GSA-5859 / PCA-5017
SIG em Software Livre

Sensoriamento Remoto

Carlos H. Grohmann

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Instituto de Energia e Ambiente
USP

Definição 1 (INPE)

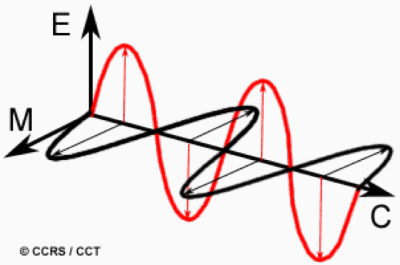
- “Utilização de sensores para aquisição de informações sobre objetos ou fenômenos sem que haja contato direto entre eles”

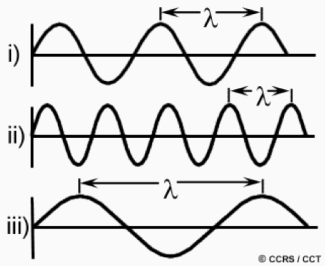
    - Sensores: são equipamentos capazes de coletar energia proveniente do objeto, convertê-la em sinal passível de ser registrado e apresentá-lo em forma adequada à extração de informações
    - Energia: na grande maioria das vezes é a energia eletromagnética ou radiação eletromagnética

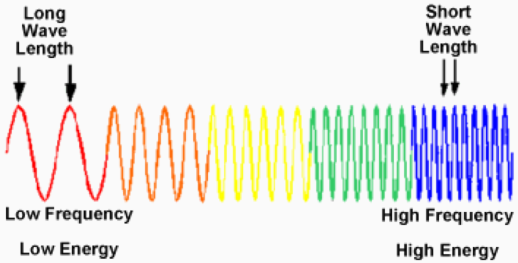
Definição 2 (INPE)

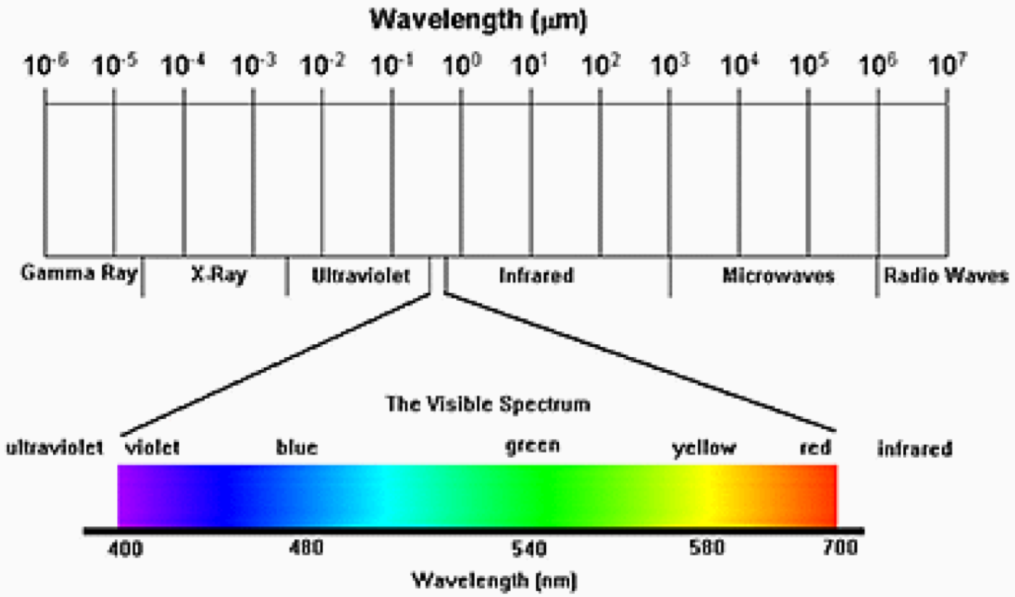
- “Conjunto das atividades relacionadas à aquisição e a análise de dados de sensores remotos”
    - Sensores remotos: sistemas fotográficos ou óptico-eletrônicos capazes de detectar e registrar, sob a forma de imagens ou não, o fluxo de energia radiante refletido ou emitido por objetos distantes

Radiação Eletromagnética (REM)









Plain frame

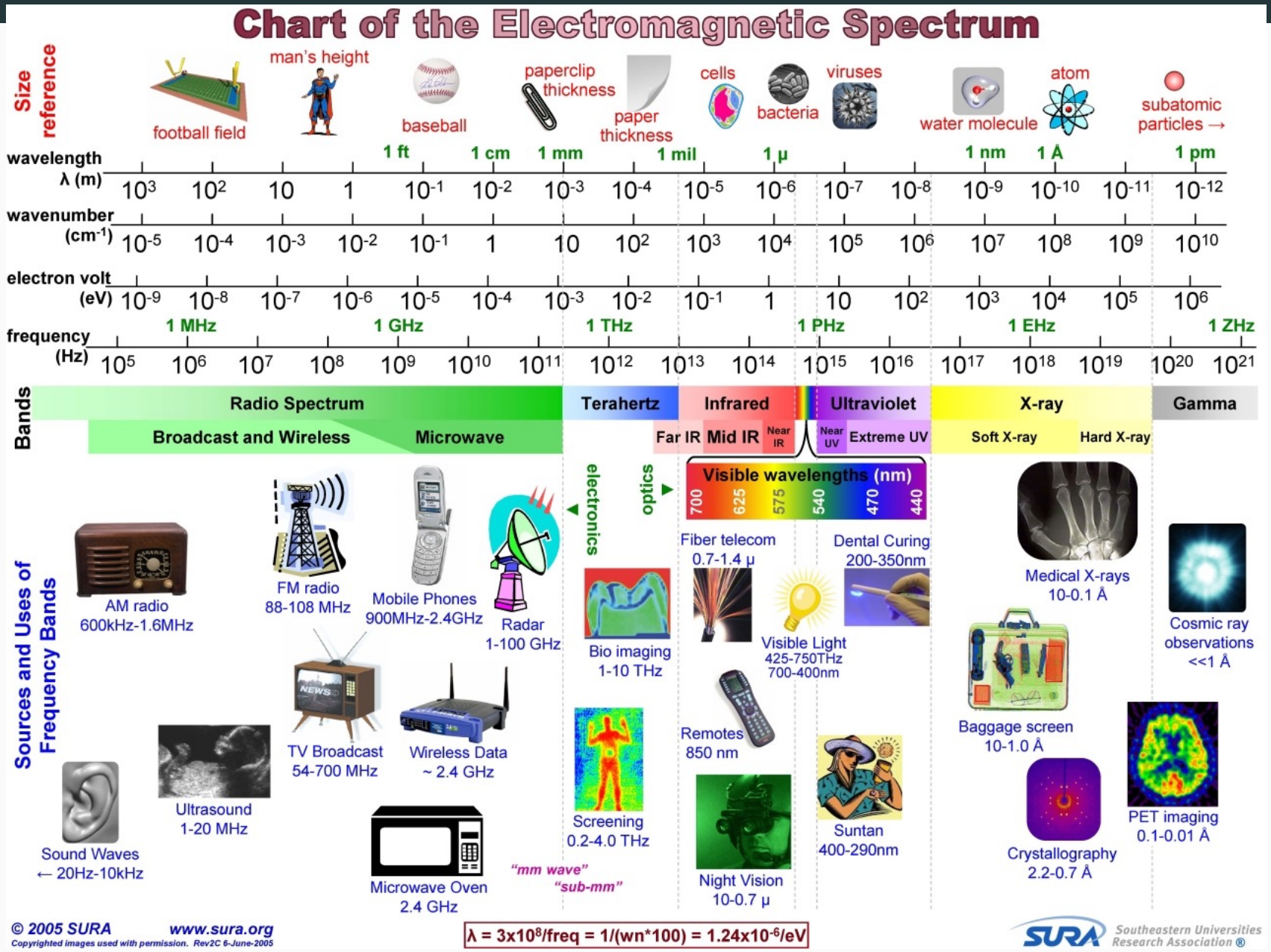


Chart of the Electromagnetic Spectrum
Size reference
football field
man's height
baseball
paperclip thickness
paper thickness
cells
bacteria
viruses
water molecule
atom
subatomic particles →
wavelength λ (m)
1 ft
1 cm
1 mm
1 mil
1 µ
1 nm
1 Å
1 pm
wavenumber (cm-1)
electron volt (eV)
frequency (Hz)
1 MHz
1 GHz
1 THz
1 PHz
1 EHz
1 ZHz
Bands
Radio Spectrum
Broadcast and Wireless
Microwave
Terahertz
Infrared
Far IR
Mid IR
Near IR
Ultraviolet
Near UV
Extreme UV
X-ray
Soft X-ray
Hard X-ray
Gamma
Visible wavelengths (nm)
700
625
575
540
470
440
electronics
optics
Sources and Uses of Frequency Bands
AM radio
600kHz-1.6MHz
FM radio
88-108 MHz
Mobile Phones
900MHz-2.4GHz
Radar
1-100 GHz
Bio imaging
1-10 THz
Fiber telecom
0.7-1.4 µ
Dental Curing
200-350nm
Visible Light
425-750THz
700-400nm
Medical X-rays
10-0.1 Å
Cosmic ray observations
<<1 Å
Baggage screen
10-1.0 Å
TV Broadcast
54-700 MHz
Wireless Data
~ 2.4 GHz
Remotes
850 nm
Ultrasound
1-20 MHz
Sound Waves
← 20Hz-10kHz
Screening
0.2-4.0 THz
Suntan
400-290nm
Crystallography
2.2-0.7 Å
PET imaging
0.1-0.01 Å
Microwave Oven
2.4 GHz
"mm wave"
"sub-mm"
Night Vision
10-0.7 µ
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λ = 3x10^8/freq = 1/(wn*100) = 1.24x10^-6/eV
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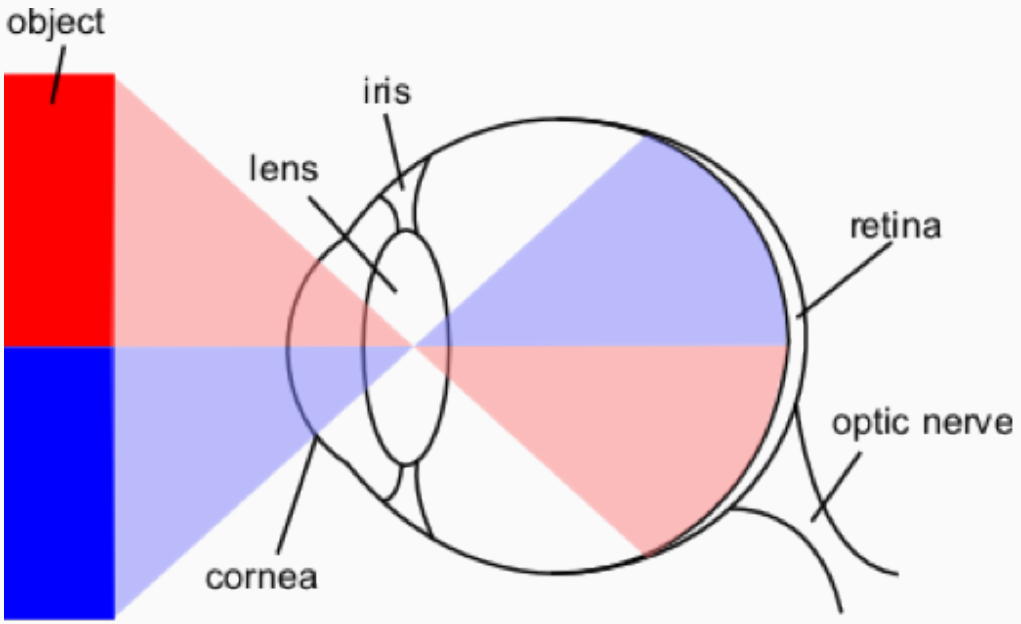
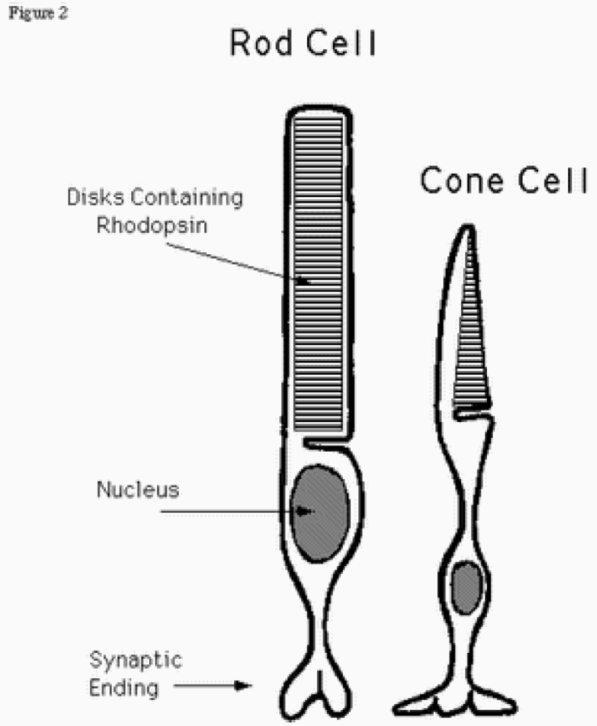
Southeastern Universities Research Association ®

Sistema Visual Humano





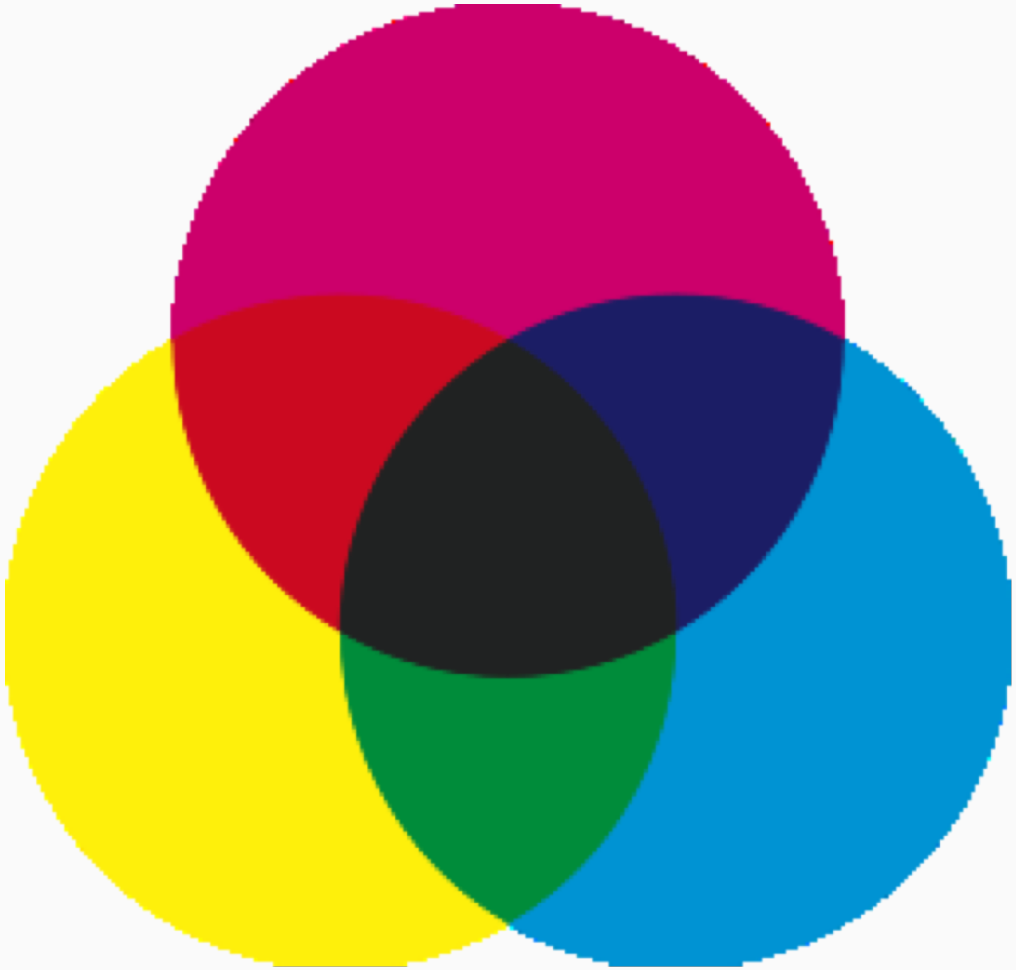
Sistema Visual Humano

- 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)

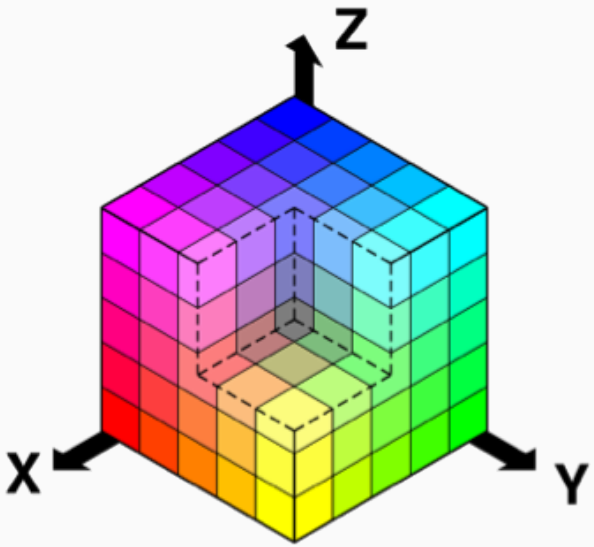
- Cones: $\sim 6 - 7 * 10^6$ principalmente no centro da retina
  - só funcionam com luminosidade (com pouca luz, enxergamos em tons de cinza)
  - aprox. 100 tonalidades cada tipo
  - 3 tipos: Vermelho, Verde, Azul = $\sim$1.000.000 cores !!
  - Somos seres Tricromáticos – exergamos a partir de 3 cores

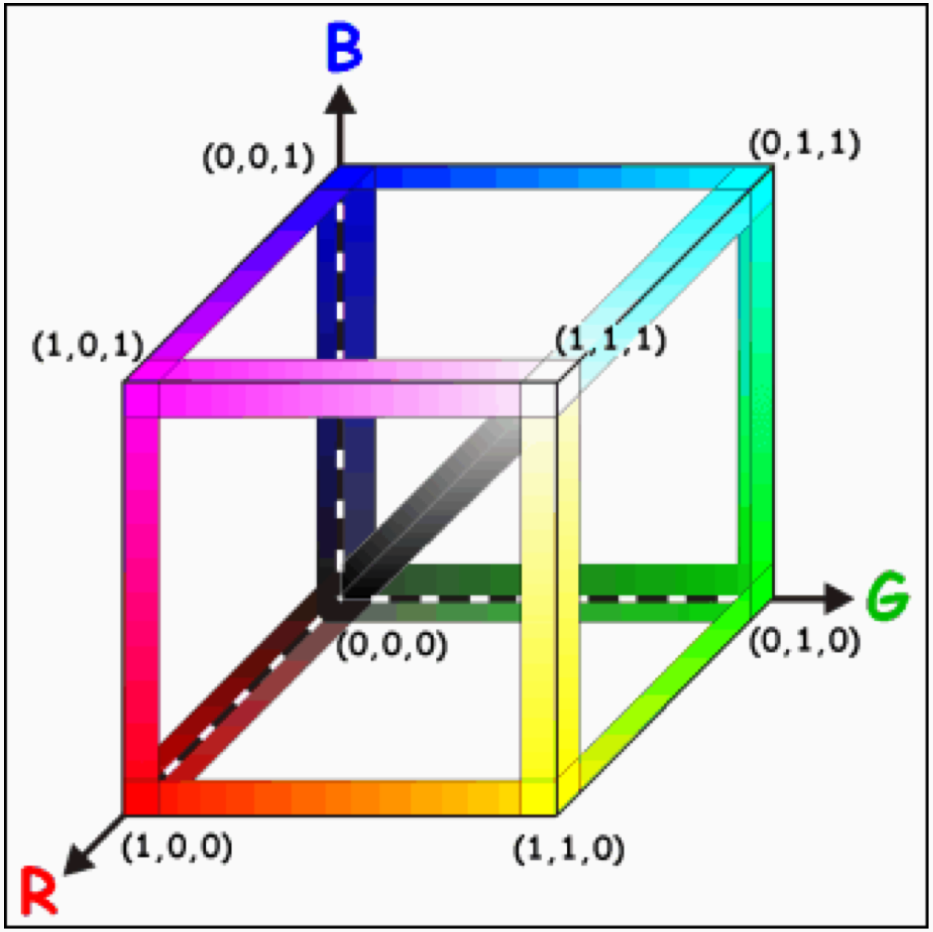
Sistema de Cores Aditivo (RGB)

Sistema de Cores Subtrativo (CMYK)

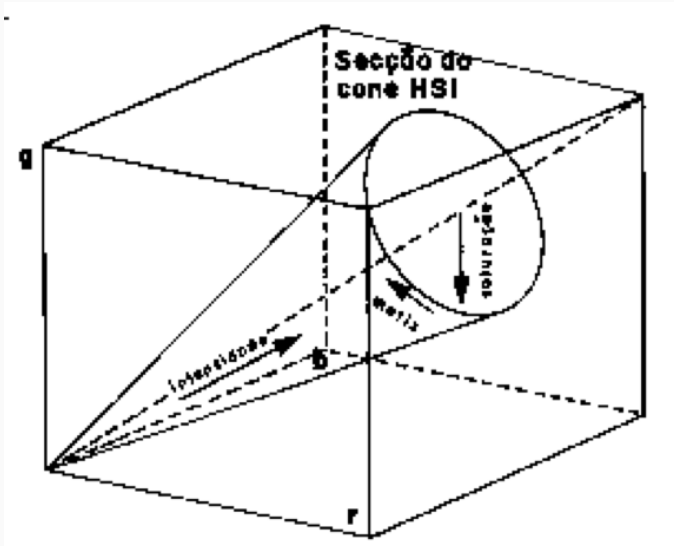


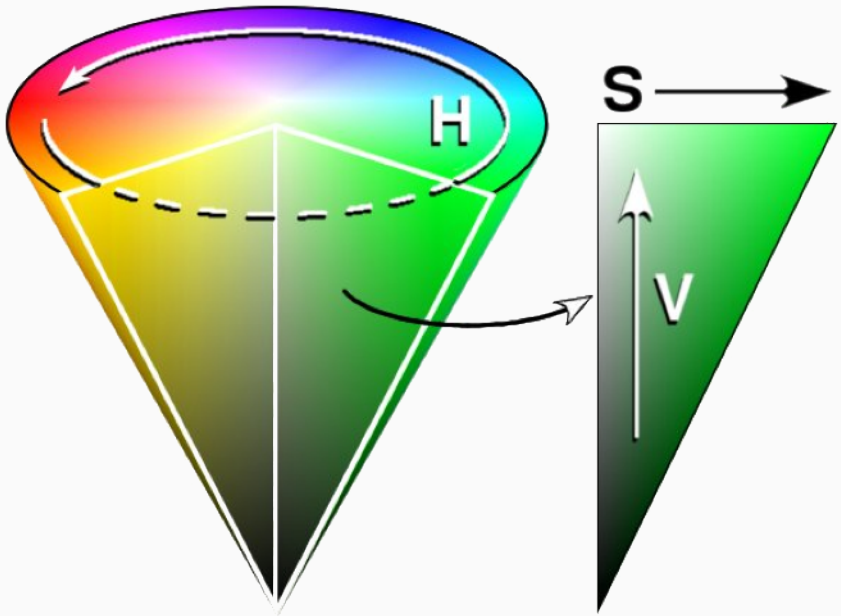
Sistema de Cores – Cubo RGB





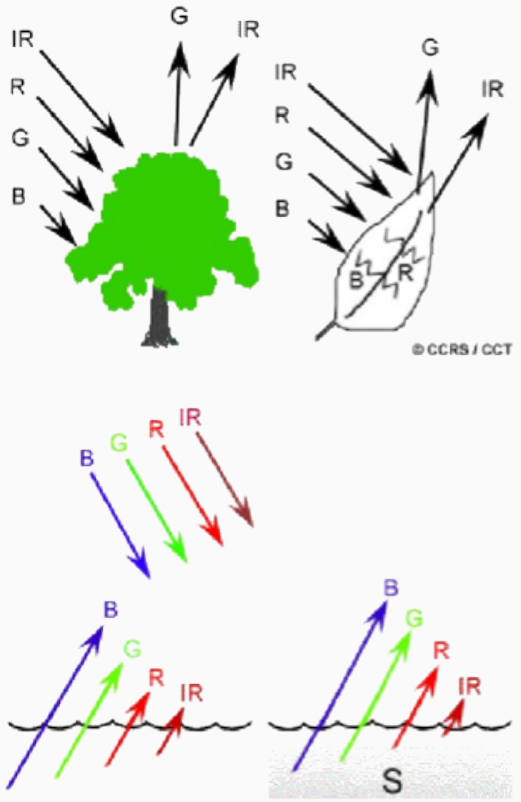
Sistema de Cores – Cone IHS





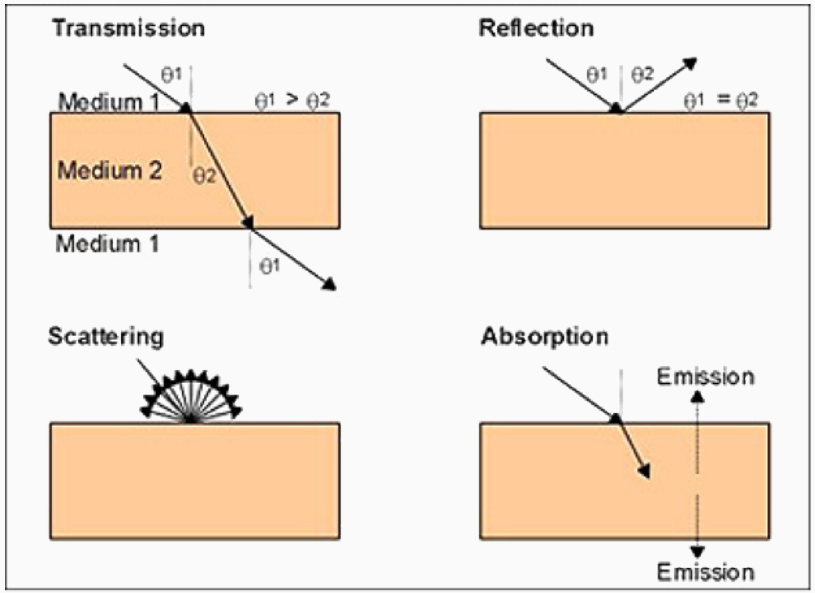
Cores dos objetos

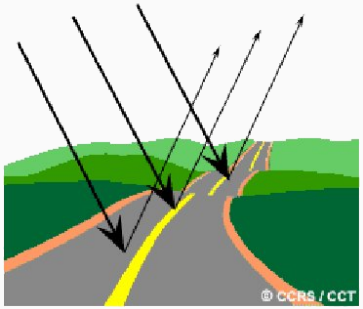
- Cor do objeto depende do comprimento de onda refletido
- folhas: clorofila
  - absorve R e B
  - reflete G e NIR
- água
  - absorve G+R+NIR (comp. onda longos do visível)
  - presença de algas ou sedimentos

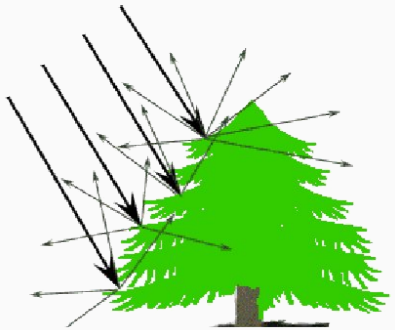


Comportamento da REM

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

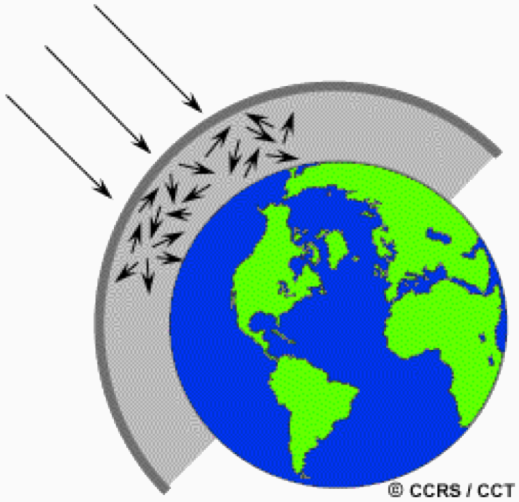






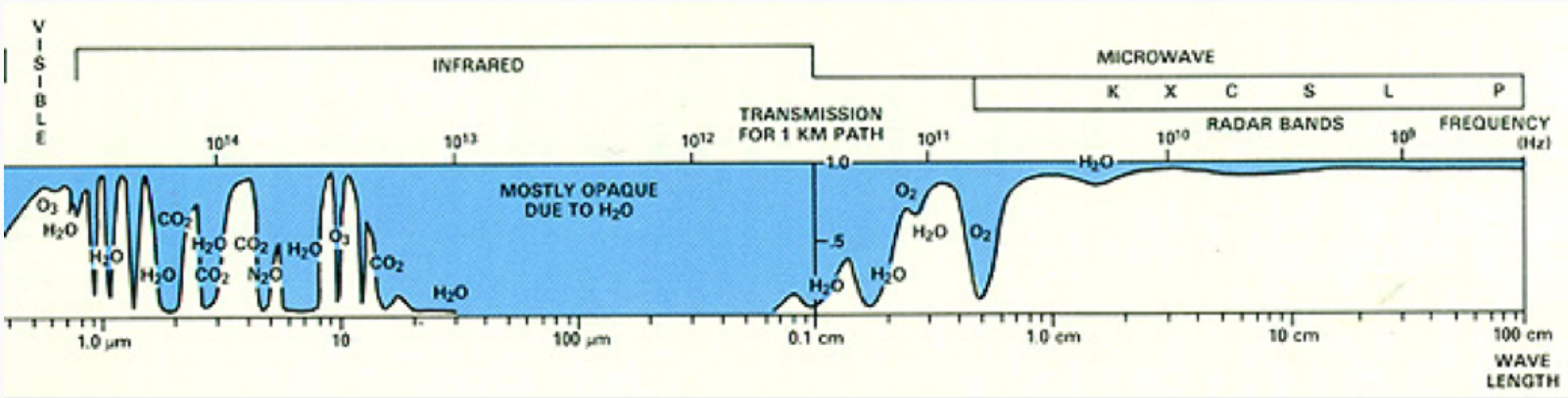
Espalhamento Atmosférico

- Espalhamento de Rayleight
  - 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

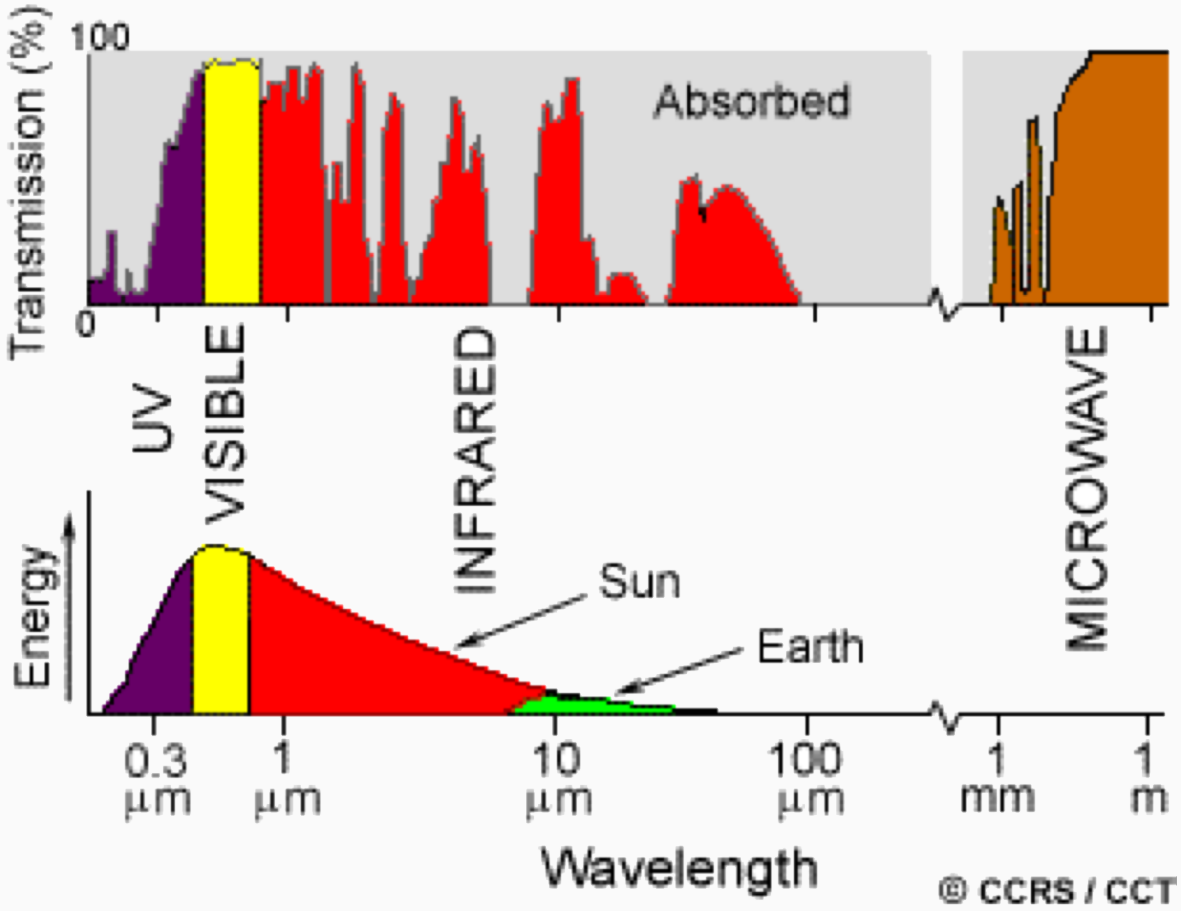
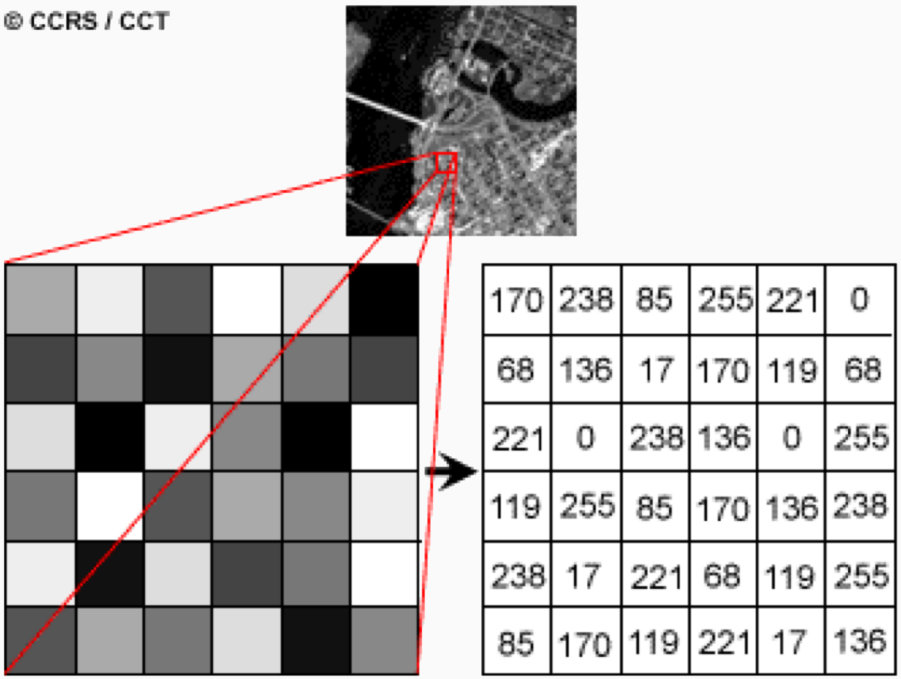


Imagem Digital

- 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



Imagens Multiespectrais

- Sensores captam diferentes faixas do espectro
- Cada faixa á 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

Imagem RGB - Banda R

Imagem RGB - Banda G

Imagem RGB - Banda B

Sensores e Satélites

Tipos de Sensores

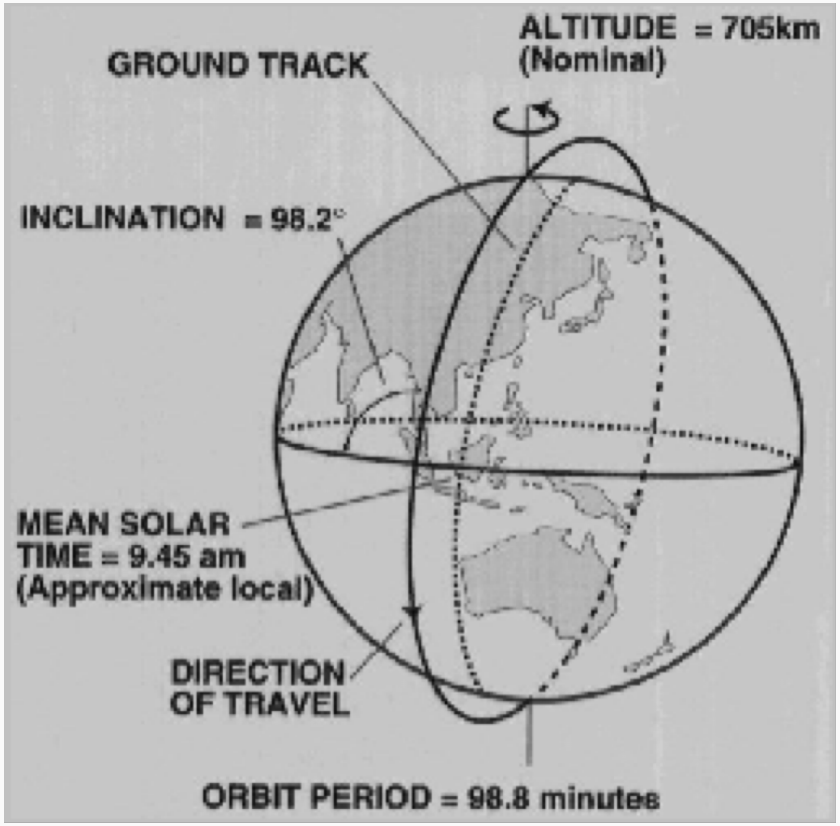
- Fotográficos
  - Imagem é capturada de uma só vez
- Não-Fotográficos
  - Imagem capturada pixel a pixel (scanner)

- 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

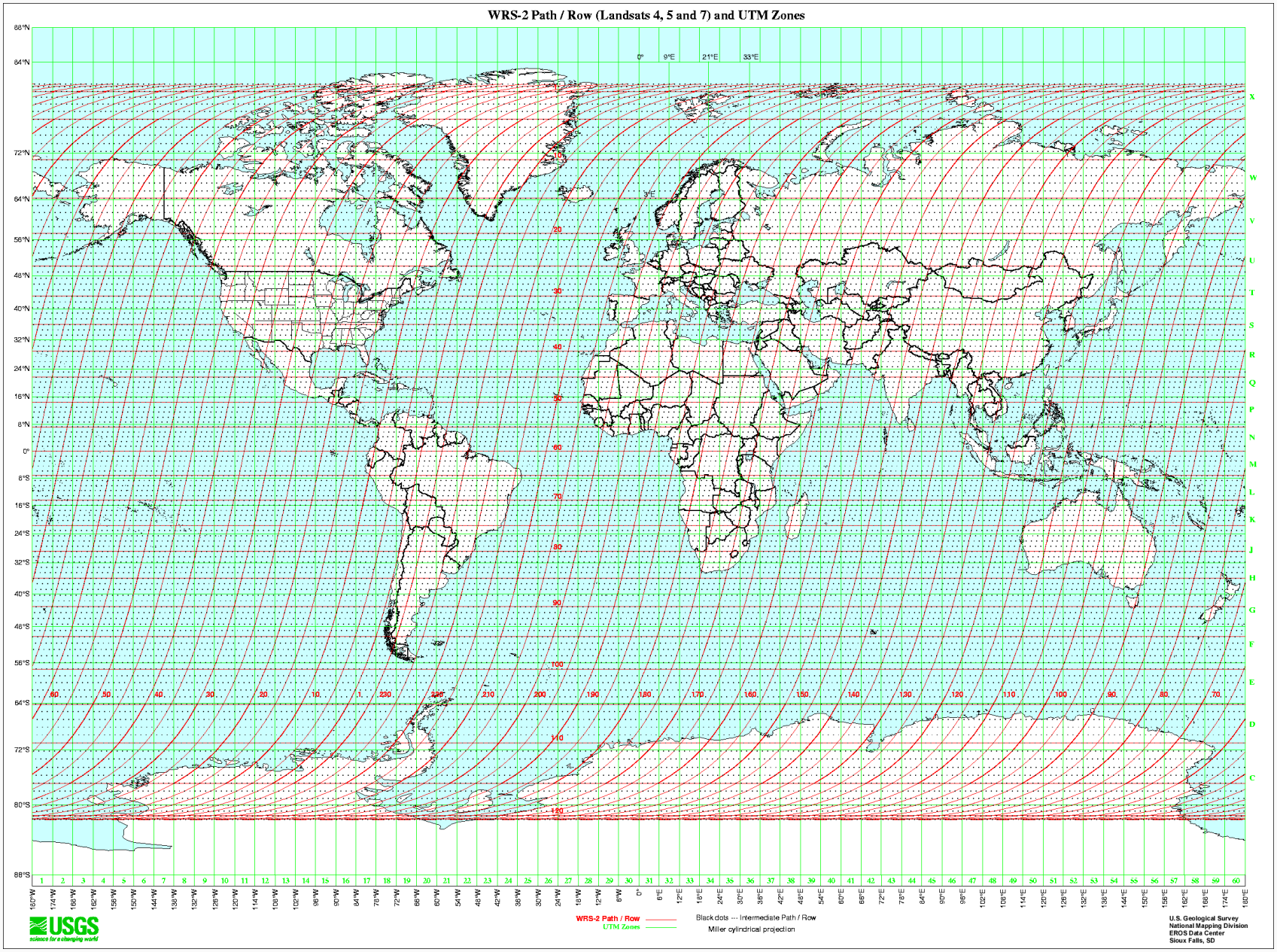
- Plataformas
  - Terrestre
  - Aeroportado
  - Orbital (Satélite, Ônibus espacial, OVNI...)

Satélites - Órbitas

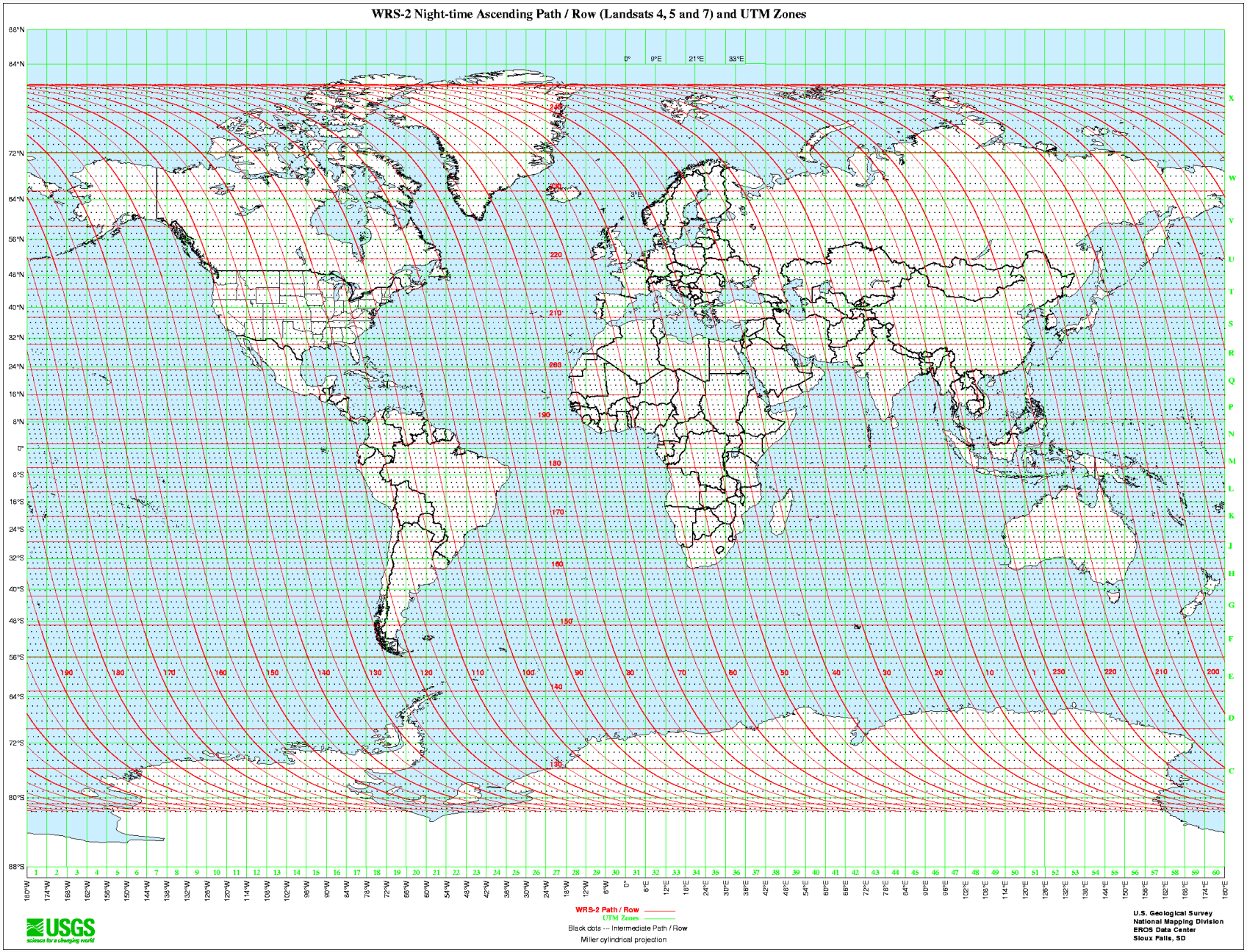
- Órbita – altitude da órbita determina campo de visão e período de revisita
- Geoestacionários – 36.000km altitude
- Heliossincrônicos – órbita acompanha horário local do sol
- órbitas:
  - descendente – dia
  - ascendente – noite
- Worldwide Reference System 2 (WRS2)



WRS2 - Órbitas Descendentes



WRS2 - Órbitas Ascendentes

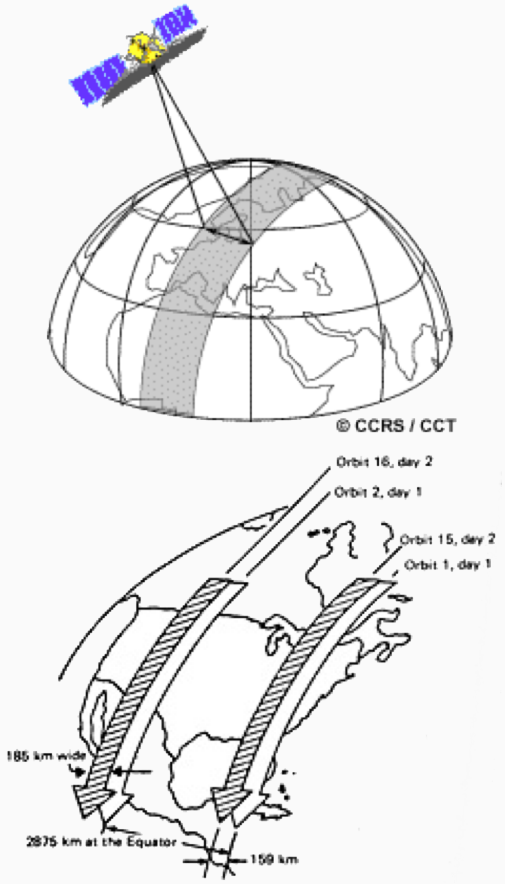


Satélites - Características

- swath - faixa imageada
- largura de dezenas a centenas de km

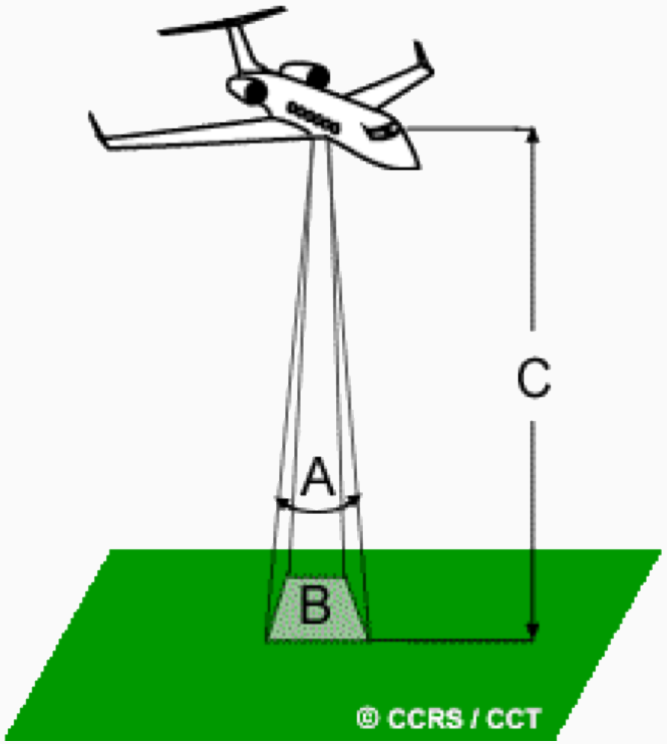
- período de revisita:
- tempo para imagear a mesma área (nadir) duas vezes

- overlap – aŕea 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



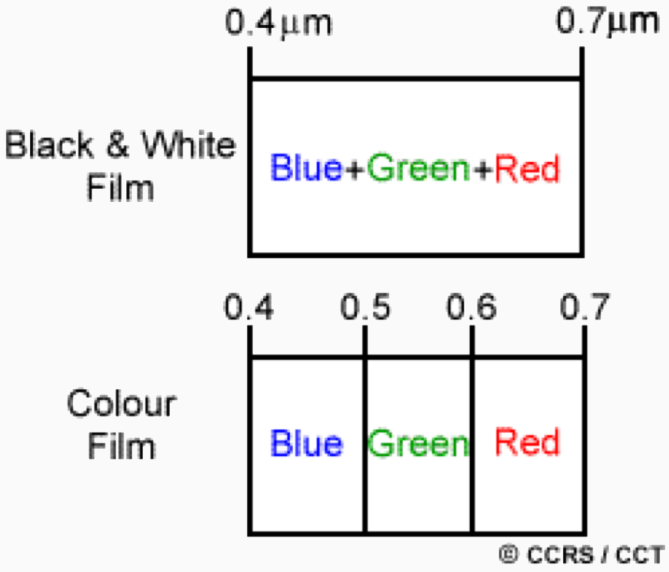
Satélites - Resolução Espacial

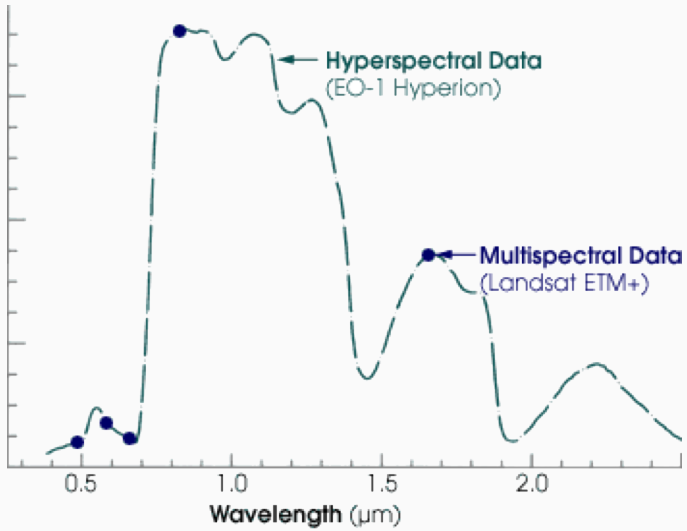
baixa

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

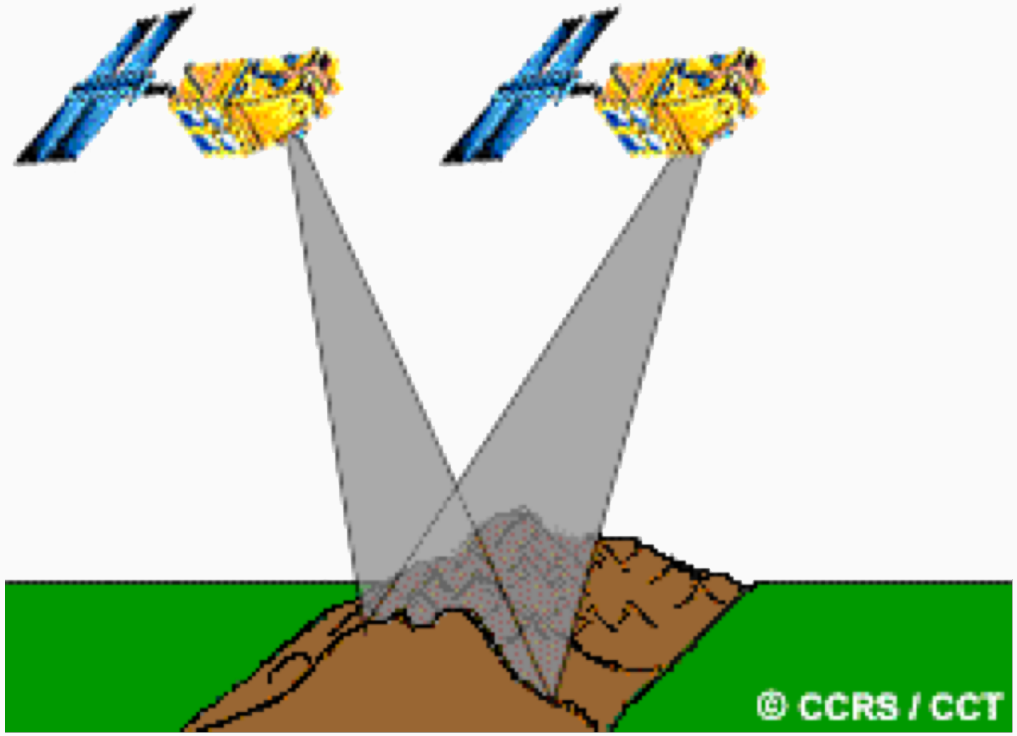
- Resolução radiométrica - Capacidade do sensor em diferenciar variação na intensidade de energia

2 bits - 4 tons de cinza

8 bits - 256 tons de cinza

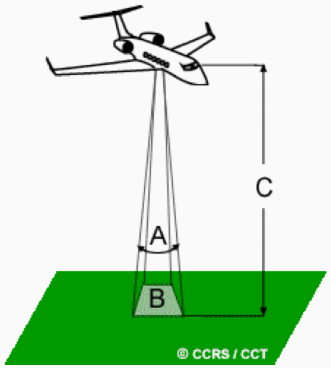
Satélites - Resolução Temporal

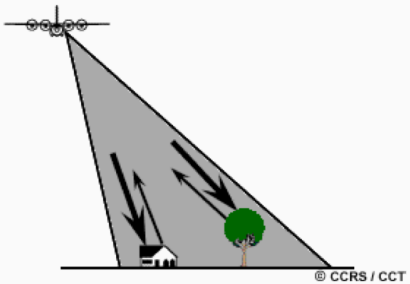
- Resolução temporal - Período de revisita
- Varia com a latitude, sobreposição entre faixas adjacentes e capacidade do sensor em off-nadir

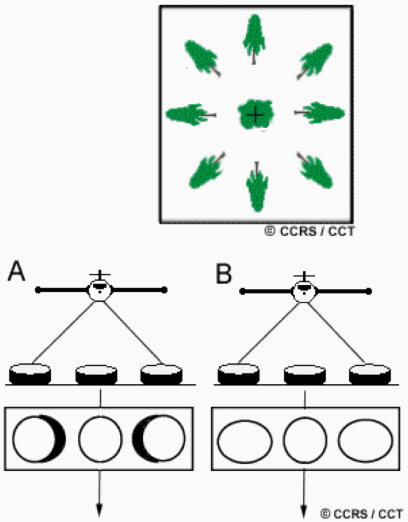


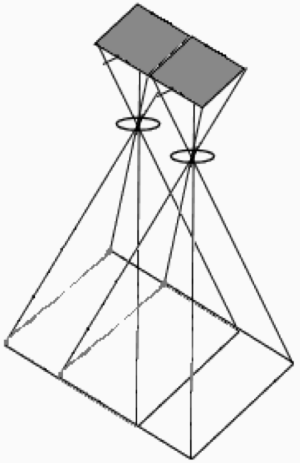
Sistemas de Imageamento - Fotografias Aéreas

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



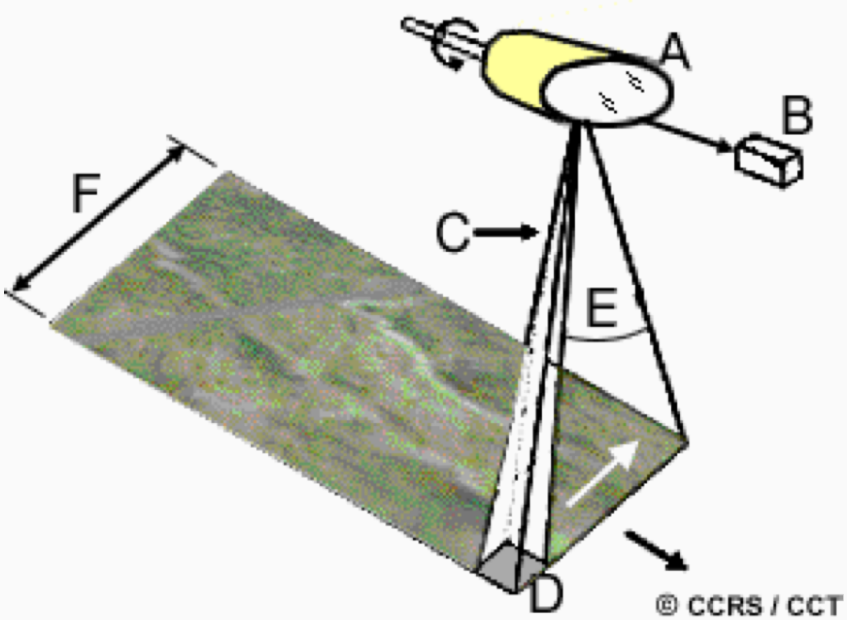


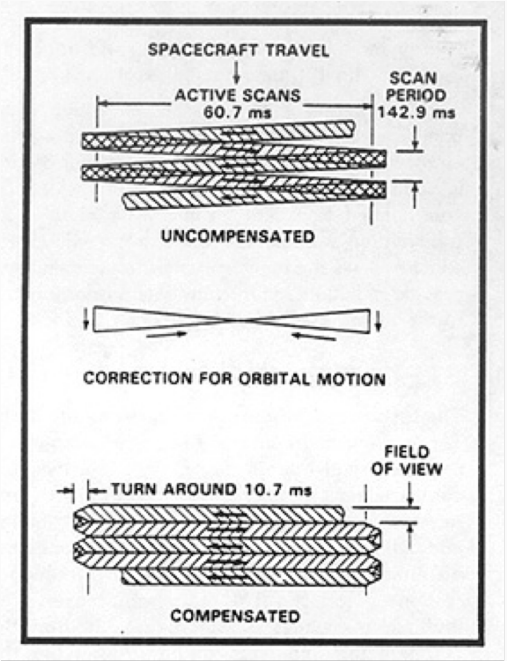




Sistemas de Imageamento - Sensores Multiespectrais (MSS)

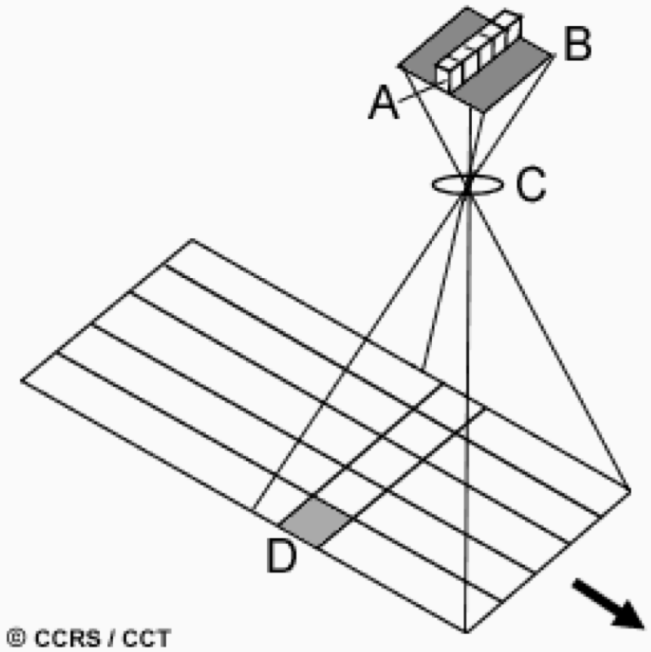
- Across-track scanners
- Série de linhas perpendiculares ao movimento do sensor
- Espelho rotativo





Sistemas de Imageamento - Sensores Multiespectrais (MSS)

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



Operações em SR

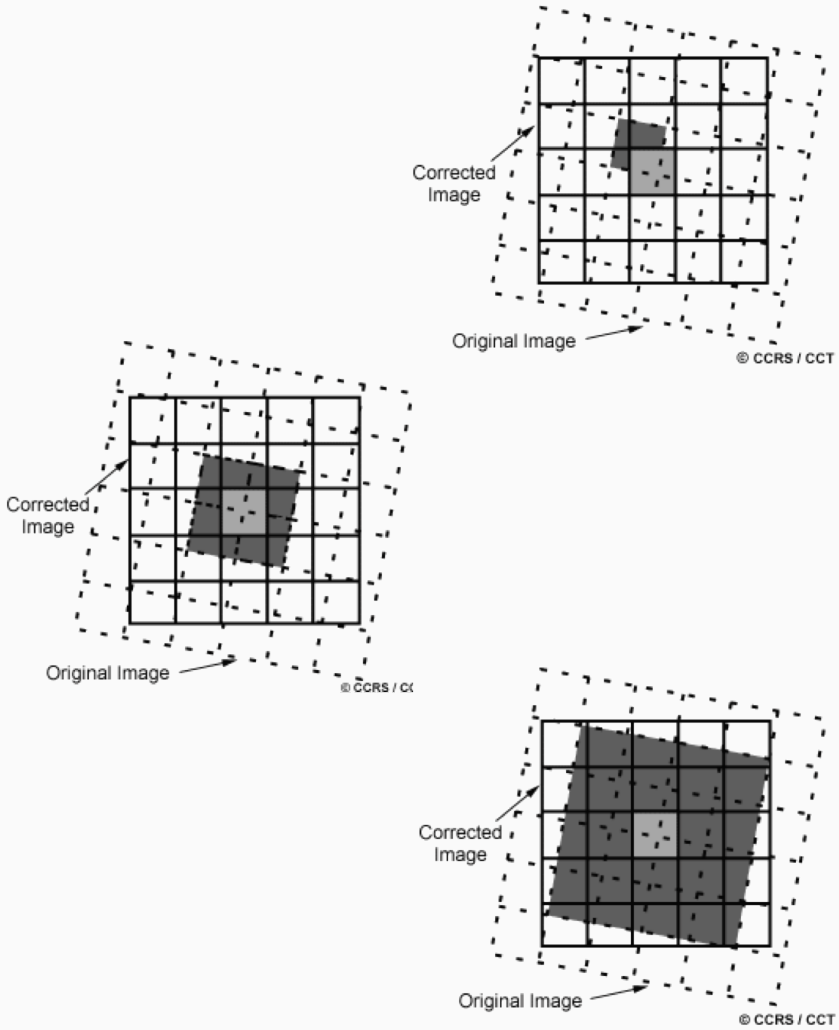
Operações em SR

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

Georreferenciamento

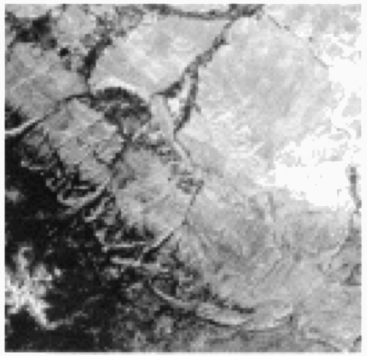
- Registro (Georreferenciamento)
- Correção geométrica
- Projeção cartográfica
- Ground Control Points (GCPs)
- image-to-map / image-to-image

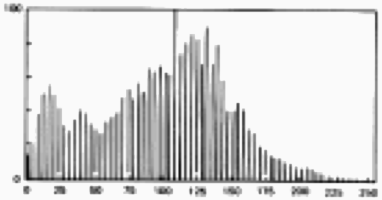
- Vizinho mais próximo
- Interpolação bilinear
- Convolução cúbica



Realce

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





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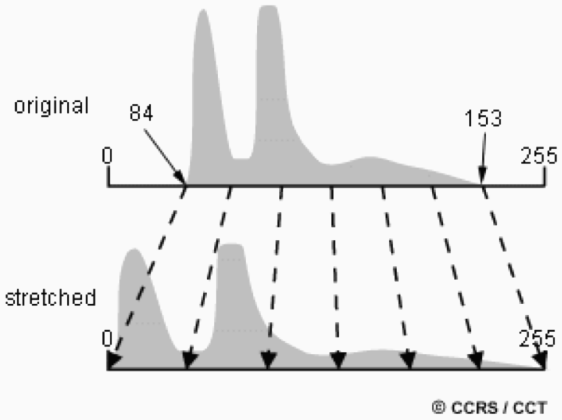

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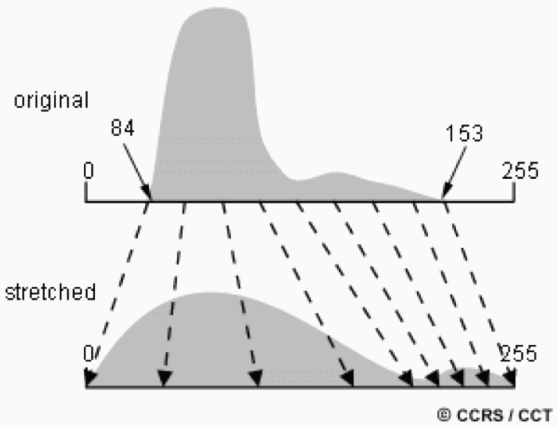
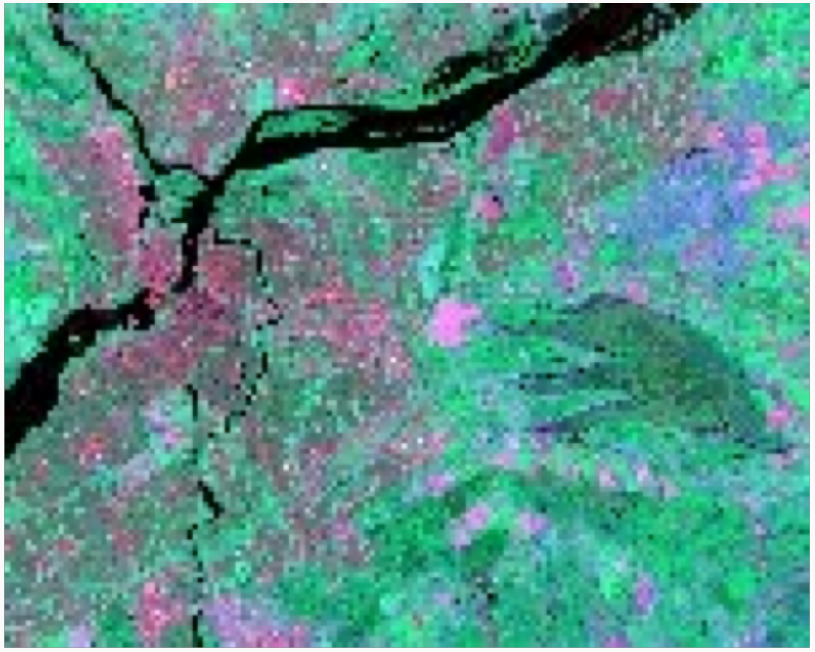


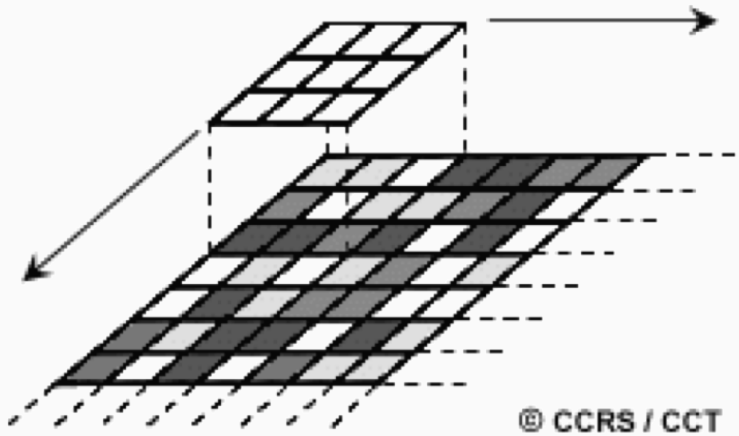
© CCRS / CCT

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

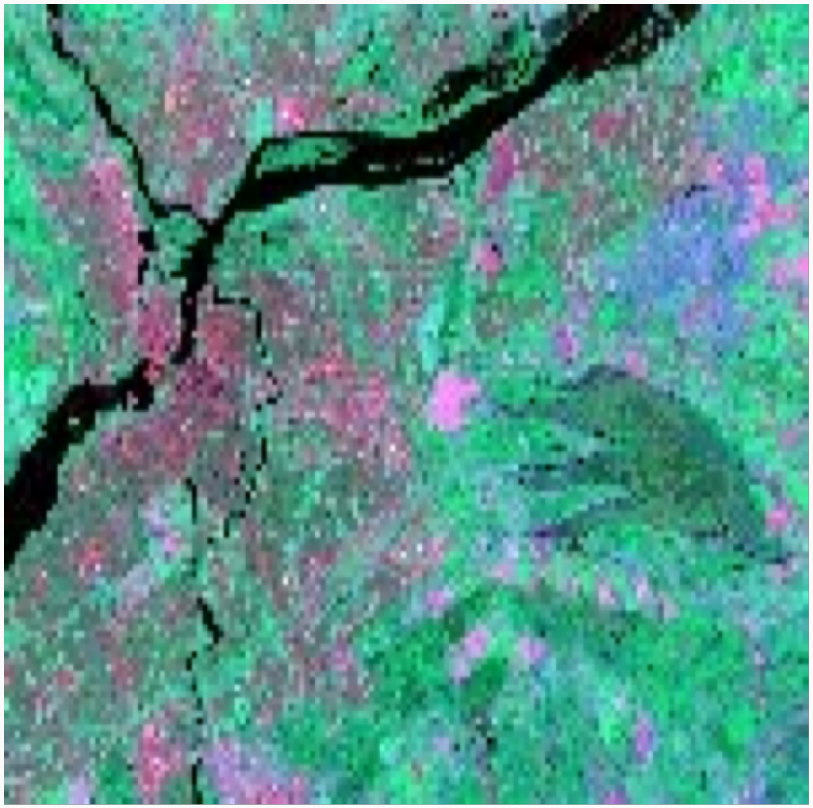
Imagem original

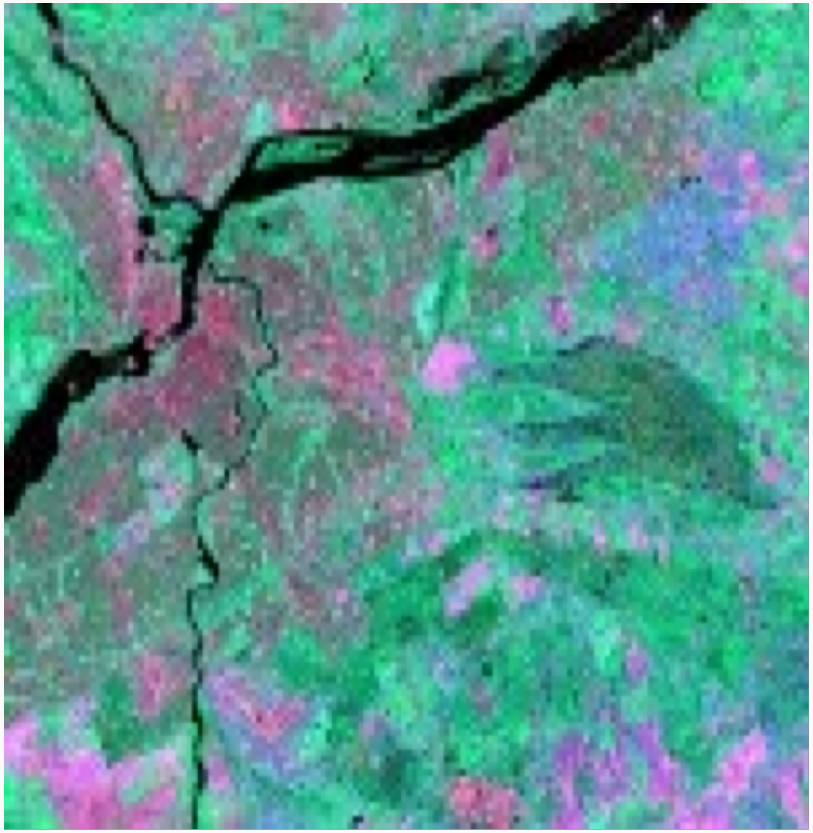
	26	25	23	22	22	
	25	26	25	24	26	
	25	27	27	27	26	
	23	26	28	29	27	
	22	25	27	27	25	

Imagem filtrada

$$\text{Pixel central} = 1/9 \begin{bmatrix} 24+26+22 \\ +28+30+27 \\ +28+32+29 \end{bmatrix} = 27$$

Filtro de média – passa-baixas





Filtro de média – passa-baixas

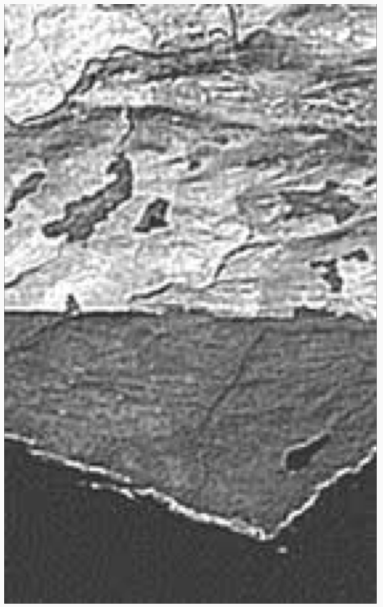
25	27	32	20	21	19	24
23	27	19	25	22	18	25
27	26	24	26	22	22	26
23	25	28	30	27	25	27
19	22	28	32	29	27	25
17	19	25	27	30	31	22
20	21	25	23	21	19	17

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	

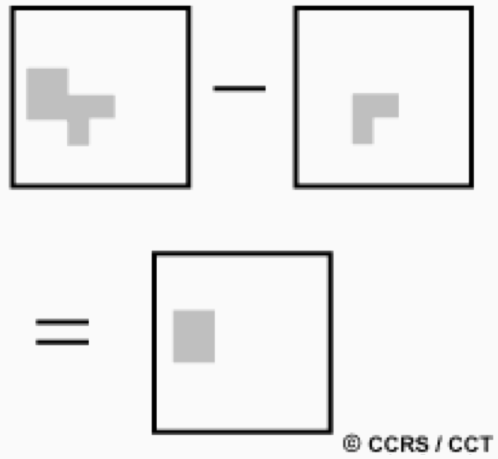
Imagem filtrada

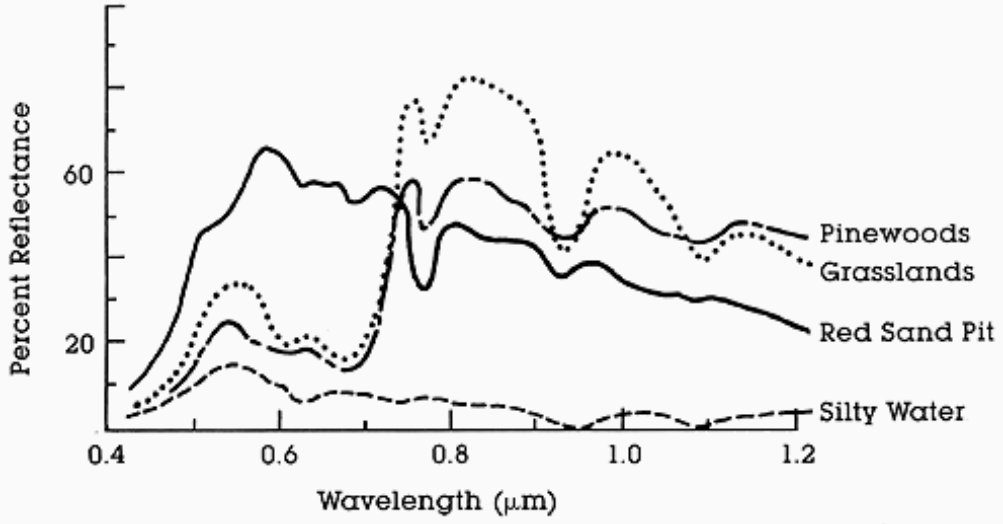
$$\text{Pixel central} = 1/9 \begin{bmatrix} 24+26+22 \\ +28+30+27 \\ +28+32+29 \end{bmatrix} = 27$$



Operações Aritméticas

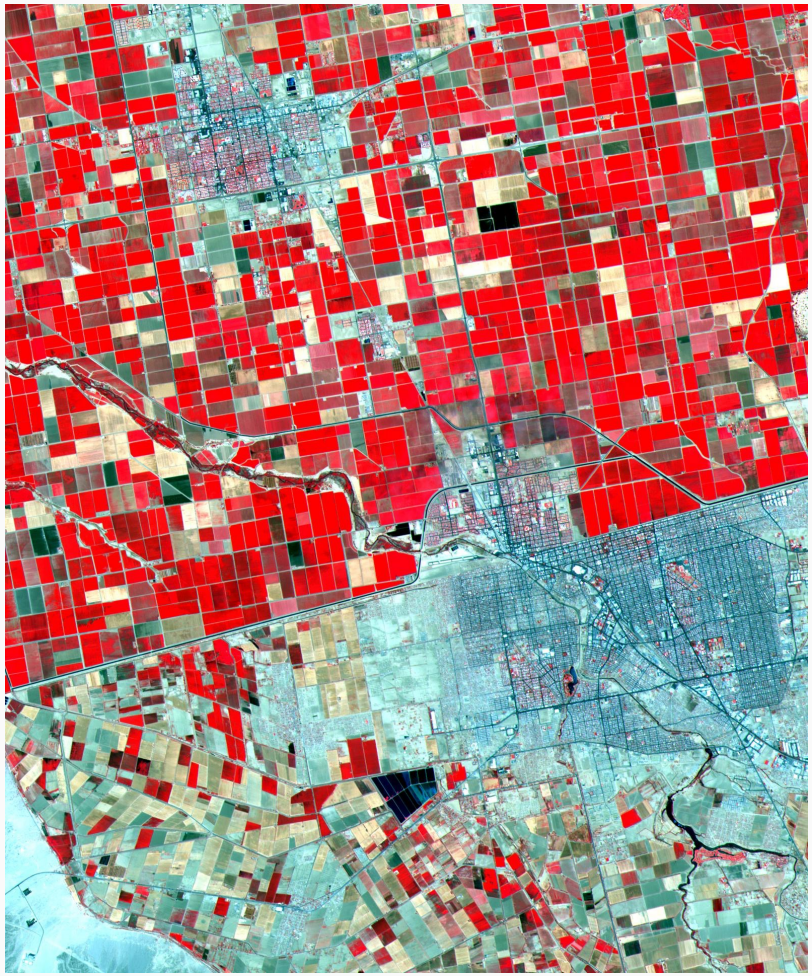
- Subtração: mais usada em análise temporal
- Razão: realça diferenças de comportamentos espectrais

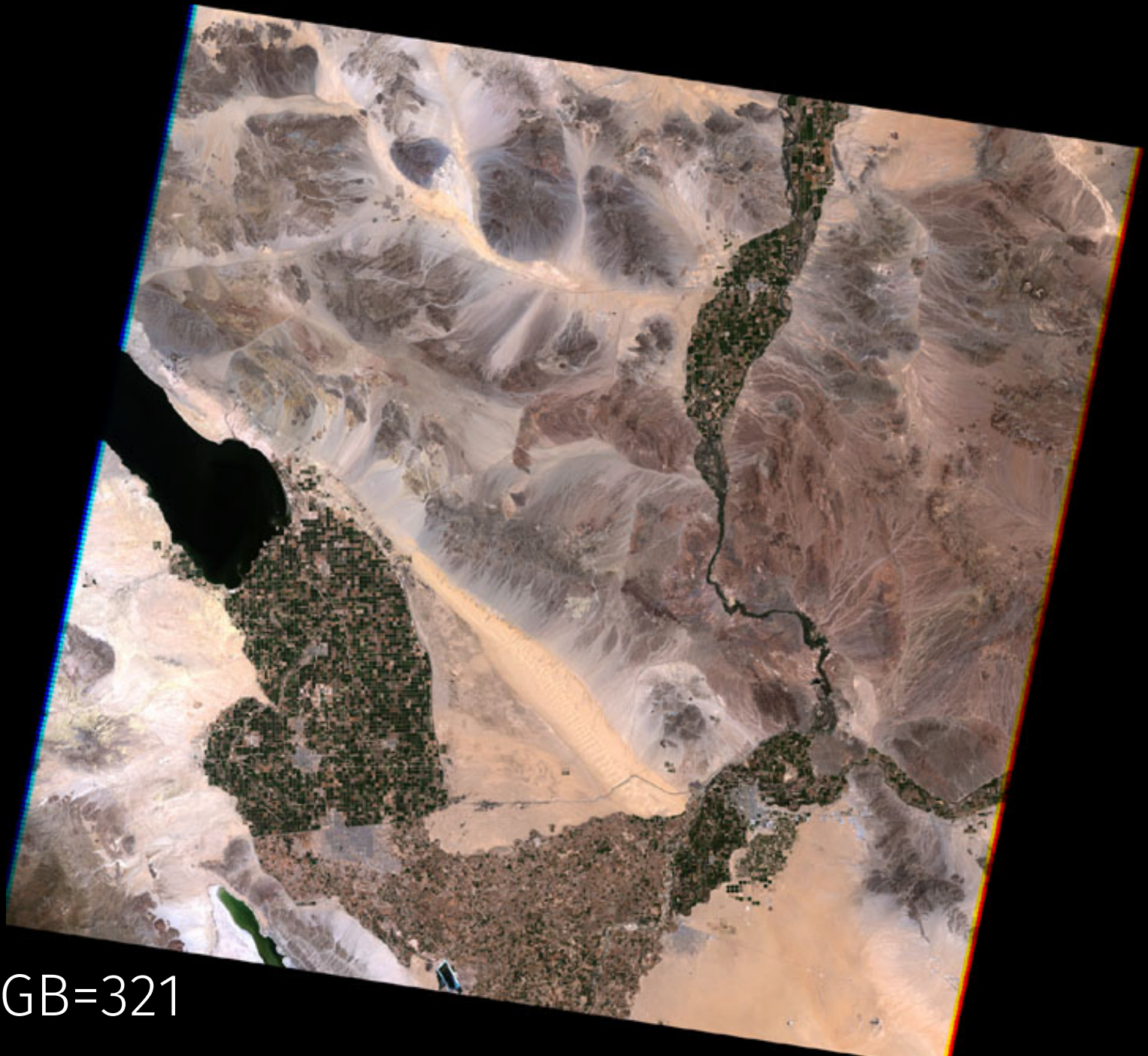


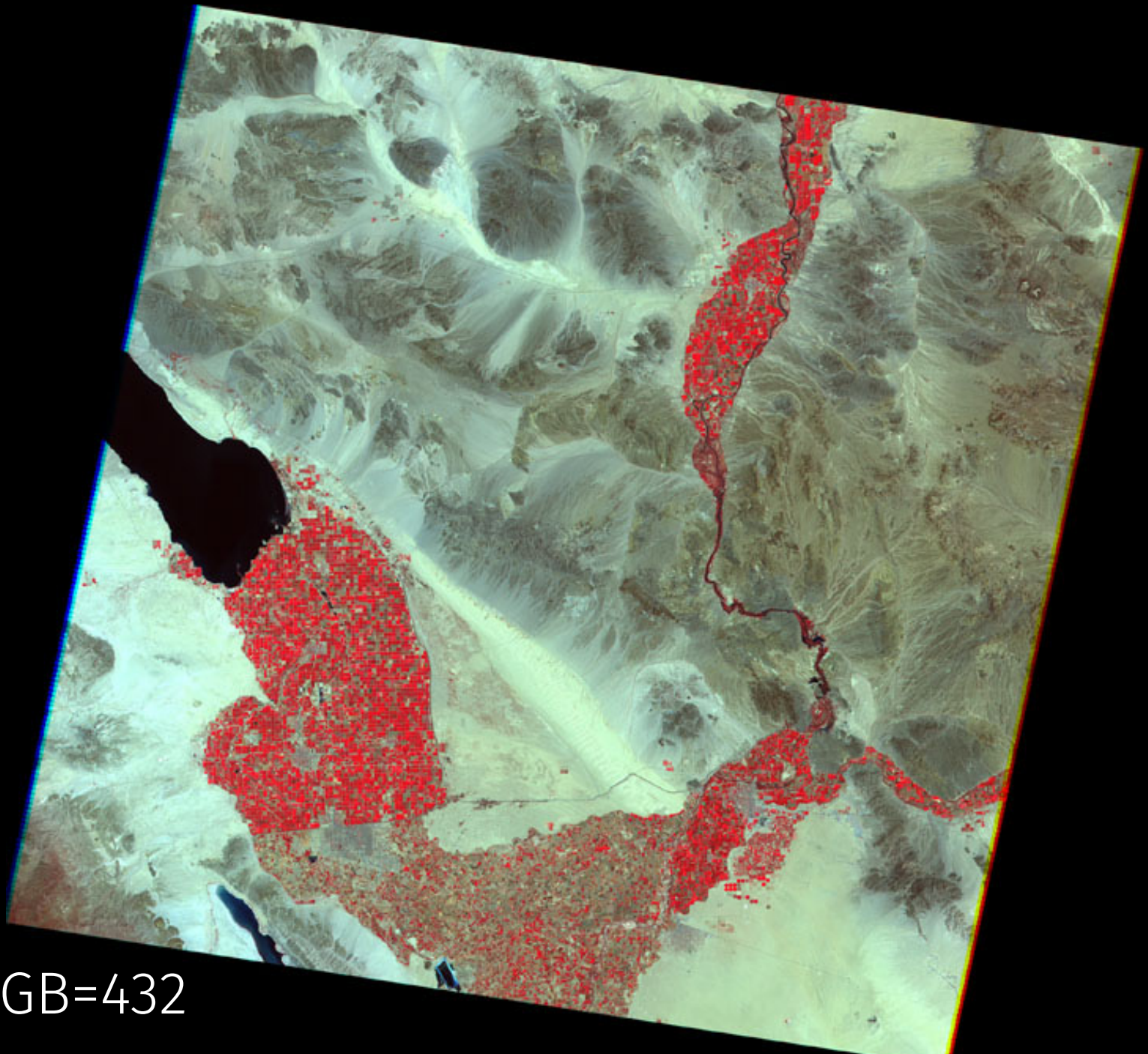


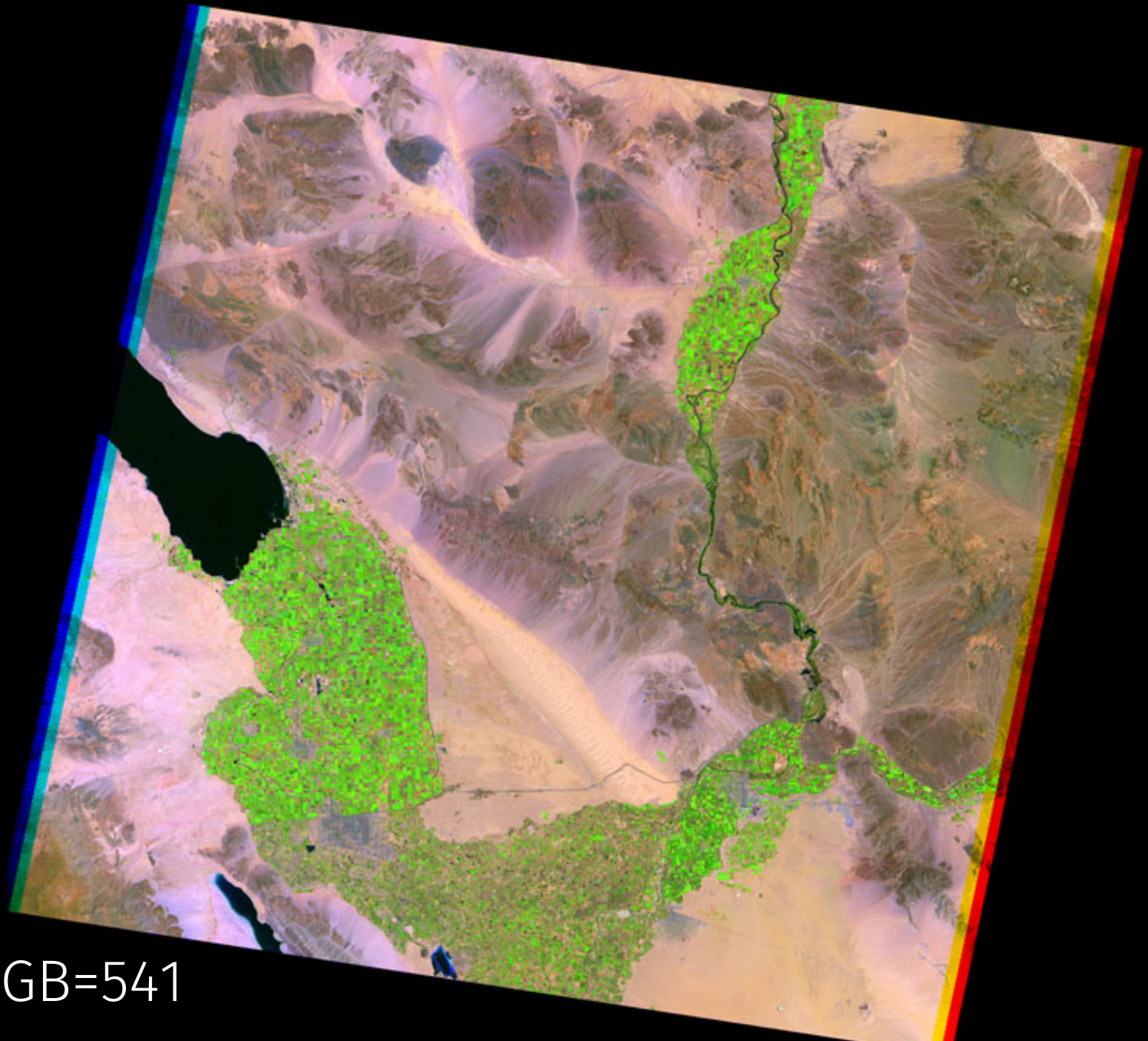
Composição RGB

- Ressaltar diferentes respostas espectrais
- feição de interesse: vermelho

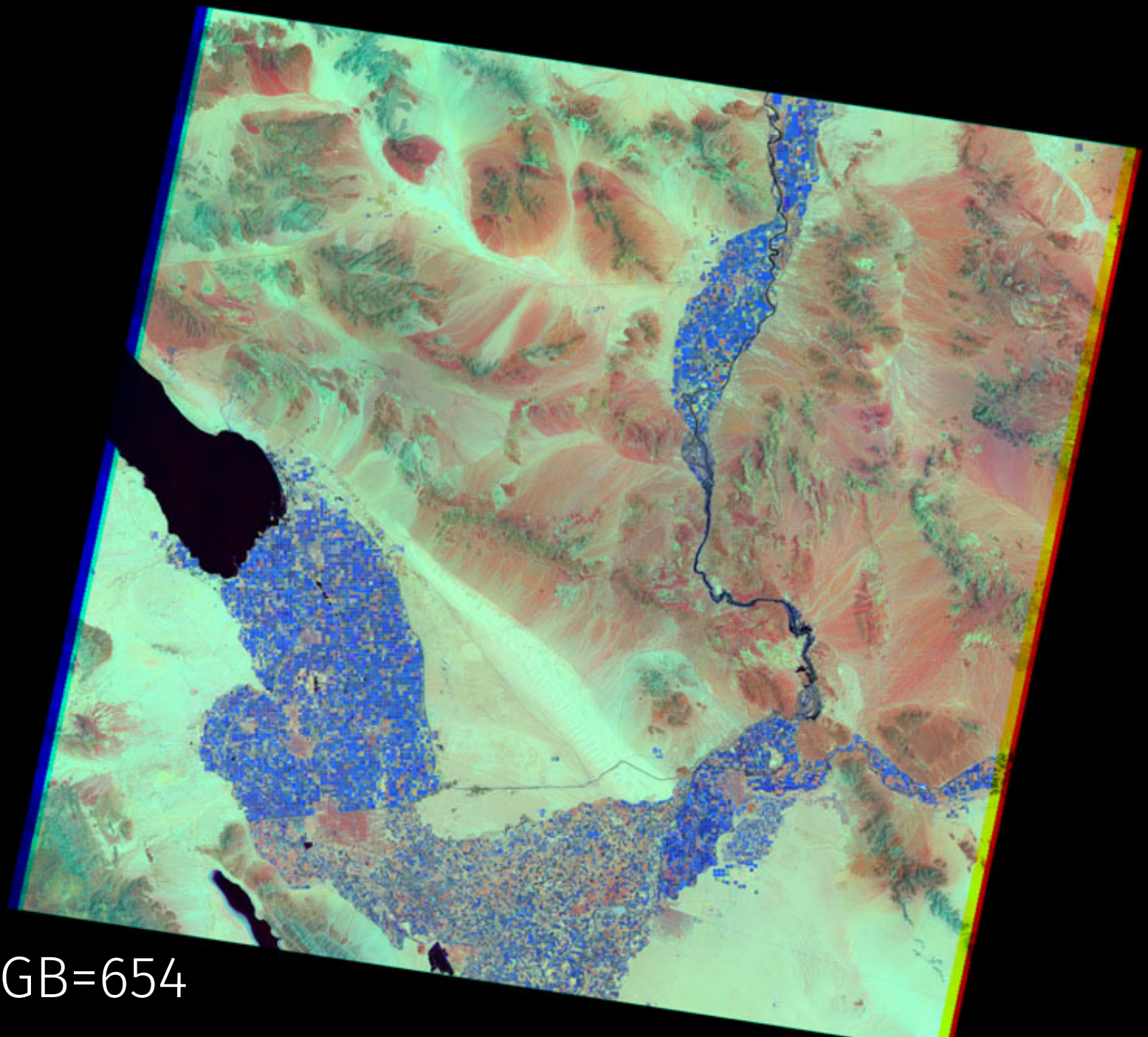



RGB=321


RGB=432

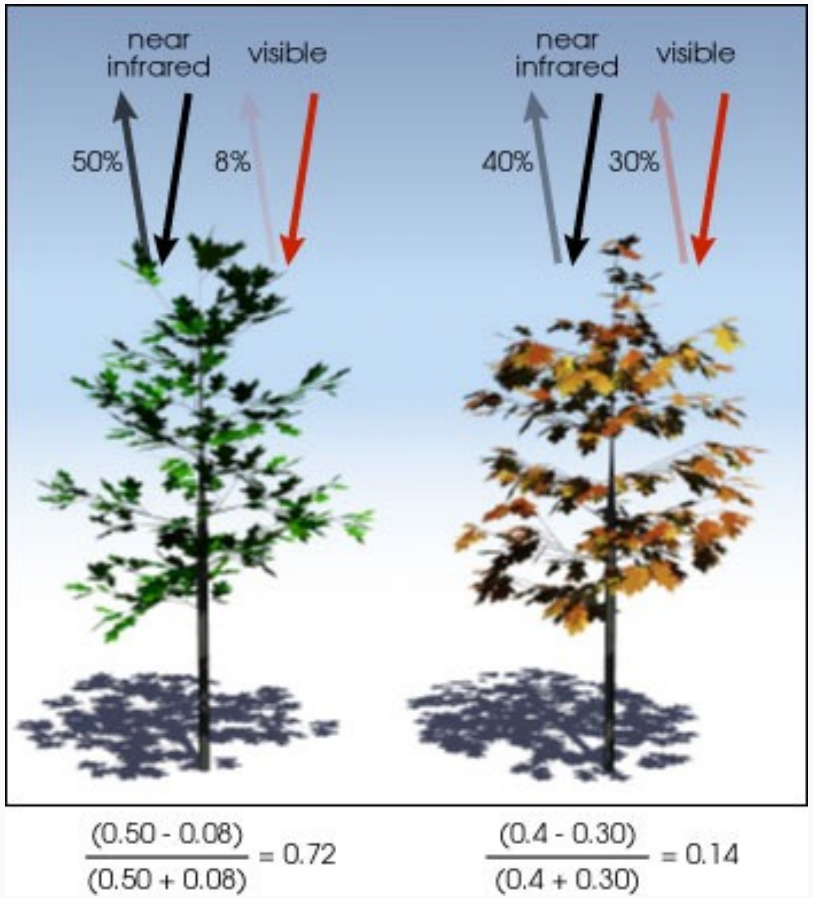


RGB=541

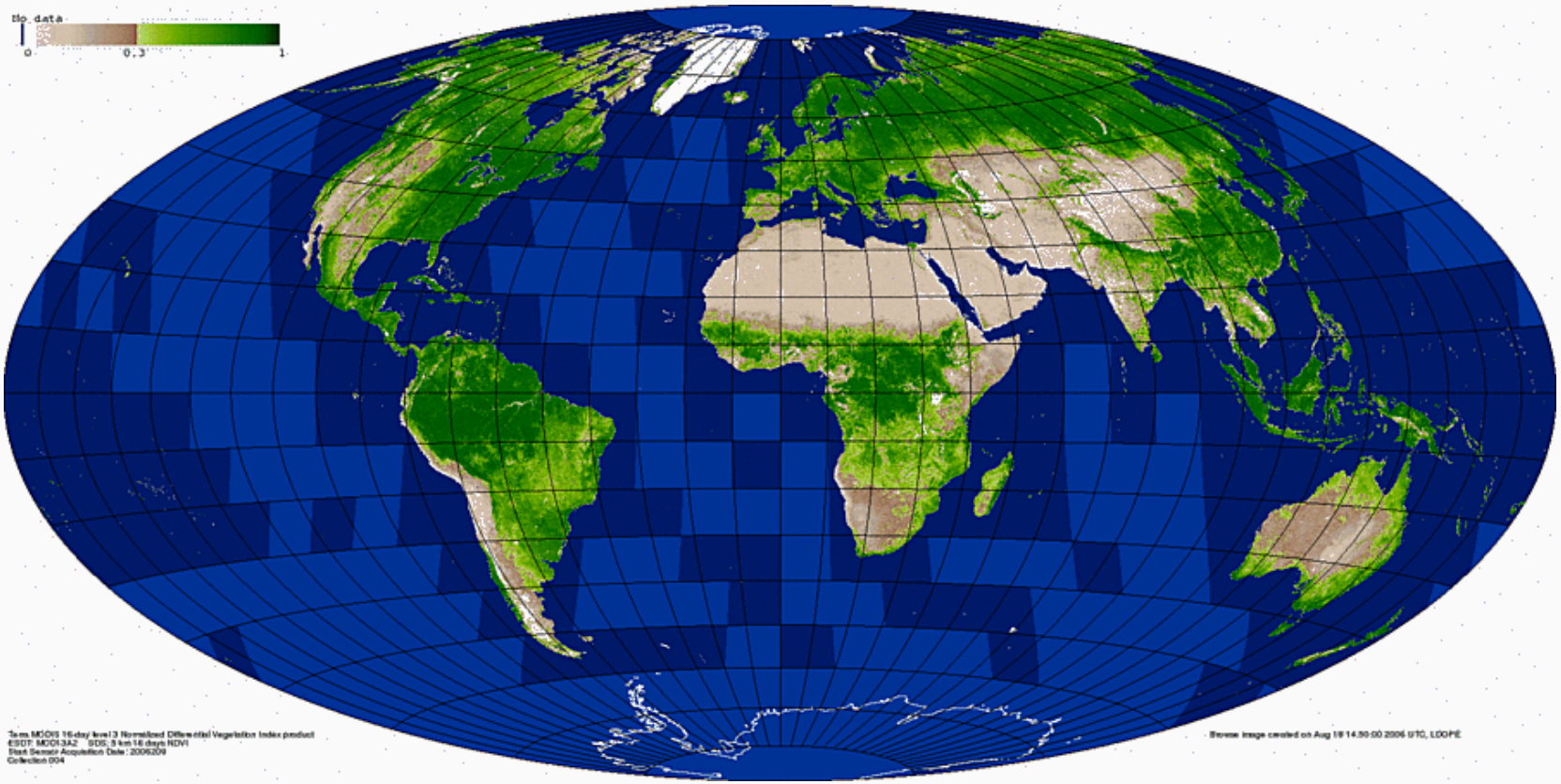

RGB=654

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

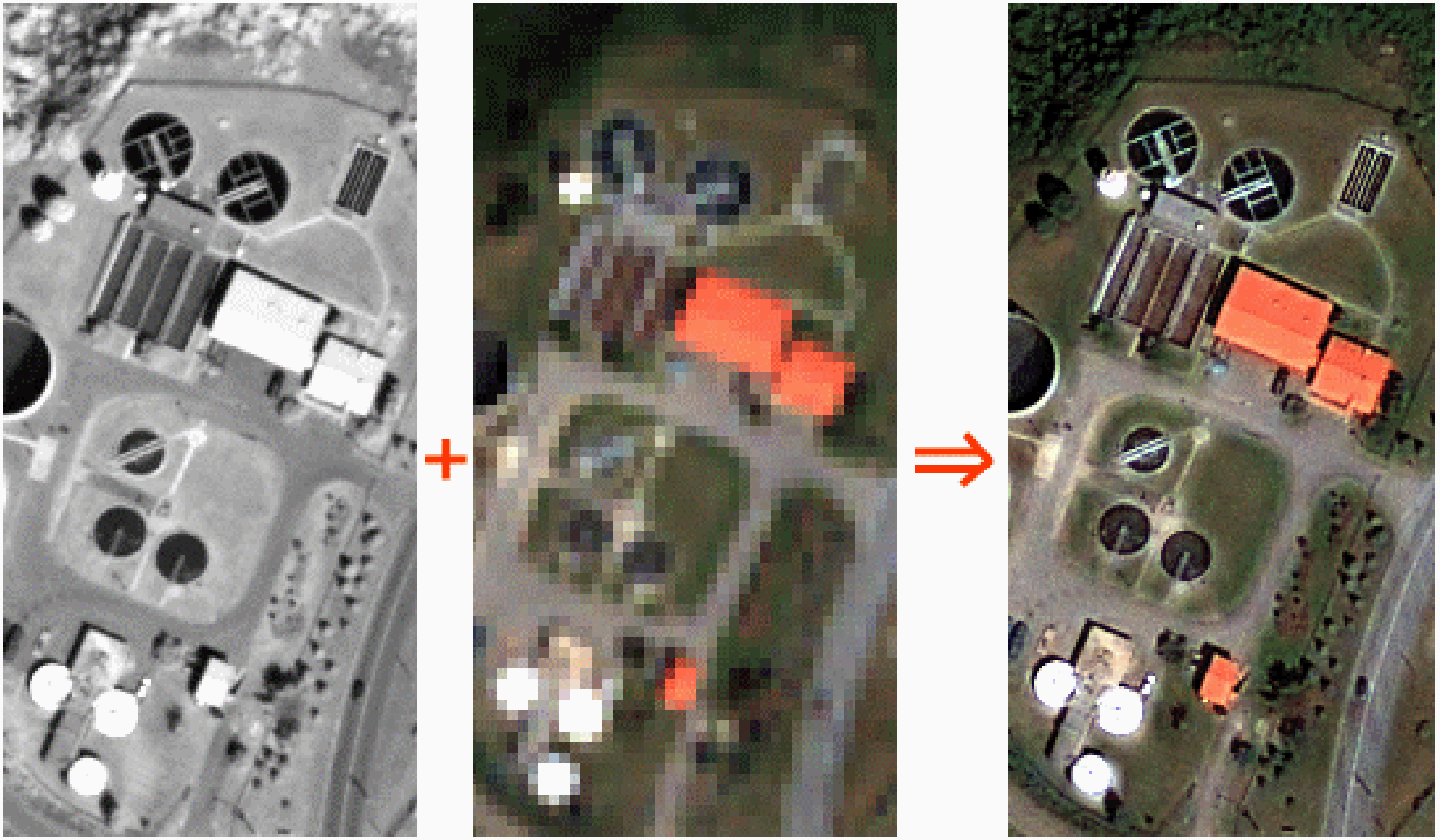


Composição IHS

- 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



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

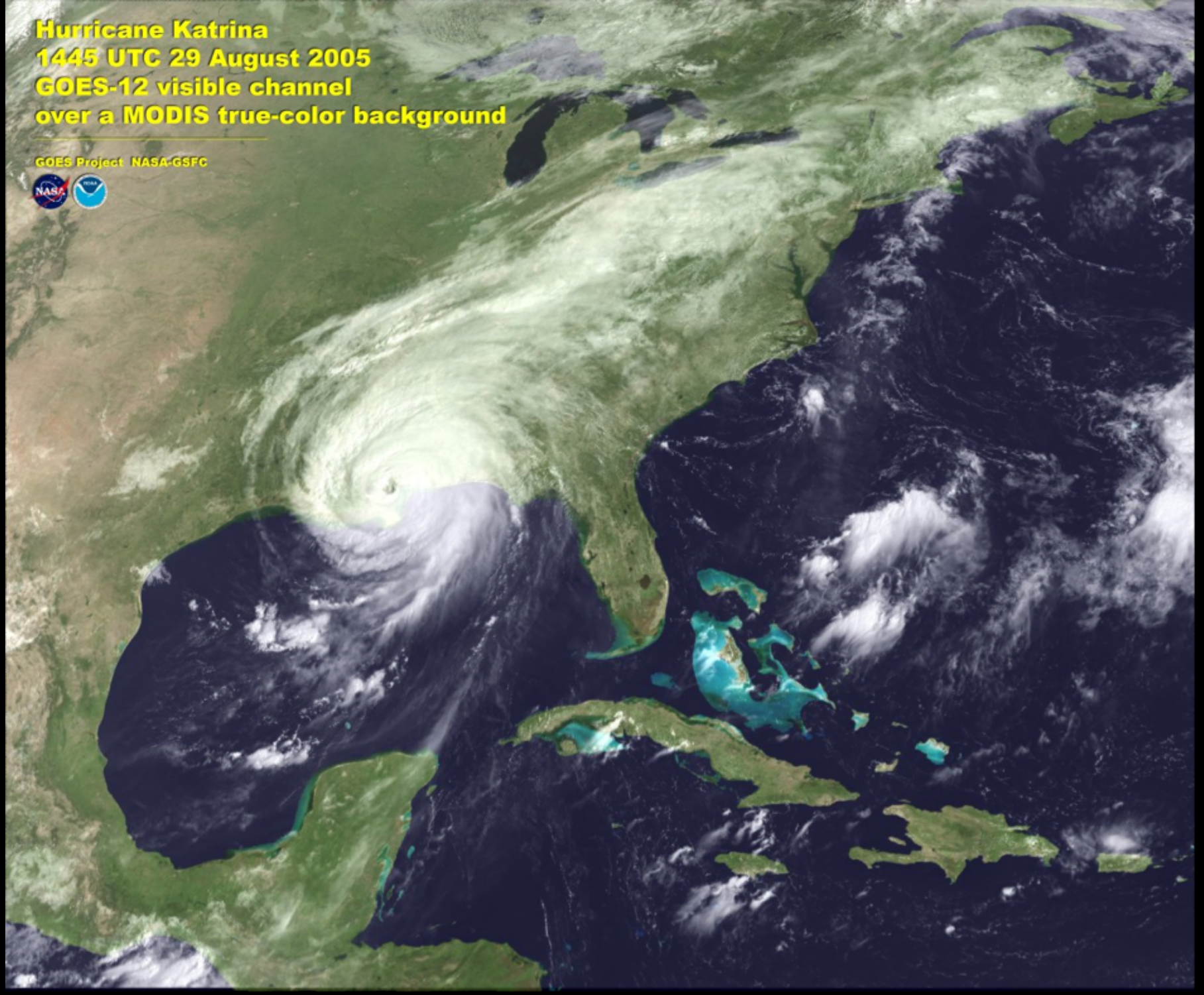
GOES - Geostationary Operational Environmental Satellite

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

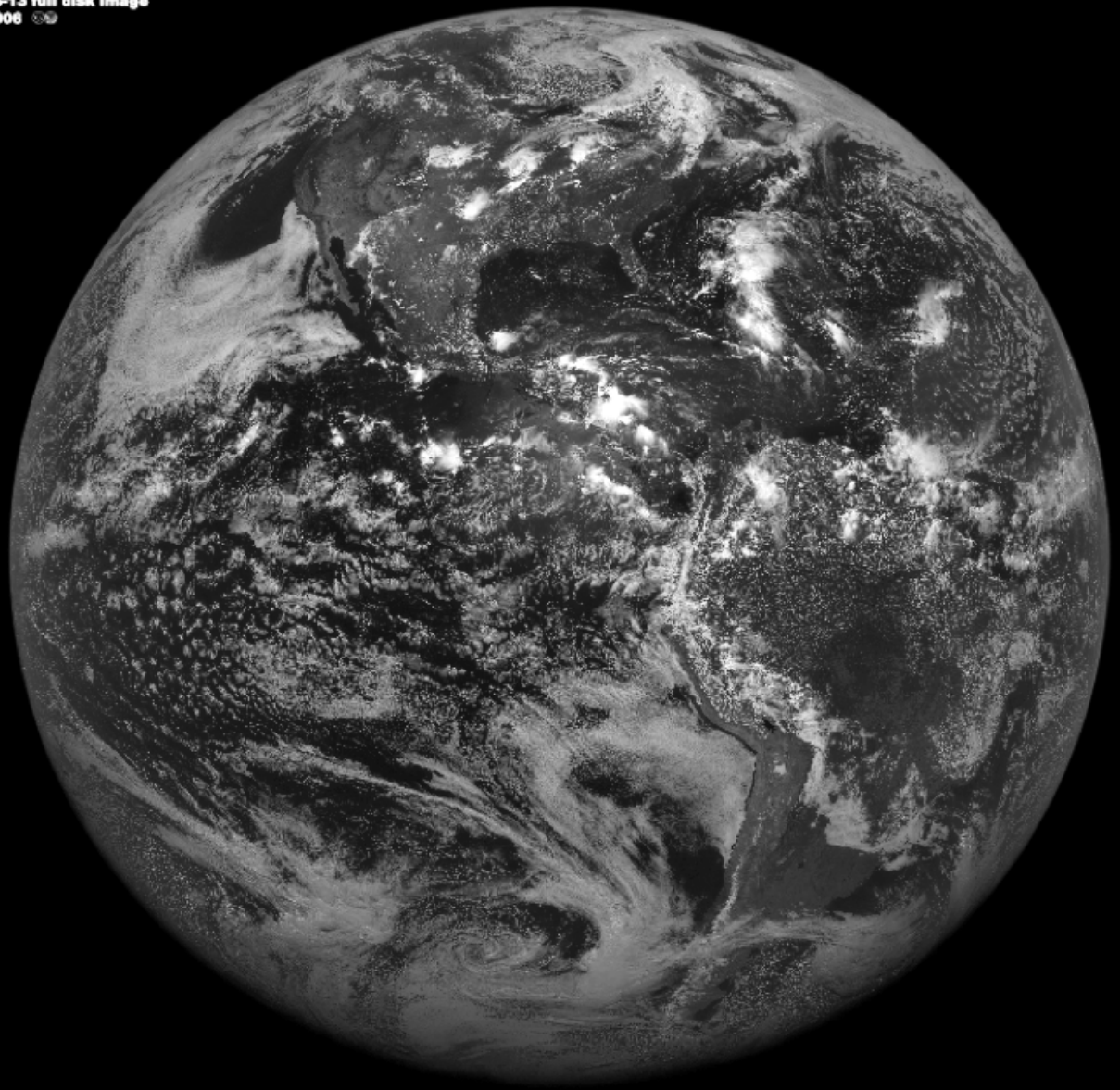
Meteorológicos - AVHRR

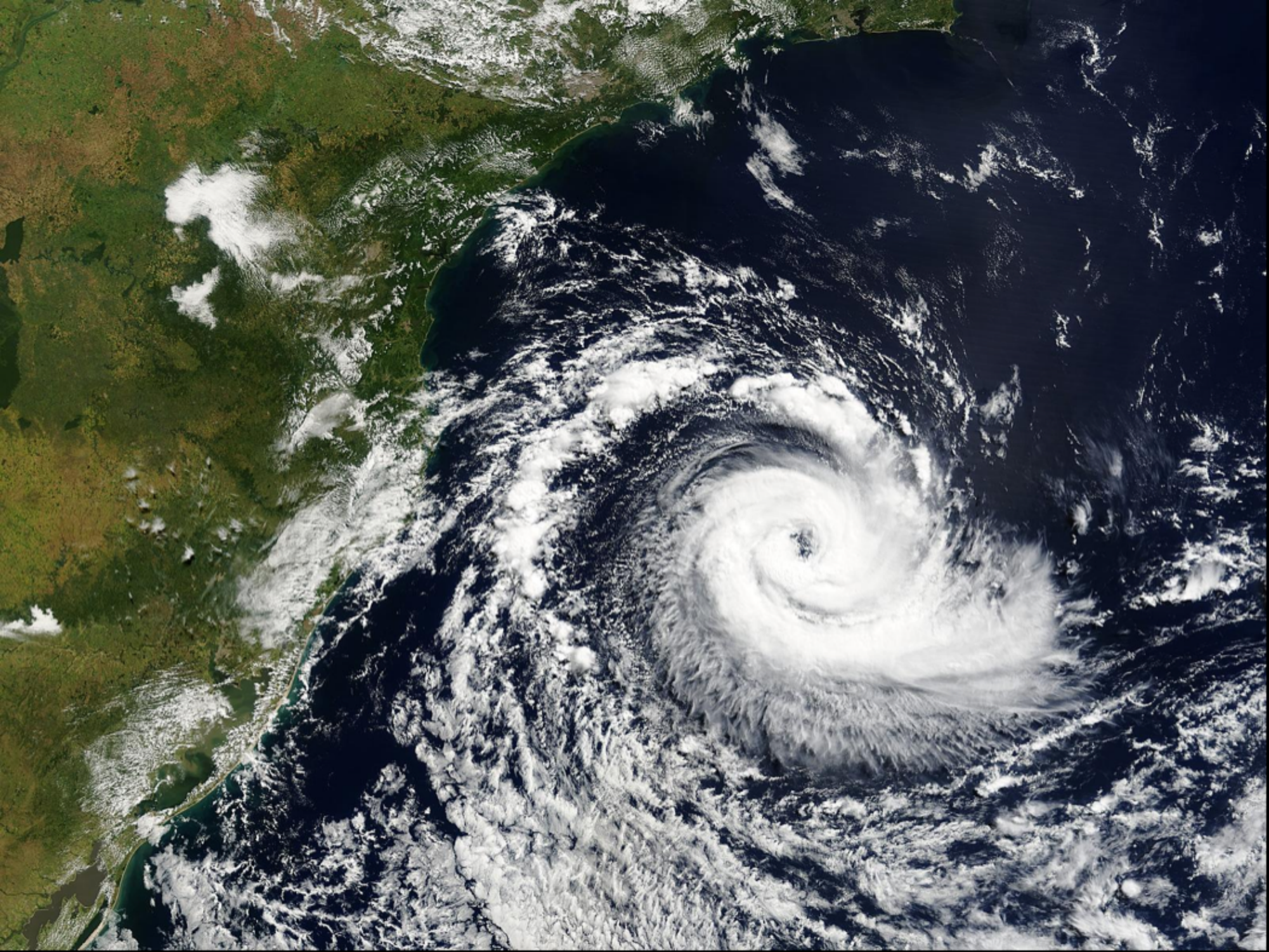
NOAA AVHRR - Advanced Very High Resolution Radiometer

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

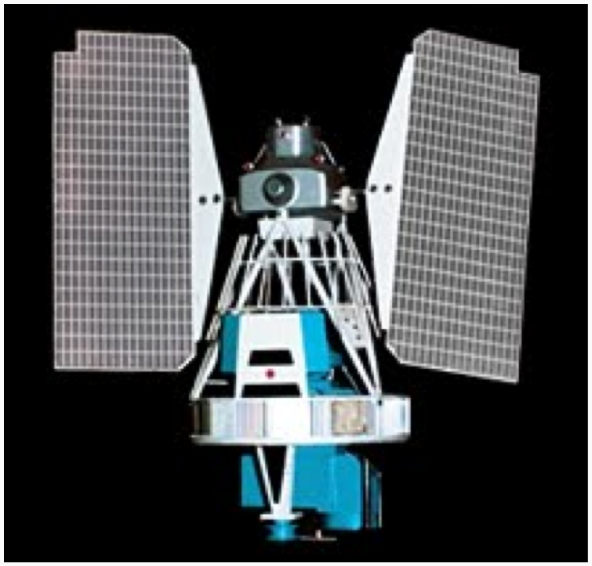
First GOES-13 full disk image
22 June 2006

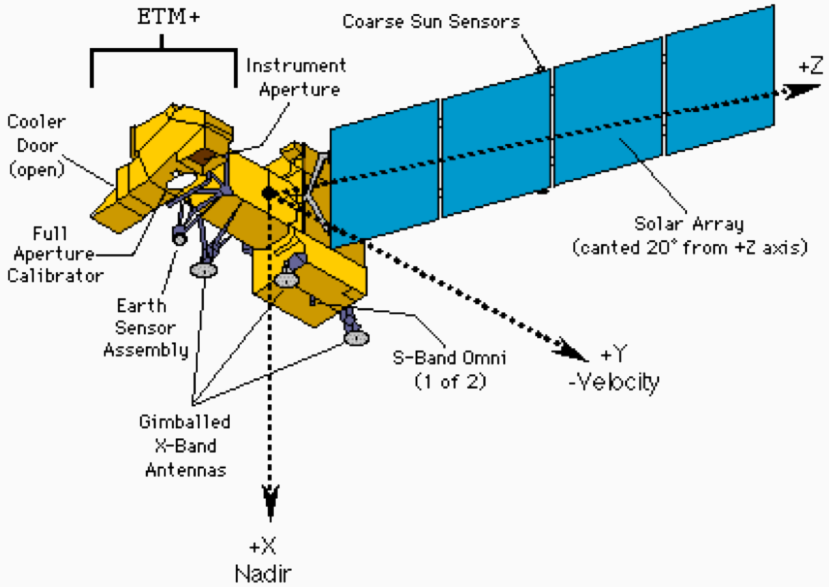




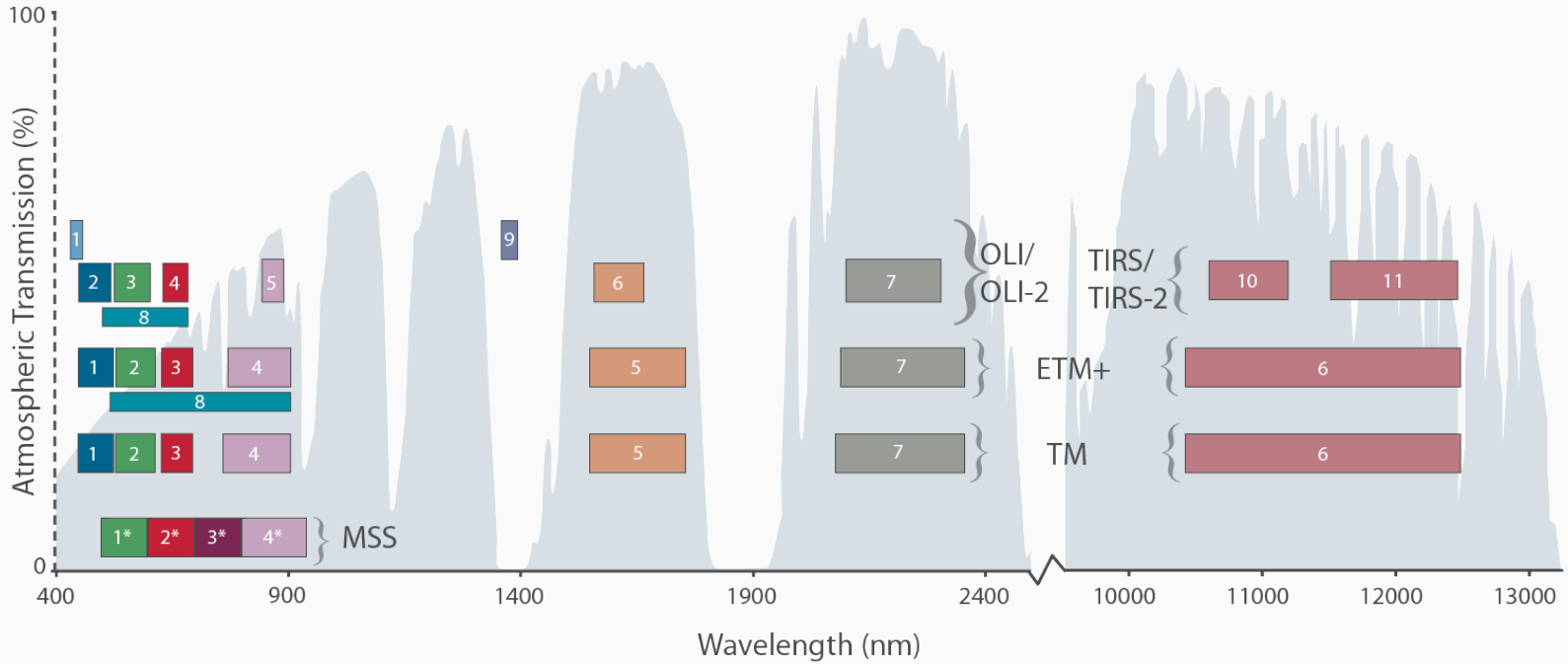
Recursos Terrestres – Landsat

- 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

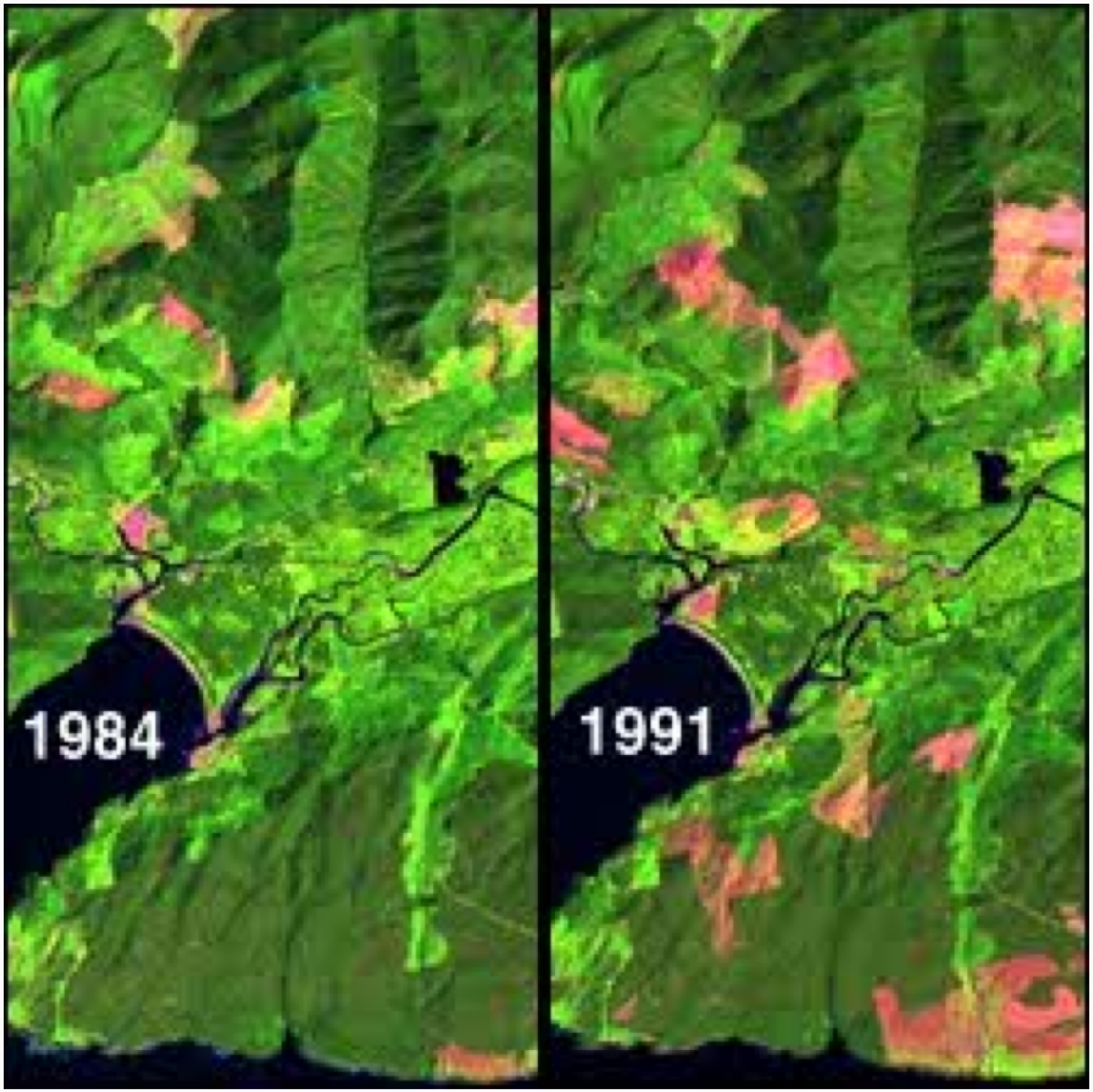


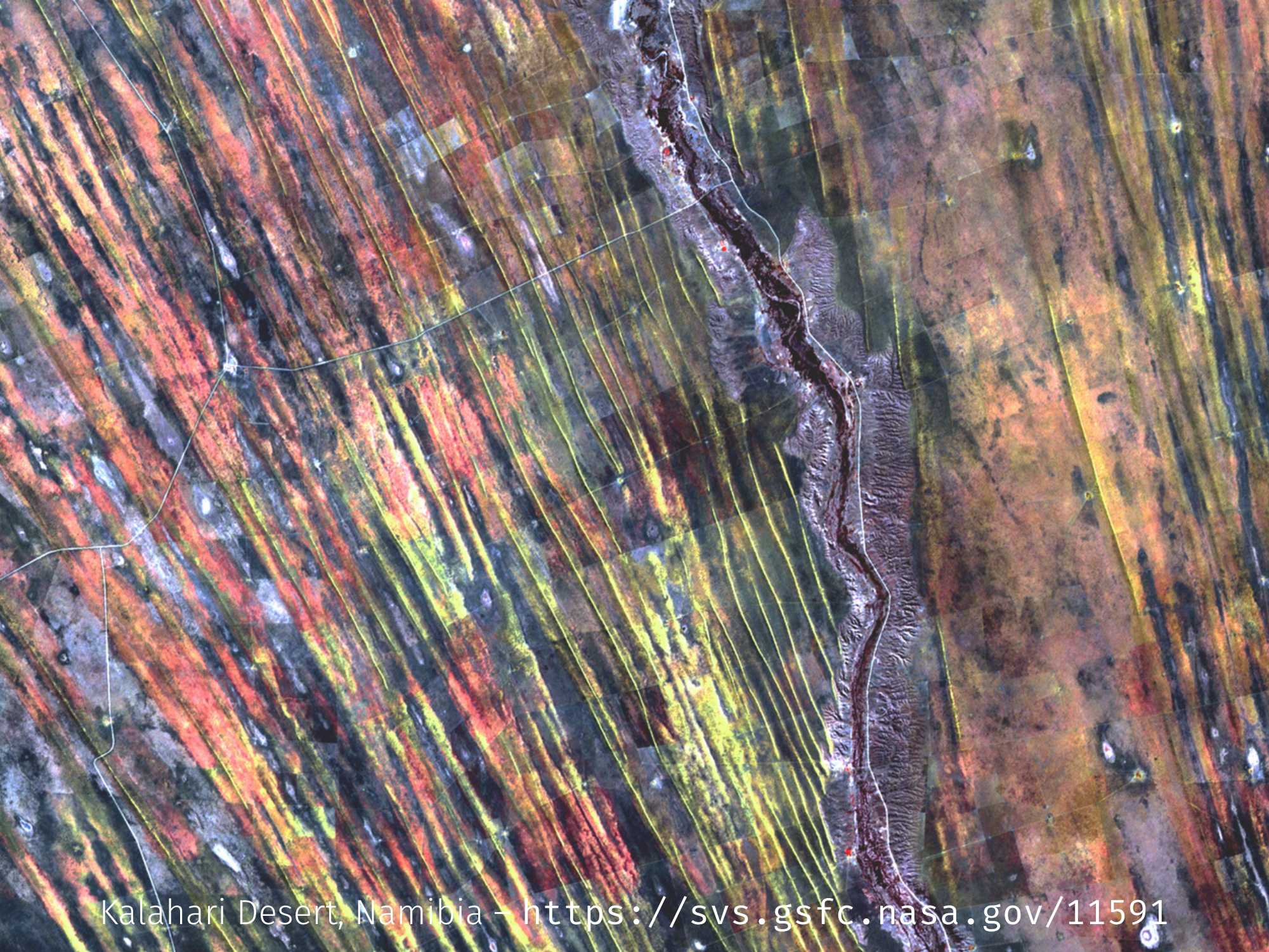


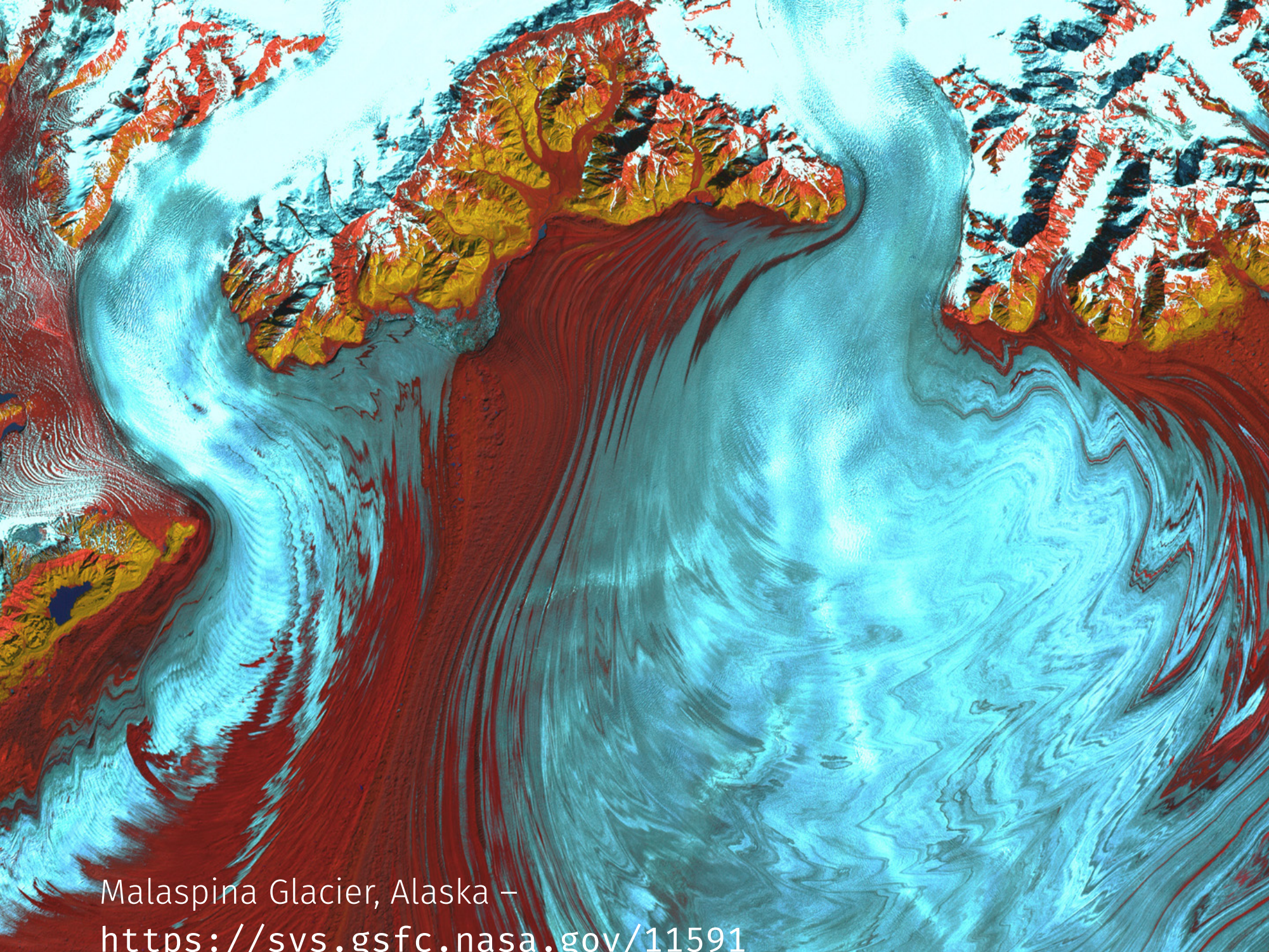
Landsat - bandas



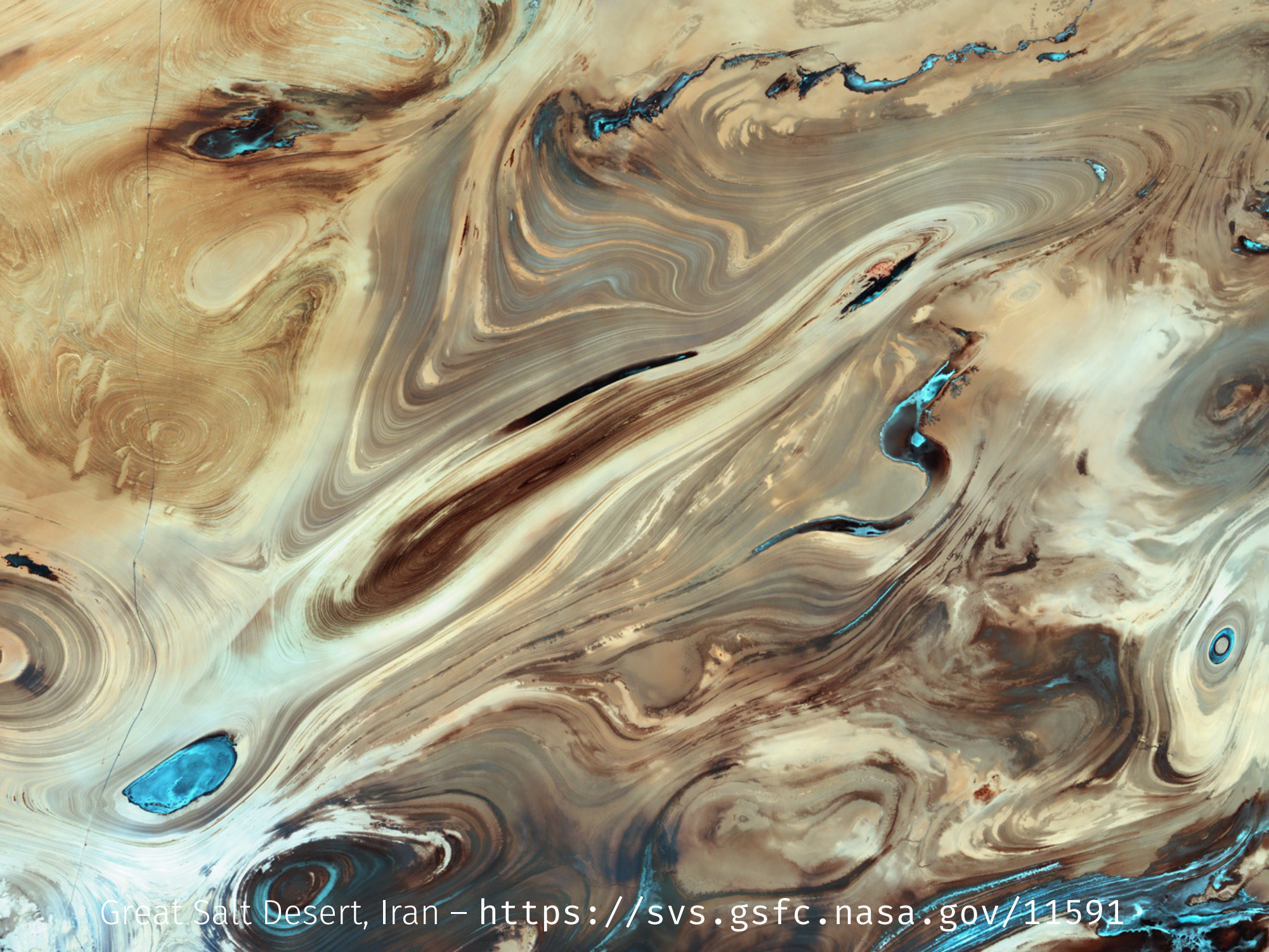
https://landsat.gsfc.nasa.gov/landsat-9/landsat-9-spectral-bands


1984
1991


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

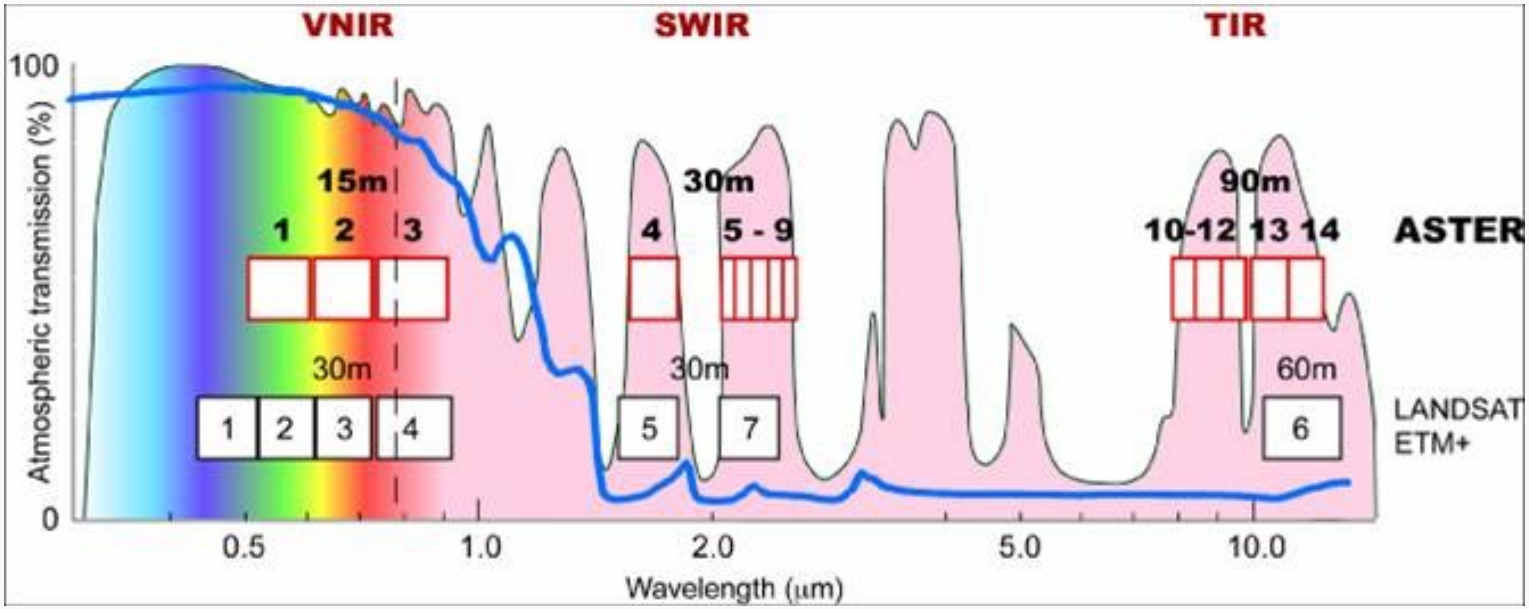
Recursos Terrestres – Terra

- 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

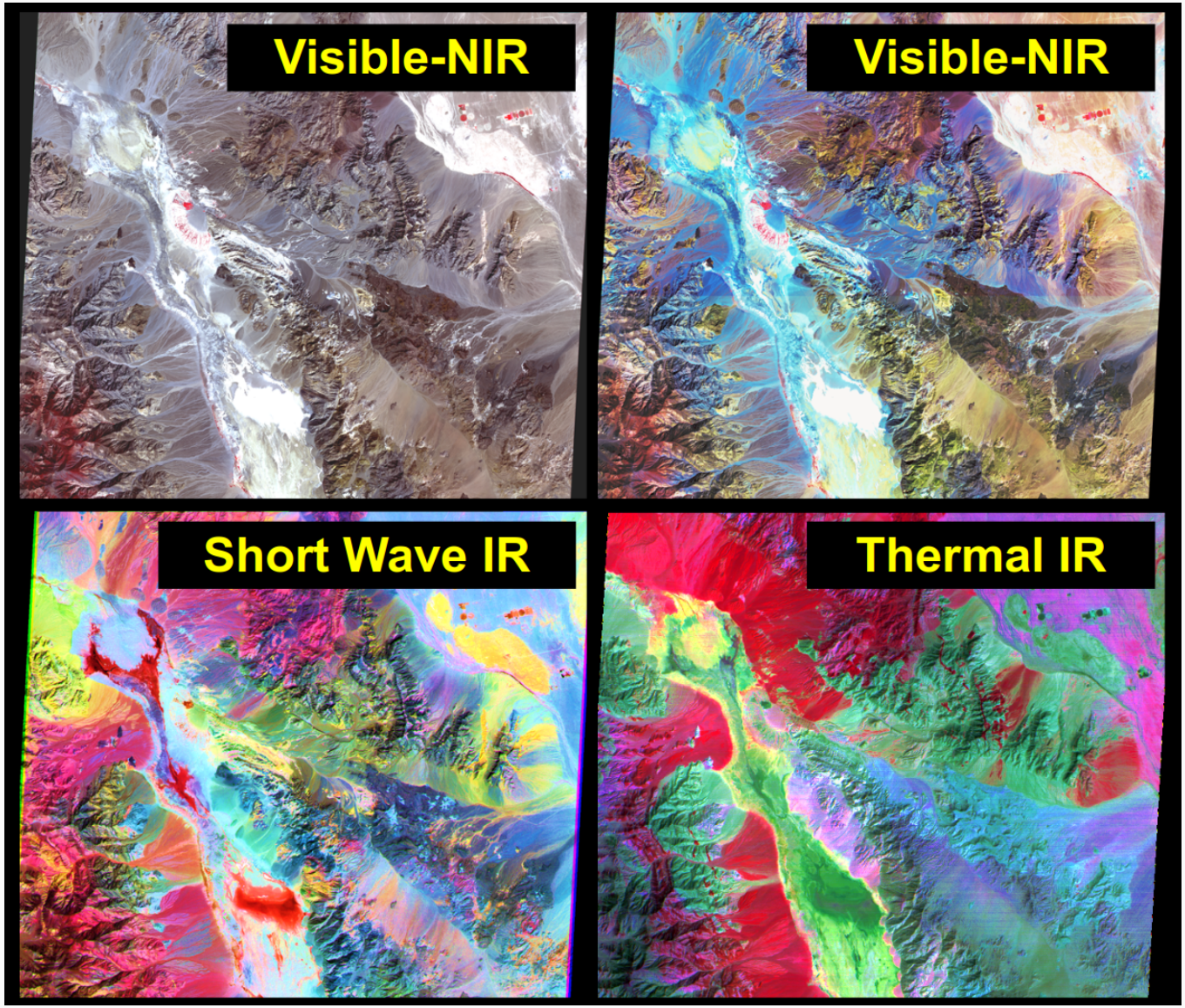
ASTER - Advanced Spaceborne Thermal Emission and Reflection Radiometer

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		

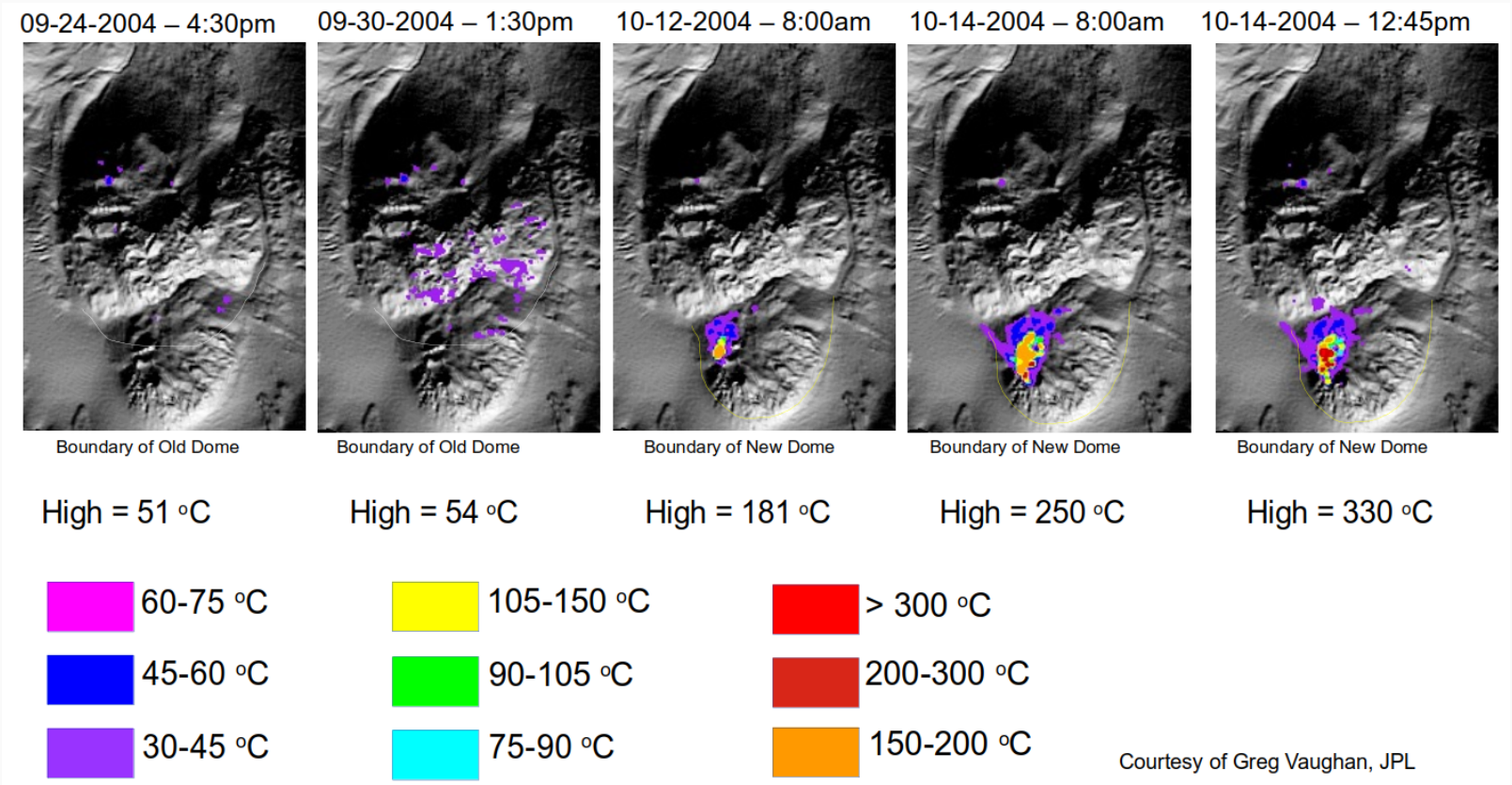
ASTER


VNIR
SWIR
TIR
100
0
Atmospheric transmission (%)
15m
1 2 3
30m
4
5 - 9
90m
10-12 13 14
ASTER
30m
1 2 3 4
30m
5 7
60m
6
LANDSAT
ETM+
0.5
1.0
2.0
5.0
10.0
Wavelength (μm)

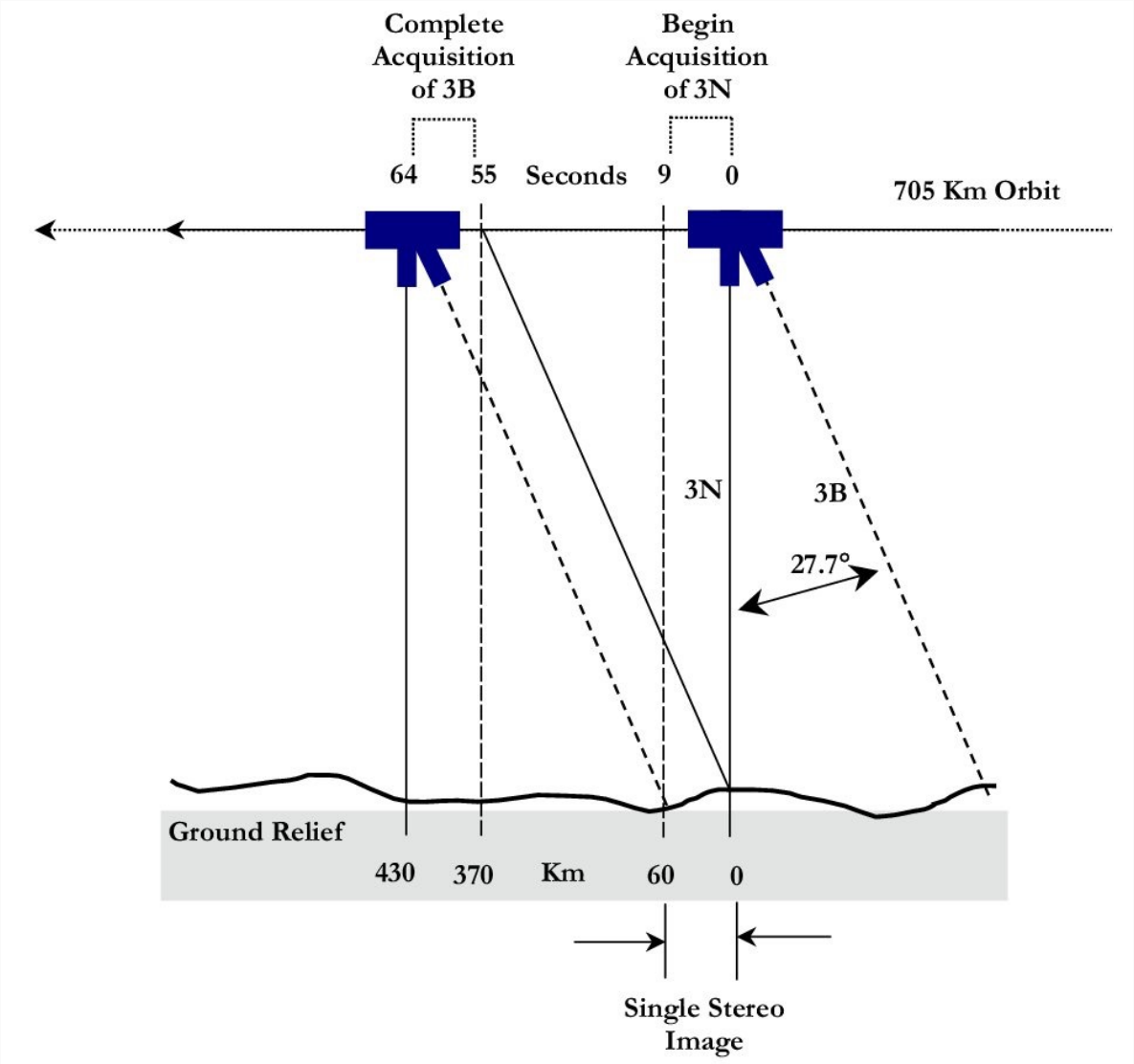
ASTER – composições coloridas

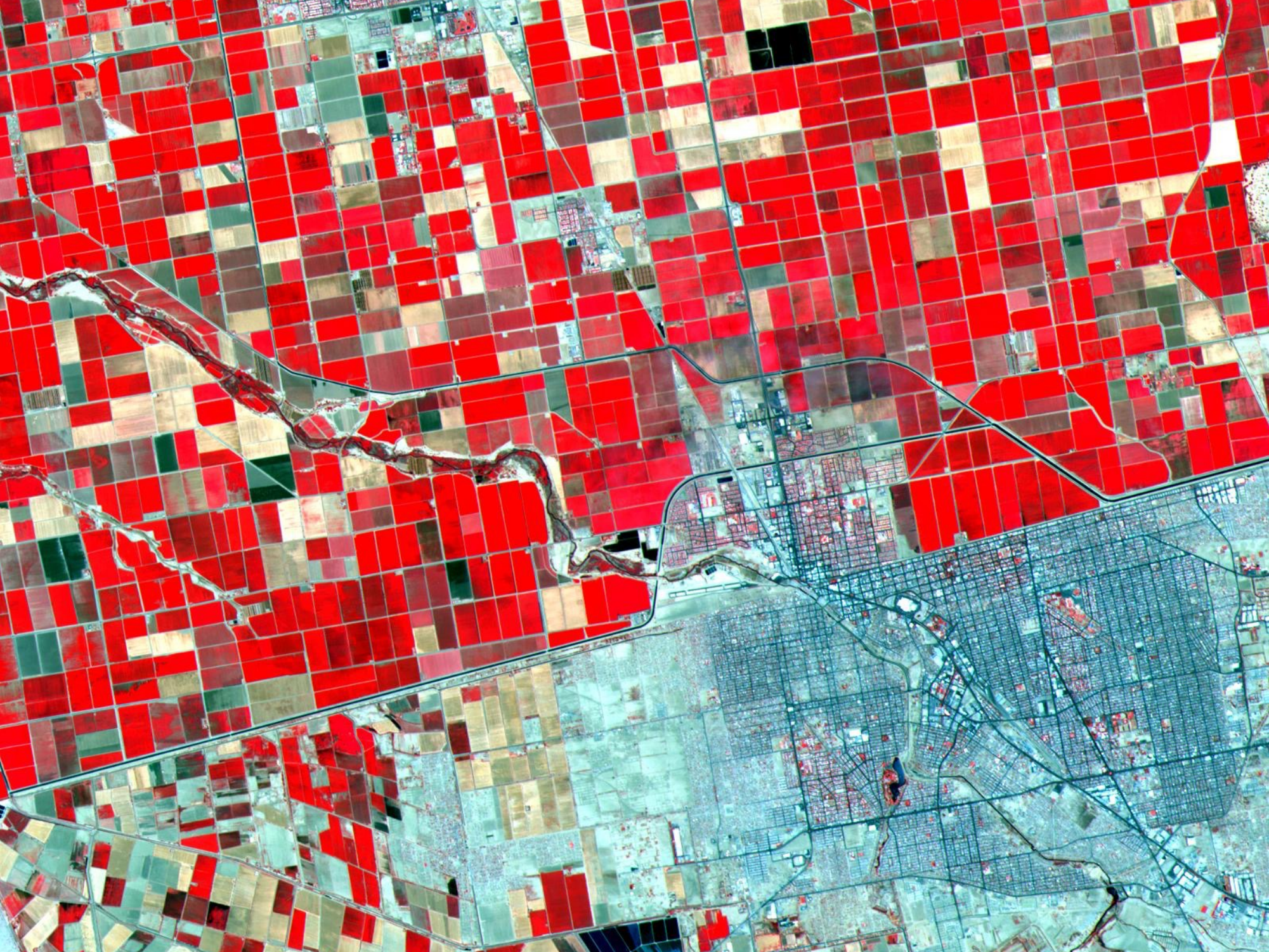


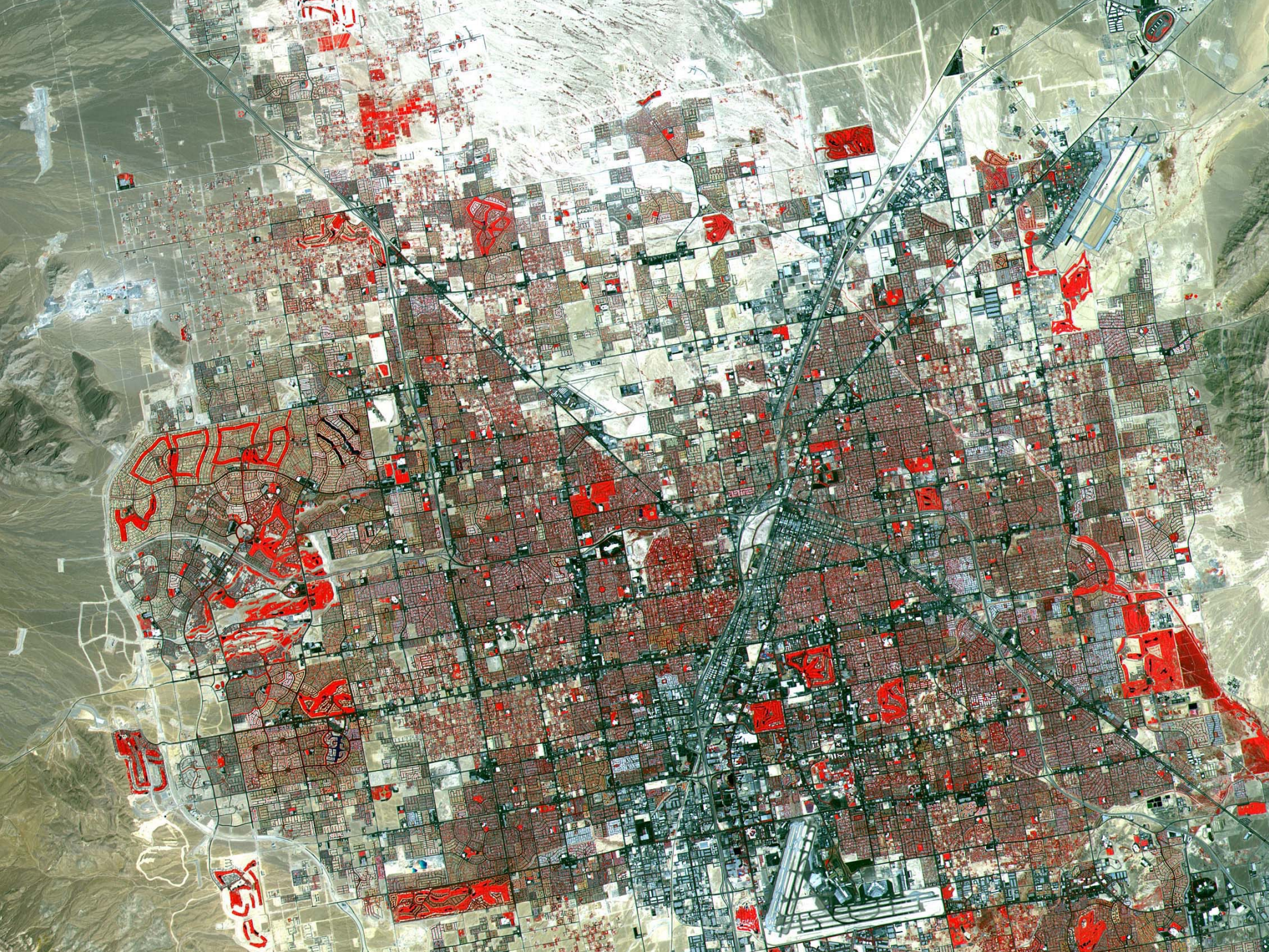
ASTER – monitoramento de vulcões

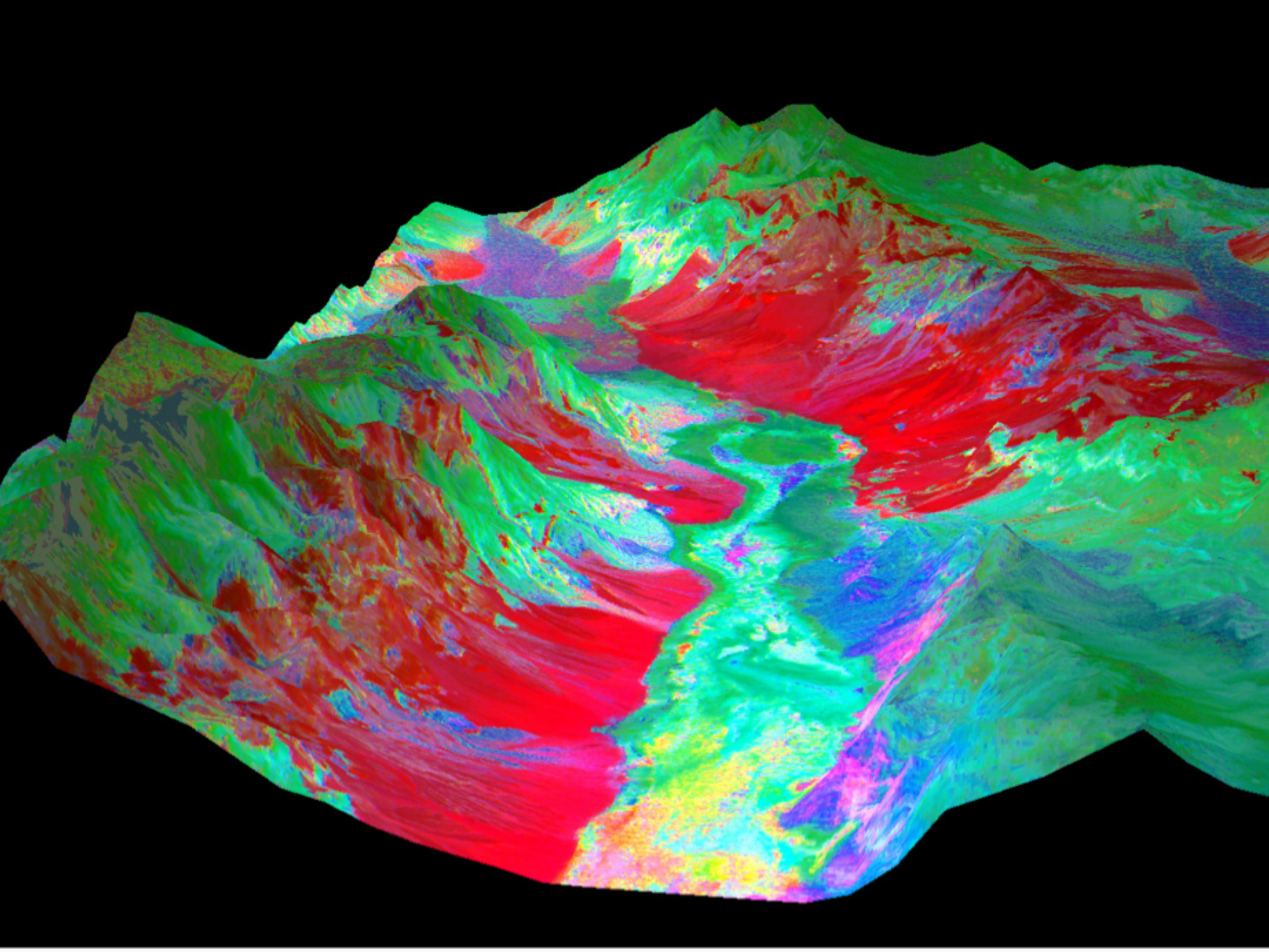


ASTER – estereoscopia



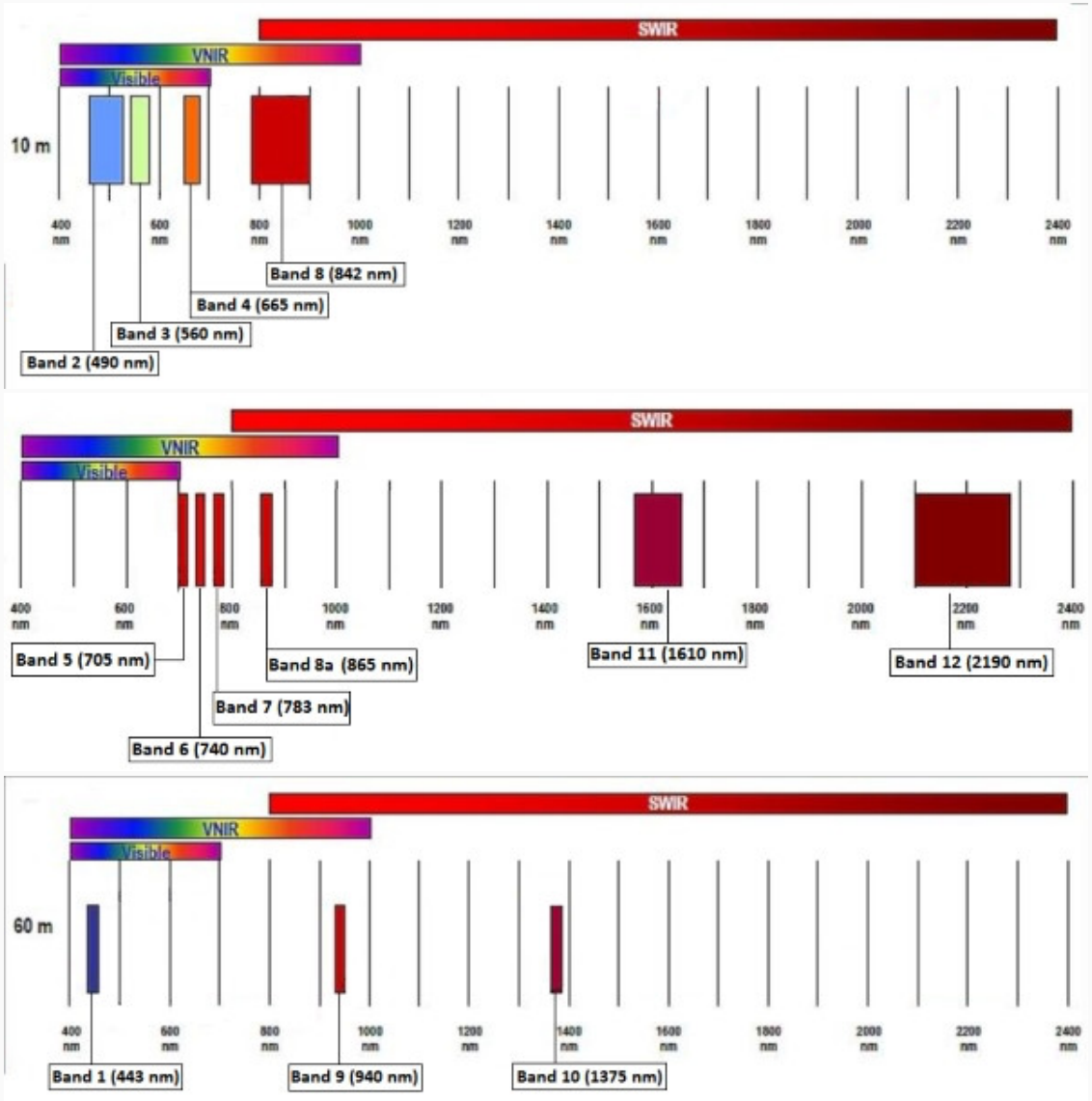




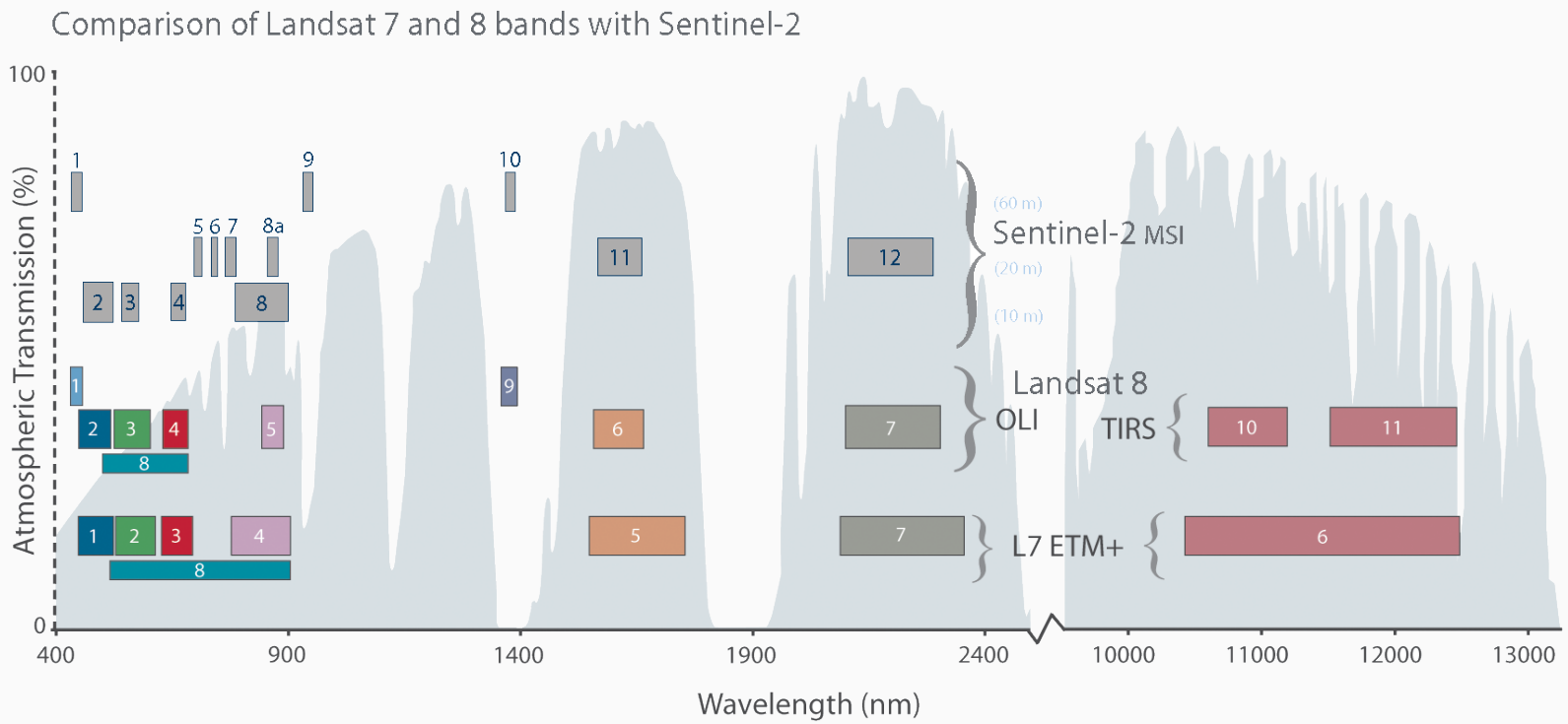


Recursos Terrestres – Sentinel 2A/2B

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



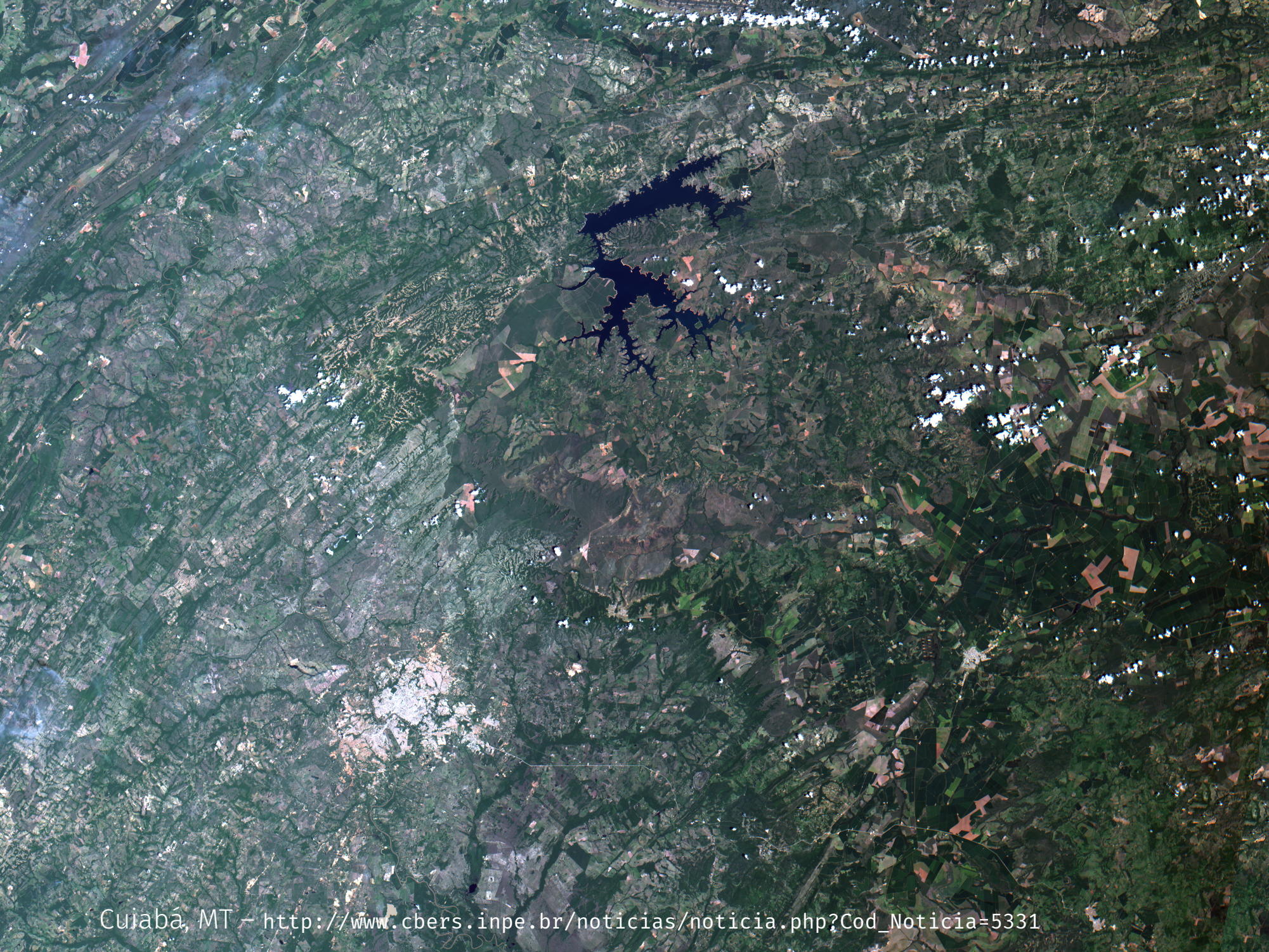
Sentinel - bandas



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
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


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

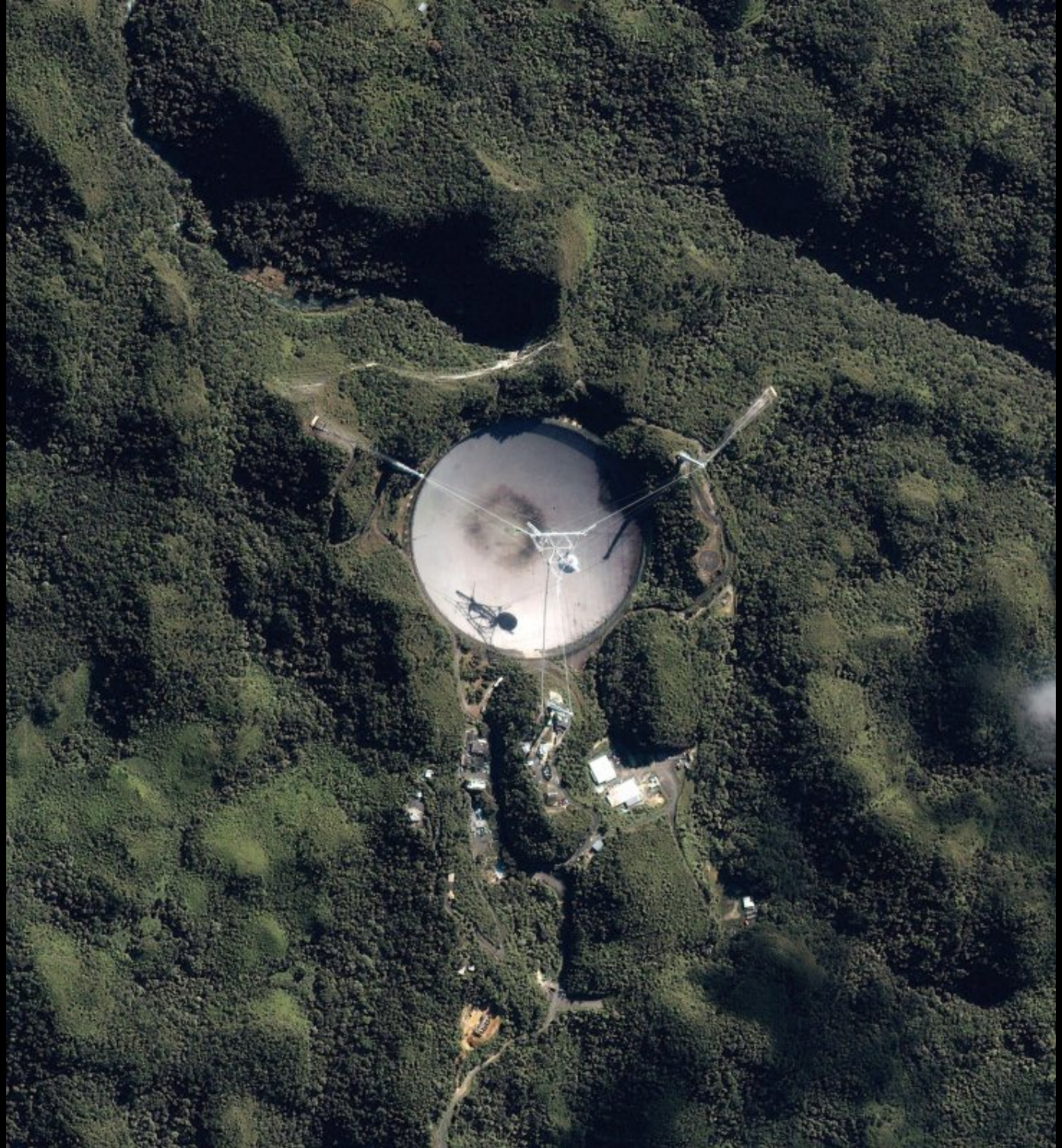
Aksu, China – http://www.cbers.inpe.br/noticias/noticia.php?Cod_Noticia=5331

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 • 60-centimeter GSD (Ground Sample Distance) at nadir • Black & White: 445 to 900 nanometers	Multispectral • 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 0.6m Resolution
Acquired on: 21-APR-2005
www.satimagingcorp.com
Satellite Imaging Corporation
12777 Jones Road, Suite 370
Houston, Texas 77070-4647 USA
Tel: 1-832-237-2910
Fax: 1-832-237-2910
Web: www.satimagingcorp.com
E-Mail: info@satimagingcorp.com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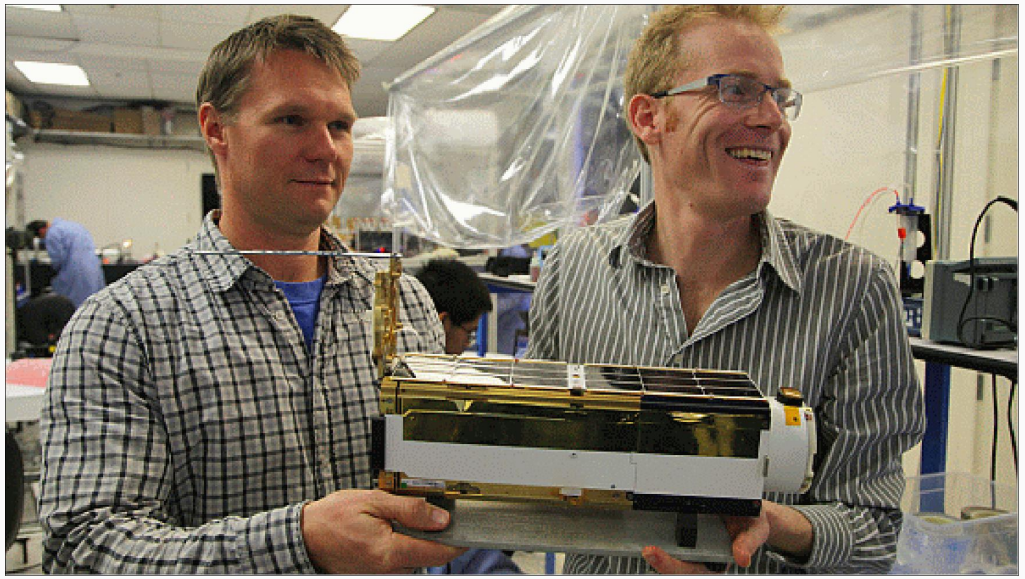
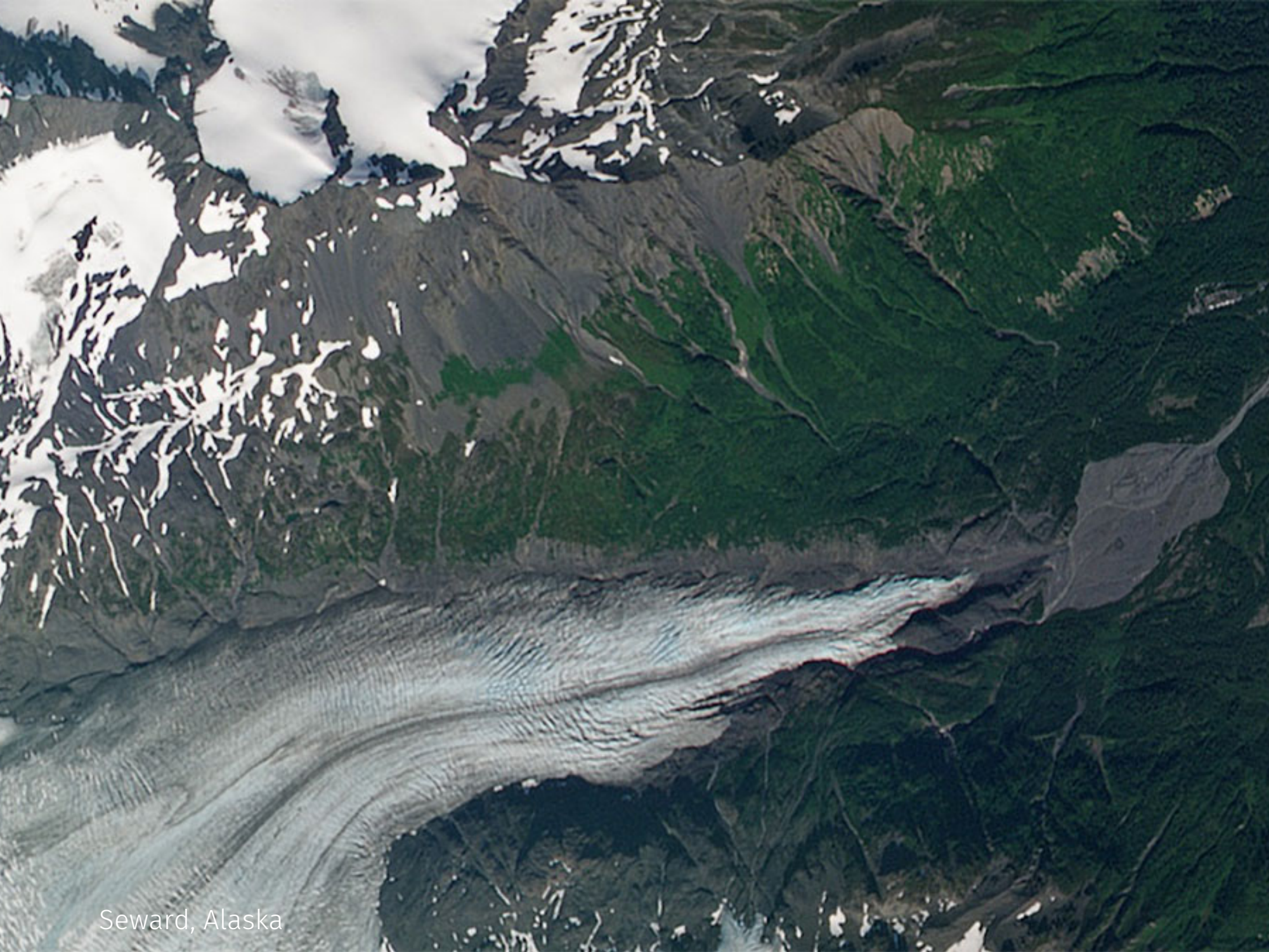
Alta Resolução - Planet

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



San Francisco, California



Seward, Alaska

Rotterdam, Netherlands

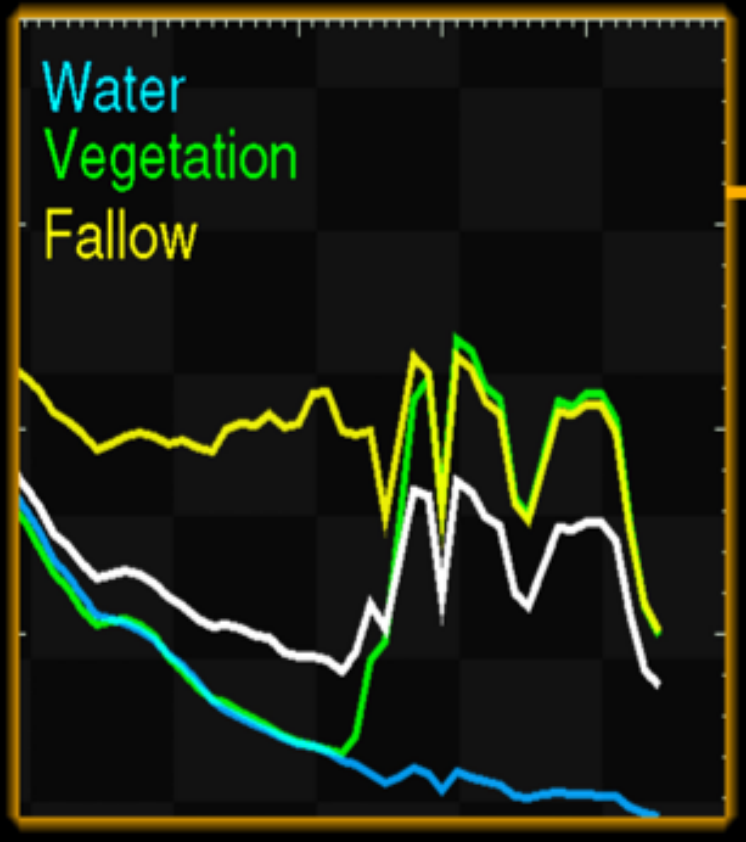
Hiperespectral - Hyperion

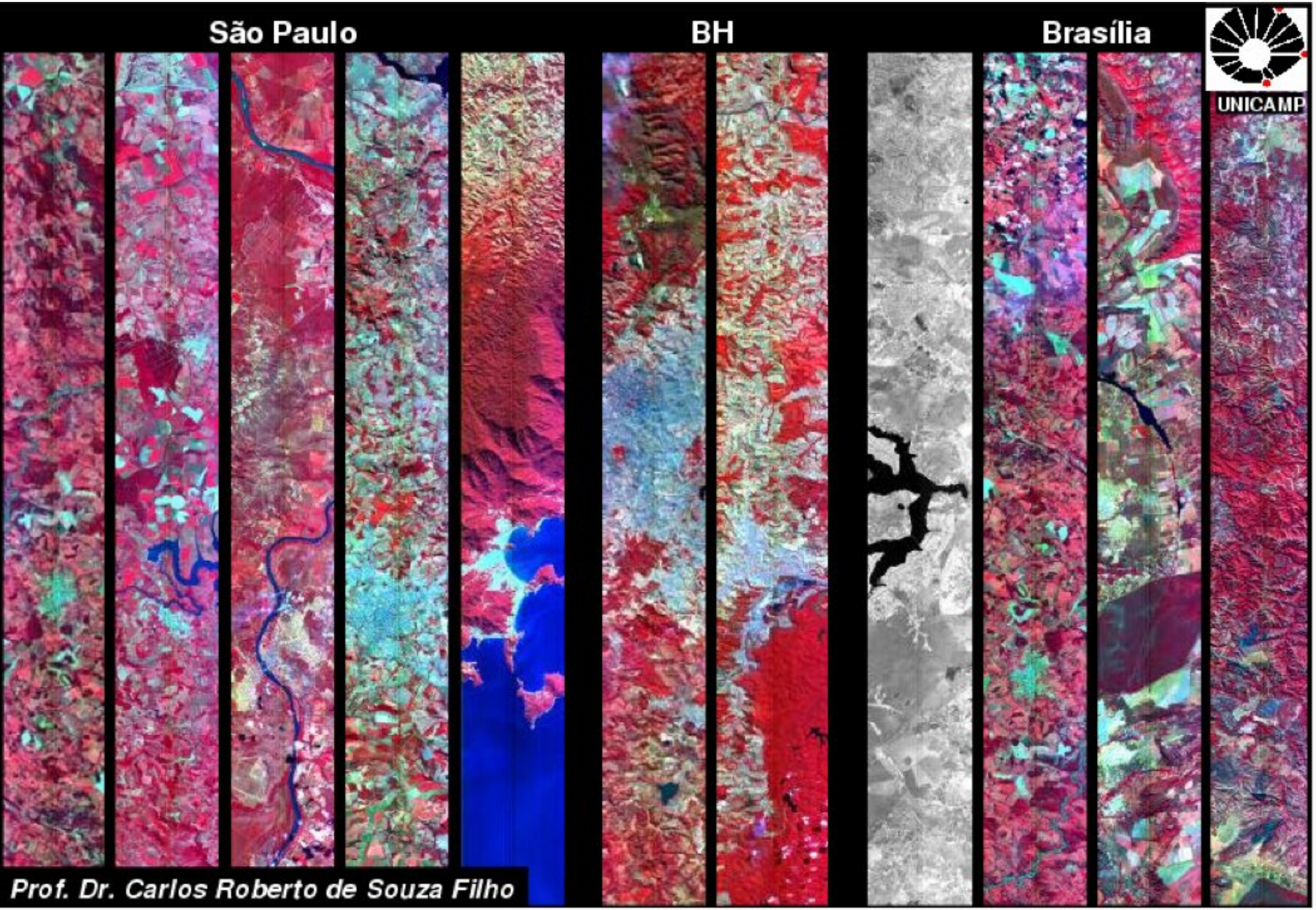
- 220 bandas
- 30m res.espacial
- faixa 7.5 x 100 km

- ALI (Advanced Land Imager)
- teste de tecnologia
- sucessor do ETM+ (OLI)

EO-1/Hyperion

Analysis




São Paulo
BH
Brasília
UNICAMP
Prof. Dr. Carlos Roberto de Souza Filho