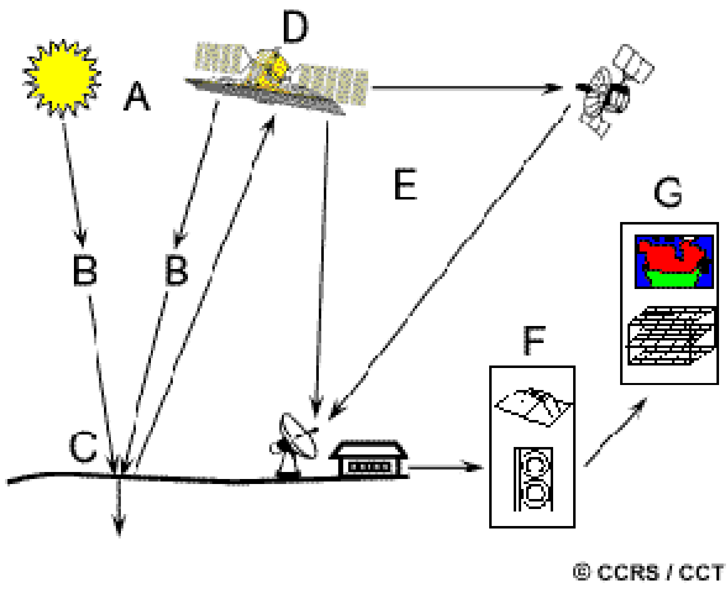
Earth Observation Laboratory
PhD Program in GeoInformation
DISP - Tor Vergata University

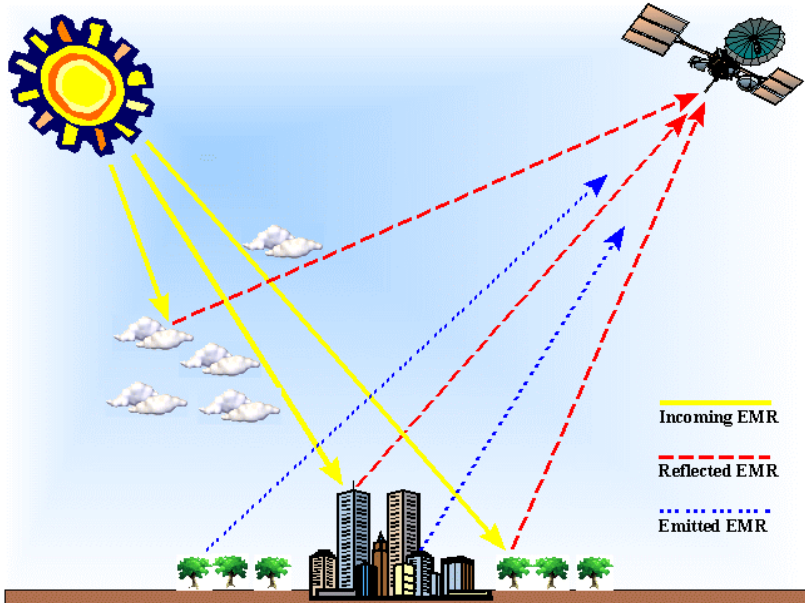
Optical multi-spectral images: processing and applications

Riccardo Duca

The last time

- What means “Optical Remote Sensing”
- The history of a success: from Bievre Valley to the entire World
- The electromagnetic spectrum





- Some applications
- The optical measurement and the signal components

The last time

- Spatial features discrimination

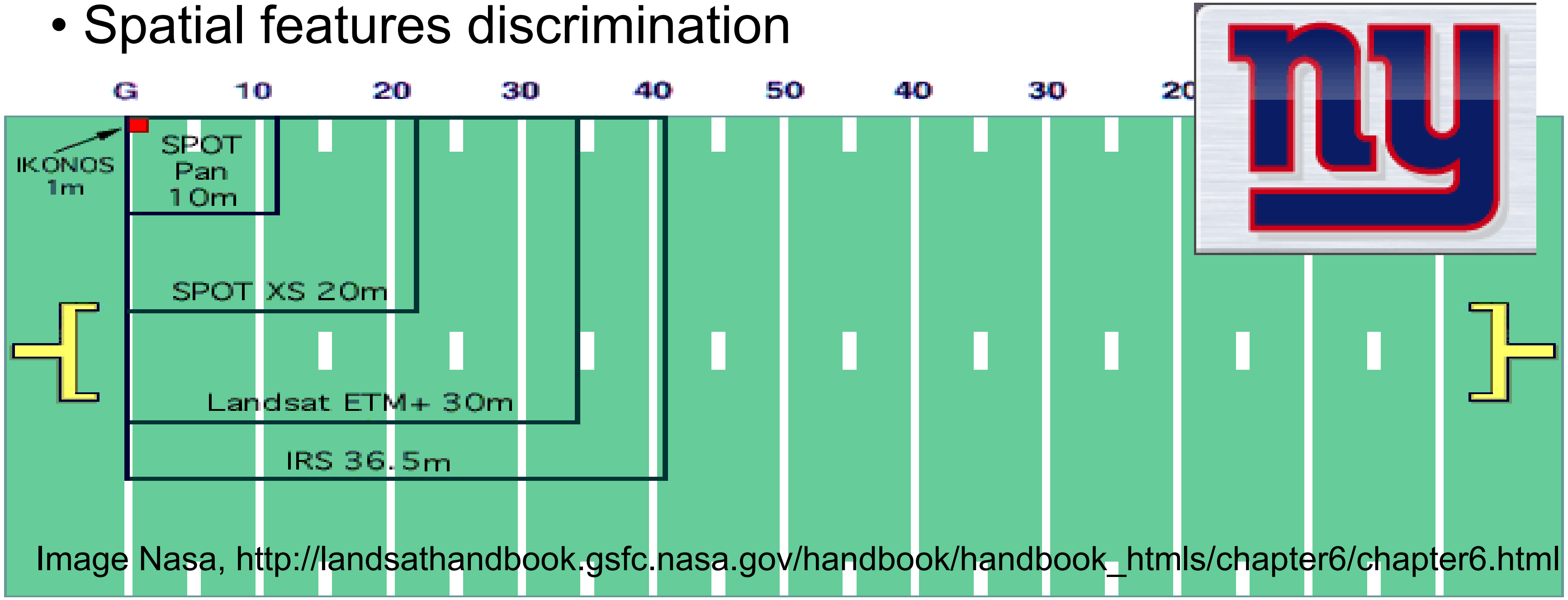


Image Nasa, http://landsathandbook.gsfc.nasa.gov/handbook/handbook_htmls/chapter6/chapter6.html

- Radiometric resolution
- The spectral resolution: from panchromatic to hyperspectral
- The evolution of optical sensors:
    - Very high resolution multi-spectral
    - High/medium resolution multi-spectral
    - High/medium resolution hyperspectral
    - Multi-spectral wide swath for global coverage

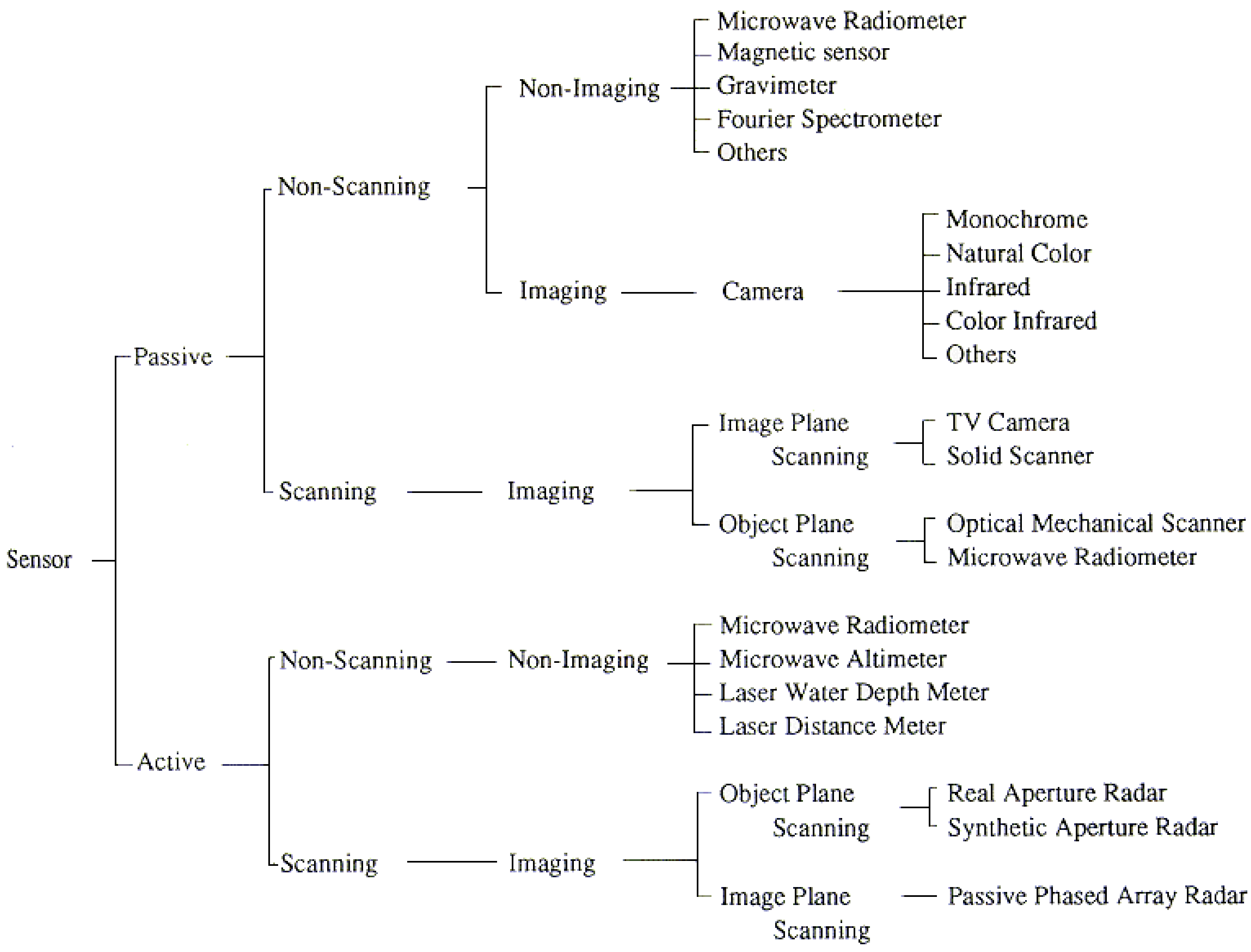


Figure 2.1.1 Classification of Sensor

And today…

Wiskbroom and pushbroom instruments

From the acquisition to the radiance

- Data reformatting and geometric correction
- Conversion to radiance
- Correction of radiometric artifacts: destriping

From the radiance to the surfaces reflectance

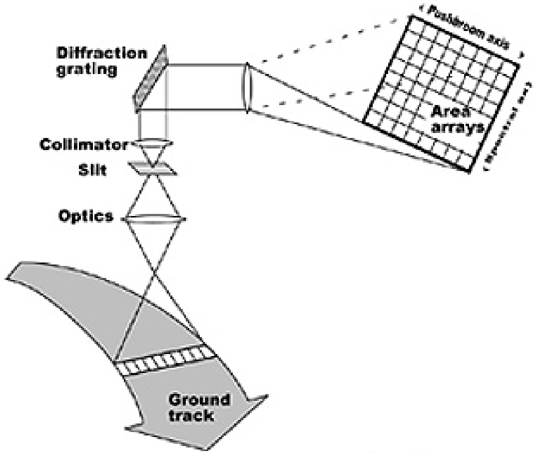
- The effects of the atmosphere
- Atmospheric correction and reflectance calculation
- Reflectance of surfaces

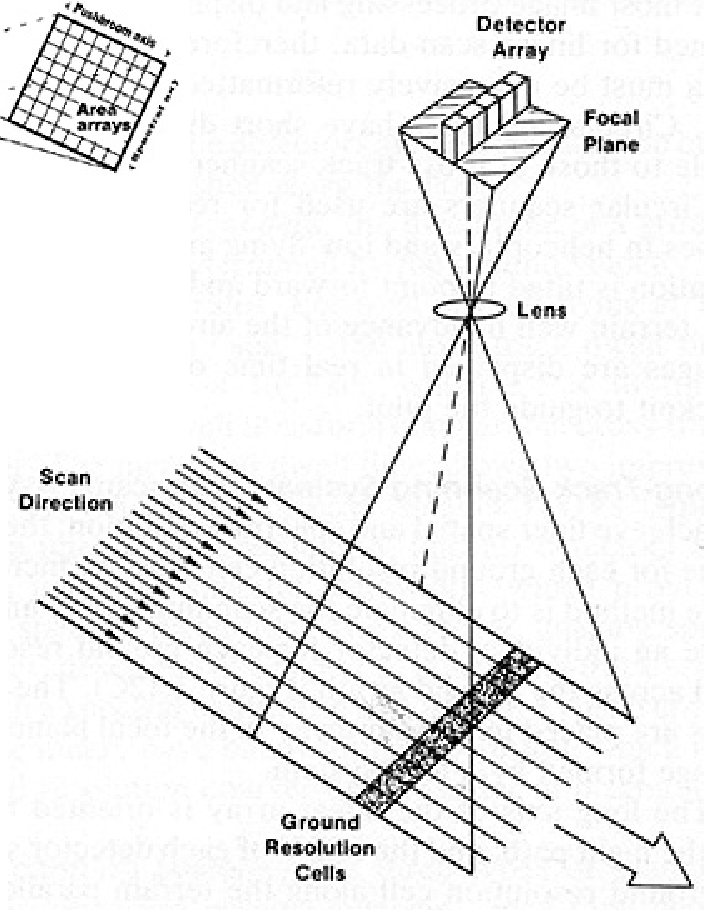
Applications

- Classification: basic concepts, techniques and examples
- Vegetation indexes: why, technique, examples

Pushbroom or along track sensors

The sensor is composed by lines of detectors oriented normal to the flight path. The scene is scanned by the lines while the spacecraft advances following its orbit



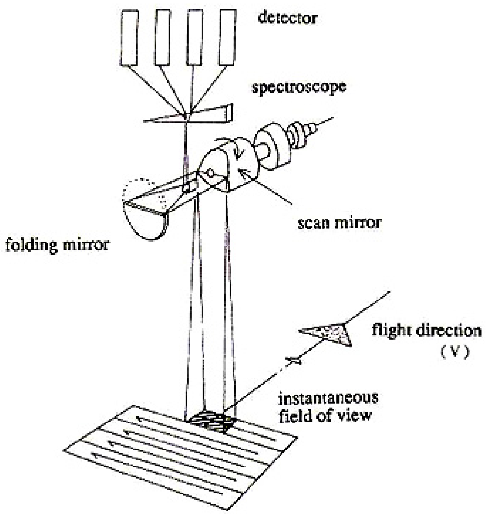


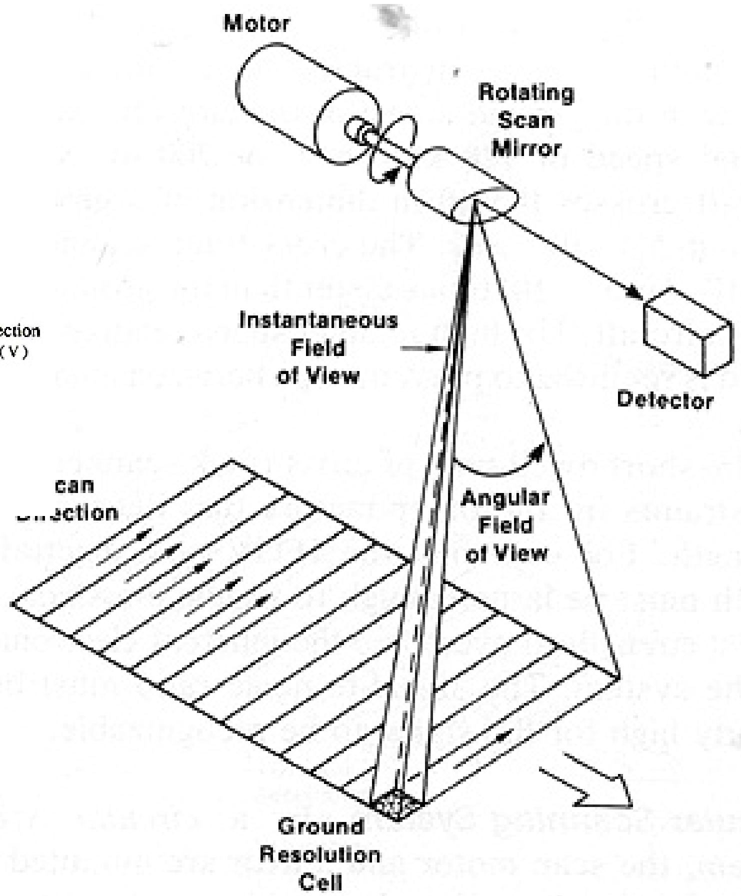
C. ALONG–TRACK SCANNER.

For each spectral band corresponds a line of detectors

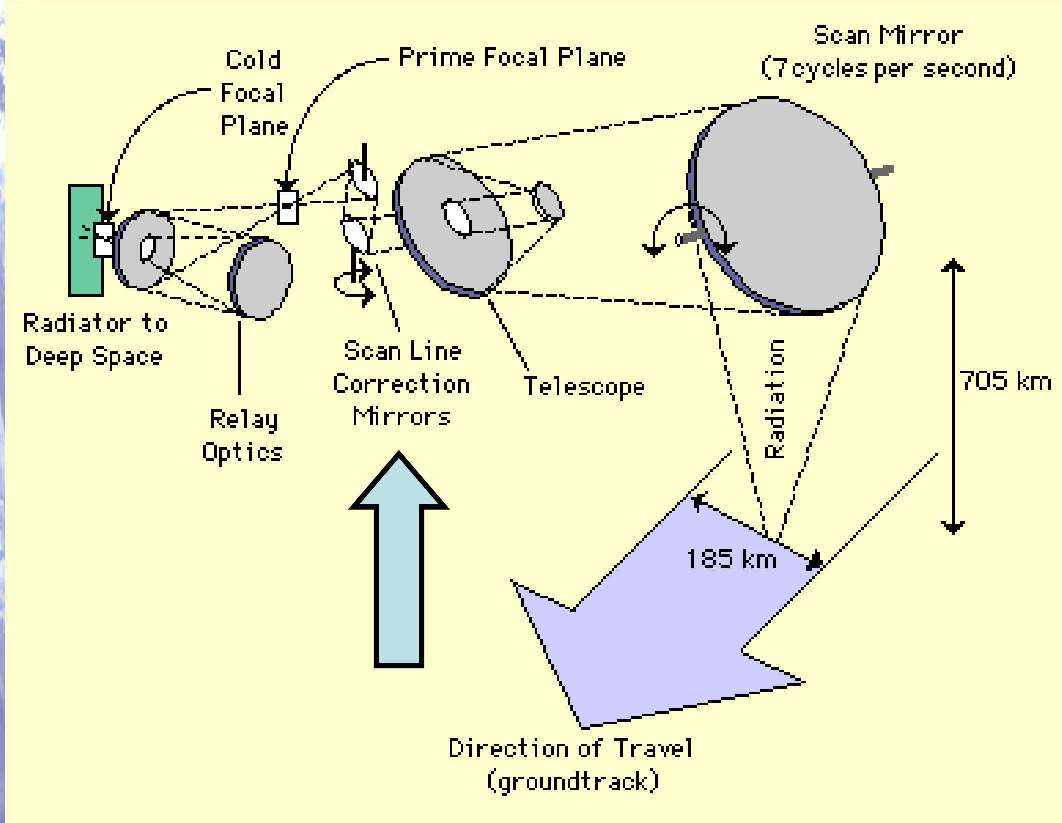
Wiskbroom or across track sensors

The radiance is addressed toward a small line of detectors by a rotating mirror which sweeps the scene along the line trasversing to the orbit direction

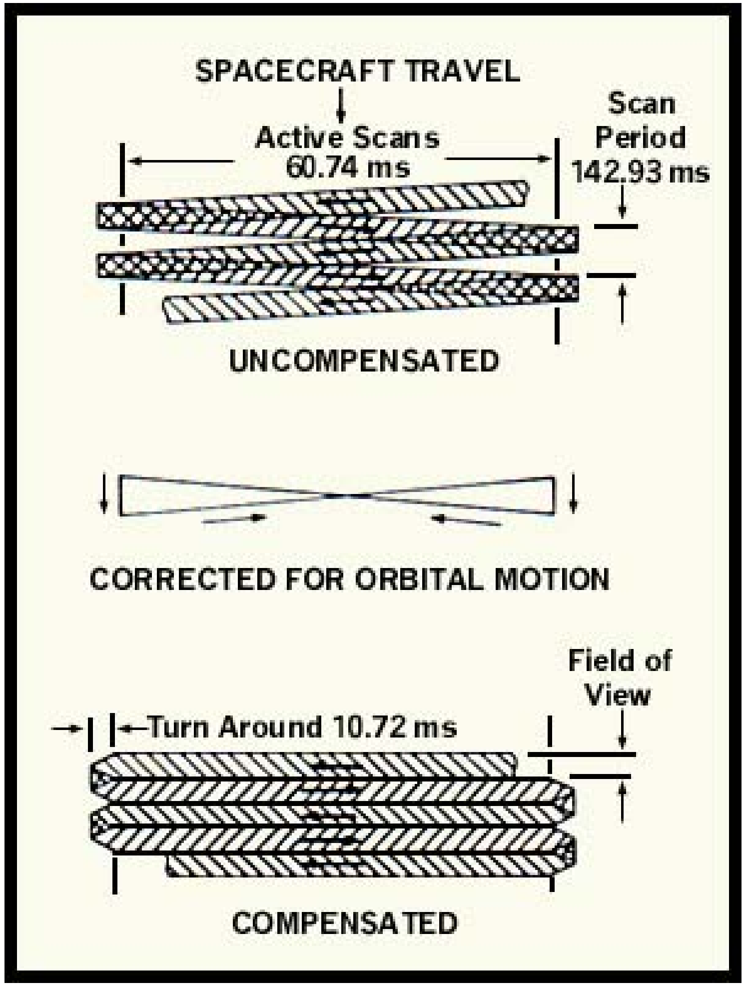




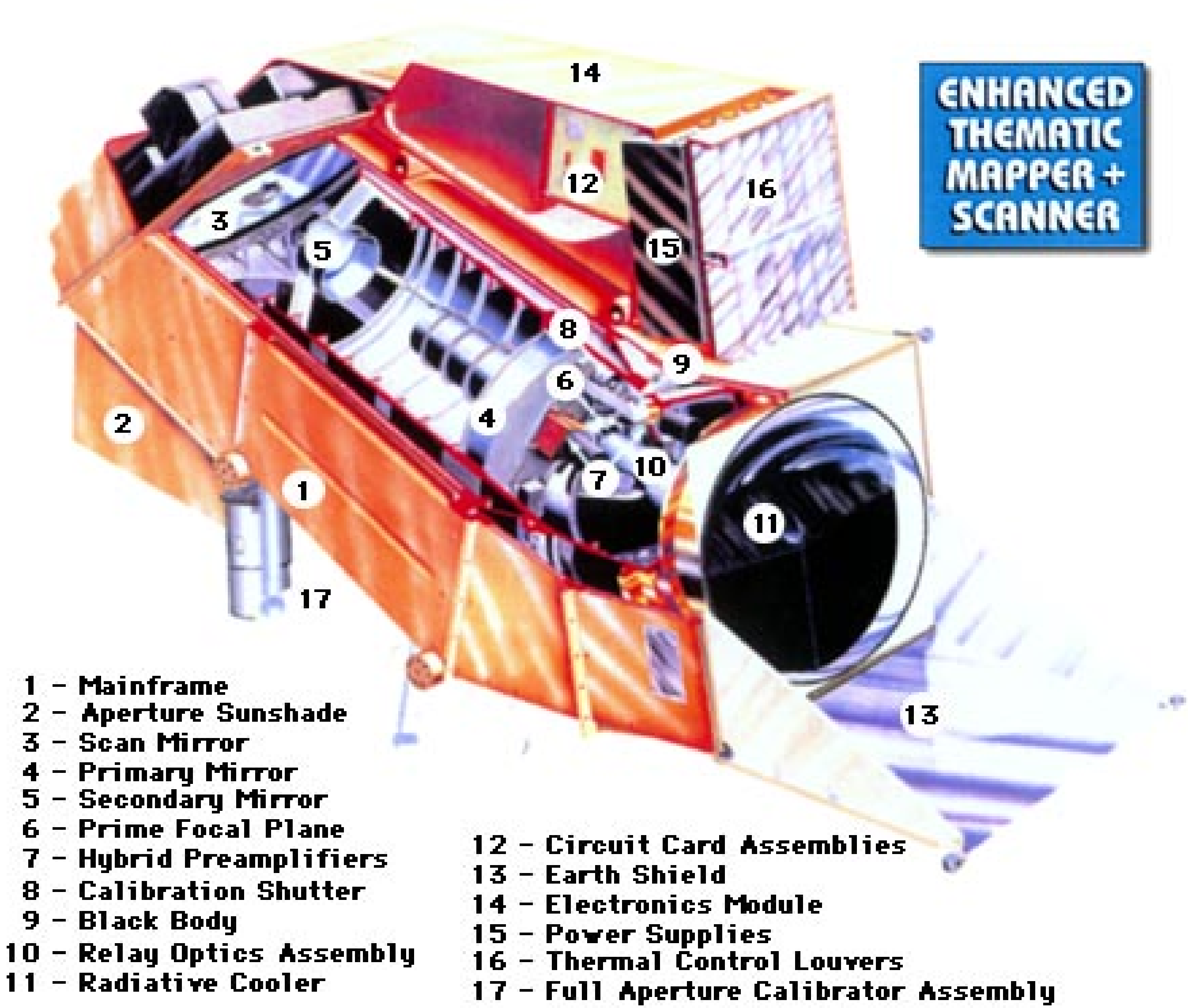
A. CROSS–TRACK SCANNER.



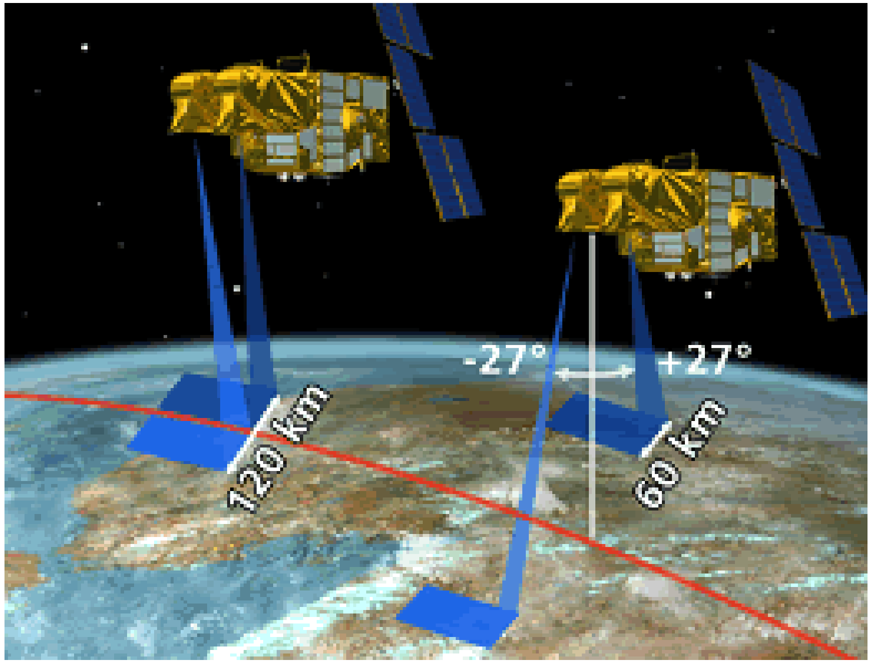
Cold
Focal
Plane
Prime Focal Plane
Scan Mirror
(7 cycles per second)
Radiator to
Deep Space
Relay
Optics
Scan Line
Correction
Mirrors
Telescope
Radiation
705 km
185 km
Direction of Travel
(groundtrack)

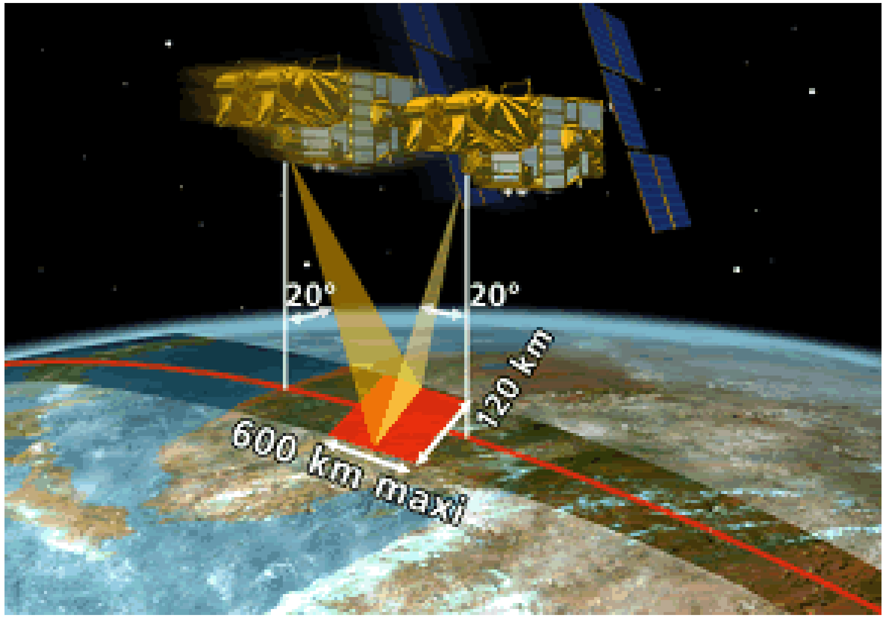


SPACECRAFT TRAVEL
Active Scans
60.74 ms
Scan
Period
142.93 ms
UNCOMPENSATED
CORRECTED FOR ORBITAL MOTION
Field of
View
Turn Around 10.72 ms
COMPENSATED


ENHANCED THEMATIC MAPPER + SCANNER
14
12
16
3
5
15
8
9
6
2
4
10
1
7
11
17
13
1 - Mainframe
2 - Aperture Sunshade
3 - Scan Mirror
4 - Primary Mirror
5 - Secondary Mirror
6 - Prime Focal Plane
7 - Hybrid Preamplifiers
8 - Calibration Shutter
9 - Black Body
10 - Relay Optics Assembly
11 - Radiative Cooler
12 - Circuit Card Assemblies
13 - Earth Shield
14 - Electronics Module
15 - Power Supplies
16 - Thermal Control Louvers
17 - Full Aperture Calibrator Assembly

Spot5 HRG camera





Data reformatting and geometric correction

The data reformatting processing aims to organize the information coming from the detectors in order to reproduce the real scenario

Geometric correction is undertaken to avoid geometric distortions from a distorted image, and is achieved by establishing the relationship between the image coordinate system and the geographic coordinate system

ETM Reformatted

ETM Geometrically corrected

Conversion to radiance (i)

This step aims to calculated the physical radiances reaching the sensor starting from the digital numbers (DN) associated to the levels of signal captured by the electro/optic transducers

The formula used:

$$\mathbf{L_{\lambda} = Gain * DN + Bias}$$

Also expressed as

$$\mathbf{L\lambda = ((L_{MAX\lambda} - L_{MIN\lambda})/(DN_{MAX} - DN_{MIN})) * (DN - DN_{MIN}) + L_{MIN\lambda}}$$

$L_{MAX\lambda}$ corresponds to the max quantized DN (DN_{MAX})
$L_{MIN\lambda}$ corresponds to the min quantized DN (DN_{MIN})

Considering values at 8 bit:
$DN_{MAX} = 255$
$DN_{MIN} = 0$ or 1 (according to the considered standard)

Ditributed by NASA, http://landsathandbook.gsfc.nasa.gov

Conversion to radiance (ii)

Values calculates during the satellite life

Table 11.2 ETM+ Spectral Radiance Range
watts/(meter squared * ster * µm)

Band Number	Before July 1, 2000				After July 1, 2000			
	Low Gain		High Gain		Low Gain		High Gain	
	LMIN	LMAX	LMIN	LMAX	LMIN	LMAX	LMIN	LMAX
1	-6.2	297.5	-6.2	194.3	-6.2	293.7	-6.2	191.6
2	-6.0	303.4	-6.0	202.4	-6.4	300.9	-6.4	196.5
3	-4.5	235.5	-4.5	158.6	-5.0	234.4	-5.0	152.9
4	-4.5	235.0	-4.5	157.5	-5.1	241.1	-5.1	157.4
5	-1.0	47.70	-1.0	31.76	-1.0	47.57	-1.0	31.06
6	0.0	17.04	3.2	12.65	0.0	17.04	3.2	12.65
7	-0.35	16.60	-0.35	10.932	-0.35	16.54	-0.35	10.80
8	-5.0	244.00	-5.0	158.40	-4.7	243.1	-4.7	158.3

Ditributed by NASA, http://landsathandbook.gsfc.nasa.gov

Correction of radiometric artifacts: destriping

The stripes problem

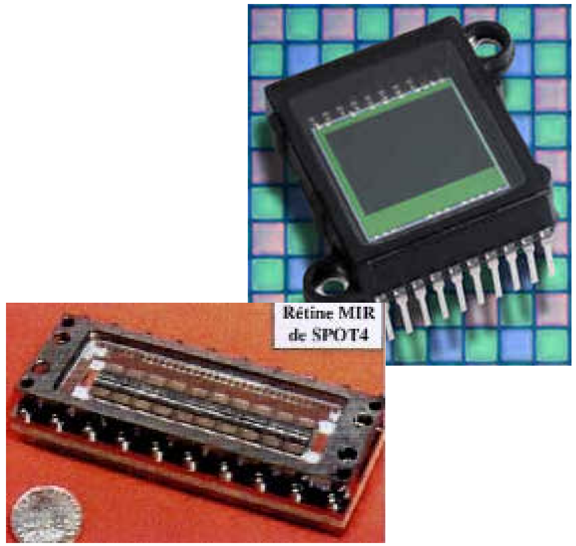
Its source can be traced to individual detectors that are miscalibrated with respect to one another. It means that illuminating the array with the same radiance, the transducers provide different quantized values

The application of the calibration coefficients (gain and bias) could in some cases delete this noise.

But in many cases an additional processing is required in order to compensate the residual stripes effect

Solution

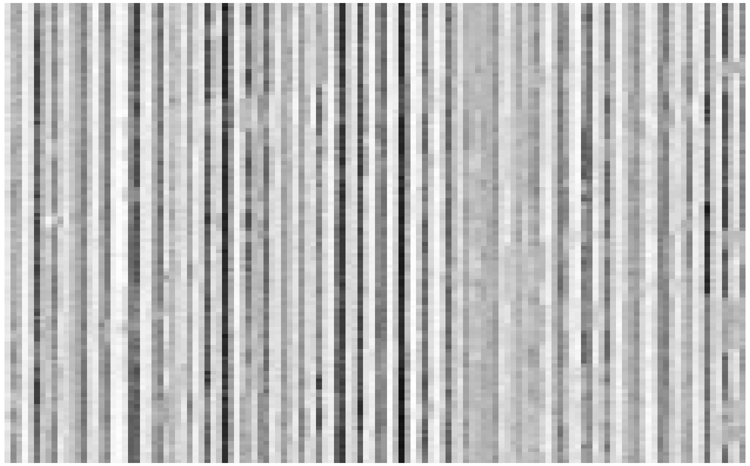
- Spatial filtering
- Histogram matching using the recalibration formula
- Advanced filtering



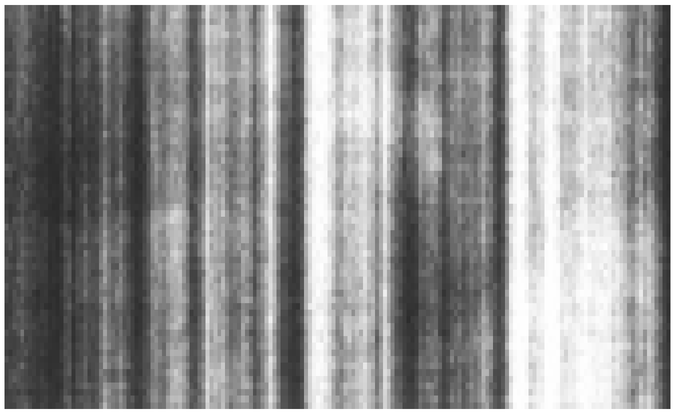
Some examples

More than 30 years of hard work against the stripes!

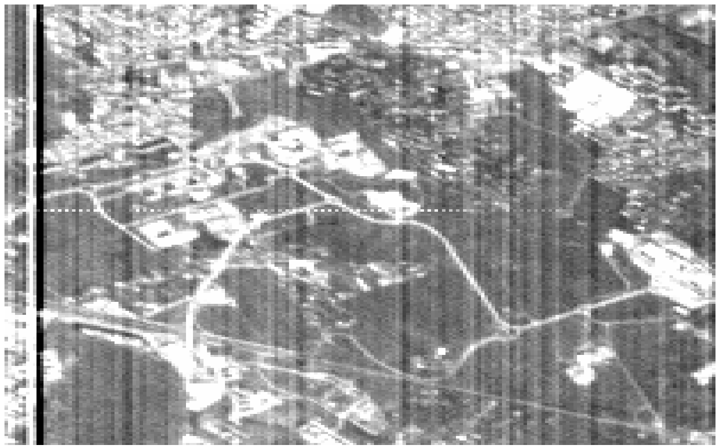
Landsat MSS



Hyperion band 1



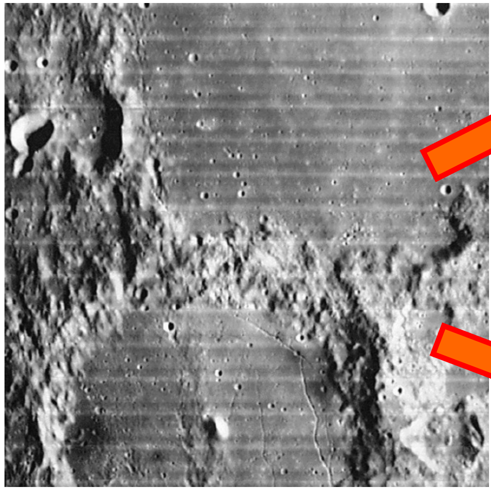
MOS-B band 12



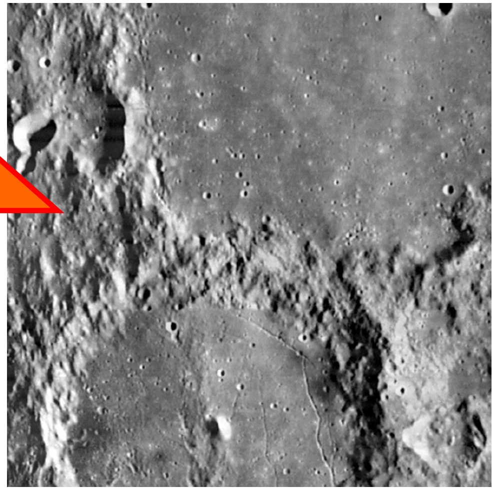
CHRIS band 1

Destriping using spatial filters

Low pass filter
Very wide
Not very tall



+



High pass filter
Very wide
Very short

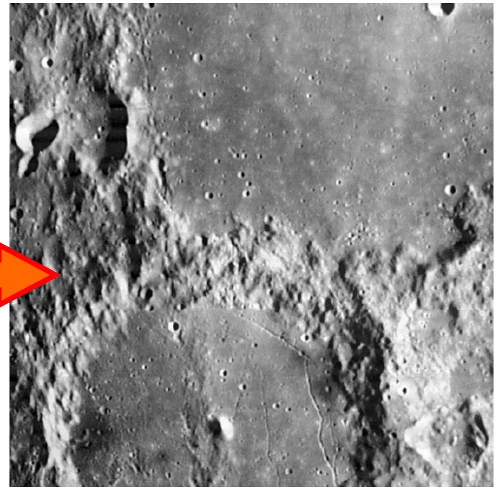


Immagine combinata
Depurata da stripes

•http://isis.astrogeology.usgs.gov/IsisWorkshop/Lessons/Destripe/

Destriping based on advanced filtering

Since two years also the Tor Vergata PhD Programme has given an important contribution to the solution for the stripes noise

A tool to destripe the optical images of CHRIS Proba-1 has been developed and tested in several cases

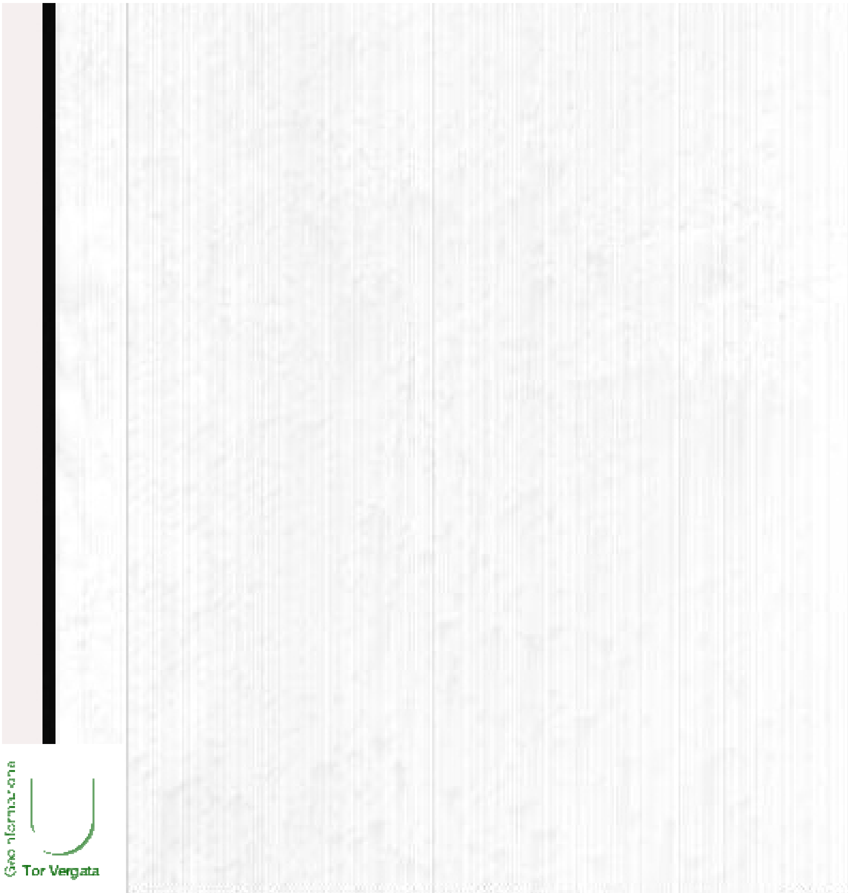
The algorithm is based on the low pass filtering in the spatial frequency domain.

PRINCIPAL STEPS:

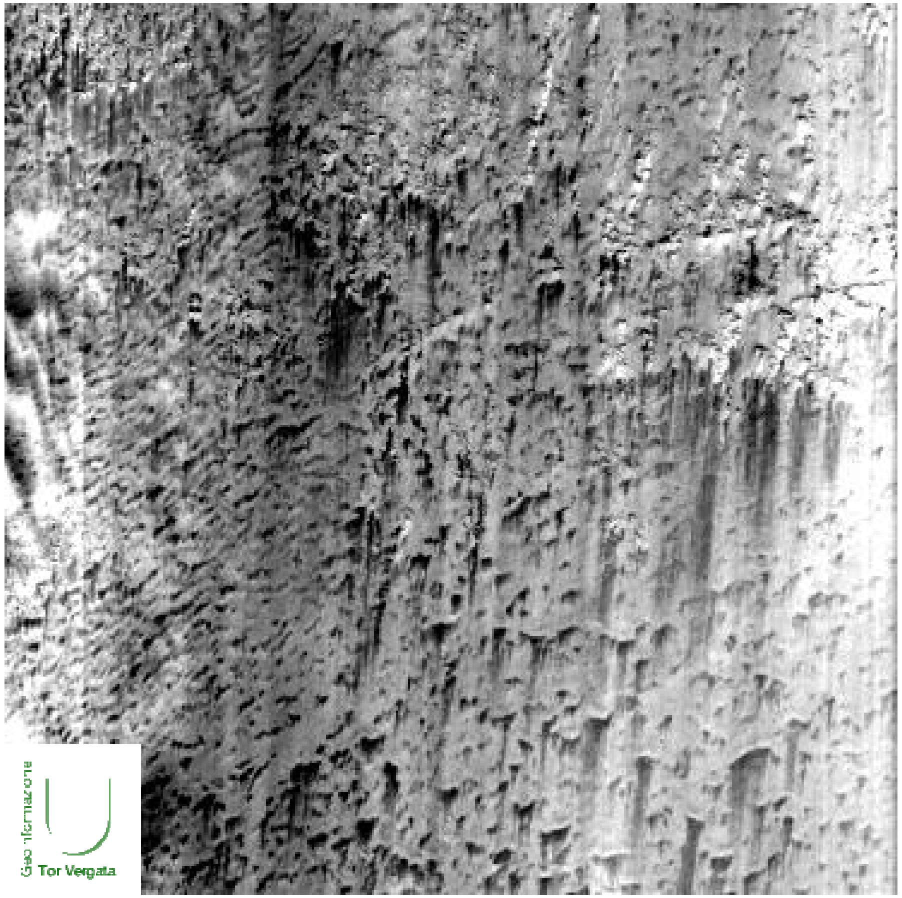
- Calculation of the radiance average of each column (each detector)
- FFT over the averages
- Low-pass filtering step
- Estimation of the parameters for the equalization
- Correction

Examples of correction

Lybian desert



Before destriping

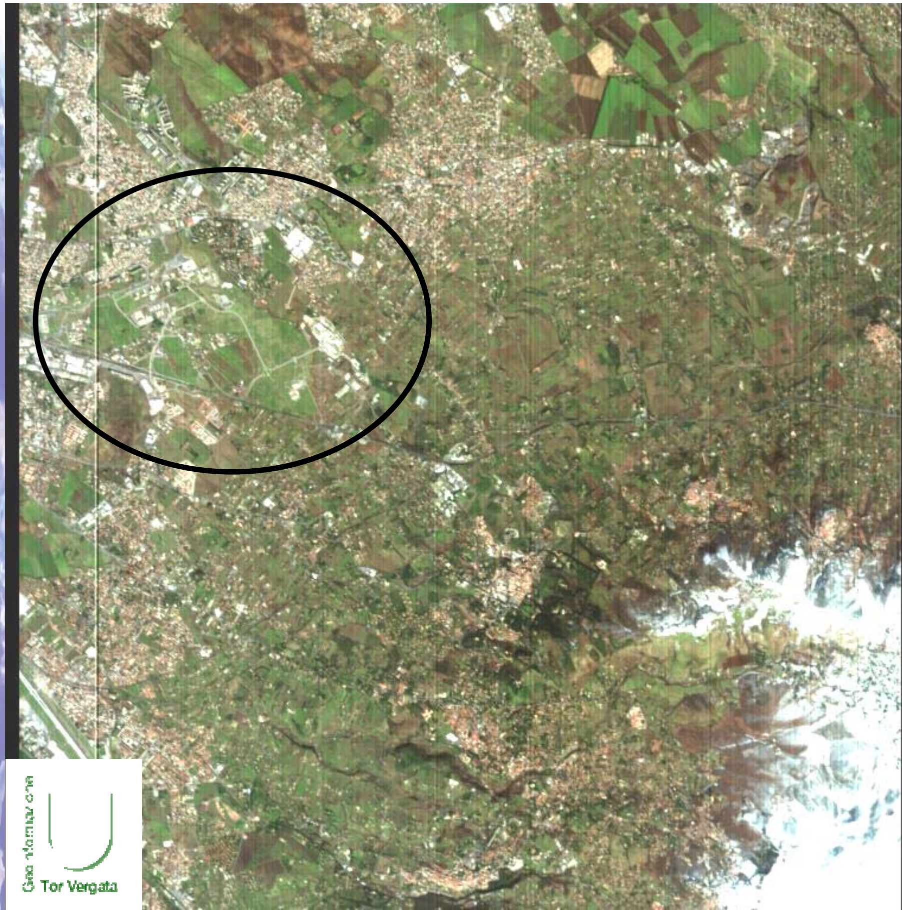


After destriping

Examples of correction

No more stripes in our campus

Frascati/Tor Vergata



Before destriping

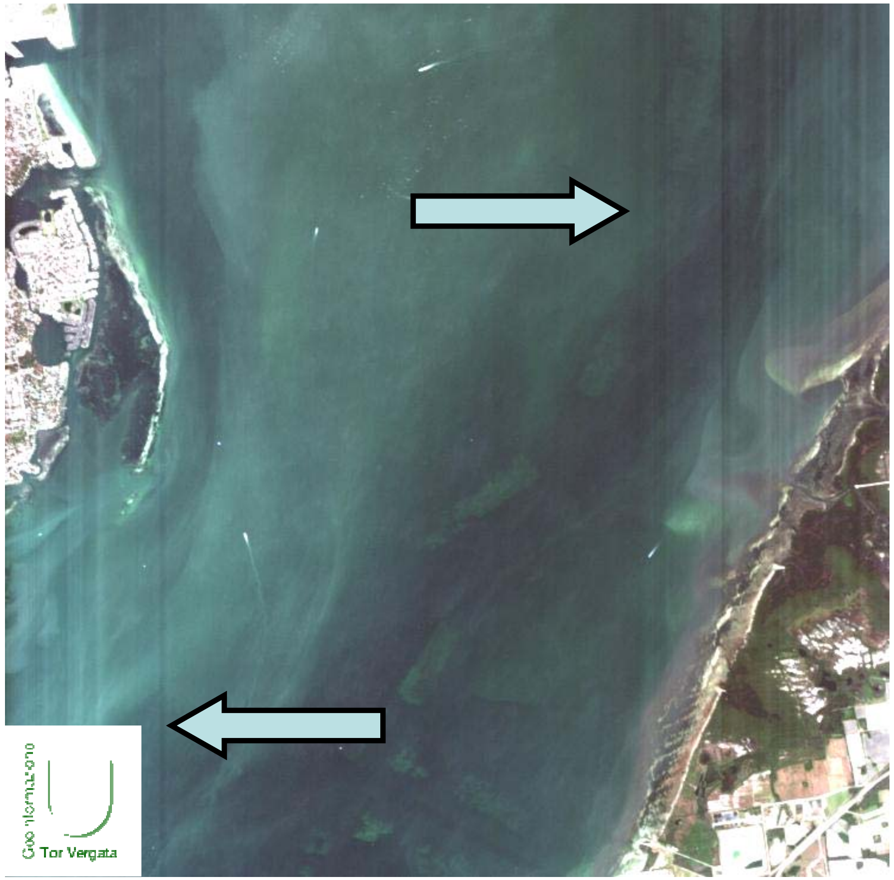
After destriping

Examples of correction

And also no more stripes in USA… but nor really…

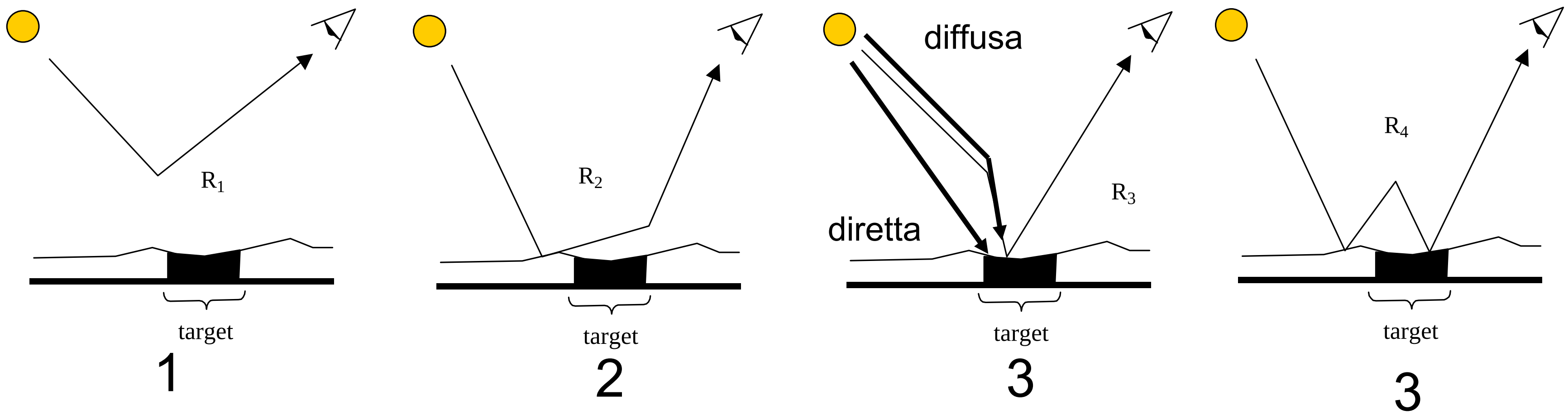
Tampa bay (USA)

Before destriping



After destriping

The components of the signal

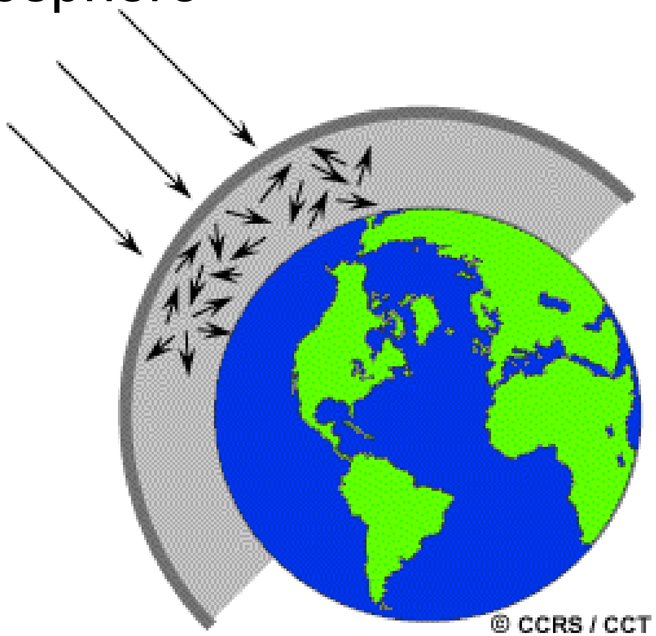


1. Radiance scattered by the atmosphere to the sensor
2. Radiance coming from adjacent targets
3. Radiance reflected by the target illuminated by direct + diffuse irradiance
4. Radiance reflected by the target illuminated by multiple scattering

THE ATMOSPHERE CONTRIBUTION PLAYS AN IMPORTANT ROLE IN THE RADIANCE CAPTURED BY THE SENSOR

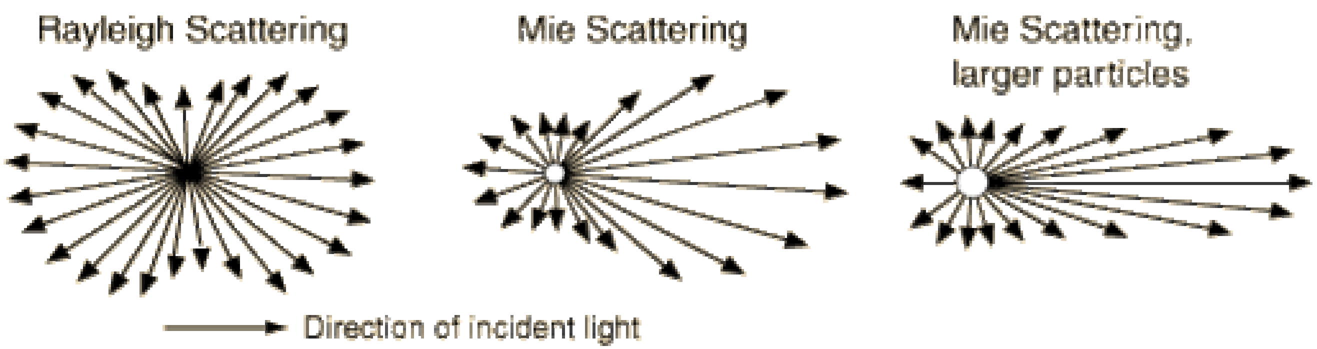
The atmospheric scattering

It is due to the gasses present in the atmosphere

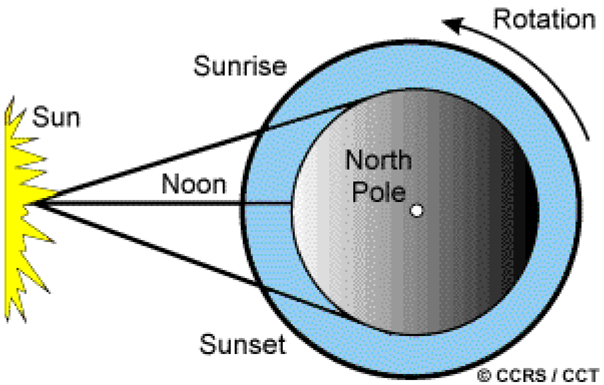


It depends by:
- λ of radiation
- amount and type of molecules of gas
- length of the path

1. Scattering of Rayleigh
2. Scattering of Mie
3. No selective



The Rayleigh scattering



Molecules << λ of radiation

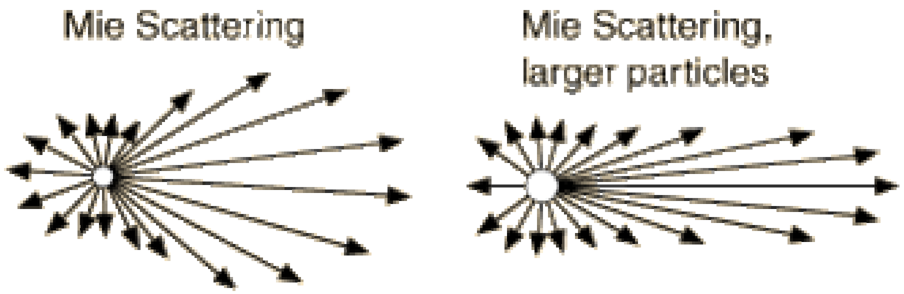
Presence of powder, N_2, O_2

It is prevalent for short λ and in the highest layers of the atmosphere

And more…

- It tends to decrease if λ increases, it is predominant in the blue with respect to the red λ
- During the day prevails in the blue visible
- During the sunset and the sunrise the blue is totally scattered, in fact the sky appears more yellow and red
- The presence of dust and powder can enhance the effect

Mie Scattering



Molecules $\underline{\approx}$ λ of radiation

Presence of powder and water vapor

It produce effects for larger λ with respect to the Rayleygh but it is less depended to the λ

It is present on the lowest part of the atmosphere

No selective

Molecules >> λ of radiation

Presence of large dust or powder, little drops of water

The scattering is the same for all λ

Presence of clouds, fog, large amounts of aerosols

White optical effects

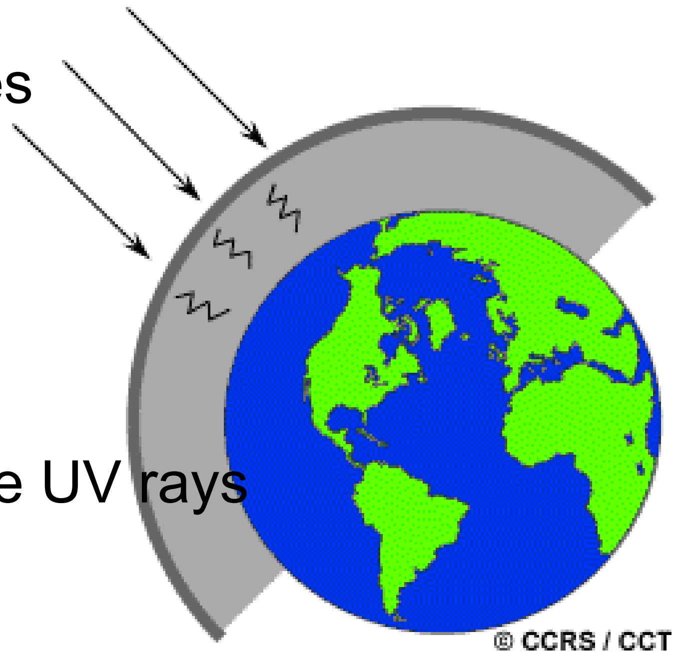
Atmospheric absorption

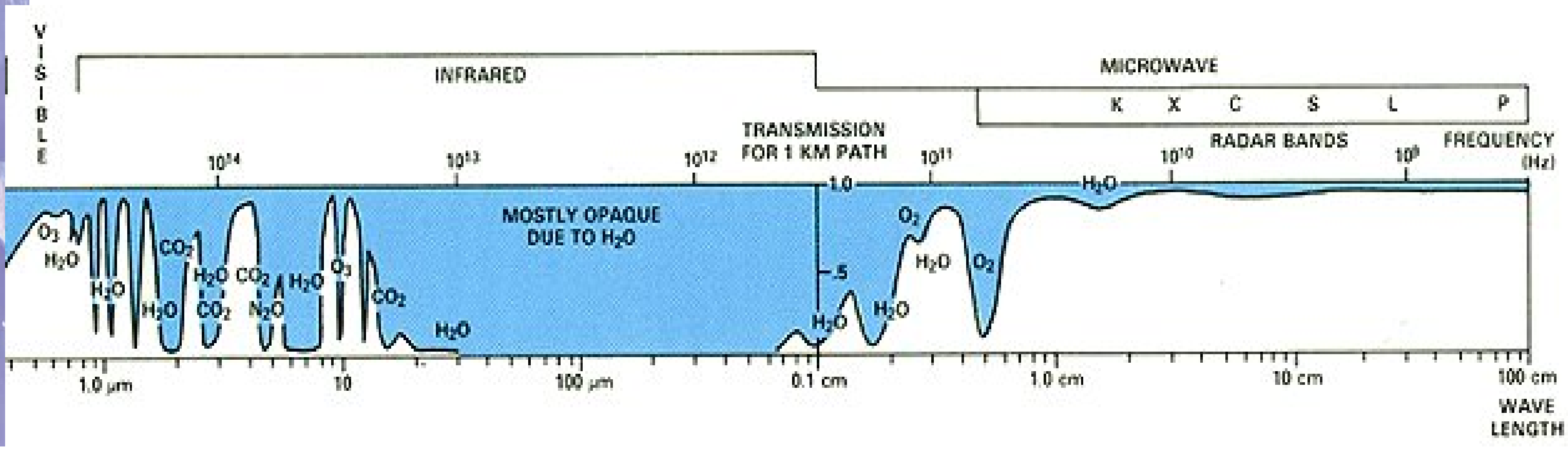
Photons absorbed by molecules of gasses

Strong dependence to the λ of radiation

Gasses like CO_2 and O_3

O3 absorbs for lower λ, for this reason the UV rays do not burn the human beings





Atmospheric correction: the problem

What does it do?

The goal of Atmospheric Correction is to completely remove the absorption and the scattering effects of the Earth's atmosphere to allow conversion of the image data to a primary physical parameters: reflectance.

$$L_{tot} = \cancel{L_{path}} + L_{target} + L_{adj}$$

But why more processing?

- Better discrimination of surfaces and materials
- Comparison among images of different dates and angles
- Vegetation indexes retrieval
- Comparison among spectral information coming from different sensors or ground instruments
- Fine classification

Atmospheric correction: the goal

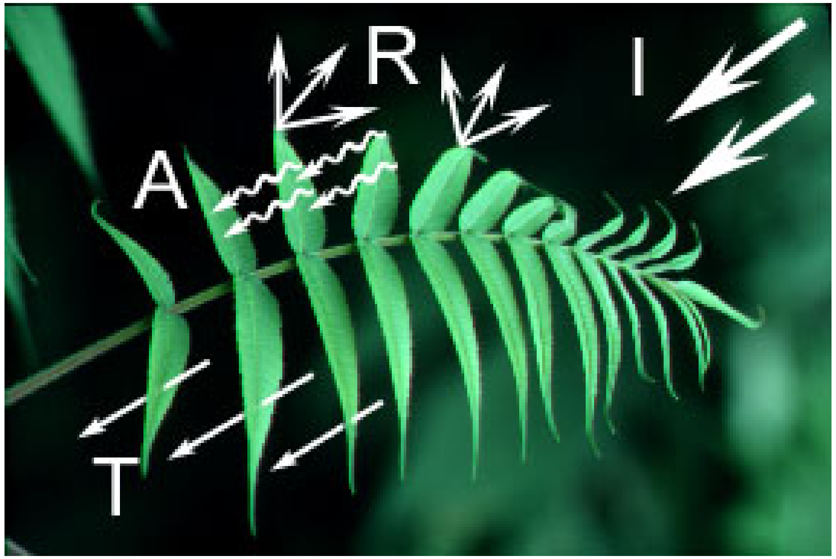
Our purpose is to compensate the atmospheric noise in order to calculate the reflectance

The flux of energy which illuminated a surface $\Phi(\lambda)$ Wμm-1 can be divided in three main components

$$\Phi(\lambda) = r\lambda + t\lambda + a\lambda \quad \Rightarrow \quad \alpha(\lambda) + \rho(\lambda) + \tau(\lambda) = 1$$

$r\,\lambda$ refelcted component
$t\lambda$ transmitted component
$a\lambda$ absorbed component

They depend on the physical and chemical properties of the target

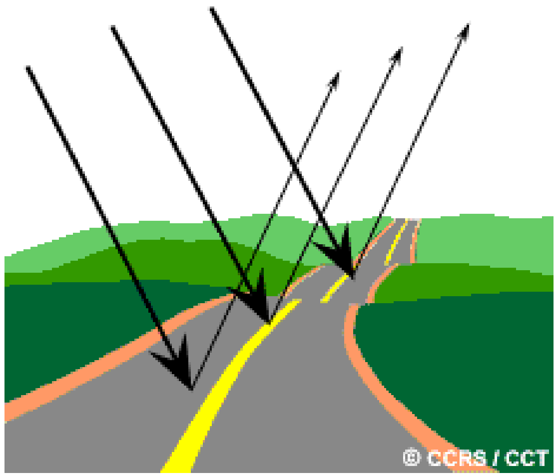


What is the reflectance?

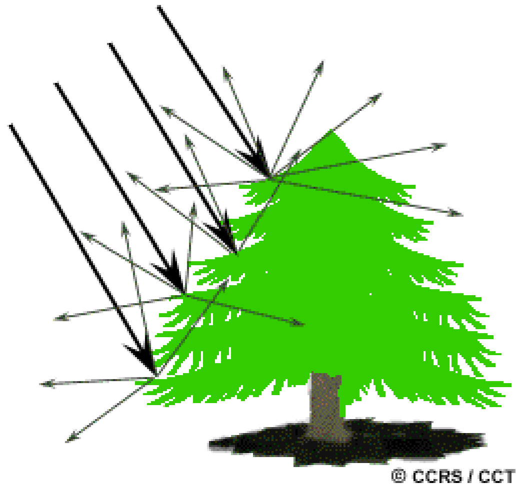
• It describes the reflective properties of target and surfaces in function of the λ
• It is indicated with a number between 0 and 1 or between 0% and 100%

SURFACES
Mirror like: energy in the angle of illumination = energy in the angle of reflection

Perfect diffusive: energy measured under every angle of view does not change



SUPERFICI
NATURALI



Surfaces

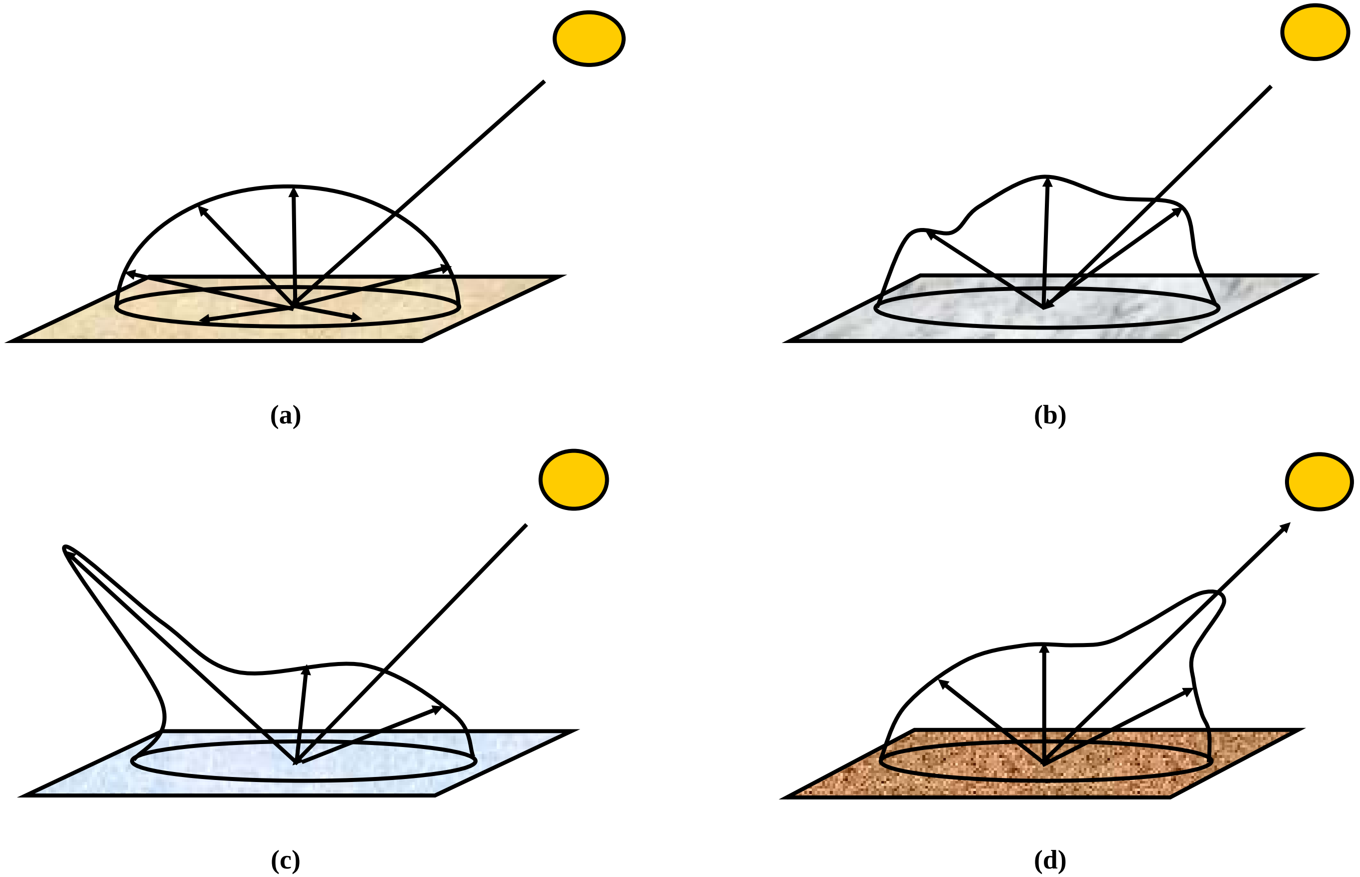
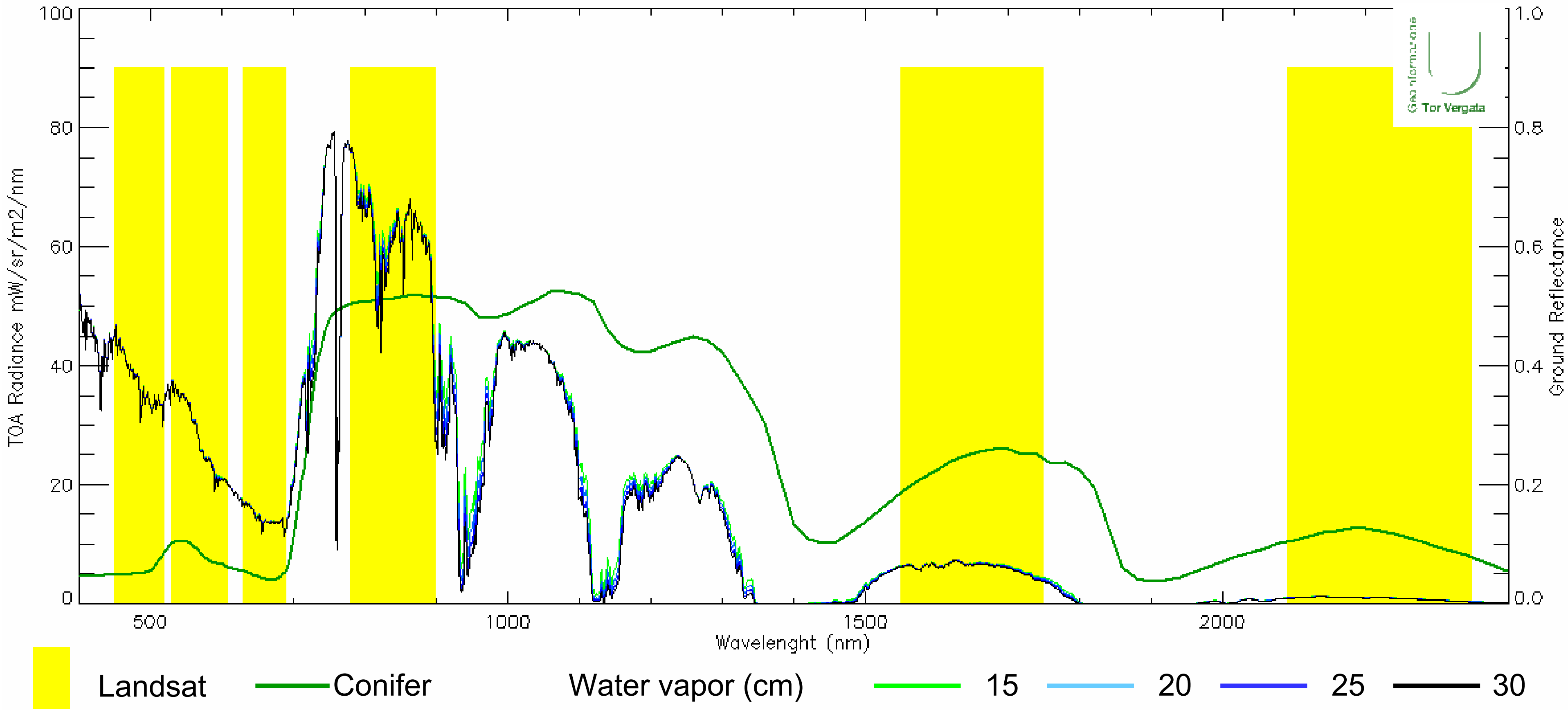


Figure 2.1 Four examples of surface reflectance: (a) Lambertian reflectance (b) non-Lambertian (directional) reflectance (c) specular (mirror-like) reflectance (d) retro-reflection peak (hotspot).

From the radiance to the reflectance

Landsat 7 multispectral channels 30 m of spatial resolution



Radiances simulated for a conifer forest, changing different water vapor content

Examples of reflectance signatures

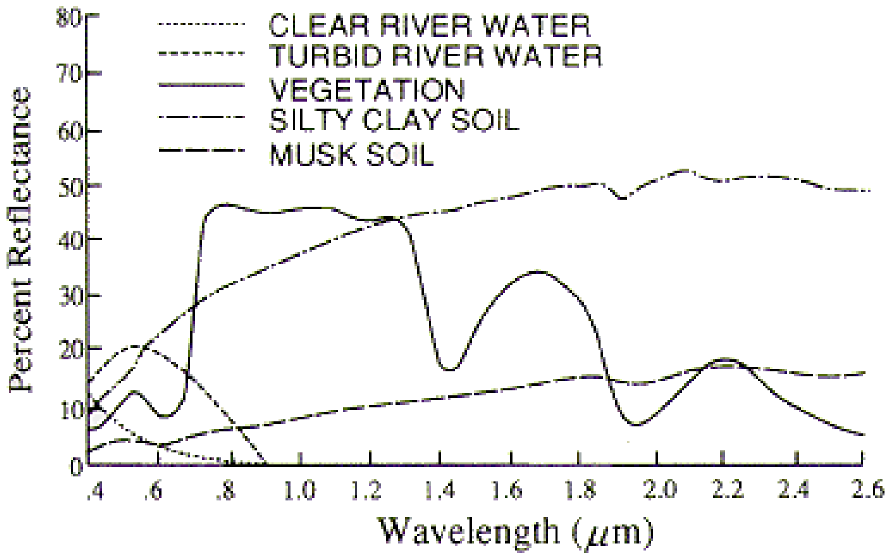


Figure 1.9.1 Spectral reflectance of vegetation, soil and water

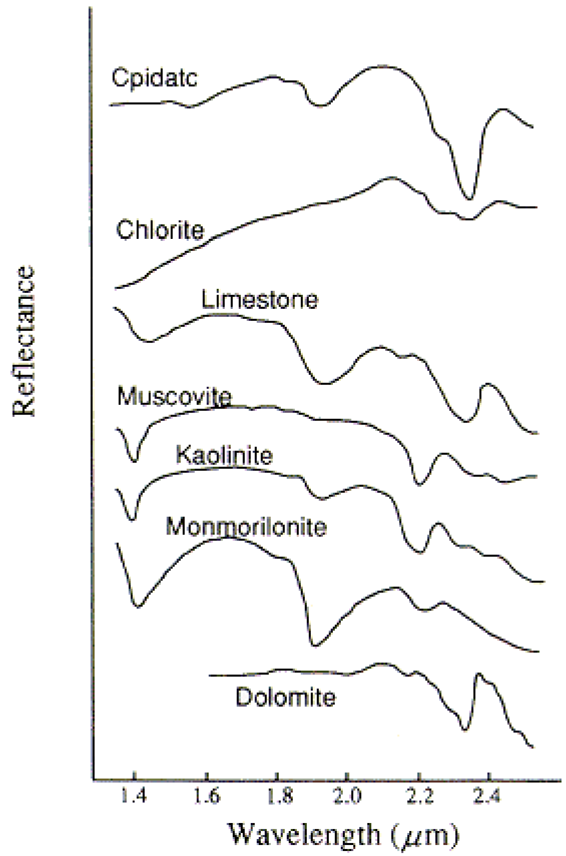


Figure 1.9.4 Spectral reflectance of rocks and minerals

Atmospheric correction: methodologies

EMPIRICAL

Is based on the knowledge of the radiometric and reflective properties of predefined areas or targets inside the image.

- ***Areas*****:** the histogram of corrupted areas is matched to the histogram of clean areas
- ***Targets***: the analysis performed using well defined spectral control points allows the correction of the whole image.

Simple methods, very fast, not much processing, mostly used

In some cases not good correction, the correction can not be absolute, a priori knowledge

ATMOSPHERIC MODELING

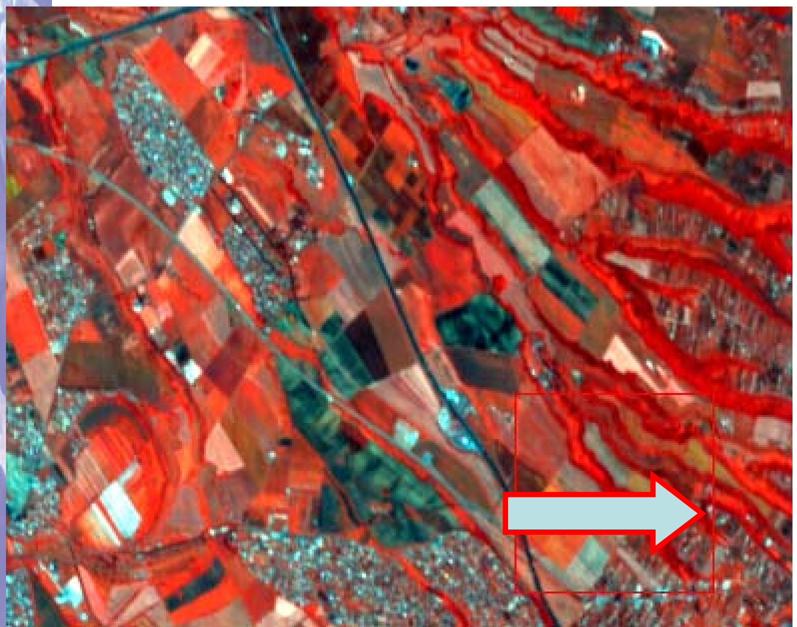
The atmospheric propertied are estimated or obtained by external sensors. The radiative quantities (irradiance, transmittance and scattering) are simulated by the use of a model and used during the correction.

Very effective methods, good correction

Expensive, in some case difficult, difficulties on the retrieval of atmospheric parameters

Esempio: Immagini corrette atmosfericamente

<u>Bosco denso</u>



CHRIS Proba 2007

Correzione atmosferica applicata

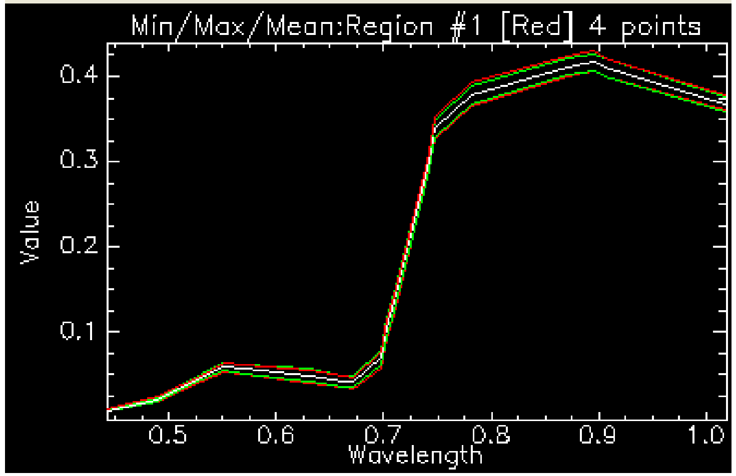
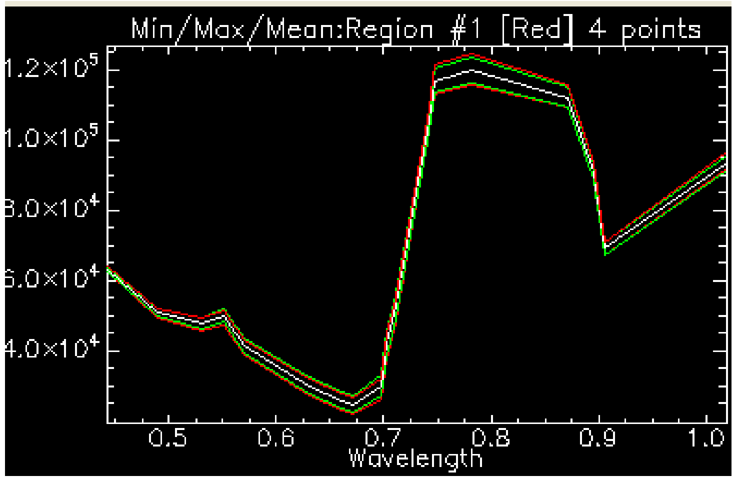


Immagine originale di radianza TOA



Esempio: Immagini corrette atmosfericamente

<u>Asfalto</u>
Parcheggio
policlinico TV

Correzione atmosferica applicata

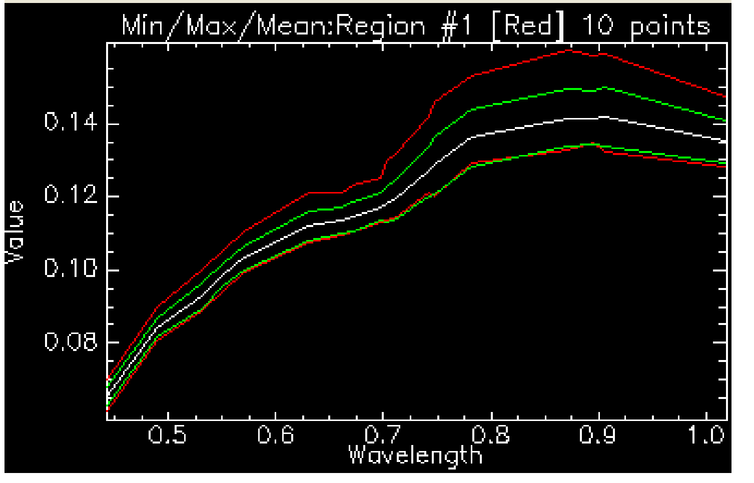
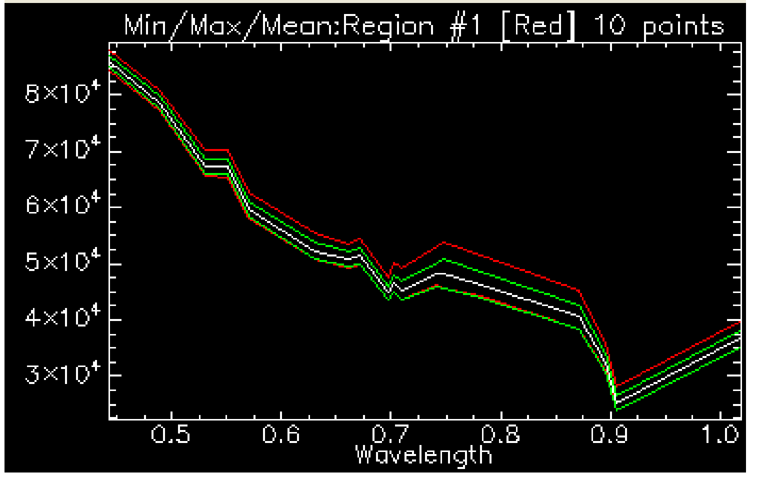


Immagine originale di radianza TOA



CHRIS Proba 2007

The classification processing (i)

Definition

Multispectral classification is the process of sorting pixels into a finite number of individual classes, or categories of data, based on their data file values. If a pixel satisfies a certain set of criteria, the pixel is assigned to the class that corresponds to that criteria.
From ERDAS field guide

The classed could be associated to real features on the ground (asphalt, vegetation, bare soil,…) or simply because they appear different according a specific criteria.

Pattern recognition

Is the science (and art) of finding meaningful patterns in data (using spectral or spatial information), which can be extracted through classification.
From ERDAS field guide

The classification processing (ii)

Training Phase

It is possible to instruct the system to identify patterns in the images

Supervised training

Several training patterns are submitted to the system and it uses these example to build the knowledge

Unsupervised training

Is more computer-automated. Some statistical information are provided to the system which organizes the knowledge in order to identify a certain number of pattern according to the information

Signatures of reference

Classifying phase

All the image are processed and the pixel are divided in classes using a pre-defined rule

The classification processing (iii)

Decision rule is a mathematical algorithm that, using data contained in the signature, performs the actual sorting of pixels into distinct class values.

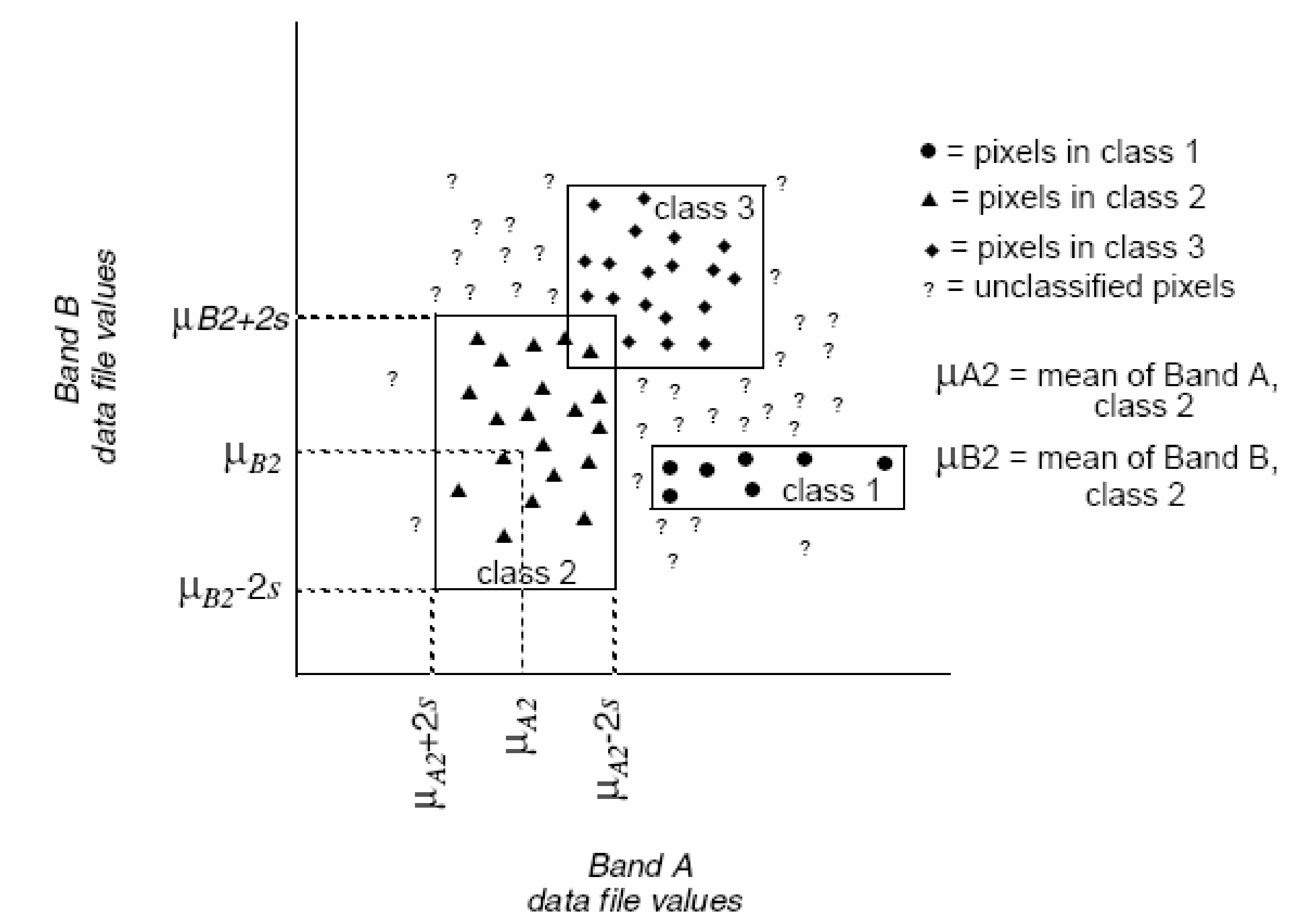
Parametric rules: there is a statistical characterization of the information contained in the signatures

- Minimum distance
- Mahalanobis distance
- Maximum Likelihood/Bayesan rule

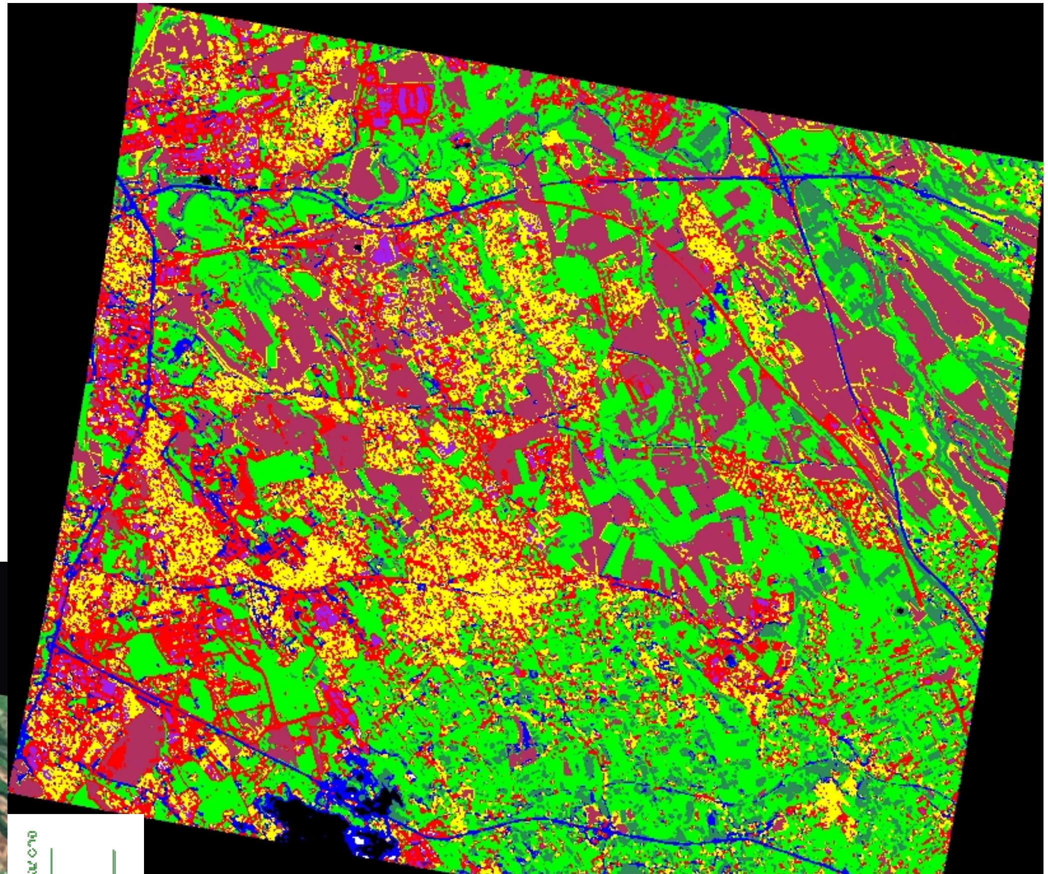
Non parametric rules: not based on the statistics, definition of intervals (spaces) related to the decision

- Parallelepiped

Non parametric rule: parallelepiped

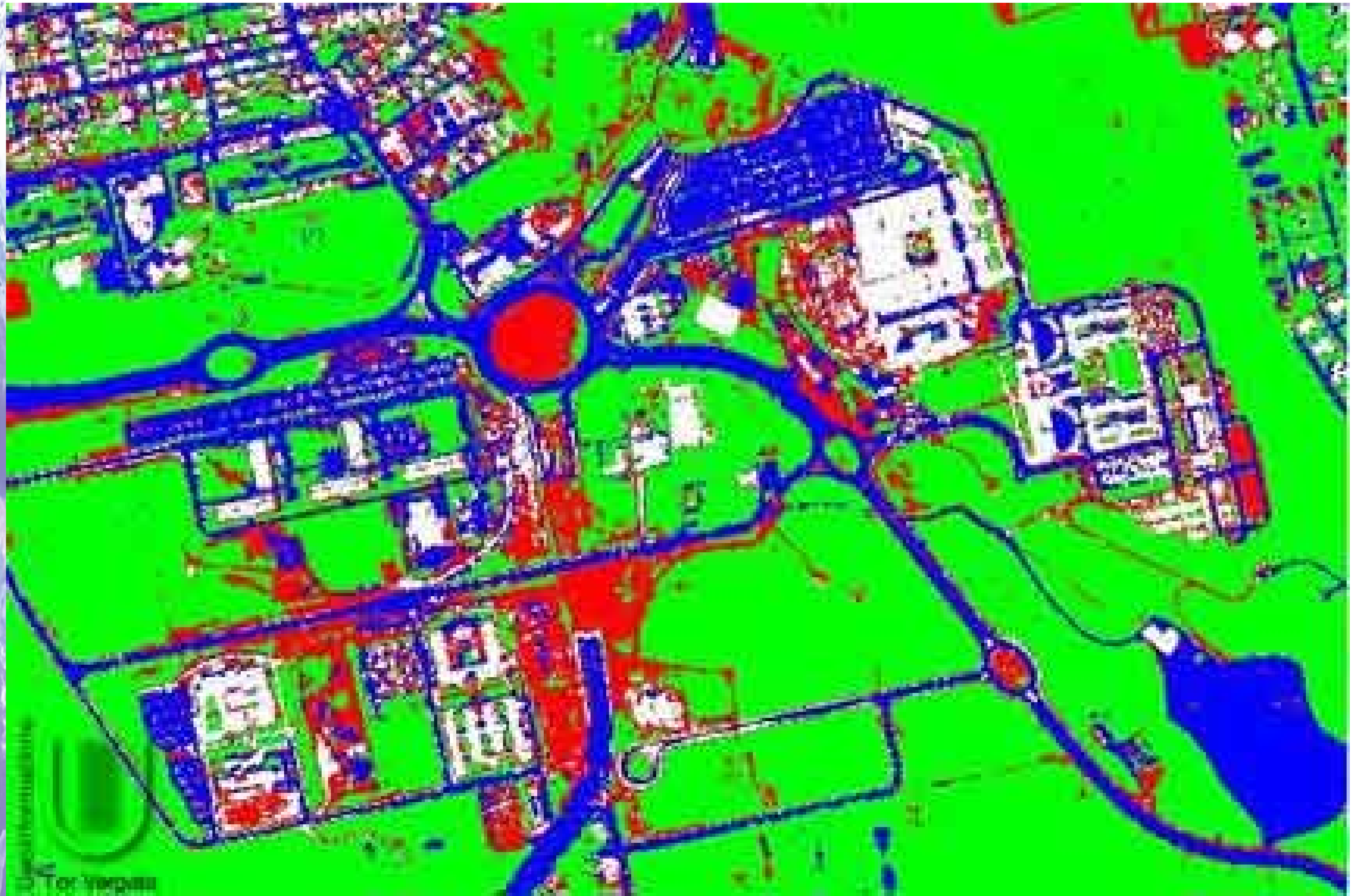


Production of land cover maps



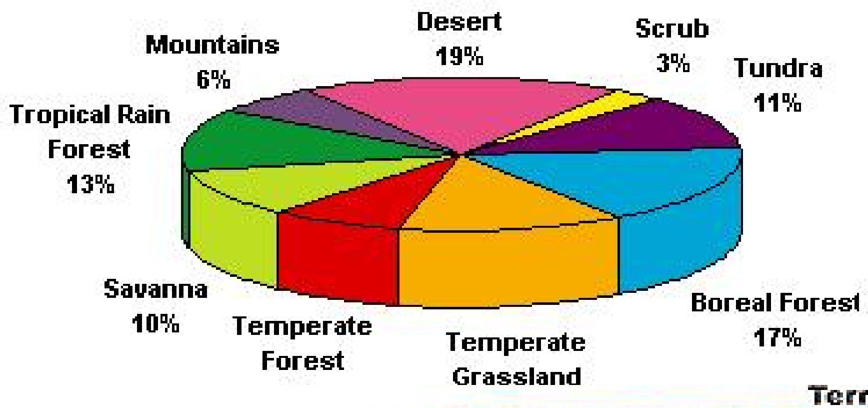
Highway asphalt
Road asphalt
Residential
Bare soil-arable land
Unclassified
Clouds (withe)
Commercial-Industrial
Vegetated areas
Forest

Very high resolution land cover

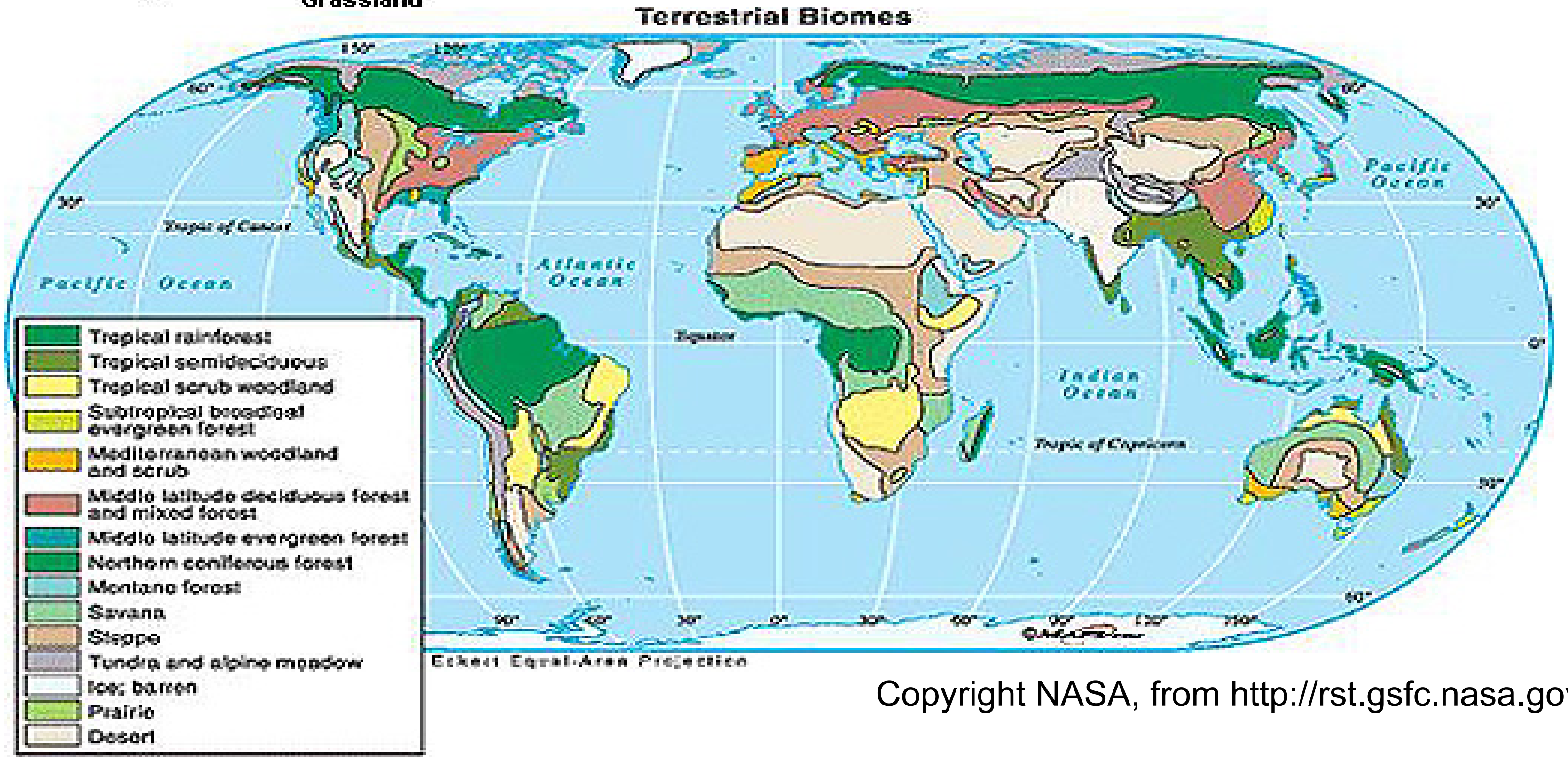


Bare Soil
Asphalt
Vegetation
Urban Fabrics (white)

The importance of vegetation monitoring



Remote sensing has proven a powerful "tool" for assessing the identity, characteristics, and growth potential of most kinds of vegetative matter at several levels (from biomes to individual plants)



Vegetation indexes and maps

Analysis of the reflective properties in several spectral bands can be carried out to monitor the status, the development, the density and the productive potentiality of vegetated areas and cultivated fields

Spectral bands are properly combined to produce indexes related to the vegetation condition

- NDVI

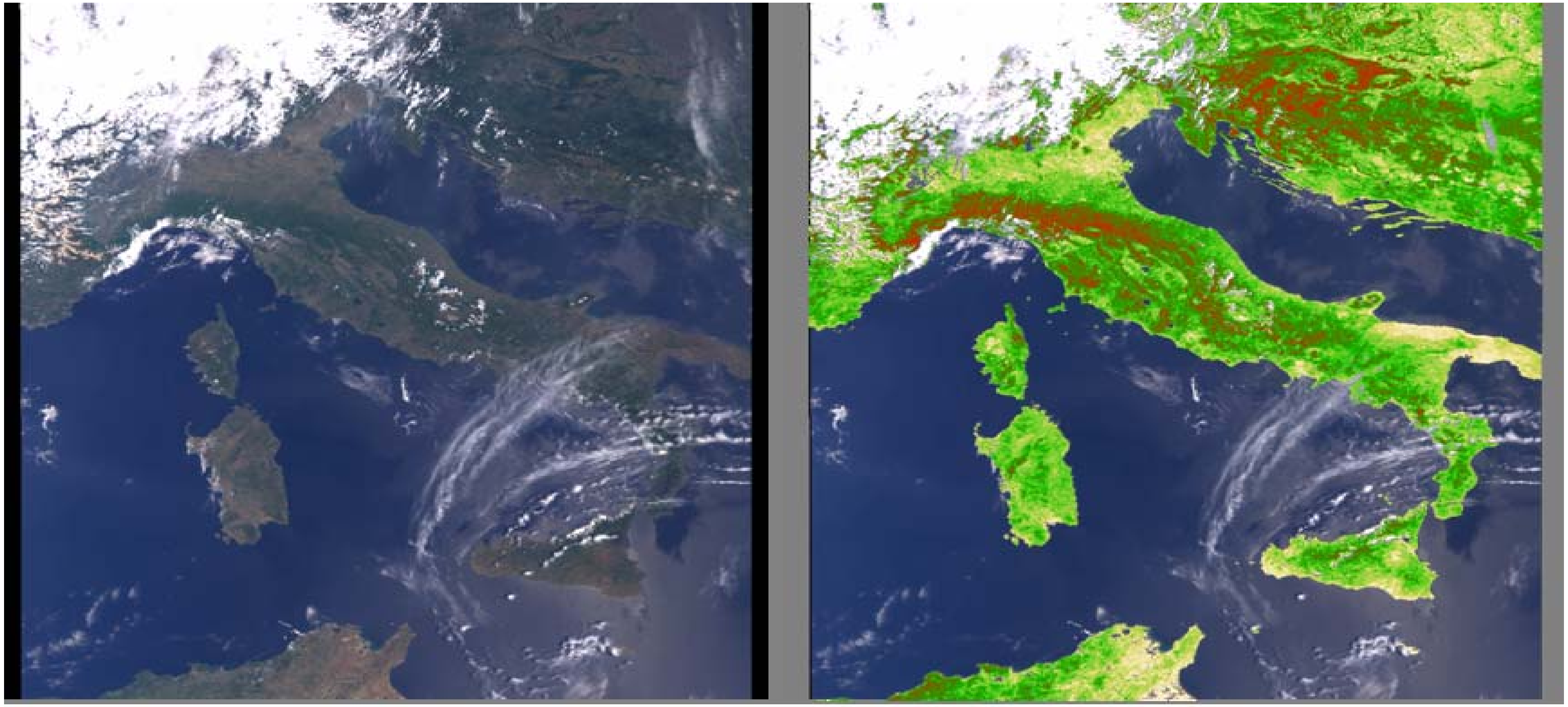
$$NDVI = (NIR - red) / (NIR + red)$$

- LAI
- FAPAR

For this kind of analysis sensors at medium and low resolution wide swath are used (MODIS, AVHRR, MERIS, SPOT Vegetation,…)

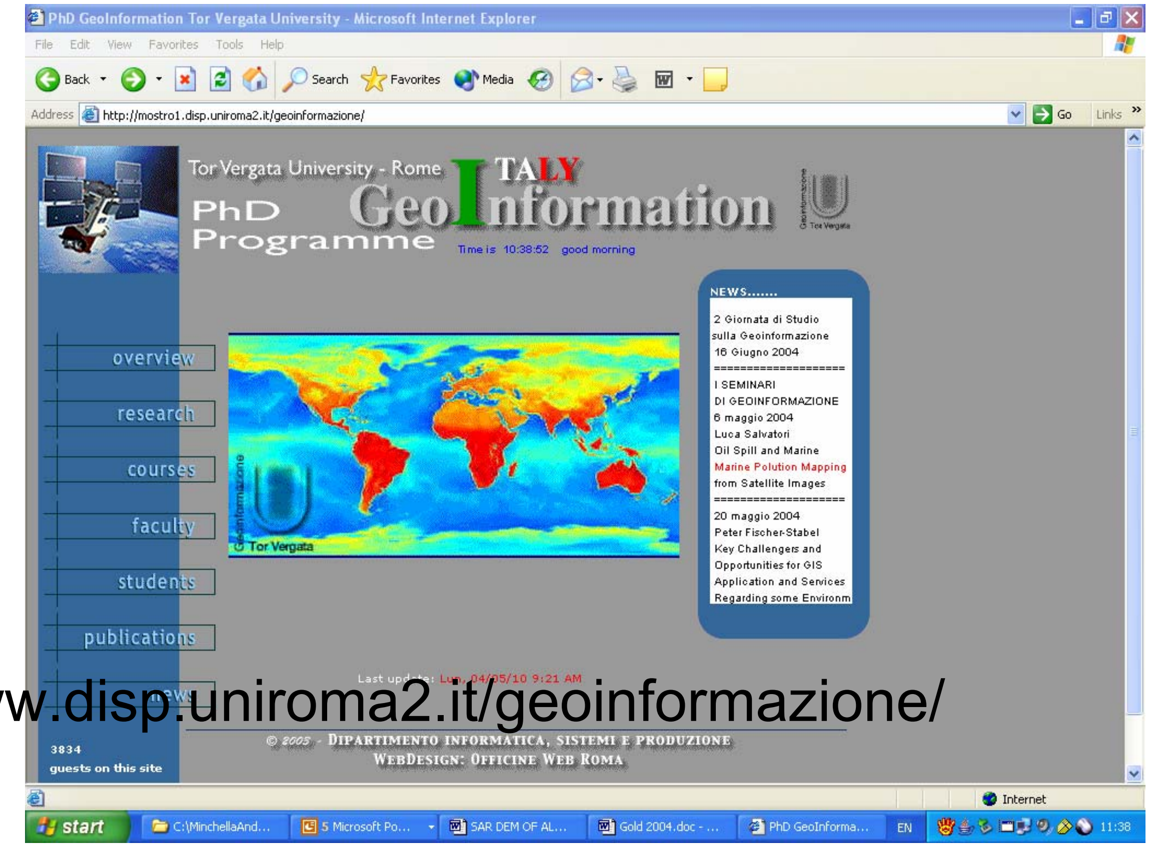
Examples

Monitoring of productive areas in Italy using MERIS processed with the FAPAR algorithm



Red areas agricultural high photosynthetic fields
Yellow areas low photosynthetic activity

And now you…



http://www.disp.uniroma2.it/geoinformazione/