



GSA-5859 / PCA-5017

SIG em Software Livre

Sensoriamento Remoto

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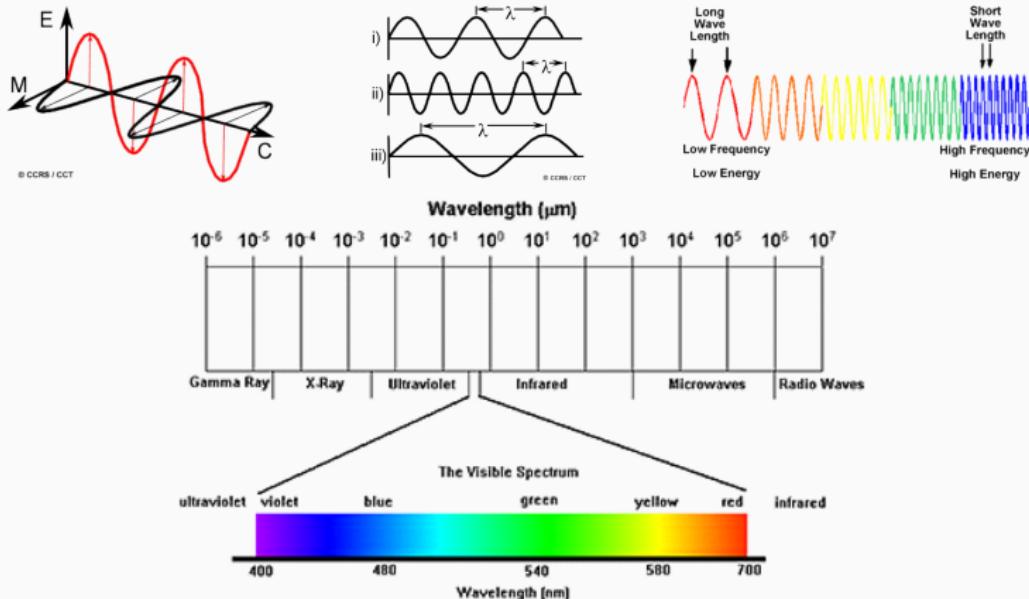
Definição 1 (INPE)

- “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 eletrromagnética ou radiação eletrromagnética

Definição 2 (INPE)

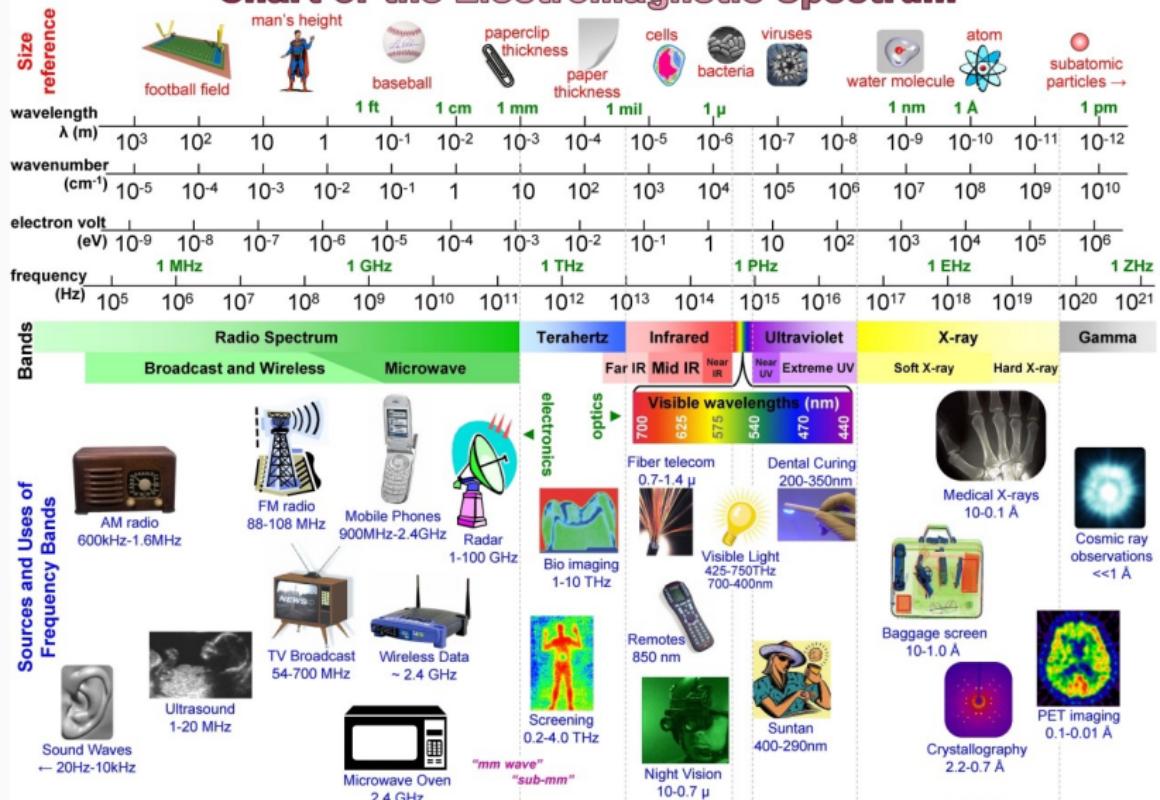
- “Conjunto das atividades relacionadas à aquisição e a análise de dados de sensores remotos”
 - Sensores remotos: sistemas fotográficos ou óptico-eletrônicos capazes de detectar e registrar, sob a forma de imagens ou não, o fluxo de energia radiante refletido ou emitido por objetos distantes

Radiação Eletromagnética (REM)



Plain frame

Chart of the Electromagnetic Spectrum



Sistema Visual Humano

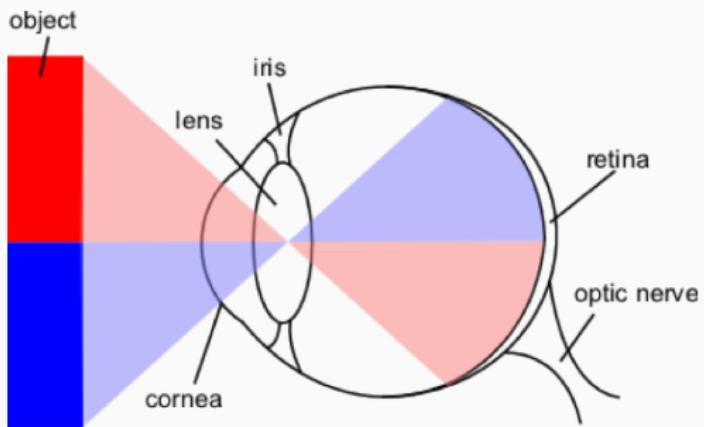
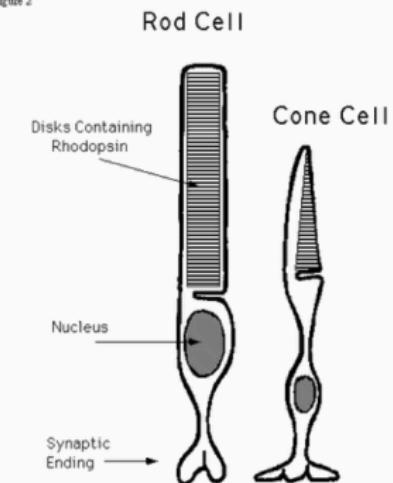


Figure 2



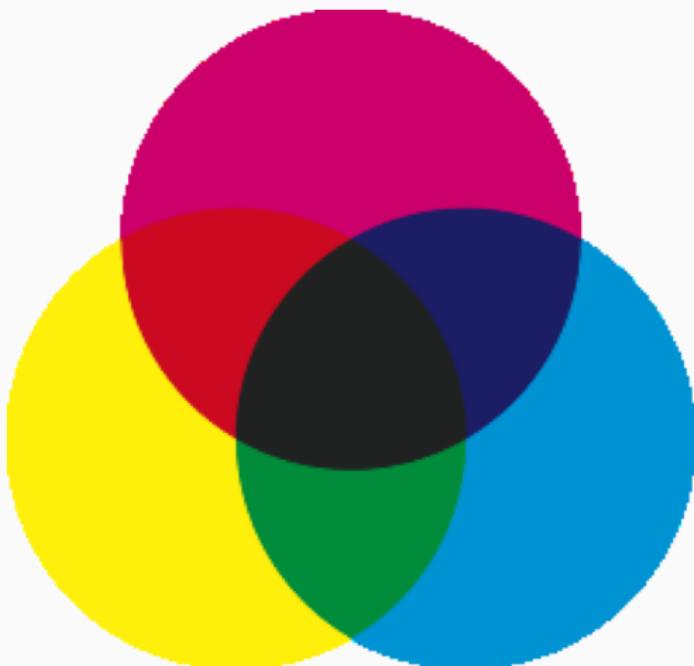
Sistema Visual Humano

- 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 – exergamos a partir de 3 cores

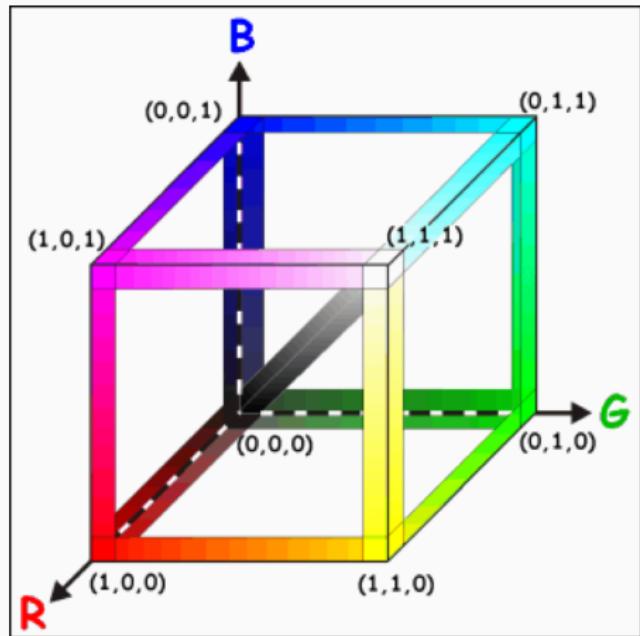
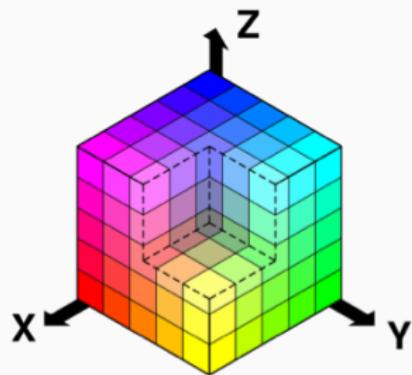
Sistema de Cores Aditivo (RGB)



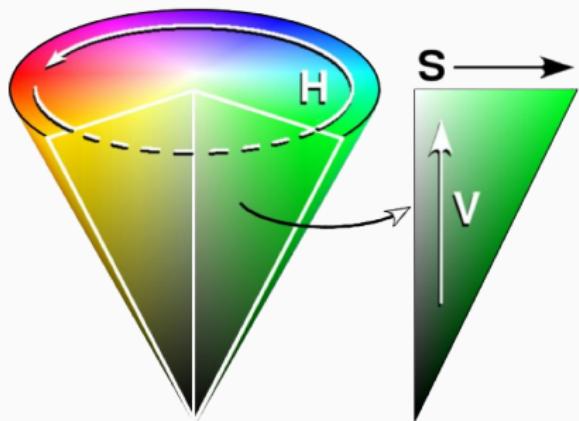
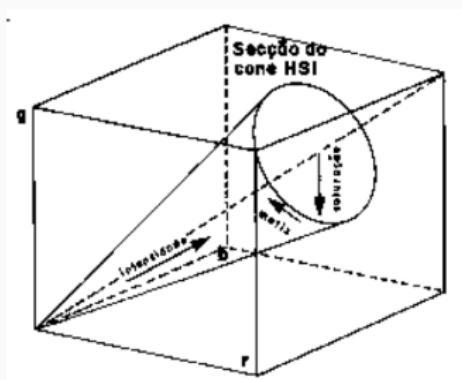
Sistema de Cores Subtrativo (CMYK)



Sistema de Cores – Cubo RGB

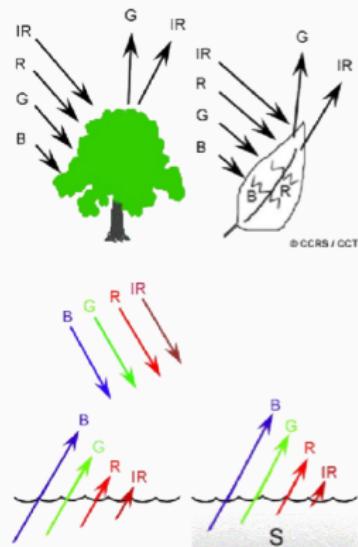


Sistema de Cores – Cone IHS



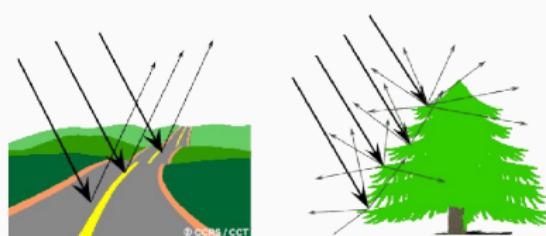
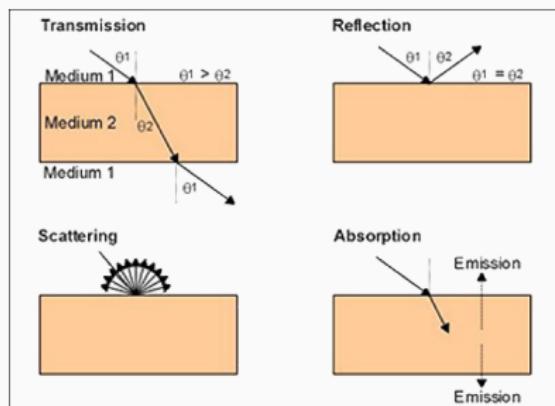
Cores dos objetos

- 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



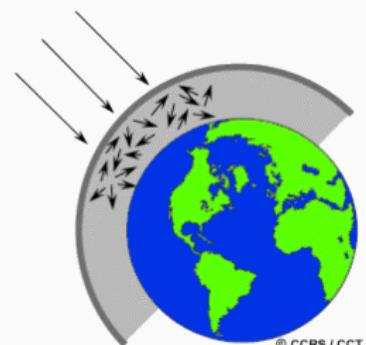
Comportamento da REM

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



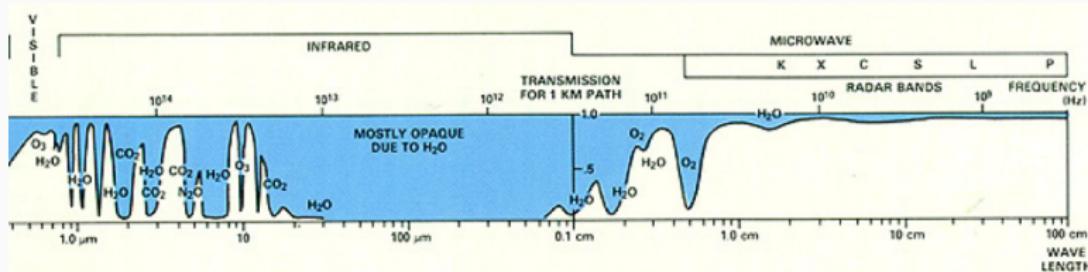
Espalhamento Atmosférico

- Espalhamento de Rayleigh
 - principal efeito de espalhamento atmosférico
 - partículas dispersas são muito menores que o comprimento de onda da REM (poeira, O₂, N₂, H₂O)
 - 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



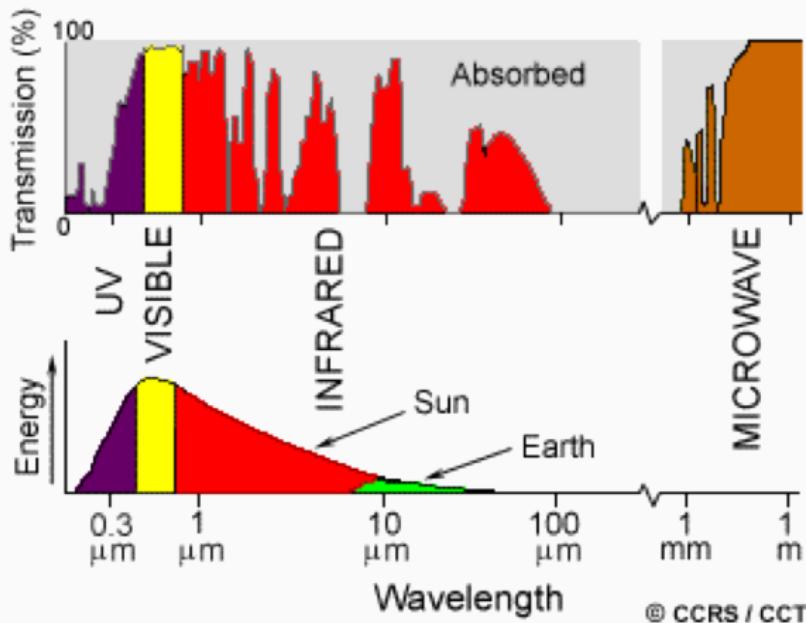
Janelas Atmosféricas

- 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

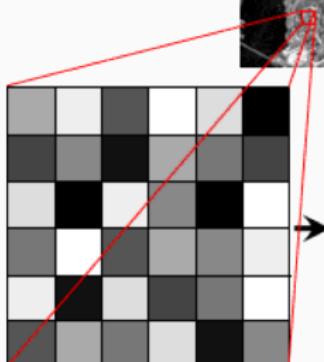
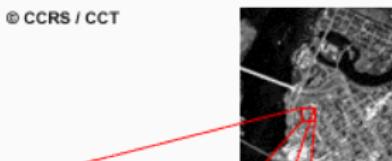


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Imagen Digital

- 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

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170	238	85	255	221	0	
68	136	17	170	119	68	
221	0	238	136	0	255	
119	255	85	170	136	238	
238	17	221	68	119	255	
85	170	119	221	17	136	

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

Imagen RGB



Imagen RGB - Banda R



Imagen RGB - Banda G



Imagen RGB - Banda B



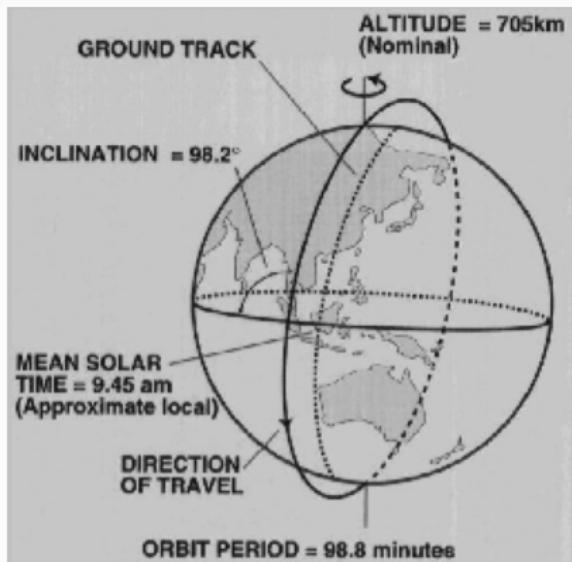
Sensores e Satélites

Tipos de Sensores

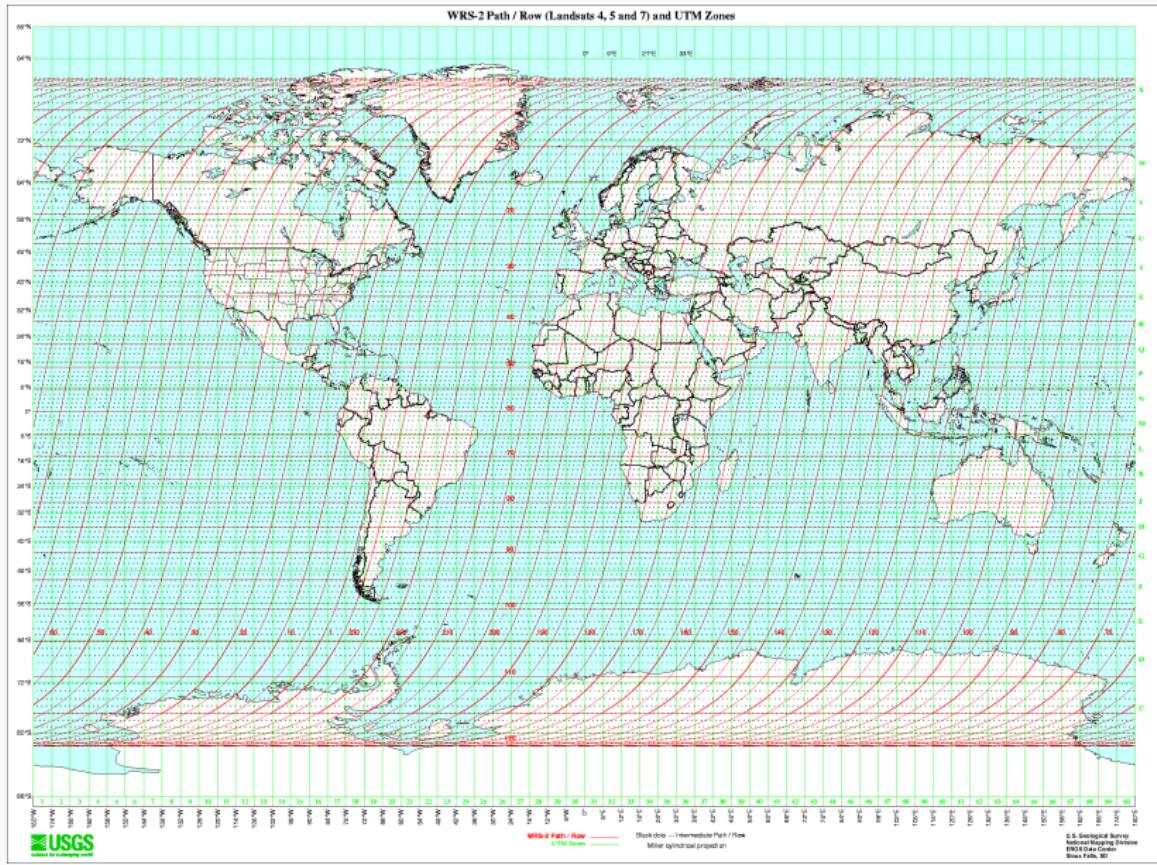
- Fotográficos
 - Imagem é capturada de uma só vez
- Não-Fotográficos
 - Imagem capturada pixel a pixel (scanner)
- Sensores Passivos
 - Registram energia refletida por fontes naturais (Sol)
 - maioria
- Sensores Ativos
 - Emitem sua própria energia e registram o sinal refletido
 - RADAR, LiDAR
 - Podem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

Satélites - Órbitas

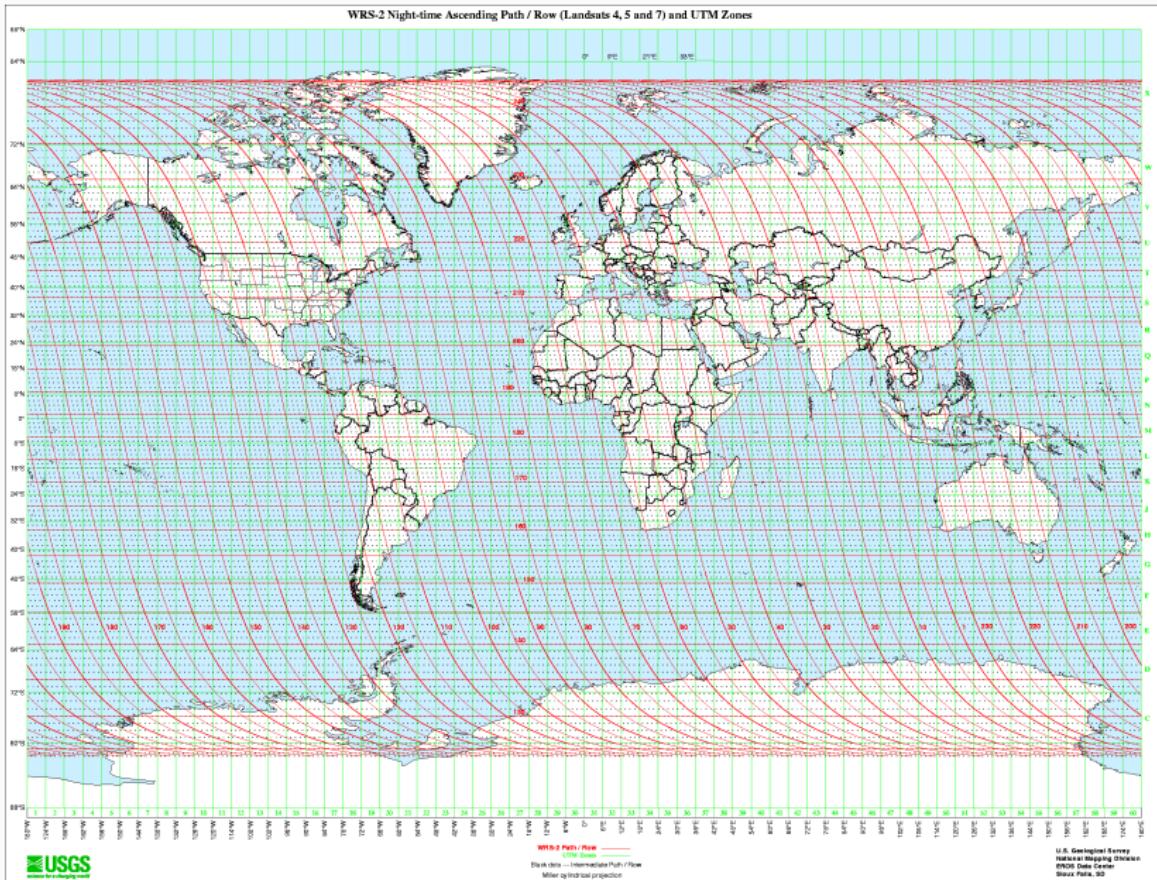
- Órbita – altitude da órbita determina campo de visão e período de revisita
- Geoestacionários – 36.000km altitude
- Heliossincrônicos – órbita acompanha horário local do sol
- órbitas:
 - descendente – dia
 - ascendente – noite
- Worldwide Reference System 2 (WRS2)



WRS2 - Órbitas Descendentes

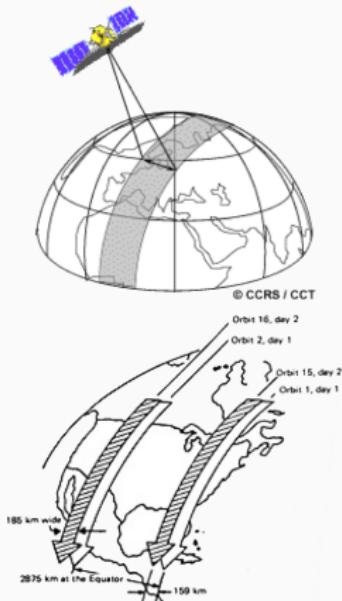


WRS2 - Órbitas Ascendentes



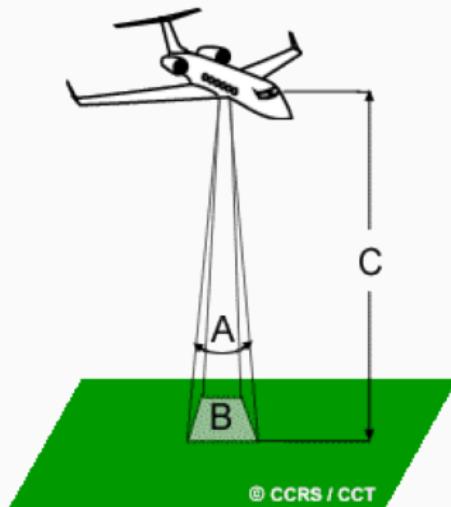
Satélites - Características

- 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
- $B=C*A$



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Satélites - Resolução Espacial

baixa

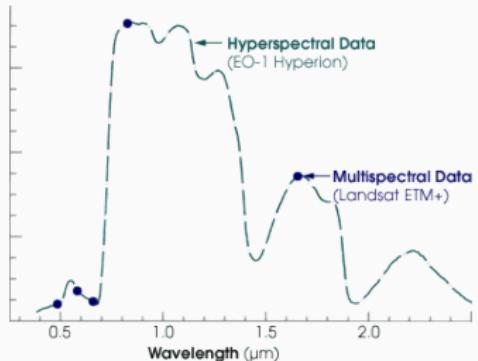
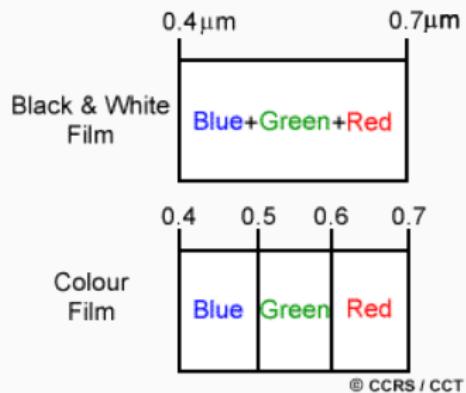


alta



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

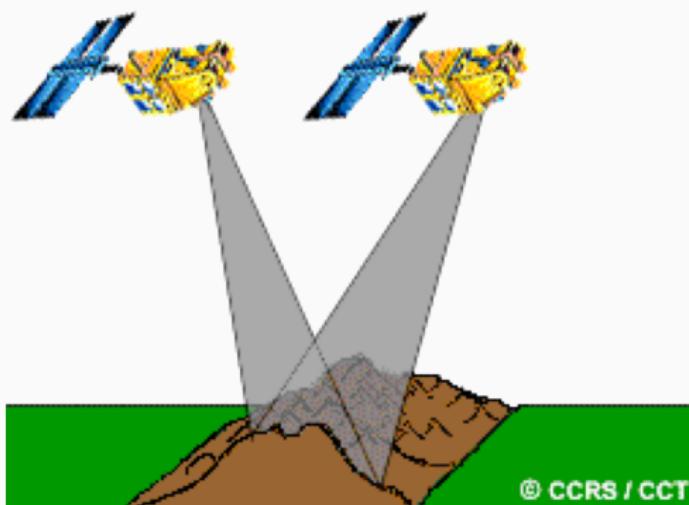
- Resolução radiométrica - Capacidade do sensor em diferenciar variação na intensidade de energia

2 bits - 4 tons de cinza 8 bits - 256 tons de cinza



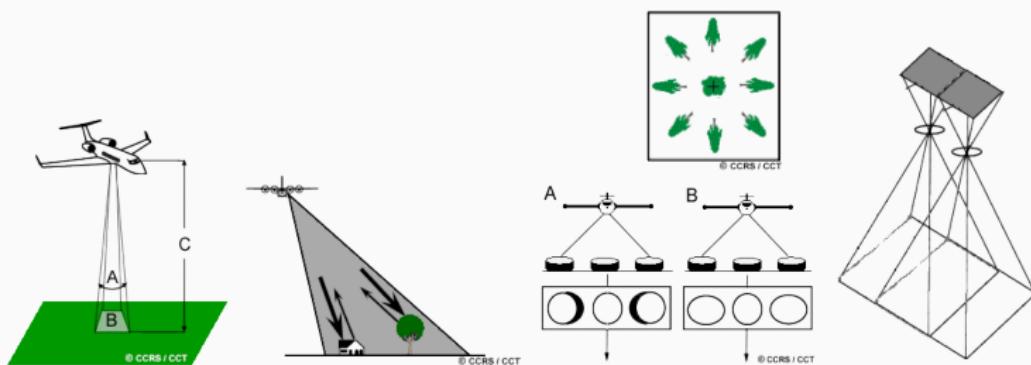
Satélites - Resolução Temporal

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



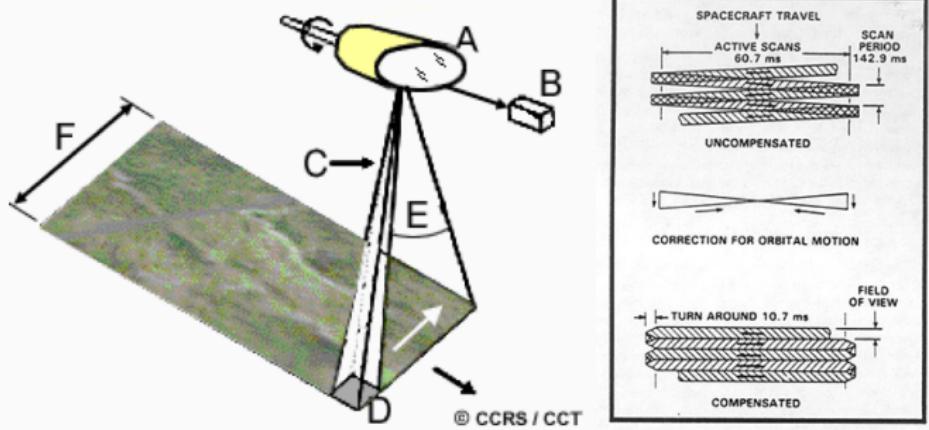
Sistemas de Imageamento - Fotografias Aéreas

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



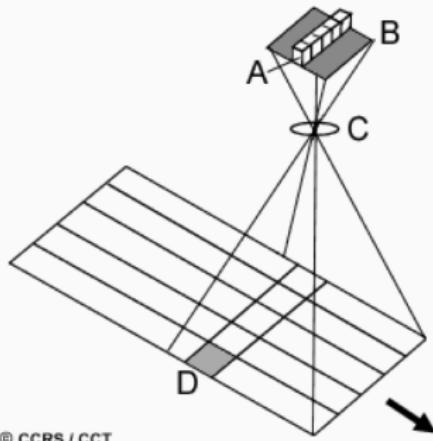
Sistemas de Imageamento - Sensores Multiespectrais (MSS)

- 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 “vêem” os objetos por mais tempo
- Calibração de centenas de sensores individuais



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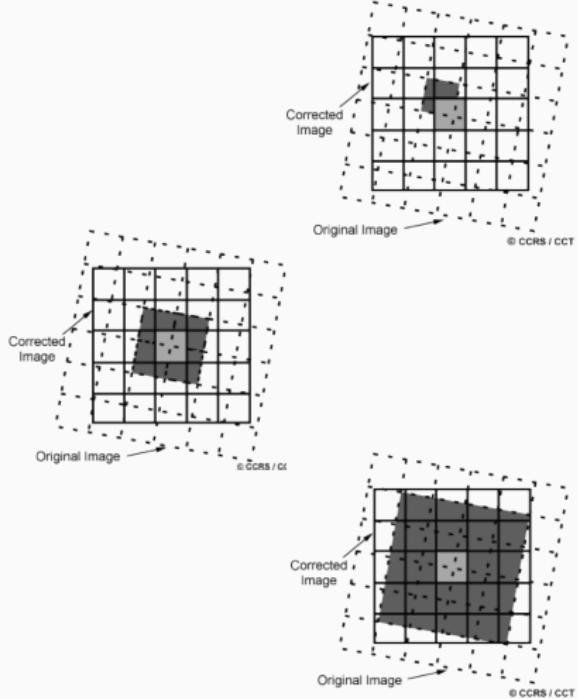
Operações em SR

Operações em SR

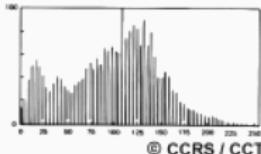
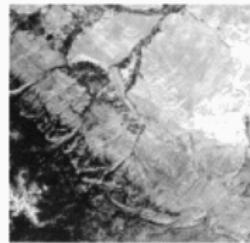
- Pré-Processamento
 - Conversão radiância-reflectância
 - Correção Atmosférica
- Registro
- Realce
- Filtragem
- Composições
 - RGB
 - IHS

Georreferenciamento

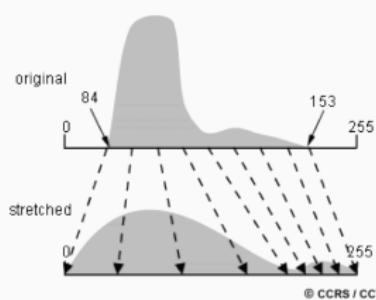
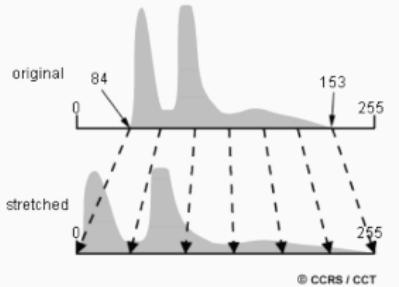
- Registro
(Georreferenciamento)
- Correção geométrica
- Projeção cartográfica
- Ground Control Points (GCPs)
- image-to-map /
image-to-image
- Vizinho mais próximo
- Interpolação bilinear
- Convolução cúbica



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

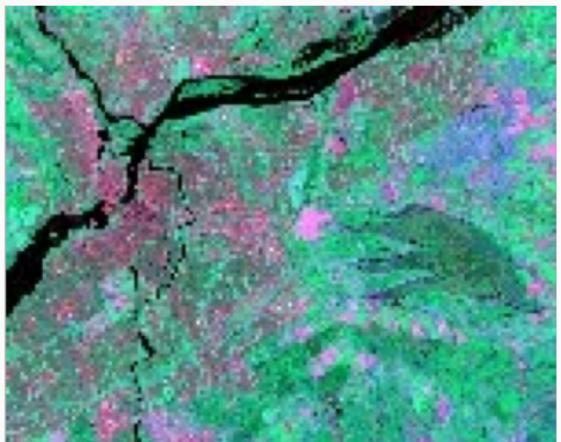
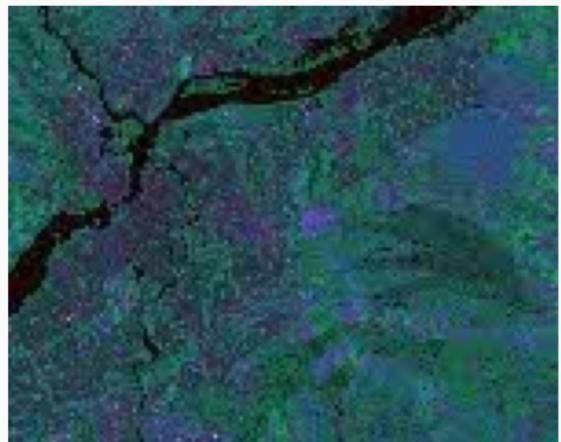


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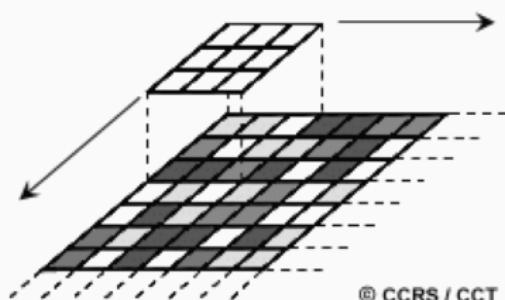
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Realce Linear



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

2	5	2	7	3	2	2	0	2	1	1	9	2	4
2	3	2	7	1	9	2	5	2	2	1	8	2	5
2	7	2	6	2	4	2	6	2	2	2	2	2	6
2	3	2	5	2	8	3	0	2	7	2	5	2	7
1	9	2	2	2	8	3	2	2	9	2	7	2	5
1	7	1	9	2	5	2	7	3	0	3	1	2	2
2	0	2	1	2	5	2	3	2	1	1	9	1	7

Imagem original

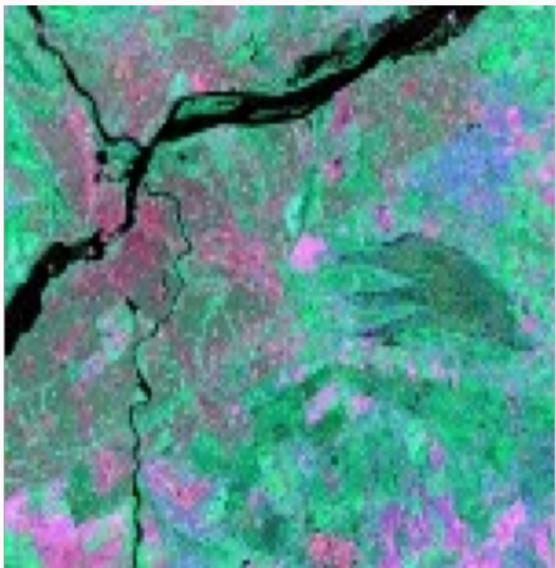
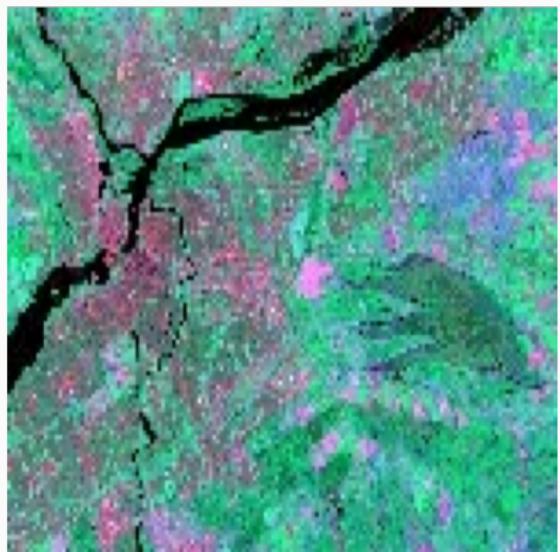
2	6	2	5	2	3	2	2	2	2				
2	5	2	6	2	5	2	4	2	6				
2	5	2	7	2	7	2	7	2	6				
2	3	2	6	2	8	2	9	2	7	2	7		
2	2	2	5	2	7	2	7	2	7	2	5		

Imagem filtrada

Pixel central = 1/9

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

Filtro de média – passa-baixas



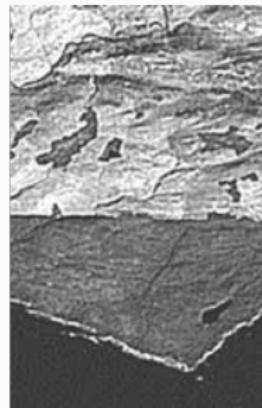
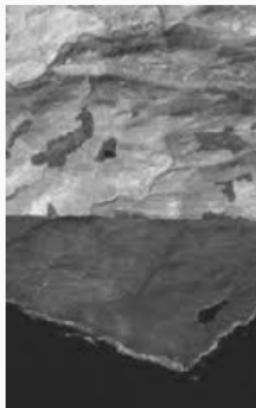
Filtro laplaciano – passa-altas

Exemplos de filtros Lapacianos:

$$\begin{matrix} 0 & -1 & 0 \\ -1 & 4 & -1 \\ 0 & -1 & 0 \end{matrix} \quad \begin{matrix} -1 & -1 & -1 \\ -1 & 8 & -1 \\ -1 & -1 & -1 \end{matrix} \quad \begin{matrix} 1 & -2 & 1 \\ -2 & 4 & -2 \\ 1 & -2 & 1 \end{matrix}$$

Exemplos de filtros Lapacianos + Original

$$\begin{matrix} 0 & -1 & 0 \\ -1 & 5 & -1 \\ 0 & -1 & 0 \end{matrix} \quad \begin{matrix} -1 & -1 & -1 \\ -1 & 9 & -1 \\ -1 & -1 & -1 \end{matrix} \quad \begin{matrix} 1 & -2 & 1 \\ -2 & 5 & -2 \\ 1 & -2 & 1 \end{matrix}$$

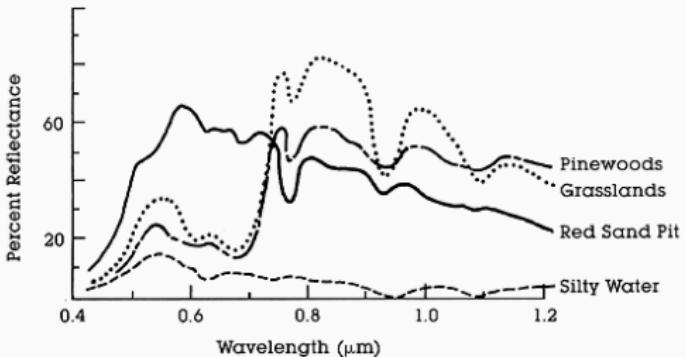


Operações Aritméticas

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

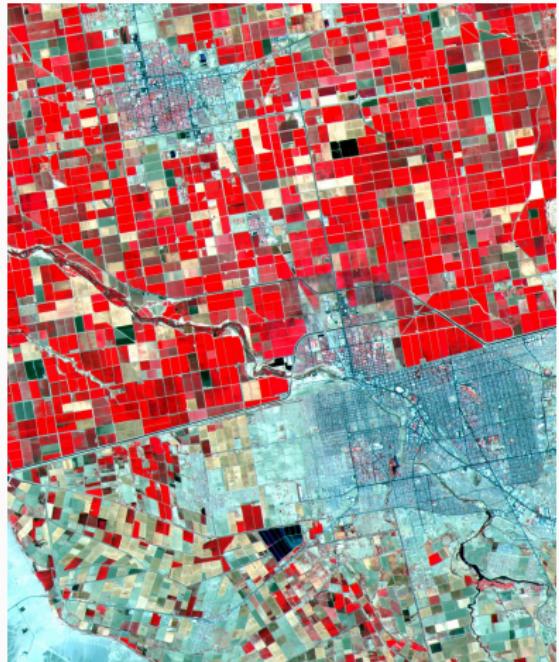
$$\begin{array}{c} \boxed{\text{+}} \\ - \\ \boxed{\text{-}} \\ = \\ \boxed{\text{=}} \end{array}$$

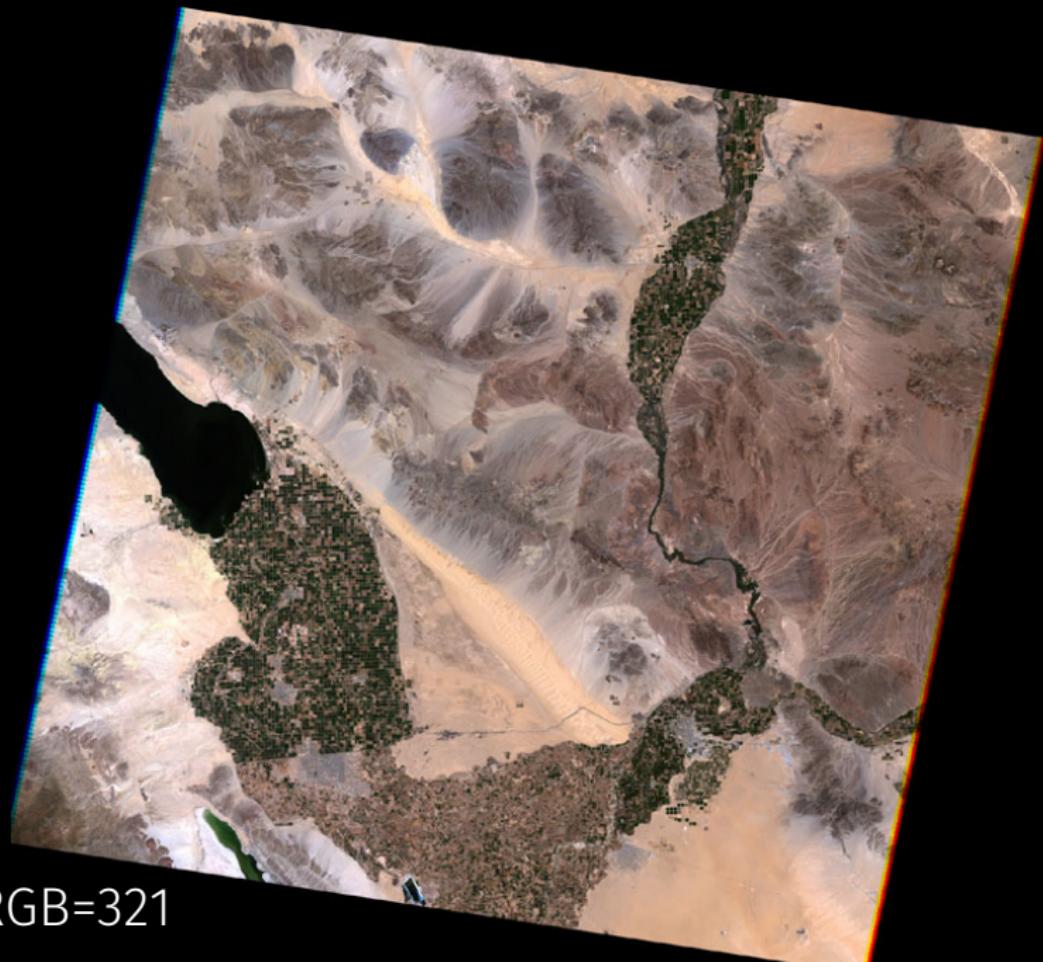
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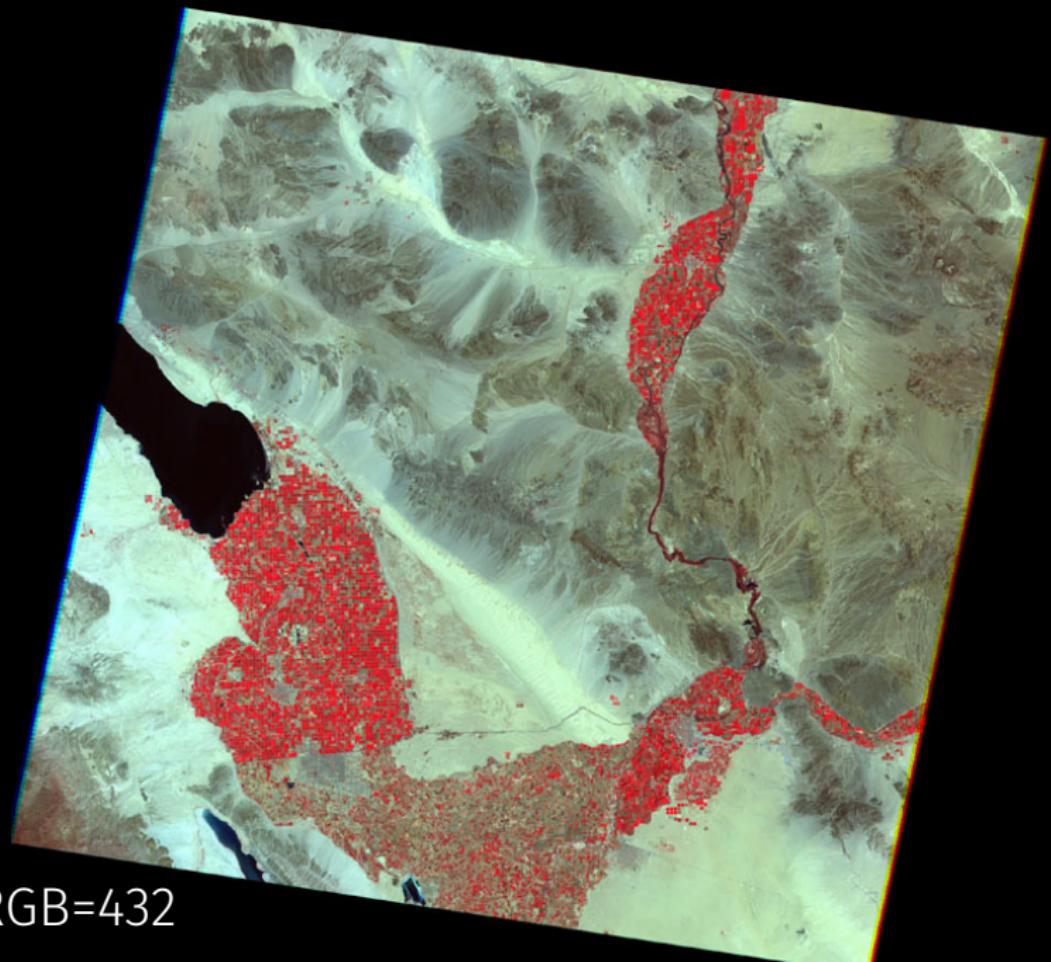
Composição RGB

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

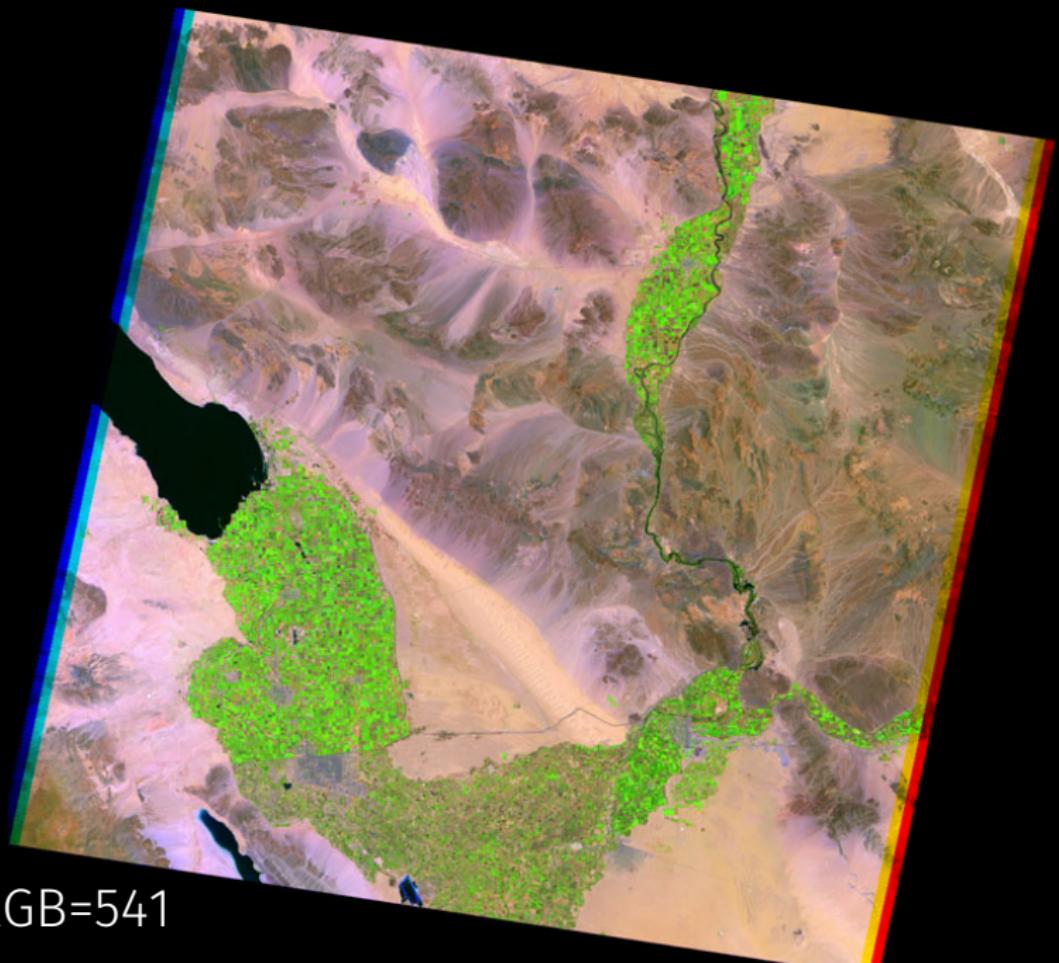




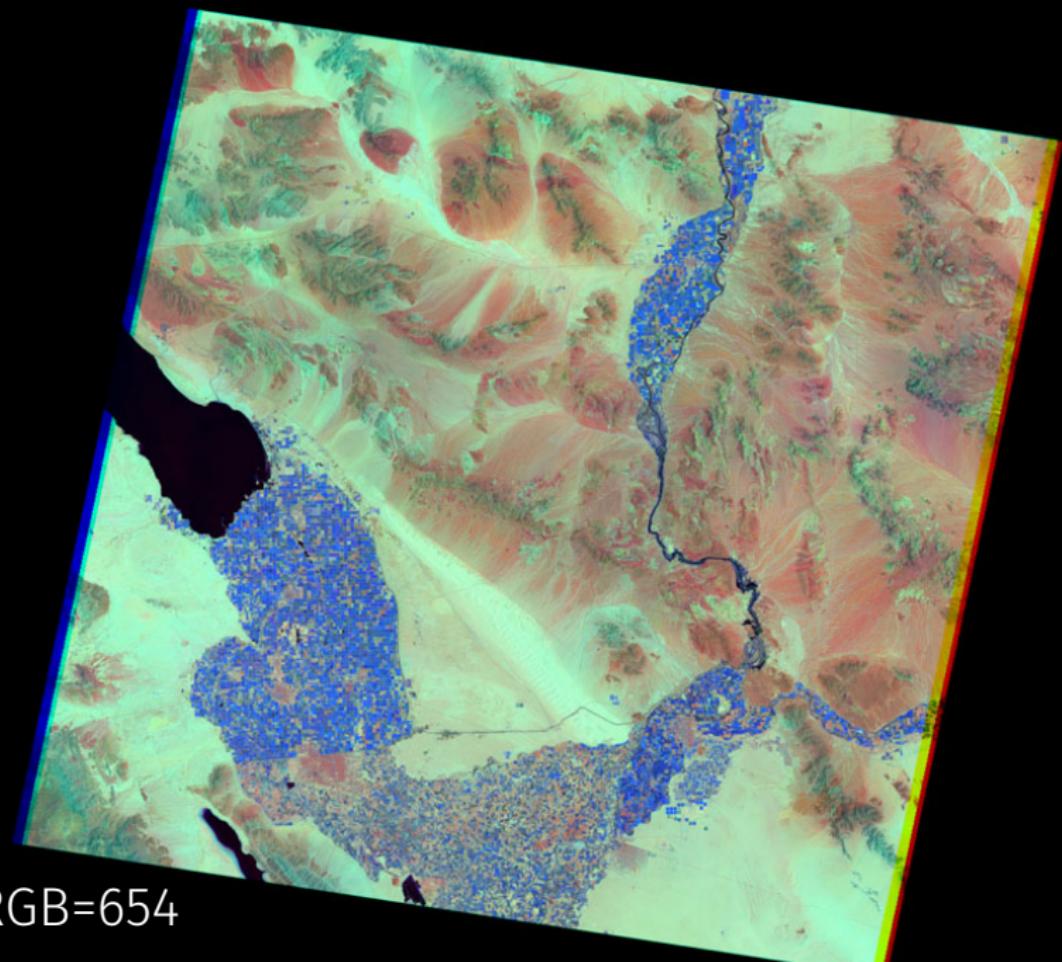
RGB=321



RGB=432



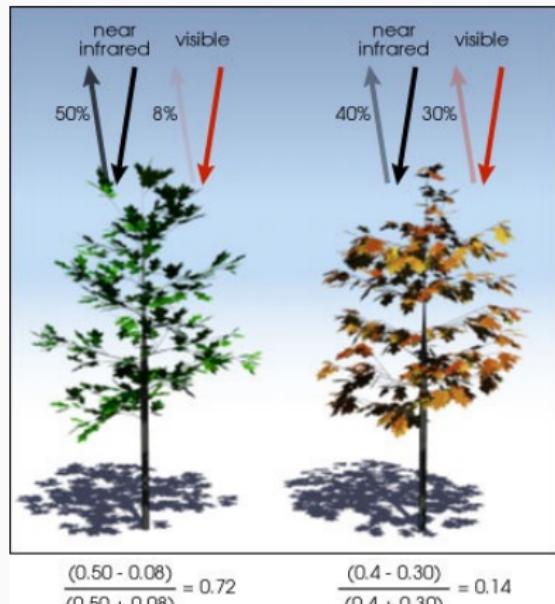
RGB=541



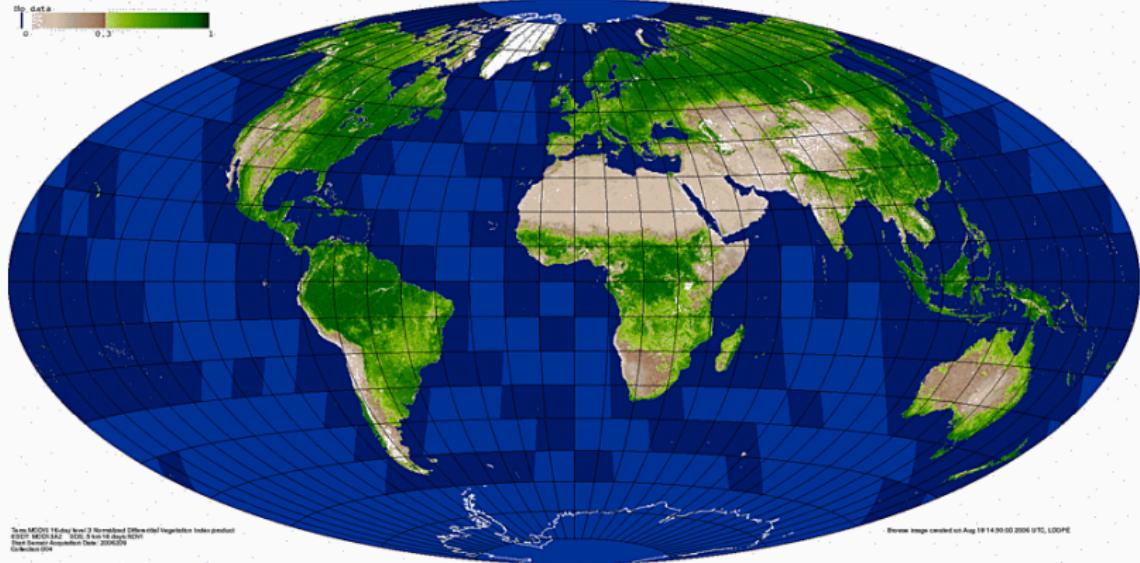
RGB=654

Índices de Vegetação

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



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

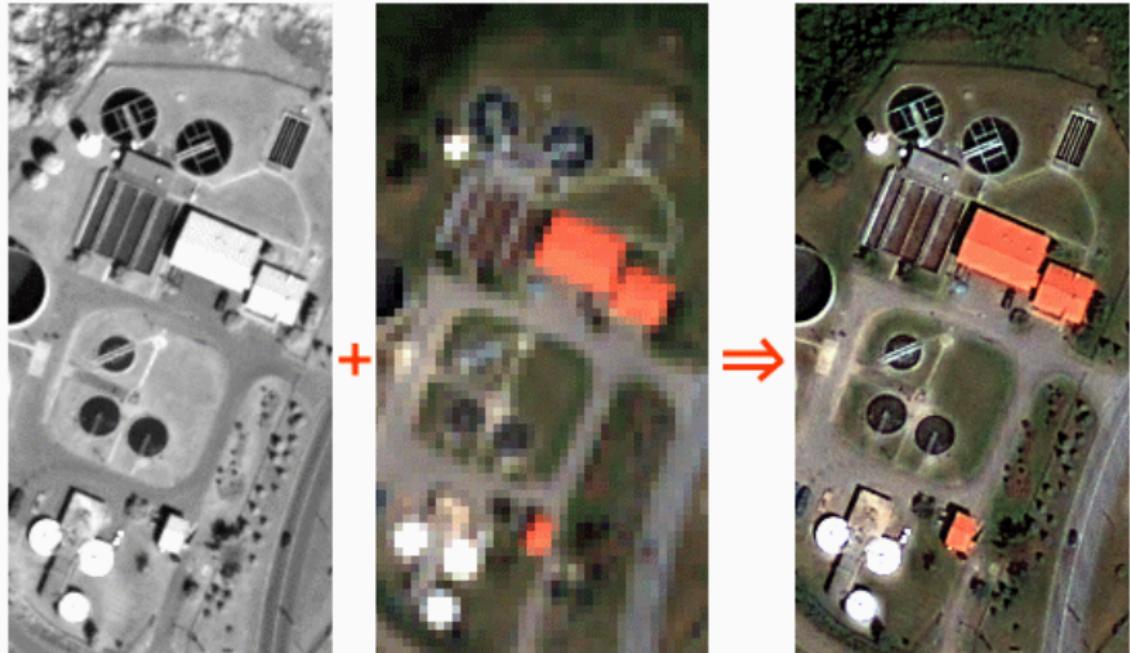


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Pan-sharpening



Principais Satélites e Sensores

Satélites e Sensores

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

Meteorológicos - GOES

GOES - Geostationary Operational Environmental Satellite

Band	Wavelength Range (> μm)	Spatial Resolution	Application
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

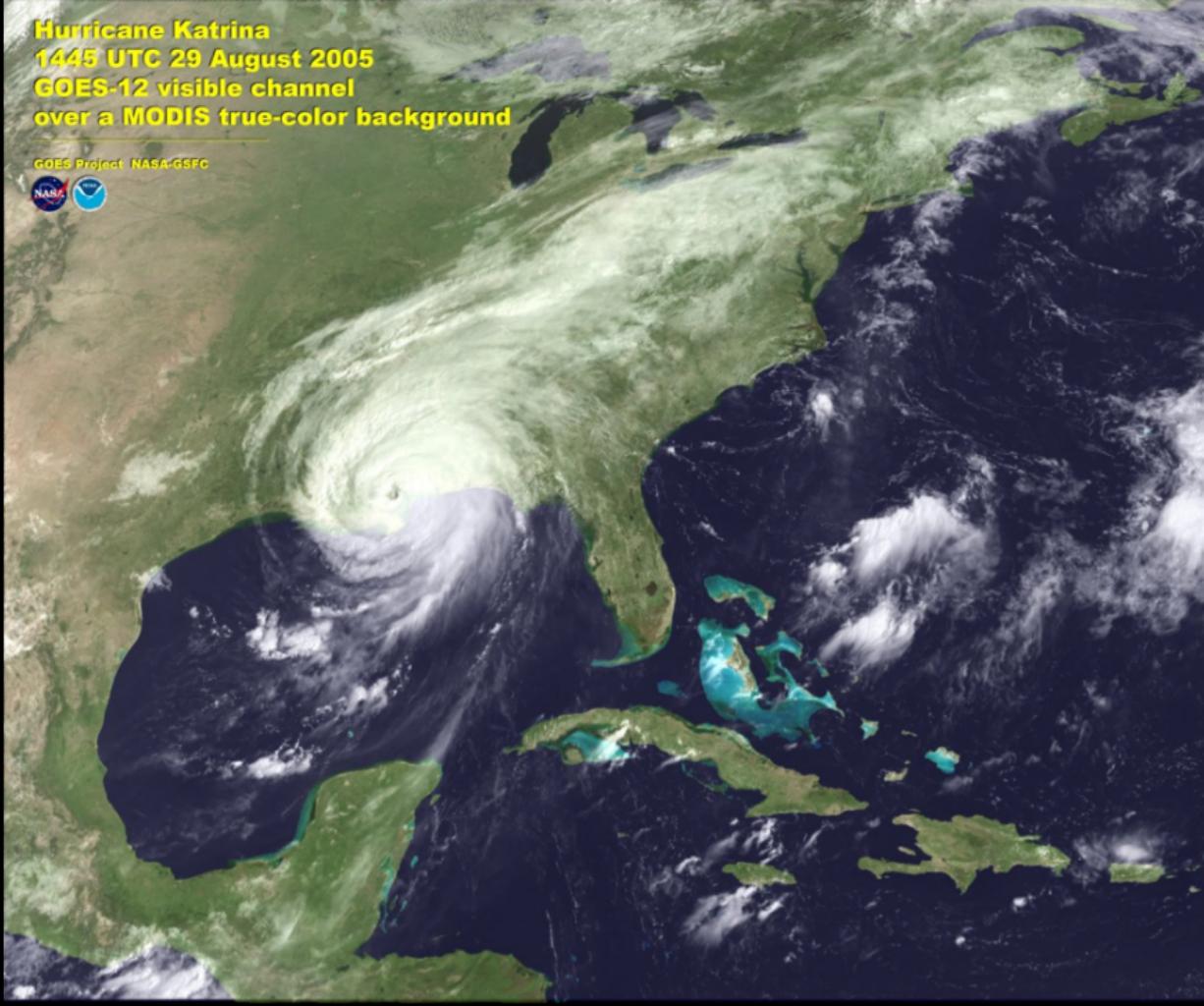
Meteorológicos - AVHRR

NOAA AVHRR - Advanced Very High Resolution Radiometer

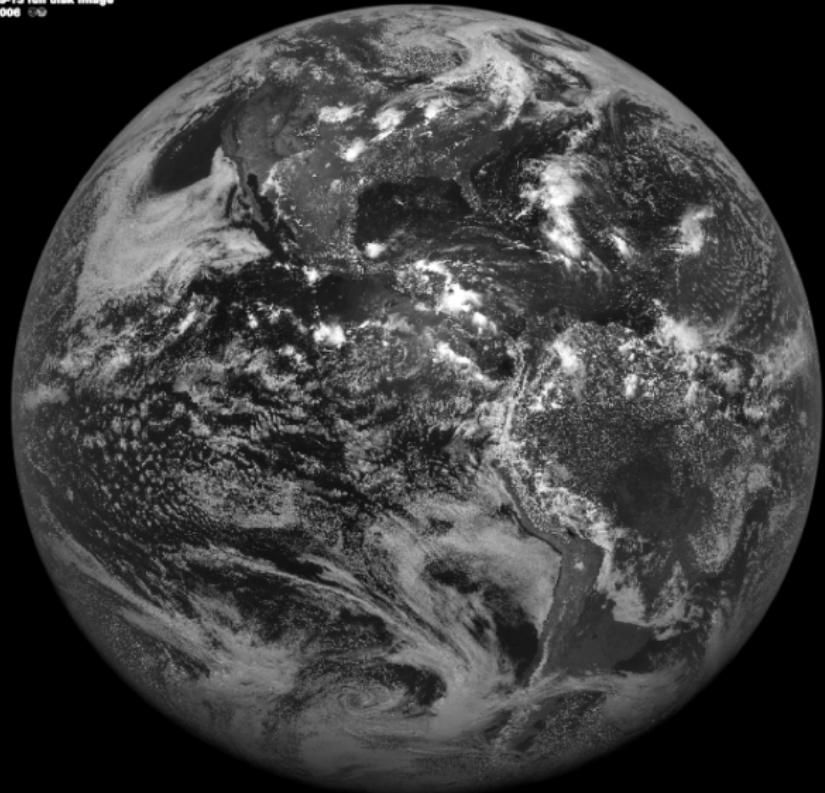
Band	Wavelength Range (μm)	Spatial Resolution	Application
1	0.58 - 0.68 (red)	1.1 km	cloud, snow, and ice monitoring
2	0.725 - 1.1 (near IR)	1.1 km	water, vegetation, and agriculture surveys
3	3.55 -3.93 (mid IR)	1.1 km	sea surface temperature, volcanoes, and forest fire activity
4	10.3 - 11.3 (thermal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

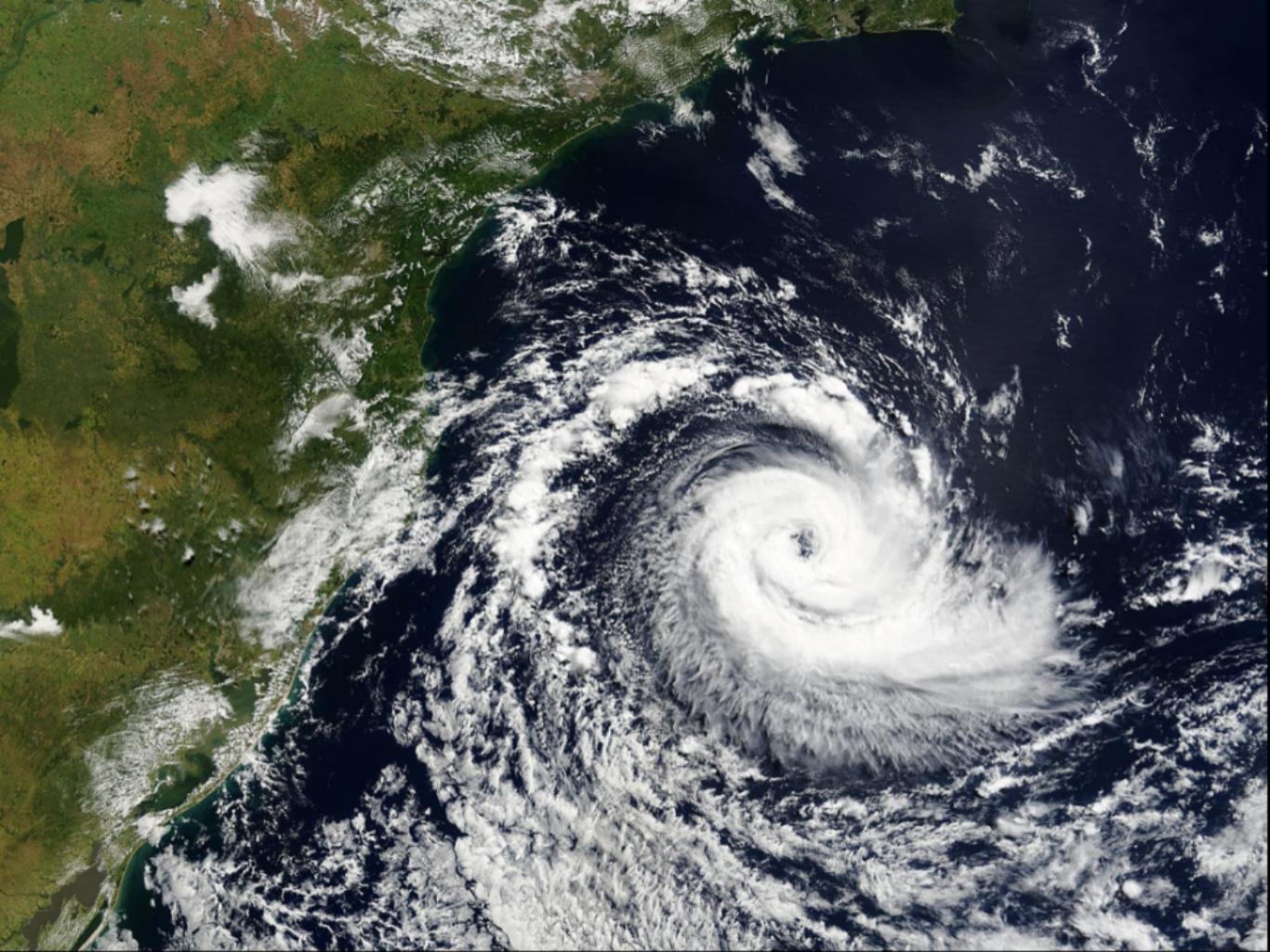
Hurricane Katrina
1445 UTC 29 August 2005
GOES-12 visible channel
over a MODIS true-color background

GOES Project NASA-GSFC



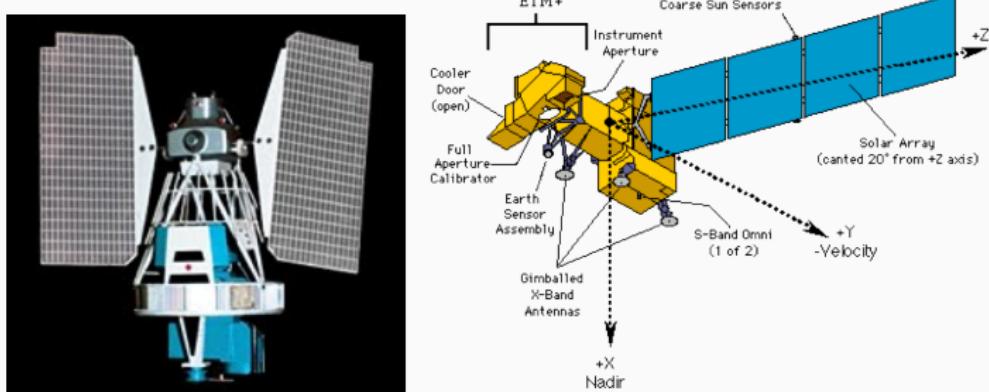
First GOES-13 full disk image
22 June 2006



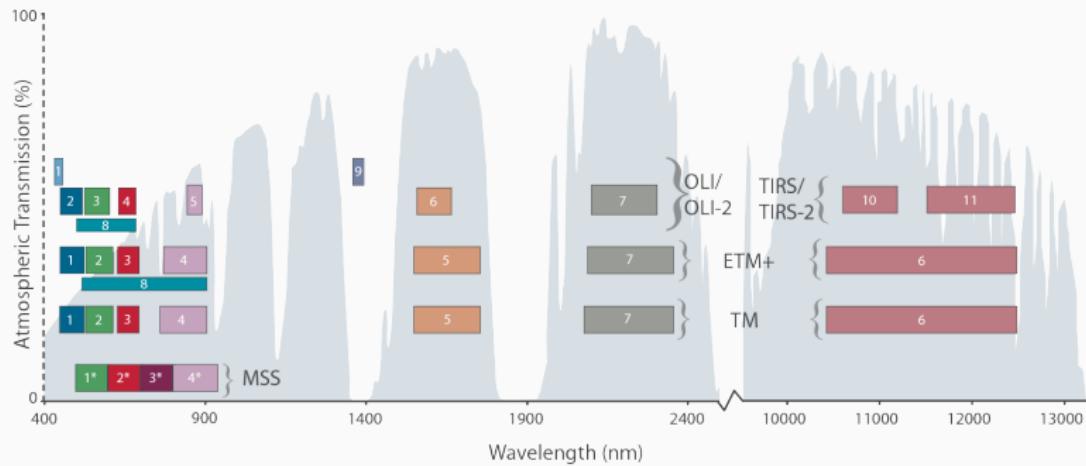


Recursos Terrestres – Landsat

- 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

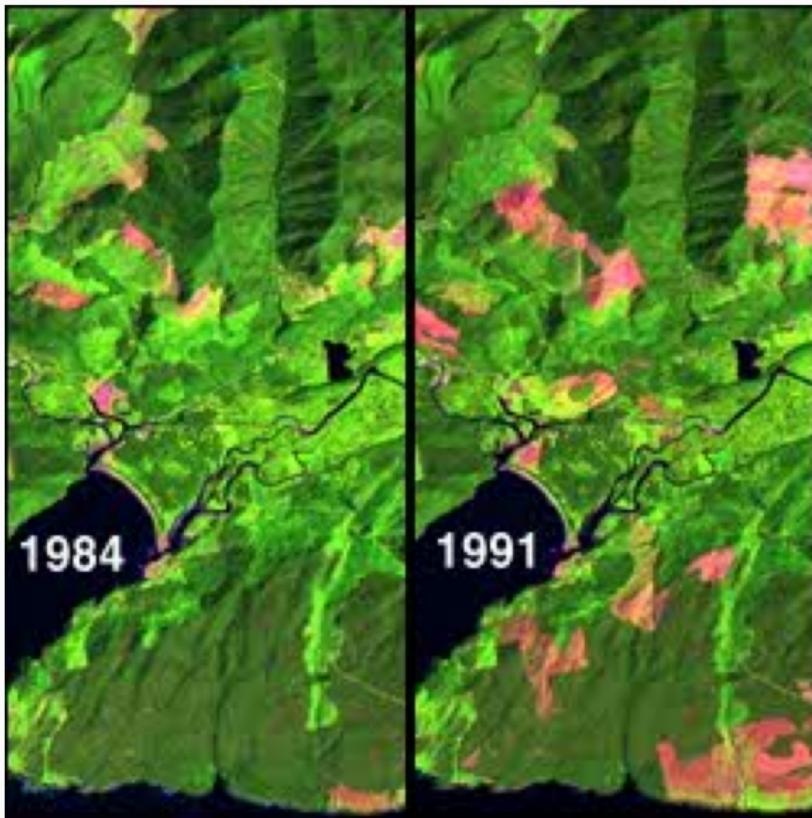


Landsat - bandas



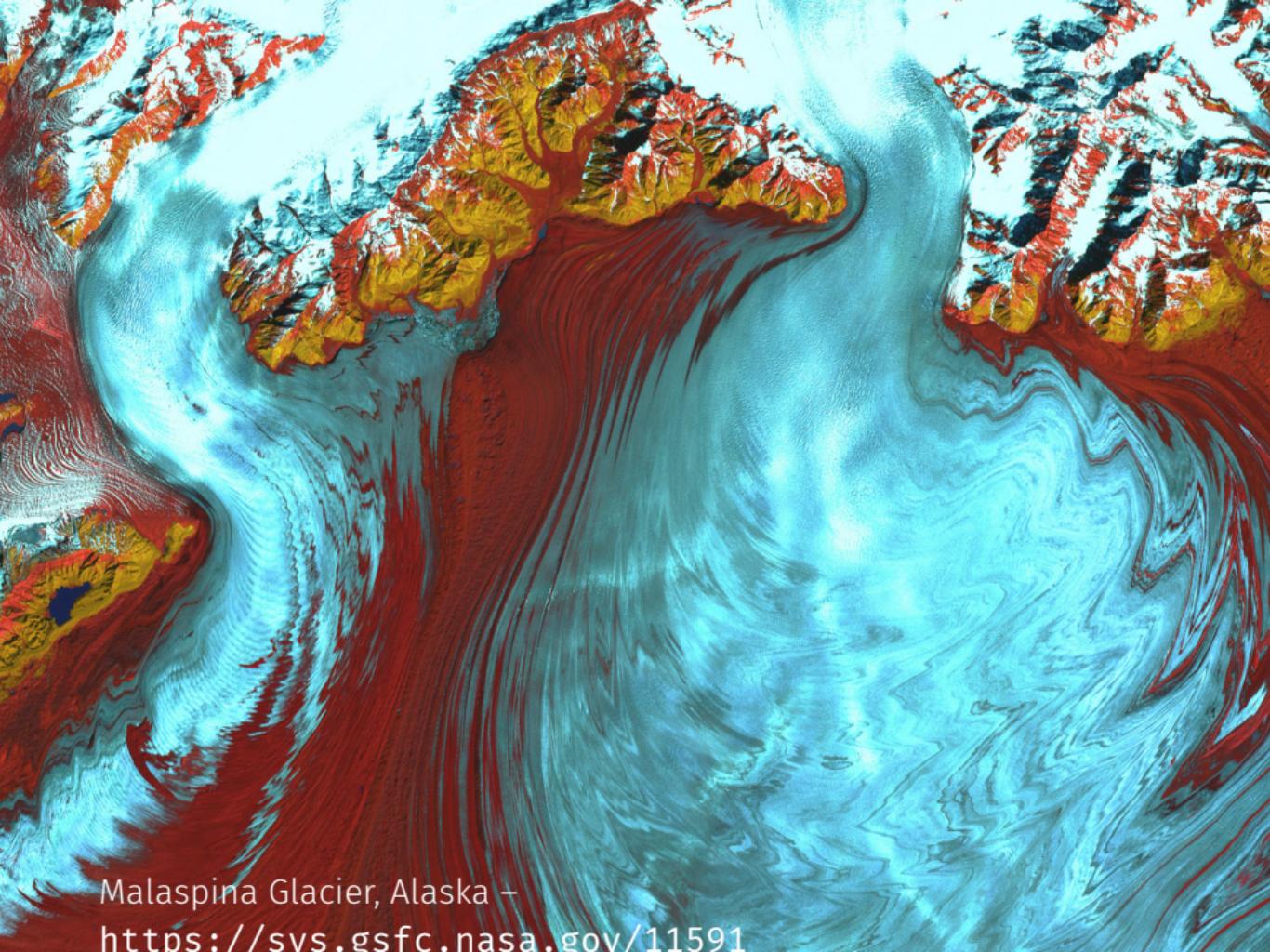
[https:](https://landsat.gsfc.nasa.gov/landsat-9/landsat-9-spectral-bands)

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



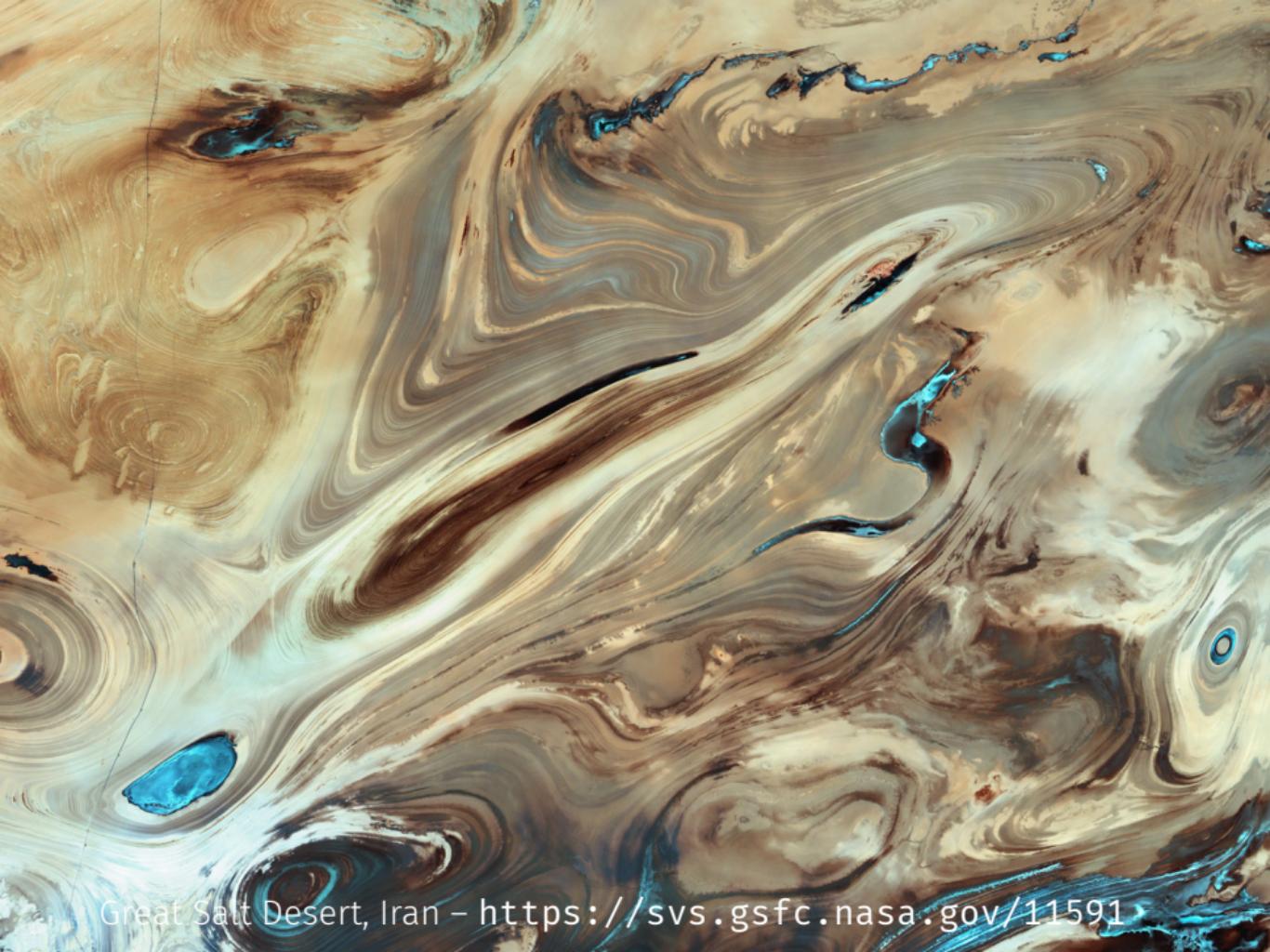


Kalahari Desert, Namibia - <https://svs.gsfc.nasa.gov/11591>



Malaspina Glacier, Alaska –

<https://svs.gsfc.nasa.gov/11591>



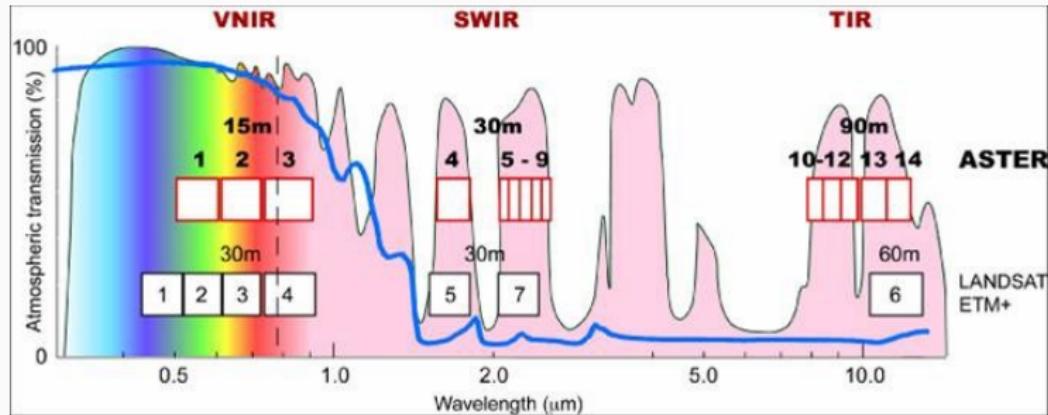
Great Salt Desert, Iran - <https://svs.gsfc.nasa.gov/11591>

Recursos Terrestres – Terra

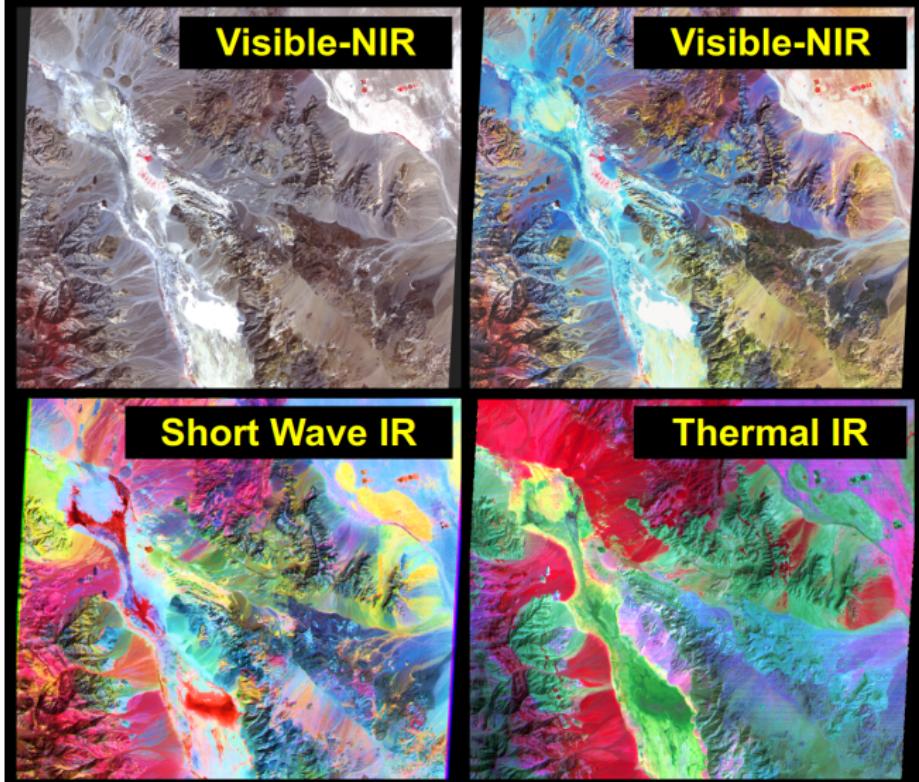
- EOS AM-1
 - ASTER - Advanced Spaceborne Thermal Emission and Reflection Radiometer
 - CERES - Clouds and the Earth's Radiant Energy System
 - MISR - Multi-angle Imaging SpectroRadiometer
 - MODIS - Moderate-resolution Imaging Spectroradiometer
 - MOPITT - Measurements of Pollution in the Troposphere

ASTER - Advanced Spaceborne Thermal Emission and Reflection Radiometer

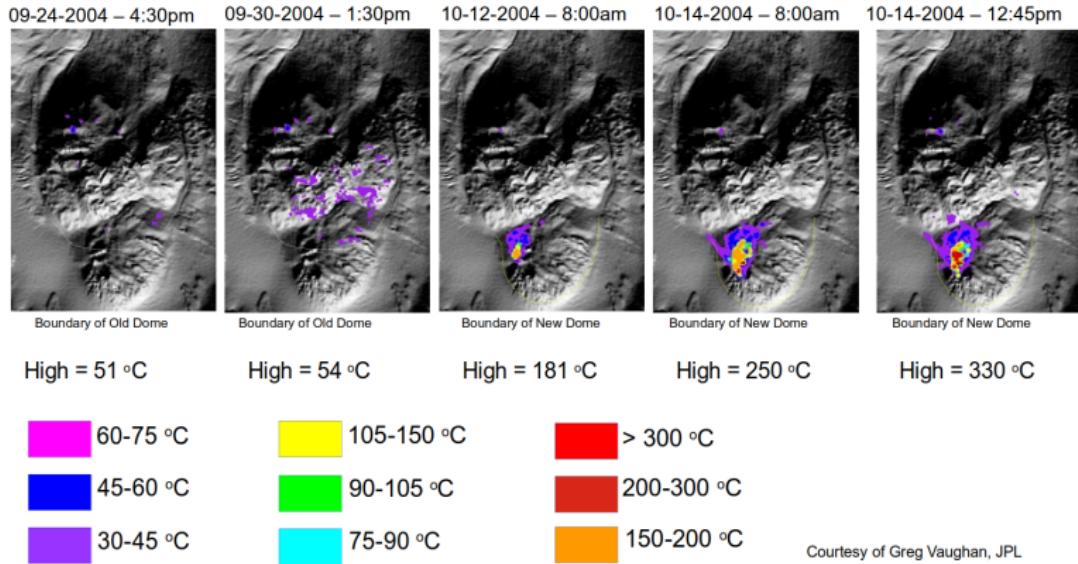
Subsystem	Band No.	Spectral Range (μm)	Spatial Resolution, m	Quantization Levels
VNIR	1	0.52-0.60	15	8 bits
	2	0.63-0.69		
	3N	0.78-0.86		
	3B	0.78-0.86		
SWIR	4	1.60-1.70	30	8 bits
	5	2.145-2.185		
	6	2.185-2.225		
	7	2.235-2.285		
	8	2.295-2.365		
	9	2.360-2.430		
TIR	10	8.125-8.475	90	12 bits
	11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



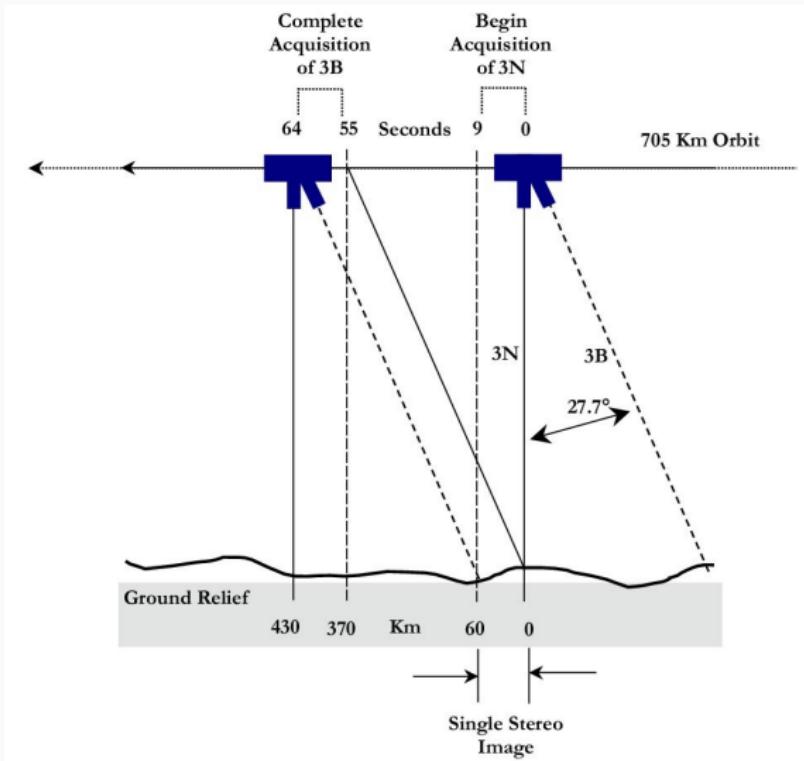
ASTER – composições coloridas



ASTER – monitoramento de vulcões

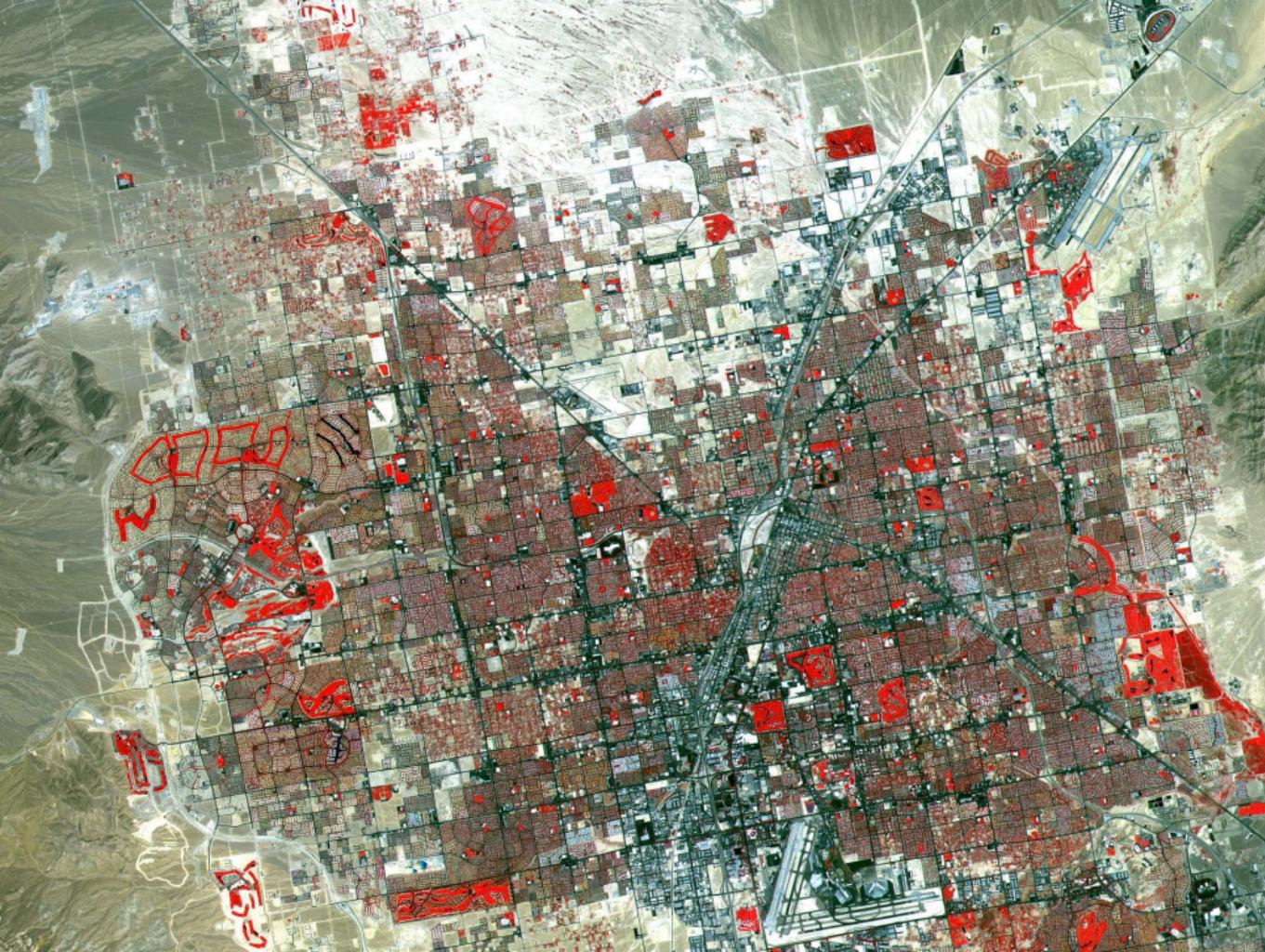


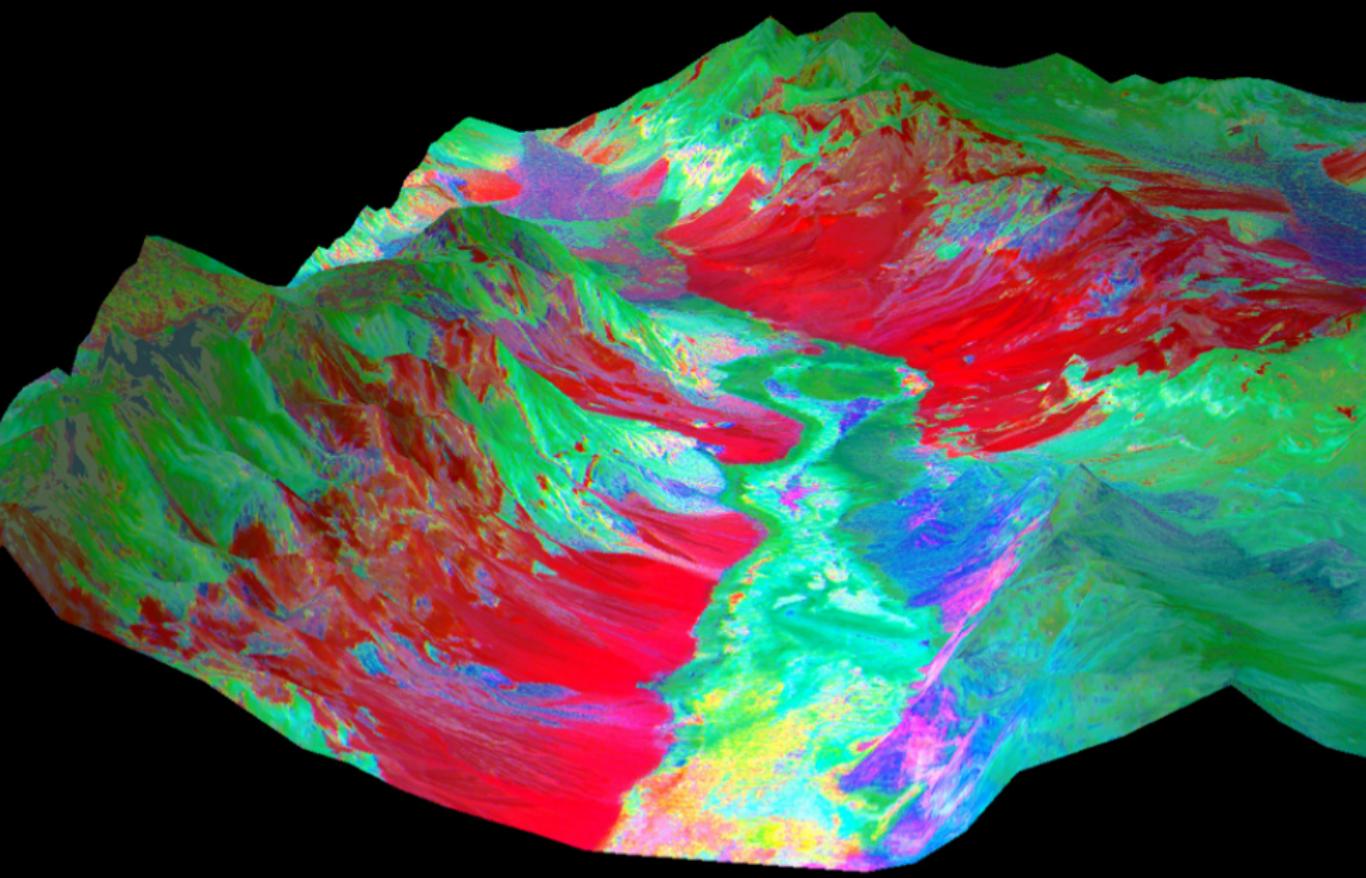
ASTER – estereoscopia





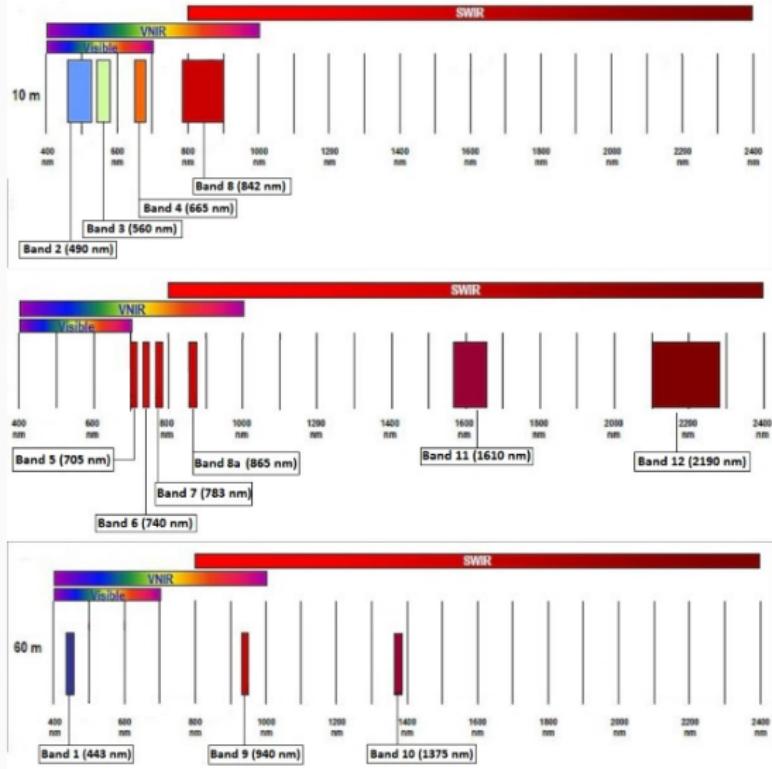




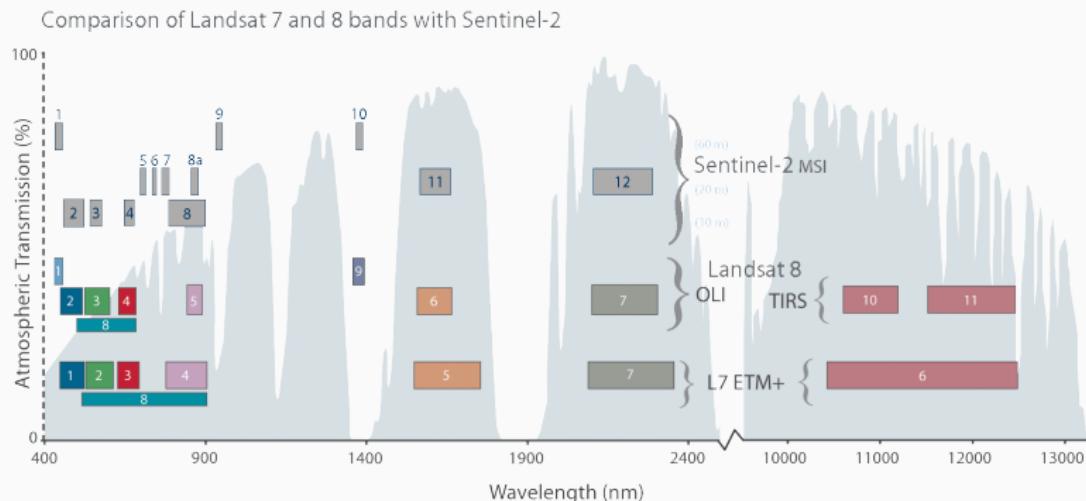


Recursos Terrestres – Sentinel 2A/2B

- ESA Copernicus
 - 10m, 20m, 60m
 - 13 bandas
 - revisita 10 dias



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	0,45-0,52μm (B) 0,52-0,59μm (G) 0,63-0,69μm (R) 0,77-0,89μm (NIR) 0,45-0,90 μm (PAN)	0,45-0,52μm (B) 0,52-0,59μm (G) 0,63-0,69μm (R) 0,77-0,89μm (NIR)	0,45-0,52μm (B) 0,52-0,59μm (G) 0,63-0,69μm (R) 0,77-0,89μm (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
Revisão	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



Cuiabá, MT – http://www.cbers.inpe.br/noticias/noticia.php?Cod_Noticia=5331



Jardins, MS – http://www.cbers.inpe.br/noticias/noticia.php?Cod_Noticia=5331



Aksu, China – http://www.cbers.inpe.br/noticias/noticia.php?Cod_Noticia=5331



Primavera do Leste, MT –

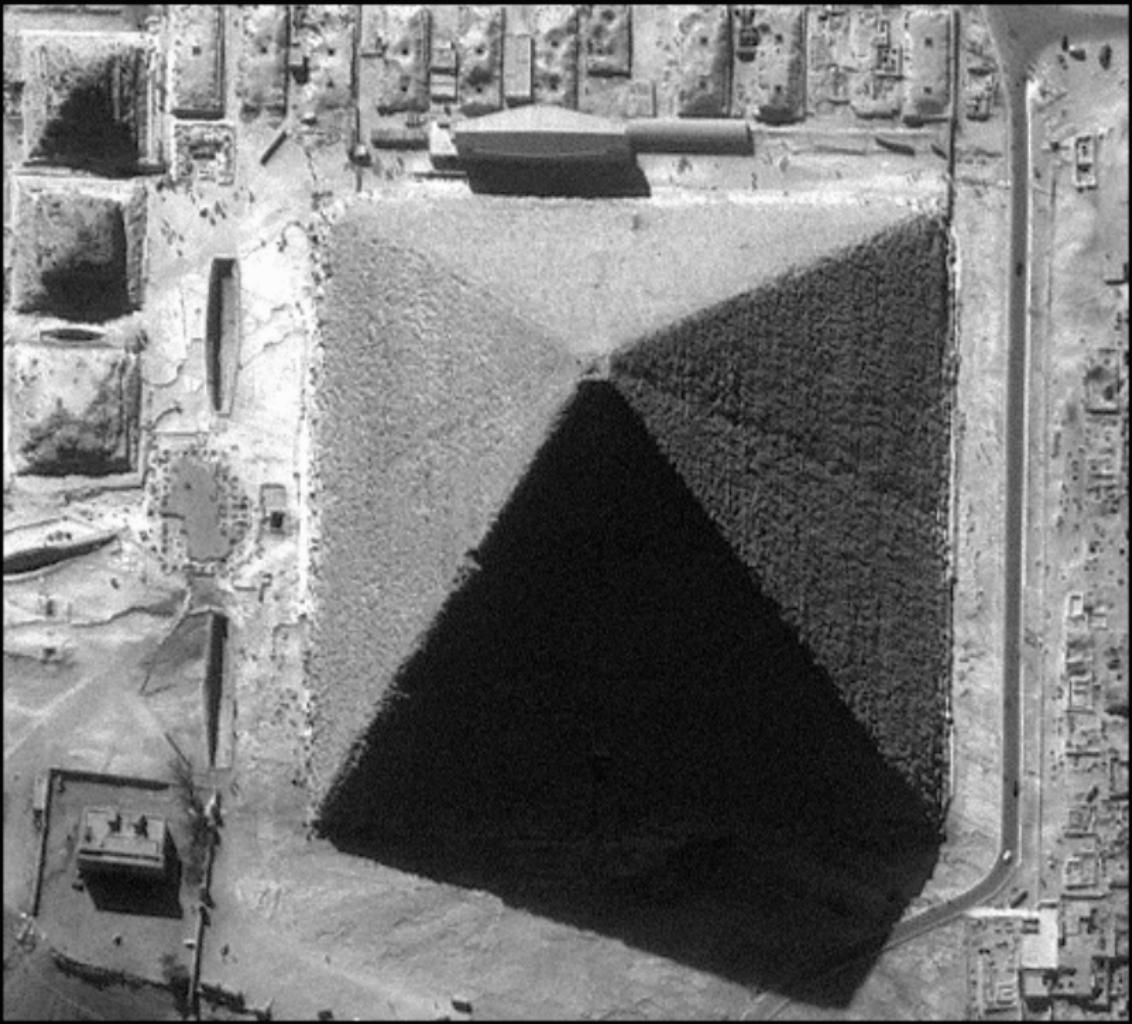
Alta Resolução - Ikonos

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

Band	1-m PAN	4-m MS & 1-m PS
1 (Blue)	0.45-0.90 µm	0.445-0.516 µm
2 (Green)	*	0.506-0.595 µm
3 (Red)	*	0.632-0.698 µm
4 (Near IR)	*	0.757-0.853 µm







Alta Resolução - Quickbird

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

SPACE SHUTTLE - DISCOVERY - 2005

Launch Pad 39B - NASA Kennedy Space Center in Florida, USA

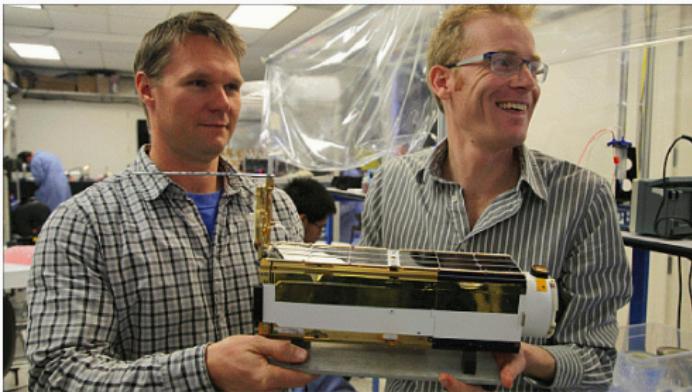


QuickBird Satellite Image at 6 m Resolution
Acquired on 21 APR 2005



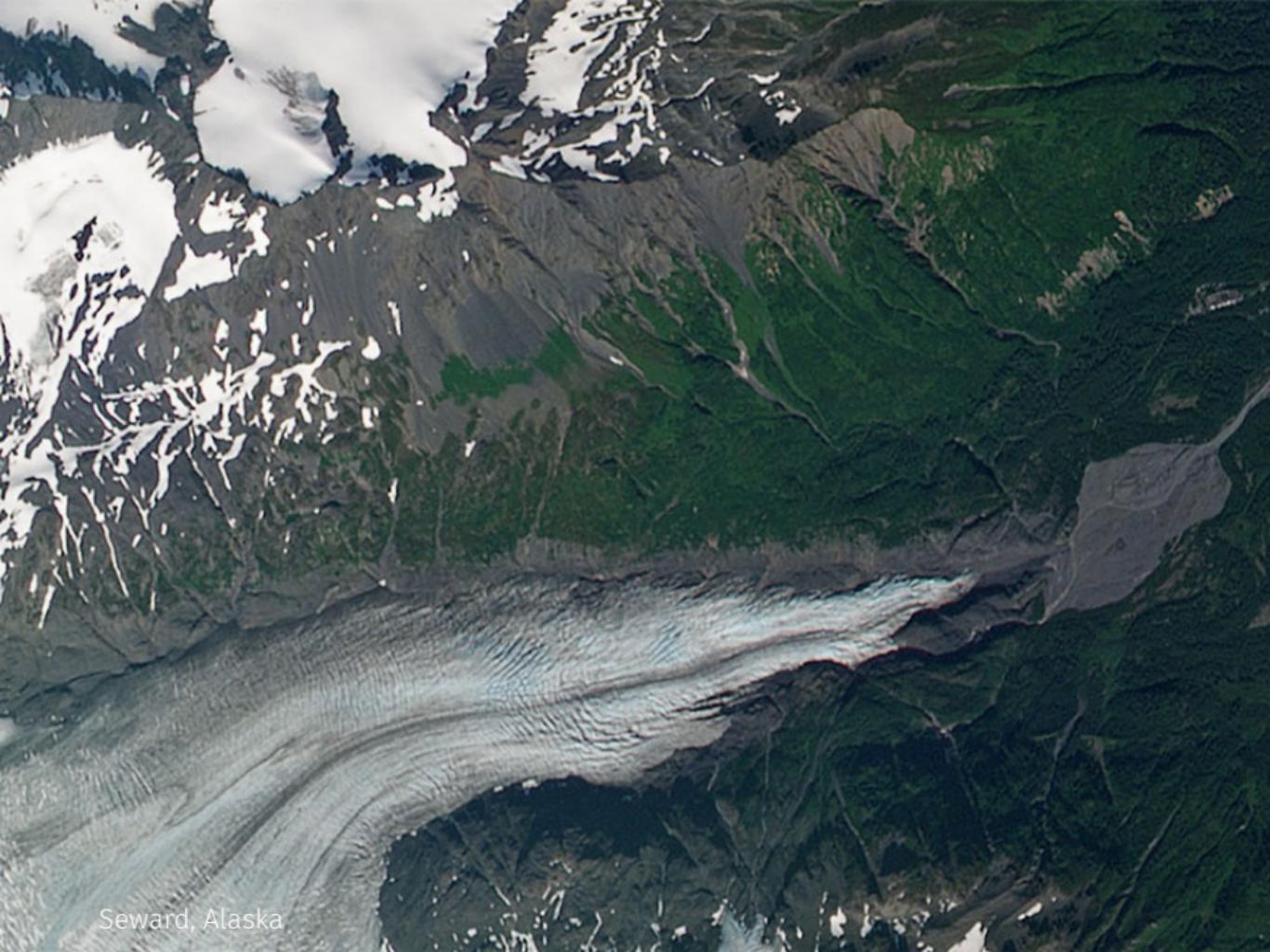
Alta Resolução - Planet

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





San Francisco, California



Seward, Alaska



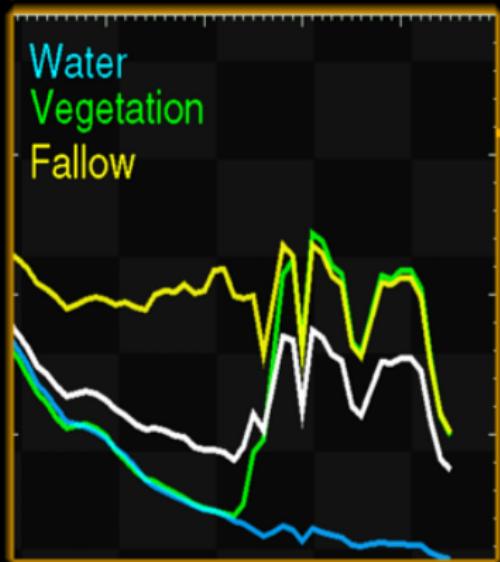
Rotterdam, Netherlands

Hiperespectral - Hyperion

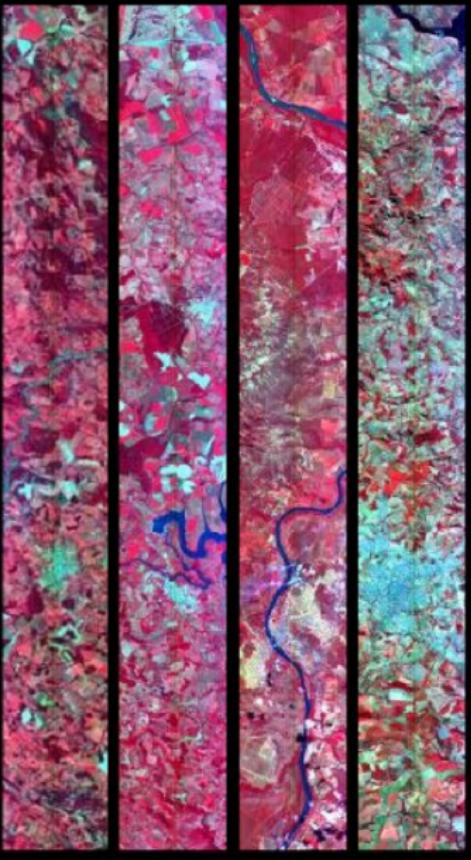
- 220 bandas
 - 30m res.espacial
 - faixa 7.5 x 100 km
-
- ALI (Advanced Land Imager)
 - teste de tecnologia
 - sucessor do ETM+ (OLI)

E0-1/Hyperion

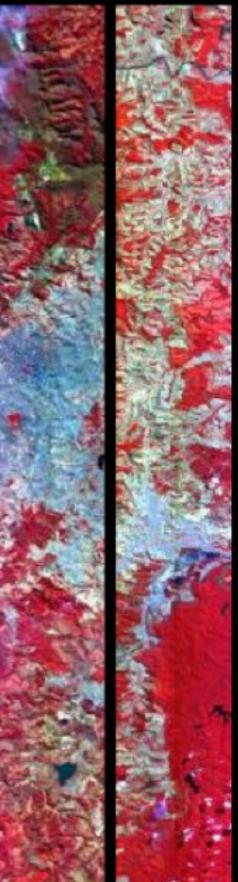
Analysis



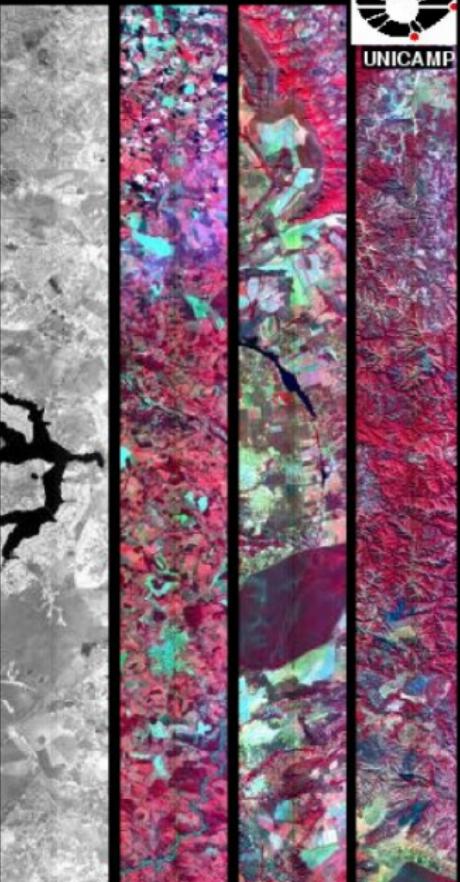
São Paulo



BH



Brasília



Prof. Dr. Carlos Roberto de Souza Filho