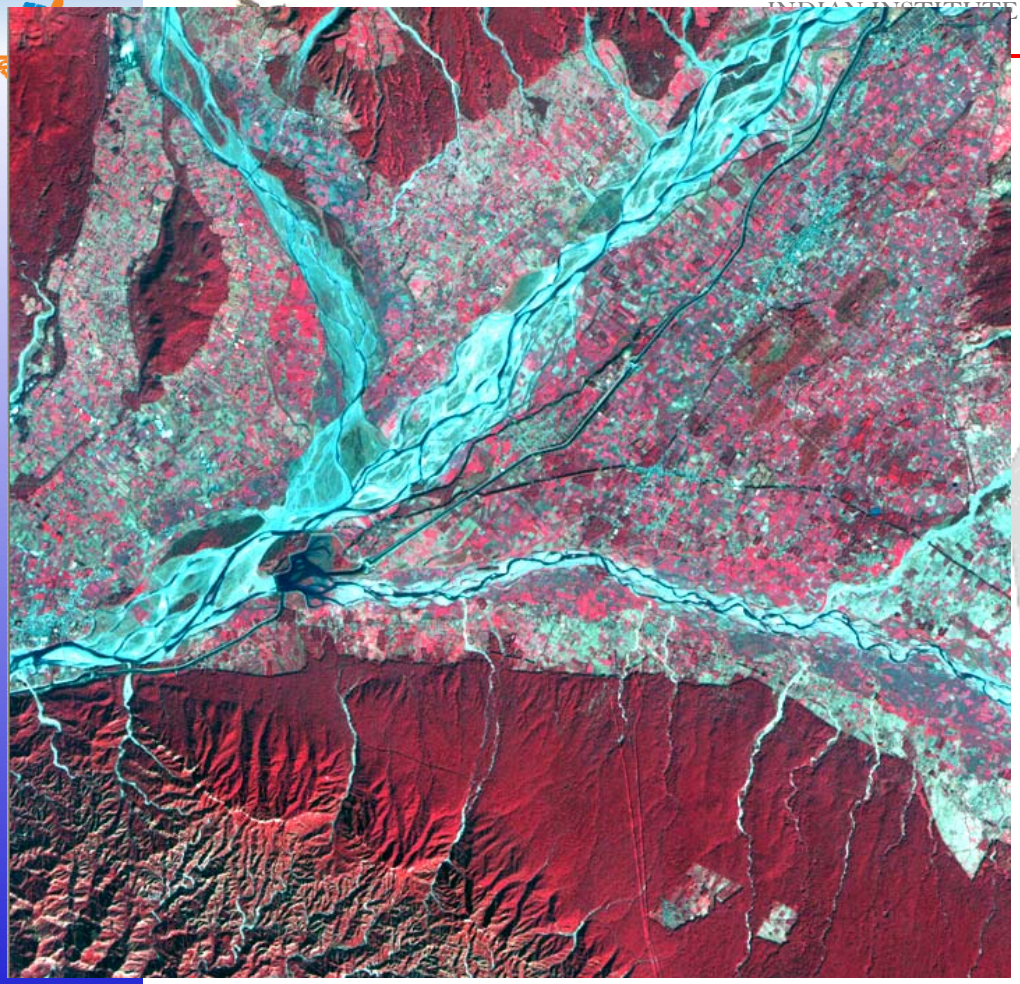
$$BV_{i,j} = \max\left\{1, \max_{i=0}^{7}\left[Abs\left(5S_i - 3T_i\right)\right]\right\}$$

where

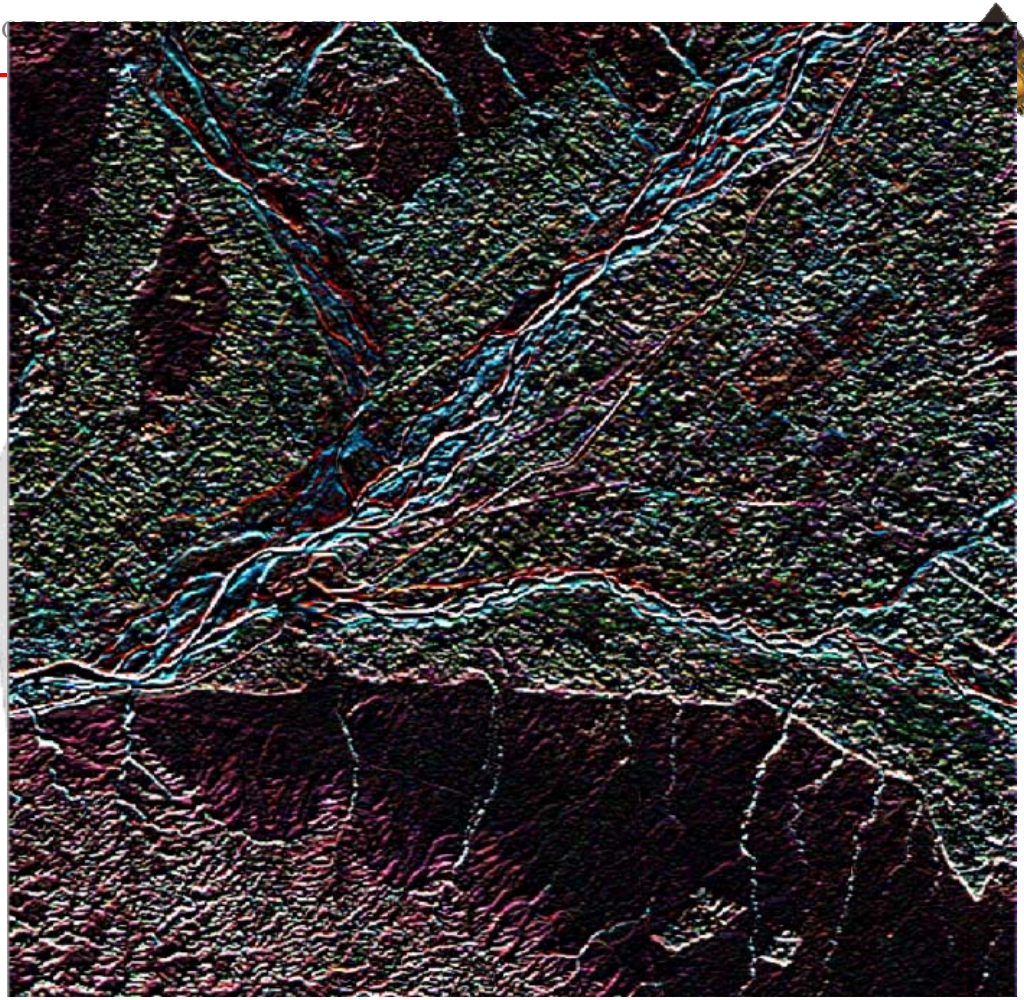
$$S_i = BV_i + BV_{i+1} + Bv_{i+2}$$

$$T_i = BV_{i+3} + BV_{i+4} + Bv_{i+5} + BV_{i+6} + Bv_{i+7}$$

The subscripts of *BV* are evaluated modulo ***8***, meaning that the computation moves around the perimeter of the mask in eight steps. The edge enhancement computes the maximal compass gradient magnitude about input image points although the input pixel value $BV_{i,j}$ is never used in the computation



Original Image



Output from Kirsch Filter

Thank-You

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Email- poonam@iirs.gov.in