



# GSA-5859 / PCA-5017

## SIG em Software Livre

Sensoriamento Remoto

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2021

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## Definição 1 (INPE)

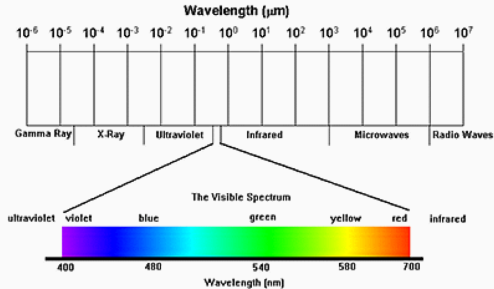
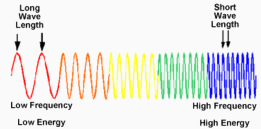
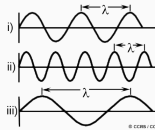
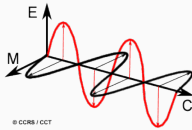
- “Utilização de sensores para aquisição de informações sobre objetos ou fenômenos sem que haja contato direto entre eles”
  - Sensores: são equipamentos capazes de coletar energia proveniente do objeto, convertê-la em sinal passível de ser registrado e apresentá-lo em forma adequada à extração de informações
  - Energia: na grande maioria das vezes é a energia eletromagnética ou radiação eletromagnética



## Definição 2 (INPE)

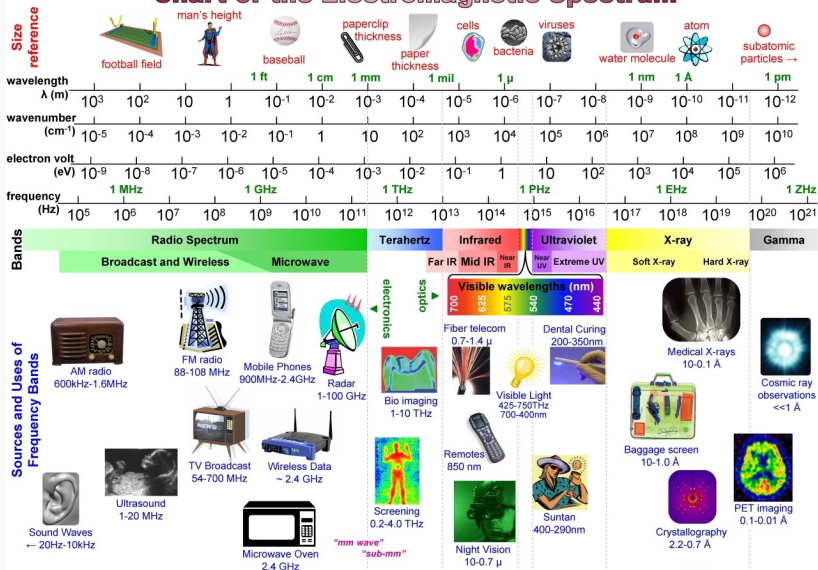
- “Conjunto das atividades relacionadas à aquisição e a análise de dados de sensores remotos”
  - Sensores remotos: sistemas fotográficos ou óptico-eletrônicos capazes de detectar e registrar, sob a forma de imagens ou não, o fluxo de energia radiante refletido ou emitido por objetos distantes

# Radiação Eletromagnética (REM)



# Plain frame

## Chart of the Electromagnetic Spectrum



# Sistema Visual Humano

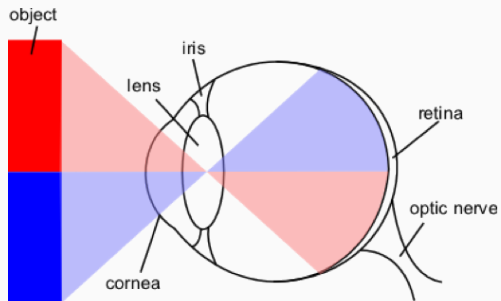
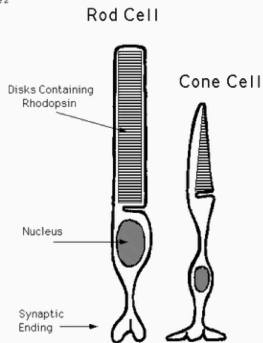


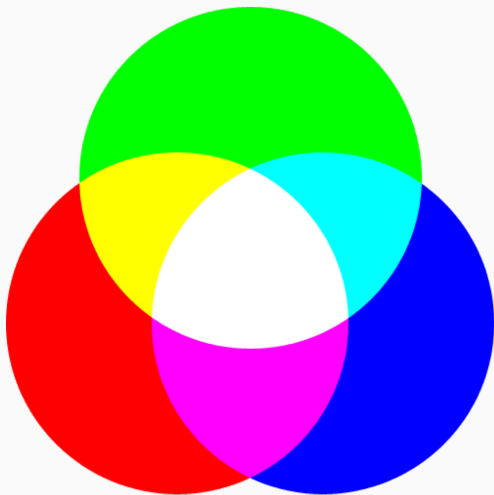
Figure 2



# Sistema Visual Humano

- Bastonetes:  $\sim 100 * 10^6$  por toda a retina, exceto no centro, onde a visão é mais acurada
  - para distinguir a variação no tom de cinza:  $\sim 1\%$
  - aprox. 100 tons de cinza (idealmente)
- Cones:  $\sim 6 - 7 * 10^6$  principalmente no centro da retina
  - só funcionam com luminosidade (com pouca luz, enxergamos em tons de cinza)
  - aprox. 100 tonalidades cada tipo
  - 3 tipos: Vermelho, Verde, Azul =  $\sim 1.000.000$  cores !!
  - Somos seres Tricromáticos – enxergamos a partir de 3 cores

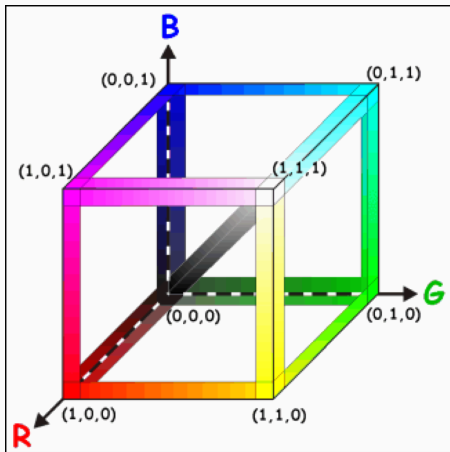
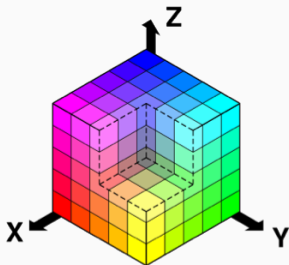
## Sistema de Cores Aditivo (RGB)



## Sistema de Cores Subtrativo (CMYK)

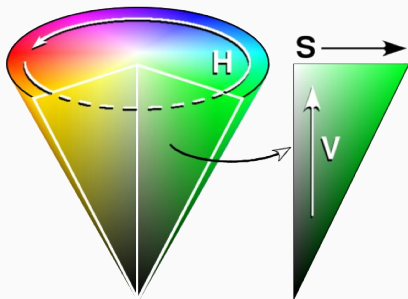
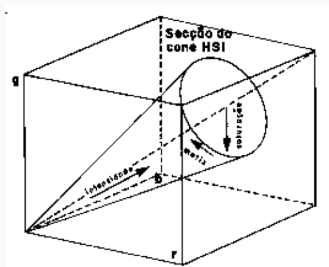


# Sistema de Cores – Cubo RGB



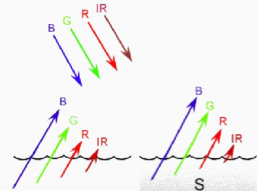
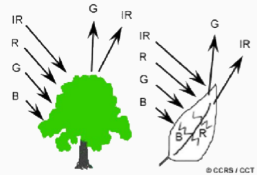


# Sistema de Cores – Cone IHS



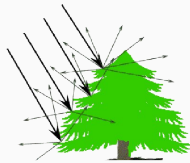
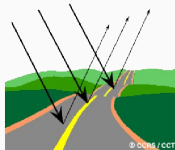
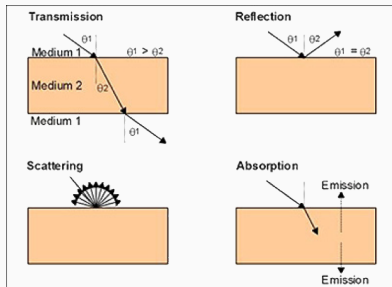
# Cores dos objetos

- Cor do objeto depende do comprimento de onda refletido
- folhas: clorofila
  - absorve R e B
  - reflete G e NIR
- água
  - absorve G+R+NIR (comp. onda longos do visível)
  - presença de algas ou sedimentos



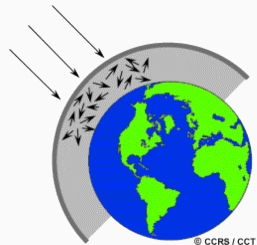
# Comportamento da REM

- Transmissão
- Reflexão (especular/difusa)
- Espalhamento
- Absorção



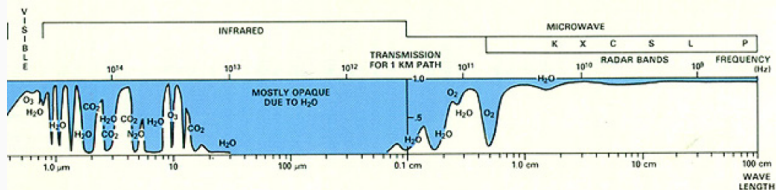
# Espalhamento Atmosférico

- Espalhamento de Rayleigh
  - principal efeito de espalhamento atmosférico
  - partículas dispersas são muito menores que o comprimento de onda da REM (poeira, O<sub>2</sub>, N<sub>2</sub>, H<sub>2</sub>O)
  - comprimentos de onda pequenos (UV, azul) sofrem muito mais espalhamento que comprimentos de onda maiores
- Espalhamento Não-Seletivo
  - afeta todos os comprimentos de onda
  - nuvens brancas



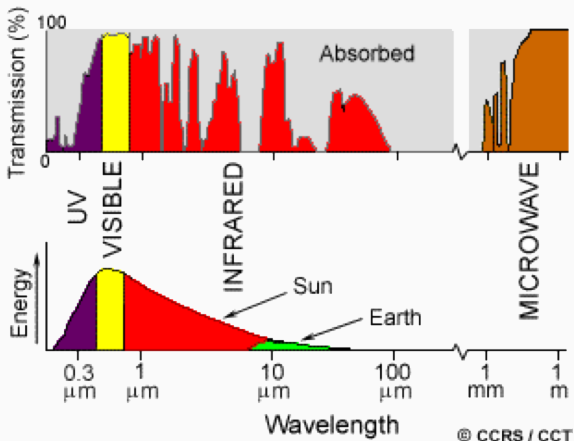
# Janelas Atmosféricas

- Transmissão da REM pela atmosfera não é contínua
- Existem “janelas” criadas pela absorção da REM, principalmente pela água



# Janelas Atmosféricas

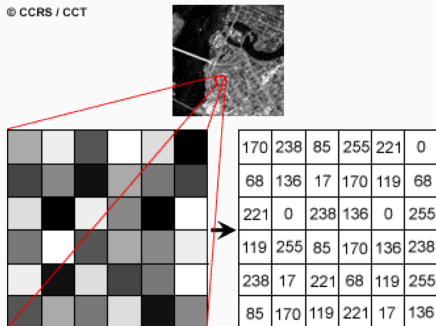
- Energia das fontes (Sol, Terra) x janelas atm.
- Determinar os melhores comp. onda para SR
- Visível: janela + pico de energia solar



# Imagem Digital

- matriz de pixels (raster)
- valor do pixel – digital number (DN)
- radiância no sensor
- imagem 8bits
  - $2^8=256$  (0-255)
  - 256 tons de cinza
  - 0 = preto
  - 255 = branco

© CCRS / CCT



# Imagens Multiespectrais

- Sensores captam diferentes faixas do espectro
- Cada faixa é armazenada em uma **banda**
- Cada banda é representada em tons de cinza
- A fusão das bandas gera a imagem colorida
- pixel = picture element





# Imagem RGB - Banda R



# Imagem RGB - Banda G



## Imagem RGB - Banda B



# Sensores e Satélites

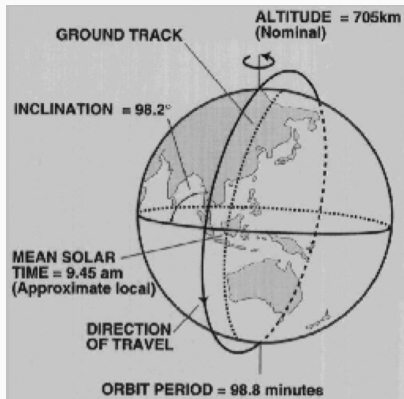
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# Tipos de Sensores

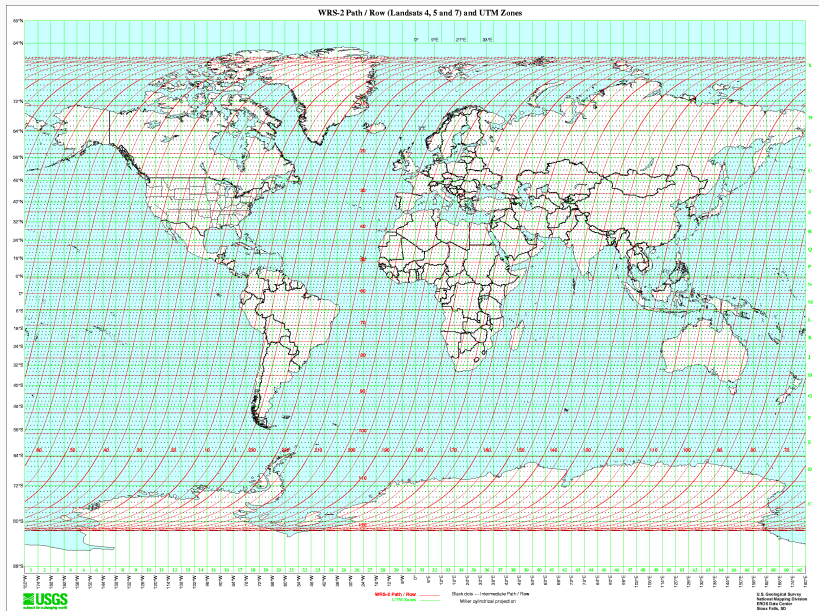
- **Fotográficos**
  - Imagem é capturada de uma só vez
- **Não-Fotográficos**
  - Imagem capturada pixel a pixel (scanner)
  
- **Sensores Passivos**
  - Registram energia refletida por fontes naturais (Sol)
  - maioria
- **Sensores Ativos**
  - Emitem sua própria energia e registram o sinal refletido
  - RADAR, LiDAR
  - Podem ser usados à noite
  
- **Plataformas**
  - Terrestre
  - Aeroportado
  - Orbital (Satélite, Ônibus espacial, OVNI...)

# Satélites - Órbitas

- Órbita – altitude da órbita determina campo de visão e período de revisita
- Geoestacionários – 36.000km altitude
- Heliossincrônicos – órbita acompanha horário local do sol
- órbitas:
  - descendente – dia
  - ascendente – noite
- Worldwide Reference System 2 (WRS2)

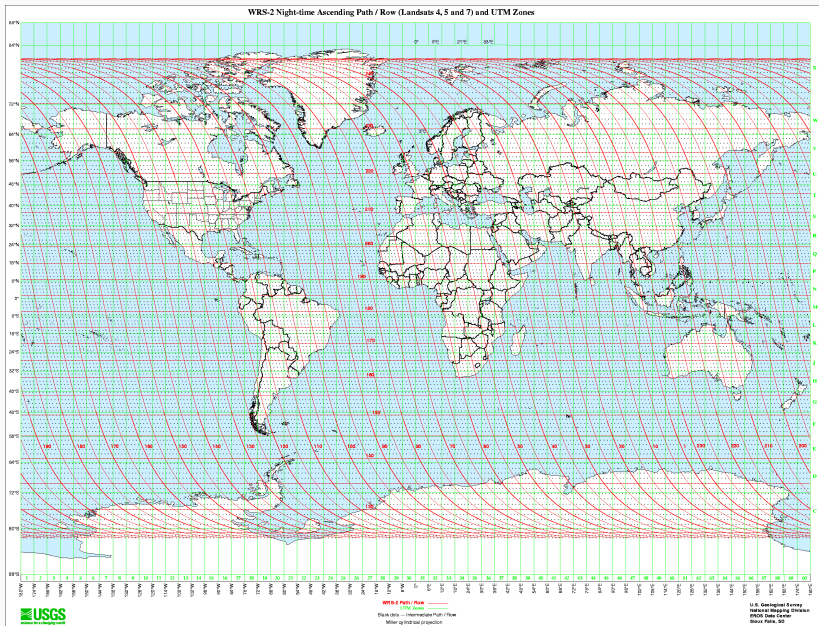


# WRS2 - Órbitas Descendentes



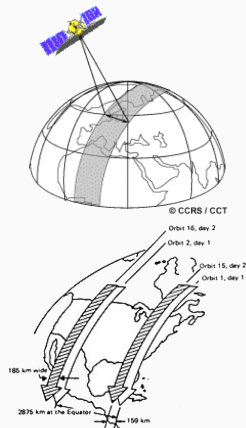


# WRS2 - Órbitas Ascendentes



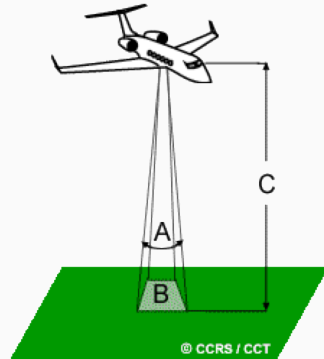
# Satélites - Características

- swath - faixa imageada
- largura de dezenas a centenas de km
- período de revisita:
- tempo para imagear a mesma área (nadir) duas vezes
- overlap – área próximas dos pólos são imageadas mais frequentemente



# Satélites - Resolução Espacial

- Resolução espacial – determina o tamanho do menor objeto que podemos reconhecer em uma imagem (tamanho do pixel)
- IFOV (Instantaneous Field Of View) – cone de visibilidade do sensor
- Altitude do sensor
- $B=C*A$



# Satélites - Resolução Espacial

baixa

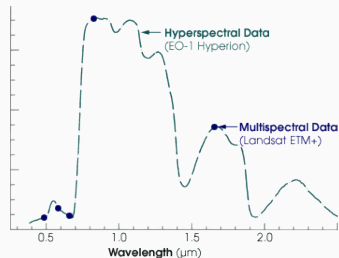
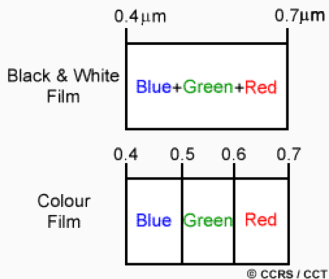


alta



# Satélites - Resolução Espectral

- Resolução espectral - Capacidade do sensor em separar faixas no espectro EM
- Sensores Multiespectrais – 3...20 bandas
- Sensores Hiperespectrais – centenas !!



# Satélites - Resolução Radiométrica

- Resolução radiométrica - Capacidade do sensor em diferenciar variação na intensidade de energia

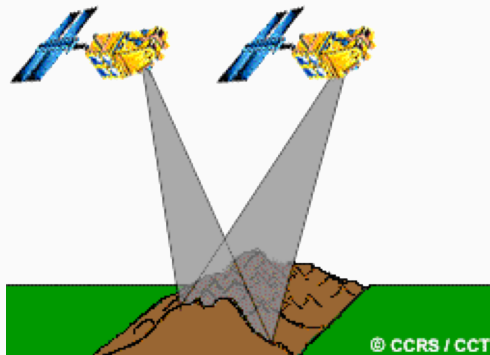
2 bits - 4 tons de cinza

8 bits - 256 tons de cinza



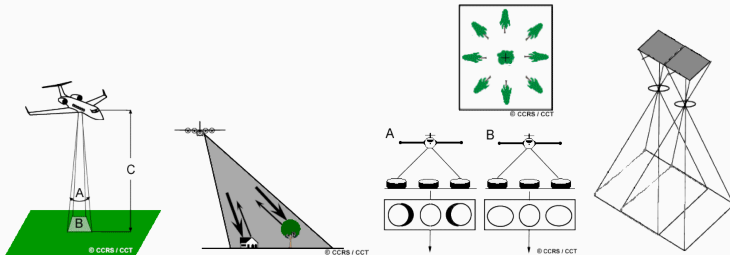
# Satélites - Resolução Temporal

- Resolução temporal - Período de revisita
- Varia com a latitude, sobreposição entre faixas adjacentes e capacidade do sensor em off-nadir



# Sistemas de Imageamento - Fotografias Aéreas

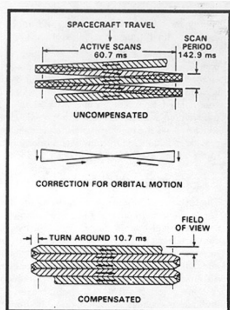
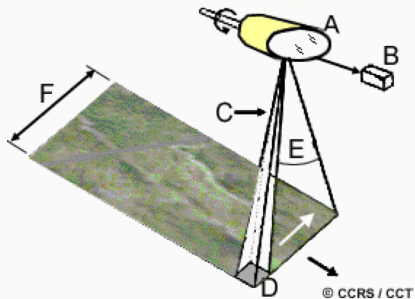
- Alta resolução espacial
- Efeitos de distorção nas bordas
- Sobreposição: estereoscopia
- Fotografias digitais





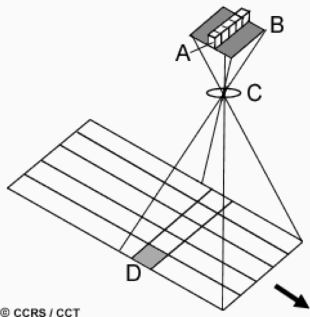
# Sistemas de Imageamento - Sensores Multiespectrais (MSS)

- Across-track scanners
- Série de linhas perpendiculares ao movimento do sensor
- Espelho rotativo



# Sistemas de Imageamento - Sensores Multiespectrais (MSS)

- Along-track scanners (pushbroom scanners)
- Array linear de sensores “empurrados” na direção do movimento
- Sensores “vêm” os objetos por mais tempo
- Calibração de centenas de sensores individuais



# Operações em SR

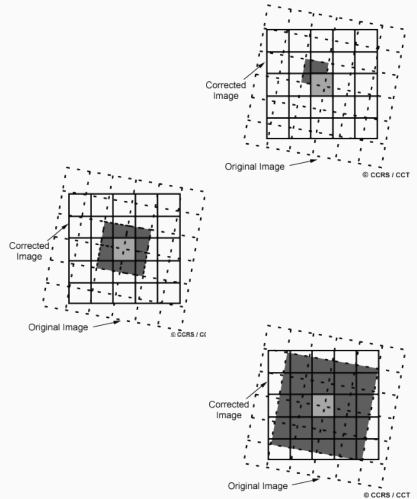
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# Operações em SR

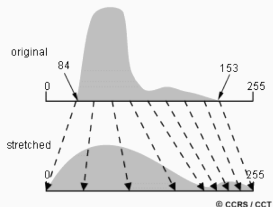
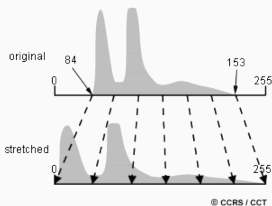
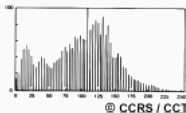
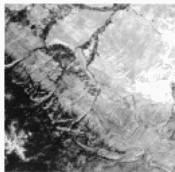
- Pré-Processamento
  - Conversão radiância-reflectância
  - Correção Atmosférica
  
- Registro
- Realce
- Filtragem
- Composições
  - RGB
  - IHS

# Georreferenciamento

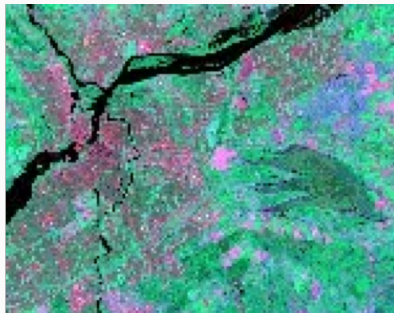
- Registro  
(Georreferenciamento)
- Correção geométrica
- Projeção cartográfica
- Ground Control Points (GCPs)
- image-to-map /  
image-to-image
- Vizinho mais próximo
- Interpolação bilinear
- Convolução cúbica



- Histograma – representação dos DNs
- Função de transferência de contraste (stretch)
  - linear
  - equalizada

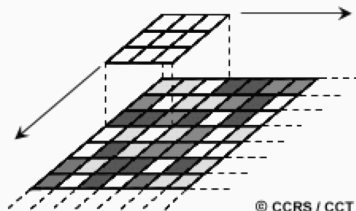


# Realce Linear



# Filtragem espacial

- Janelas Móveis (moving-windows)
- 3x3, 5x5,...
- Freqüência espacial
  - alta freqüência: rodovias, bordas
  - baixa freqüência: áreas homogêneas
- Passa-baixas: média, moda
- Passa-altas: laplacianos
- Direcionais





## Filtro de média – passa-baixas

25	27	32	20	21	19	24
23	27	19	25	22	18	25
27	26	24	26	22	22	26
23	25	28	30	27	25	27
19	22	28	32	29	27	25
17	19	25	27	30	31	22
20	21	25	23	21	19	17

Imagem original

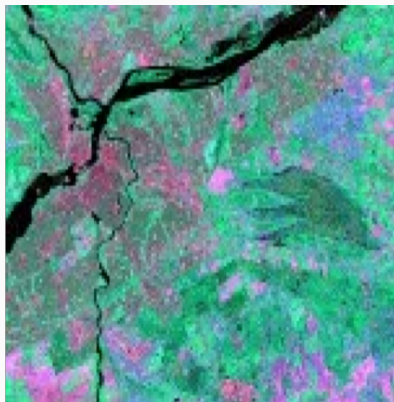
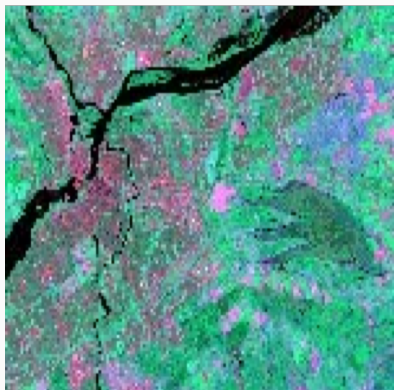
	26	25	23	22	22	
	25	26	25	24	26	
	25	27	27	27	26	
	23	26	28	29	27	
	22	25	27	27	25	

Imagem filtrada

Pixel central = 1/9

$$\left[ \begin{array}{l} 24 + 26 + 22 \\ + 28 + 30 + 27 \\ + 28 + 32 + 29 \end{array} \right] = 27$$

## Filtro de média – passa-baixas



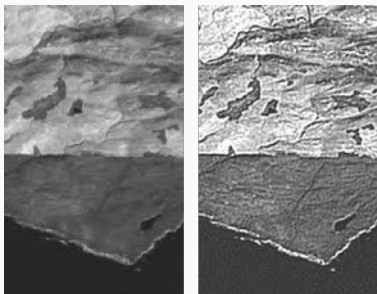
# Filtro laplaciano – passa-altas

Exemplos de filtros Laplacianos:

0	-1	0	-1	-1	-1	1	-2	1
-1	4	-1	-1	8	-1	-2	4	-2
0	-1	0	-1	-1	-1	1	-2	1

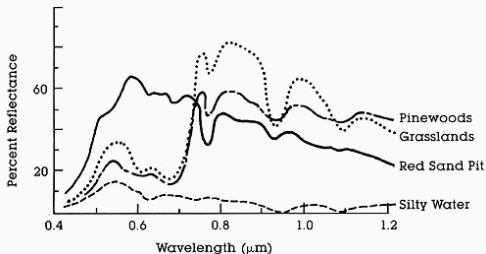
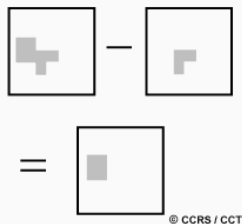
Exemplos de filtros Laplacianos + Original

0	-1	0	-1	-1	-1	1	-2	1
-1	5	-1	-1	9	-1	-2	5	-2
0	-1	0	-1	-1	-1	1	-2	1



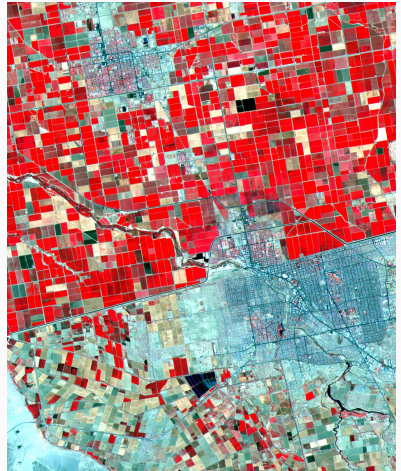
# Operações Aritméticas

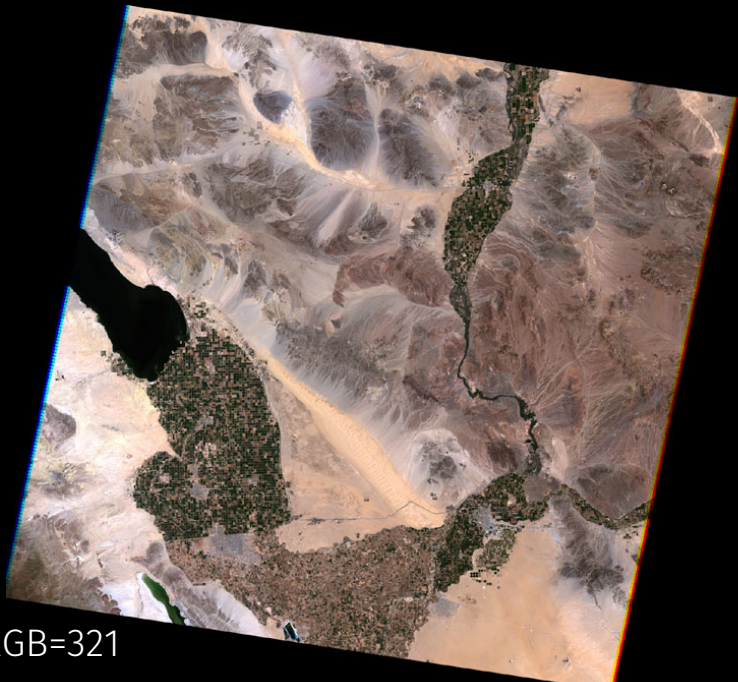
- Subtração: mais usada em análise temporal
- Razão: realça diferenças de comportamentos espectrais



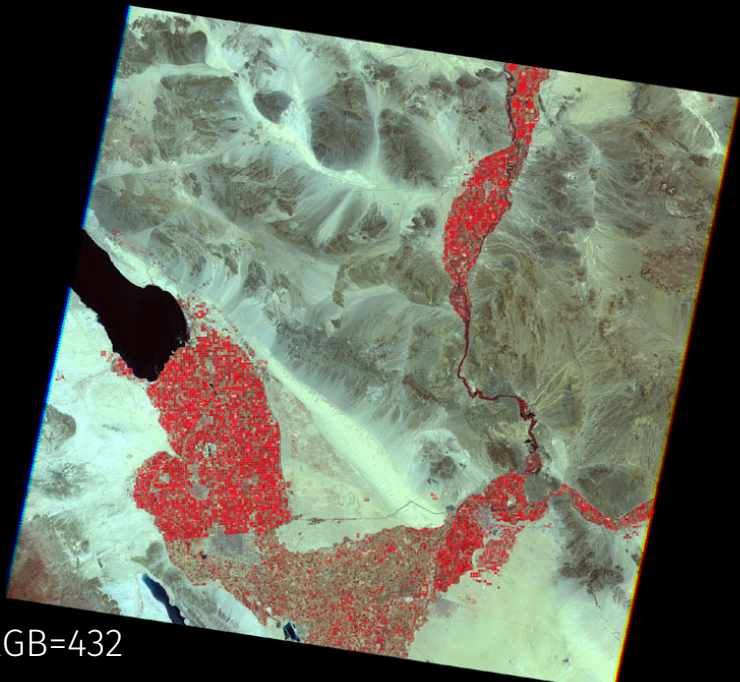
# Composição RGB

- Ressaltar diferentes respostas espectrais
- feição de interesse: **vermelho**

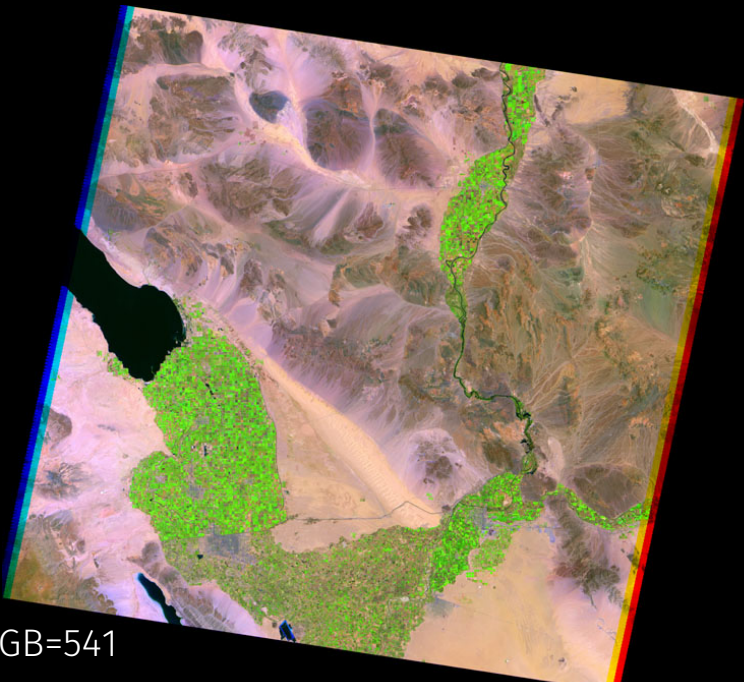




RGB=321

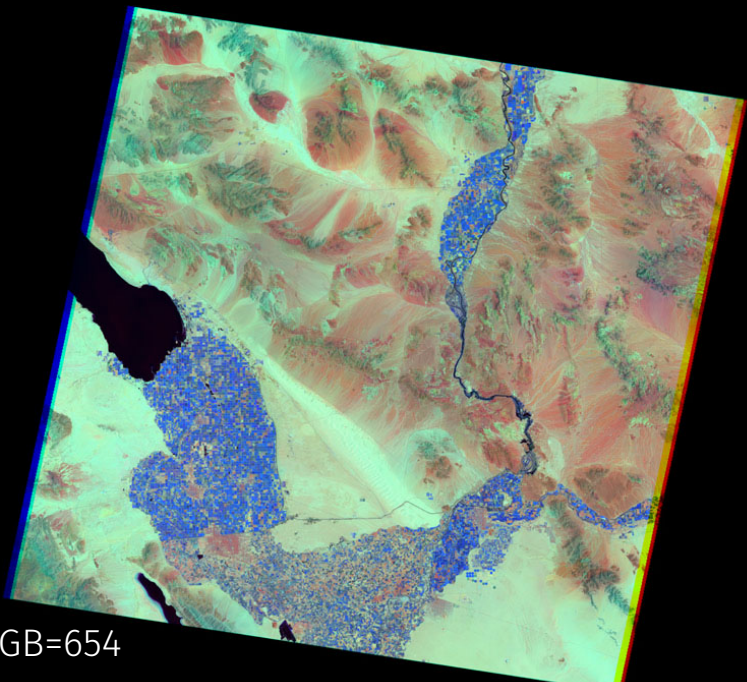


RGB=432



RGB=541

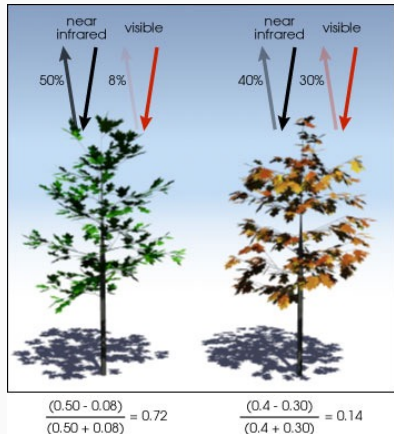




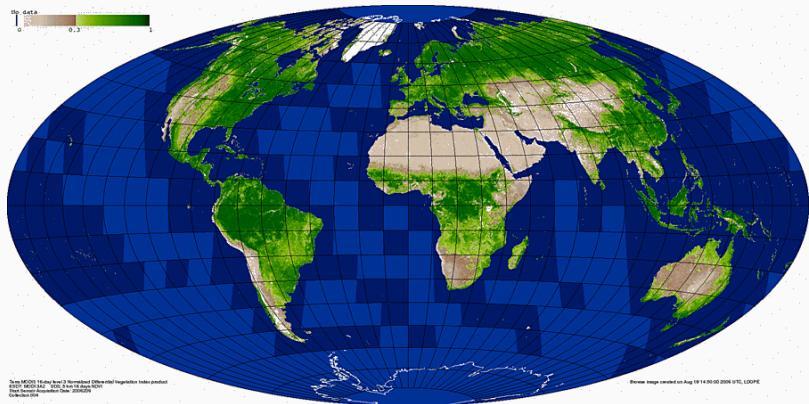
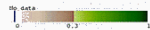
RGB=654

# Índices de Vegetação

- Normalized Difference Vegetation Index (NDVI)
- $NDVI = (NIR - R) / (NIR + R)$
- TN/ETM+
  - $NDVI = (4 - 3) / (4 + 3)$
- AVHRR
  - $NDVI = (2 - 1) / (2 + 1)$
- MODIS
  - $NDVI = (2 - 1) / (2 + 1)$



# NDVI



# Composição IHS

- Composições IHS (ou HSV, HSB..)
- Pan-sharpening
- Adicionar informação textural da banda pan à informação textural das bandas multiespectrais
- RGB p/ IHS
- substitui o canal de Intensidade pela banda Pan
- IHS p/ RGB

# Pan-sharpening

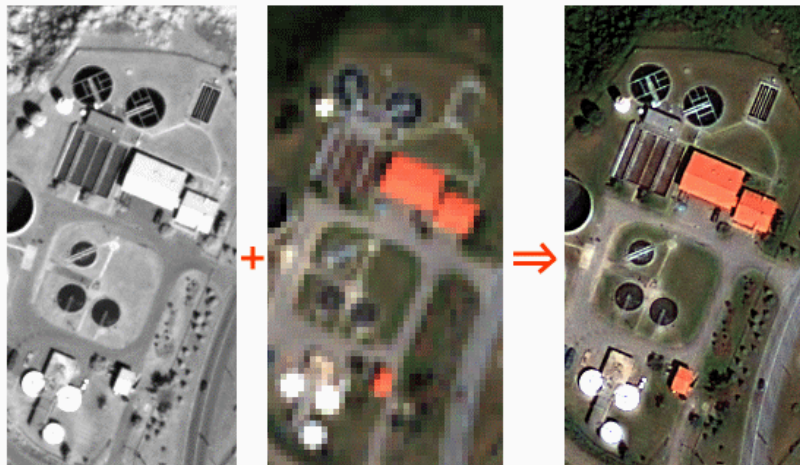


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# Pan-sharpening



# Principais Satélites e Sensores

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- Meteorológicos
  - GOES, AVHRR
- Recursos Terrestres
  - Landsat, SPOT, CBERS, ASTER, Sentinel
  - RADAR – Radarsat, JERS, SRTM, Sentinel
- Alta Resolução
  - Ikonos, QuickBird, WorldView, Planet
- Hiperespectrais
  - Hyperion



## GOES - Geostationary Operational Environmental Satellite

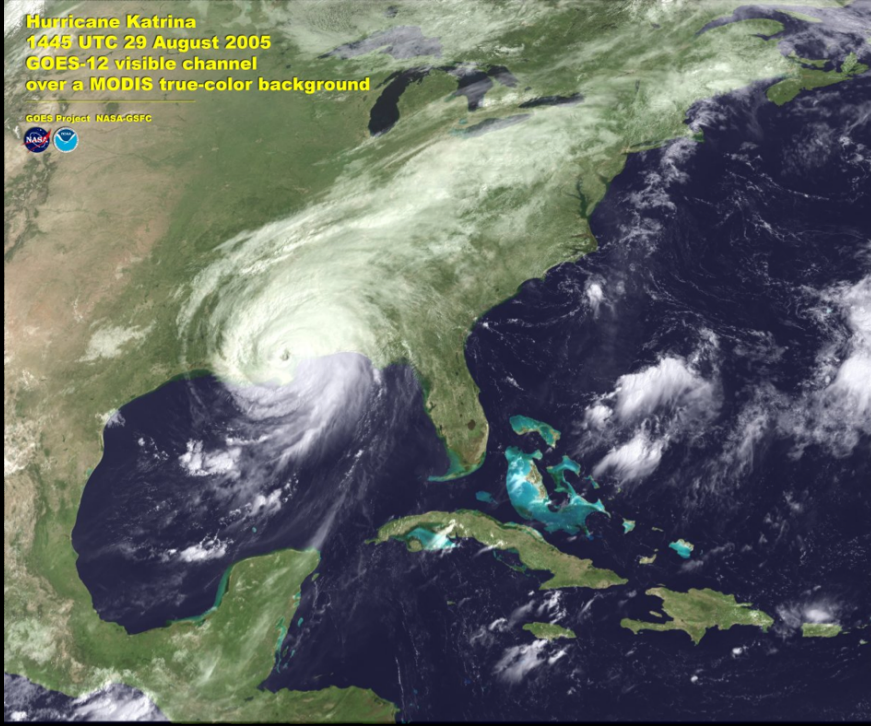
<b>Band</b>	<b>Wavelength Range (&gt;<math>\mu</math>m)</b>	<b>Spatial Resolution</b>	<b>Application</b>
1	0.52 - 0.72 (visible)	1 km	cloud, pollution, and haze detection; severe storm identification
2	3.78 - 4.03 (shortwave IR)	4 km	identification of fog at night; discriminating water clouds and snow or ice clouds during daytime; detecting fires and volcanoes; night time determination of sea surface temperatures
3	6.47 - 7.02 (upper level water vapour)	4 km	estimating regions of mid-level moisture content and advection; tracking mid-level atmospheric motion
4	10.2 - 11.2 (longwave IR)	4 km	identifying cloud-drift winds, severe storms, and heavy rainfall
5	11.5 - 12.5 (IR window sensitive to water vapour)	4 km	identification of low-level moisture; determination of sea surface temperature; detection of airborne dust and volcanic ash

## NOAA AVHRR - Advanced Very High Resolution Radiometer

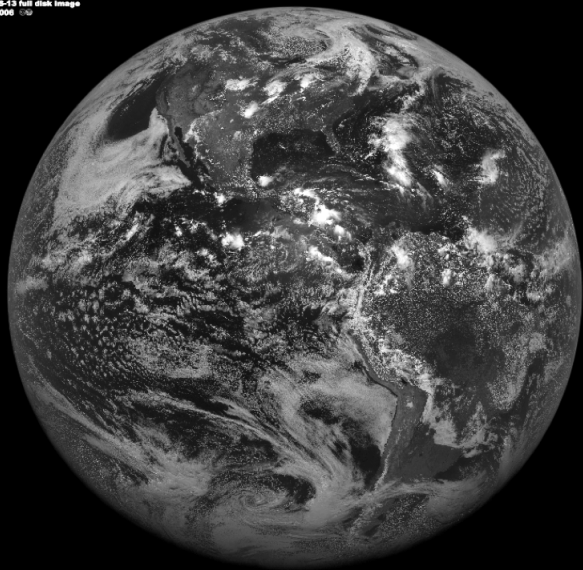
<b>Band</b>	<b>Wavelength Range (<math>\mu\text{m}</math>)</b>	<b>Spatial Resolution</b>	<b>Application</b>
1	0.58 - 0.68 (red)	1.1 km	cloud, snow, and ice monitoring
2	0.725 - 1.1 (near IR)	1.1 km	water, vegetation, and agriculture surveys
3	3.55 - 3.93 (mid IR)	1.1 km	sea surface temperature, volcanoes, and forest fire activity
4	10.3 - 11.3 (thermal IR)	1.1 km	sea surface temperature, soil moisture
5	11.5 - 12.5 (thermal IR)	1.1 km	sea surface temperature, soil moisture

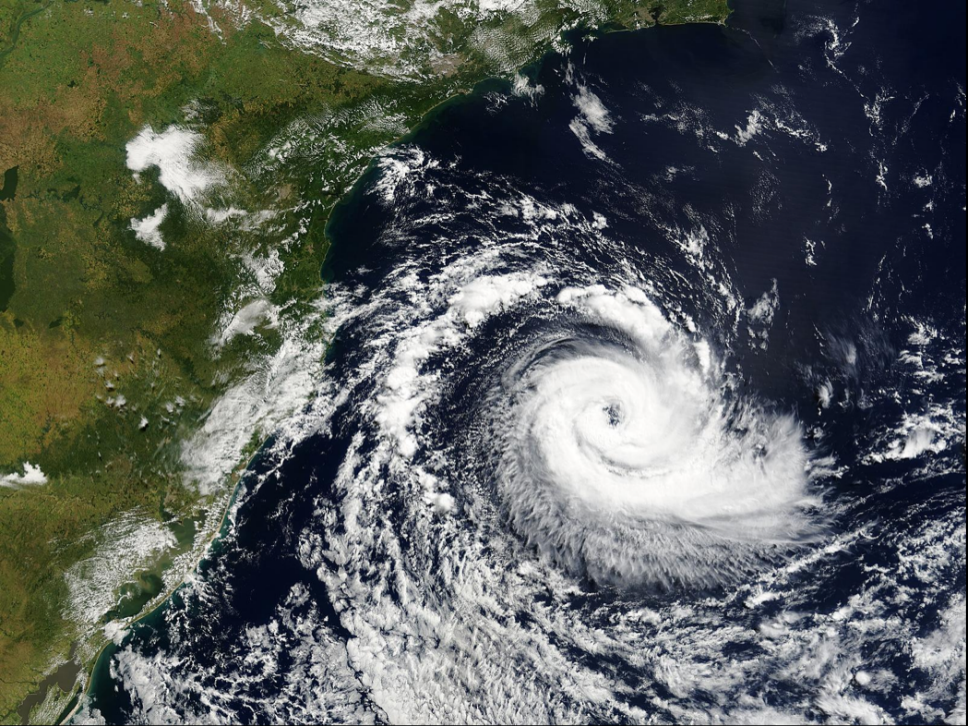
**Hurricane Katrina**  
**1445 UTC 29 August 2005**  
**GOES-12 visible channel**  
**over a MODIS true-color background**

GOES Project NASA/GSFC



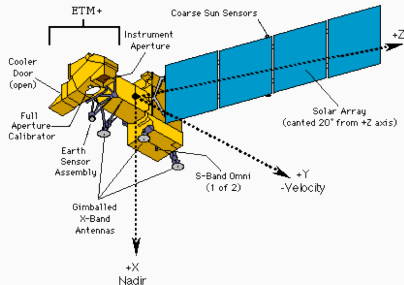
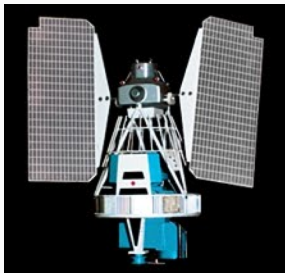
First GOES-13 full disk image  
22 June 2006 01:00



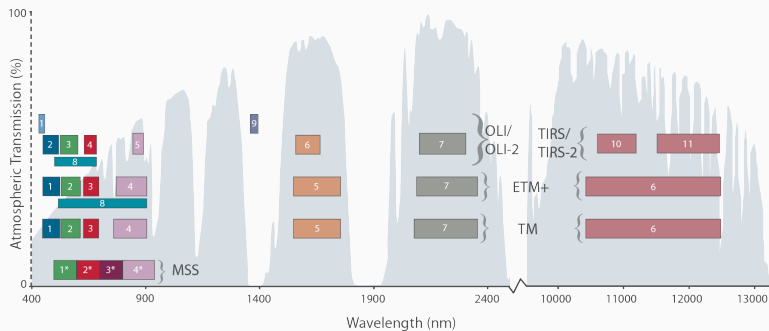


# Recursos Terrestres – Landsat

- Landsat 1 – 1972 – sensor MSS (MultiSpectral Scanne)
- Landsat 5 – 1984 – sensor TM (Thematic Mapper)
- Landsat 7 – 1999 – sensor ETM+ (Enhanced Thematic Mapper plus)
- Landsat 8 – 2013 – sensor OLI (Operational Land Imager)
- Landsat 9 – 2021/09 - sensor OLI-2

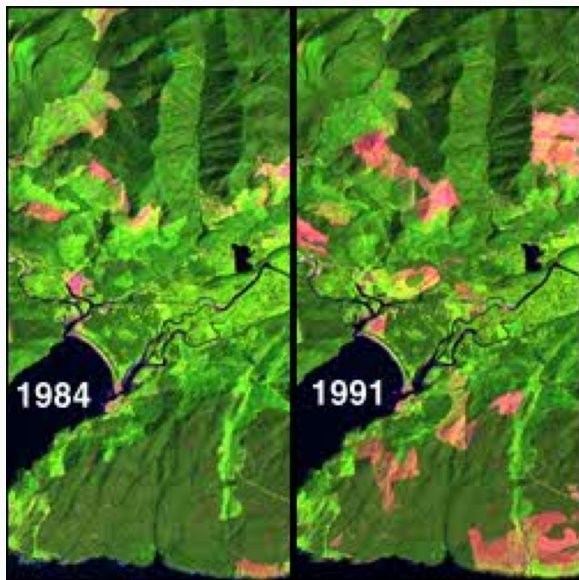


# Landsat - bandas

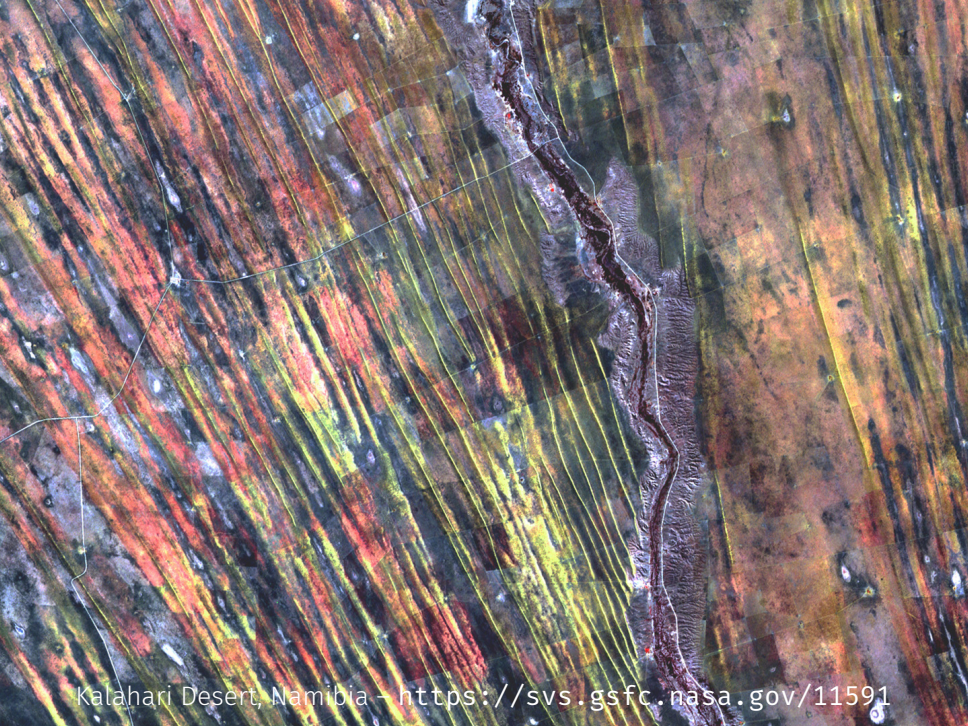


https:

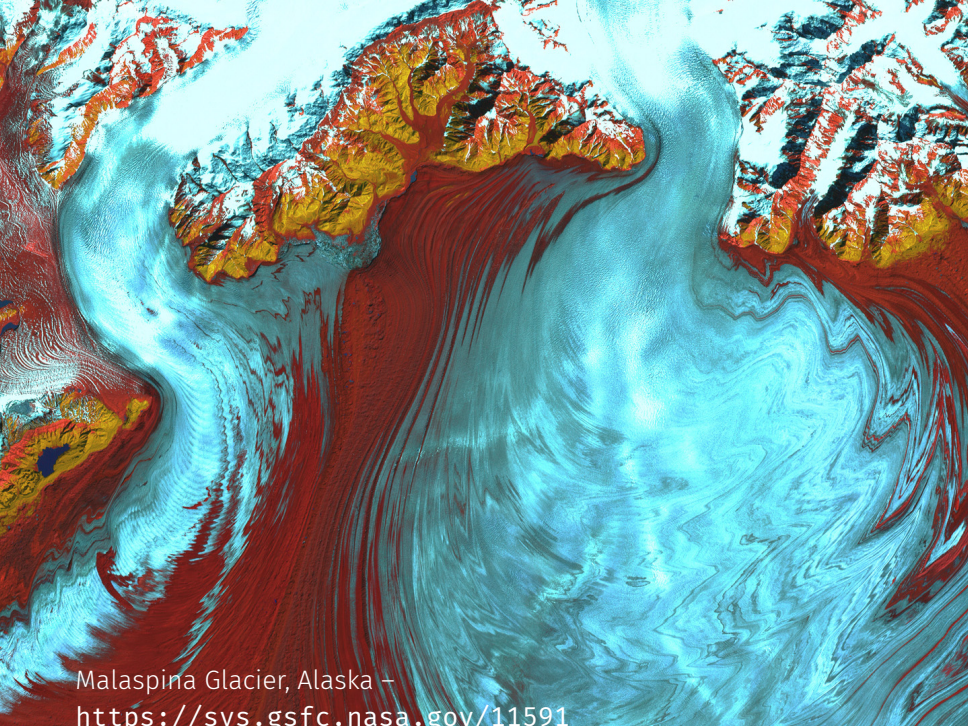
//landsat.gsfc.nasa.gov/landsat-9/landsat-9-spectral-bands





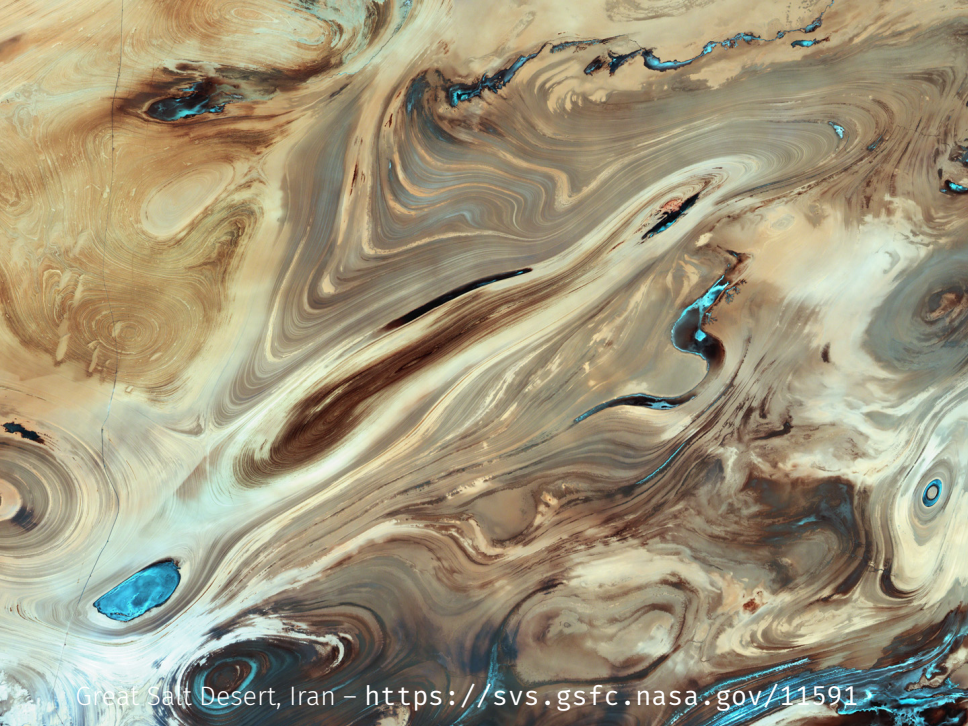


Kalahari Desert, Namibia – <https://svs.gsfc.nasa.gov/11591>



Malaspina Glacier, Alaska –  
<https://svs.gsfc.nasa.gov/11591>





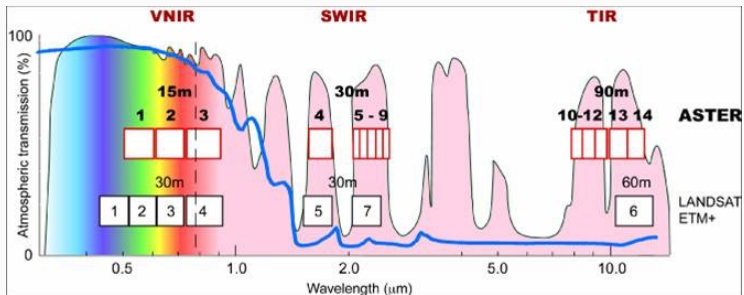
Great Salt Desert, Iran – <https://svs.gsfc.nasa.gov/11591>

- EOS AM-1
  - ASTER - Advanced Spaceborne Thermal Emission and Reflection Radiometer
  - CERES - Clouds and the Earth's Radiant Energy System
  - MISR - Multi-angle Imaging SpectroRadiometer
  - MODIS - Moderate-resolution Imaging Spectroradiometer
  - MOPITT - Measurements of Pollution in the Troposphere

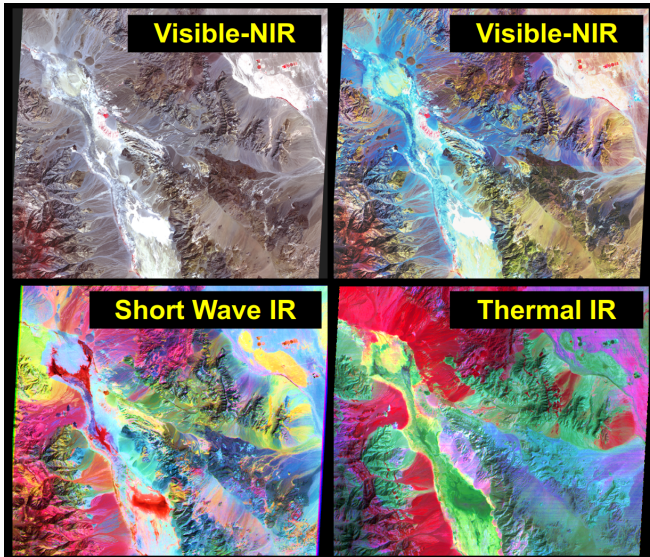
## ASTER - Advanced Spaceborne Thermal Emission and Reflection Radiometer

Subsystem	Band No.	Spectral Range ( $\mu\text{m}$ )	Spatial Resolution, m	Quantization Levels
VNIR	1	0.52-0.60	15	8 bits
	2	0.63-0.69		
	3N	0.78-0.86		
	3B	0.78-0.86		
SWIR	4	1.60-1.70	30	8 bits
	5	2.145-2.185		
	6	2.185-2.225		
	7	2.235-2.285		
	8	2.295-2.365		
	9	2.360-2.430		
TIR	10	8.125-8.475	90	12 bits
	11	8.475-8.825		
	12	8.925-9.275		
	13	10.25-10.95		
	14	10.95-11.65		

# ASTER

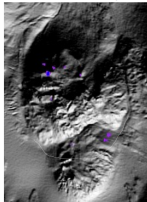


# ASTER – composições coloridas



# ASTER – monitoramento de vulcões

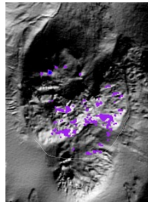
09-24-2004 – 4:30pm



Boundary of Old Dome

High = 51 °C

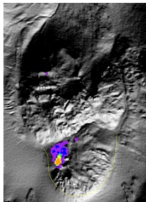
09-30-2004 – 1:30pm



Boundary of Old Dome

High = 54 °C

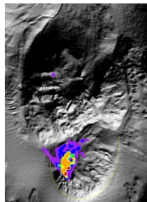
10-12-2004 – 8:00am



Boundary of New Dome

High = 181 °C

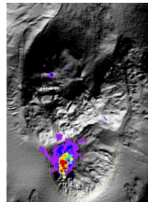
10-14-2004 – 8:00am



Boundary of New Dome

High = 250 °C

10-14-2004 – 12:45pm



Boundary of New Dome

High = 330 °C

60-75 °C

45-60 °C

30-45 °C

105-150 °C

90-105 °C

75-90 °C

> 300 °C

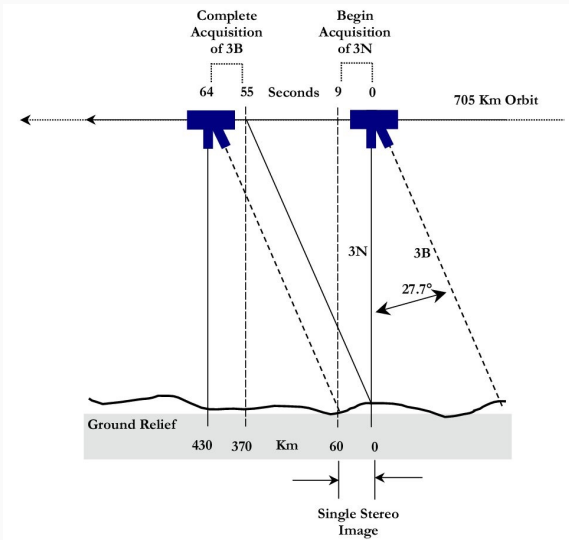
200-300 °C

150-200 °C

Courtesy of Greg Vaughan, JPL

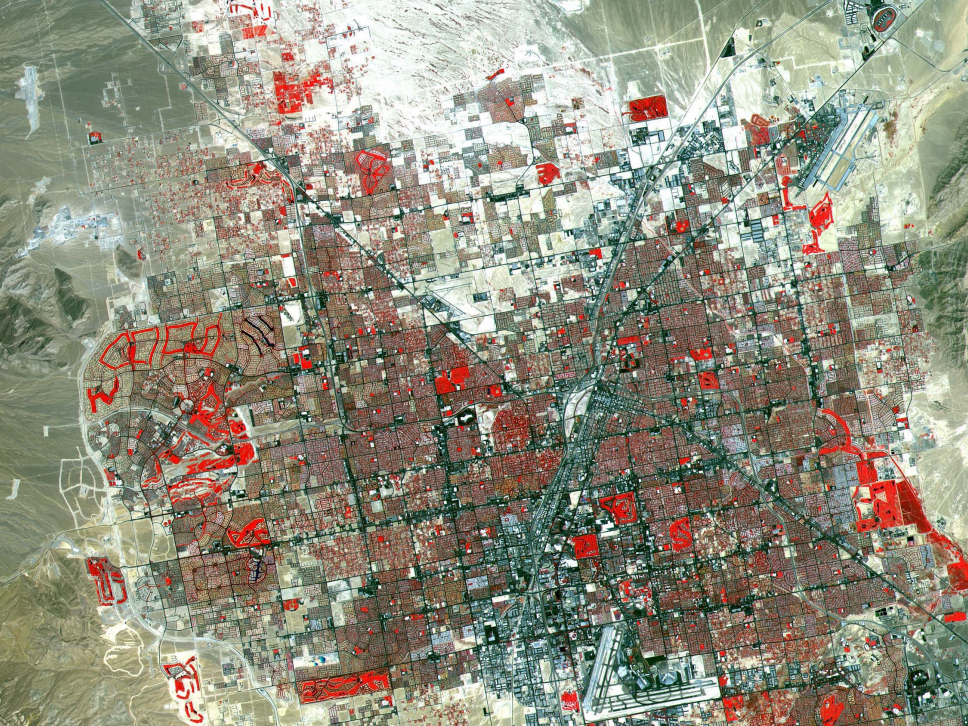


# ASTER – estereoscopia

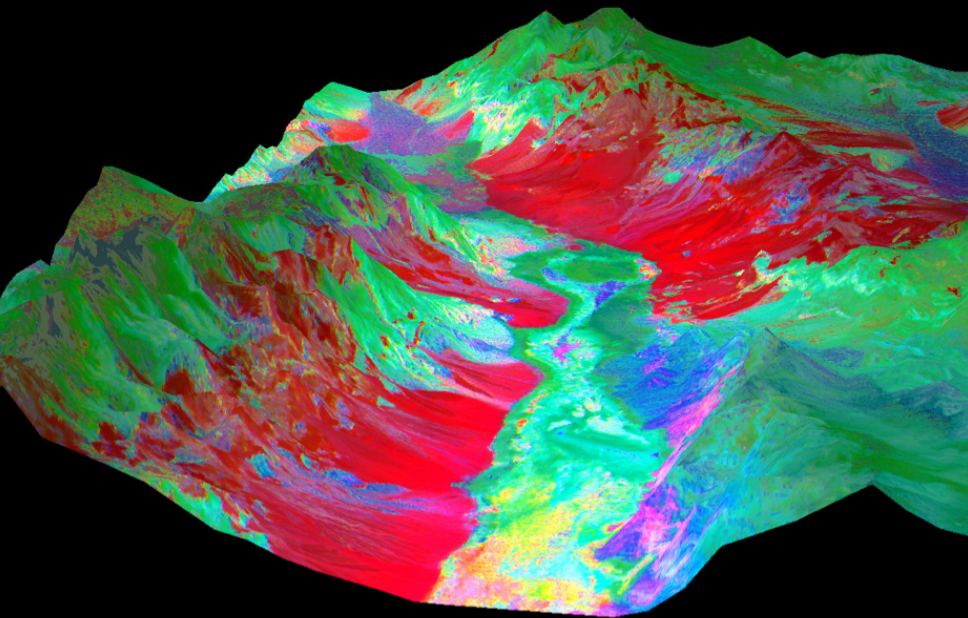








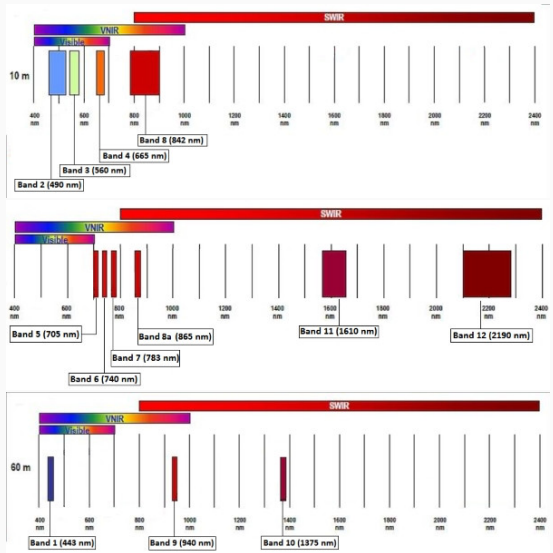




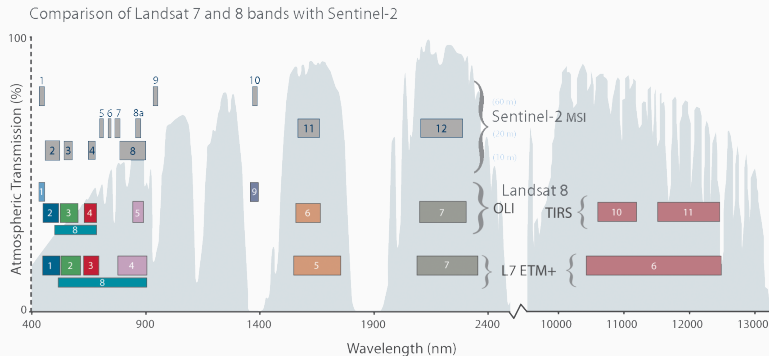
# Recursos Terrestres – Sentinel 2A/2B

- ESA Copernicus

- 10m, 20m, 60m
- 13 bandas
- revisita 10 días



# Sentinel - bandas

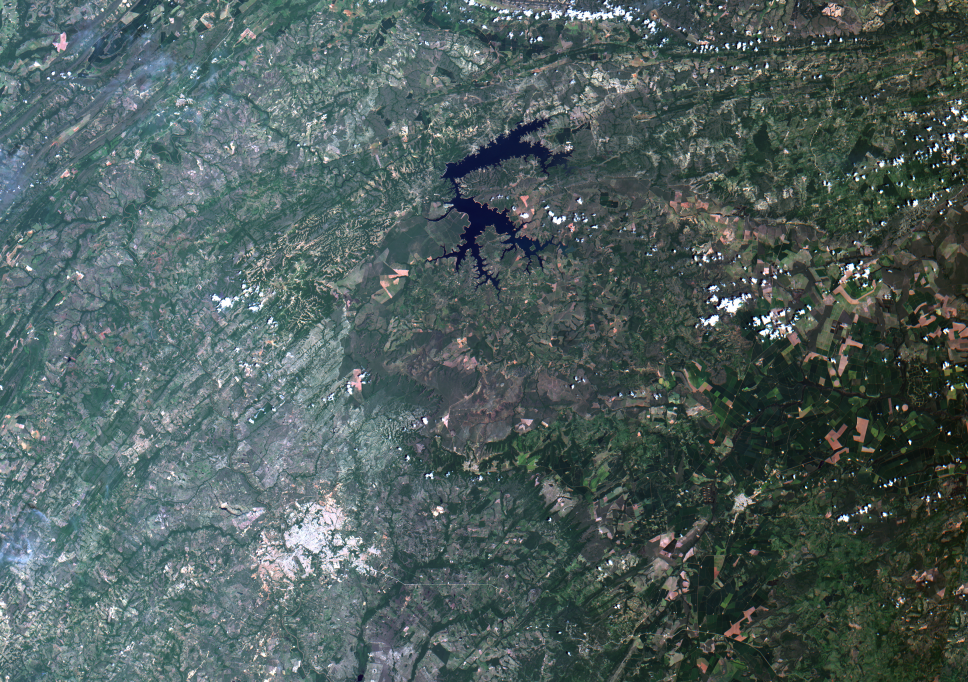


# Recursos Terrestres – CBERS

- China-Brazil Earth Resources Satellite
- políticas de imagens gratuitas

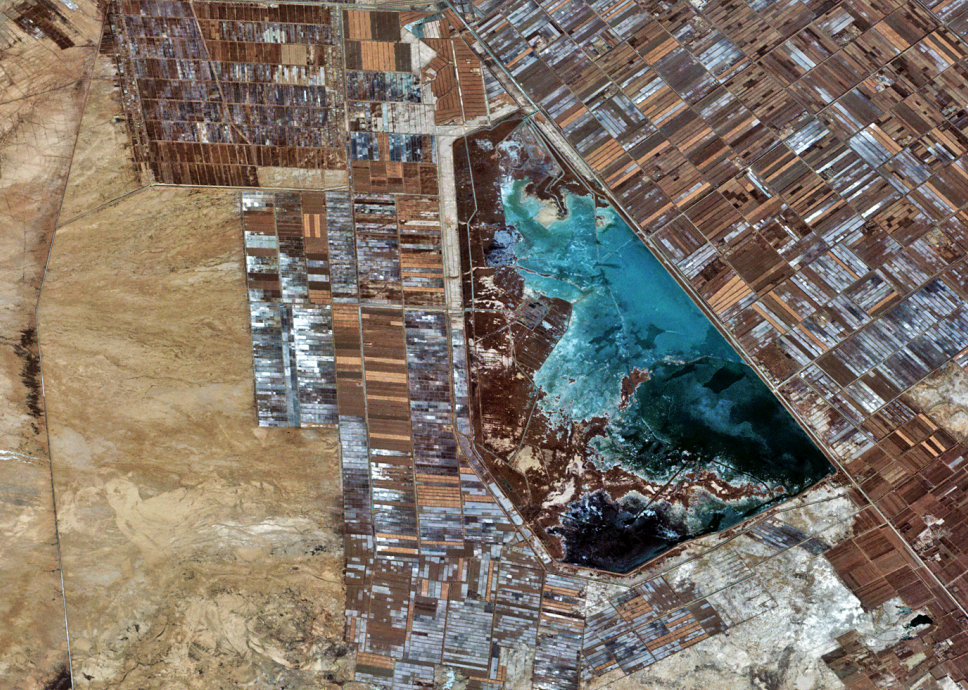
Características das câmeras do CBERS 04A			
Característica	WPM	MUX	WFI
Bandas Espectrais	0,45-0,52 $\mu$ m (B) 0,52-0,59 $\mu$ m (G) 0,63-0,69 $\mu$ m (R) 0,77-0,89 $\mu$ m (NIR) 0,45-0,90 $\mu$ m (PAN)	0,45-0,52 $\mu$ m (B) 0,52-0,59 $\mu$ m (G) 0,63-0,69 $\mu$ m (R) 0,77-0,89 $\mu$ m (NIR)	0,45-0,52 $\mu$ m (B) 0,52-0,59 $\mu$ m (G) 0,63-0,69 $\mu$ m (R) 0,77-0,89 $\mu$ m (NIR)
Resolução	2 m 8 m	16,5 m	55 m
Largura da Faixa Imageada	92 km	95 km	684 km
Visada Lateral de Espelho	não	não	não
Revisita	31 dias	31 dias	5 dias
Quantização	10 bits	8 bits	10 bits
Taxa de Dados Bruta	1800.8 Mbps 450.2 Mbps	65 Mbps	50 Mbps













Primavera do Leste, MT –

## Alta Resolução - Ikonos

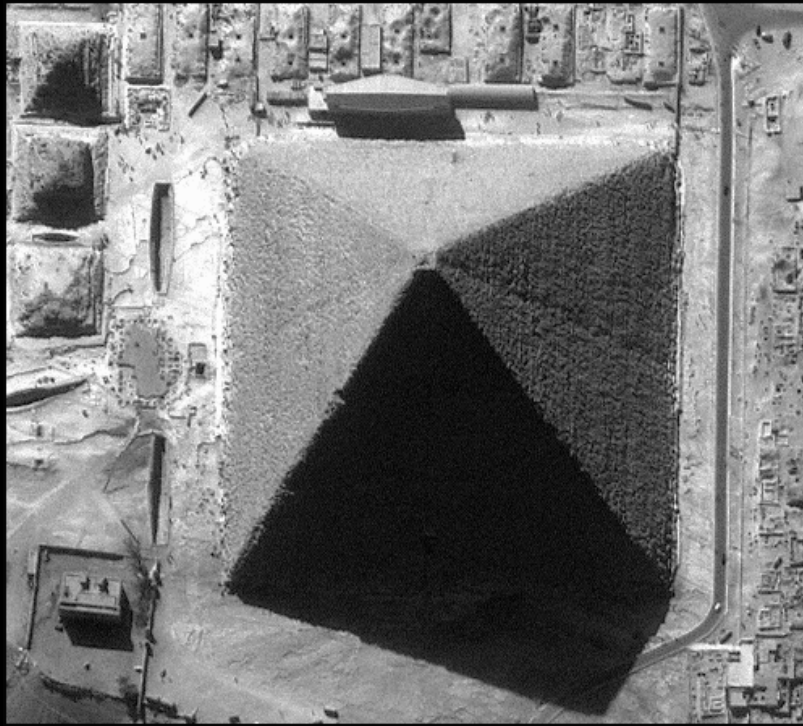
- 0.82m PAN, 3.2m MS
- 3-5 dias off-nadir, 144 dias nadir

<b>Band</b>	<b>1-m PAN</b>	<b>4-m MS &amp; 1-m PS</b>
1 (Blue)	0.45-0.90 $\mu\text{m}$	0.445-0.516 $\mu\text{m}$
2 (Green)	*	0.506-0.595 $\mu\text{m}$
3 (Red)	*	0.632-0.698 $\mu\text{m}$
4 (Near IR)	*	0.757-0.853 $\mu\text{m}$











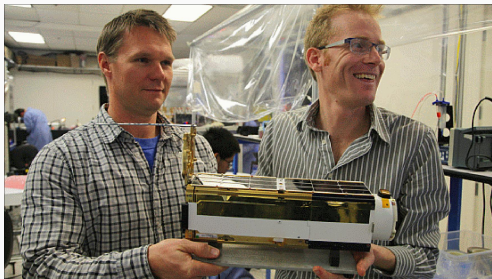
<b>Sensor Resolution &amp; Spectral Bandwidth</b>	<b>Panchromatic</b> <ul style="list-style-type: none"><li>● 60-centimeter GSD (Ground Sample Distance) at nadir</li><li>● Black &amp; White: 445 to 900 nanometers</li></ul>	<b>Multispectral</b> <ul style="list-style-type: none"><li>● 2.4-meter GSD at nadir</li><li>● Blue: 450 to 520 nanometers</li><li>● Green: 520 to 600 nanometers</li><li>● Red: 630 to 690 nanometers</li><li>● Near-IR: 760 to 900 nanometers</li></ul>
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# Alta Resolução - Planet

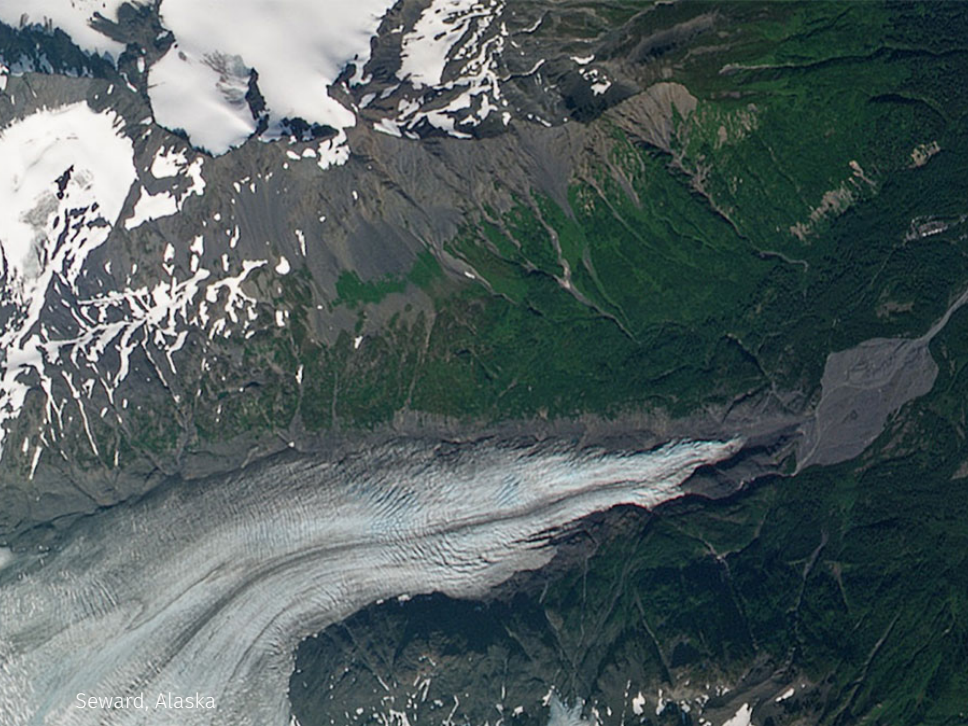
- PlanetScope – 3.7m (+180 sat.)
- RapidEye – 5m (5 sat.)
- SkySat – 50cm (21 sat.)





San Francisco, California





Seward, Alaska



Rotterdam, Netherlands

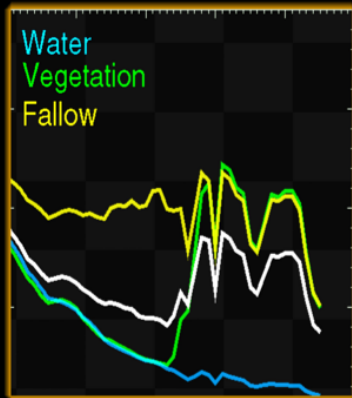
# Hiperespectral - Hyperion

- 220 bandas
- 30m res.espacial
- faixa 7.5 x 100 km
  
- ALI (Advanced Land Imager)
- teste de tecnologia
- sucessor do ETM+ (OLI)

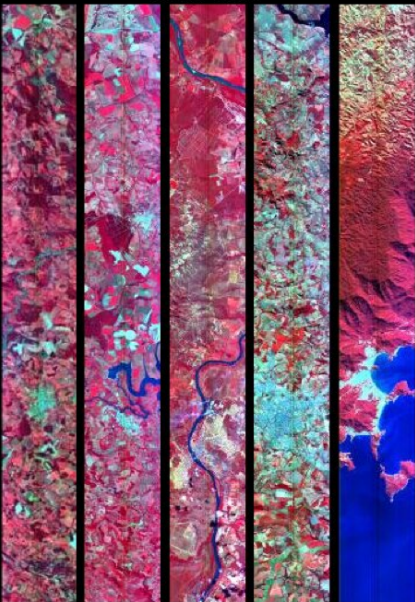


# EO-1/Hyperion

## Analysis



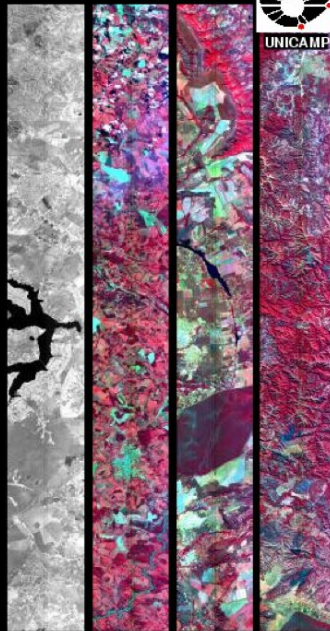
São Paulo



BH



Brasília



UNICAMP