Remote sensing in archaeology – from optical to lidar

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"Always start your presentation with a joke, but be careful not to offend anyone! Don't mention religion, politics, race, age, money, technology, men, women, children, plants, animals, food...."

Contents

- Introduction
- Optical remote sensing
  - Systems
  - Search for anomalies
  - Case studies
- Lidar
  - What is
  - Data acquisition
  - Processing
- Conclusions

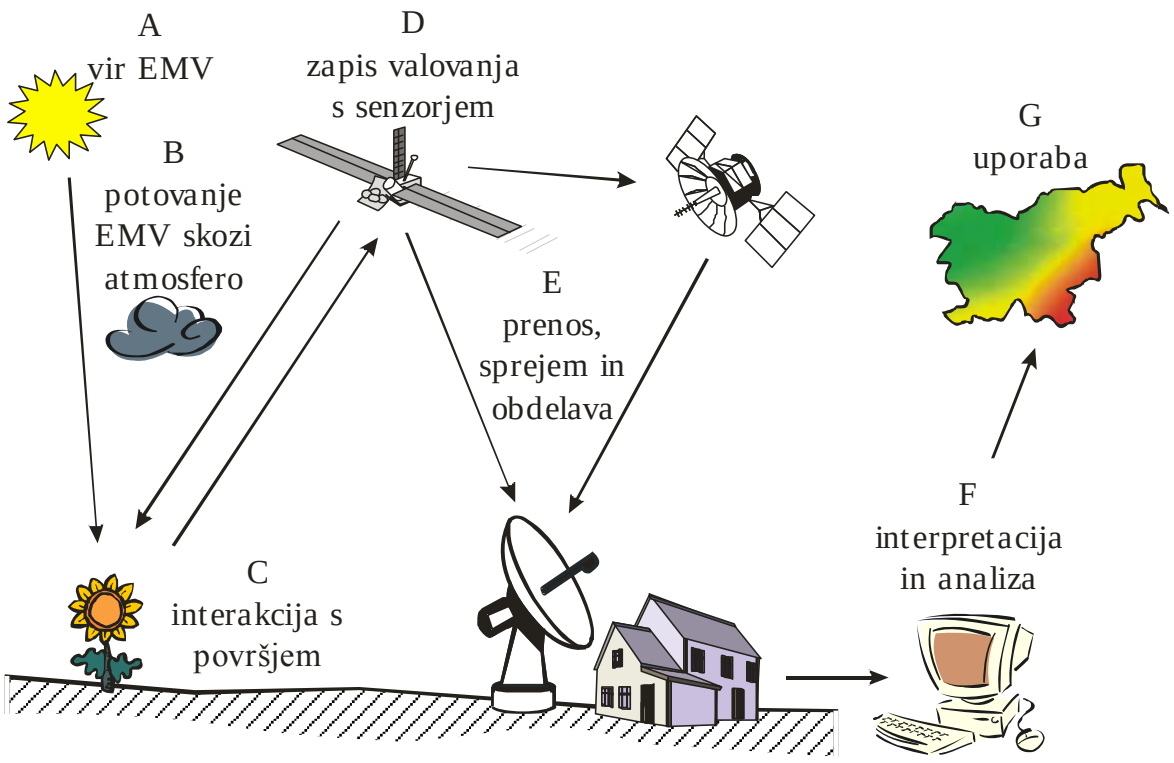
Introduction to remote sensing

Remote sensing is the science (and to some extent, art) of acquiring information about the Earth's surface without actually being in contact with it. This is done by sensing and recording reflected or emitted energy and processing, analyzing, and applying that information.

Definition

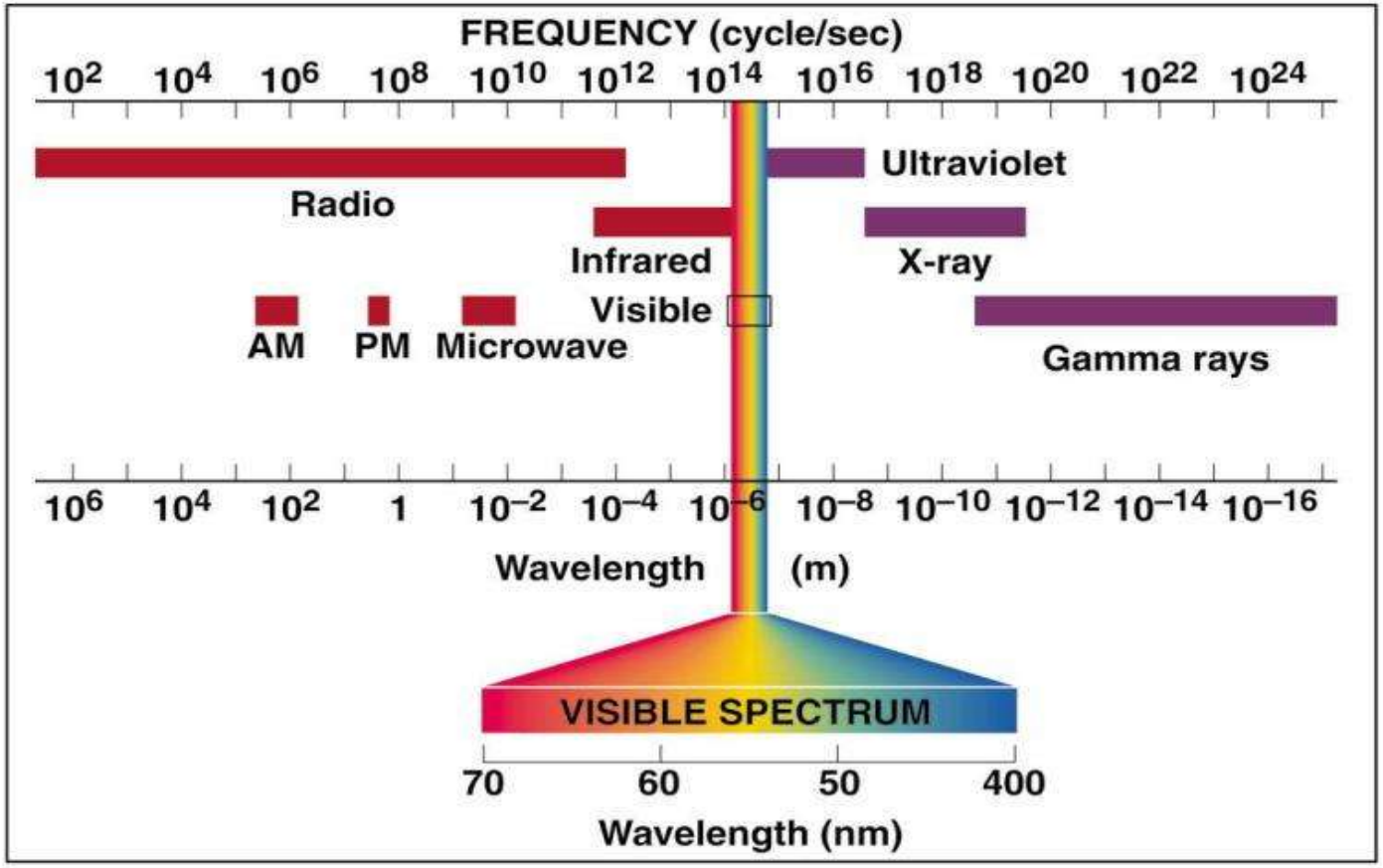
- One of the most expensive ways of photography
- Legalised voyeurism
- Inverse astronomy
- Making Earth look like a supermodel
- Feeling of being watched

Remote sensing process



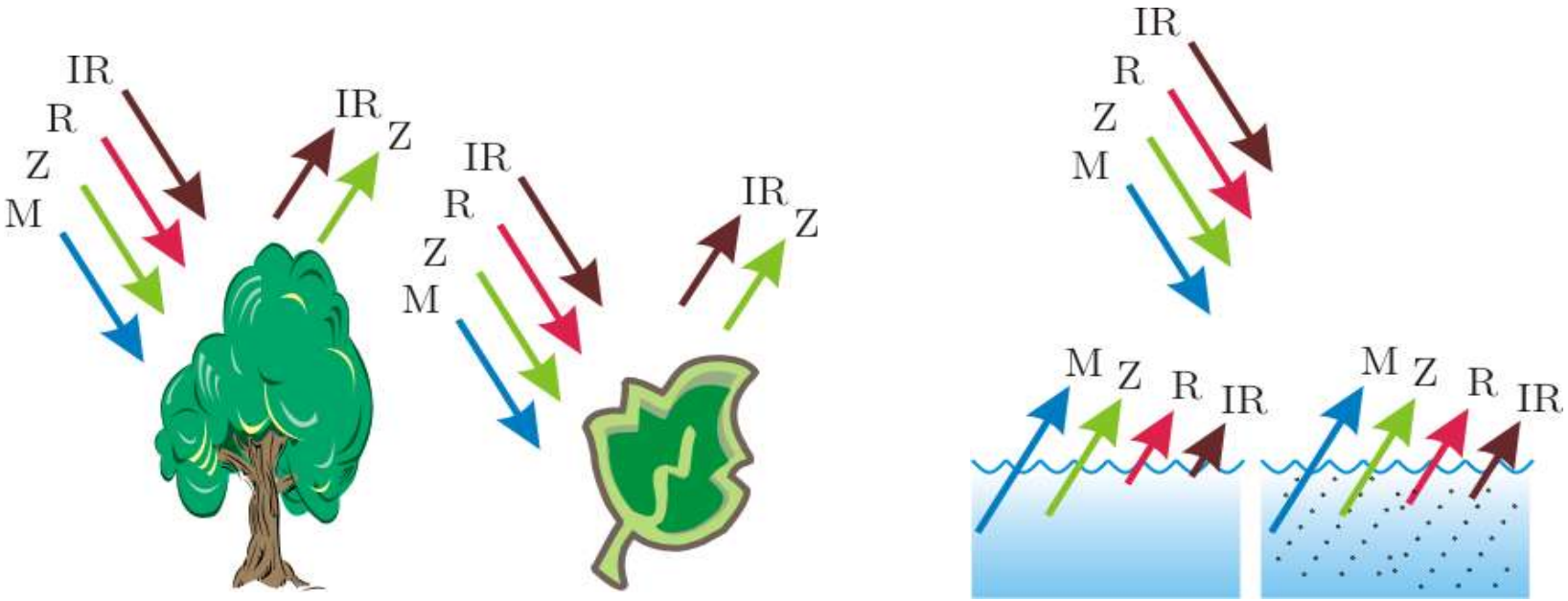
- Energy Source or Illumination (A)
- Radiation and the Atmosphere (B)
- Interaction with the Target (C)
- Recording of Energy by the Sensor (D)
- Transmission, Reception, and Processing (E)
- Interpretation and Analysis (F)
- Application (G)

EMR spectra

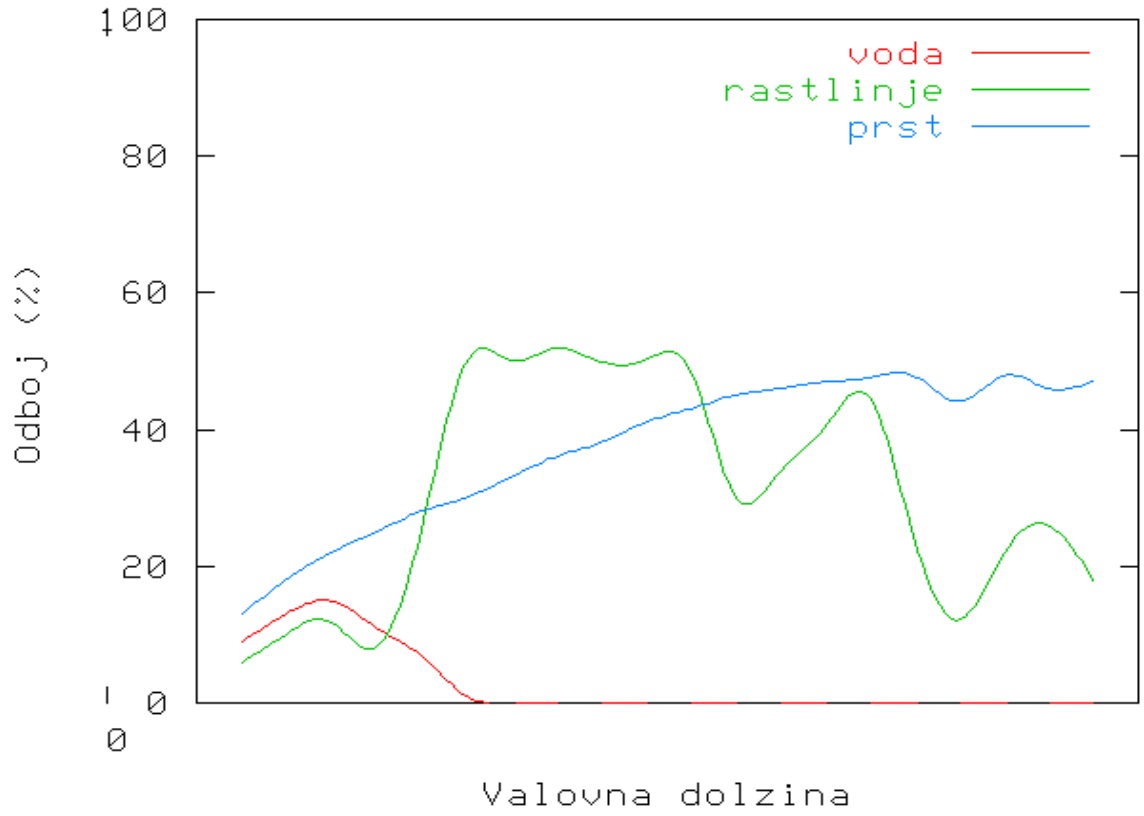

FREQUENCY (cycle/sec)
10^2 10^4 10^6 10^8 10^{10} 10^{12} 10^{14} 10^{16} 10^{18} 10^{20} 10^{22} 10^{24}
Radio
Infrared
Visible
Ultraviolet
X-ray
Gamma rays
AM
PM
Microwave
10^6 10^4 10^2 1 10^{-2} 10^{-4} 10^{-6} 10^{-8} 10^{-10} 10^{-12} 10^{-14} 10^{-16}
Wavelength (m)
VISIBLE SPECTRUM
70 60 50 400
Wavelength (nm)

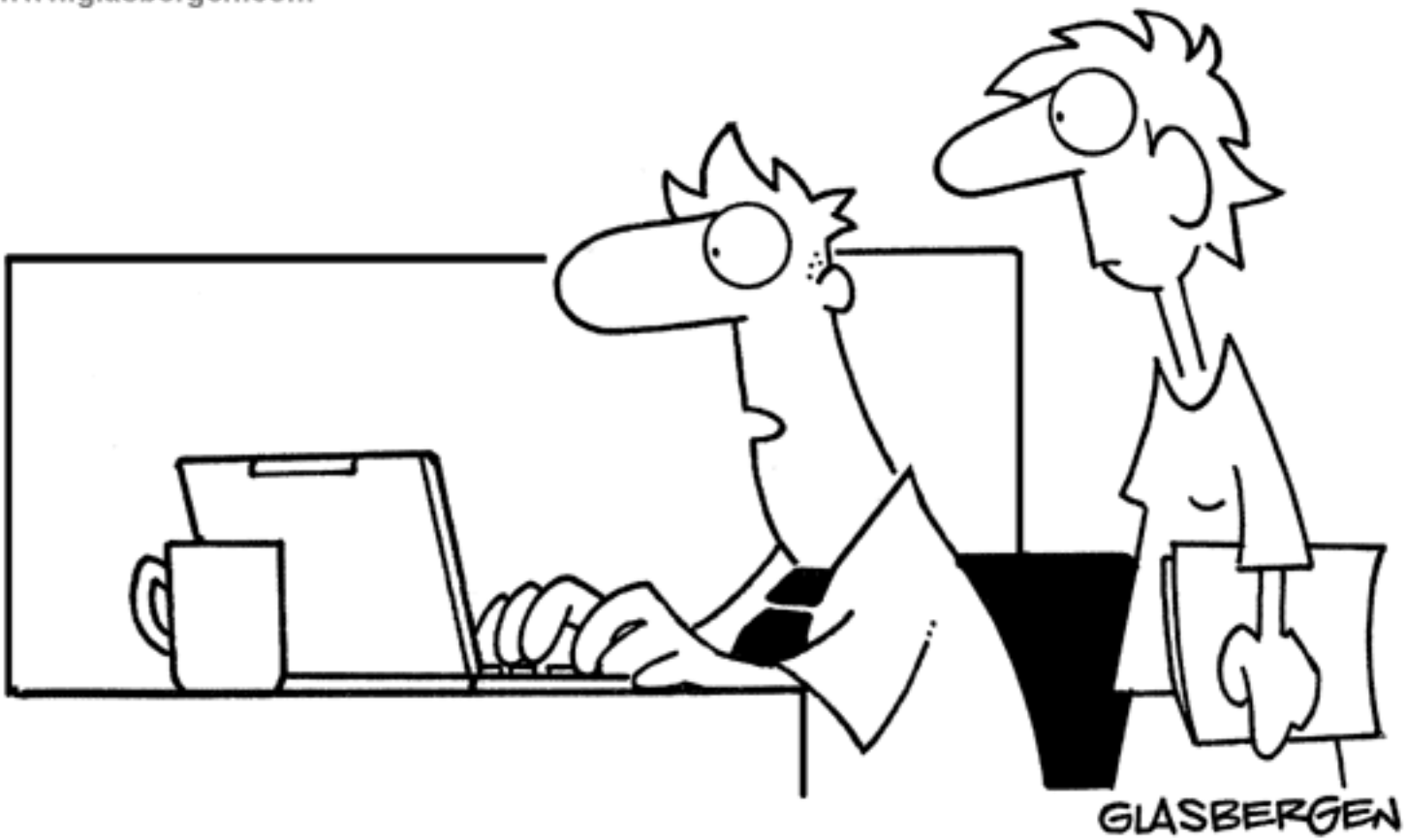
"I had to quit drinking coffee. It keeps me awake during presentations."

Interaction with surface



Spectral response



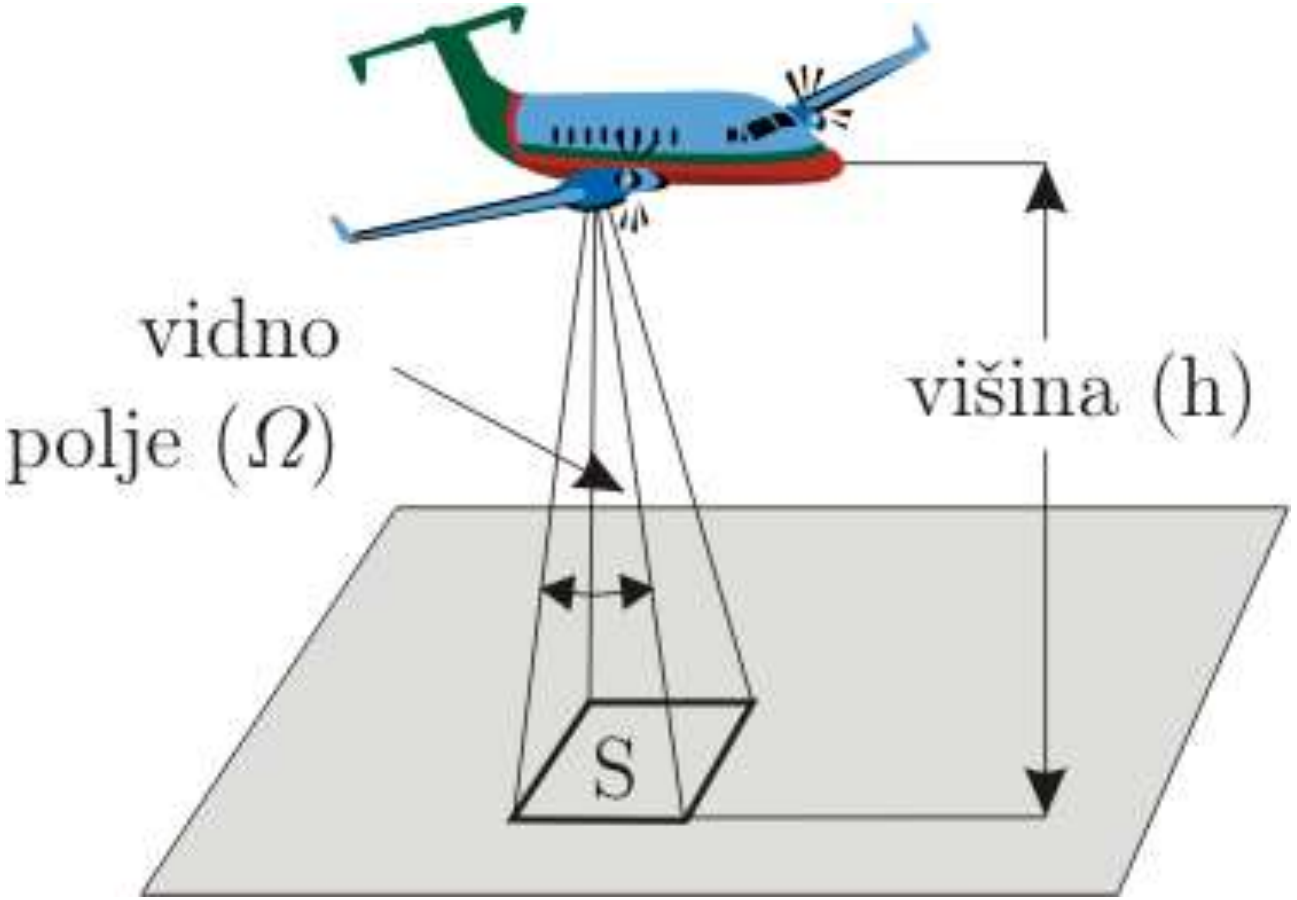


**"My presentation lacks power and it has no point.
I assumed the software would take care of that!"**

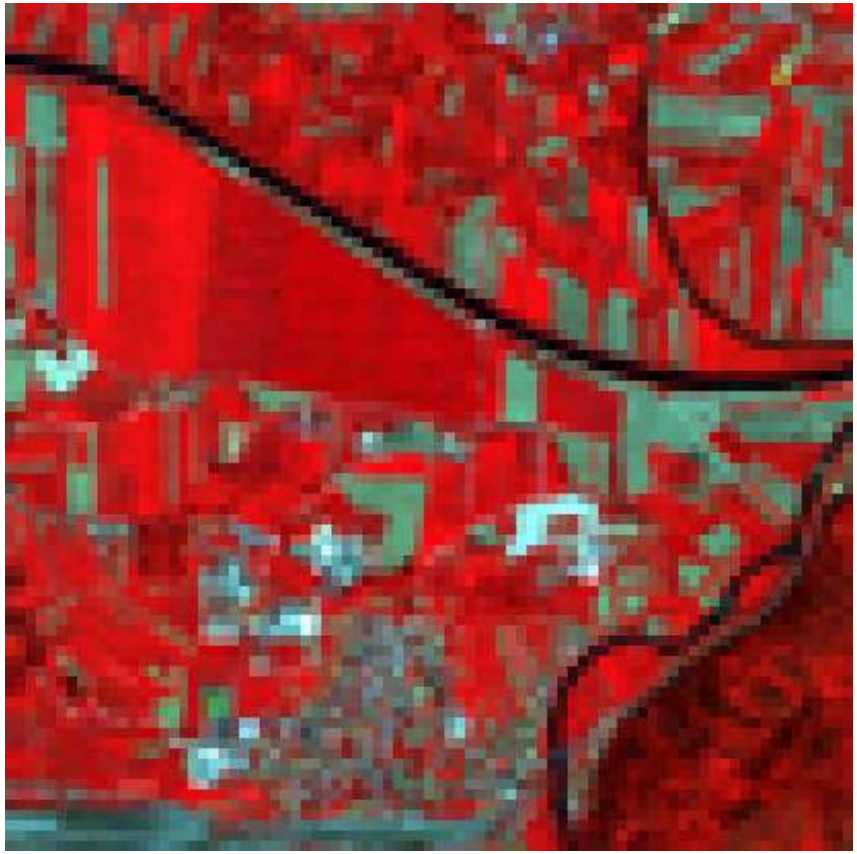
Resolution

- Spatial – smallest recognizable object, related to pixel dimension
- Spectral – number of bands, width of bands
- Radiometric – number of bits (bytes) per band, detectable grey values
- Temporal – time between image acquisitions

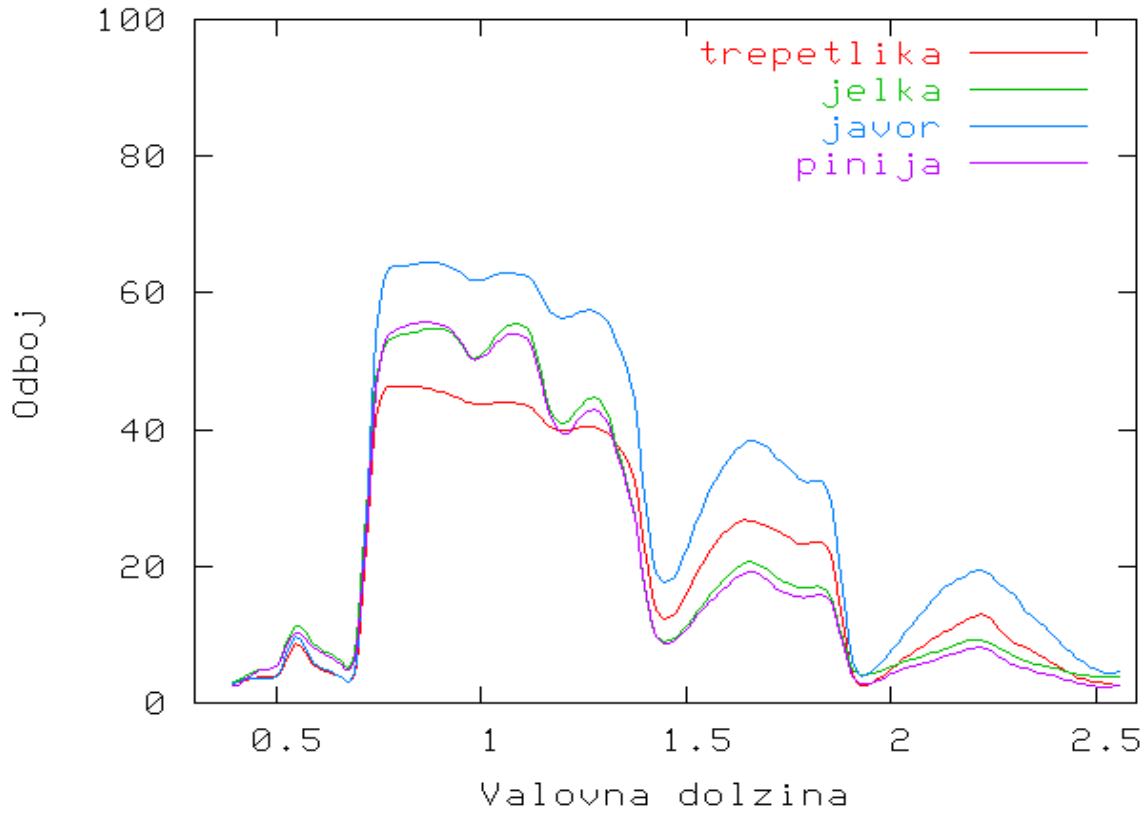
Spatial resolution



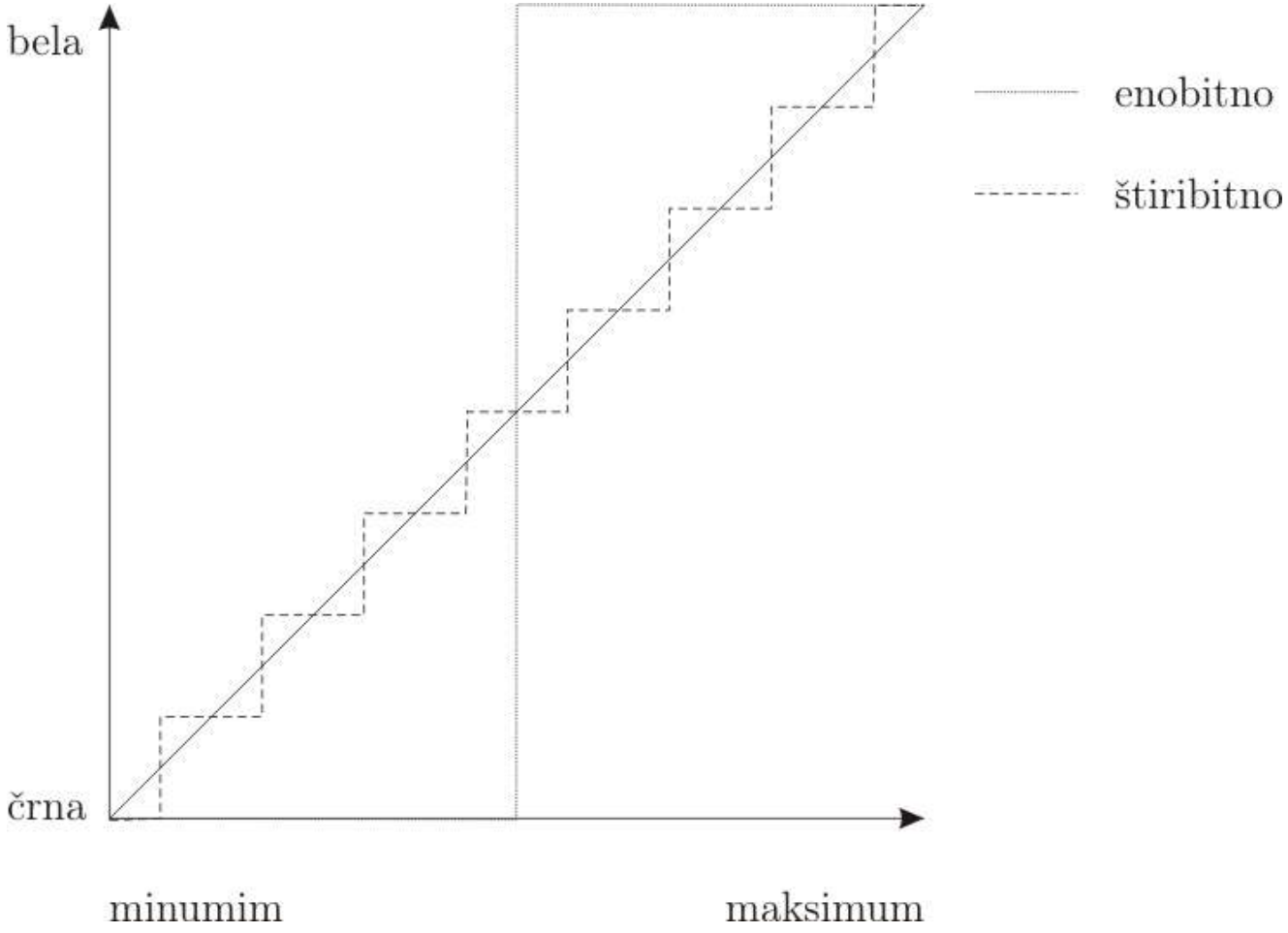
Spatial resolution



Spectral response

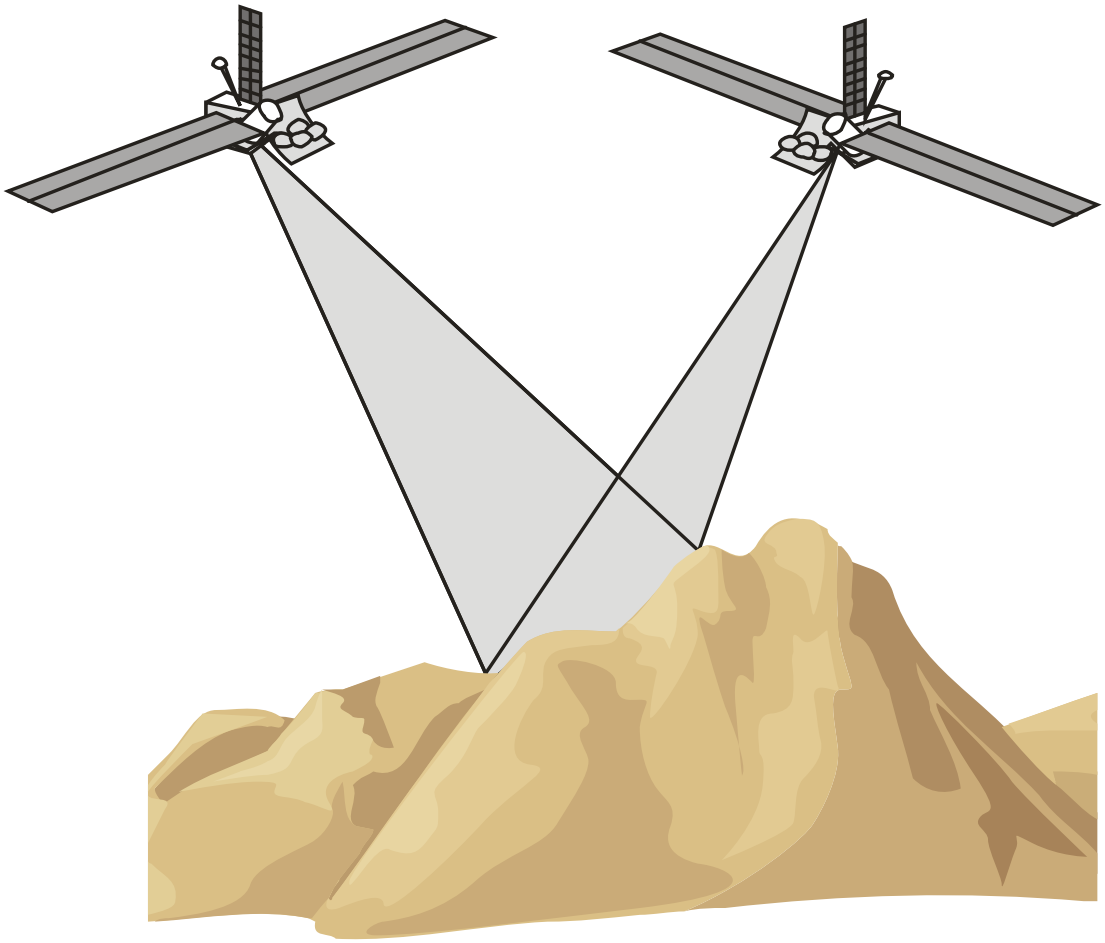


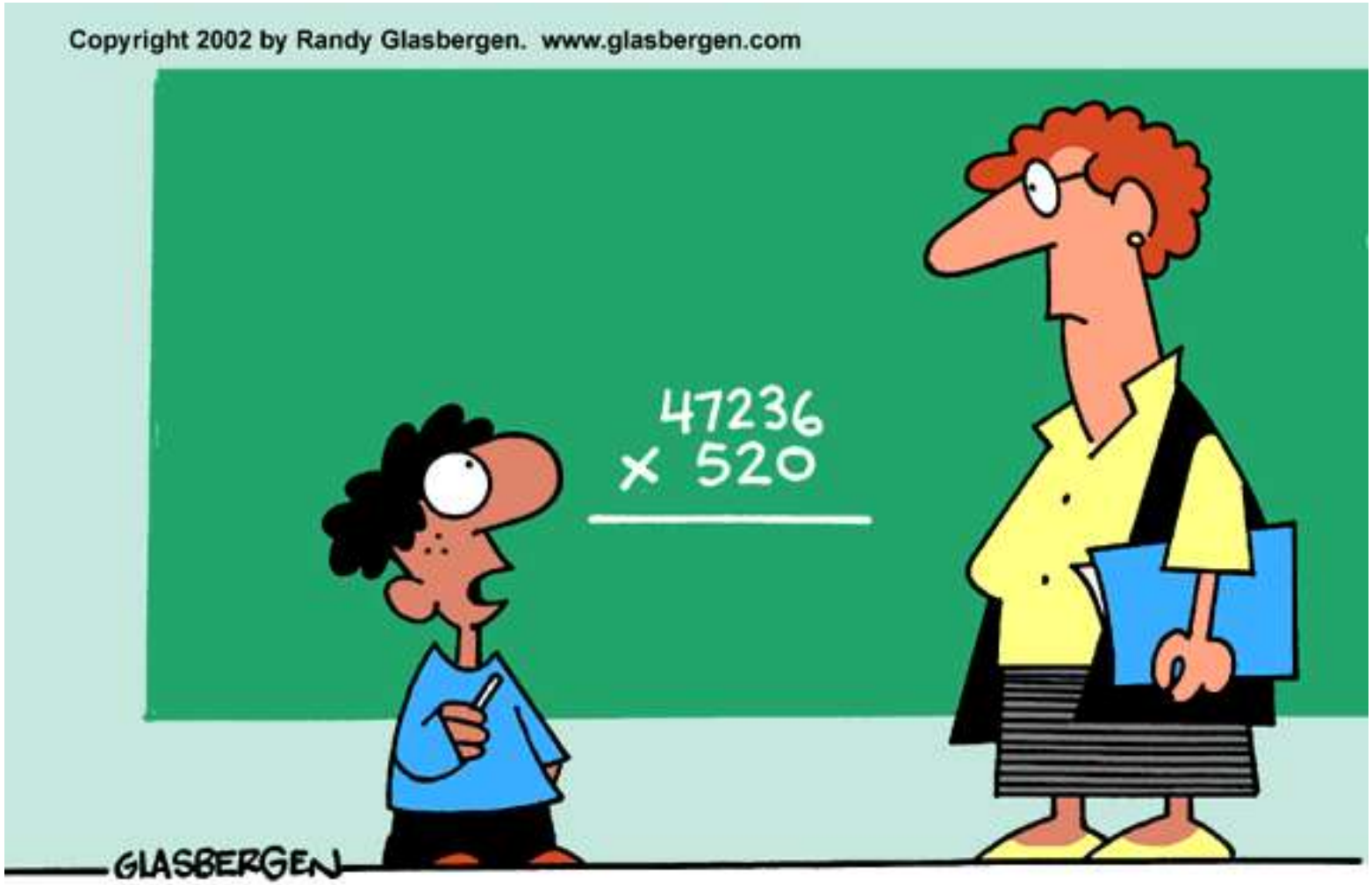
Radiometric resolution



Radiometric resolution

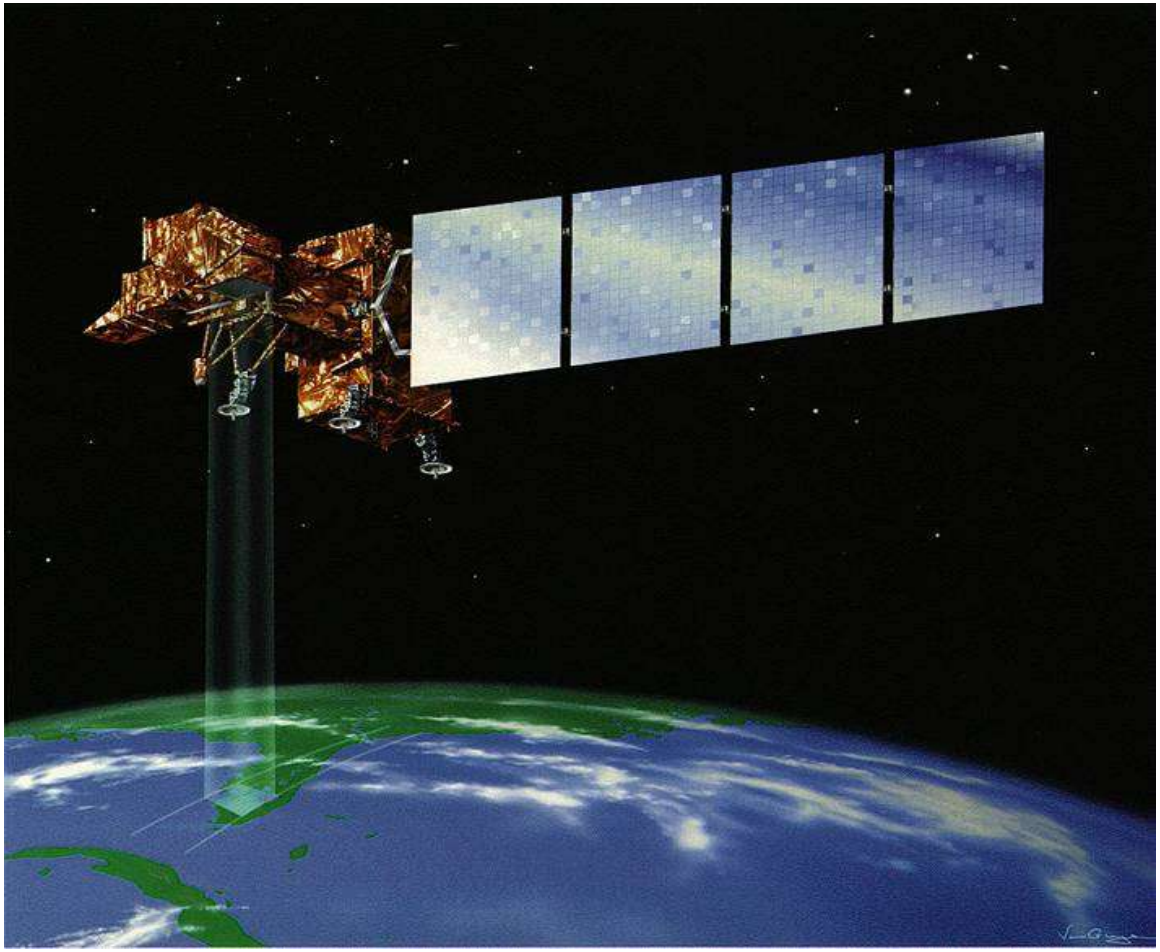
Temporal resolution





"AREN'T THERE ENOUGH PROBLEMS IN THE WORLD ALREADY?"

Landsat



Landsat

- History
- Sensors
  - Return Beam Vidicon (RBV)
  - MultiSpectral Scanner (MSS)
  - Thematic Mapper (TM)
  - Enhanced Thematic Mapper Plus (ETM+)
- Success
  - sensor combination and number of spectral bands
  - very good spatial resolution (multispectral)
  - excellent coverage
  - huge archive (from 1972)

TM/ETM+ Properties

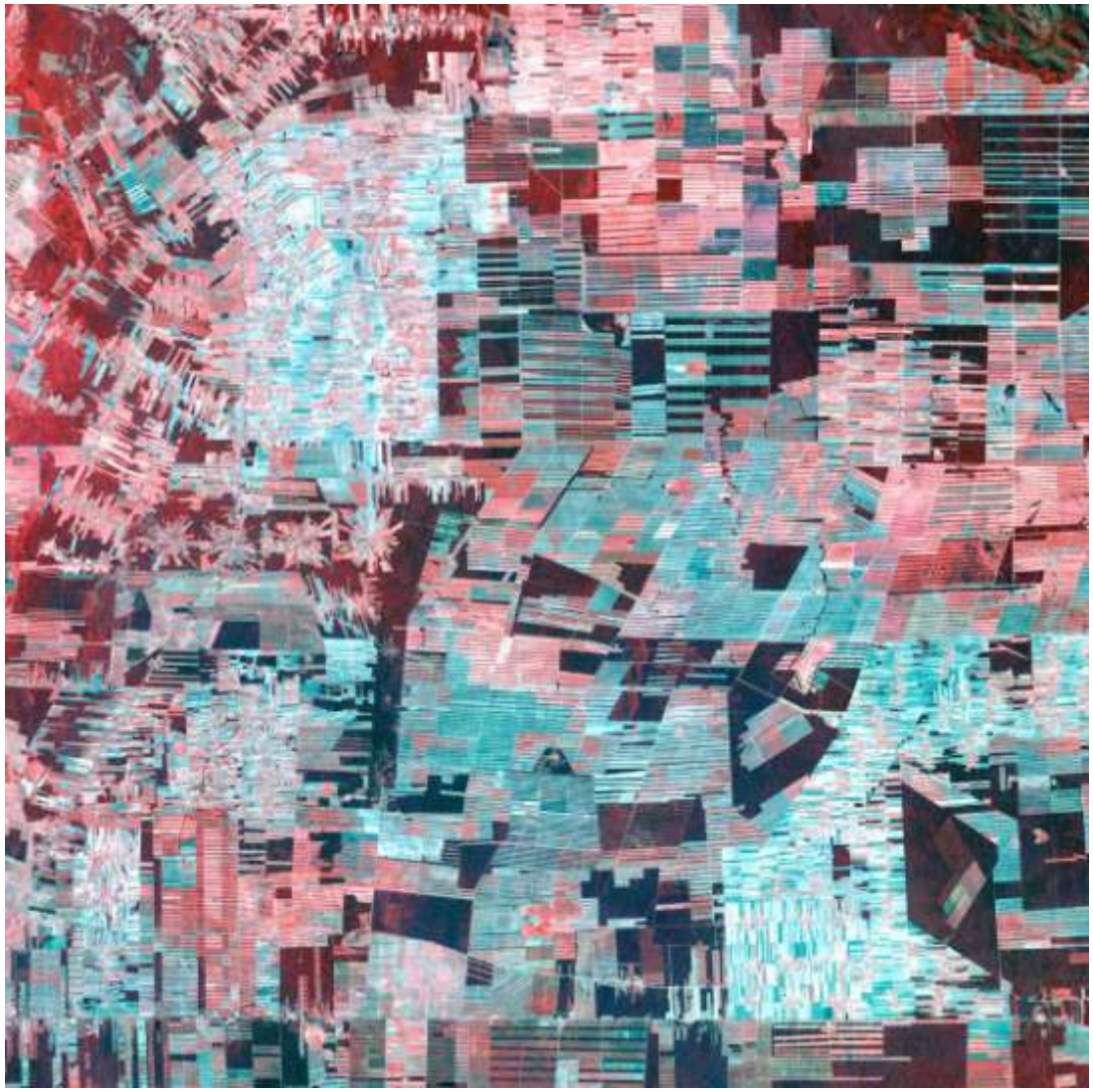
- 7 bands + panchromatic
- Spatial resolution
  - 30 m multispectral
  - 120/60 m thermal
  - 15 m panchromatic
- 8-bit radiometric resolution
- 16 sensors per band

TM/ETM+ Bands

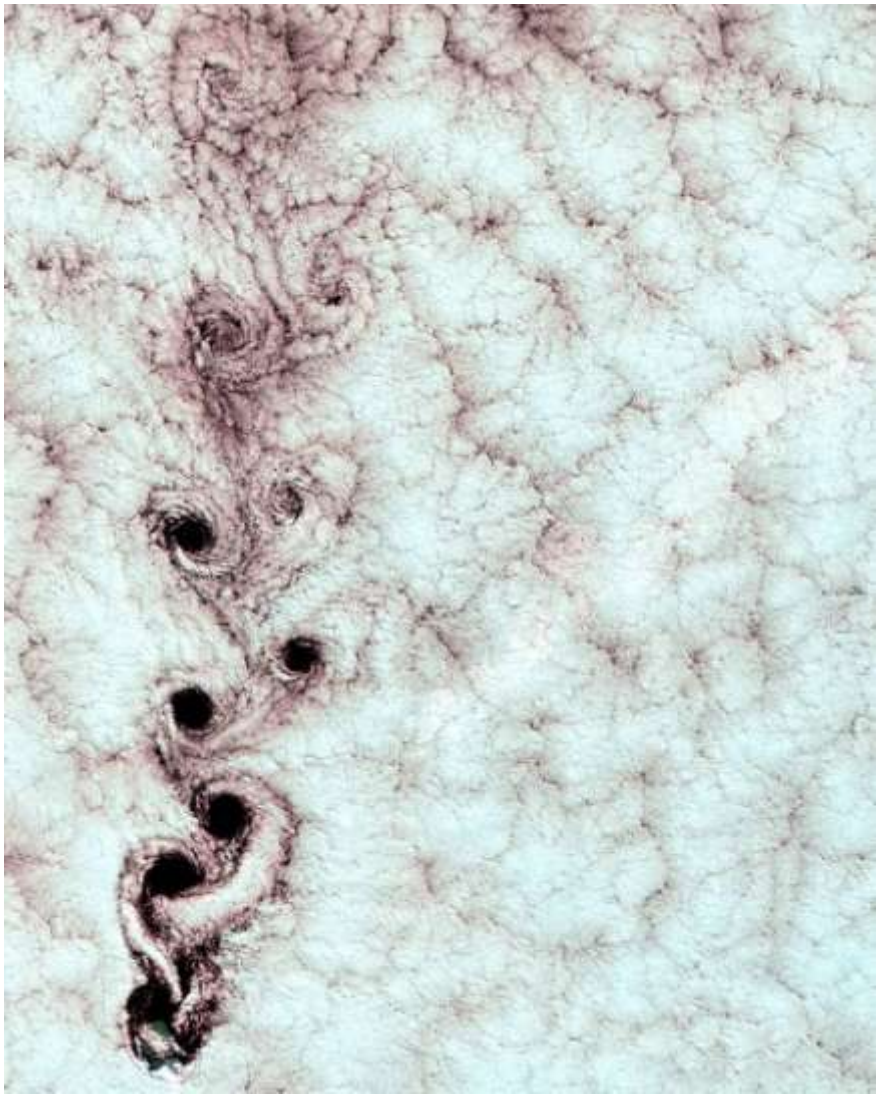
Channel	Wavelength Range (mm)	Resolution (m) TM/ETM+	Application
TM 1	0.45 - 0.52 (blue)	30	soil/vegetation discrimination; bathymetry/coastal mapping; cultural/urban feature identification
TM 2	0.52 - 0.60 (green)	30	green vegetation mapping (measures reflectance peak); cultural/urban feature identification
TM 3	0.63 - 0.69 (red)	30	vegetated vs. non-vegetated and plant species discrimination (plant chlorophyll absorption); cultural/urban feature identification
TM 4	0.76 - 0.90 (near IR)	30	identification of plant/vegetation types, health, and biomass content; water body delineation; soil moisture
TM 5	1.55 - 1.75 (short wave IR)	30	sensitive to moisture in soil and vegetation; discriminating snow and cloud-covered areas
TM 6	10.4 - 12.5 (thermal IR)	120/60	vegetation stress and soil moisture discrimination related to thermal radiation; thermal mapping (urban, water)
TM 7	2.08 - 2.35 (short wave IR)	30	discrimination of mineral and rock types; sensitive to vegetation moisture content
PAN	0.52 − 0.90 (panchromatic)	-/15	image sharpening, vegetation observation

Guinea-Bissau

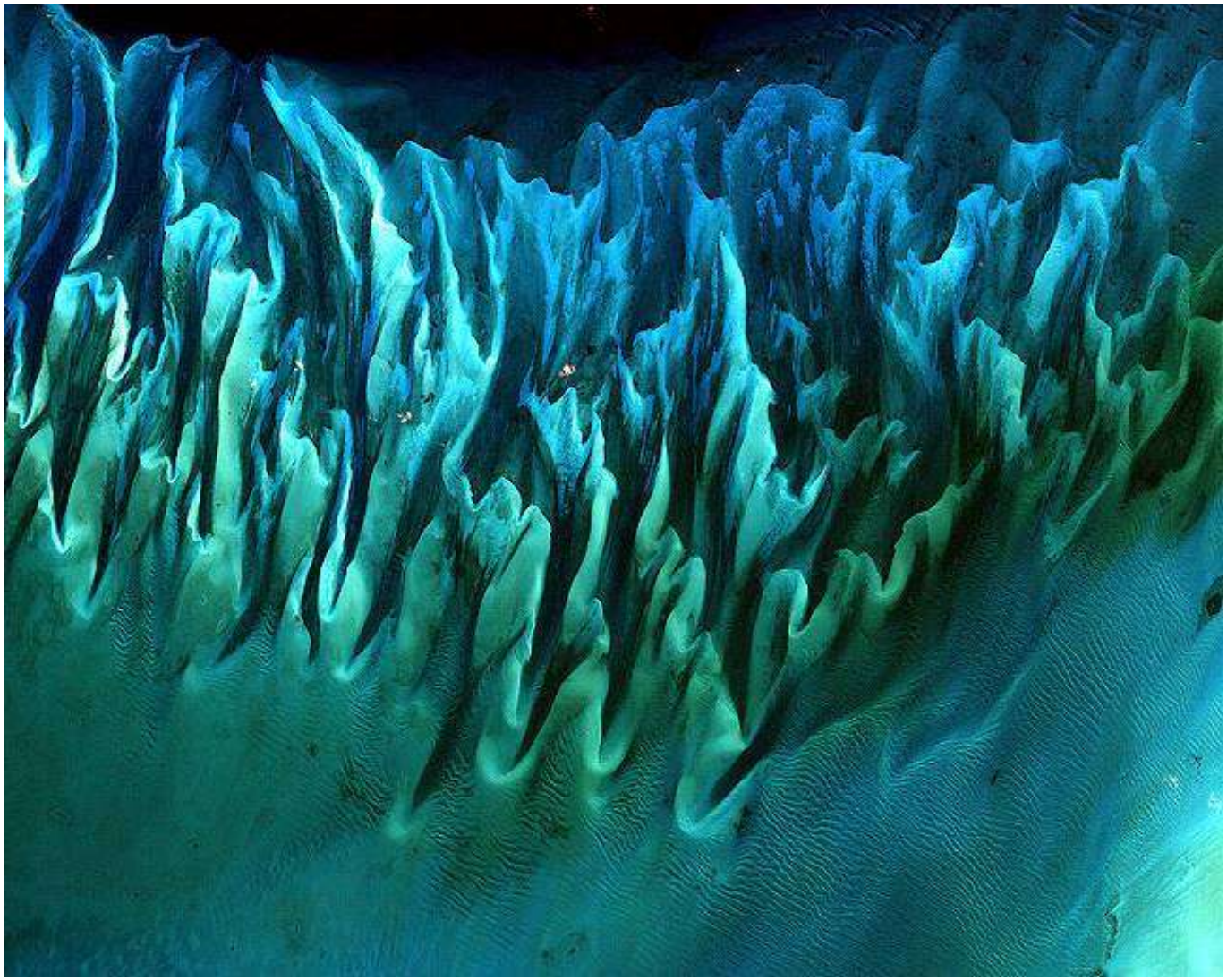
Deforestation in Bolivia



Von Karman Vortices



Ocean Sand



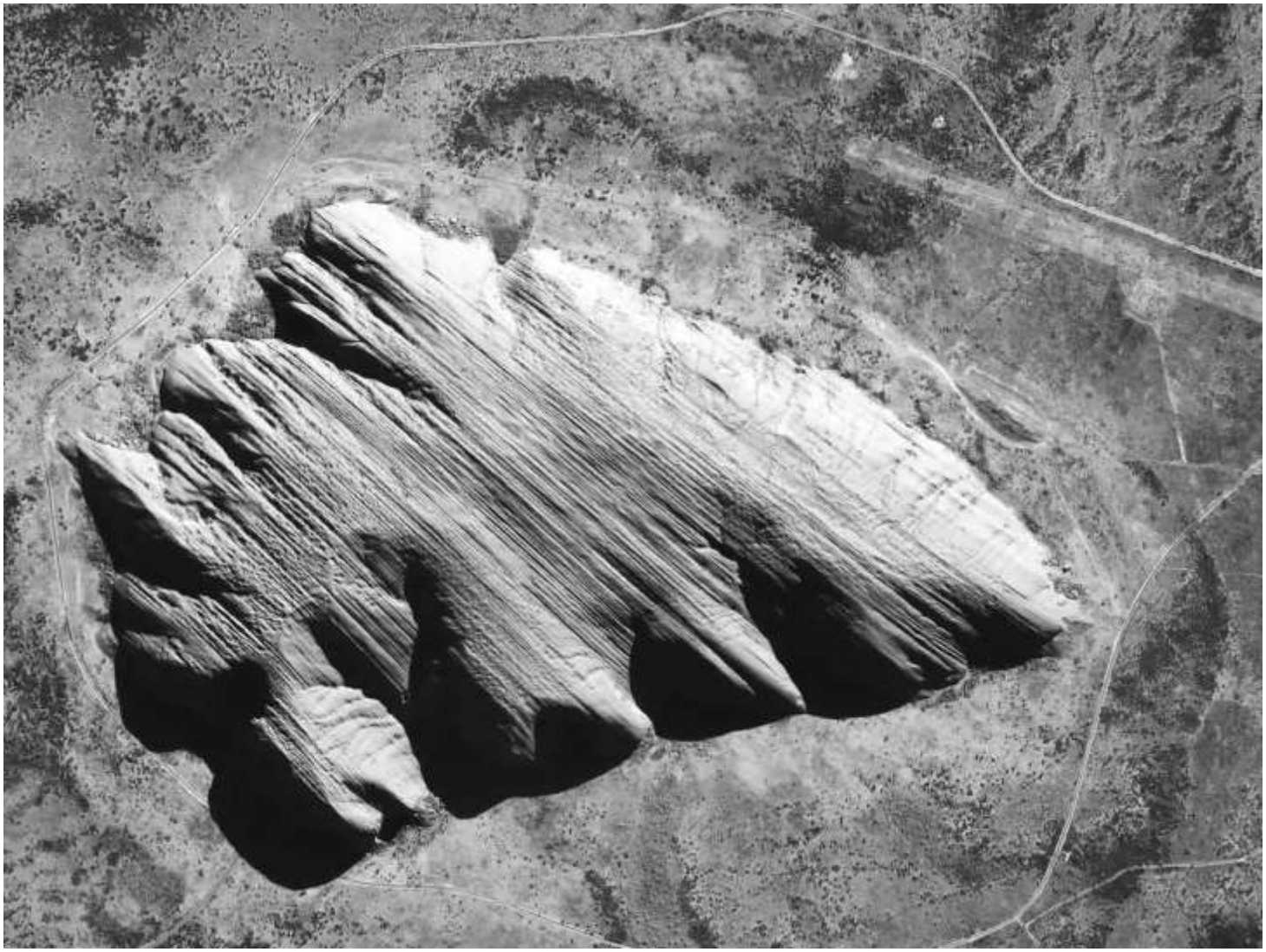
IKONOS

- Launched in 1999
- Bands similar to Landsat
- Spatial resolution
  - 4 m multispectral
  - 1 m panchromatic
- 11-bit radiometric resolution (2048 grey values)
- Image size 11 by 11 km

IKONOS – sensor

Band	Resolution (m)	Wavelength (μm)	Spectral range
MS1	4	0.45 - 0.52	blue
MS2	4	0.52 - 0.60	green
MS3	4	0.63 - 0.69	red
MS4	4	0.76 - 0.90	near infrared
PAN	1	0.45 - 0.90	panchromatic

Ayers



Øresund

QuickBird

QuickBird

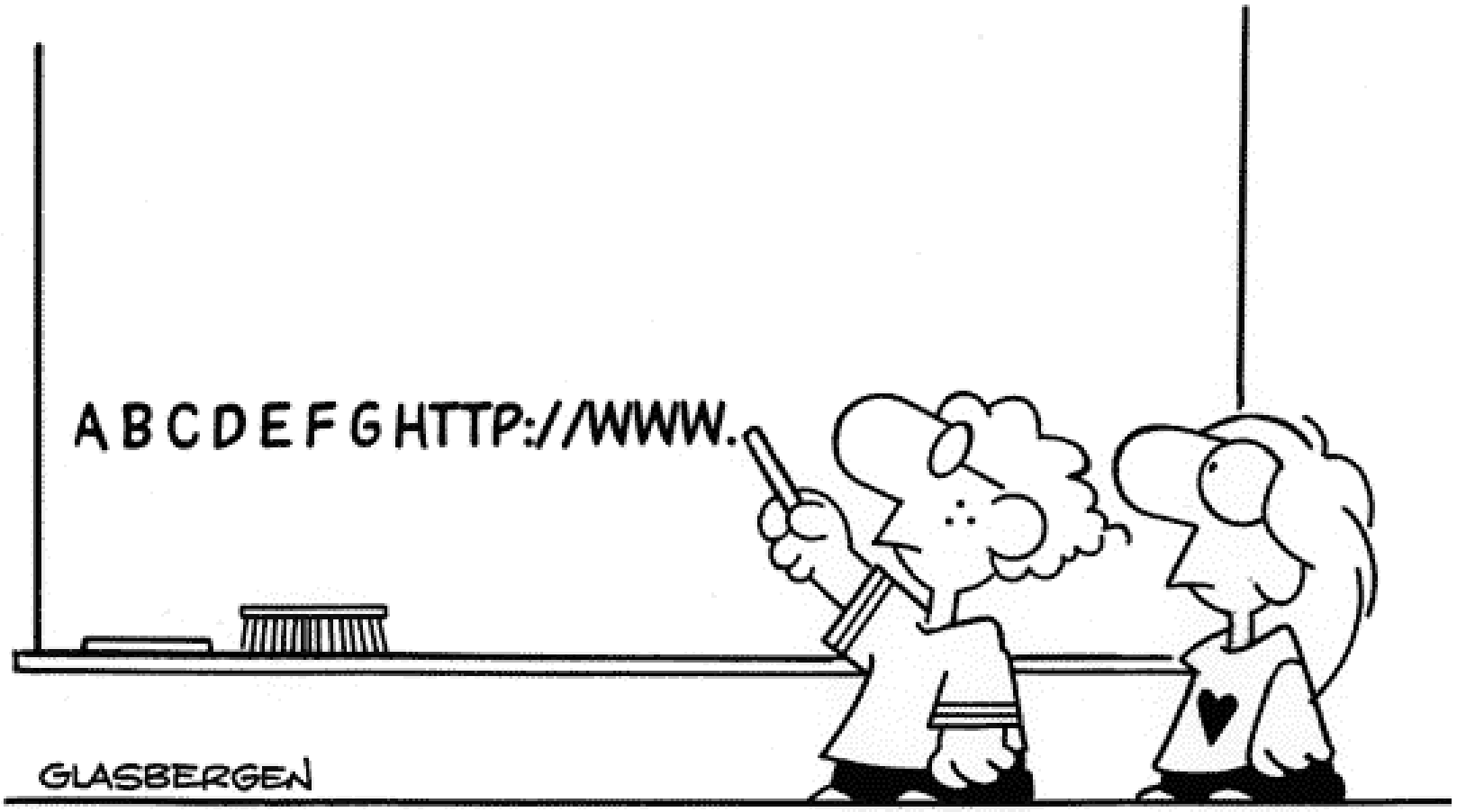
- Launched in 2001
- Bands similar to Landsat (identical to IKONOS)
- Spatial resolution
  - 2.44 m multispectral
  - 0.61 m panchromatic
- 11-bit radiometric resolution
- Image size 16 by 16 km

QuickBird – sensor

Band	Resolution (m)	Wavelength (μm)	Spectral range
MS1	2.44	0.45 - 0.52	blue
MS2	2.44	0.52 - 0.60	green
MS3	2.44	0.63 - 0.69	red
MS4	2.44	0.76 - 0.90	near infrared
PAN	0.61	0.45 - 0.90	panchromatic

Giza

Mecca



Medium versus high resolution

	Medium resolution	High resolution
Spectral resolution	excelent	good
Spatial resolution	good	excelent
Radiometric resolution	8-bit	11-bit
Temporal resolution	several weeks	several days
Archive	long-term, continous	short-term, on demand imaging
Size of data	medium	enormous
Image size	>100 km	~10 km
MB per km2	~0.01	>1
Cost per km2	0.02 EUR	30 EUR
Cost per MB	~2 EUR	~10 EUR
Georeferencing	control points	orthorectification
Processing	interpretation, normal	interpretation, object oriented

Image selection

- Archives are usually online
- Image parameters
- Geographical position
- Time frame
- Cloud coverage
- Quicklook – low resolution image
- Availability

Where to search

- IKONOS
  - http://carterraonline.spaceimaging.com
- QuickBird
  - http://archivetool.digitalglobe.com
- SPOT
  - http://sirius.spotimage.fr
- Landsat
  - http://www.eurimage.com/einet/choose.html

Price comparison

System	Price (EUR)	Size (km x km)	Price EUR/km2	Bands	MS (m)	PAN (m)	kb/km2	Price EUR/Mb
IKONOS		11	23.1	4	4	1	1200	20
IKONOS archive		11	18.6	4	4	1	1200	16
QuickBird		16.5	23.6	4	2.44	0.61	3300	7.3
QuickBird archive		16.5	18.9	4	2.44	0.61	3300	5.9
Landsat 5	1500	185	0.04	7	30		7.6	5.9
Landsat 5 quarter	1300	90	0.16	7	30		7.6	22
Landsat 5 mini	1200	50	0.48	7	30		7.6	65
Landsat 7	600	180	0.02	7	30	15	12	1.6
Landsat 7 quarter	550	90	0.07	7	30	15	12	5.8
Landsat 7 mini	500	50	0.2	7	30	15	12	17
Landsat 7 micro	450	25	0.72	7	30	15	12	61
SPOT 4	1900	60	0.53	4	20	10	20	27
SPOT 4 archive	1200	60	0.33	4	20	10	20	17
SPOT 5	2700	60	0.75	4	10	5	78	9.8
SPOT 5 half	2025	40	1.27	4	10	5	78	17
SPOT 5 quarter	1350	30	1.5	4	10	5	78	20
SPOT 5 eighth	1020	20	2.55	4	10	5	78	33

**"I always give 110% to my job.
40% on Monday, 30% on Tuesday, 20% on
Wednesday, 15% on Thursday, and 5% on Friday."**

Analog versus digital image processing

Analog (visual)

- skilled interpretators
- has long history
- no or little equipment
- one channel or one image at once
- very subjective

Digital

- enabled by electronic data acquisition and computer development
- dedicated software and hardware
- multi channel images (from one or multiple sources, taken at the same or different times)
- more objective

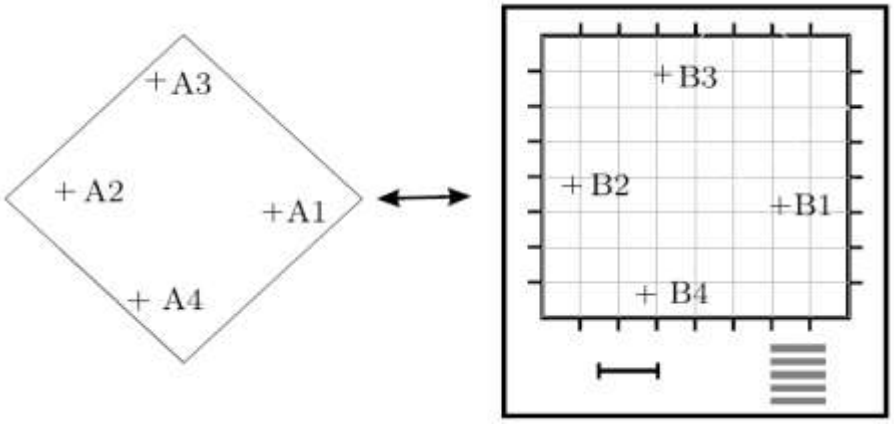
Photo interpretation

- Tone
- Shape
- Size
- Pattern
- Texture
- Shadow
- Association

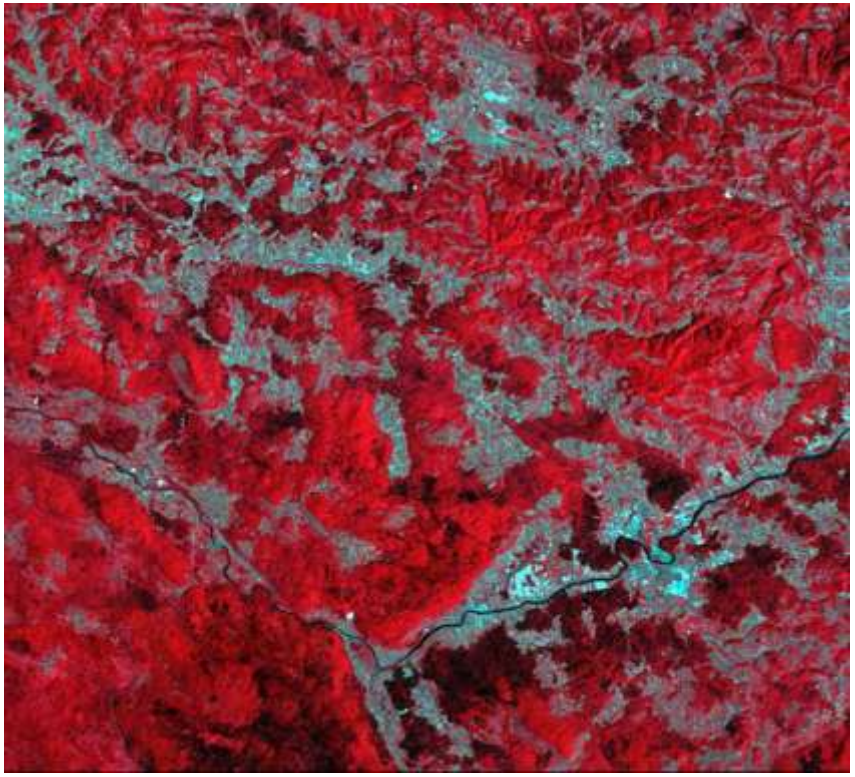
"We found someone overseas who can drink coffee and talk about sports all day for a fraction of what we're paying you."

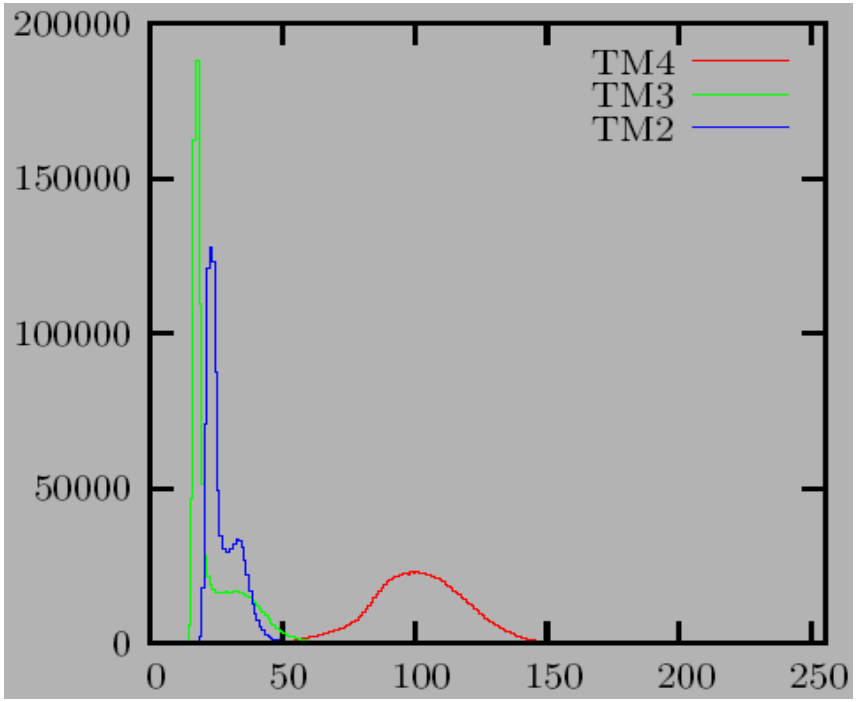
Geometric correction and registration

- images are not maps
  - no projection
  - no real scale
- geometric errors
- photogrammetric methods
- use of control points and simple transformation
  - image coordinates (line, column)
  - map coordinates
  - transformation

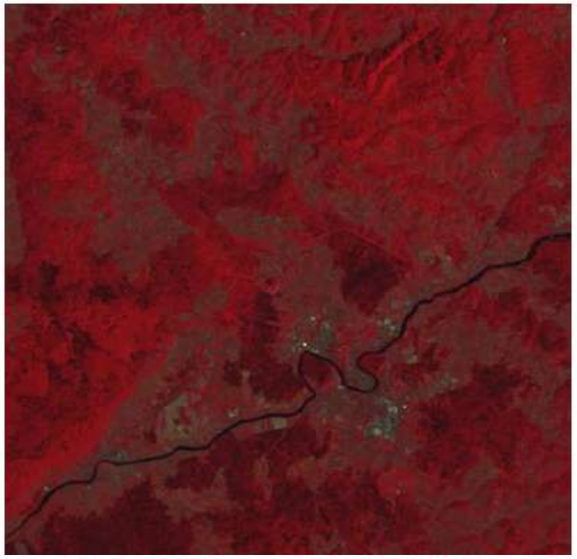


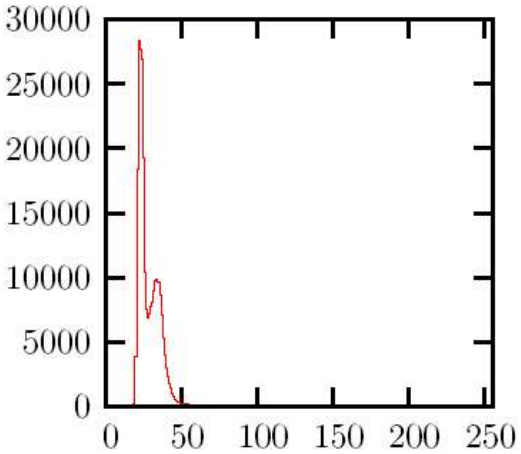
Histogram



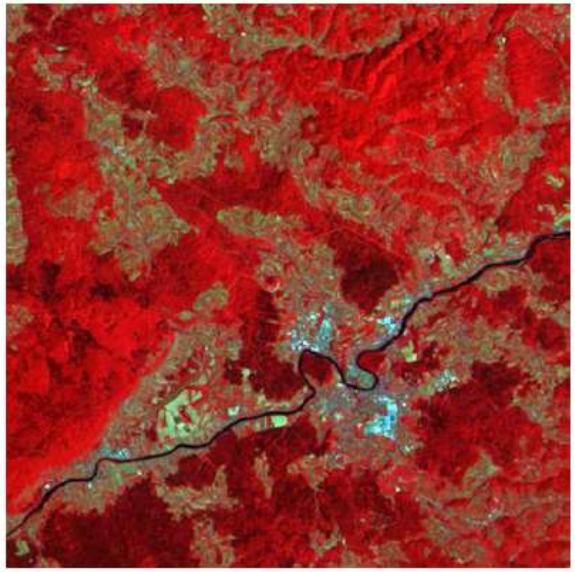


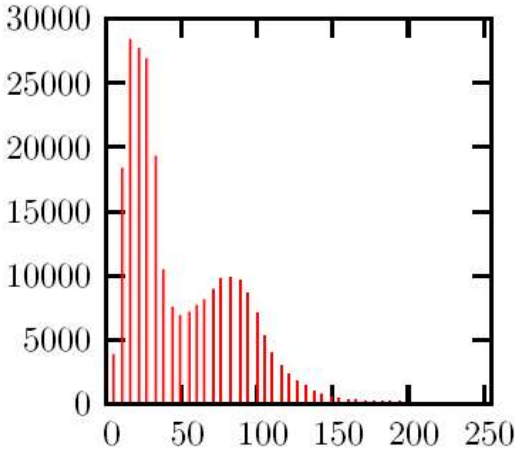
Linear contrast stretch





$$I_{lin\_razt} = R_{max} \frac{I - I_{min}}{I_{max} - I_{min}}$$



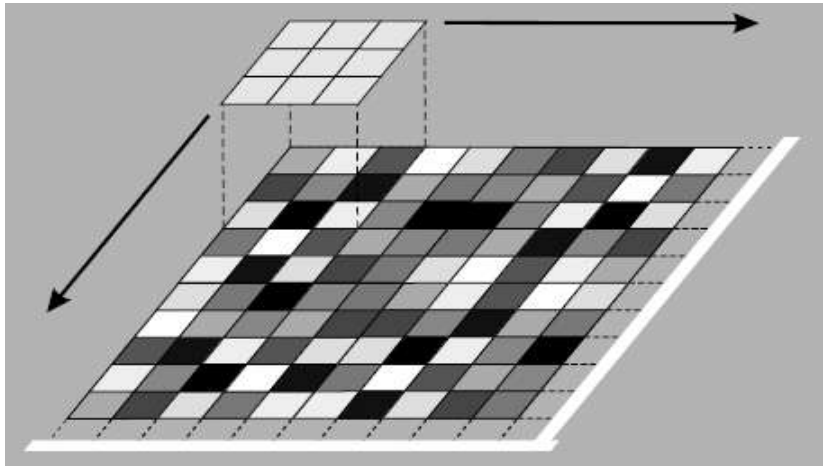


Filtering

- uses spatial data information
- image = background + detail + noise
- image = low frequency + high frequency + noise

Convolution filtering

- filtering windows
- every pixel
- mathematical operation
  - smoothing
  - sharpening
  - edge detection



$$IF_{i,j} = \sum_{k=-a}^{a} \sum_{l=-b}^{b} F_{k,l}\, I_{i+k,j+l}$$

Low-pass filter

$$Fnp_{3x3} = \frac{1}{9}\begin{bmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{bmatrix}$$

$$Fnp_{5x5} = \frac{1}{25}\begin{bmatrix} 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 \end{bmatrix}$$

Low-pass filter

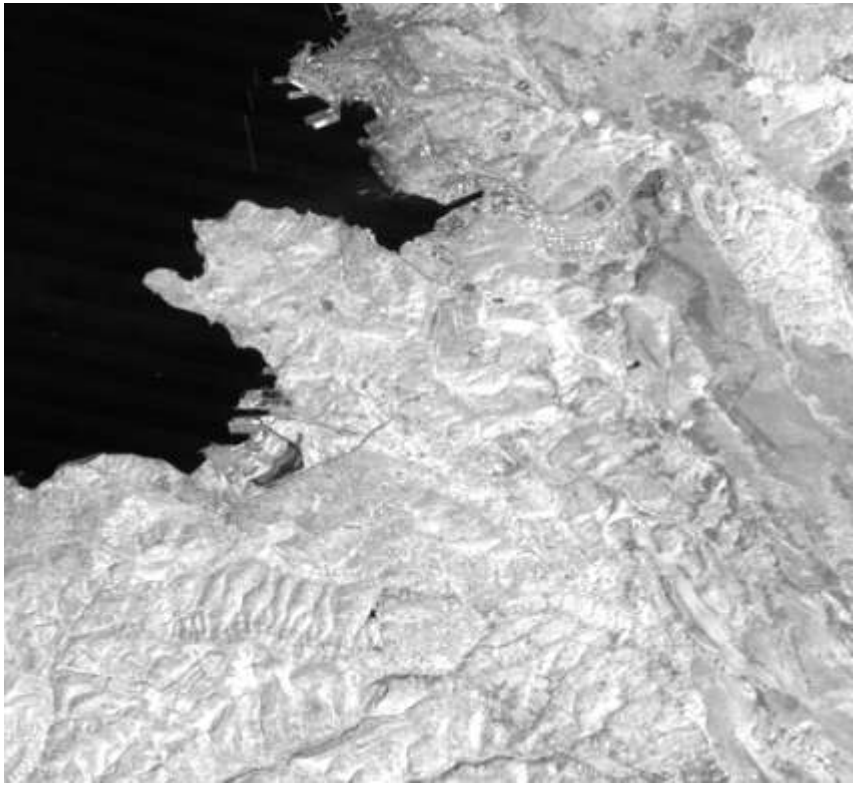
Edge detection filters

- rapid change of values
- related to anthropogenic activity
- high-pass filters
- Sobel
- Roberts

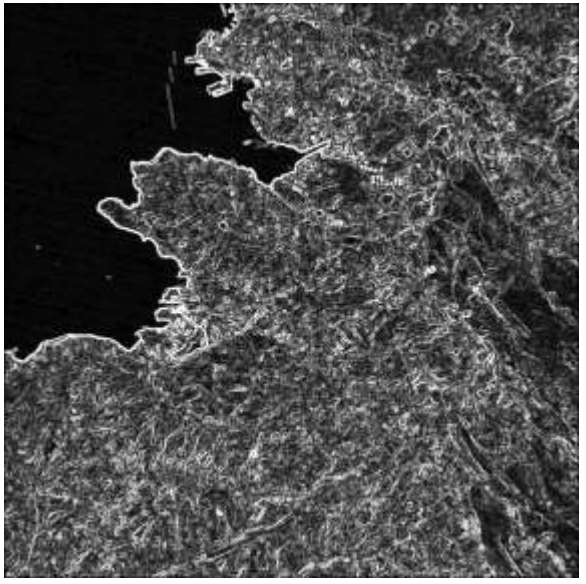
$$Fsob_x = \begin{bmatrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{bmatrix} \qquad Fsob_y = \begin{bmatrix} 1 & 2 & 1 \\ 0 & 0 & 0 \\ -1 & -2 & -1 \end{bmatrix}$$

$$Frob_a = \begin{bmatrix} 0 & 1 \\ -1 & 0 \end{bmatrix} \qquad Frob_b = \begin{bmatrix} 1 & 0 \\ 0 & -1 \end{bmatrix}$$

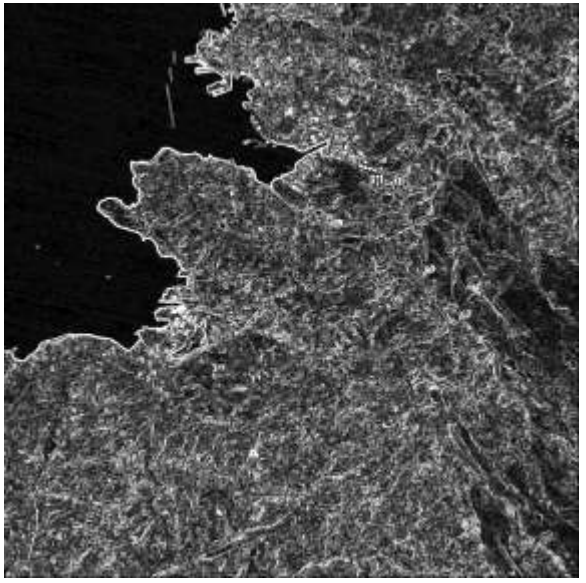
Edge filters



Sobel



Roberts



"It's the latest innovation in office safety.
When your computer crashes, an air bag is activated
so you won't bang your head in frustration."

Arithmetic operations

- addition – elimination of noise
- subtraction – differences
- multiplication
- division – band ratios (indices)

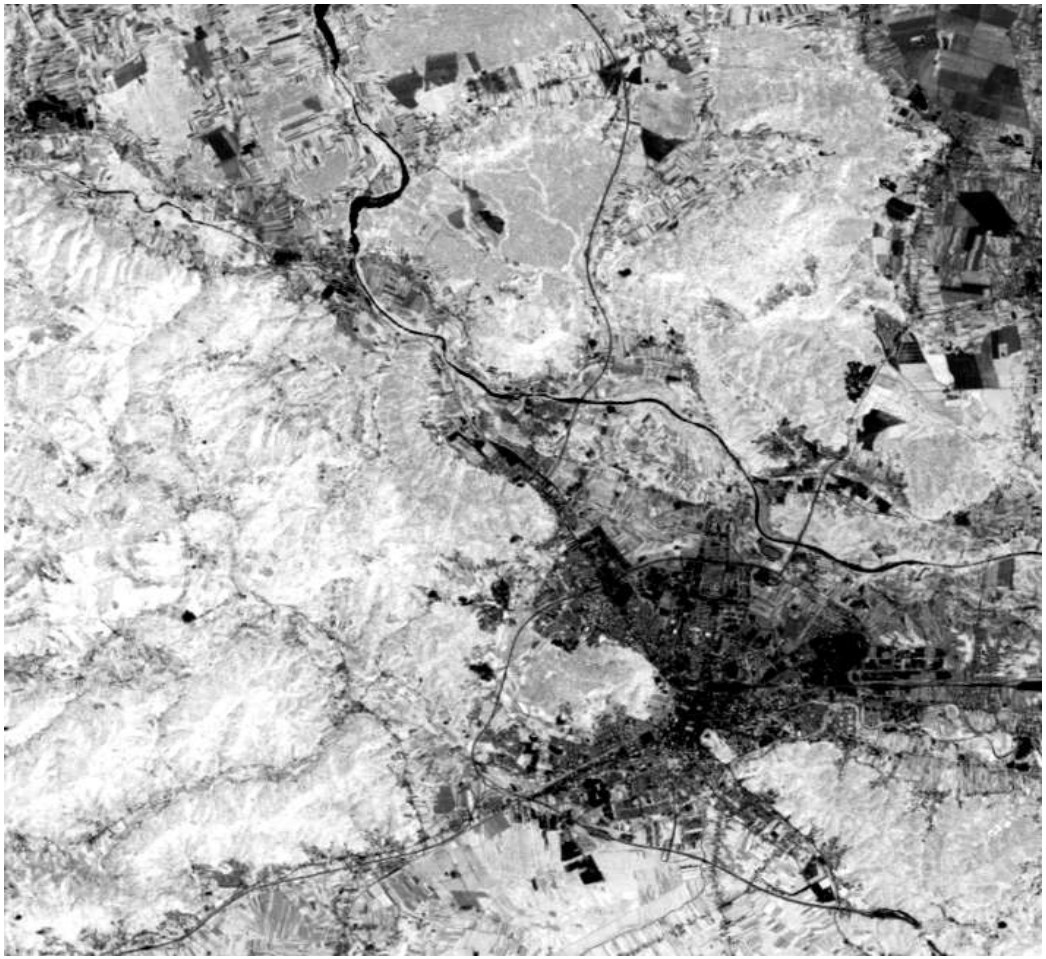
Vegetation index

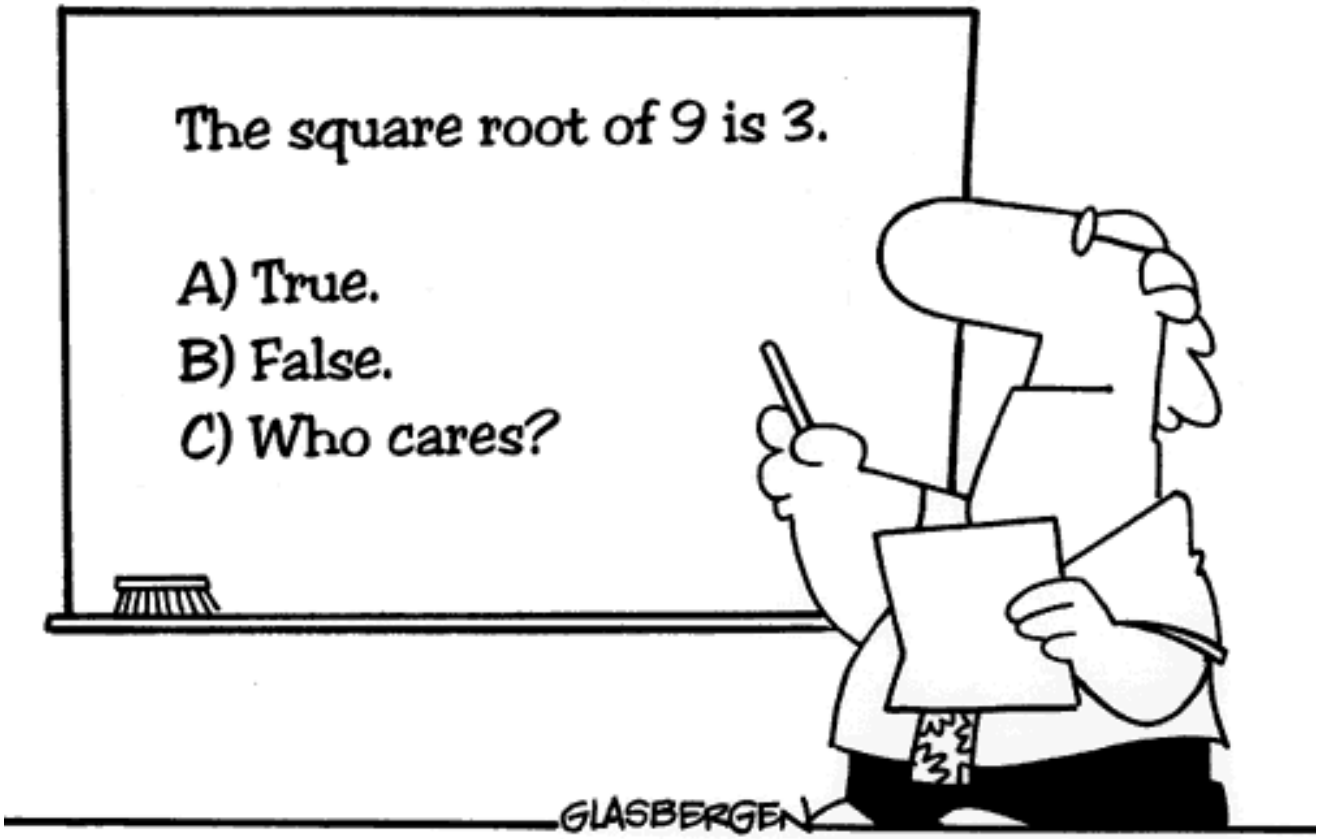
- vegetation has much higher reflectivity in IR than in R bands
- vegetation index
- normalized difference vegetation index (NDVI)

$$VI = \frac{IR}{R}$$

$$NDVI = \frac{IR - R}{IR + R}$$

Vegetation index



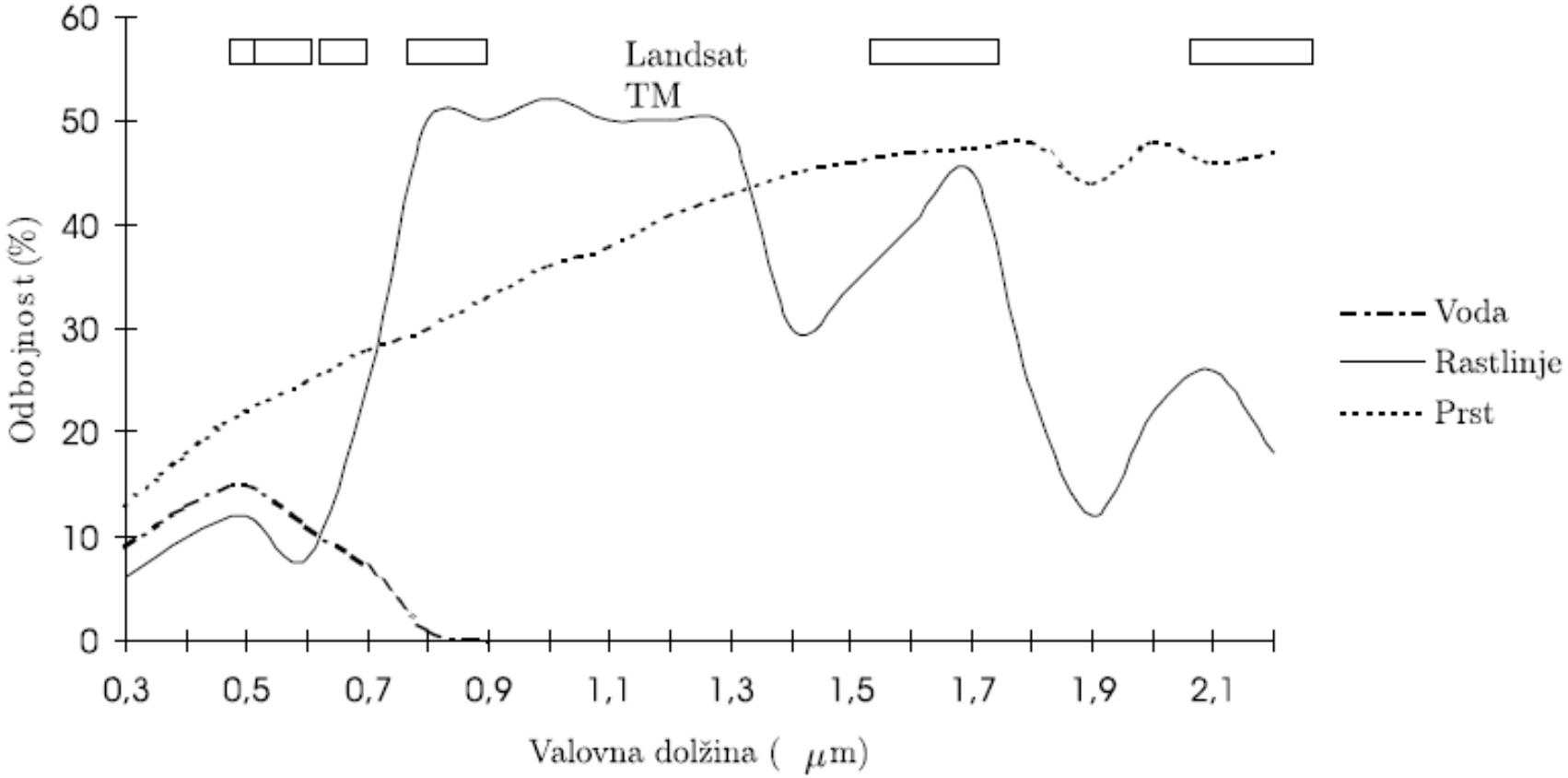


Many students actually look forward to Mr. Atwadder's math tests.

Image classification

- one of the most important processing steps
- produces a GIS layer
- pattern recognition (spectral)
- thematic map production

Spectral signature

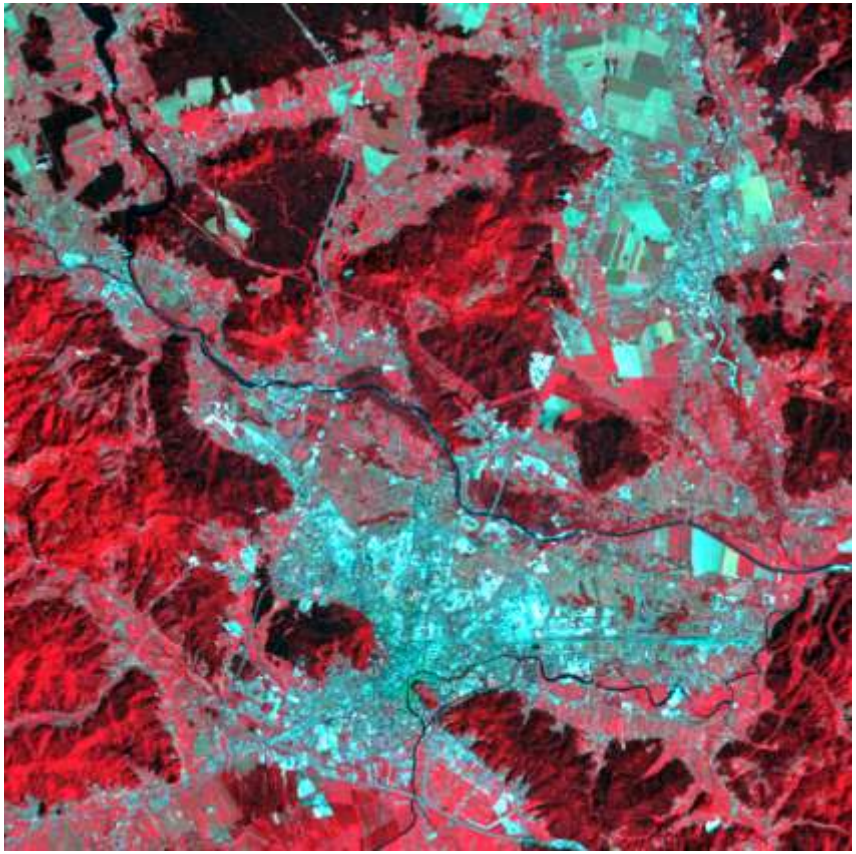


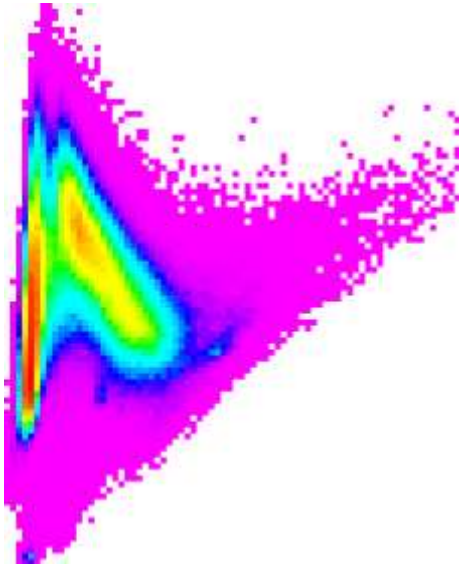
Tip tal	*TM 1*	*TM 5*
Voda	Nizek	Zelo nizek
Rastlinje	Nizek	Visok
Prst	Srednji	Visok

Classes

- information
  - categories to be recognized
  - crops, forests, geology ...
- spectral
  - similar pixels (regarding digital values) in different bands
  - humid deciduous forest, young wheat ...
- it is necessary to find the relation between spectral and information classes

Spectral space

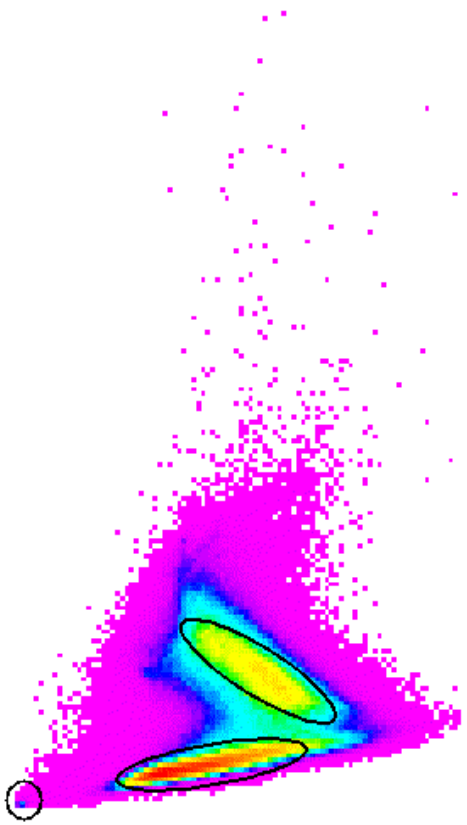




$$X_{geo}(x,y) = \begin{bmatrix} o_1(x,y) \\ o_2(x,y) \\ \vdots \\ o_n(x,y) \end{bmatrix} = X_{spek}(o_1,o_2,...,o_n)$$

Unsupervised classification

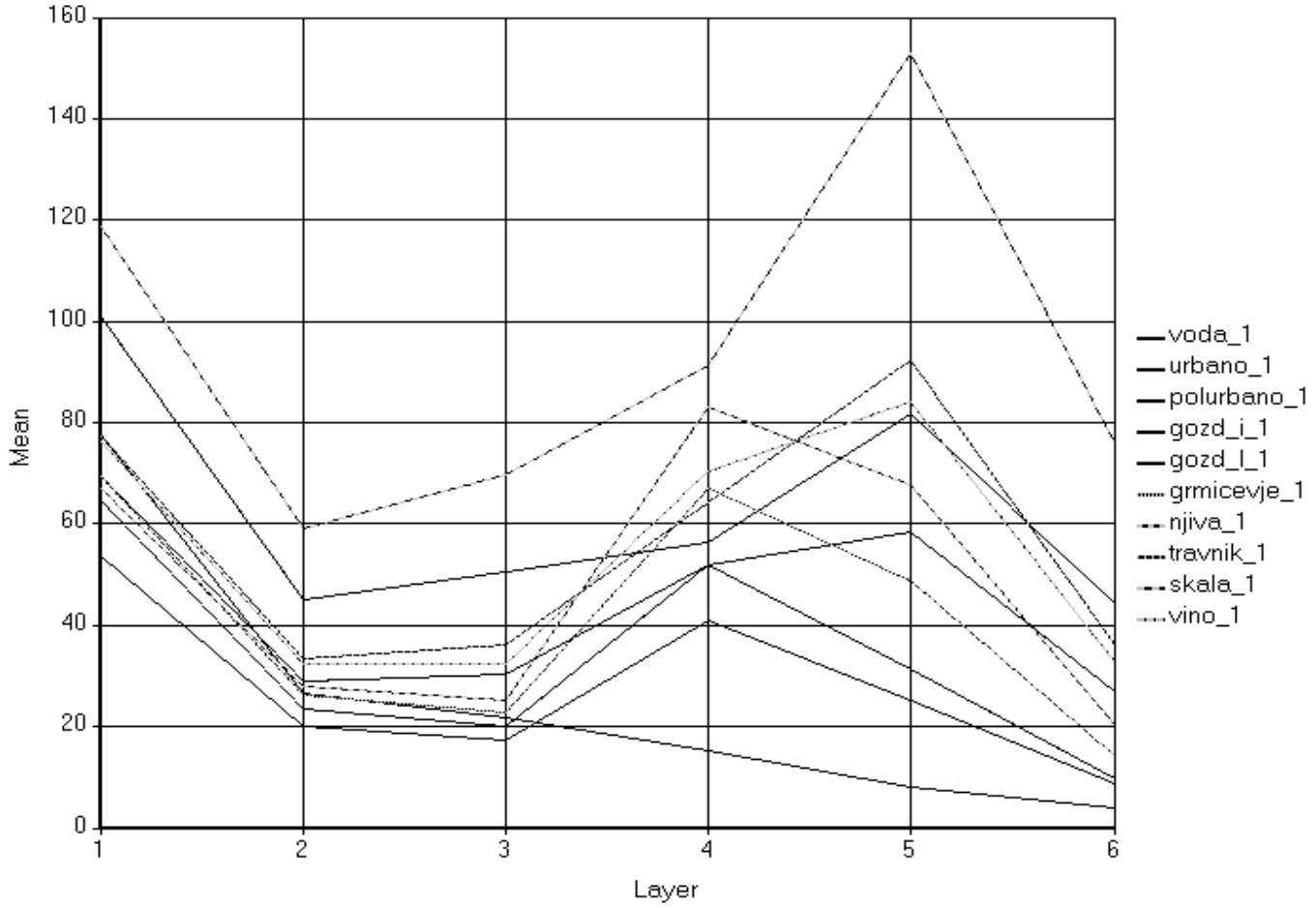
- natural grouping of pixels
- no prior knowledge of the surface
- spectral classes are determined
- information classes are later recognized
- cluster analysis



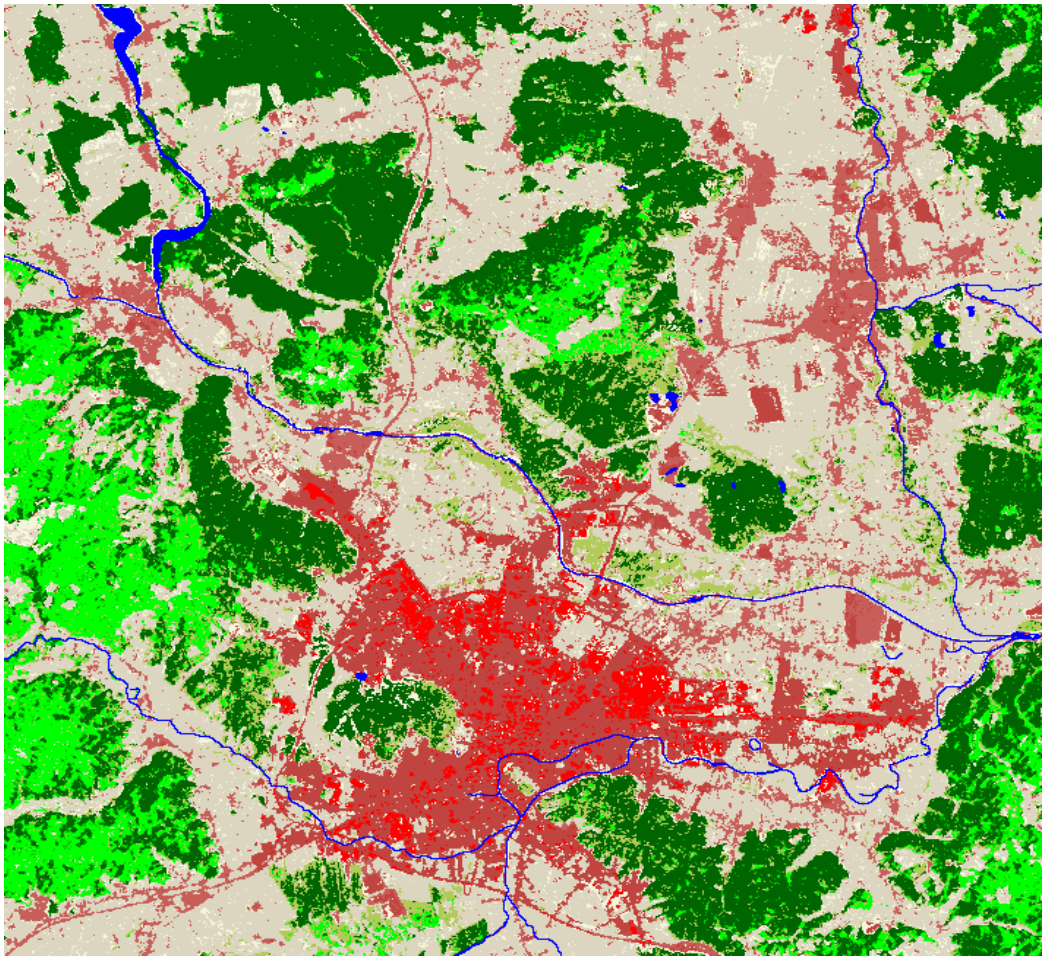
Supervised classification

- training samples are determined on the image
- the system “learns” to recognize classes
- spectral signatures are computed
  - averages
  - standard deviations

Spectral signatures



Classification results

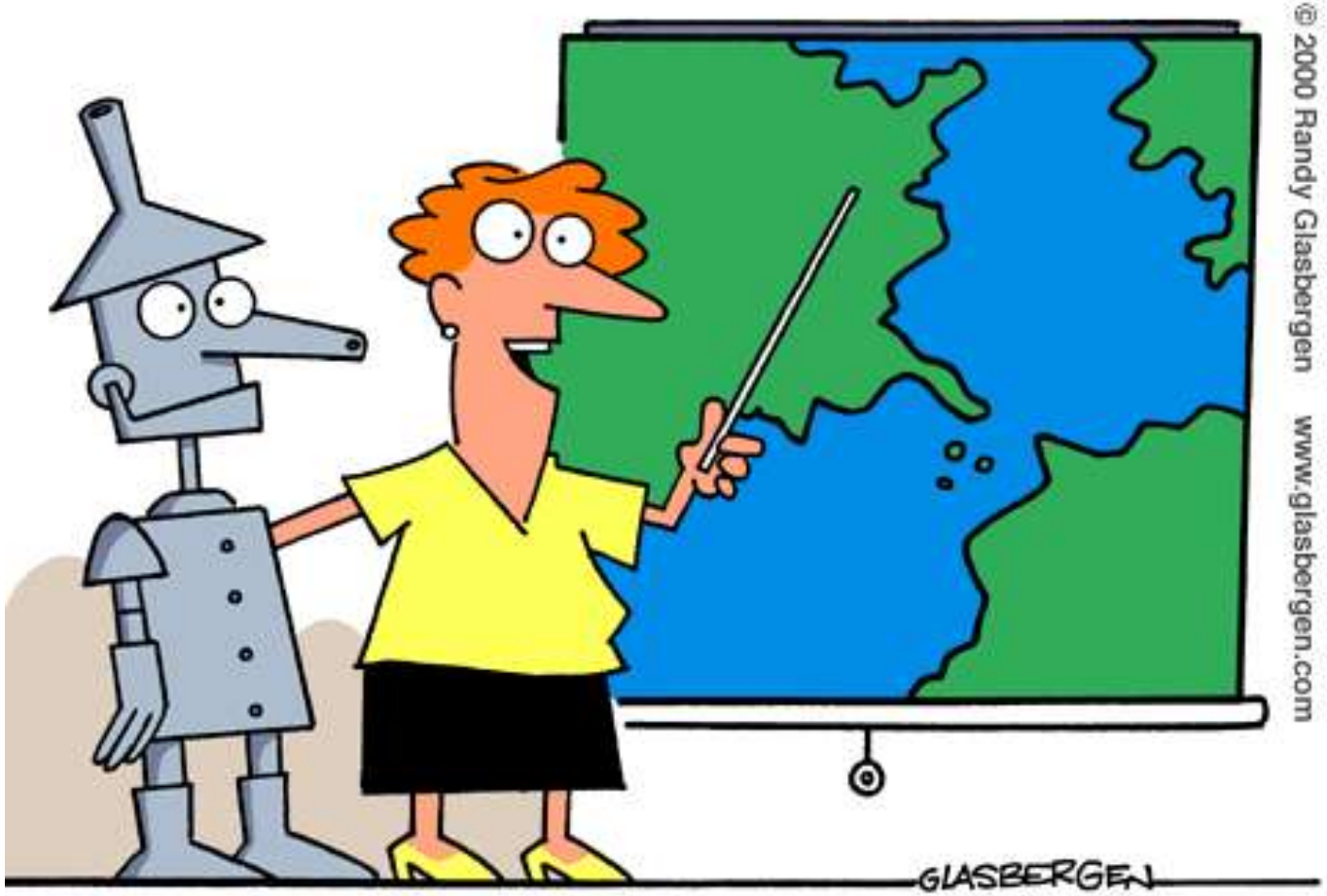


Quality assessment

- test areas distributed over the image
- known classes
  - field inspection
  - high scale maps
- comparison and statistics generation
- accuracy
  - > 90% - excellent
  - > 80% - very good

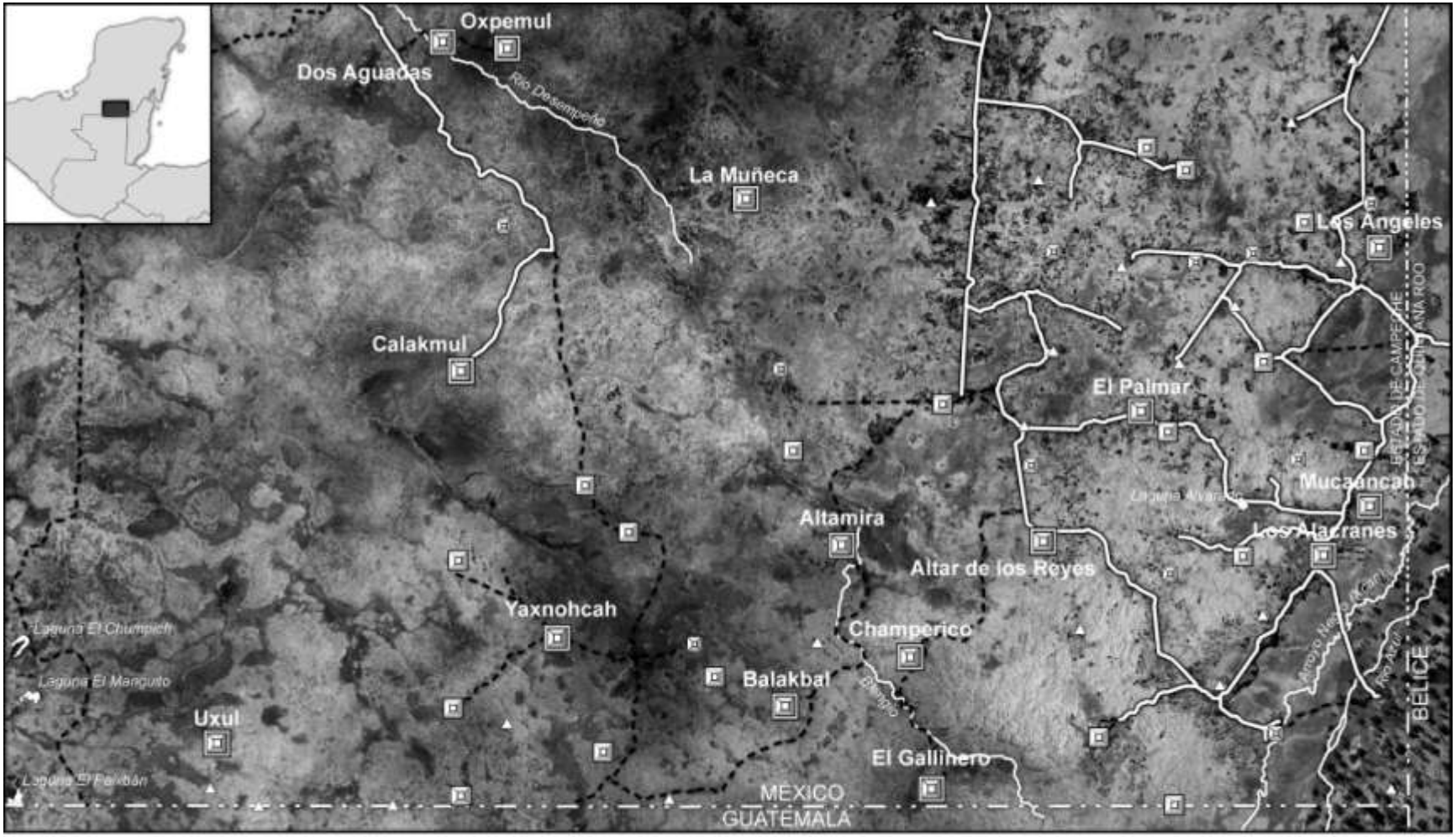
Application of remote sensing

- Archaeological sites in Yucatan, Mexico
- Detection of paleo relief in Languedoc, France



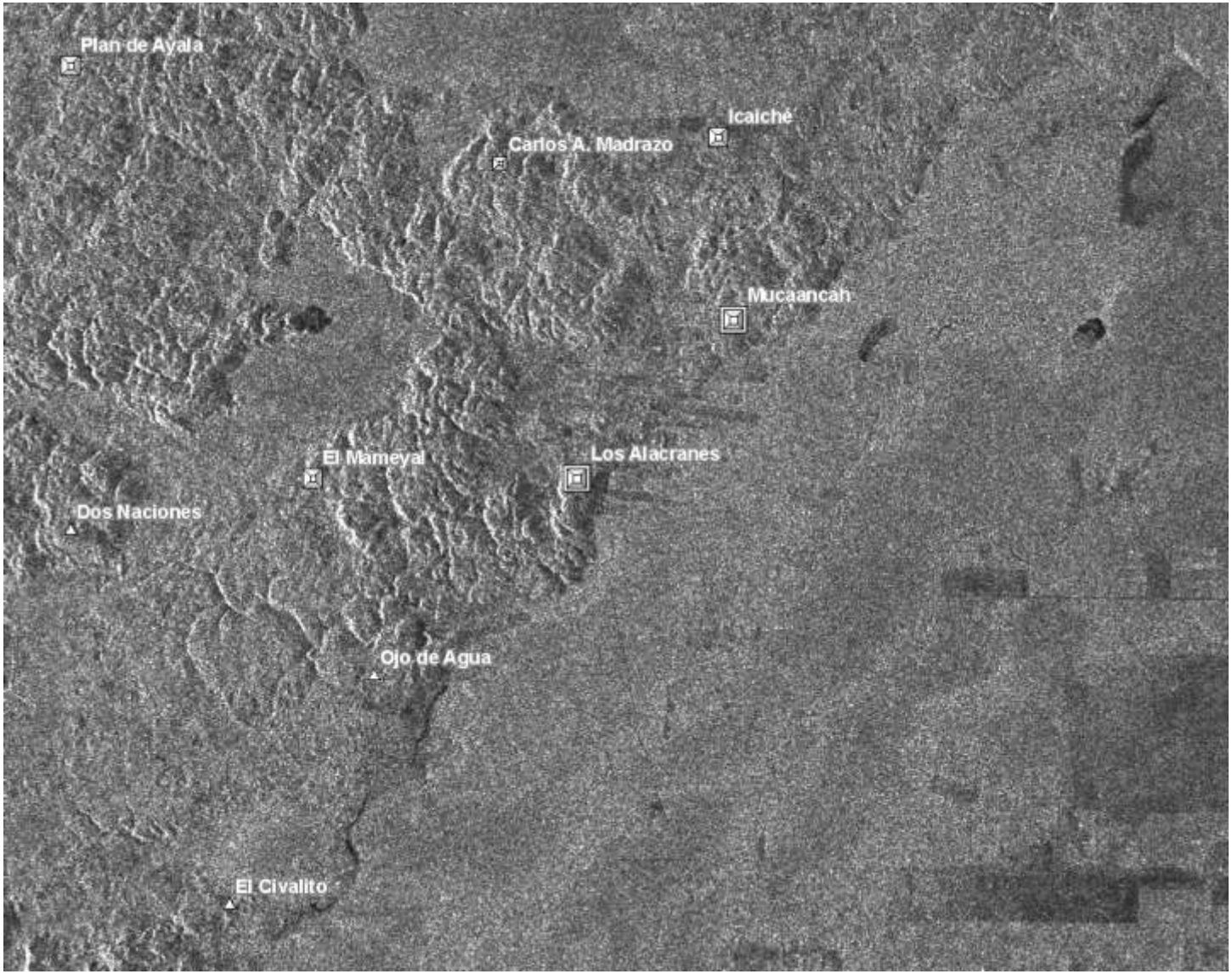
"CLASS, I'D LIKE YOU TO WELCOME OUR NEW FOREIGN EXCHANGE STUDENT! WHO'D LIKE TO COME UP HERE AND HELP US FIND "OZ" ON THE MAP?"

Yucatan, Mexico

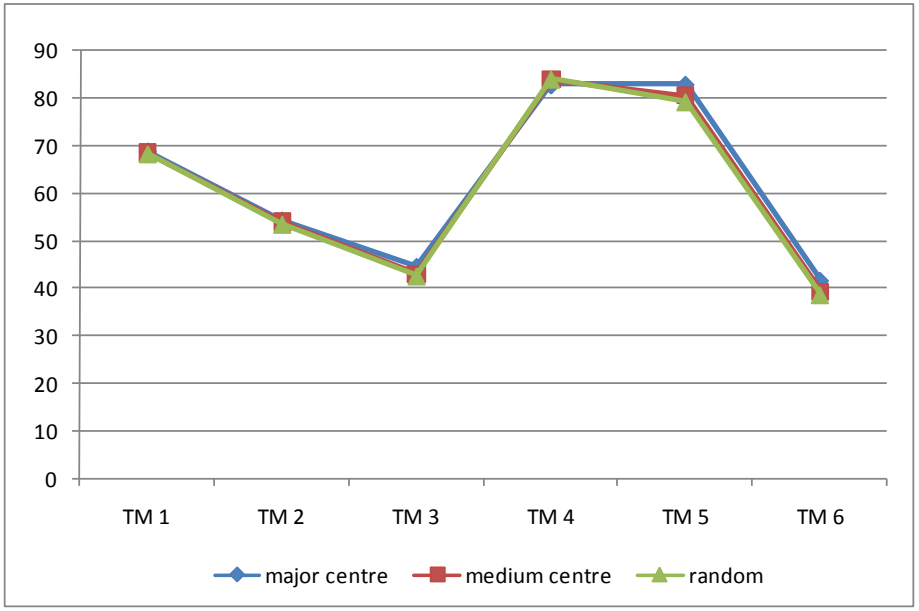


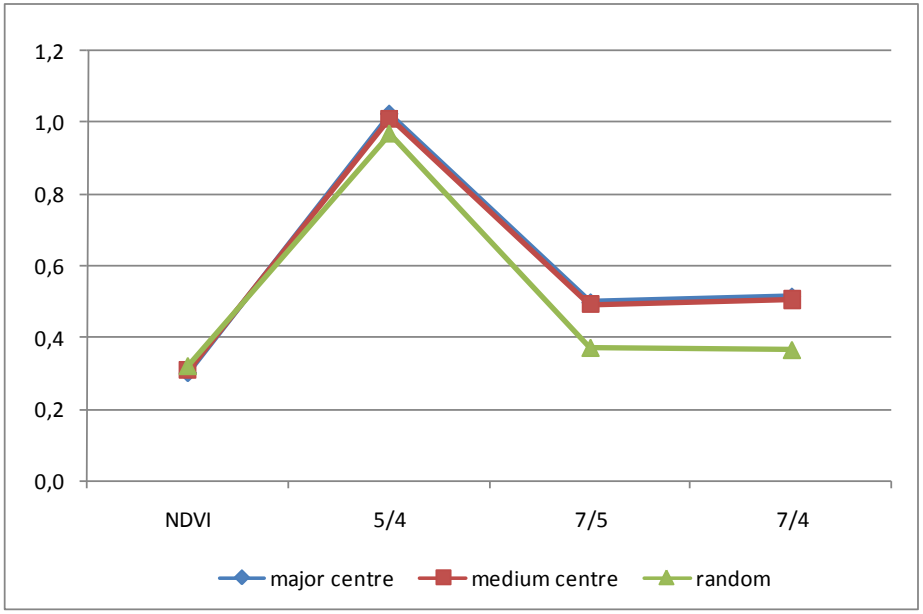
Aerial photography

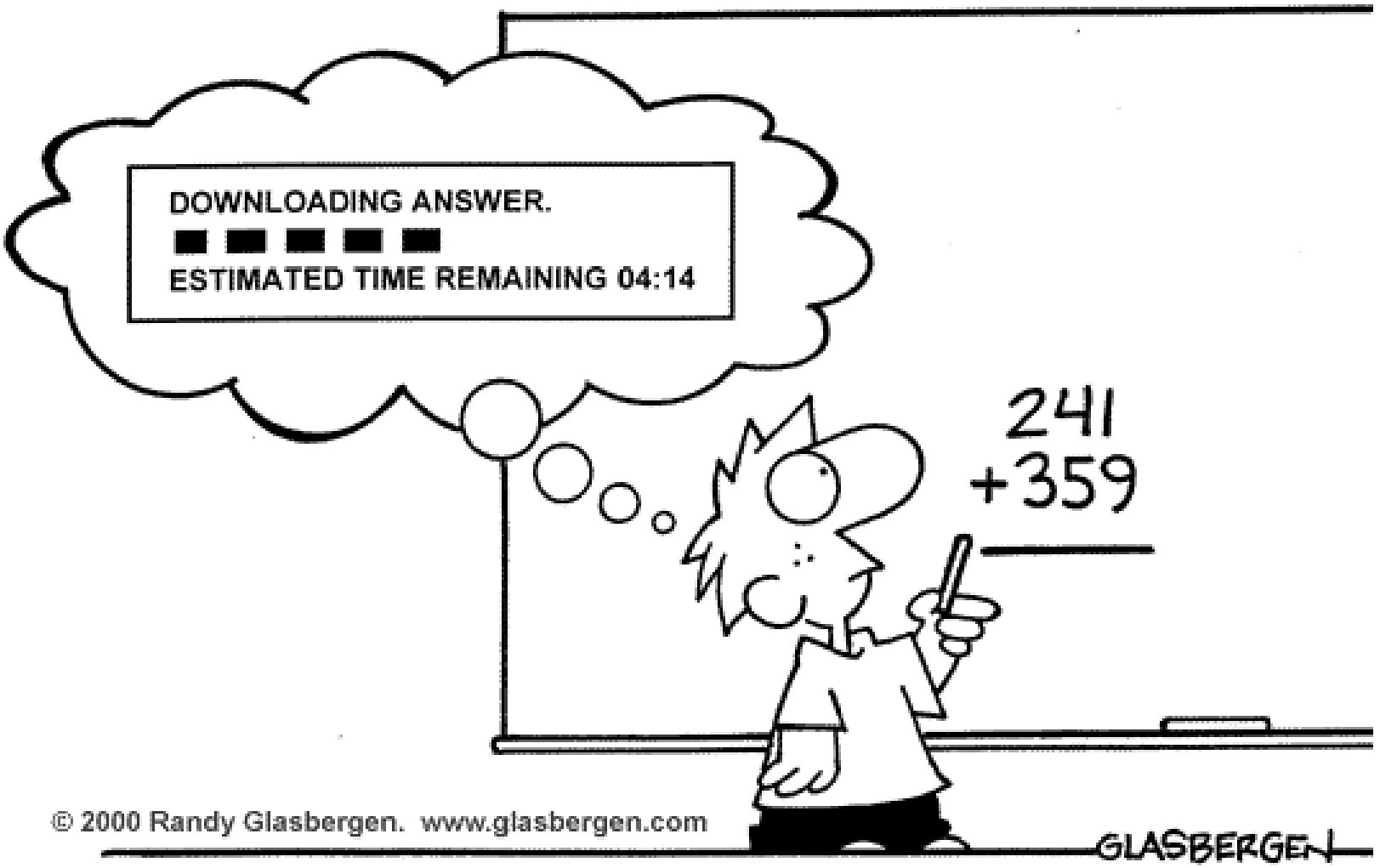
Radar imagery



Anomalies


90
80
70
60
50
40
30
20
10
0
TM 1
TM 2
TM 3
TM 4
TM 5
TM 6
major centre
medium centre
random


1,2
1,0
0,8
0,6
0,4
0,2
0,0
NDVI
5/4
7/5
7/4
major centre
medium centre
random

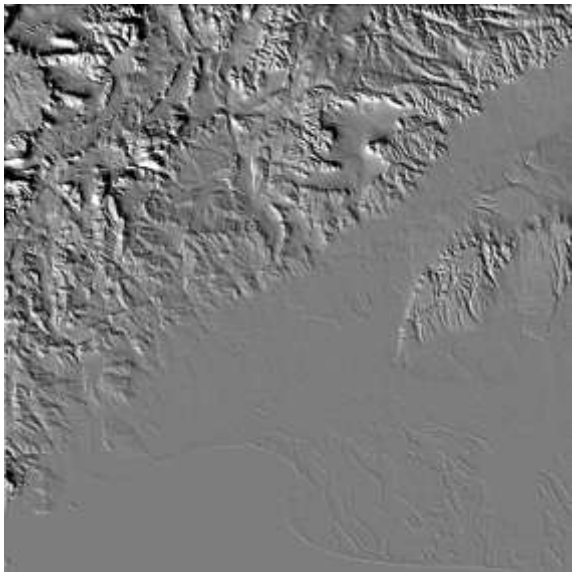

DOWNLOADING ANSWER.
ESTIMATED TIME REMAINING 04:14
241
+359
© 2000 Randy Glasbergen. www.glasbergen.com
GLASBERGEN

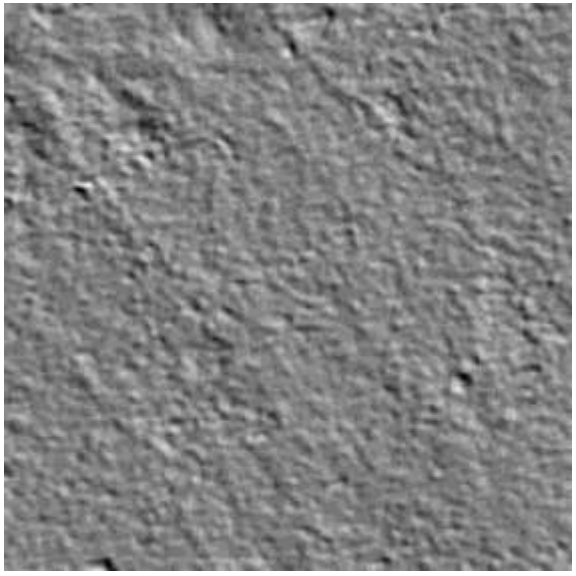
Languedoc, France

- It is not possible to observe paleorelief directly
- Indicators can be found
- Digital elevation model
  - shades
  - edges
- Satellite imagery
  - Landsat
    - edges
    - humidity
    - vegetation
  - SPOT
- Manual feature digitalization and cleaning

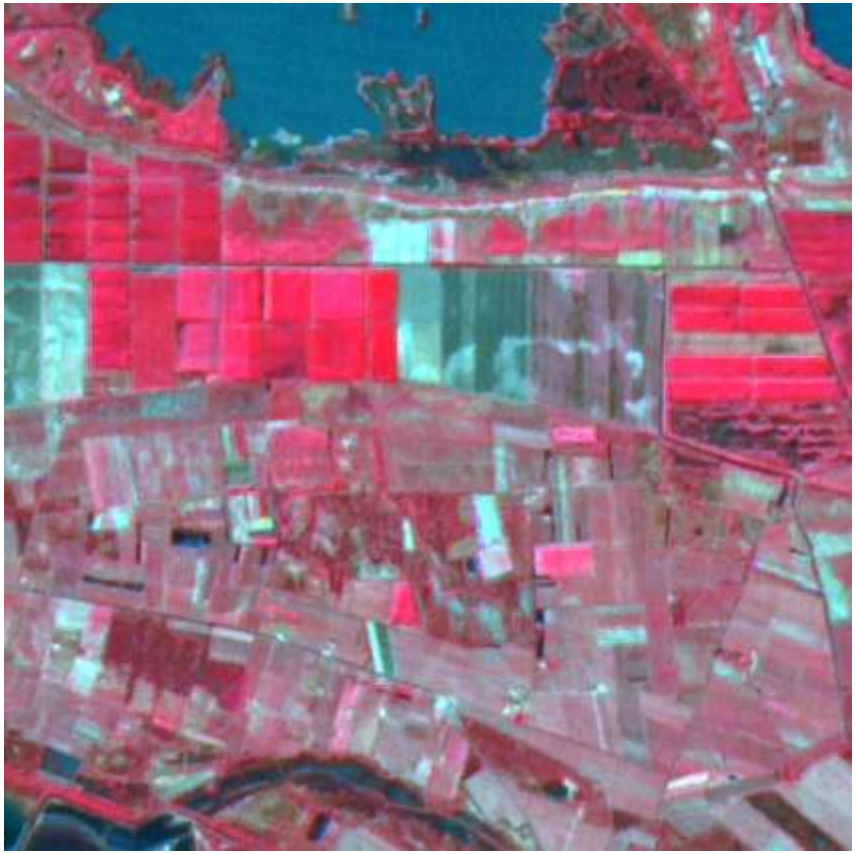
Digital elevation model

- Weighted sum of all available DEMs
  - IGN DEM – 50 m
  - Aster DEM – 30 m
  - SRTM DEM – 90 m
  - InSAR DEM – 25 m
- Resolution of 25 m
- 110 control points
  - Average difference -0.2 m
  - Standard deviation 3.7 m

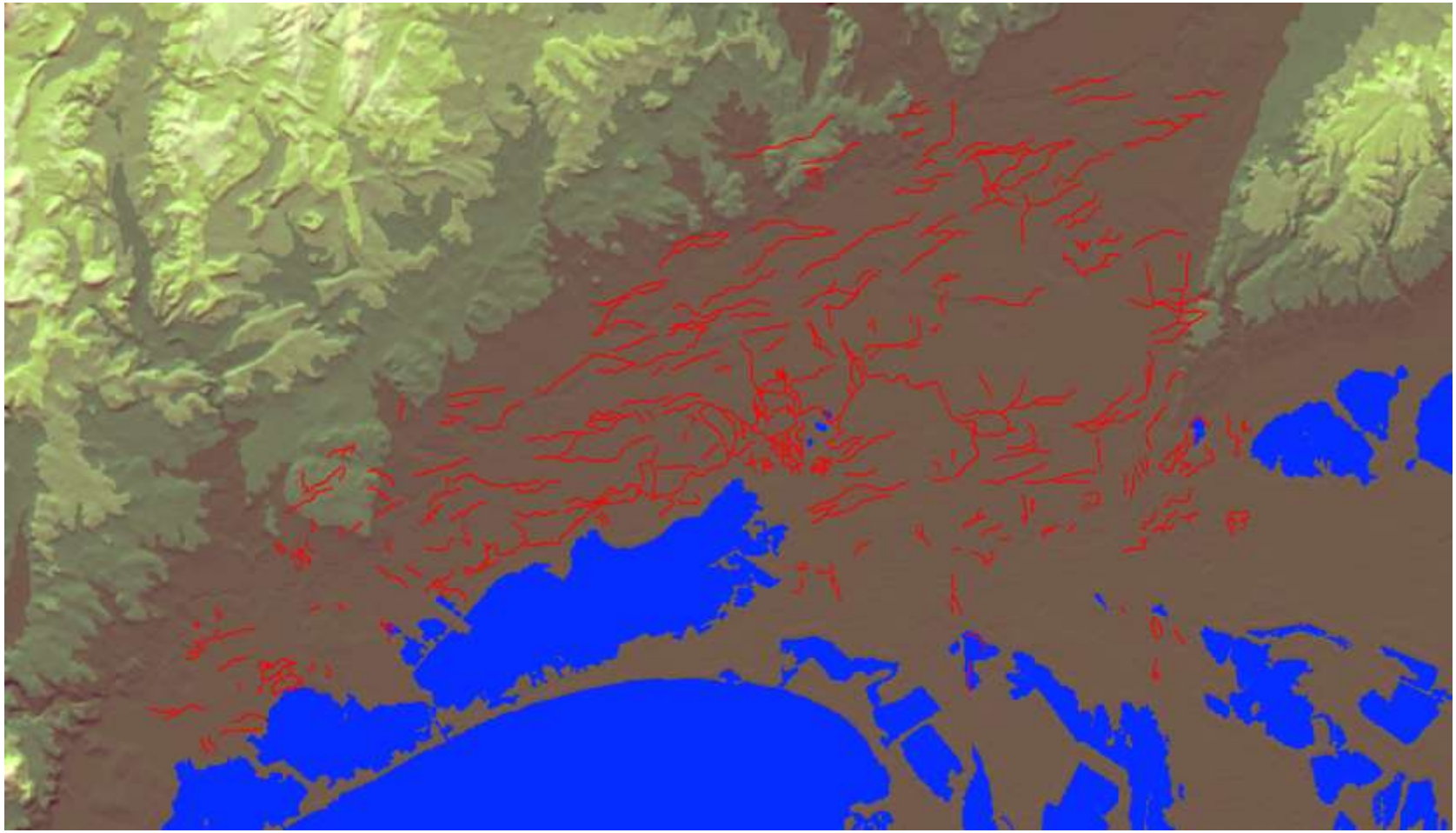




Satellite image processing

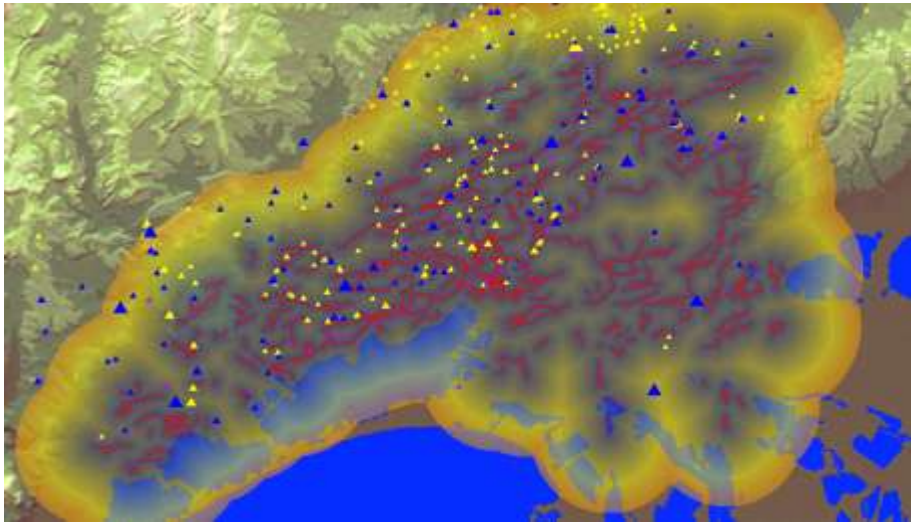


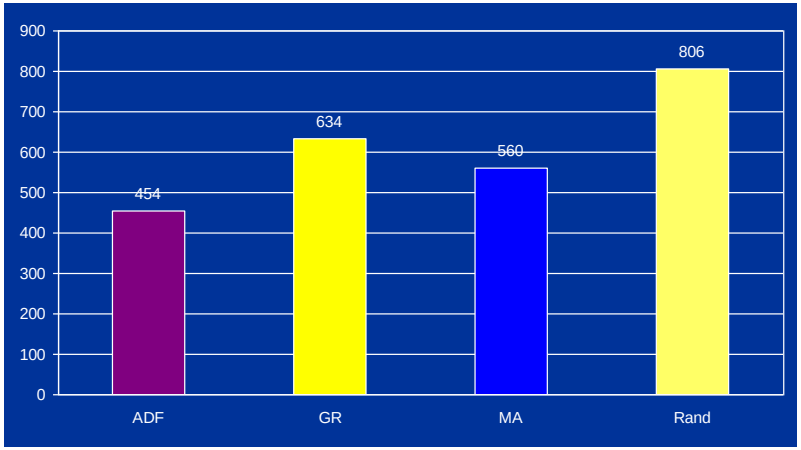
Paleo features

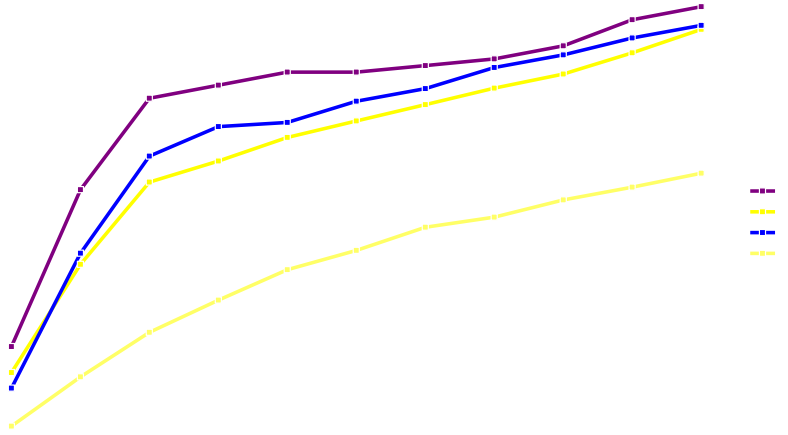


Features and archaeology

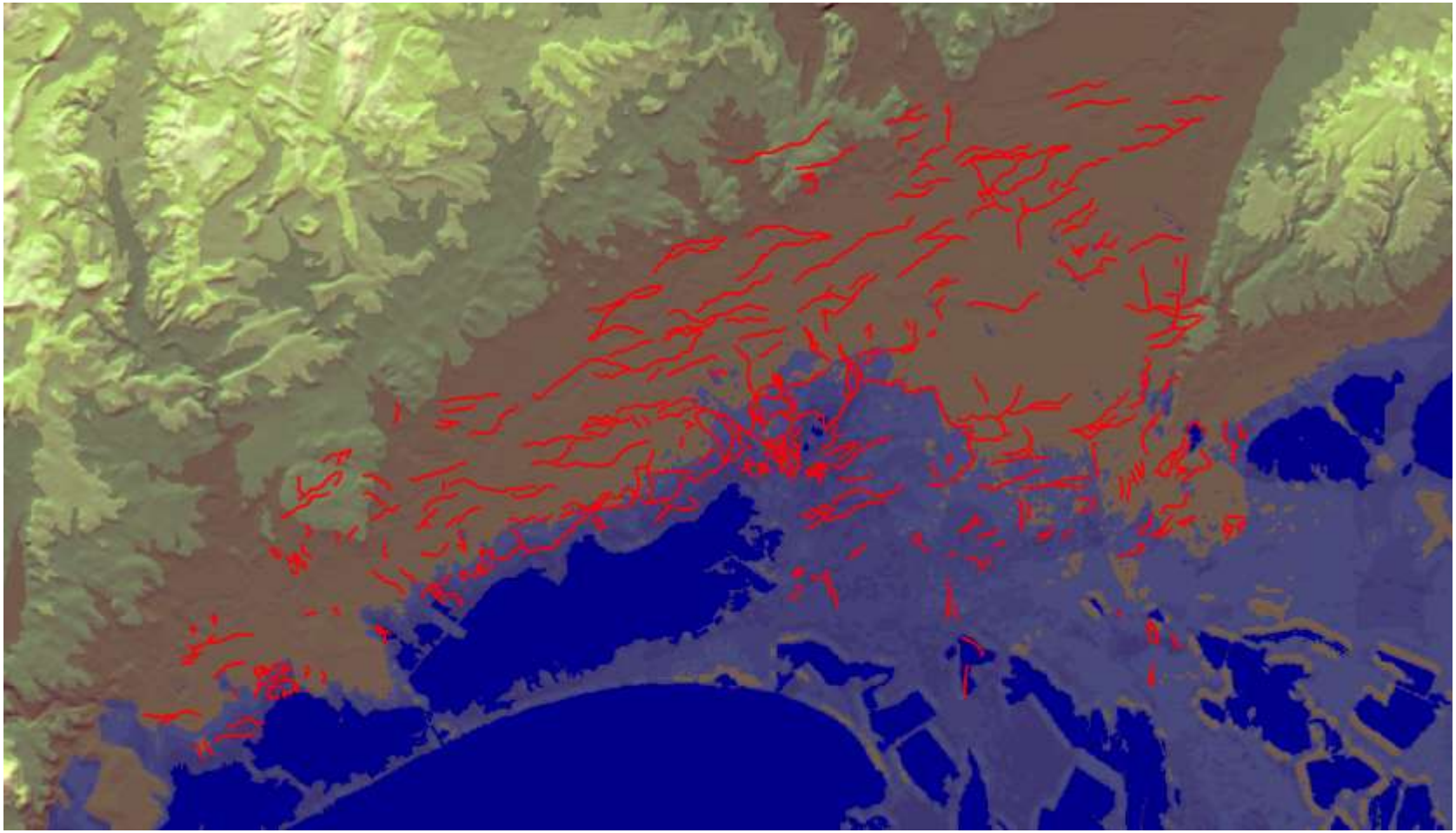
- Feature buffer zones
- Site proximity analysis
  - Prehistory
  - Roman period
  - Medieval period
- Comparison with random point distribution

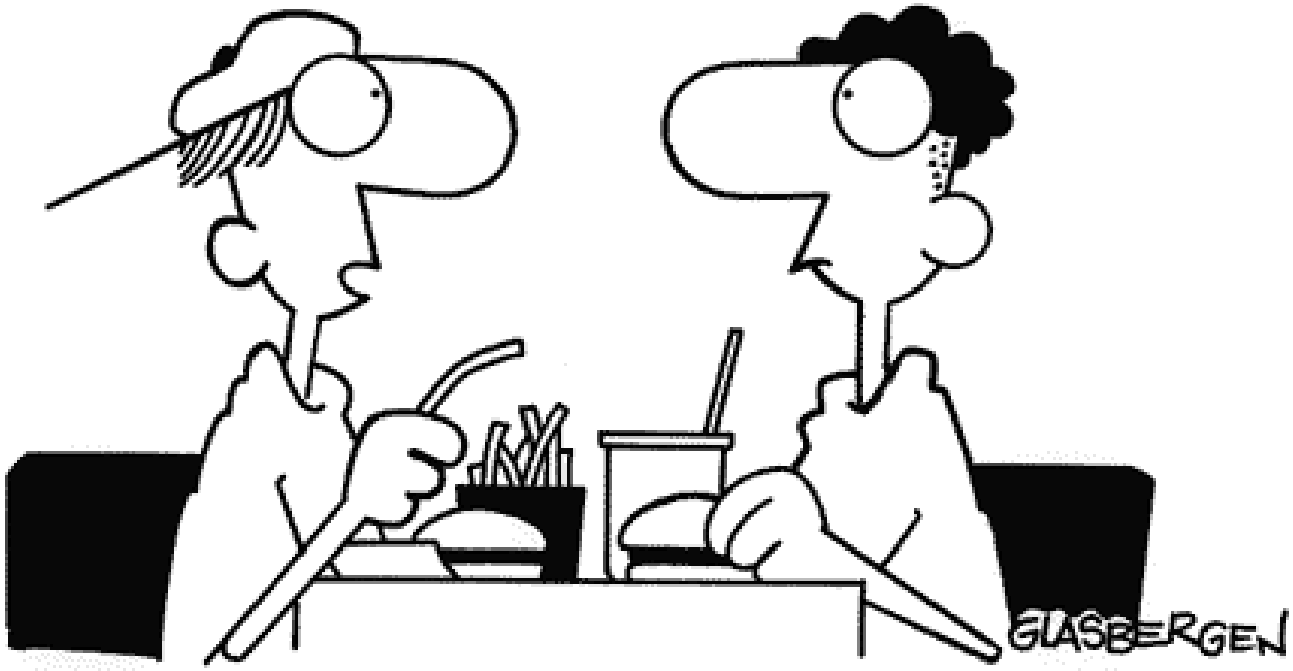






Sea level simulation





"I forgot to make a back-up copy of my brain, so everything I learned last semester was lost."