

# Earth Observation from Space: Introduction and Selected Applications

## Introduction

Prof. Sebastiano B. Serpico, Dr. Gabriele Moser

## Definition

- **Remote sensing** is the scientific discipline whose goal is the development of technologies and methods for extracting information about a given “object” or “entity” by acquiring and analyzing measurements through sensors that are not in direct contact with the object/entity itself.

The definition is very general and encompasses, for example:

- Extracting information of interest to environmental applications from data collected by satellite or airborne sensors.
- Identifying buried objects through microwave sensors (e.g., ground-penetrating radar, GPR).
- Detecting underwater objects through acoustic signals (sonar).

# Remote Sensing for Earth Observation

3

Here, we shall focus on remote sensing for Earth observation (EO).

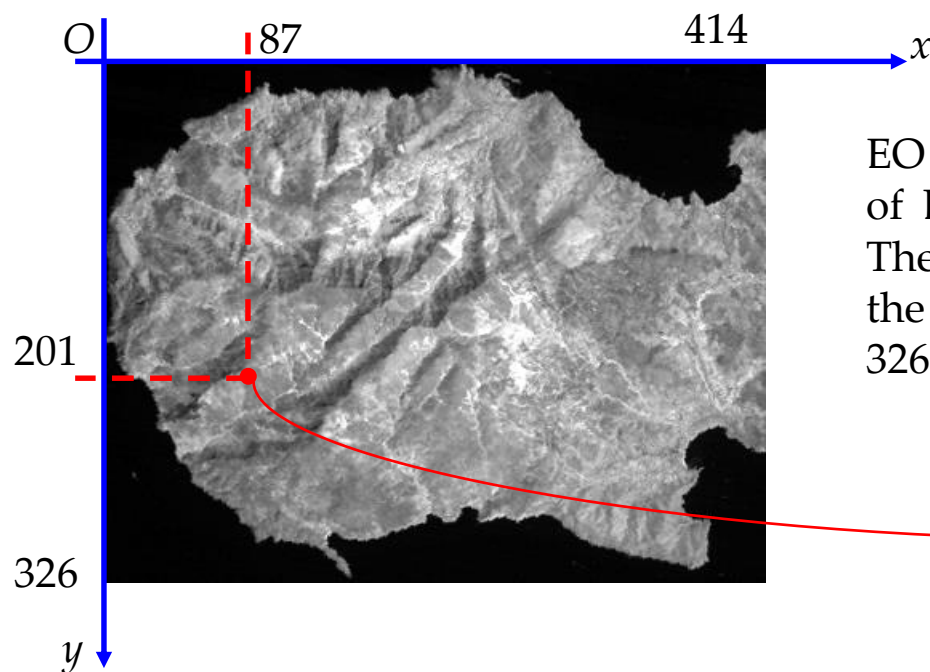
- The object/entity of interest is a portion of the Earth surface.
- The desired information is of interest for urban or environmental applications (e.g., mapping of land cover and its temporal evolution, vegetation, and built-up areas).
- The sensor is onboard a satellite (spaceborne sensor or satellite sensor) or an aircraft (airborne sensor). Here, the focus will be on the case of satellite systems.
- The interaction between the observed area and the sensor occurs through electromagnetic (e.m.) waves.

Data collected by EO sensors are typically formatted as digital images of the geographic area of interest: remote sensing images or EO images.

# Digital Images

A **digital image** is a two-dimensional matrix of points, named **pixels** (abbreviation of “picture elements”), which are associated with one or more discrete values that express light intensities.

- Since pixel intensities are discrete-valued, they take on values in an enumerable (typically finite) set.
- The physical meanings associated with the location and intensity of a pixel depend on the sensor used to acquire the image.



EO image of the West part of the Island of Elba (Italy) acquired in 1994 by the Thematic Mapper (TM) sensor onboard the Landsat-5 satellite (image size:  $414 \times 326$  pixels)

Pixel located at coordinates (87, 201) with intensity equal to 145

# Example – Forest Inventory

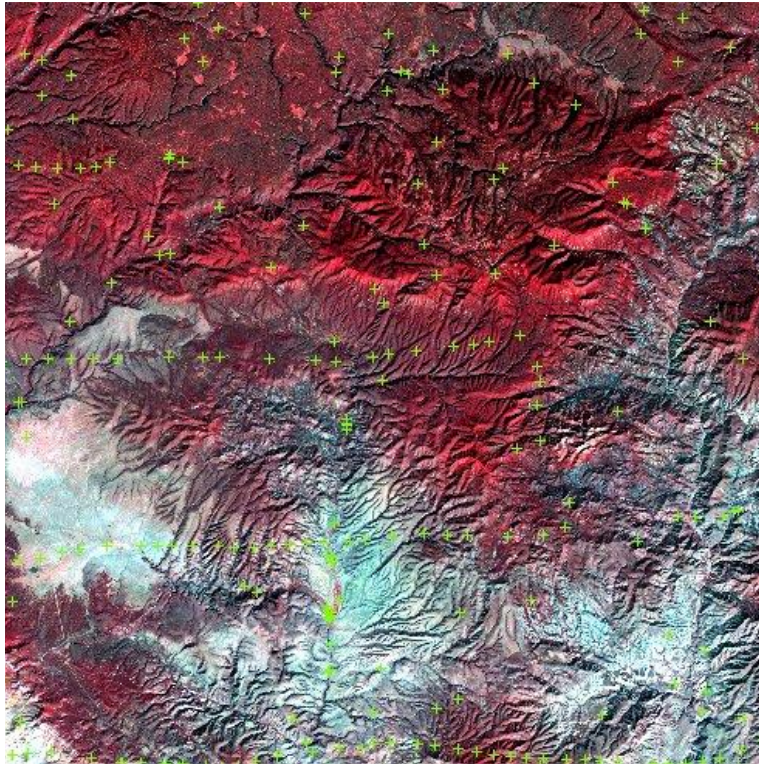
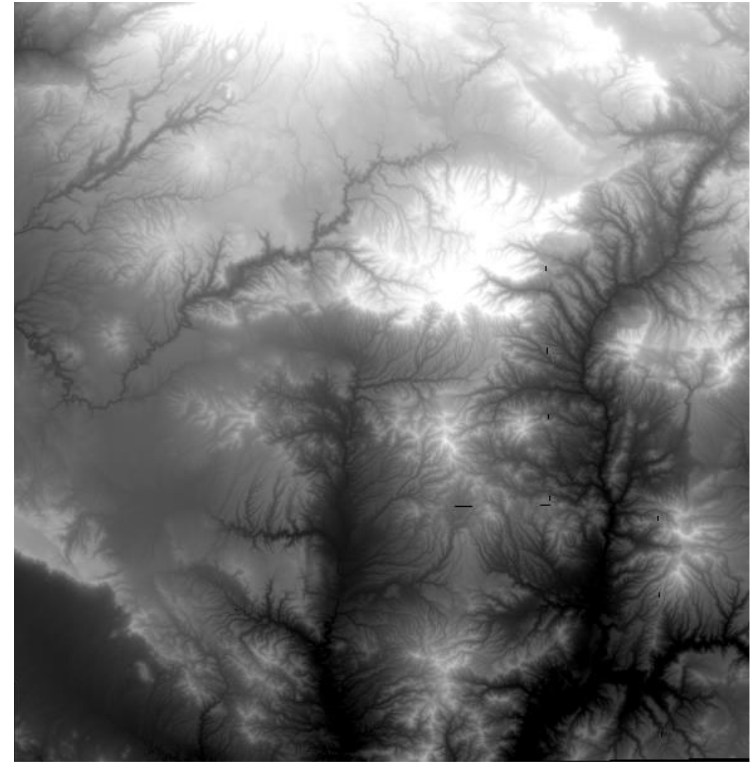
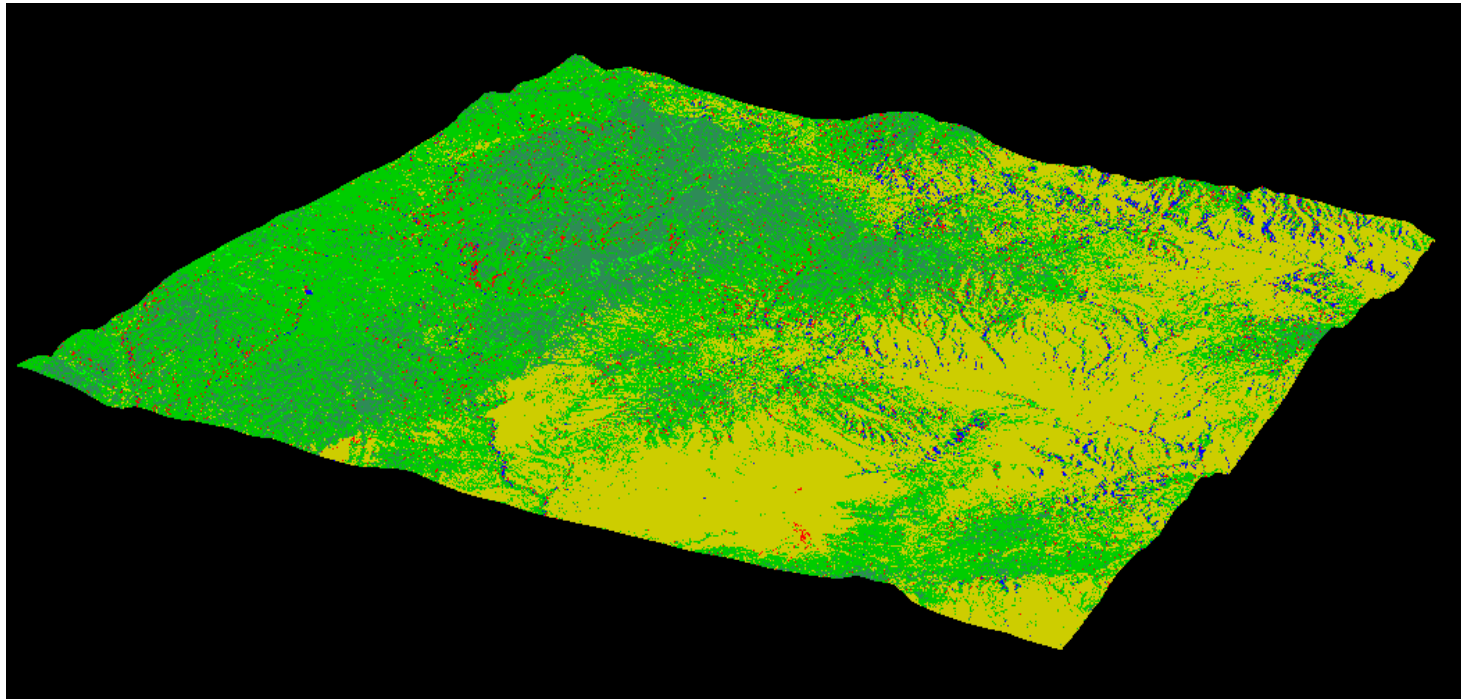


Image of a forest area in Arizona, acquired by the Enhanced Thematic Mapper Plus (ETM+) sensor onboard the Landsat-7 satellite: overall area:  $60 \times 60 \text{ km}^2$ ; spatial resolution: 30 m; false-color display.









Digital elevation model (DEM) of the area (lighter grey means higher altitude)

# Example – Forest Inventory

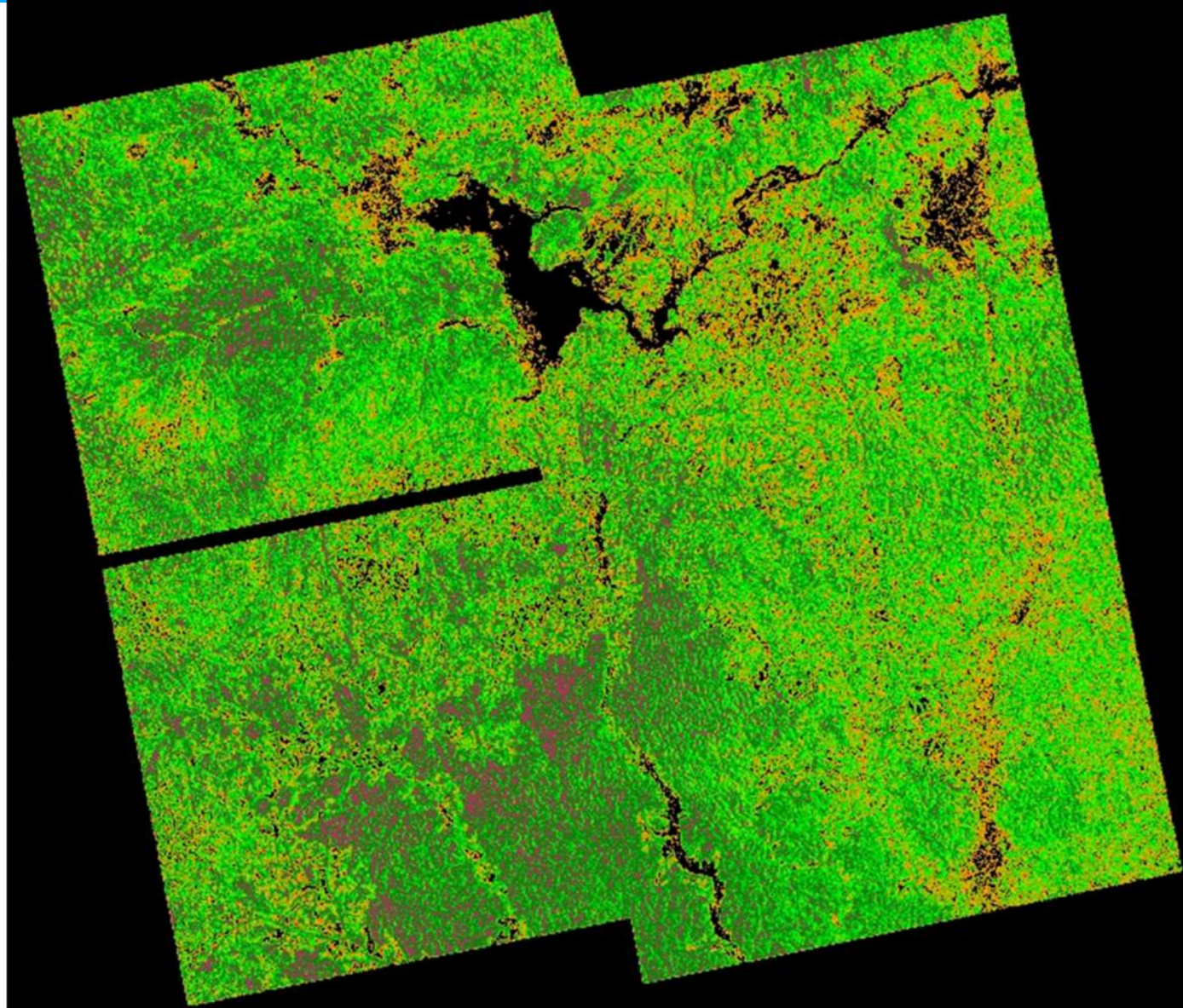
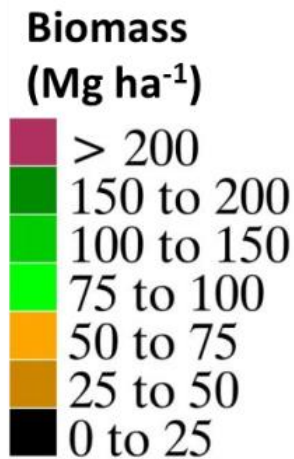


3D display of forest species classification for six land-cover classes from the Landsat ETM+ image (useful for forest monitoring in forest fire risk applications)

	Scrub Grassland	1,070 - 2,000 m
	Riparian/Mixed Broadleaf Forest	1,220 - 1830 m
	Encinal	1,220 - 2,130 m
	Mixed Meadow	2,440 - 2900 m
	Ponderosa Pine/Mixed Conifer	2,070 - 2,680 m
	Water	whole elevation range

# Example – Vegetation Biomass Retrieval

7



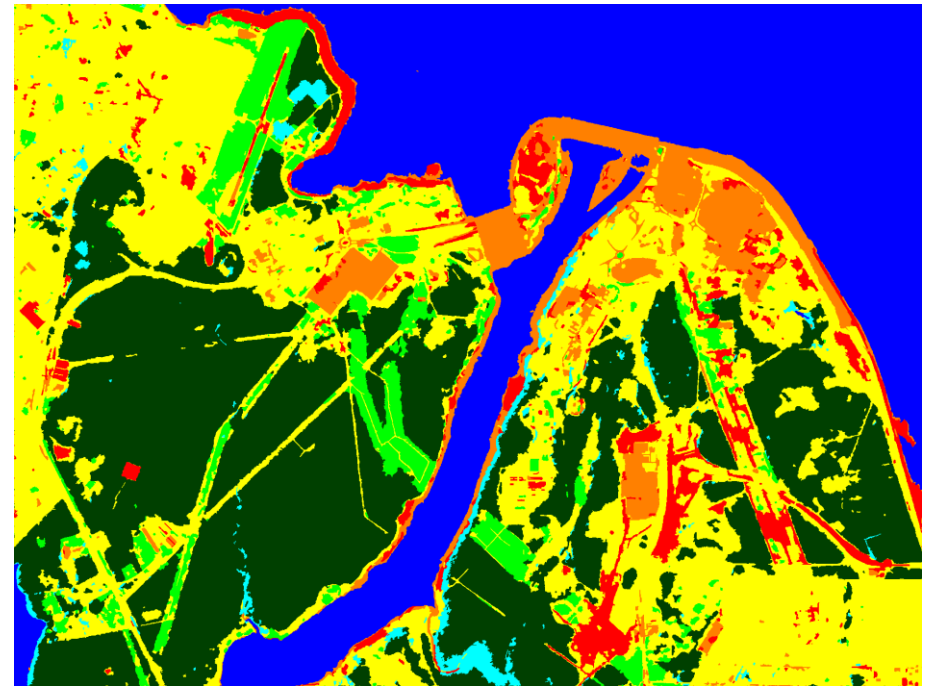
Vegetation biomass estimation over the Mbam Djerem National Park, Cameroon, from satellite ALOS-PALSAR images and *in situ* measurements from Cameroon, Mozambique, and Uganda

# Example – Land Cover Mapping at High Resolution

8



IKONOS image (spatial resolution: 4 m), Itaipu (Brazil-Paraguay), false-color display

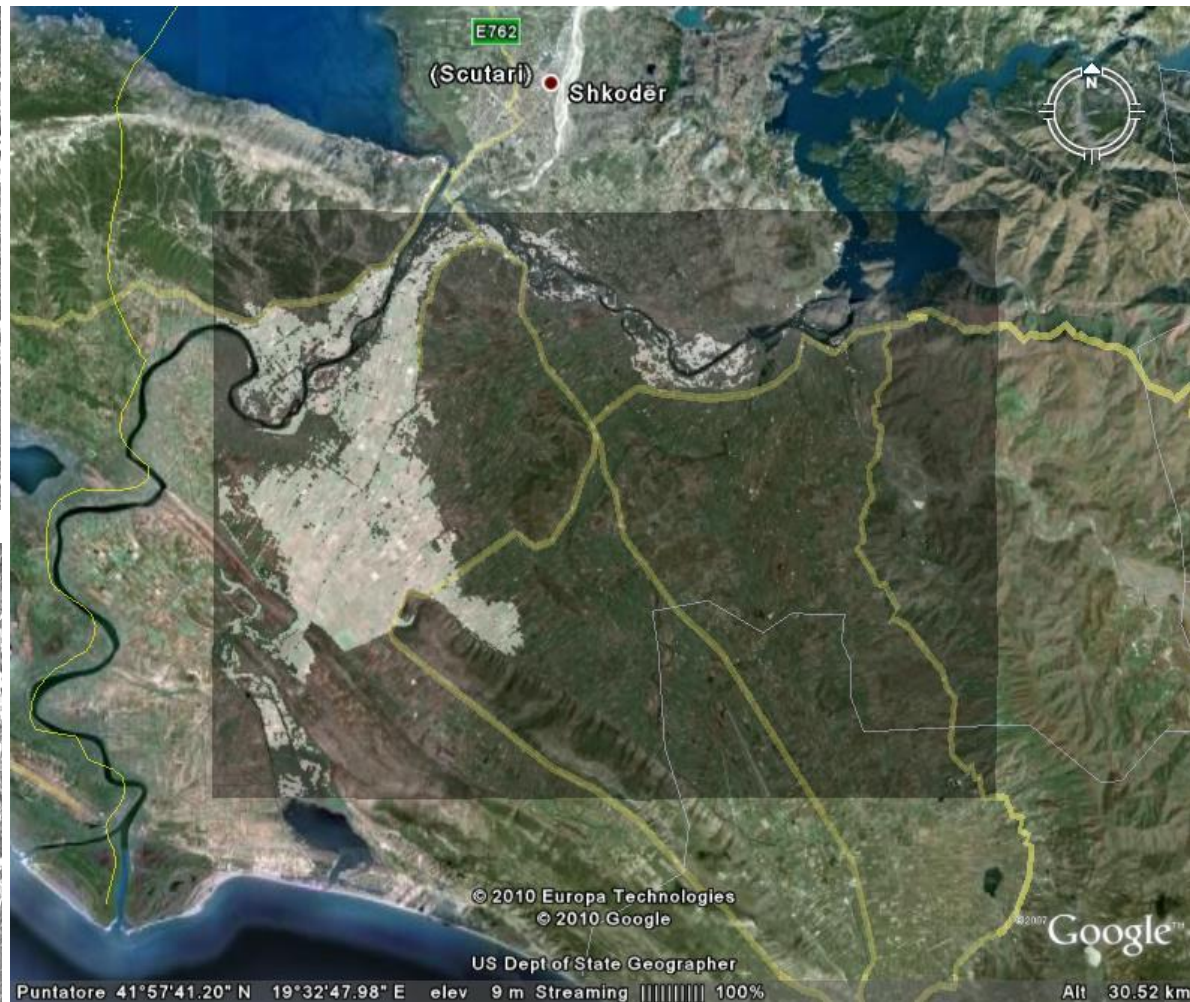
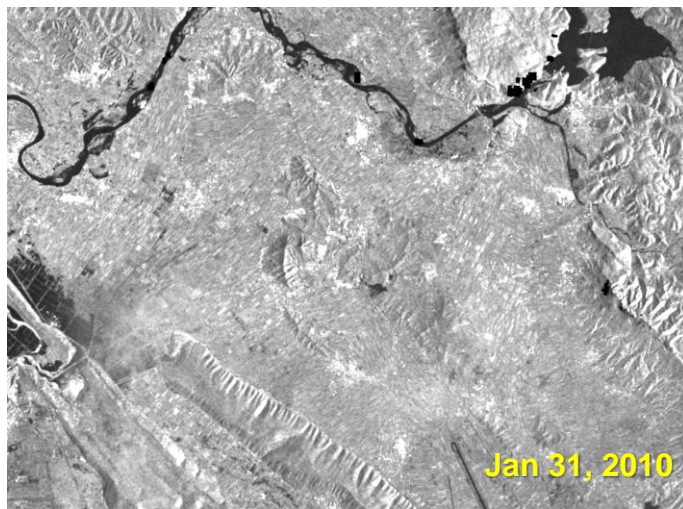


Land cover map obtained by applying classification methods to the IKONOS image

urban
herbaceous rangeland
schrub and brush rangeland
forest land
barren land
built-up (non-urban)
water

# Example – Flooded Area Detection

9

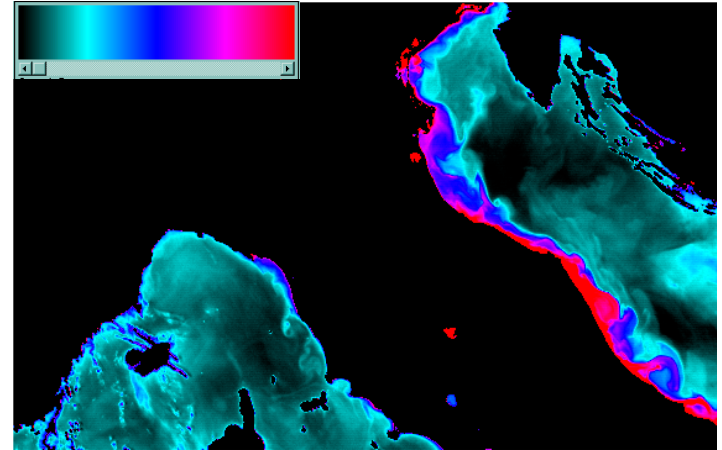


Change detection from a pair of COSMO-SkyMed images acquired over a severely flooded area near Shkodër (Albania; spatial resolution: 10 m).

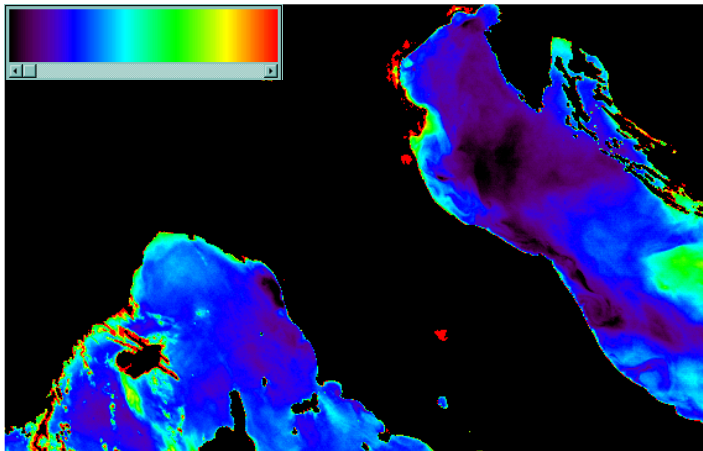
# Example – Sea Water Quality Monitoring



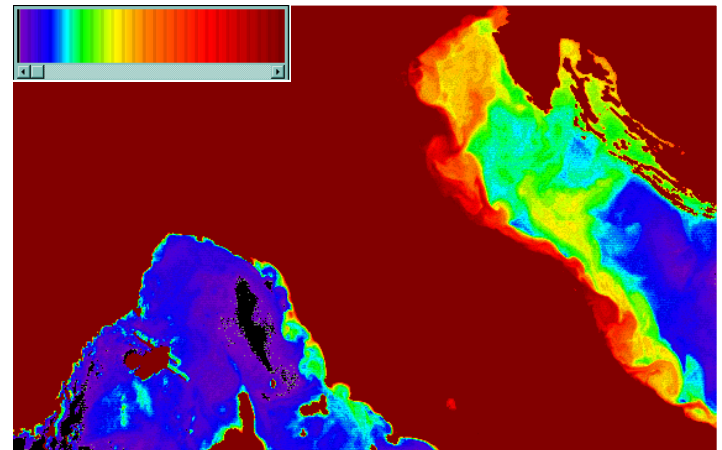
SeaWiFS image, August 1998,  
true-color display



Map of relative chlorophyll  
concentration

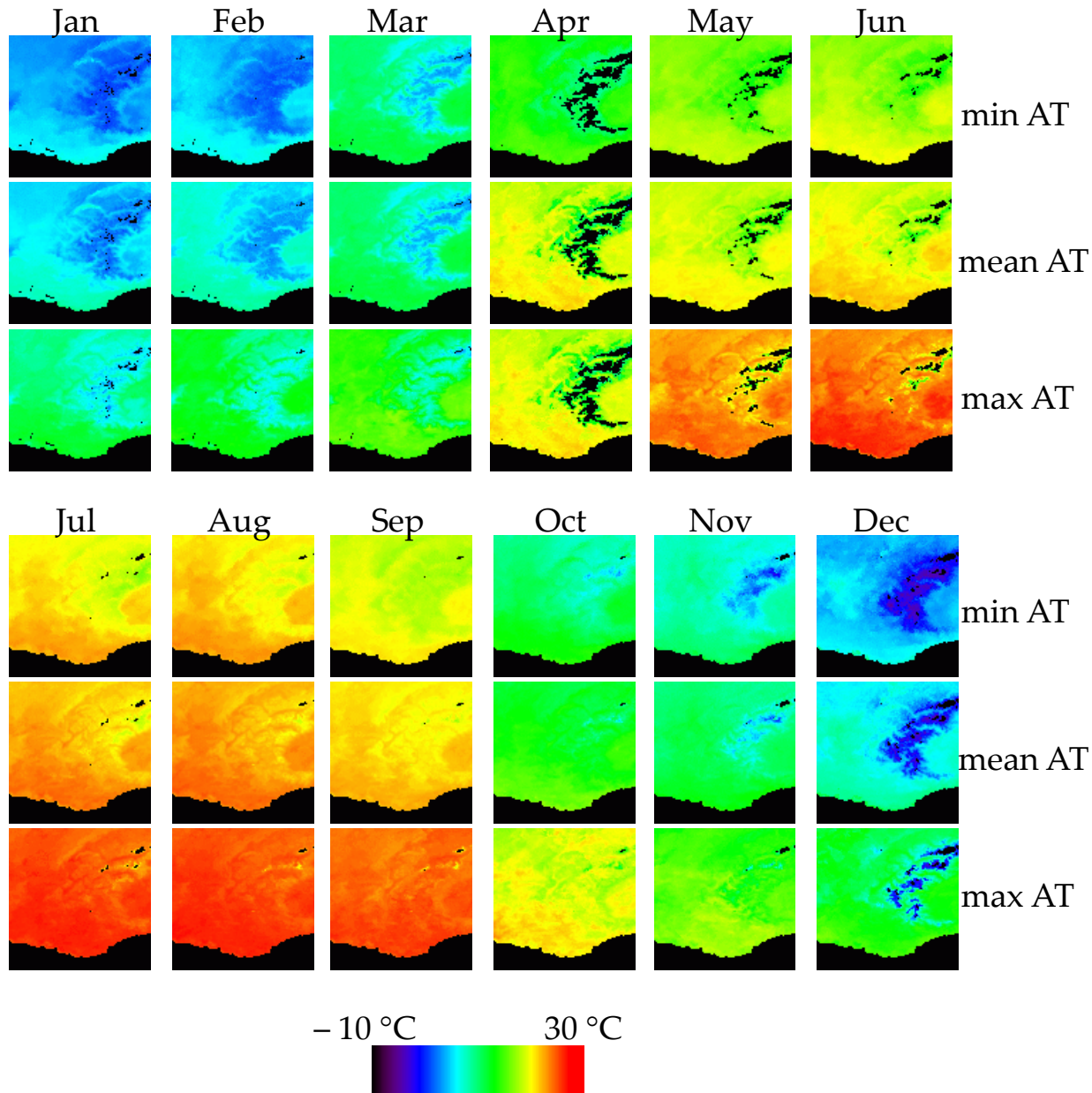


Map of relative concentration of total  
suspended matter



Map of relative concentration of total  
organic matter

# Example – Air Temperature at 2 m Height

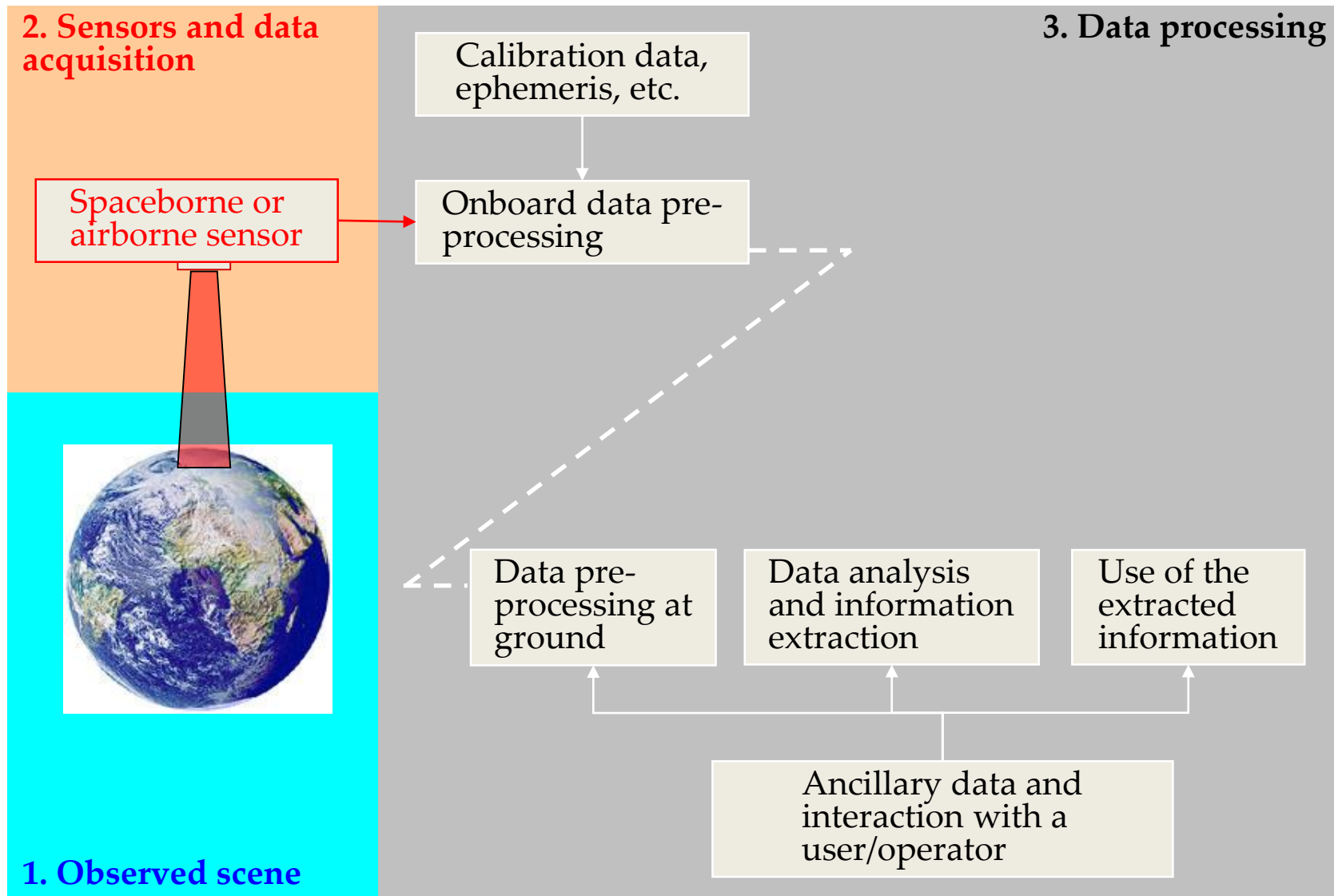


Monthly stats of air temperature at 2-m height from the ground over PACA (Provence, Alpes, Côte d'Azur; France) estimated from Meteosat Second Generation images (spatial resolution: 4 km) and from *in-situ* temperatures collected by MétéoFrance in 2009.

Air temperature close to the Earth surface is an important input for planning and monitoring systems for solar energy production.

# Components of an EO system

12



# Components of an EO system

A system for information extraction from EO data conceptually consists of three main components:

- The **observed scene** on the Earth surface.
- The **acquisition subsystem** (platform and sensor) that collects data on the observed scene.
- The **analysis subsystem** that aims at extracting the desired information from the acquired data.

The **observed scene** consists of a portion of the Earth surface and of the portion of atmosphere that may affect the acquired EO data.

- It is intrinsically the most complex and time-varying component of the EO system.
- It is outside the control of both developers of the acquisition and analysis subsystems. The properties of the observed scene act as external constraints to the design of both subsystems.

The **acquisition subsystem** consists of one or more sensors that collect data on the observed scene and one or more platforms.

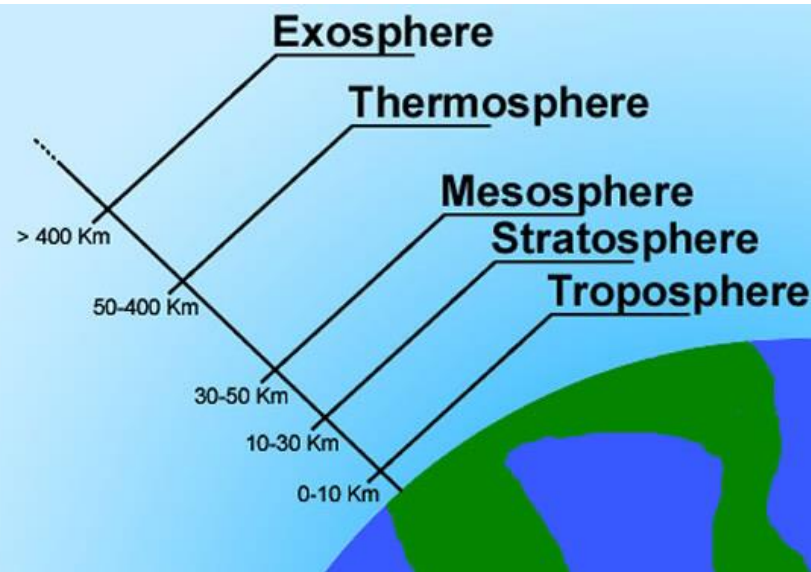
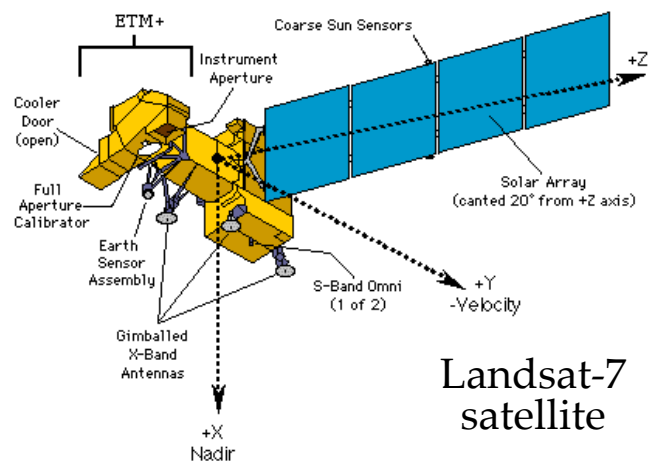
- Sensors and platforms are under the control of the designer of the acquisition subsystem and outside the control of the designer of the analysis subsystem. Their properties act as external constraints to the design of analysis methods.

**Airborne platforms** are mostly aircrafts or sometimes helicopters, balloons or drones (unmanned aerial vehicle, UAV).

- Altitude and orientation affect the geometry of the image, and acquisitions occur through *ad hoc* flights.
- Aircraft flights are often expensive. Aircrafts with EO sensors are available at national or international organizations (e.g., military authorities) or a few specialized enterprises.
- UAVs are getting increasingly popular because of their low cost but they have limitations on the weight of the sensors they can carry.

A **spaceborne platform** is generally an artificial satellite orbiting around the Earth.

- Two exceptions were the SIR-C/XSAR and SRTM missions in which radar sensors were onboard NASA Space Shuttles.
- In a spaceborne EO system, the satellite is the **space segment** of the system, while the **ground segment** is the structure on the surface that receives, validates, and preprocesses the acquired data.
- The space segment includes the sensor (**mission payload**) and all necessary infrastructures for power, orbit management, onboard pre-processing, recording, and transmission to the ground segment.

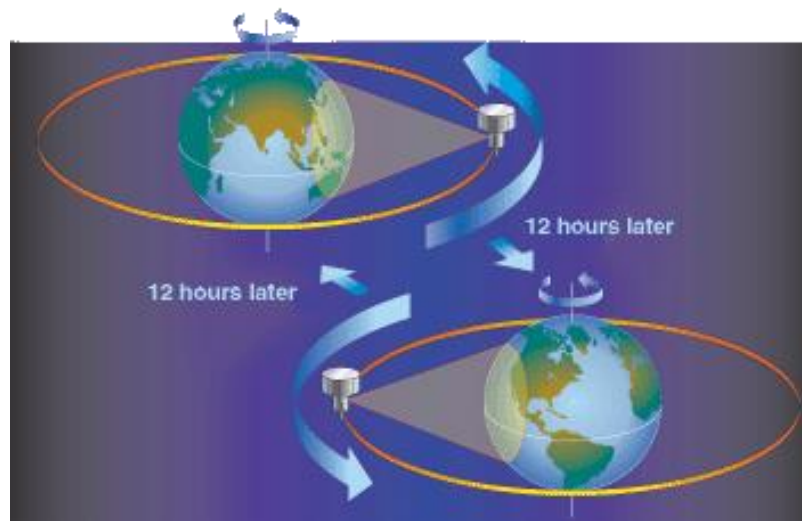


# Geostationary Orbits

The path of a satellite along the orbit is an **ellypse**. The plane that includes this ellypse is called **orbital plane**. The orbits used for EO are usually geostationary or near polar.

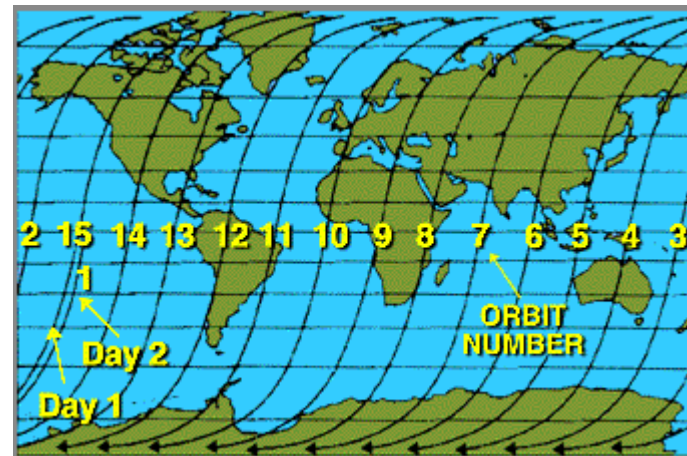
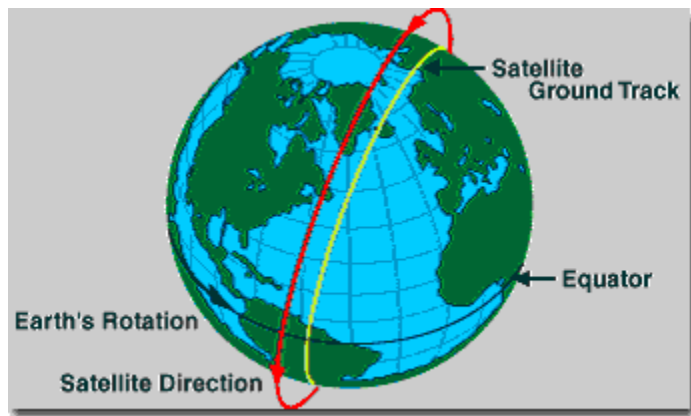
A **geostationary** orbit is circular, its orbital plane is the plane of the Earth equator, and the orbiting period around the Earth is 24 hours.

- Therefore, a sensor onboard a geostationary platform (geostationary sensor) **always observes the same portion** of the Earth surface.
- Newton's gravitation law implies that the altitude of a geostationary orbit is approximately **36000 km**.
- Weather satellites (e.g., Meteosat Second Generation, MSG) are often geostationary.



In the case of a **near polar** orbit, the angle between the orbital plane and the plane of the Equator is slightly larger than  $90^\circ$  (approximately  $95^\circ$  to  $100^\circ$ ). Altitude is generally 400 to 1000 km.

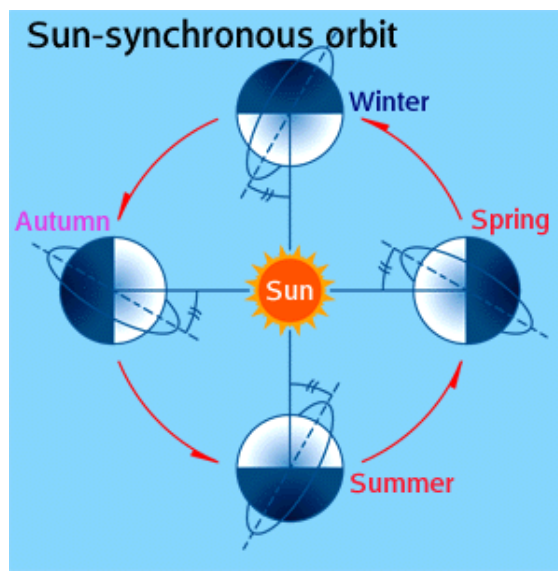
- Owing to the combination of the motion of the satellite around the Earth and of the rotation of the Earth itself on its axis, a sensor onboard a near polar satellite (near polar sensor) collects data over almost all the Earth surface.
- The projection of the satellite path on the Earth surface is called **satellite ground track**.



# Sun-synchronous Orbit

The **Sun-synchronous orbit** is a special case of near polar orbit and is very often used for EO.

- In the case of a Sun-synchronous orbit, the angle between the orbital plane and the segment joining the centers of the Earth and the Sun is nearly constant in time.
- Therefore, a sensor onboard a Sun-synchronous satellite (Sun-synchronous sensor) always observes a given ground area at approximately **the same time of the day**.
- Hence, Sun illumination conditions at different observation times are similar, an important property for passive sensors.



# Active and Passive Sensors

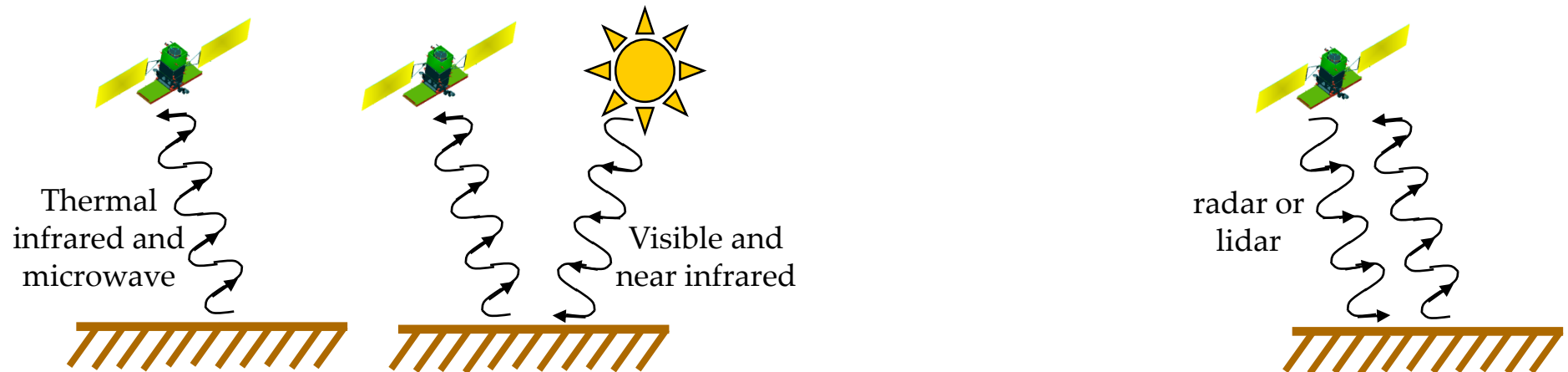
EO sensors can be either passive or active.

**Passive sensors** do not transmit any signal and just receive the incoming radiation due to:

- **Reflection** of the Sun irradiance from the Earth surface (visible and near-infrared radiation) *or*
- **Spontaneous emission** from the Earth surface (thermal infrared and microwave radiation).

**Active sensors** transmit signals towards the observed area and receive the “echo” signals backscattered by the area. The transmitted signal is usually:

- A microwave signal: **radar** (radio detection and ranging).
- A laser signal: **LiDAR** (light detection and ranging).



# Spatial Resolution

The word “**resolution**” has multiple (important) meanings in remote sensing:

- Spatial resolution
- Spectral resolution
- Temporal resolution
- Radiometric resolution

## Spatial resolution

- It is the size of the smallest spatial detail that can be distinguished in the image and is related to the size of the ground area associated with a pixel.
- The spatial resolutions of current satellite sensors for civil applications range from a few km in the case of **geostationary** sensors (e.g., 4 km for MSG) to 0.3 to 5 m with **very high resolution (VHR) near polar** sensors (e.g., QuickBird, IKONOS, WorldView-2/3, COSMO-SkyMed, TerraSAR-X).



San Francisco at different spatial resolutions: 80, 30, and 4 m from top to bottom

# Spatial Resolution



(a) 3 km



(b) 500 m



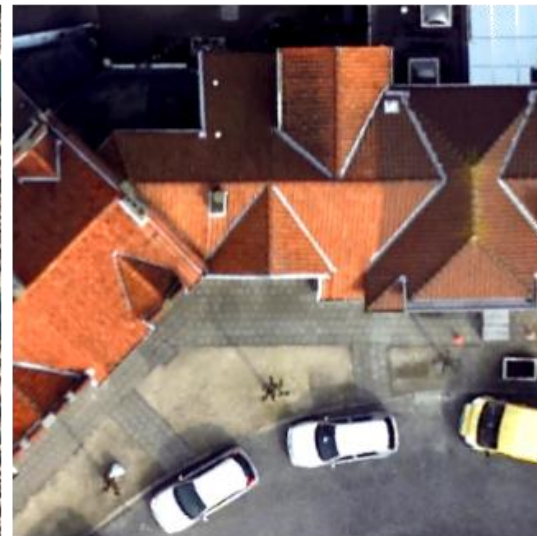
(c) 30 m



(d) 10 m



(e) 2 m



(f) 5 cm

These images have the same size in pixels ( $400 \times 400$  pixels) but different spatial resolutions (indicated below each image).

The **temporal resolution** of a spaceborne sensor is the frequency with which a given ground area is observed.

- It is generally expressed in terms of **revisit time**, i.e., the time between two consecutive satellite passes.
- Typical values range from a few dozens of minutes for **geostationary** sensors (e.g., 15 min for MSG) to a few days or weeks for **near polar** sensors (e.g., 24 hours for MODIS onboard Terra and Aqua, 16 days for Landsat).
- Current near polar sensors often exhibit a **pointing functionality**, i.e., their observation directions can be steered upon agreement with the agency/company in charge of the related space missions. This allows more frequent observations to be obtained on a given area of interest but makes revisit times no more periodical and less predictable.

As discussed later in more detail, **passive sensors** generally collect multiple measurements at once for each pixel.

- These measurements correspond to different wavelength ranges in the e.m. spectrum (**multispectral sensors**) and are generally named “bands” or “channels” of the sensor.
- The **spectral resolution** of a passive sensor is the precision with which the incoming radiation is sampled along the e.m. spectrum and is expressed in terms of the number of bands of the sensor and of the widths of the corresponding wavelength ranges.
- Current sensors for civil applications range from a few bands of moderate width (70 to 100 nm each) to a few hundreds narrow bands (2 to 10 nm each). In the latter case, one speaks of **hyperspectral sensors**.

The intensity of a pixel in a digital image (or in each band of a multispectral digital image) is encoded with a finite number of **bits**.

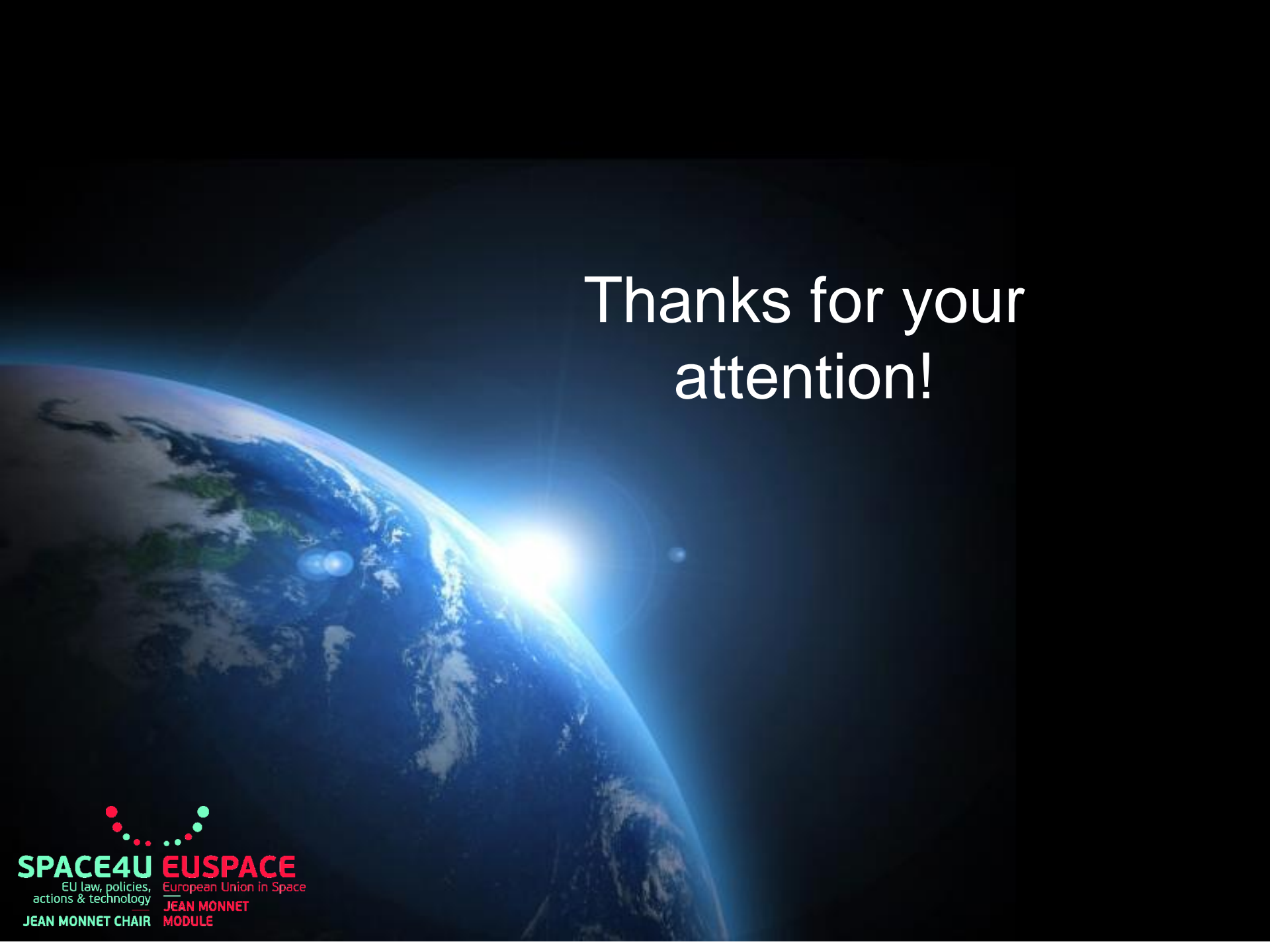
- Therefore, the pixel intensity can take on a finite number of values in a predefined discrete set. These values are named **quantization levels**.
- When  $n$  bits are used,  $2^n$  quantization levels are available and range from 0 to  $2^n - 1$ .
- A value measured by the sensor is approximated to the closest quantization level, encoded with  $n$  bits, and recorded.
- The **radiometric resolution** of a sensor is the smallest difference that is necessary between two distinct measured values so that the corresponding quantization levels still differ from each other.
- It is related to the number  $n$  of bits that are used to encode each quantized intensity and are associated with each pixel (**number of bits per pixel, bpp**, sometimes also named **bit depth**).
- Typical values range from 8 bpp (levels 0 to 255) to 16 bpp (levels 0 to 65535).

The **processing subsystem** may typically include:

- **Onboard preprocessing operations**, especially in the case of spaceborne platforms, based on information on the states of the sensors and of the platforms (e.g., ephemeris, calibration).
- **At-ground preprocessing operations**, such as further calibration, correction of geometric or radiometric distortions, and georeferencing.
- **Analysis operations** aimed at extracting the desired information on the basis of the acquired EO data and of possible additional information sources (e.g., ancillary data or ground measurements).

Now we shall provide some examples of case studies.

- Richards J. A., *Remote sensing digital image analysis*, Springer, 2013
- Landgrebe D., *Signal theory methods in multispectral remote sensing*, Wiley, 2003
- Long D. and Ulaby F. T., *Microwave radar and radiometric remote sensing*, Artech House, 2015
- Campbell J. B. and Wynne R. H., *Introduction to remote sensing*, Guilford Press, 2011
- Moser G. and Zerubia J. (eds.), *Mathematical models for remote sensing image processing*, Springer, 2018
- Moser G., *Analisi di immagini telerilevate per osservazione della Terra*, ECIG, 2007



Thanks for your  
attention!