

# SENSORES REMOTOS

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# Tratamiento de imágenes de satélite

Existen una gran cantidad de procedimientos para el análisis de imágenes de satélite. En este curso nos concentraremos en 4 de ellas:

- Pro-procesamiento de imágenes
- Mejoramiento de imágenes
- Transformaciones de imágenes
- Clasificación de imágenes.

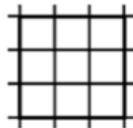
Single band	Multispectral
Radiometric correction	Algebraic operation with bands
Geometric correction	Vegetation indices (VI)
Image to image registration	Tasseled Cap
Histogram modification	Principal components analysis (PCA)
Digital filter	Classification

Cualquier imagen adquirida por un sensor remoto presenta una serie de alteraciones radiométricas y geométricas debidas a factores como:

Error	Cause	Type of distortion
Radiometric	Sensor	Radiometric calibration of the sensor Anomalies in the scansion (line striping effect)
	Geometry of the system	Effect of the Sun angle elevation Soil inclination (leaning)
	Atmosphere	Radiation absorption (subtractive) Atmospheric diffusion (additive)
Geometric	Acquisition system	Perspective deformation (asset variation, velocity and altitude) Panoramic distortion Distortion due to the opto-mechanical scan system oscillation
	Atmosphere	Atmospheric refraction
	Earth shape	Rotation, Earth curvature and orography

## CALIBRACIÓN RADIOMÉTRICA

Nivel Digital de gris



calibración del sensor

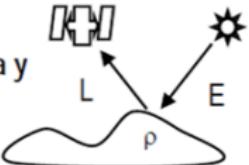
radiancia  $L$  en el sensor

corrección atmosférica

radiancia  $L$  en la superficie

corrección topográfica y solar

reflectancia  $\rho$  de la superficie



## CALIBRACIÓN GEOMÉTRICA

puntos de control y modelos polinómico- matriciales

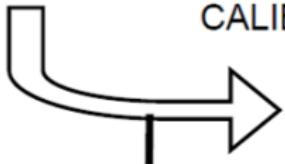


Imagen transformada geométricamente

Remuestreo (interpolación)

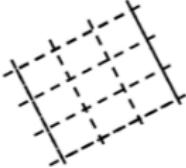
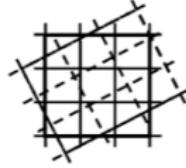
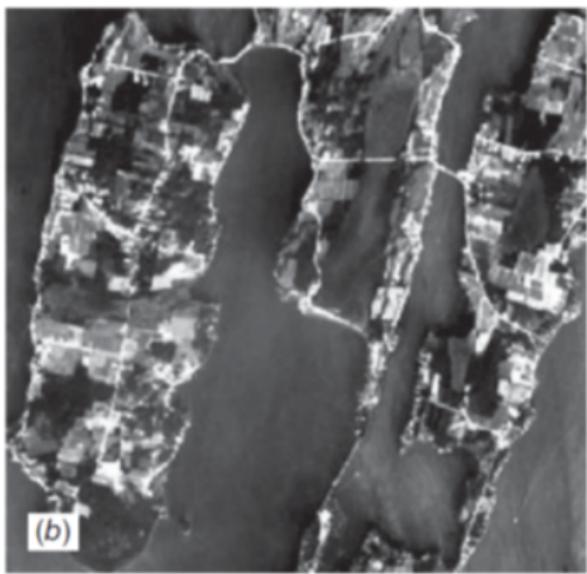
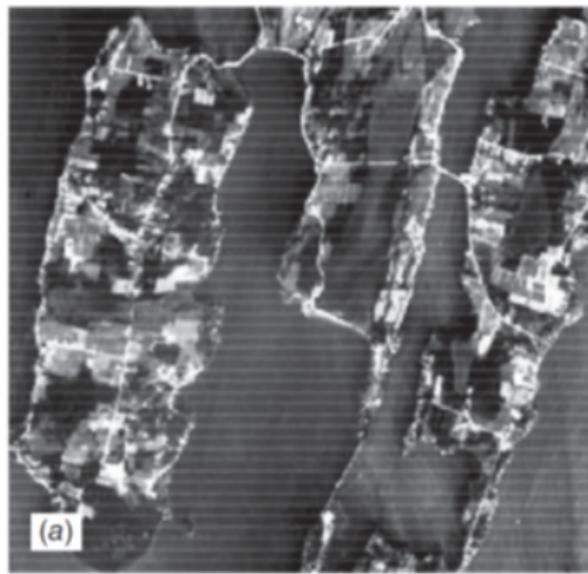


Imagen corregida (ortoimagen)

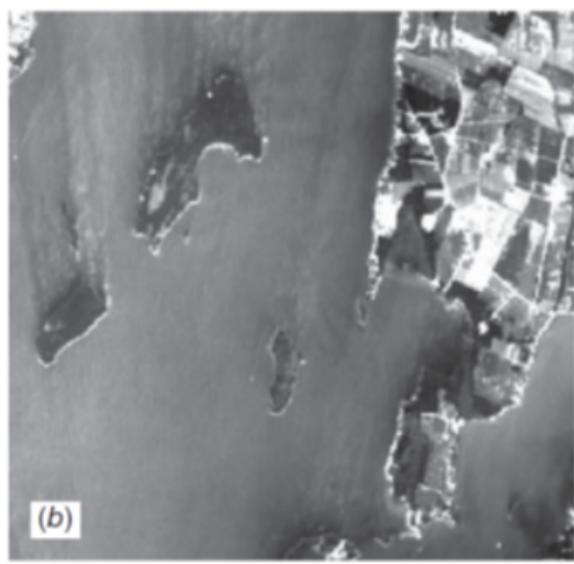
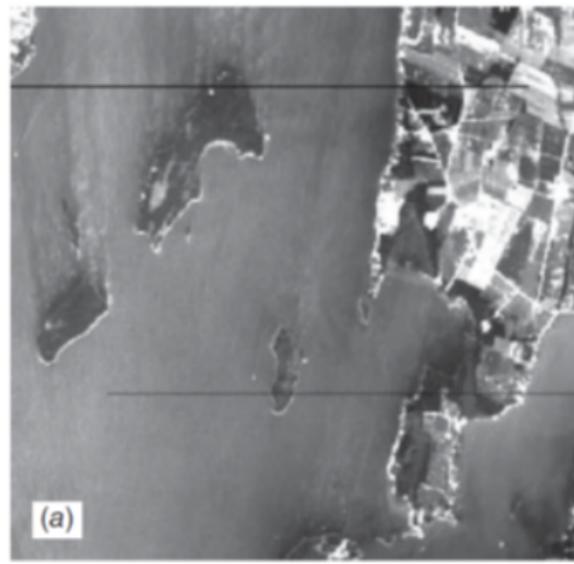


# Striping



**Figure 7.1** Destriping algorithm illustration: (a) original image manifesting striping with a six-line frequency; (b) restored image resulting from applying histogram algorithm. (Author-prepared figure.)

# Line Drop



**Figure 7.2** Line drop correction: (a) original image containing two line drops; (b) restored image resulting from averaging pixel values above and below defective line. (Author-prepared figure.)

# Bit Error

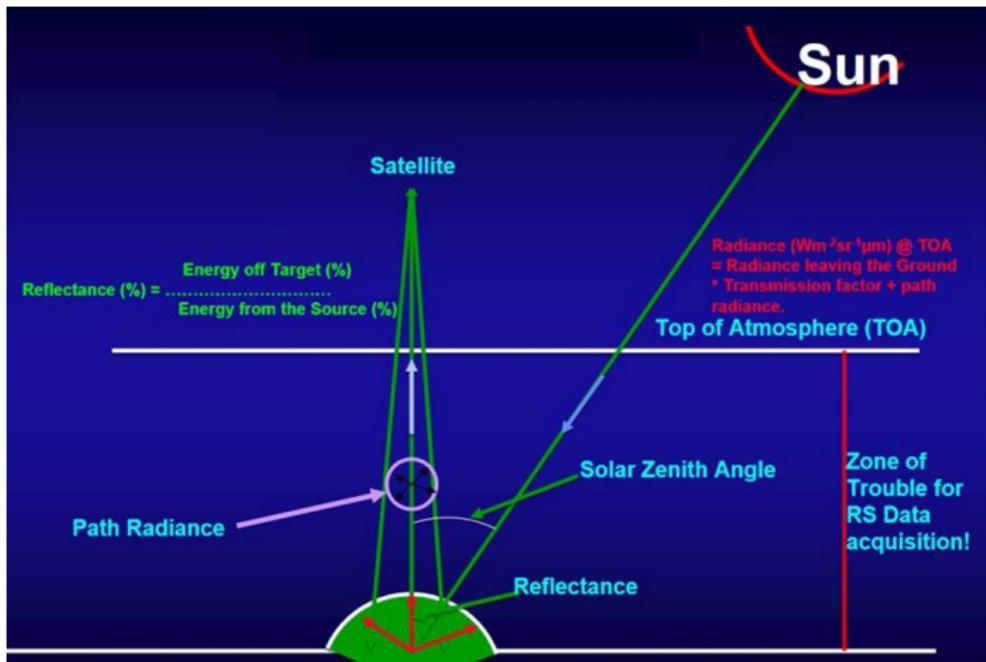


(a)



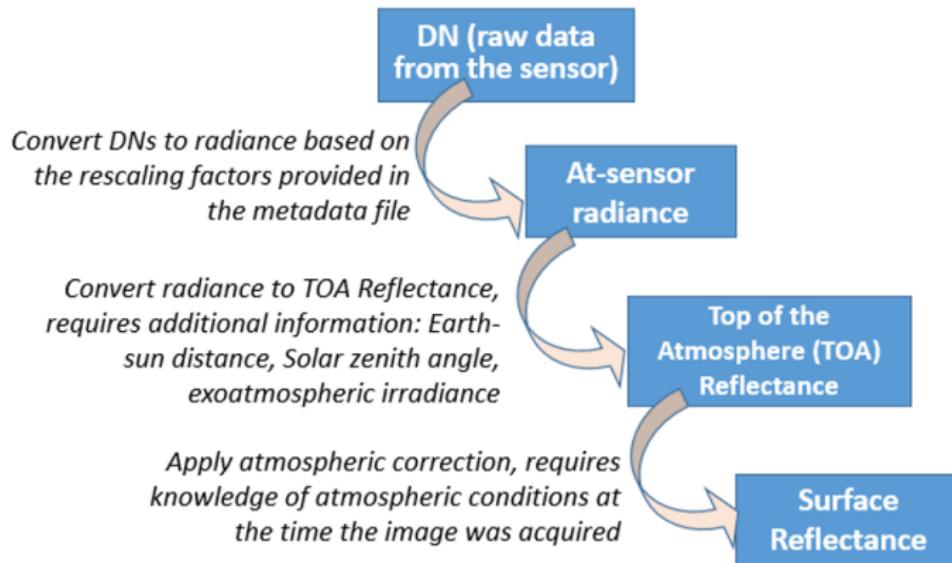
(b)

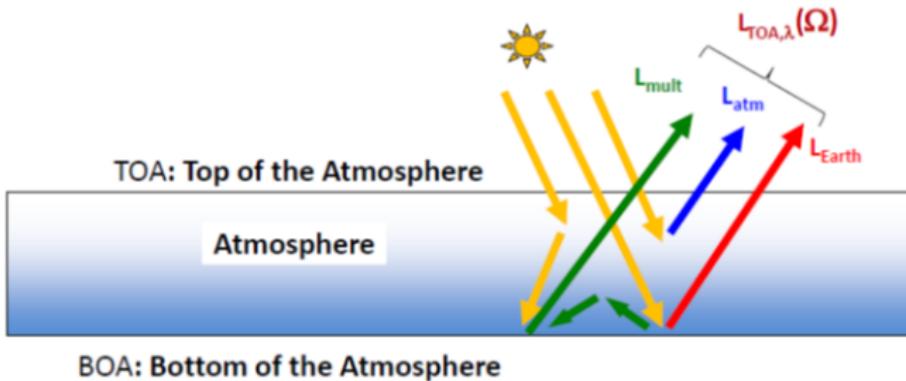
**Figure 7.3** Result of applying noise reduction algorithm: (a) original image data with noise-induced “salt-and-pepper” appearance; (b) image resulting from application of noise reduction algorithm. (Author-prepared figure.)



# Corrección & Calibración

## Radiometric Calibration & Correction Process





$L_{\text{TOA},\lambda}(\Omega)$  = "Radiance  $L_{\text{Earth,TOA},\lambda}(\Omega)$  due to scattering of sun flux by the Earth, only"

+

"Radiance  $L_{\text{atm,TOA},\lambda}(\Omega)$  due to scattering of sun flux by the Atmosphere, only"

+

"Radiance  $L_{\text{mult,TOA},\lambda}(\Omega)$  due to scattering of sun flux by {Earth + Atmosphere}"

# Conversión a Radiancia espectral TOA

$$L_\lambda = ML \cdot Q_{cal} + AL$$

Donde:

$L_\lambda$  = Es el valor de radiancia espectral en el techo de la atmósfera (TOA) medida en valores de (Watts /m<sup>2</sup> \* srad \* μm))

$ML$  = Banda – Es el factor multiplicativo de escalado específico obtenido del metadato (RADIANC\_E\_MULT\_BAND\_x, donde x es el número de la banda)

$AL$  = Banda – Es el factor aditivo de escalado específico obtenido del metadato (RADIANC\_E\_ADD\_BAND\_x, donde x es el número de la banda)

$Q_{cal}$  = Producto estándar cuantificado y calibrado por valores de pixel (DN). Este valor se refiere a cada una de las bandas de la imagen.

```
END_GROUP = MIN_MAX_PIXEL_VALUE
GROUP = RADIOMETRIC_RESCALING
RADIANC_E_MULT_BAND_1 = 1.2517E-02
RADIANC_E_MULT_BAND_2 = 1.2764E-02
RADIANC_E_MULT_BAND_3 = 1.1687E-02
RADIANC_E_MULT_BAND_4 = 9.8985E-03
RADIANC_E_MULT_BAND_5 = 6.0065E-03
RADIANC_E_MULT_BAND_6 = 1.5133E-03
RADIANC_E_MULT_BAND_7 = 4.9729E-04
```

```
RADIANC_E_ADD_BAND_1 = -62.58381
RADIANC_E_ADD_BAND_2 = -63.81901
RADIANC_E_ADD_BAND_3 = -58.43669
RADIANC_E_ADD_BAND_4 = -49.49229
RADIANC_E_ADD_BAND_5 = -30.03248
RADIANC_E_ADD_BAND_6 = -7.56668
RADIANC_E_ADD_BAND_7 = -2.46143
RADIANC_E_ADD_BAND_8 = -55.74004
```

# Conversión a Reflectividad TOA

$$\rho_{\lambda'} = M_p * Q_{cal} + A_p$$

Donde:

$\rho_{\lambda'}$  = Es el valor de reflectancia planetaria, sin corrección por ángulo solar. Note que  $\rho_{\lambda'}$  no contiene una corrección por el ángulo solar.

$M_p$  = Es el factor multiplicativo de escalado específico por banda obtenido del metadato **(REFLECTANCE\_MULT\_BAND\_X)**, donde x es el numero de la banda).

$A_p$  = Es el factor aditivo de escalado específico por banda obtenido del metadato **(REFLECTANCE\_ADD\_BAND\_X)**, donde x es el numero de la banda).

$Q_{cal}$  = Es el producto estándar cuantificado y calibrado para valores de pixel (DN). Este valor se refiere a cada una de las bandas de la imagen.

```
REFLECTANCE_MULT_BAND_1 = 2.0000E-05
REFLECTANCE_MULT_BAND_2 = 2.0000E-05
REFLECTANCE_MULT_BAND_3 = 2.0000E-05
REFLECTANCE_MULT_BAND_4 = 2.0000E-05
REFLECTANCE_MULT_BAND_5 = 2.0000E-05
REFLECTANCE_MULT_BAND_6 = 2.0000E-05
REFLECTANCE_MULT_BAND_7 = 2.0000E-05
REFLECTANCE_MULT_BAND_8 = 2.0000E-05
REFLECTANCE_MULT_BAND_9 = 2.0000E-05
REFLECTANCE_ADD_BAND_1 = -0.100000
REFLECTANCE_ADD_BAND_2 = -0.100000
REFLECTANCE_ADD_BAND_3 = -0.100000
REFLECTANCE_ADD_BAND_4 = -0.100000
REFLECTANCE_ADD_BAND_5 = -0.100000
REFLECTANCE_ADD_BAND_6 = -0.100000
```



(Moreno, 2014)

# Radiación Termal

La Temperatura cinética es la manifestación interna de la energía traslacional promedio de la moléculas que componen un cuerpo (temperatura cinética). Como consecuencia los objetos irradian energía en función de su temperatura (Temperatura radiante), adicionalmente esta temperatura sensada es de los primeros 50 cm, puede no ser representativa de todo el objeto. Sin embargo debido a la diferencia de emisividad que tienen los objetos, un cuerpo puede tener la misma temperatura y aun así tener diferente radiancia. Solo los cuerpos negros presentan que  $\text{Trad} = \text{T}_{\text{cin}}$ , para los demás cuerpos la temperatura radiante siempre es menor, ya que la emisividad es menor que 1.

**TABLE 4.4 Kinetic versus Radiant Temperature for Four Typical Material Types**

Object	Emissivity $\varepsilon$	Kinetic Temperature $T_{\text{kin}}$		Radiant Temperature $T_{\text{rad}} = \varepsilon^{1/4} T_{\text{kin}}$	
		K	°C	K	°C
Blackbody	1.00	300	27	300.0	27.0
Vegetation	0.98	300	27	298.5	25.5
Wet soil	0.95	300	27	296.2	23.2
Dry soil	0.92	300	27	293.8	20.8

# Conversión a T de brillo

Las bandas del TIRS puede ser convertidas de radiancia espectral a temperatura de brillo en grados Kelvin usando la constante térmica suministrada en el archivo de metadatos:

$$T = \frac{K_2}{\ln\left(\frac{K_1}{L_\lambda} + 1\right)}$$

Donde:

T = temperatura de brillo aparente en grados Kelvin

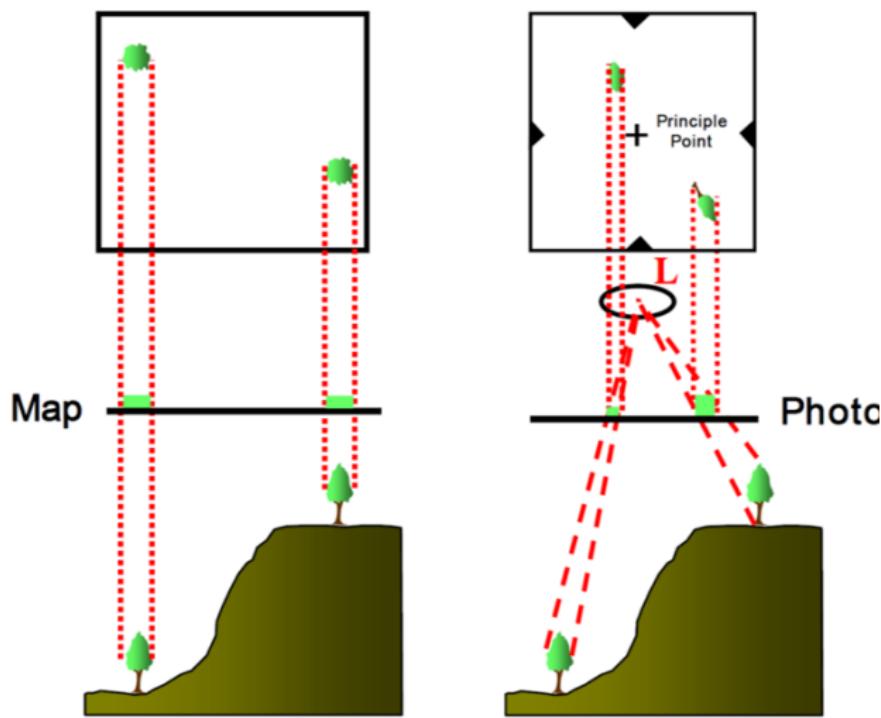
L = Radiancia espectral en el techo de la atmosfera TOA (watts/m<sup>2</sup>\*sradi\*um)

K1 = es la constante de conversión específica para cada banda denominada en el metadato K1\_CONSTANT\_BAND\_x, donde x es la banda 10 U 11.

K2 = es la constante específica para cada banda denominada en el metadato como K2\_CONSTANT\_BAND\_x

```
GROUP = TIRS THERMAL CONSTANTS
K1_CONSTANT_BAND_10 = 774.89
K1_CONSTANT_BAND_11 = 480.89
K2_CONSTANT_BAND_10 = 1321.08
K2_CONSTANT_BAND_11 = 1201.14
END_GROUP = TIRS_THERMAL_CONSTANTS
```

# Ortorectificación



## Aerial Photograph

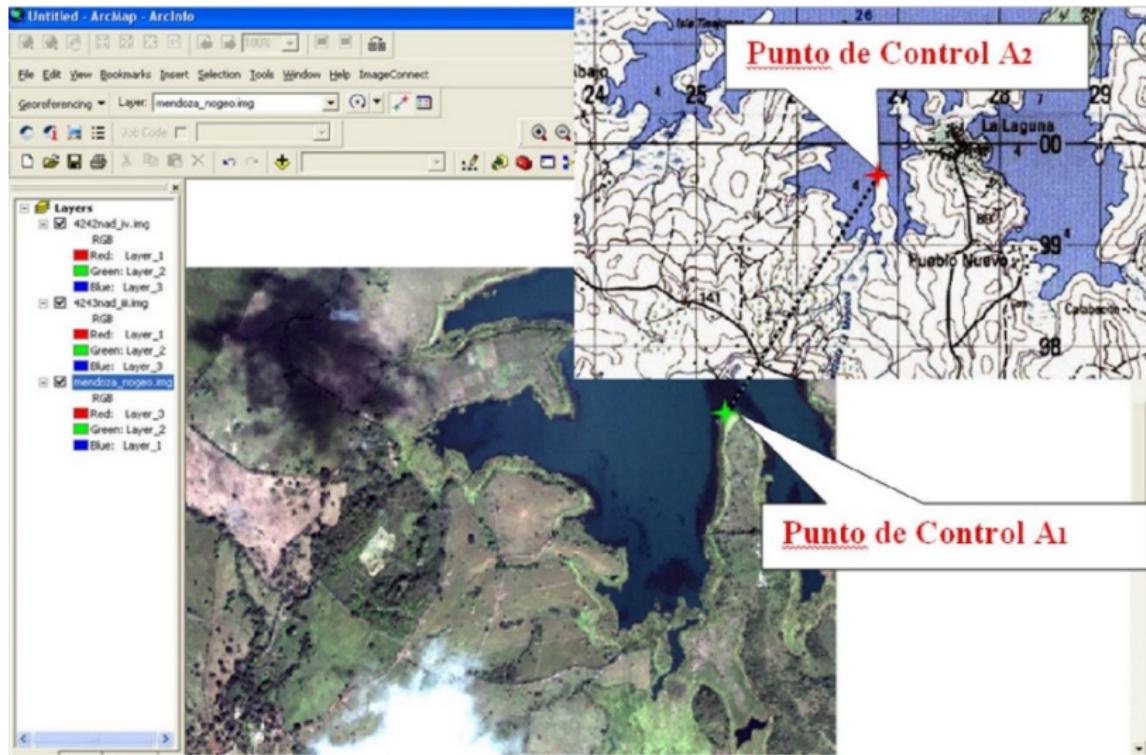
Tenth Legion, VA

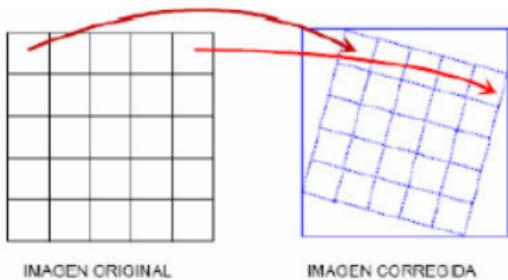


## Digital Orthophoto

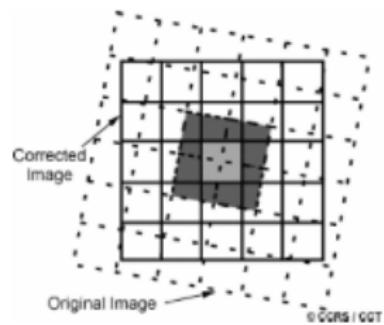
Tenth Legion, VA



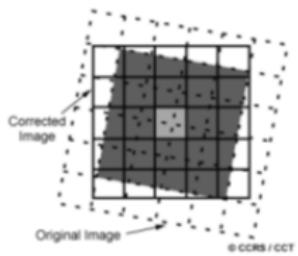




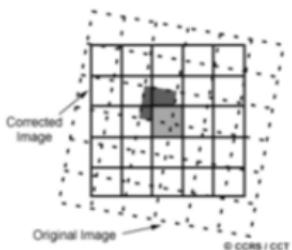
(a) Directa



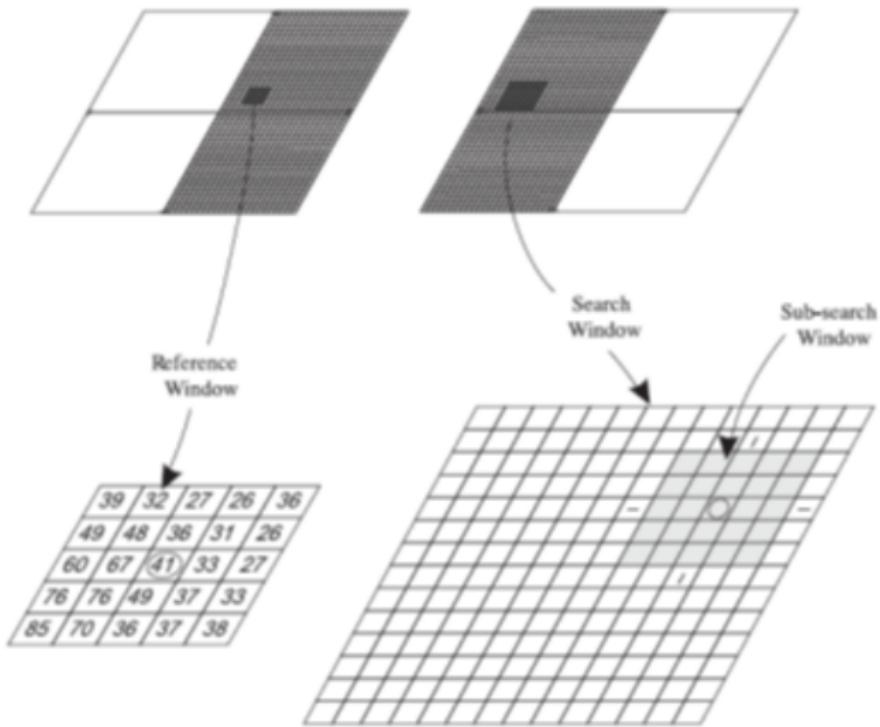
(b) Interpolación bilineal



(c) Interpolación cúbica



(d) Vecino mas Cercano



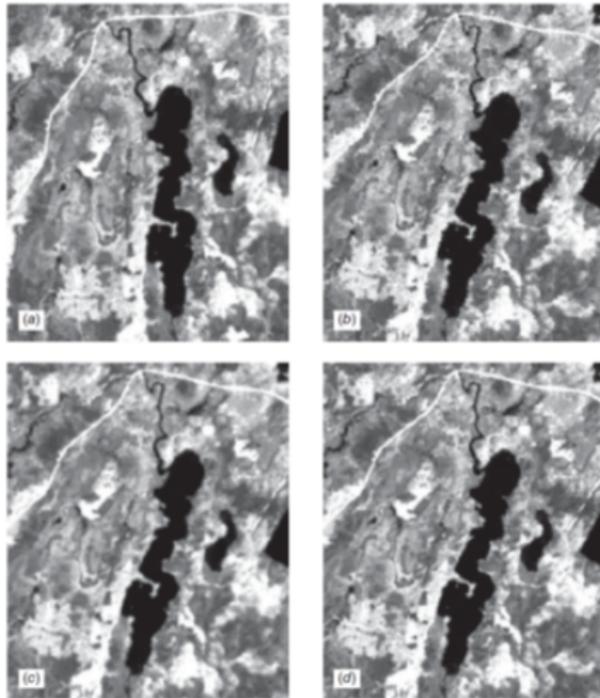
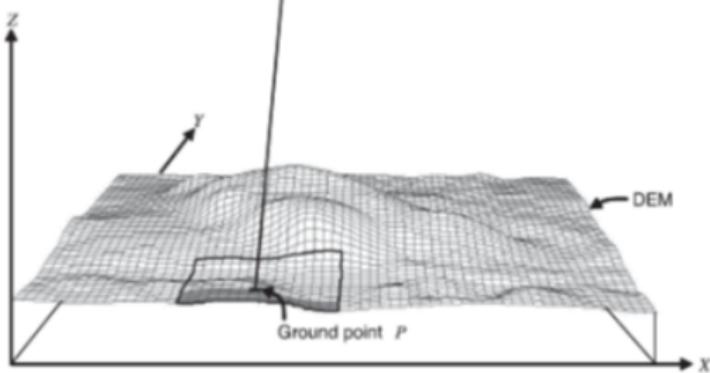
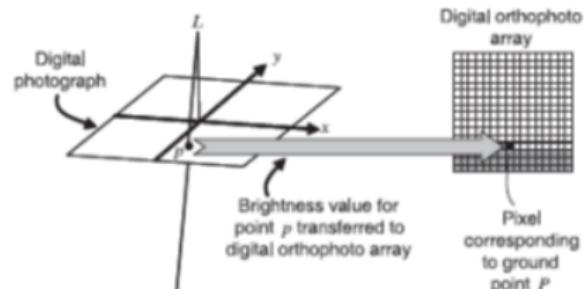
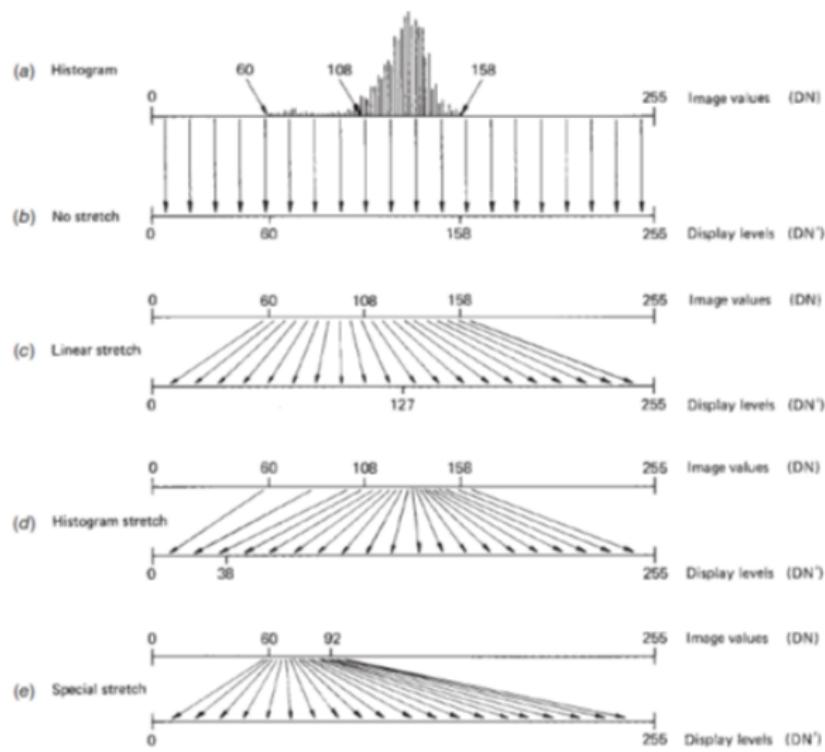


Figure 7.7 Resampling results: (a) original Landsat TM data; (b) nearest neighbor assignment; (c) bilinear interpolation; (d) cubic convolution. Scale 1:100,000. (Author-prepared figure.)

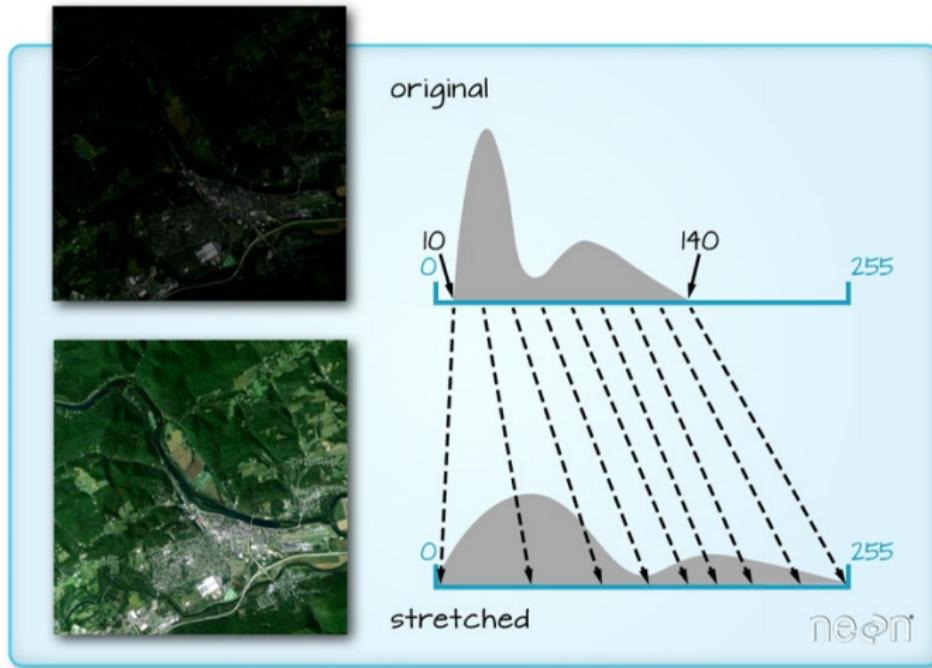


# Mejoramiento de Imágenes



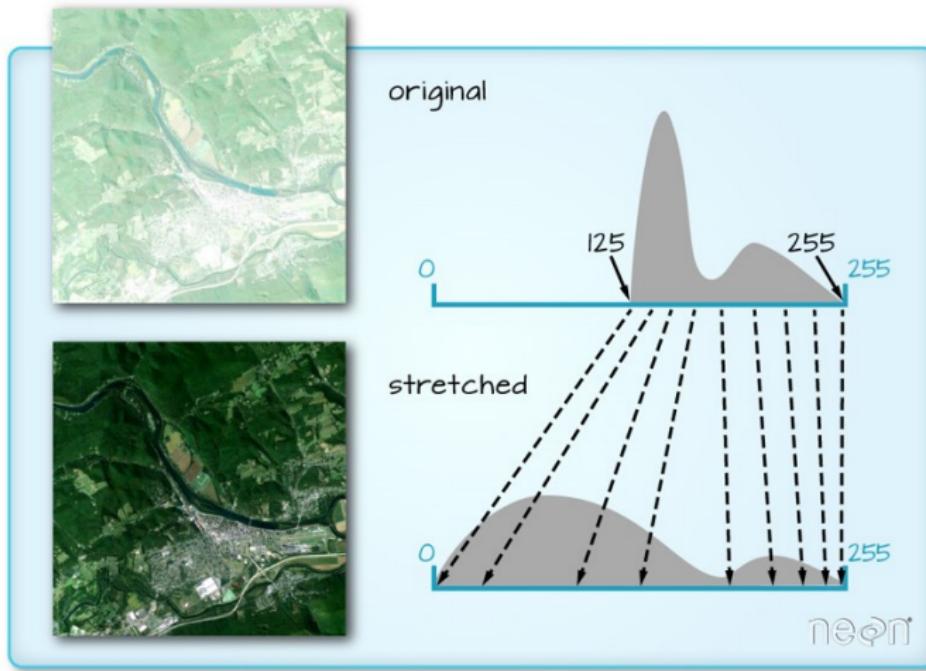
# Ajustes del Histograma

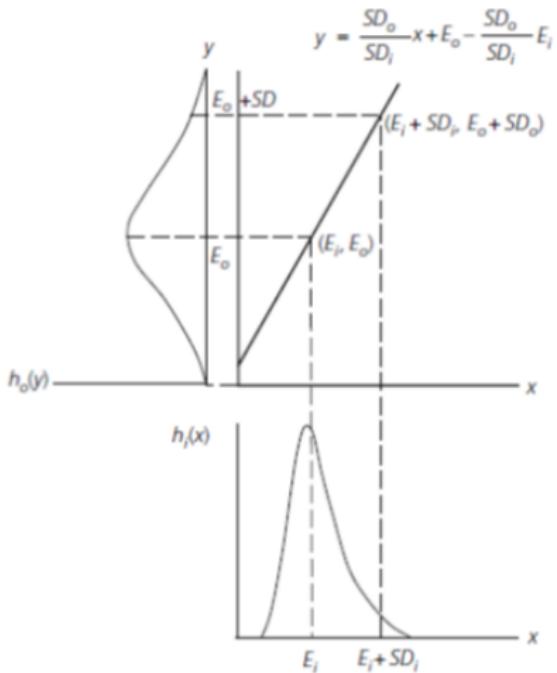
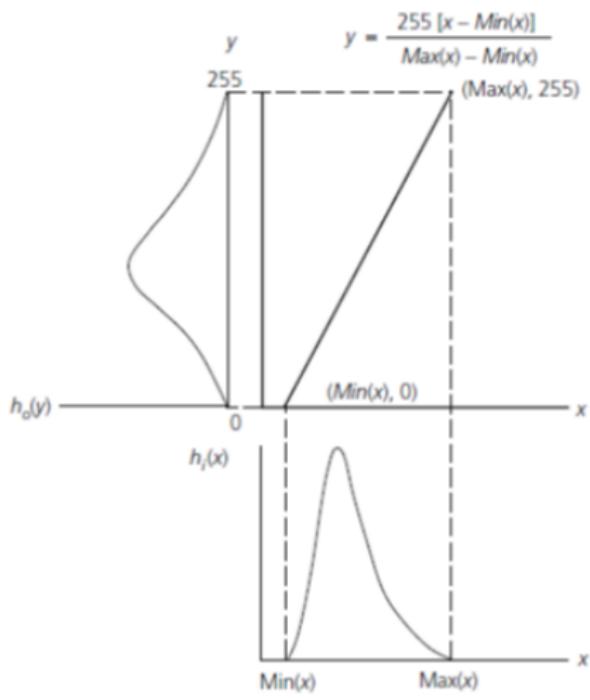
Strech



# Ajustes del Histograma

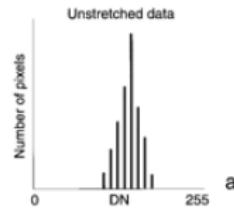
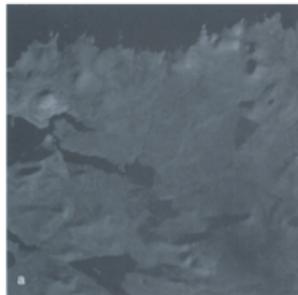
Strech





# Ajustes del Histograma

Landsat TM Band-5 image and Histogram

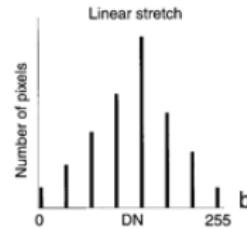
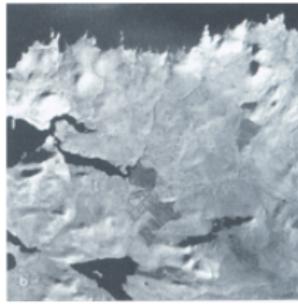


8-bit

Rango DN entre 60-158

0-59 y 159-255 no son utilizados

Linearly stretched Landsat TM Band-5 image and Histogram



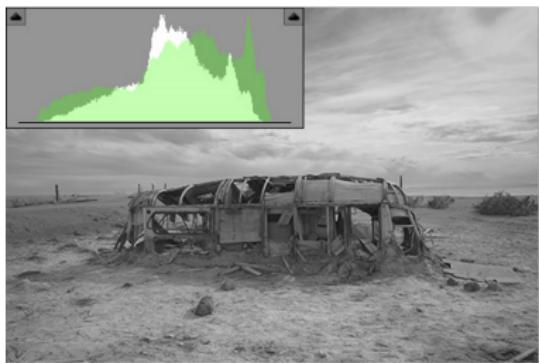
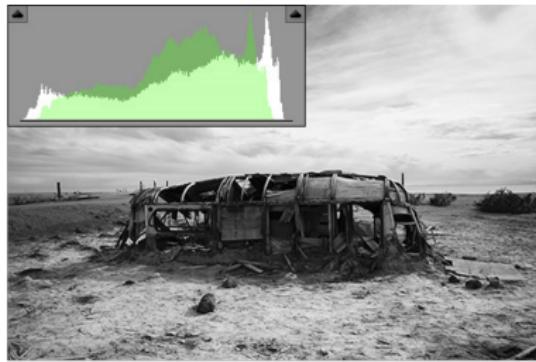
DN es ampliado a 0-255

Mejora contraste

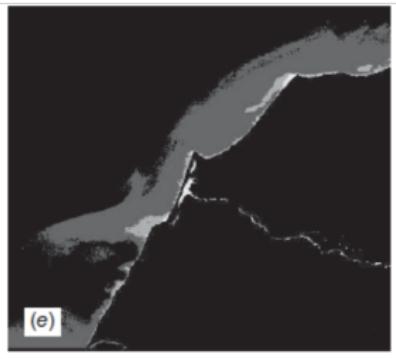
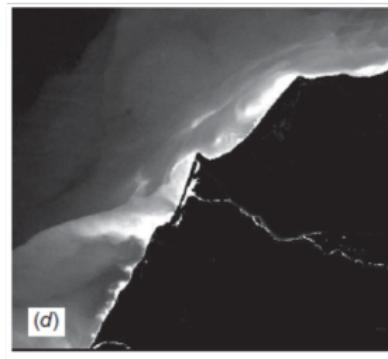
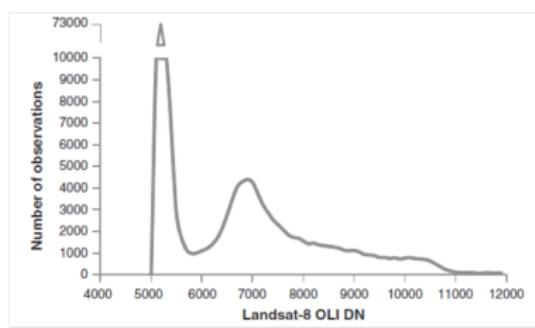
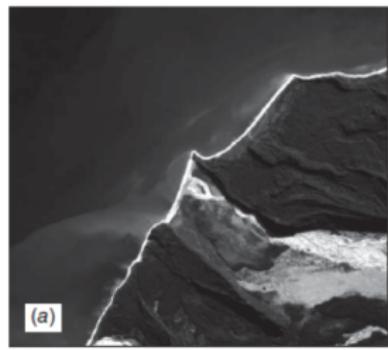
Colores claros aparecen mas claros

Colores oscuros mas oscuros

# Ajustes del Histograma



# Umbrales y Segmentación



# Filtros

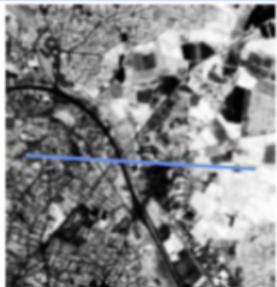
## FILTERS

### HIGH-PASS FILTERS:

Emphasize the detailed high frequency components of an image and de-emphasize the more general low frequency information.

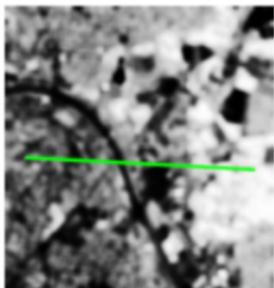


«Edge Enhancement»

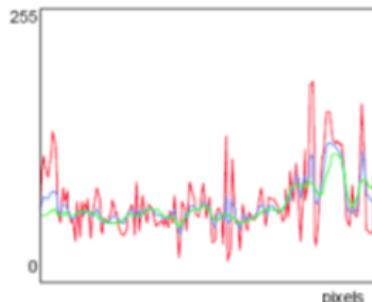


### LOW-PASS FILTERS:

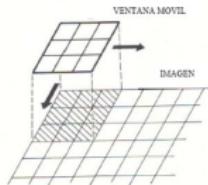
Emphasize low frequency features (large areas changes in brightness) and de-emphasize the high frequency components of an image (local detail). They are used to reduce noise and artefacts.



«Smoothing»



# Ventana móvil



12	14	17	<b>24</b>	32	34
10	18	21	35	38	40
25	15	<b>17</b>	<b>27</b>	40	43
18	16	18	<b>24</b>	<b>29</b>	39
14	16	20	20	27	36

Imagen original

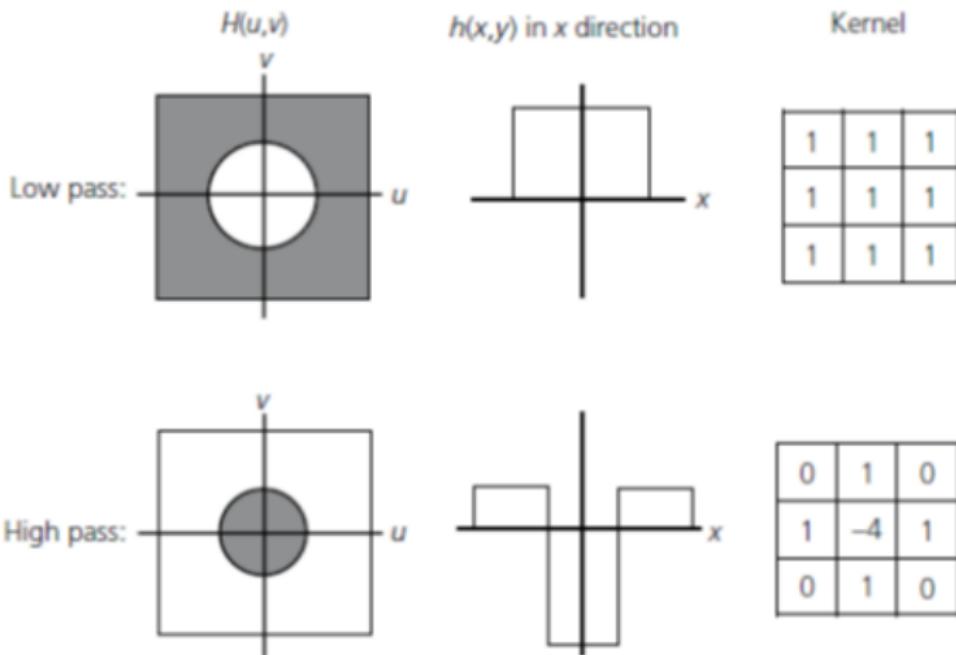
1	1	1
1	2	1
1	1	1

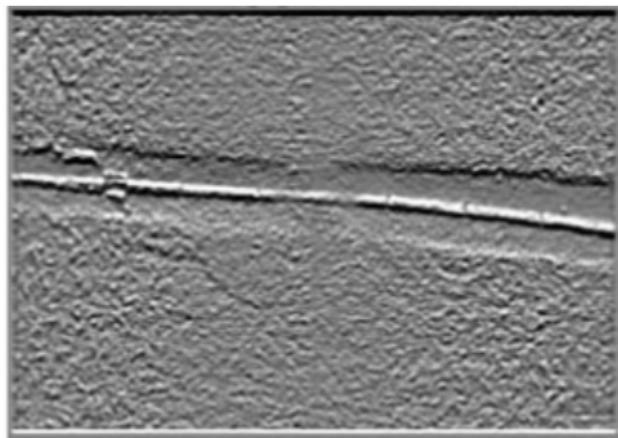
Matriz móvil de  
coeficientes de  
filtraje

(Mascara, operador o kernel)

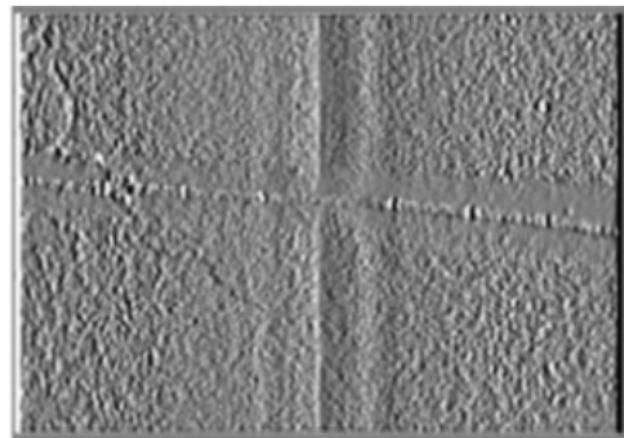
0	0	0	0	0	0
0	17	<b>21</b>	29	35	0
0	17	21	28	35	0
0	18	19	25	31	0
0	0	0	0	0	0

Imagen filtrada





*North edge enhancement*



*East edge enhancement*

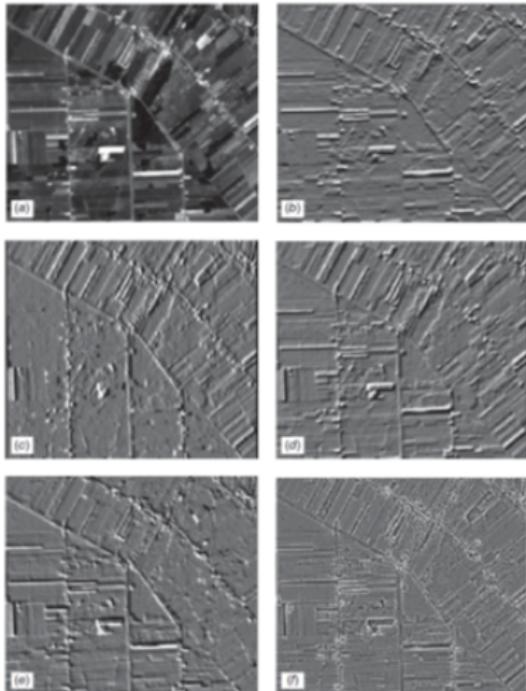
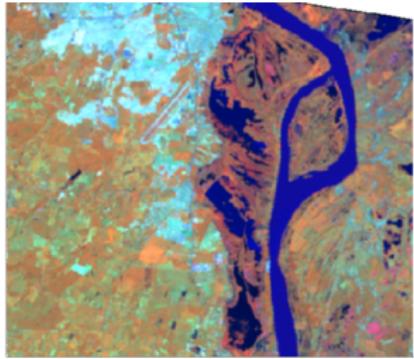


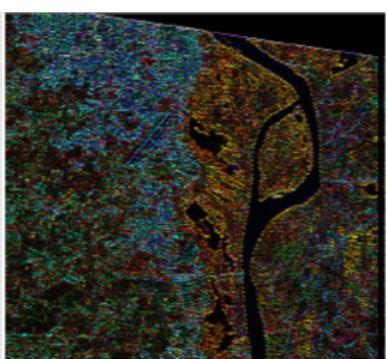
Figure 7.15 Edge enhancement through directional first differencing: (a) original image; (b) horizontal first difference; (c) vertical first difference; (d) right diagonal first difference; (e) left diagonal first difference; (f) Laplacian edge detector. (Author-prepared figure.)



Paso bajo → Homogenizar

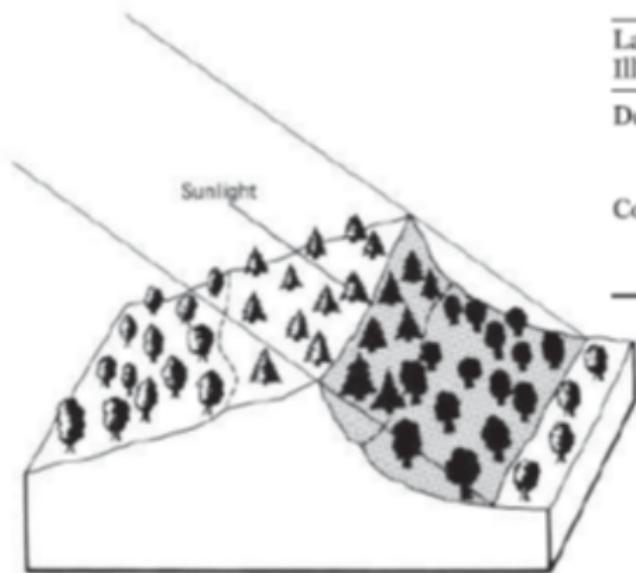


Paso alto → Resaltar



Direccionales → detección de  
bordes

# Cociente



Land Cover/ Illumination	Digital Number		
	Band A	Band B	Ratio (Band A/Band B)
Deciduous			
Sunlit	48	50	0.96
Shadow	18	19	0.95
Coniferous			
Sunlit	31	45	0.69
Shadow	11	16	0.69

Figure 7.20 Reduction of scene illumination effects through spectral ratioing. (Adapted from Sabins, 1997.)

# Índices

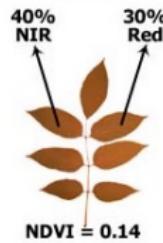
N	Remote Sensing Based Indices	Equation
1	Normalized Difference Vegetation Index	$NDVI = \frac{NIR - RED}{NIR + RED}$
2	Normalized Difference Water Index	$NDWI = \frac{NIR - SWIR}{NIR + SWIR}$
3	Vegetation Condition Index	$VCI = \frac{(NDVIj - NDVImin)}{(NDVImax + NDVImin)} \times 100\%$
4	Temperature Condition Index	$TCI = \frac{Tmax - Tj}{Tmax - Tmin} \times 100\%$
5	Vegetation Health Index	$VHI = a \times VCI + (1 - a) \times TCI$
6	Normalized Multi-Band Drought Index	$NMDI = \frac{NIR - (SWIR1 - SWIR2)}{NIR - (SWIR1 + SWIR2)}$
7	Vegetation Supply Water Index	$VSWI = Ts / NDVI$
8	Normalized Difference Drought Index	$NDDI = \frac{(NDVI - NDWI)}{(NDVI + NDWI)}$

# NDVI

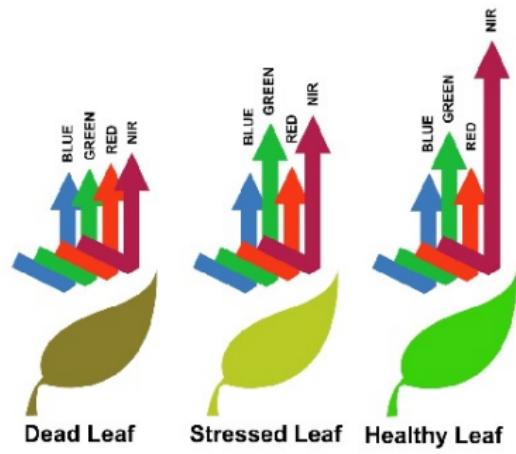
**Healthy Vegetation Reflectance**



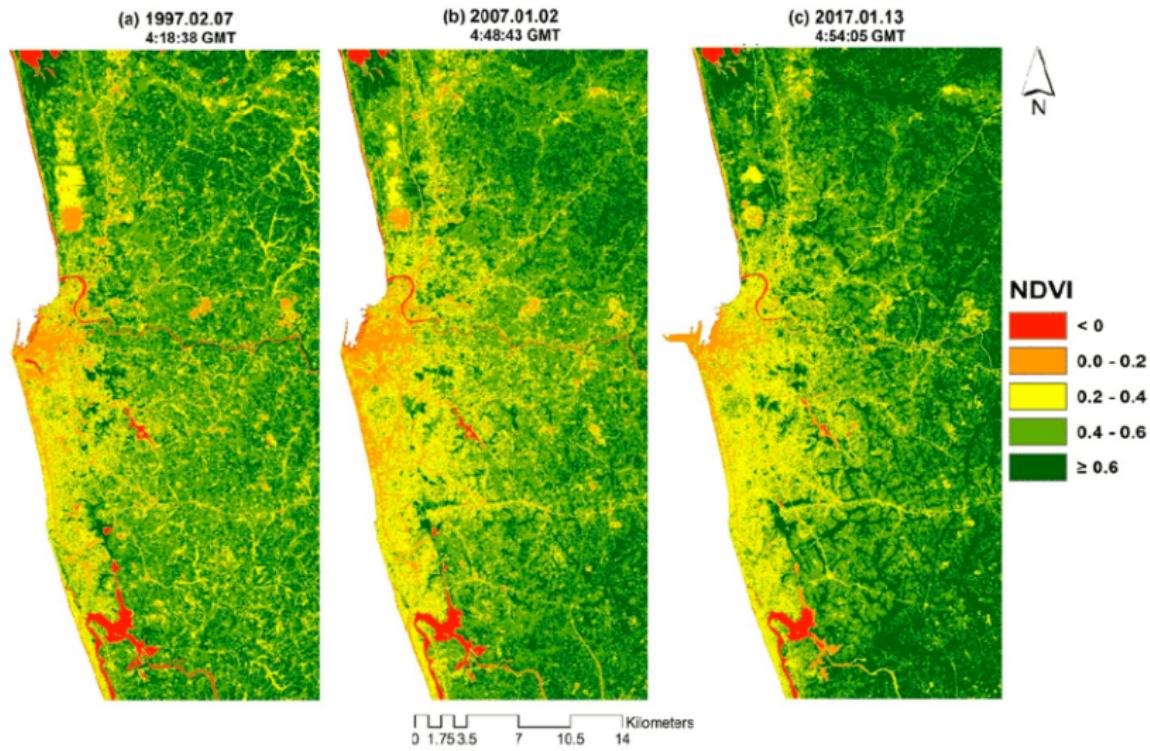
**Stressed Vegetation Reflectance**



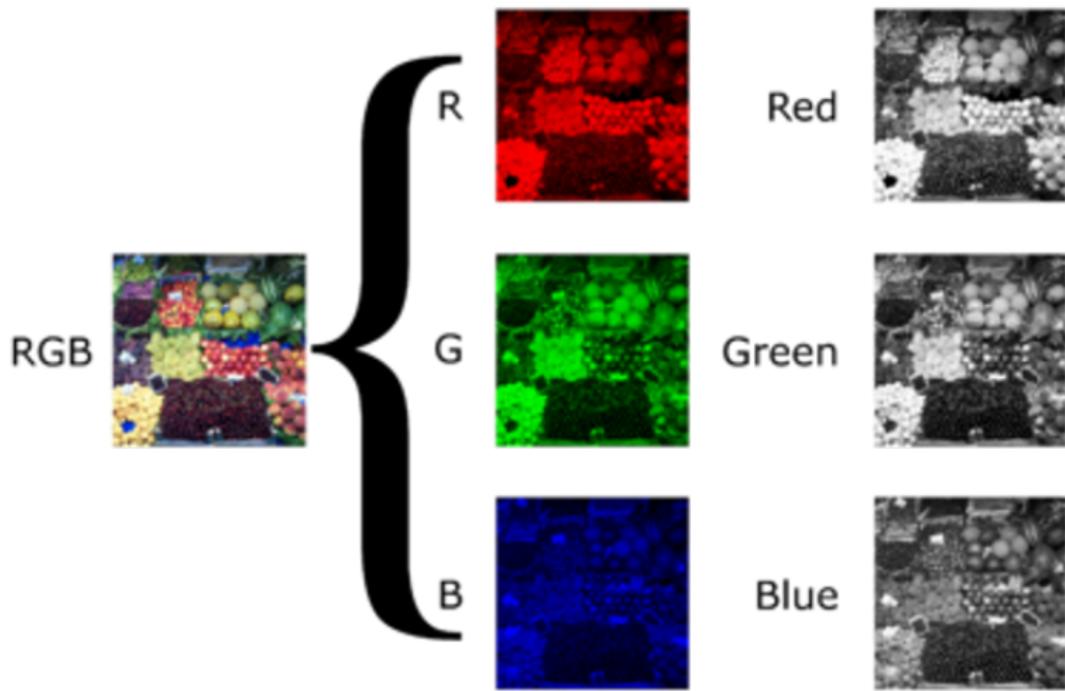
$$\text{NDVI} = \frac{\text{NIR} - \text{Red}}{\text{NIR} + \text{Red}}$$



# NDVI



# Combinación de bandas



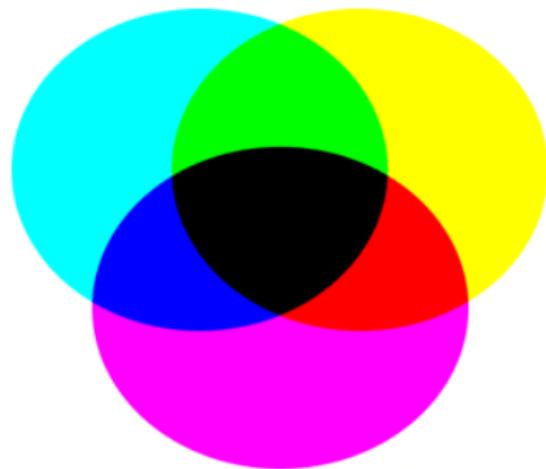
# Combinación de bandas

PC & TV



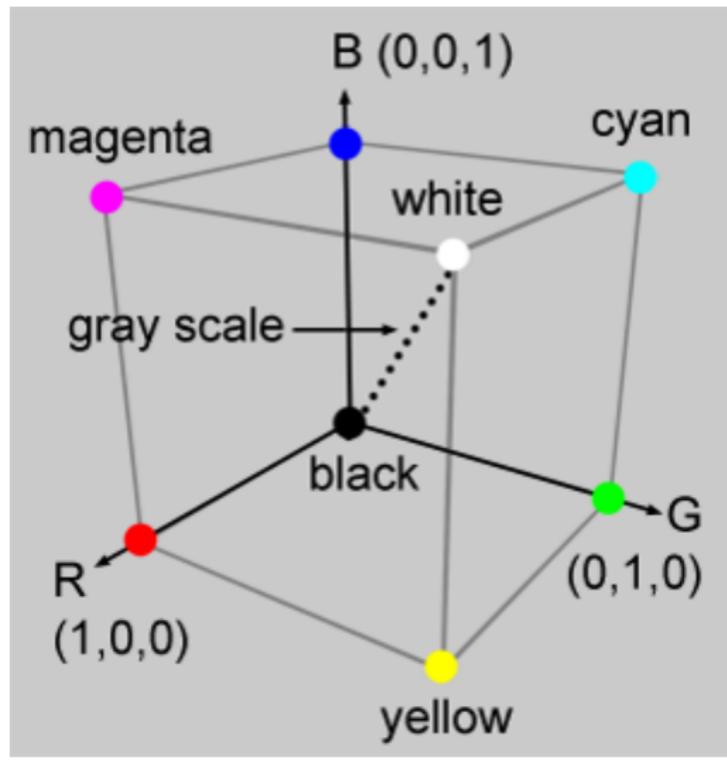
$$\boxed{\text{R}} + \boxed{\text{G}} + \boxed{\text{B}} = \boxed{\text{BLANCO}}$$

Color film photography

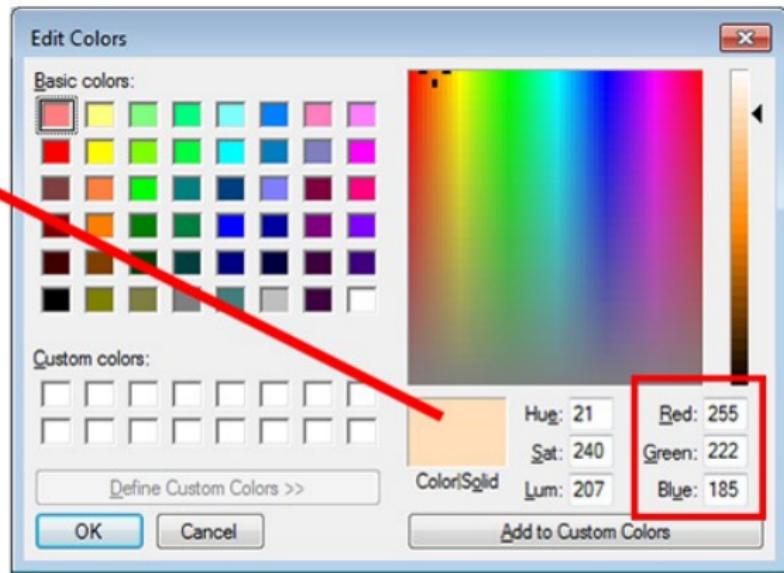
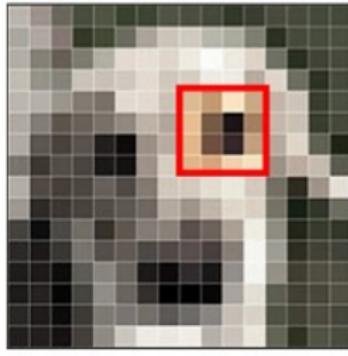
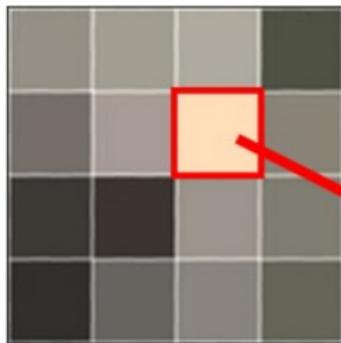


$$\boxed{\text{C}} + \boxed{\text{M}} + \boxed{\text{Y}} = \boxed{\text{K}}$$

# Combinación de bandas



# Combinación de bandas





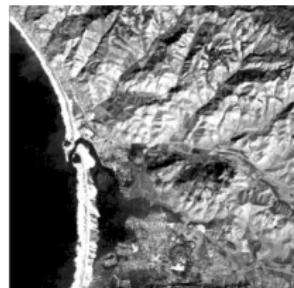
Morro Bay,  
California.



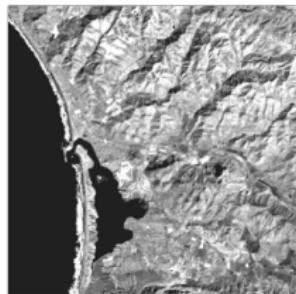
TM band 1



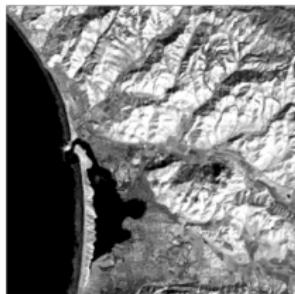
TM band 2



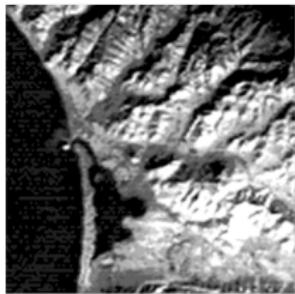
TM band 3



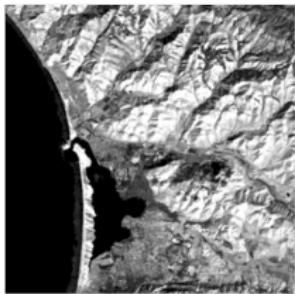
TM band 4



TM band 5



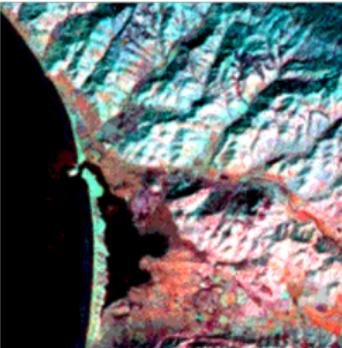
TM band 6



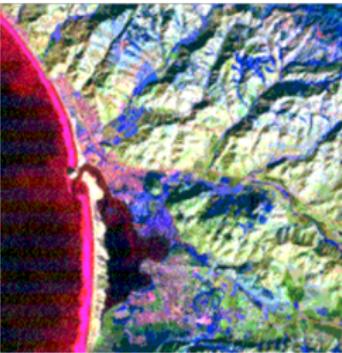
TM band 7



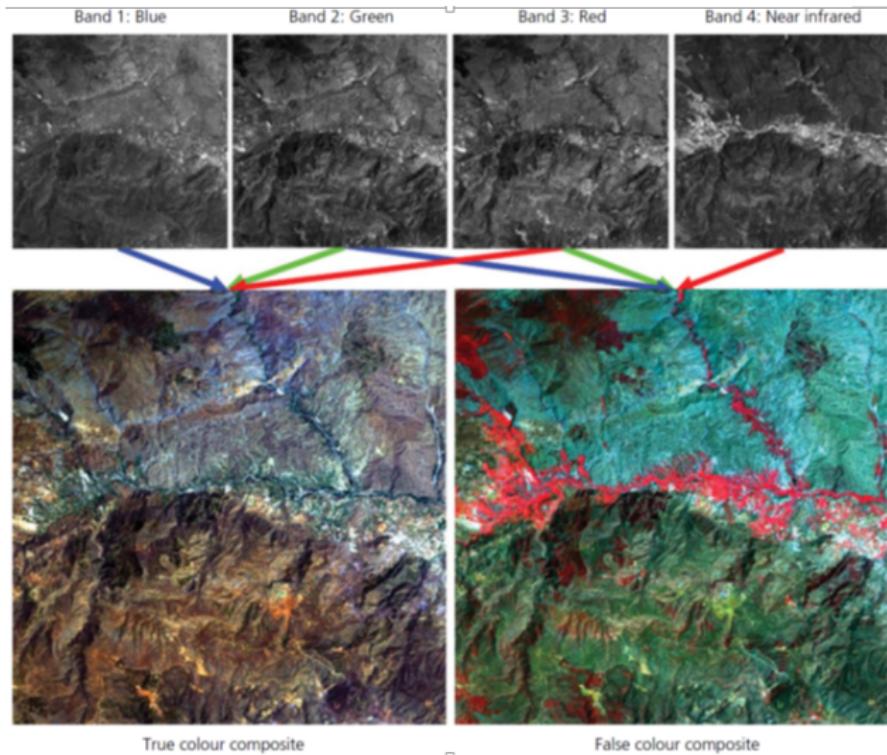
Morro Bay, California.



- TM Band 6 = red
- TM Band 7 = green
- TM Band 5 = blue



- TM Band 7 = green
- TM Band 4 = blue
- TM Band 1 = red



# Combinación de bandas y cociente

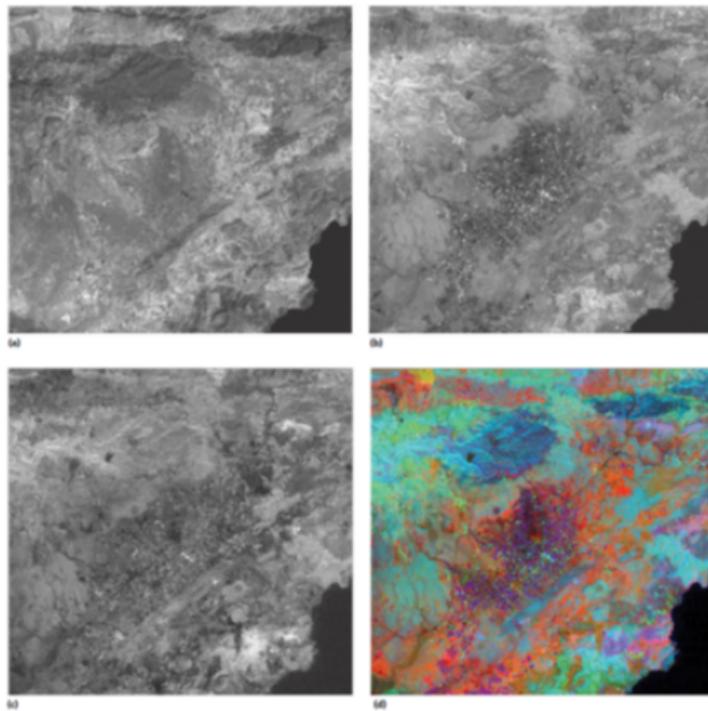
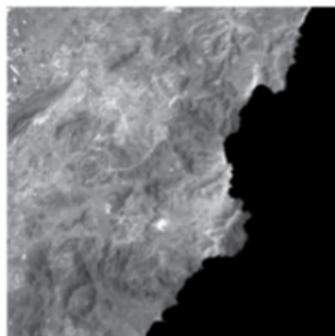


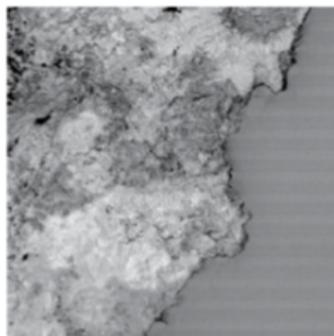
Fig. 3.4 Ratio images and ratio colour composite: (a) the ratio image of TM3/TM1; (b) the ratio image of TM4/TM3; (c) the ratio image of TM5/TM7; and (d) the ratio colour composite of TM5/TM7 in blue, TM4/TM3 in green and TM3/TM1 in red.

# Transformación de imágenes

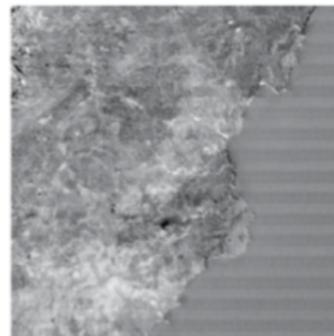
## Componentes Principales



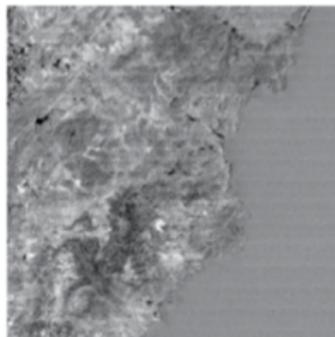
PC1



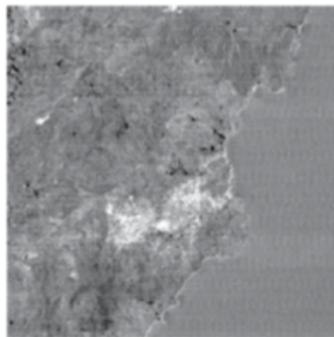
PC2



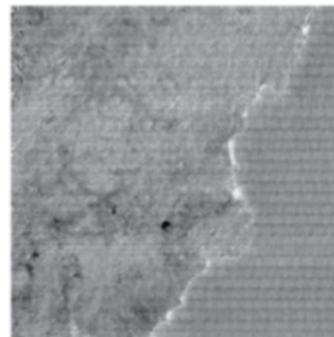
PC3



PC4



PC5



PC6

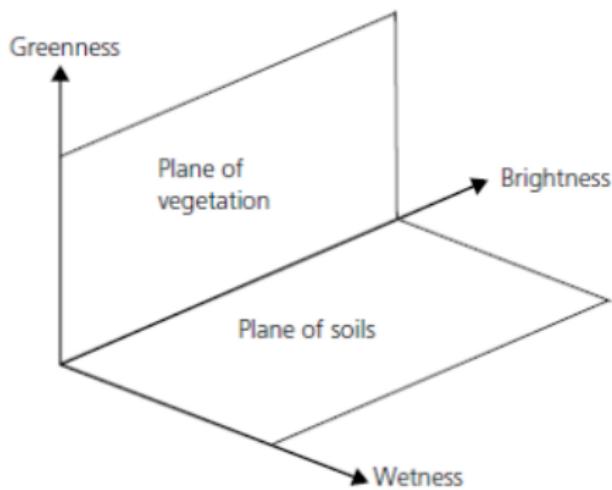
**Table 7.2** The covariance matrix of bands 1–5, 7 of a TM sub-scene.

Covariance	TM1	TM2	TM3	TM4	TM5	TM7
<b>TM1</b>	232.202	196.203	305.763	348.550	677.117	345.508
<b>TM2</b>	196.203	178.980	284.415	335.185	660.570	335.997
<b>TM3</b>	305.763	284.415	460.022	545.336	1083.993	551.367
<b>TM4</b>	348.550	335.185	545.336	674.455	1347.927	678.275
<b>TM5</b>	677.117	660.570	1083.993	1347.927	2802.914	1402.409
<b>TM7</b>	345.508	335.997	551.367	678.275	1402.409	711.647

**Table 7.3** The eigenvector matrix and eigenvalues of the covariance matrix of bands 1–5, 7 of a TM sub-scene.

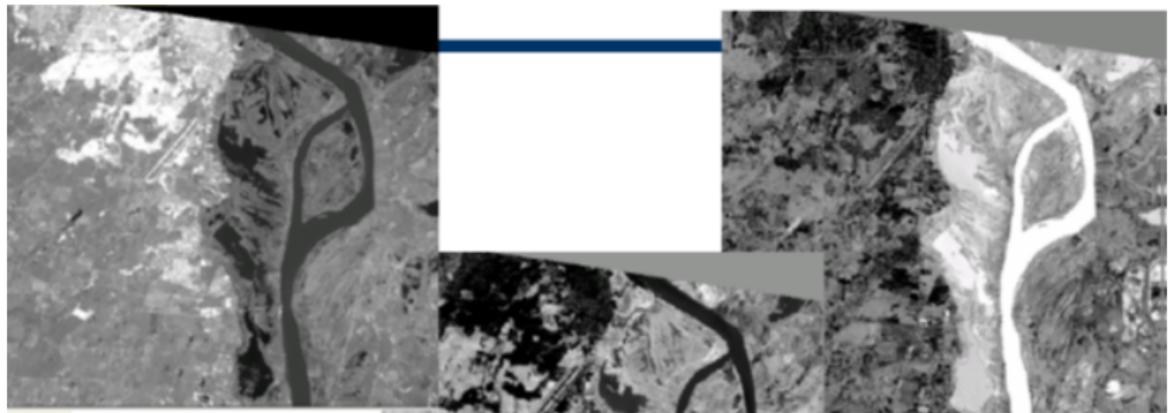
Eigenvectors	PC1	PC2	PC3	PC4	PC5	PC6
<b>TM1</b>	0.190	-0.688	-0.515	-0.260	-0.320	-0.233
<b>TM2</b>	0.183	-0.362	0.032	0.050	0.136	0.902
<b>TM3</b>	0.298	-0.418	0.237	0.385	0.638	-0.354
<b>TM4</b>	0.366	-0.136	0.762	-0.330	-0.389	-0.079
<b>TM5</b>	0.751	0.433	-0.296	-0.318	0.242	0.013
<b>TM7</b>	0.378	0.122	-0.093	0.756	-0.511	0.011
<b>Eigenvalues</b>	4928.731	102.312	15.581	9.011	3.573	1.012
<b>Information</b>	97.4%	2.02%	0.31%	0.18%	0.07%	0.02%

# Tasselled cap



**Fig. 7.5** The tasseled cap transformation coordinate system (Mather, 2004. Reproduced with permission of John Wiley & Sons.)

$$\begin{pmatrix} \text{Brightness} \\ \text{Greenness} \\ \text{Wetness} \end{pmatrix} = \begin{pmatrix} 0.3037 & 0.2793 & 0.4343 & 0.5585 & 0.5082 & 0.1863 \\ -0.2848 & -0.2435 & -0.5436 & 0.7243 & 0.0840 & -0.1800 \\ 0.1509 & 0.1793 & 0.3299 & 0.3406 & -0.7112 & -0.4572 \end{pmatrix} \begin{pmatrix} \text{TMI} \\ \text{TM2} \\ \text{TM3} \\ \text{TM4} \\ \text{TM5} \end{pmatrix}$$



BRILLO

HUMEDAD

VERDOR

# Transformación RGB - IHS

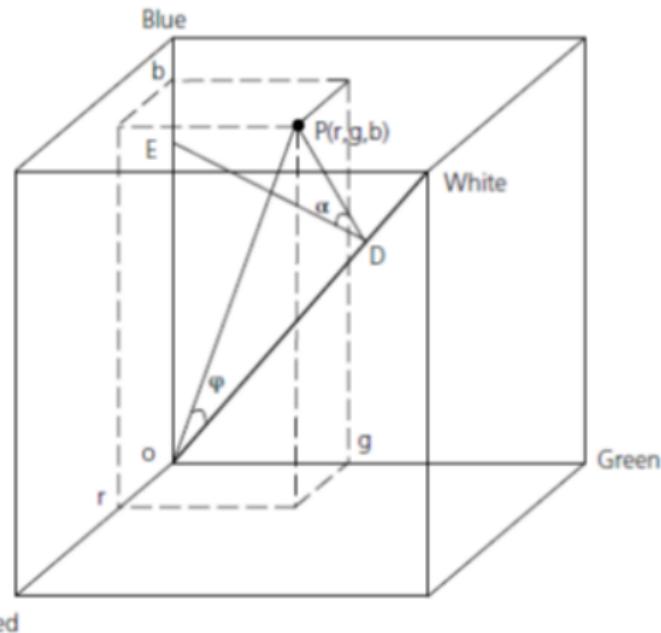


Fig. 5.1 The colour cube model for RGB-IHS transformation.

# Transformación RGB - IHS

