The Abdus Salam International Centre for Theoretical Physics

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School on Modelling Tools and Capacity Building in Climate and Public Health

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Remote sensing of climate and environment: theory and potential products for health

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HEALTHY FUTURES

Quantifying Weather & Climate Impacts
QWeCI
on health in developing countries

Remote Sensing

Definition: acquisition of information about an object or phenomenon, without making physical contact with the object itself, but through the variation of electromagnetic fields induced by the presence of the object.

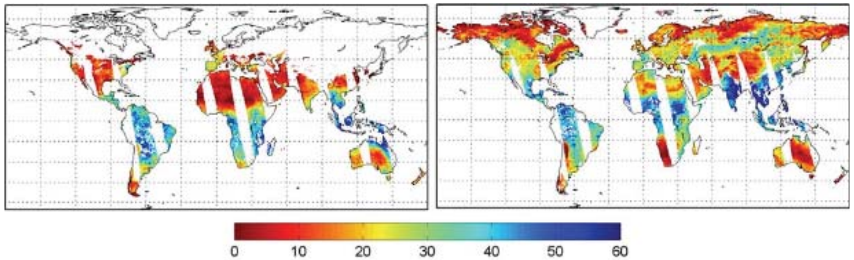
The information is created and transported by electromagnetic (em) waves

Remote Sensing system components

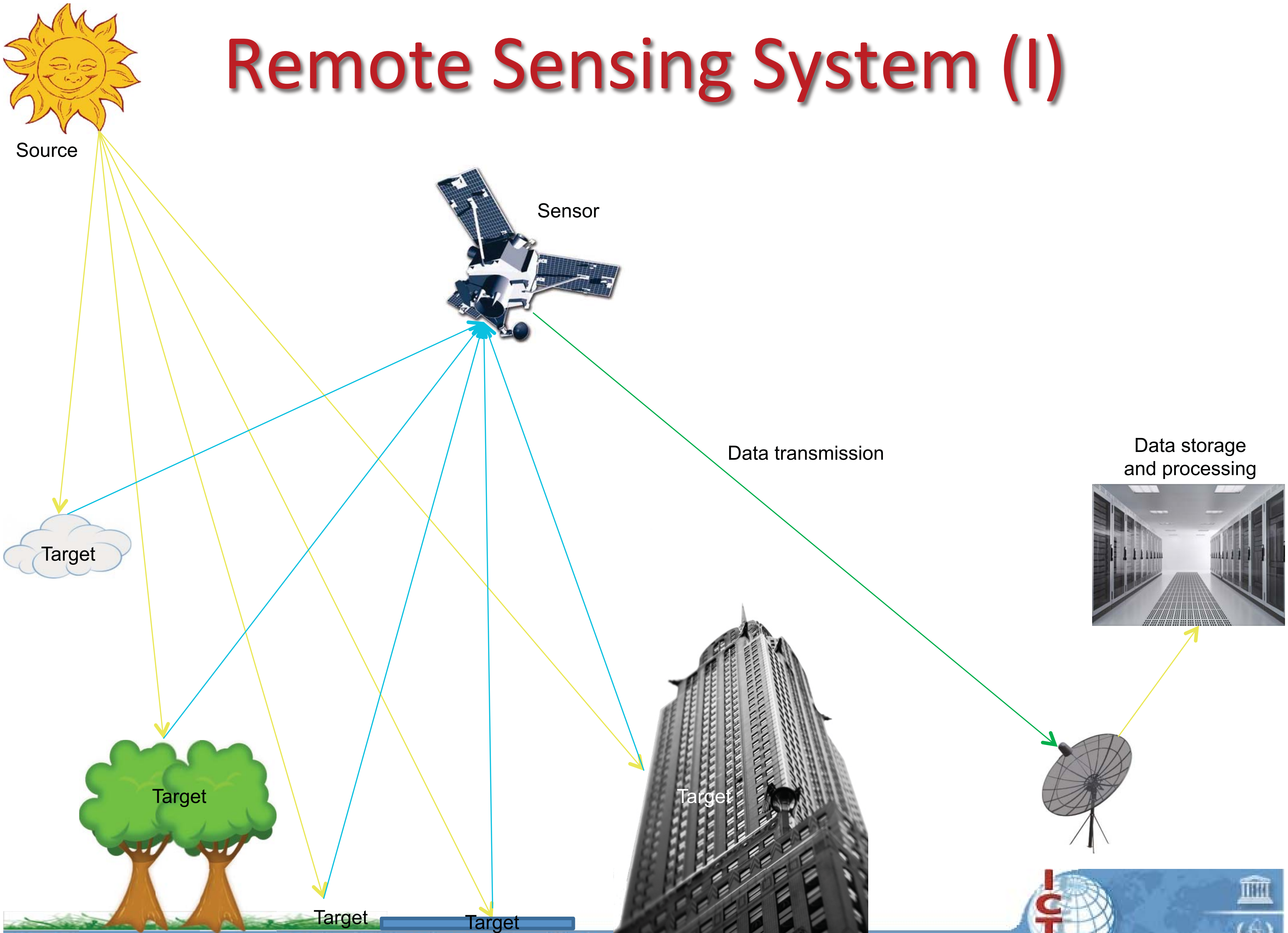
Target (object to be studied)
Radiation source
Radiation path
Platform/Sensor
Data recording system

Remote Sensing

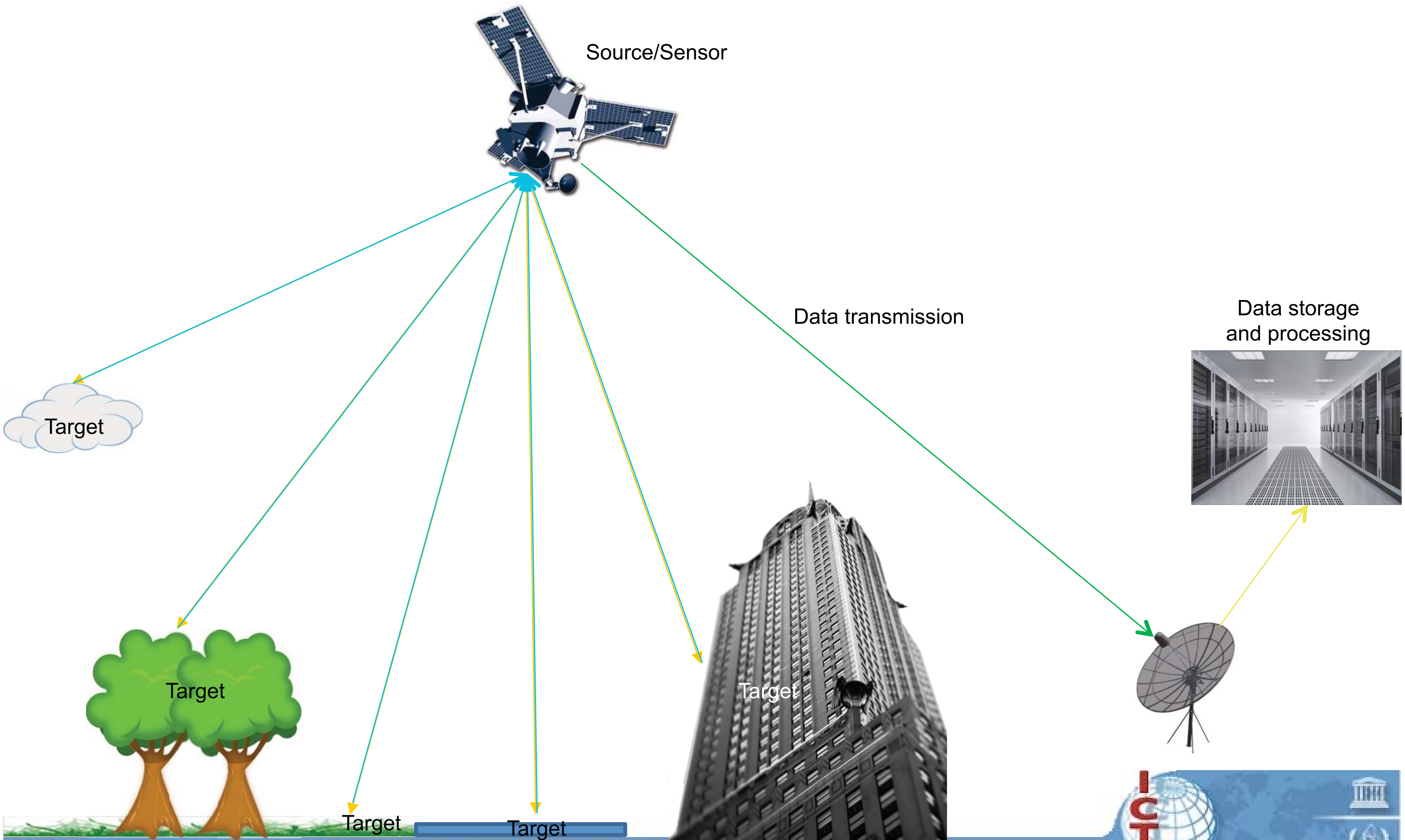
We will focus here on:
satellite remote sensing
and
land surface products



Remote Sensing System (I)



Remote Sensing System (II)



Remote Sensing Applications

Agriculture

Forestry

Water resources

Land cover and land use

Atmospheric monitoring

Oceanography

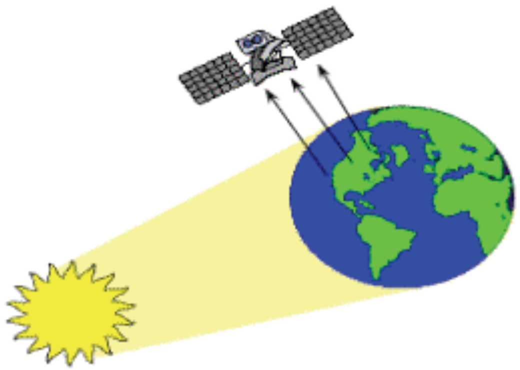
Disasters warning/management

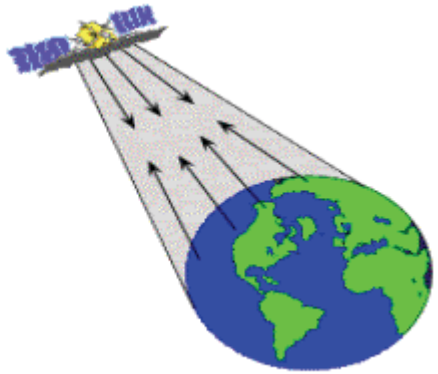
Environment

Remote Sensing Sensors (I)

The sensor measures the em radiation reflected and/or emitted by the Earth surface and the atmosphere within chosen frequency periods

Passive sensors (Radiometers)	**Active sensors** (Radar, lidar, acustic sondes …)
• Measure the em radiation emitted by the target • Measure the solar radiation reflected or diffused by the target	• Measure the em radiation generated by the sensor itself, reflected or diffused by the target

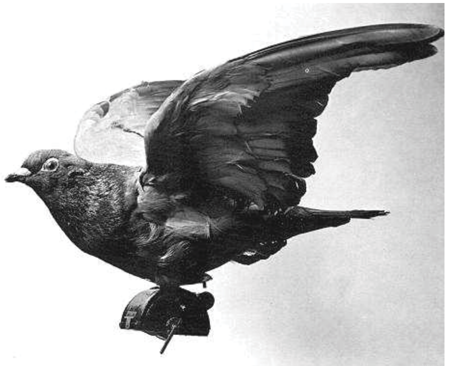




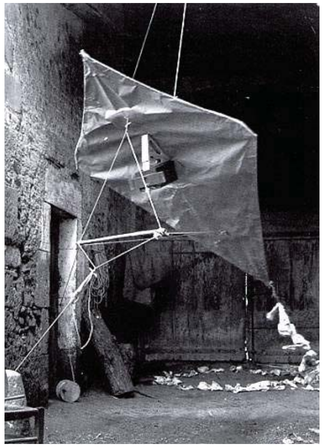
Remote Sensing Sensors (II)

Platforms

Historical platforms



Pigeons



Kites

Radiosondes

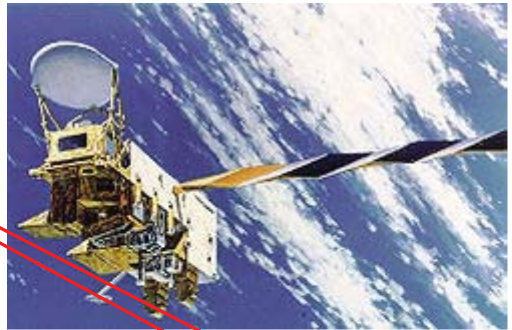
Ground based

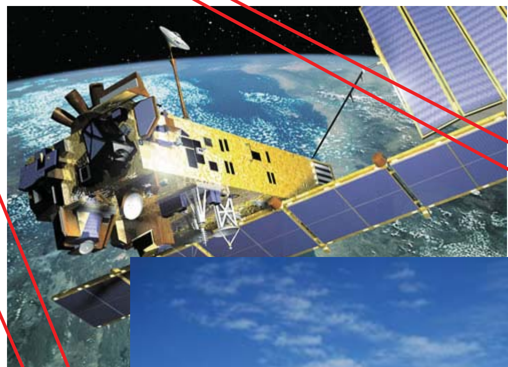
Remote Sensing Sensors (III)

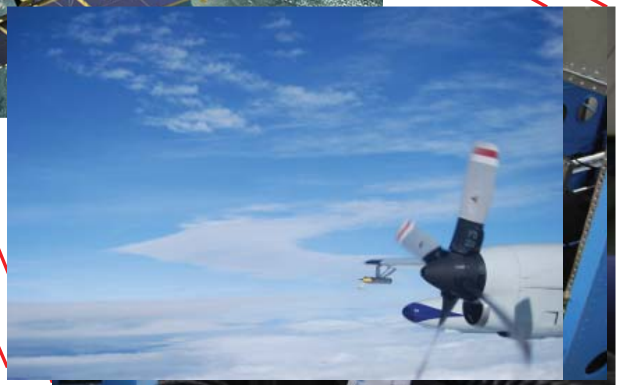
Platforms

Aircrafts

Satellites







International Space Station (ISS)

Choice of the sensor or dataset

What is the target?
Choice of frequency and the platform

What is the purpose of your study?
Choice of temporal and spatial resolution

Right sensor

Where is the target located?
Choice of coverage

What is the period of interest?
Choice of data availability

Measurements and Estimations

You can directly measure a parameter when you touch the target (e.g. weather station, radiosonde), otherwise you estimate it (e.g. satellite, radiometers)
Also when you touch the target you may not be able to measure it directly (e.g. aircraft)

How to know what you are working with?
How to know if you are working with the right products?

LPRM-AMSR_E_L2_A_SOILM2_V002-20120512T104029Z_20020619011910.nc

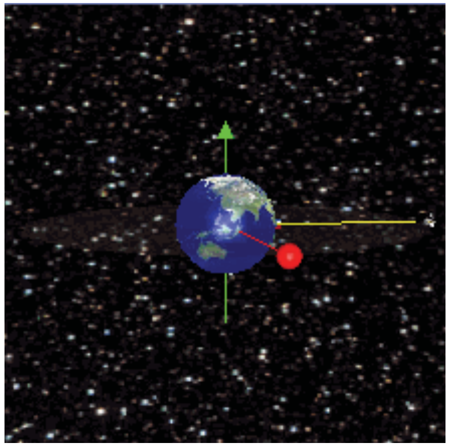
Algorithm
Sensor
Level
Orbit
Product
Version
Date
Format

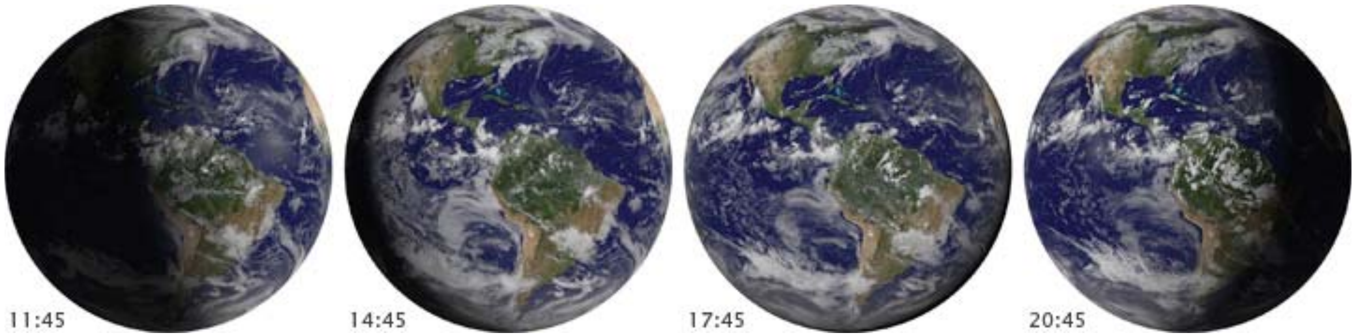
Technical Specifications

Satellite remote sensing (I)

Geostationary orbit

A satellite in a circular geosynchronous orbit directly over the equator (eccentricity and inclination at zero) will have a geostationary orbit that does not move at all relative to the ground. It is always directly over the same place on the Earth's surface. When a satellite reaches exactly 42,164 kilometers from the center of the Earth (about 36,000 kilometers from Earth's surface), its orbit matches Earth's rotation. They are valuable for weather monitoring and communications.



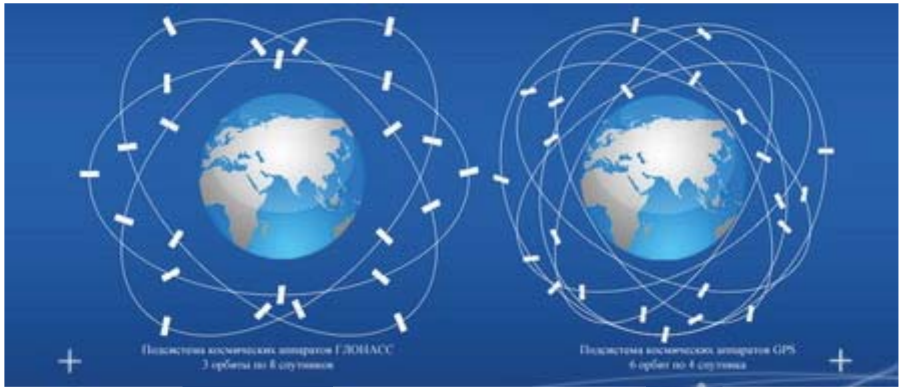


Examples: GOES (USA), Meteosat (EU), GMS (Japan), MTSAT (Japan), Fengyun (China), Elektro L1 (Russia), INSAT (India)

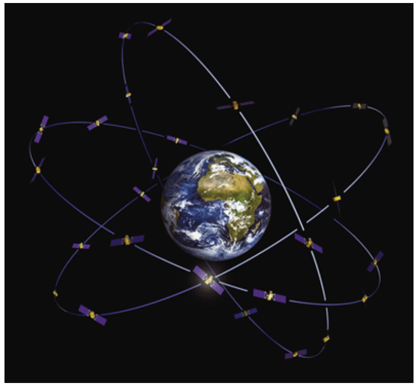
Satellite remote sensing (II)

Medium Earth Orbit (MEO)

The semi-synchronous orbit is a near-circular orbit (low eccentricity) 26,560 kilometers from the center of the Earth (about 20,200 kilometers above the surface). A MEO satellite takes 12 hours to complete an orbit. As the satellite moves, the Earth rotates underneath it. In 24-hours, the satellite crosses over the same two spots on the equator every day. It is the orbit used by the GPS satellites.



GLONASS GPS



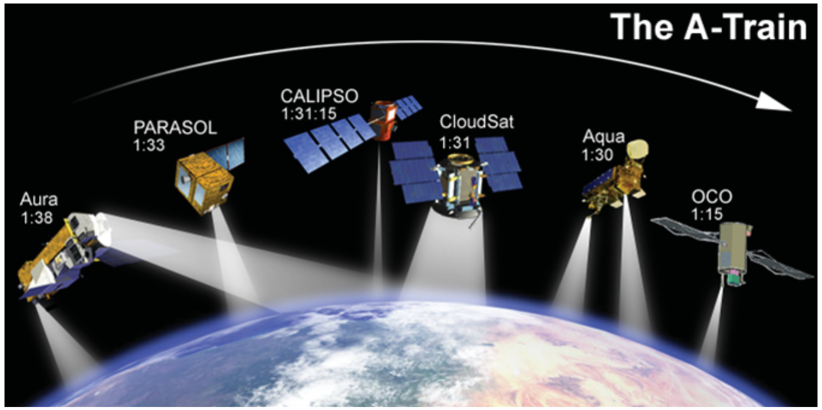
GALILEO

Examples: GPS (USA), Glonass (Russia), GALILEO (EU), Compass (China), IRNSS (India), QZSS (Japan)

Satellite remote sensing (III)

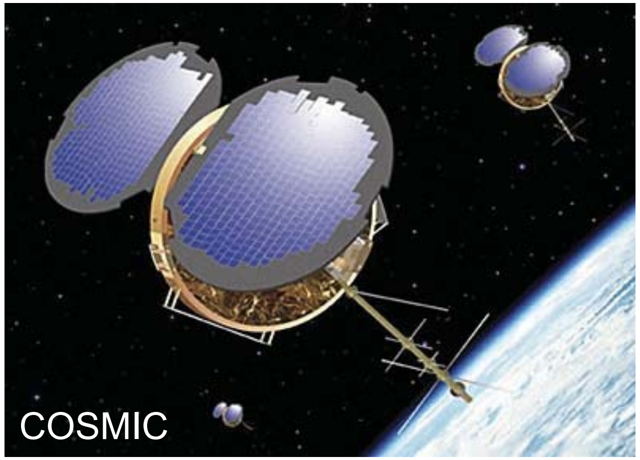
Polar orbit and Low Earth Orbits (LEO)

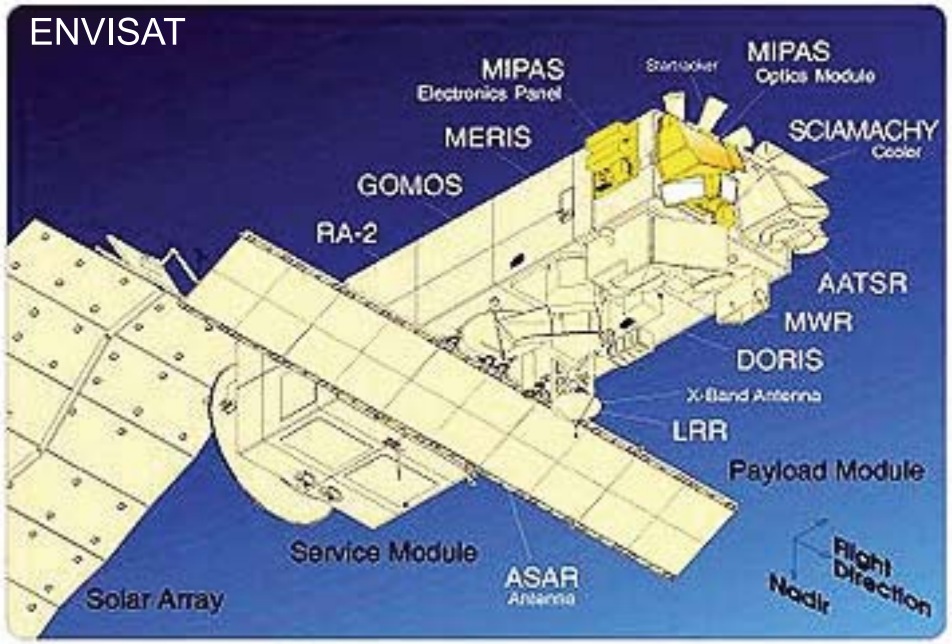
Most scientific satellites and many weather satellites are in a nearly circular, Low Earth Orbit (less than 2000 km of altitude). The satellite's inclination depends on what the satellite was launched to monitor. Many of the satellites in Earth Observing System have a nearly polar orbit. In this highly inclined orbit, the satellite moves around the Earth from pole to pole, taking about 99 minutes to complete an orbit. During one half of the orbit, the satellite views the daytime side of the Earth. At the pole, satellite crosses over to the nighttime side of Earth.

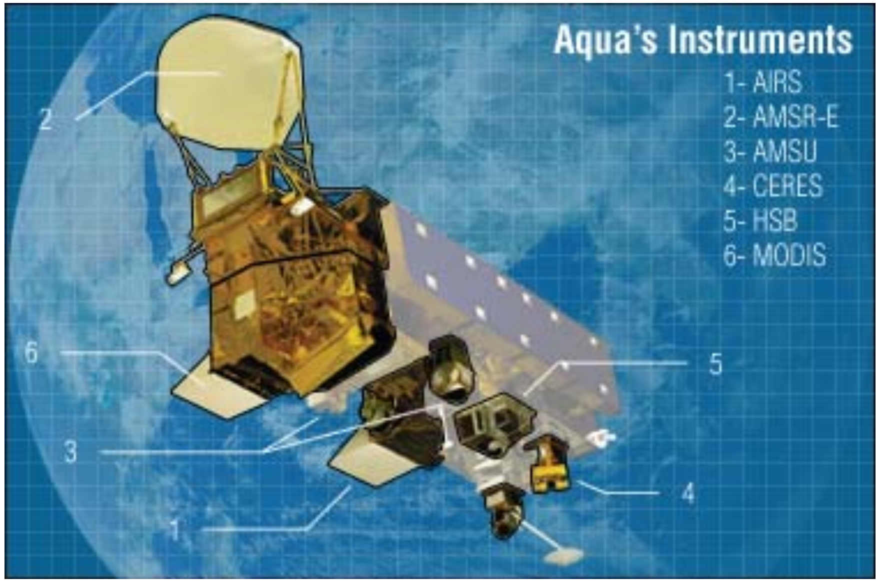


Examples: A-Train (USA), ENVISAT(EU), TRMM (USA), ISS (International Space Station)

Satellite Remote Sensing Sensors



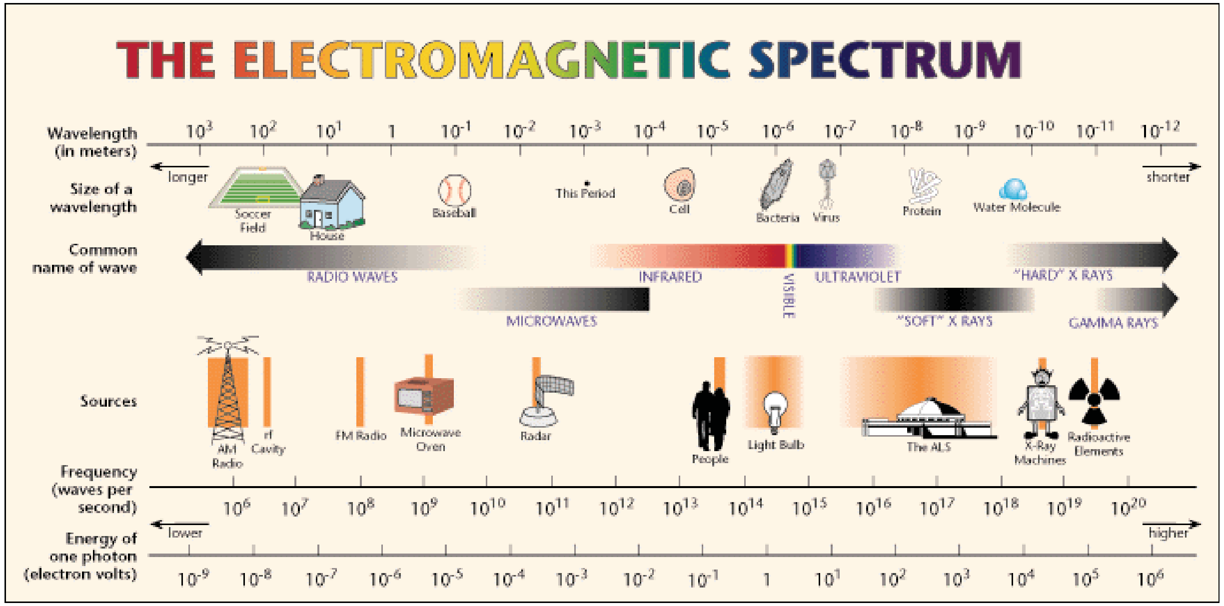




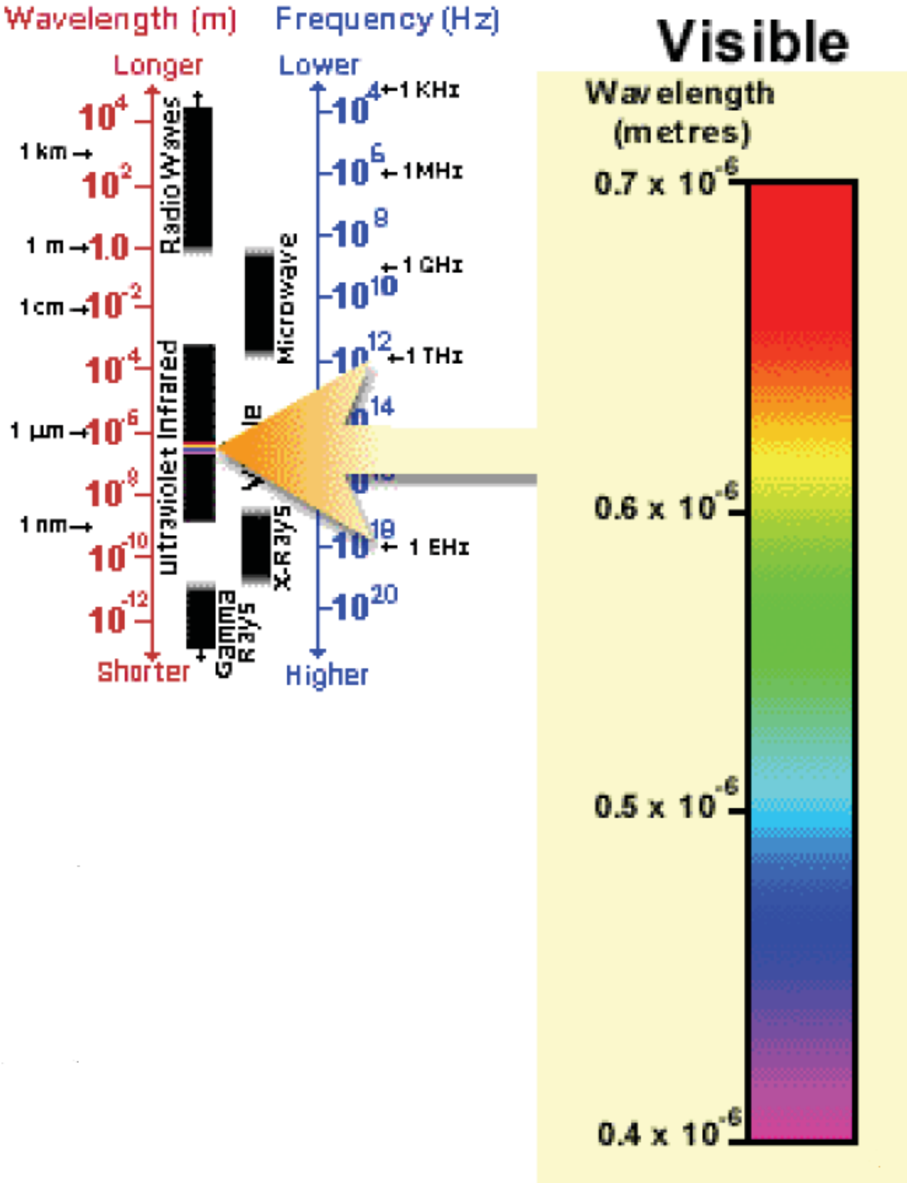
Electromagnetic Waves (I)

Electromagnetic waves are energy transported through space in the form of periodic disturbances of electric and magnetic fields. The parameters that characterize a wave motion are **wavelength (lambda)**, **frequency (f)** and **velocity (c)** related by the equation c=f*lambda with c=2.99792458x10^8 m/s

Electromagnetic radiation is composed of many discrete units called photons/quanta. The energy of photons is Q=hc/lambda=hf where Q is the energy of quantum, h= Plank's constant. Greater is the frequency of em radiation, higher is the energy.



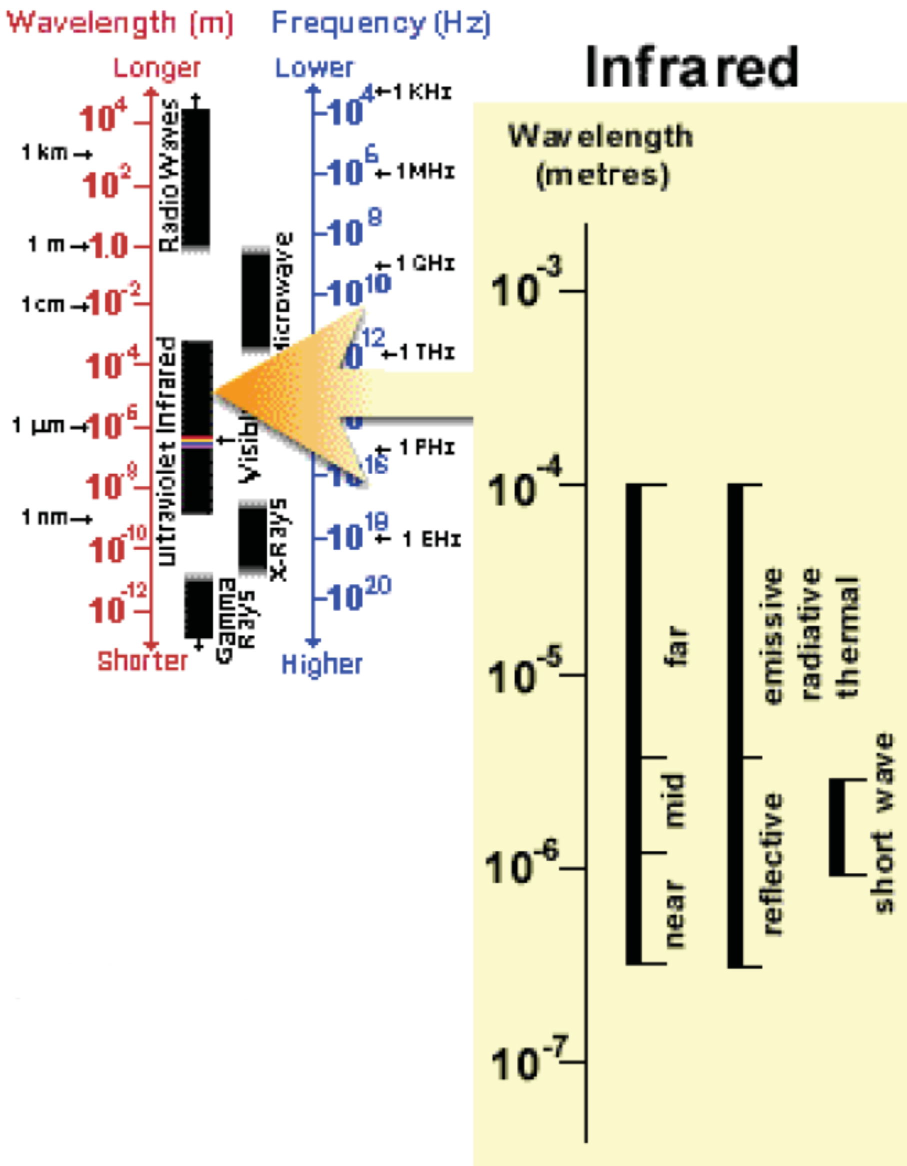
Electromagnetic Waves (II)



The energy detected by human eyes is in the visible frequency range which is a small part of the spectrum.
Most of the radiation is invisible to the human eyes but it can be detected using remote sensing sensors.

VIOLET:	0.400 - 0.446 µm
BLUE:	0.446 - 0.500 µm
GREEN:	0.500 - 0.578 µm
YELLOW:	0.578 - 0.592 µm
ORANGE:	0.592 - 0.620 µm
RED:	0.620 - 0.700 µm

Electromagnetic Waves (III)



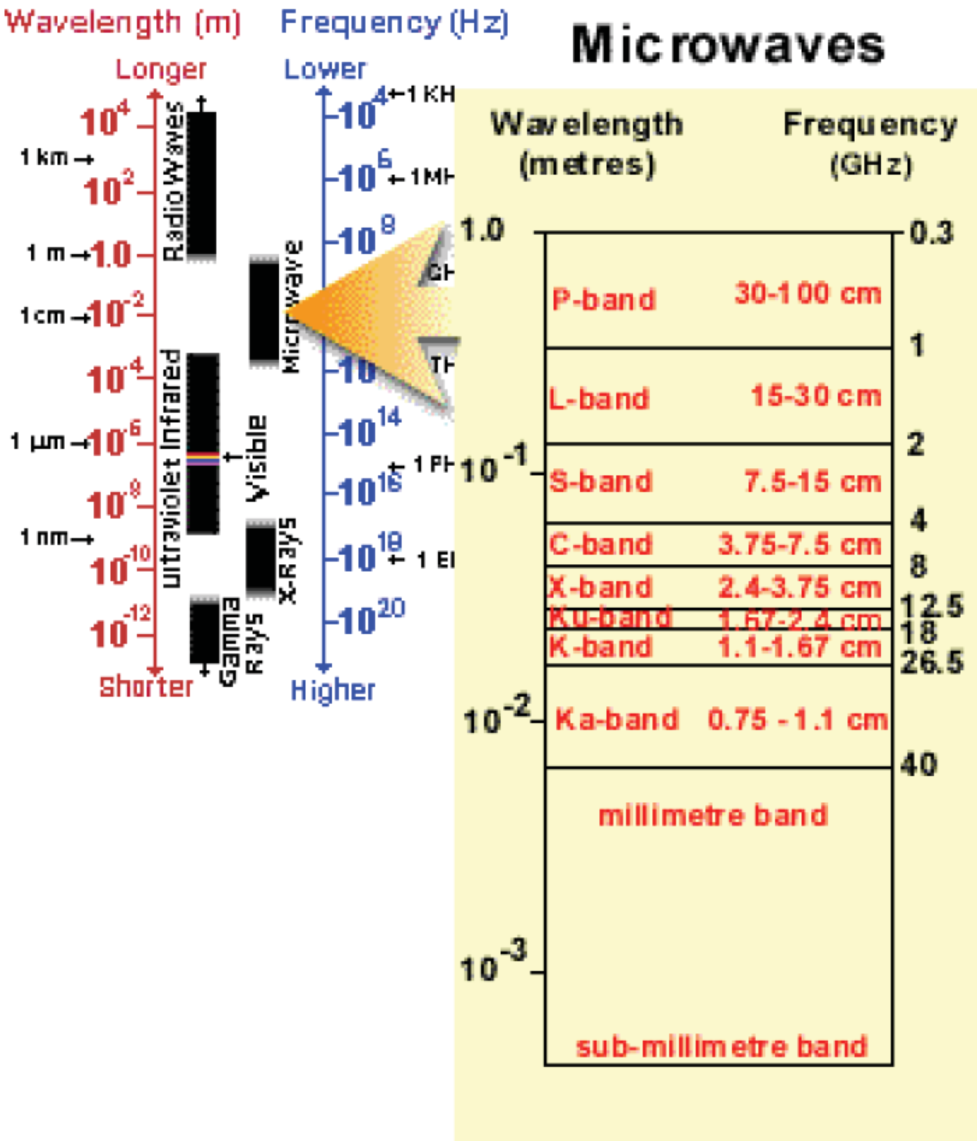
The infrared (IR) spectrum ranges from 0.7 µm to 100 µm

The IR region can be divided into 2 different sub-regions based on the radiation characteristics of the target:

-Reflective IR from 0.7 µm to 3 µm

-Thermic IR from 3 µm to 100 µm

Electromagnetic Waves (IV)



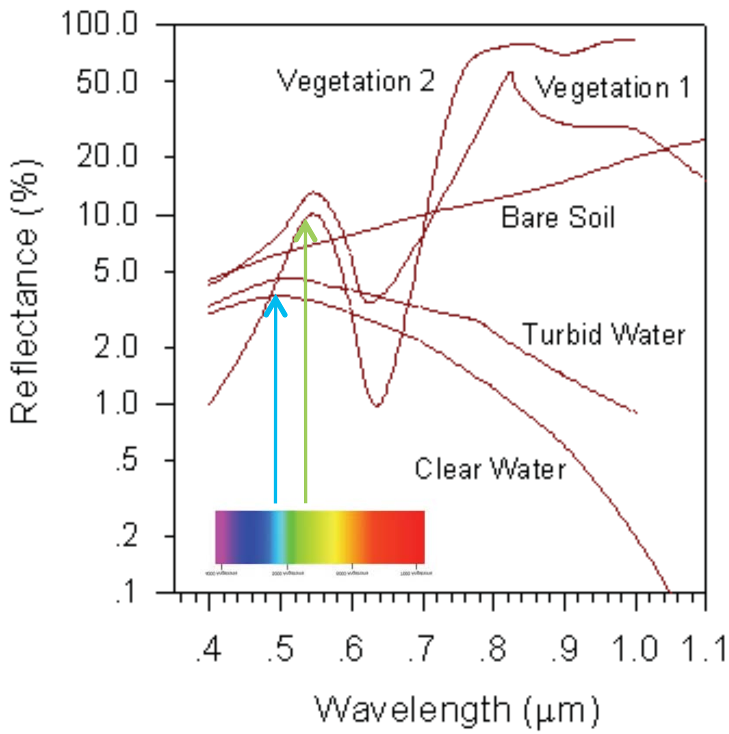
The microwave (MW) spectrum ranges from 1 mm to 1 m

Electromagnetic Waves (V)

Interaction of elctromagnetic waves and the Earth surface

When solar radiation hits a target surface, it may be transmitted, absorbed or reflected.
Different materials reflect and absorb differently at different wavelengths.
The reflectance spectrum is a unique signature for the material.

The reflectance of **clear water** is generally low. However, the reflectance is maximum at the blue end of the spectrum and decreases as wavelength increases. Hence, clear water appears dark-bluish. **Turbid water** has some sediment suspension which increases the reflectance in the red end of the spectrum, accounting for its brownish appearance. The reflectance of **bare soil** generally depends on its composition. **Vegetation** has a unique spectral signature which enables it to be distinguished readily from other types of land cover in an optical/near-infrared image. The reflectance is low in both the blue and red regions of the spectrum, due to absorption by chlorophyll for photosynthesis. It has a peak at the green region which gives rise to the green colour of vegetation. In the **near infrared** (NIR) region, the reflectance is much higher than that in the **visible** band due to the cellular structure in the leaves. Hence, vegetation can be identified by the high NIR but generally low visible reflectances.



Remote Sensing requirements (I)

Spectral requirements

- Number of spectral bands
- Spectral resolution

refers to the specific wavelength intervals in the electromagnetic spectrum for which a satellite sensor can record the data: the number and dimension of specific wavelength intervals in the em spectrum to which a remote sensing instrument is sensitive.

Radiometric requirements

Radiometric resolution

Is the sensitivity of a remote sensing detector to differentiate in signal strength as it records the radiant flux reflected or emitted from the terrain. This is referred to by the number of bits into which the recorded energy is divided.

Spatial requirements

- Spatial resolution
- Coverage

Spatial resolution is the measure of smallest object that can be detected by a satellite sensor. The smaller the spatial resolution, the greater the resolving power of the sensor system. The coverage is the portion of Earth where the sensor is able to acquire data.

Temporal requirements

Temporal resolution

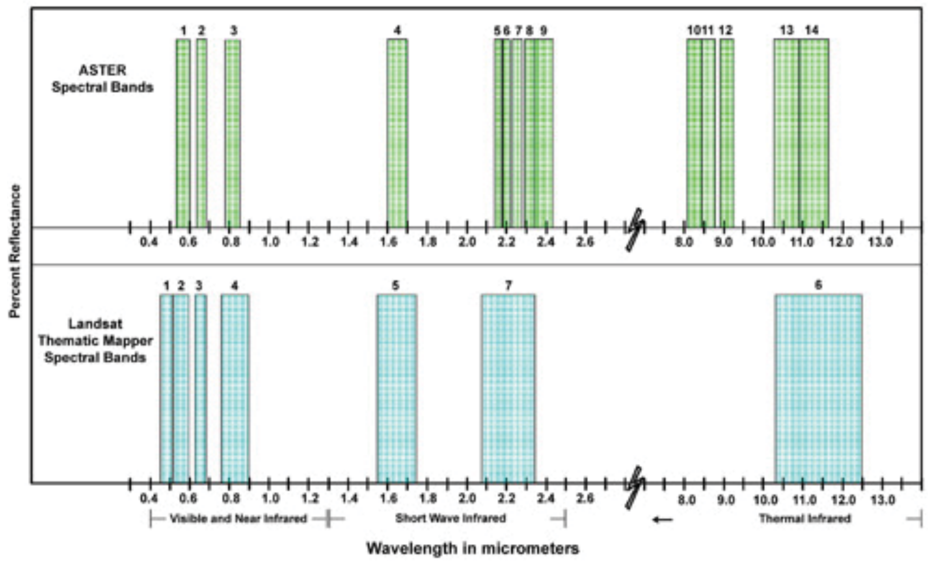
how frequently the sensor records imagery of a particular area.

Remote Sensing requirements (II)

Spectral resolution

The spectral resolution specifies the number of spectral bands in which the sensor can collect reflected radiance, it is the ability of the sensor to detect and “separate” independent spectral emissions

	Spectral Resolution	
	Band	Range (µm)
Landsat ETM+ Multispectral	Blue	0.45-0.52
	Green	0.52-0.60
	Red	0.63-0.69
	Near Infrared	0.76-0.90
	Middle IR	1.55-1.75
	Middle IR	2.08-2.35
Landsat ETM+ Panchromatic	Visible-NIR	0.45–0.90
QuickBird Multispectral	Blue	0.45-0.52
	Green	0.52-0.60
	Red	0.63-0.69
	Near Infrared	0.76-0.90
QuickBird Panchromatic	Visible-NIR	0.45-0.90



Multispectral refers to the sensor's spectral resolution. Sensors collecting between 2 and 16 portions (bands) along the em spectrum are typically considered multispectral. Landsat and SPOT are examples of multispectral sensors.

Hyperspectral is a term which typically denotes a continuous sampling along the EMS with greater than 16 bands. Hyperspectral sensors collect a set of contiguous observations across a large range of reflected light.

Remote Sensing requirements (III)

Radiometric resolution

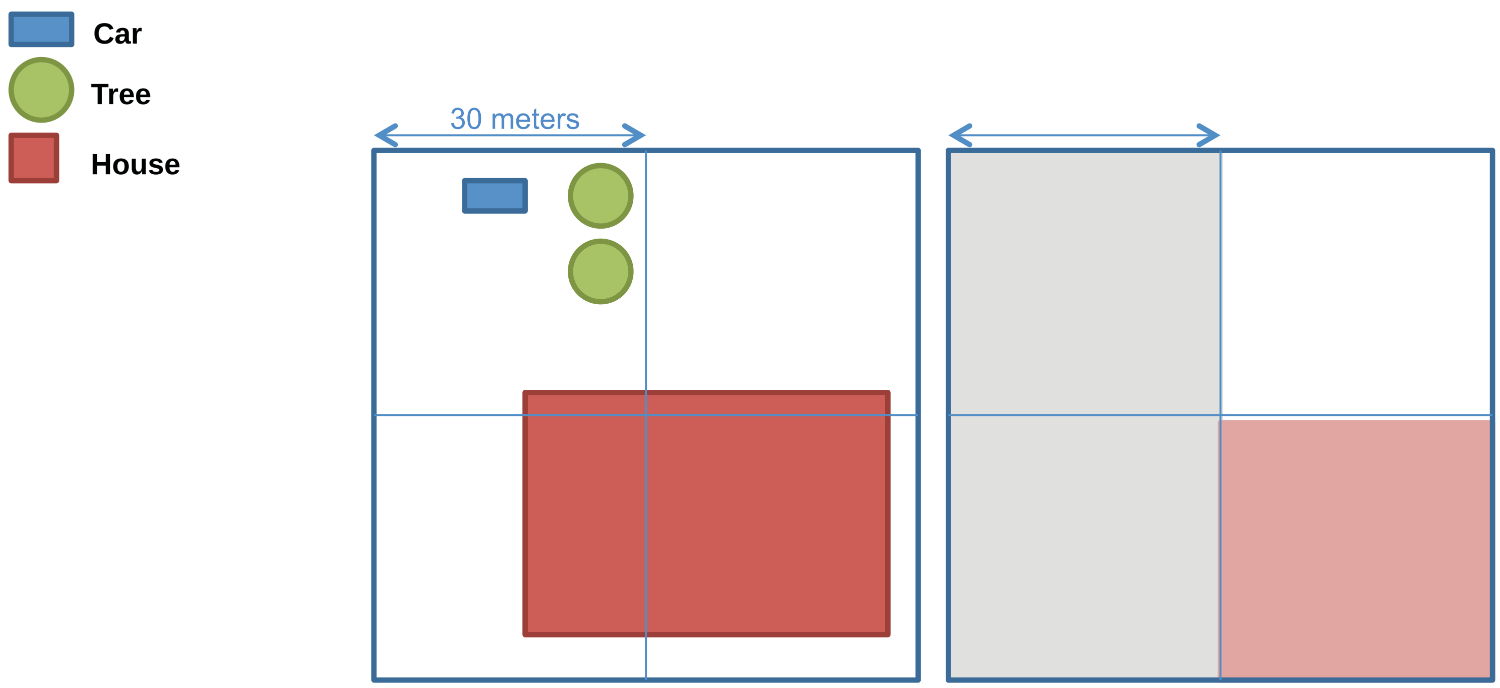
The radiometric resolution is sensitivity of the sensor to the magnitude of the electromagnetic energy, the smallest change in intensity level that can be detected by the sensing system

The radiometric resolution of an imaging system describes its ability to discriminate very slight differences in energy. The finer the radiometric resolution of a sensor, the more sensitive it is to detecting small differences in reflected or emitted energy.

Remote Sensing requirements (IV)

Spatial resolution

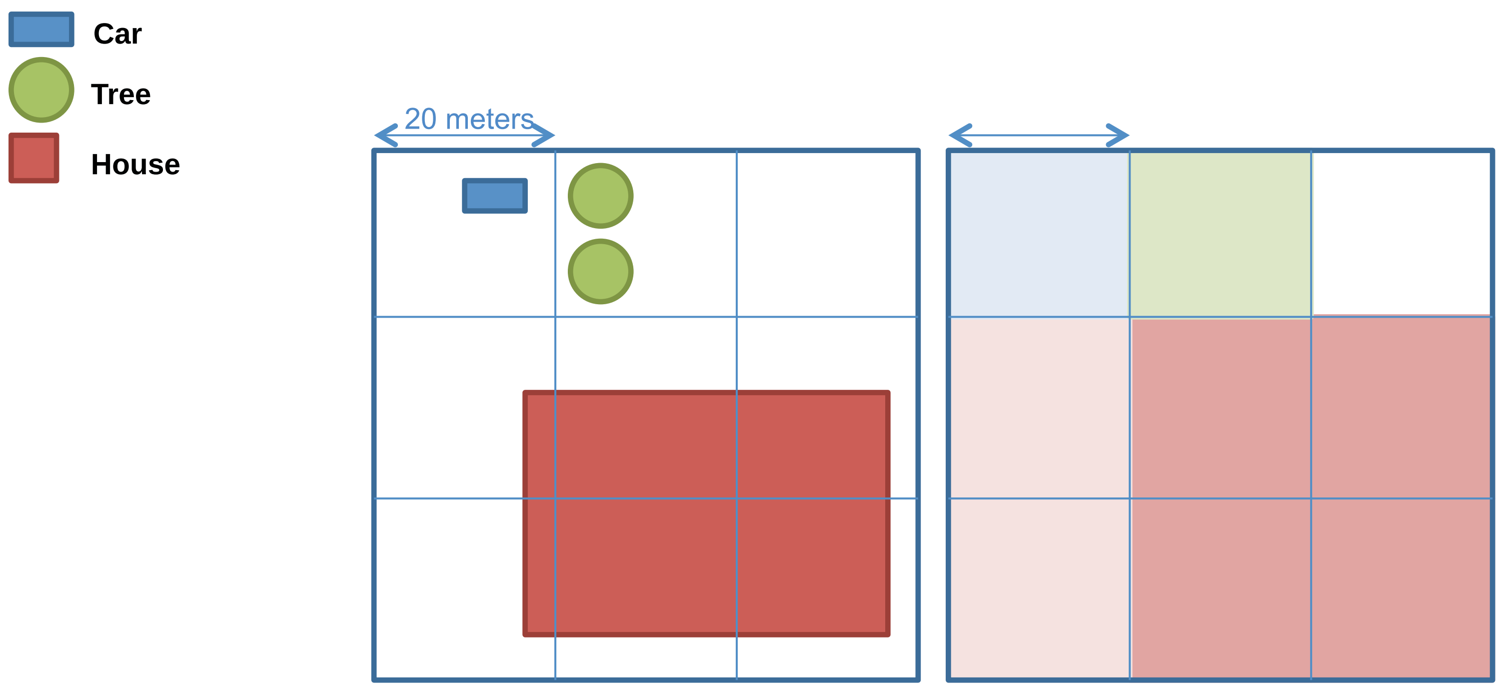
The spatial resolution is the minimum distance between distinguishable targets, the ability of the sensor to distinguish the object.



Remote Sensing requirements (IV)

Spatial resolution

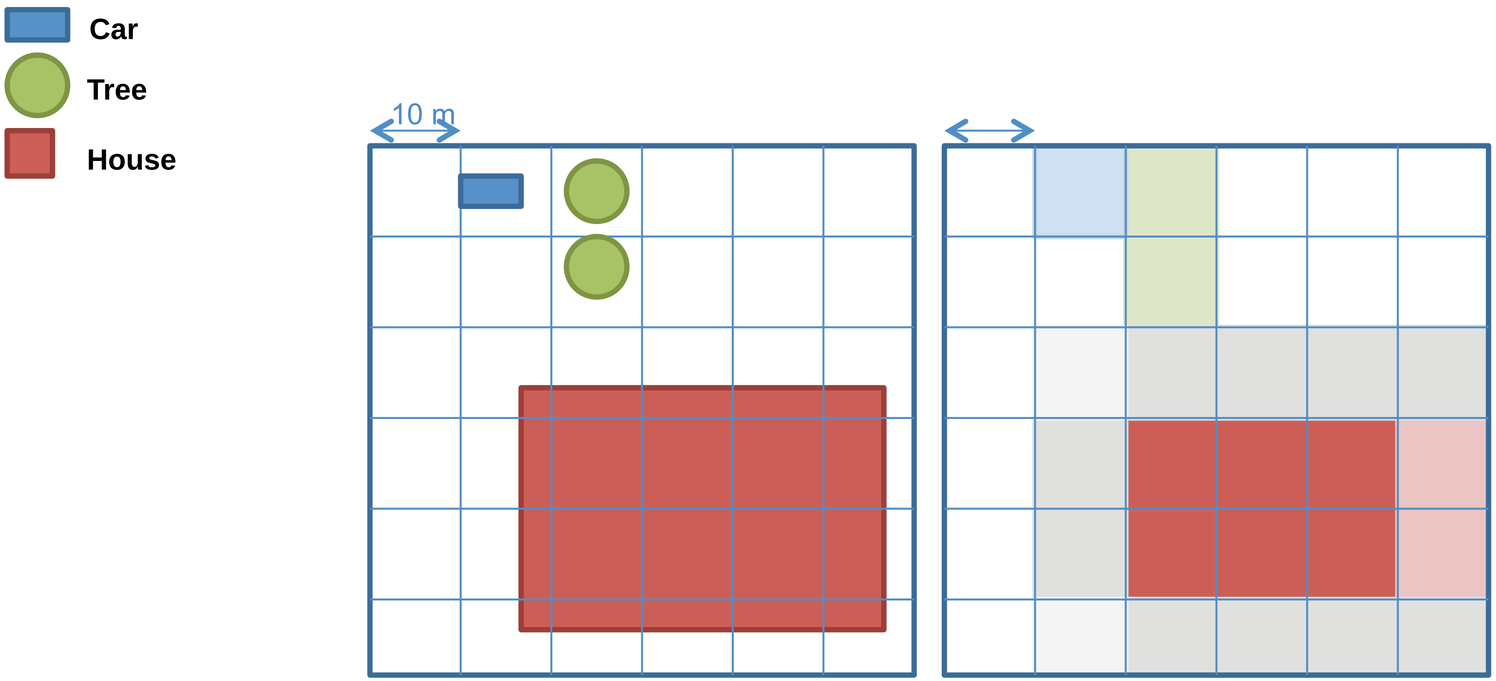
Increasing the resolution …



Remote Sensing requirements (IV)

Spatial resolution

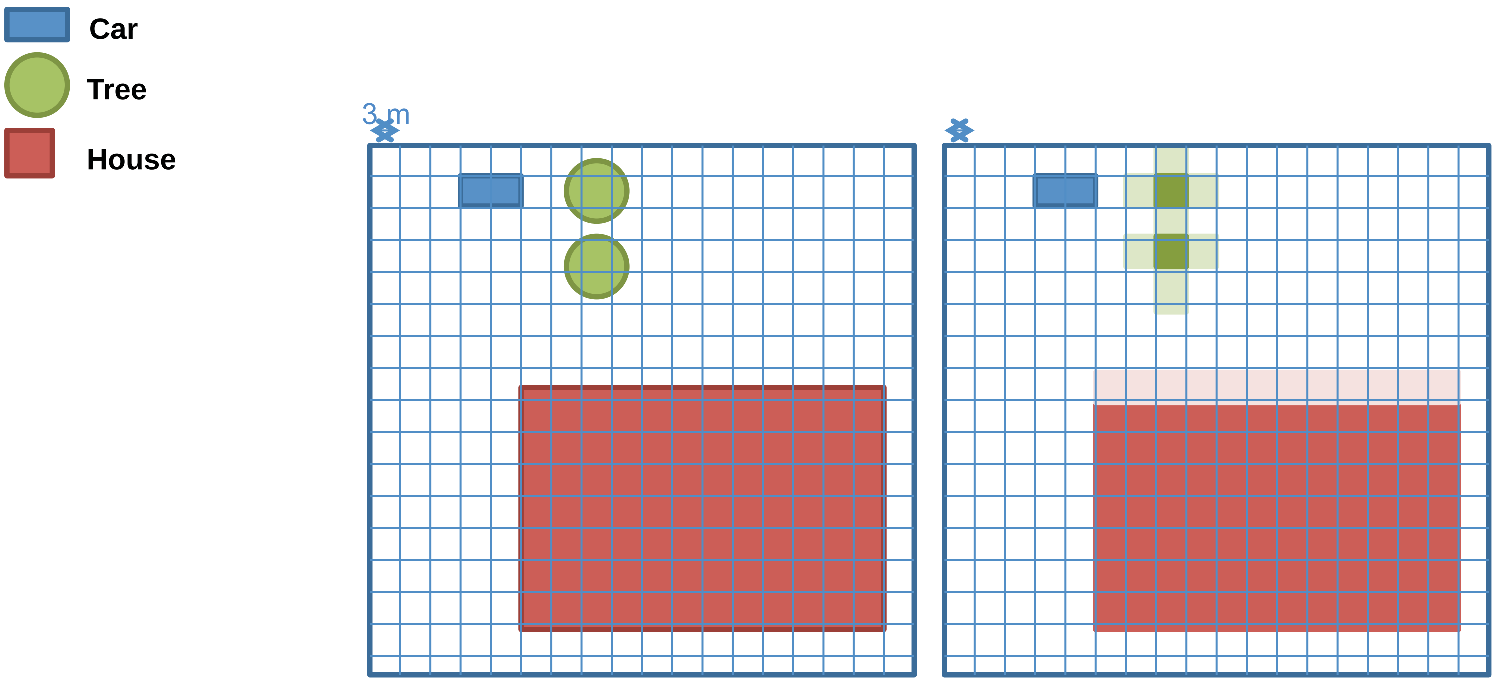
Increasing the resolution …



Remote Sensing requirements (IV)

Spatial resolution

Increasing the resolution …



You see the trees, the car and the house!!

Remote Sensing requirements (V)

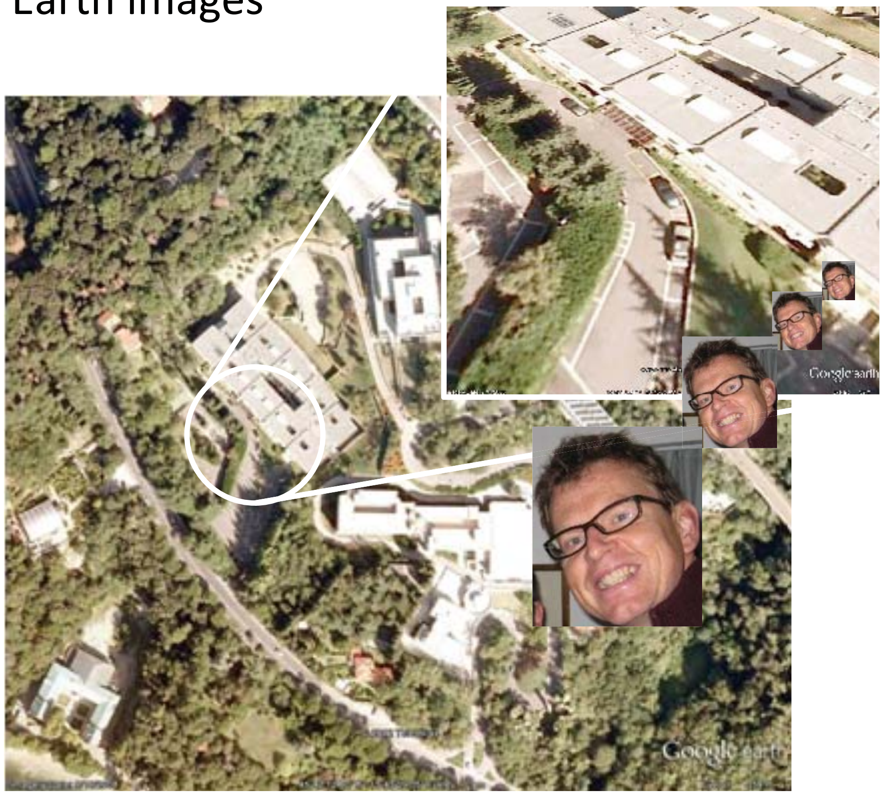
Spatial resolution

Real case: Google Earth images

You can't distinguish the details

From Landsat (15 meters resolution)

You can distinguish the white lines of the parking lot!

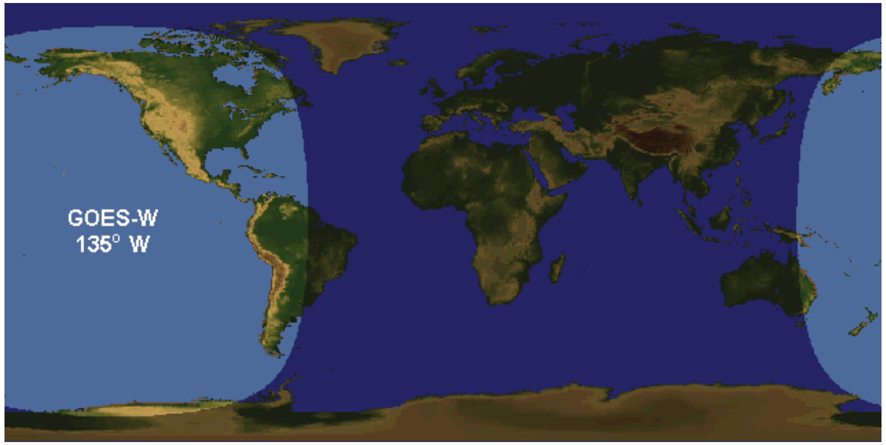


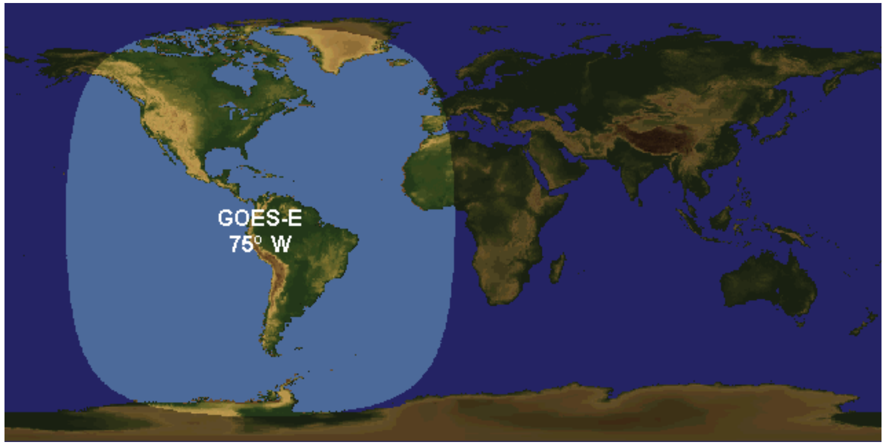
ICTP Trieste
45 cm resolution

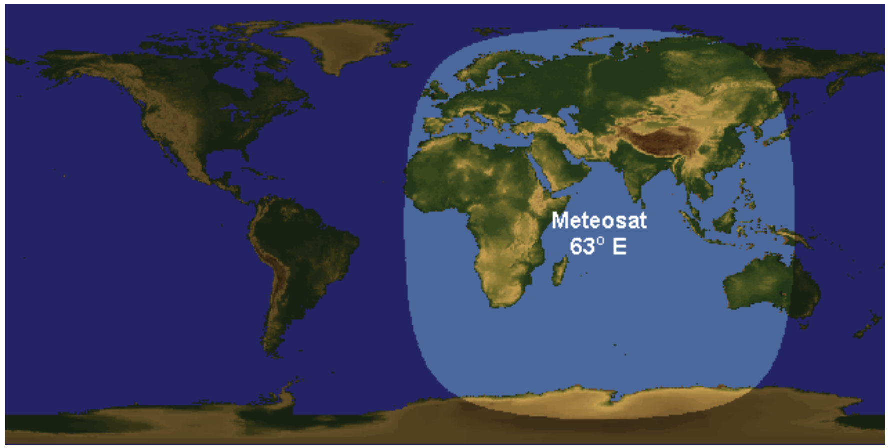
Remote Sensing requirements (VI)

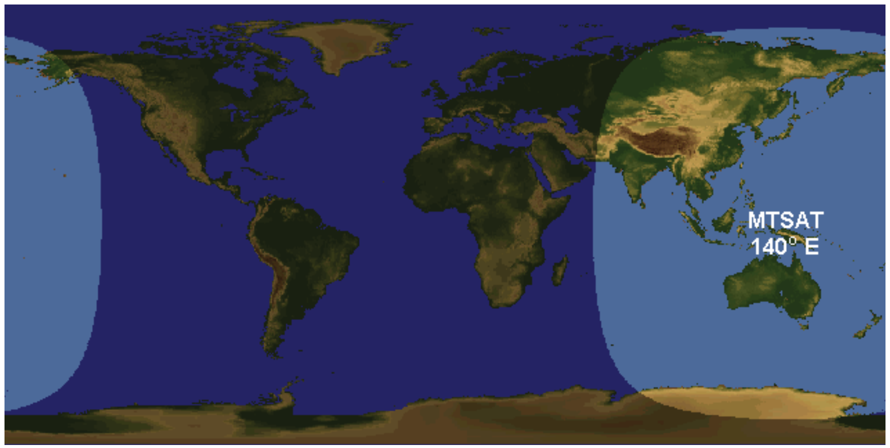
Coverage

The coverage is the portion of Earth where the sensor is able to acquire data









Remote Sensing requirements (VII)

Temporal resolution

Temporal resolution refers to how often the same geographic area is revisited by a sensor: the more frequently data are captured the better or finer is the temporal resolution

Temporal resolution is governed by the orbital characteristics of the satellite vehicle. Temporal resolution is often quoted as a "**revisit time**", the satellite revisit time is the time elapsed between observations of the same point on earth by a satellite. It depends on the satellite's orbit, target location, and swath of the sensor.

Temporal resolution is used for all the satellites, but revisit time is not usually used for geostationary satellites.

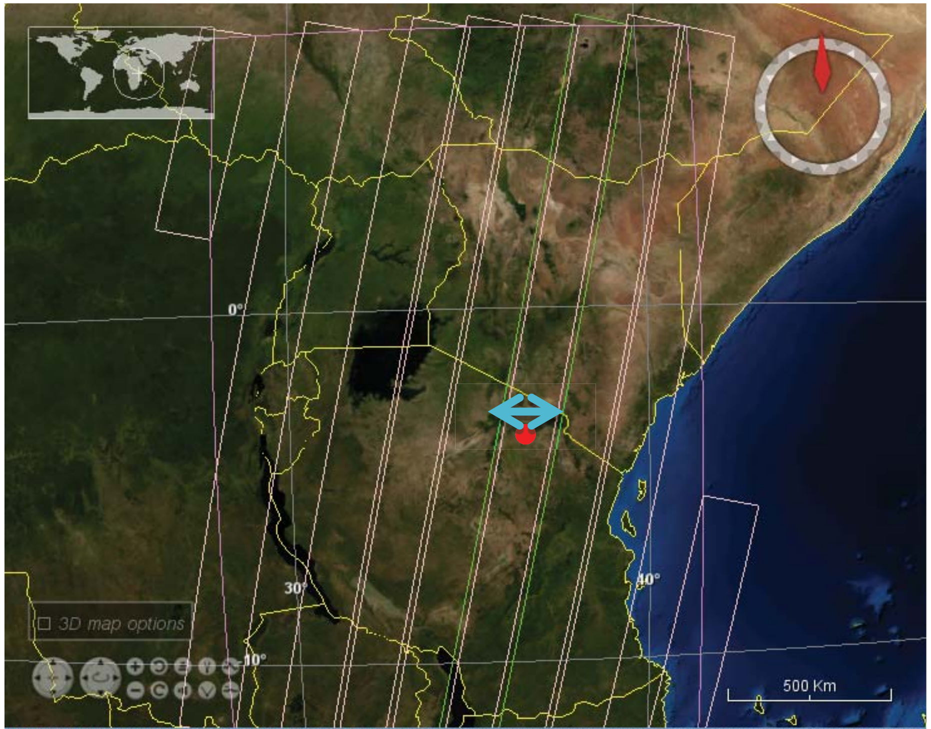
Examples:
- Meteosat temporal resolution is 15 minutes
- National Oceanic and Atmospheric Administration's (NOAA) Advanced Very High Resolution Radiometer (AVHRR) revisit time is 12 hours.
- Landsat Thematic Mapper revisits the same point every 16 days.
- SPOT revisits the same point every 14 days.

Remote Sensing requirements (VIII)

Temporal resolution

Temporal resolution refers to how often the same geographic area is revisited by a sensor: the more frequently data are captured the better or finer is the temporal resolution

Landsat (1 month) → 1 orbit



11 item(s) in Catalogue (11 out of 11 from last Query) - 1 item(s) selected

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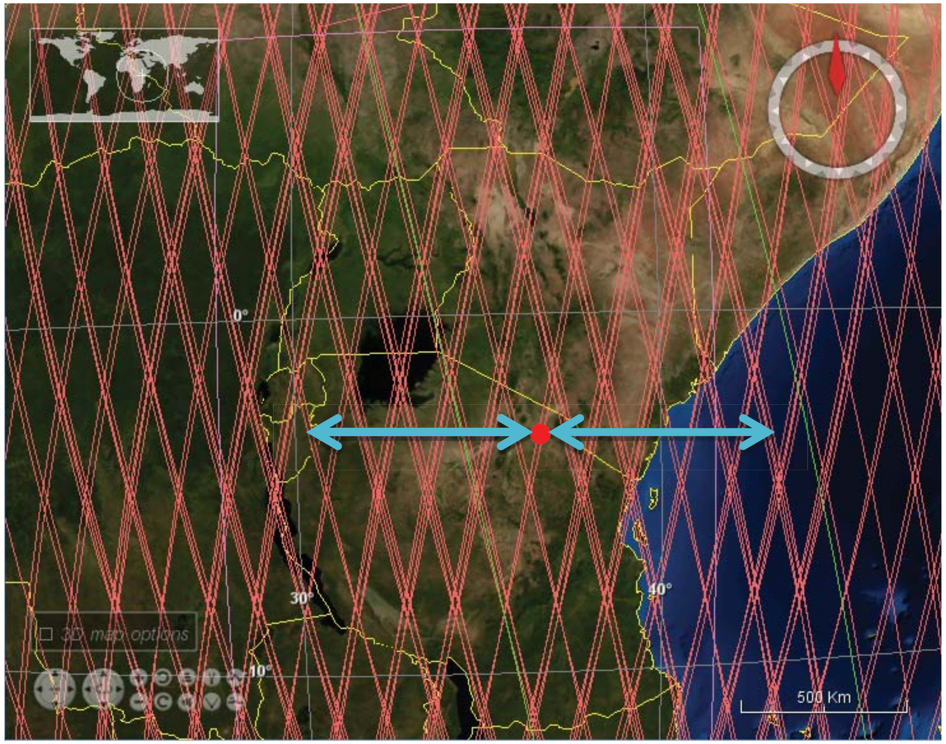
✔	☐	1	Landsat-5	TM	TM__TM__OP	Potential	2012-05-01 06:23:23.39	2012-05-01 06:2
✔	☐	2	Landsat-5	TM	TM__TM__OP	Potential	2012-05-02 07:00:54.45	2012-05-02 07:0
✔	☐	3	Landsat-5	TM	TM__TM__OP	Potential	2012-05-04 06:48:32.81	2012-05-04 06:5
✔	☐	4	Landsat-5	TM	TM__TM__OP	Potential	2012-05-05 07:31:48.52	2012-05-05 07:3
✔	☐	5	Landsat-5	TM	TM__TM__OP	Potential	2012-05-06 06:36:16.32	2012-05-06 06:4
✔	☐	6	Landsat-5	TM	TM__TM__OP	Potential	2012-05-07 07:19:26.89	2012-05-07 07:2

SMOS (1 month) → 40 orbits

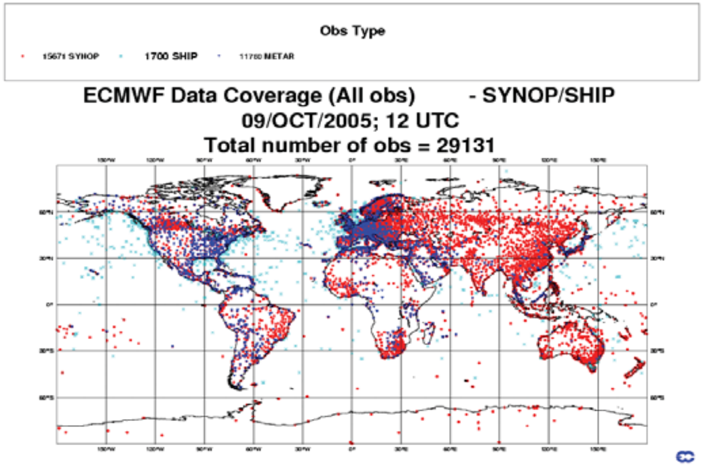


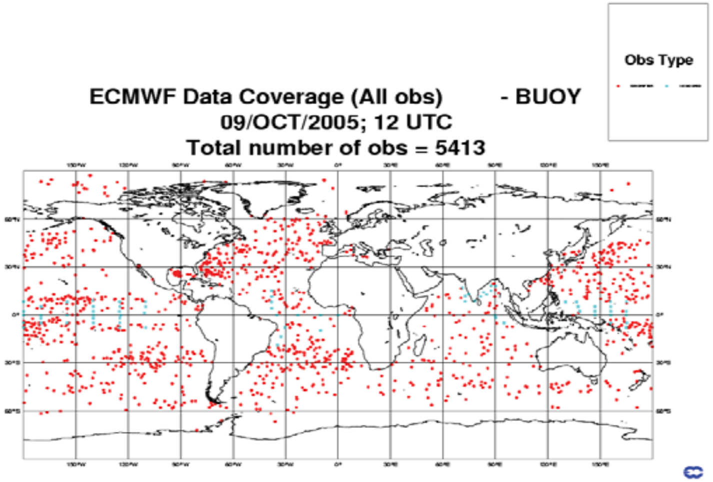
↔ Swath

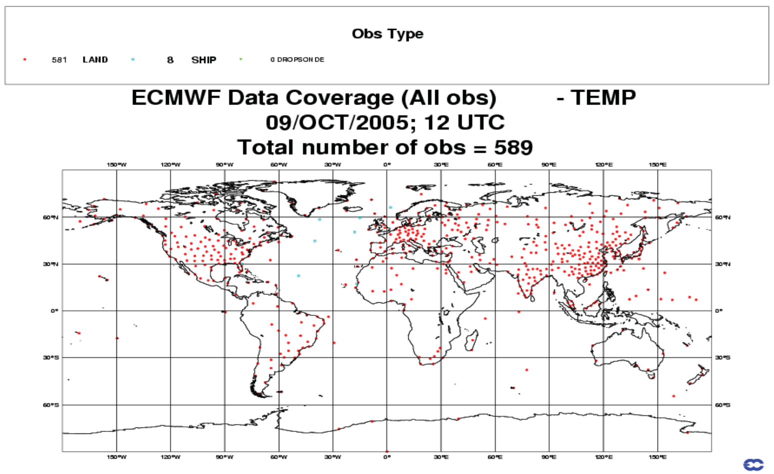
Satellite Remote Sensing

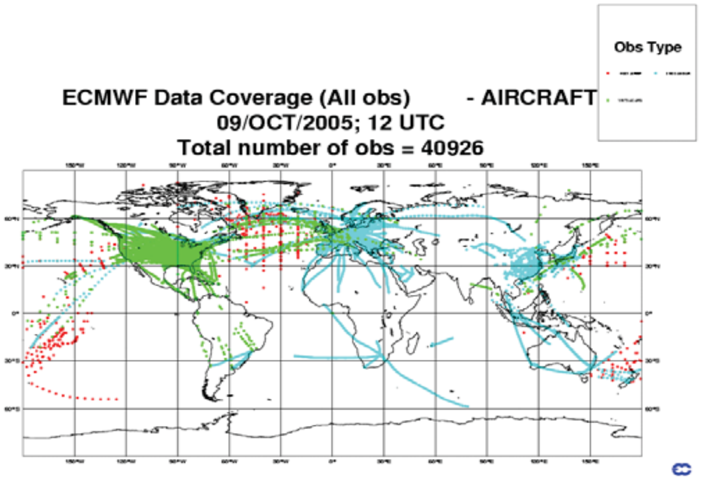
Why should we care about satellites??

Conventional data coverage





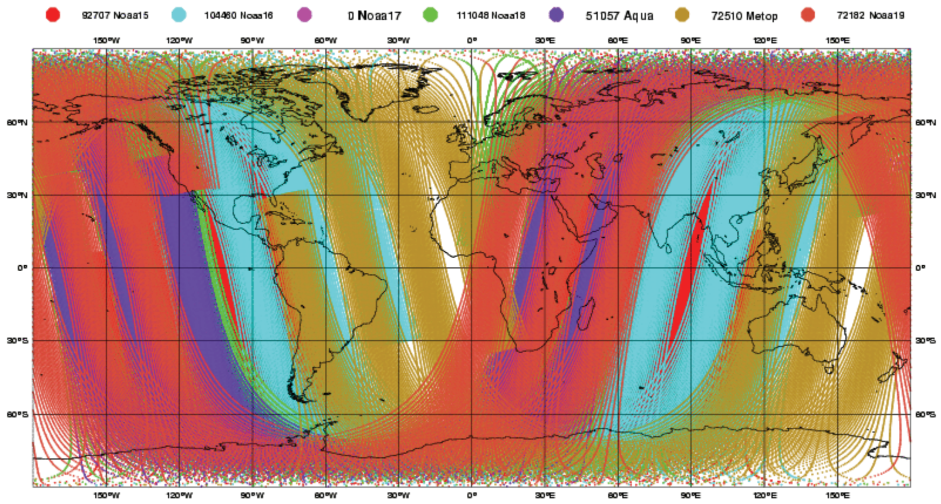




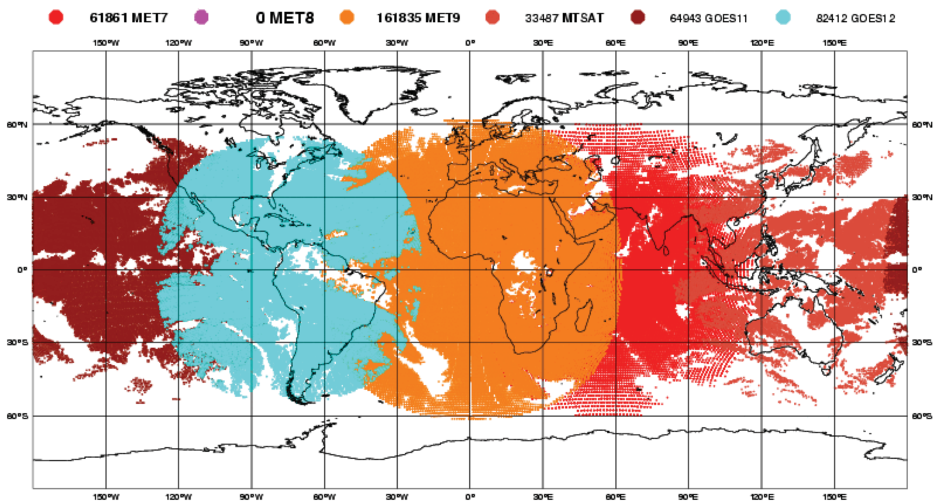
Satellite Remote Sensing

Why should we care about satellites??

Satellite data coverage



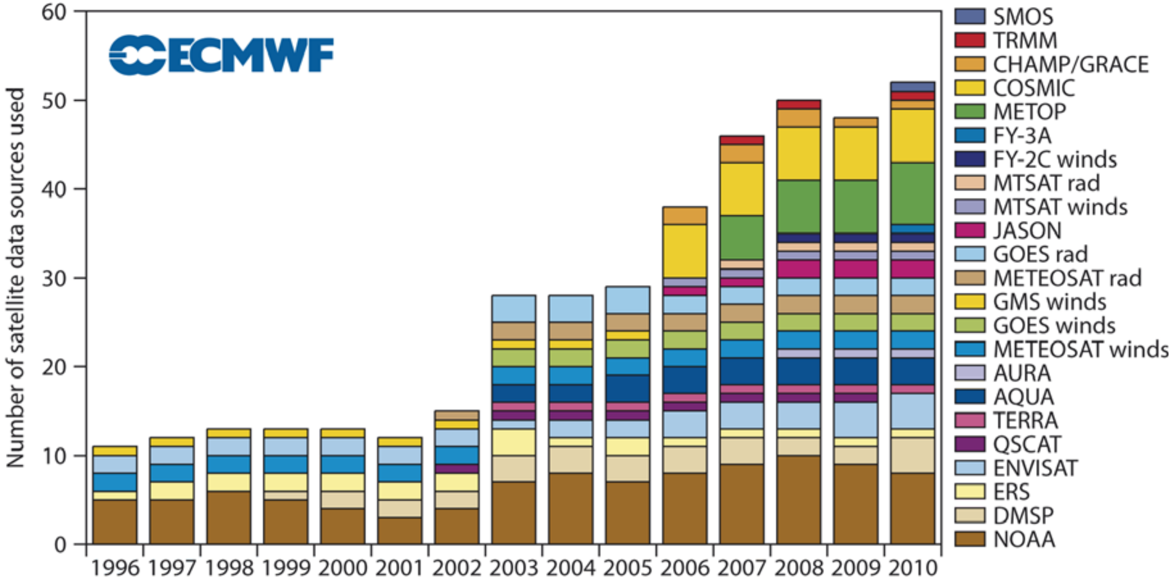
LEO satellites

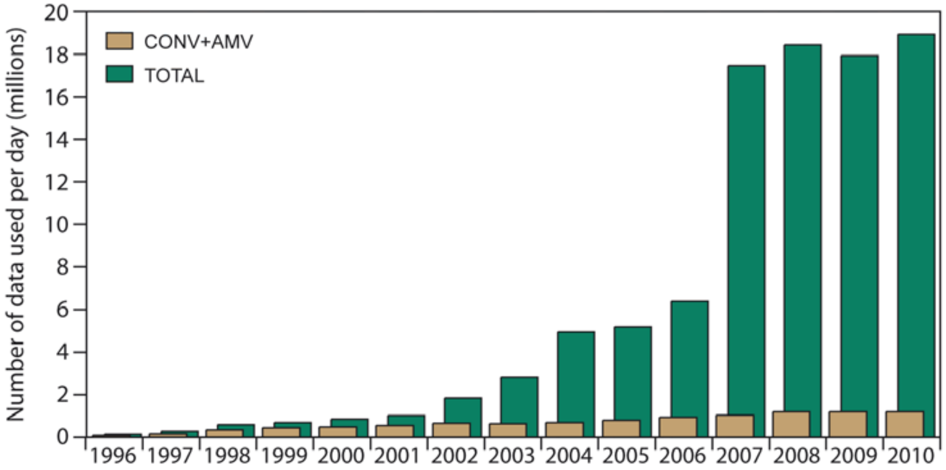


GEO satellites

Satellite data assimilation

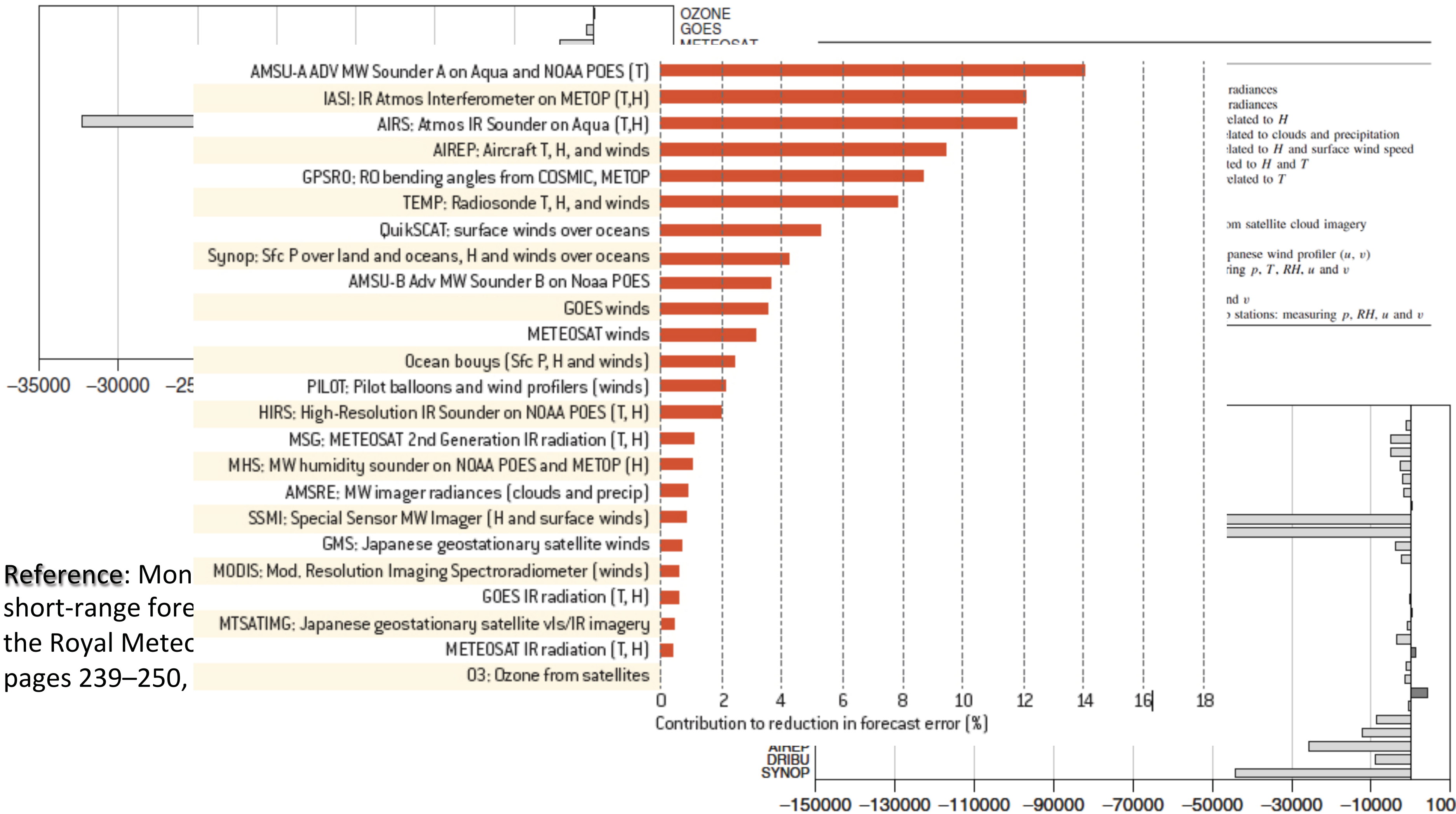
ECMWF





Satellite data assimilation

ECMWF



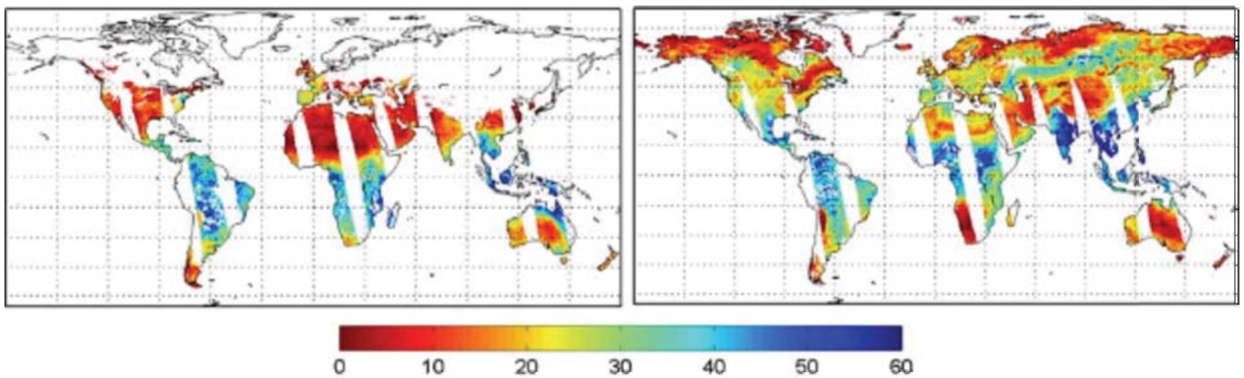
Reference: Mon
short-range fore
the Royal Metec
pages 239–250,

Surface parameters (I)

Platform: satellite **Aqua**
Orbit: polar orbit (LEO) at about 700 km of altitude with inclination 98 deg
Sensor: **AMSR-E** (Advanced Microwave Scanning Radiometer - EOS)
Passive sensor working at 6 different frequencies: 6.9, 10.6, 18.7, 23.8, 36.5, 89.0 GHz
Radiometric resolution: 0.6 K
Spatial resolution: 5.4-56 km
Coverage: global
Temporal resolution: (revisit time) 1-2 days

Available products (25 km, daily, EASE grid)

Air temperature Water fraction Soil moisture Vegetation opacity Integrated water vapor



Surface parameters (II)

AMSR-E land surface is very useful because it is the only one providing at the same time 5 different products with the same spatial and temporal resolution and the same field of view!

- Available from June 2002 to October 2011 (AMSR-E2 ??)
- All the data available at ICTP in nc format at daily and monthly temporal resolution for ascending and descending orbits

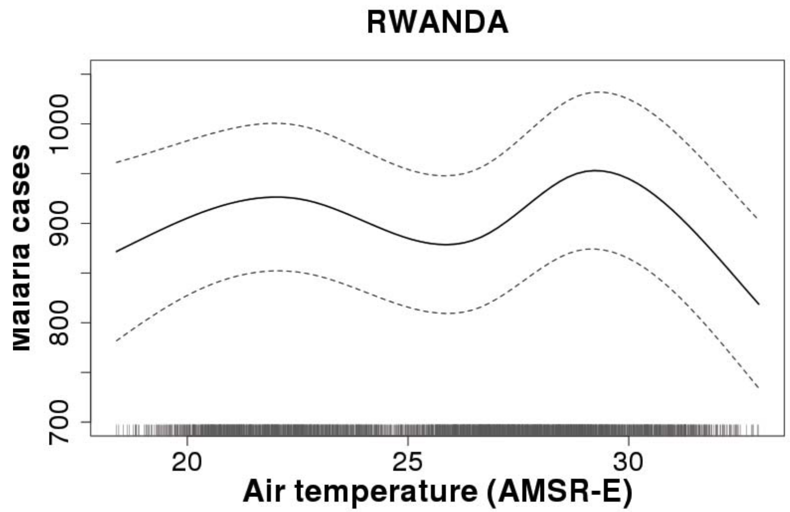
What is in the product?

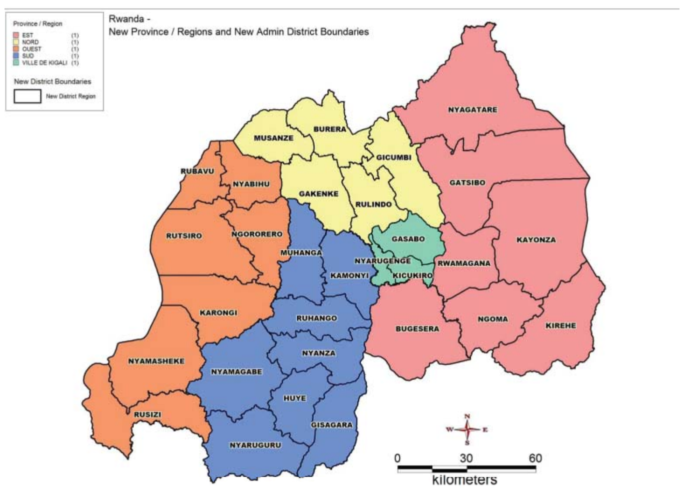
- Quality flag
- Air temperature at 2m height (same as meteo station)
- Fractional open water on land
- Vegetation canopy microwave transmittance
- Surface soil moisture (~2cm of depth)
- Integrated water vapor content of the atmosphere

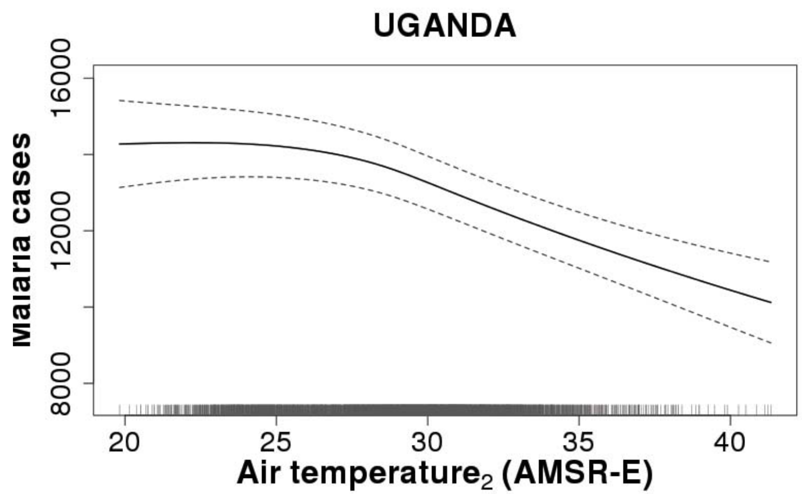
ftp://ftp.ntsg.umt.edu/pub/data/AMSRE_params/README_amsre_params_v1_2_u1.pdf

Surface parameters (III)

Application VECTRI (Felipe Colon Gonzalez)

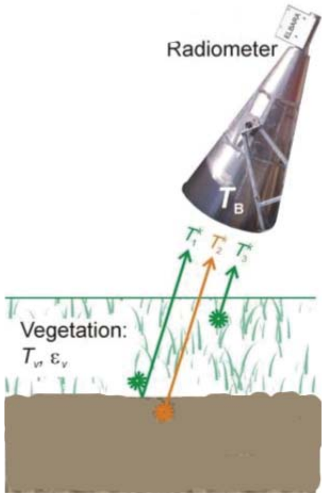


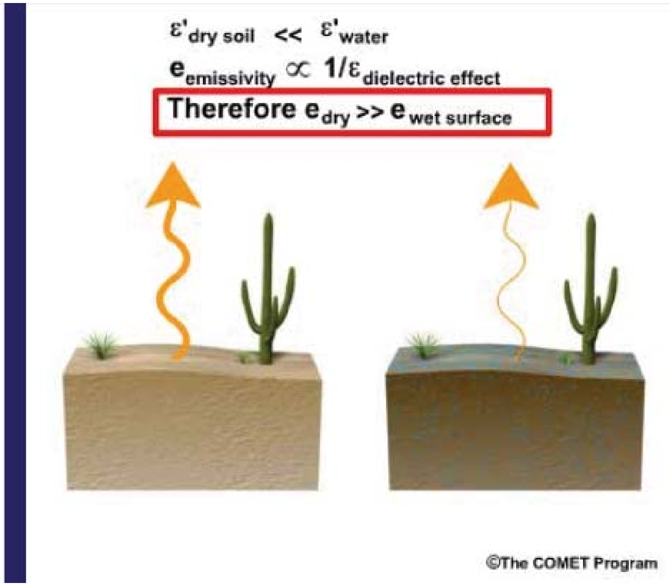




Soil moisture Remote Sensing (I)

The radiance detected by the sensor is due to the temperature (T) and emissivity (E), where the emissivity depends on the dielectric constant (ε) of the target and the dielectic constant depends on the water content





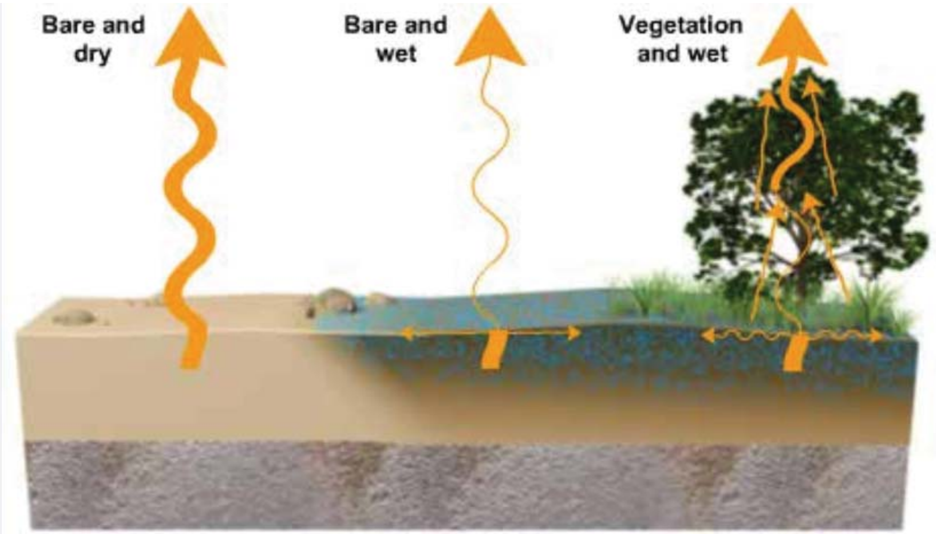
The emissivity is 1/ε so an increase of dielectric constant means a decrease of emissivity which detected by the sensor

Soil moisture Remote Sensing (II)

Is soil moisture from satellite reliable?

Difficult estimation in absolute value and impossible to penetrate deep vegetation
Any sensor gives different values (and they often use different units)
Different frequencies have different penetration depth (difficult to compare them)
Difficult to get in situ measurements for calibration/validation especially in remote areas

What is reliable is the trend and the anomaly
Don’t trust too much to the absolute value but trust to the trend!



Soil moisture Remote Sensing (III)

Platform: satellite **SMOS** (Soil moisture and Ocean salinity)
Orbit: polar orbit (LEO) at about 700 km of altitude with inclination 98 deg
Sensor: **MIRAS** (Microwave Imaging Radiometer by Aperture Synthesis)
Passive sensor working at 1.41 GHz (L-band) microwave spectrum (21 cm)
Radiometric resolution: 0.8-2.2 K
Spatial resolution: 30-50 km
Coverage: global
Temporal resolution: (revisit time) 3 days
Availability: 05/2010 - present

Platform: satellite **MetOp**
Orbit: polar orbit (LEO) at about 800 km of altitude with inclination 99 deg
Sensor: **ASCAT** (Advanced SCATterometer)
Active sensor working at 5.255 GHz
Radiometric resolution: 3%
Spatial resolution: 25/12,5 km
Coverage: global
Temporal resolution: (revisit time) 1/2 days
Availability: 2007-present

Soil moisture Remote Sensing (IV)

Platform: satellite **ERS**
Orbit: polar orbit (LEO) at about 800 km of altitude with inclination 99 deg
Sensor: **SCAT** (SCATterometer)
Active sensor working at 5.255 GHz
Radiometric resolution: 3%
Spatial resolution: 25 km
Coverage: global
Temporal resolution: (revisit time) 1/2 days
Availability: 1991-2001

Platform: **ENVISAT/ERS/All SAR satellites**
Orbit: polar orbit (LEO) at about 800 km of altitude with inclination 99 deg
Sensor: **SAR/ASAR**
Active sensor working at 5.255 GHz
Radiometric resolution: 3%
Spatial resolution: 50 km (25 km)
Coverage: global
Temporal resolution: (revisit time) 1/2 days

TBD

Soil moisture Remote Sensing (V)

FUTURE

Platform: satellite **SMAP** (Soil moisture Active Passive)
Orbit: polar orbit (LEO) at 680 km of altitude
Sensor: **SAR (Synthetic Aperture Radar) and radiometer**
Passive sensor working at 1.41 GHz (L-band) and active sensor working at 1.26 GHz
Radiometric resolution: 1.3 K, 4% soil moisture
Spatial resolution: 39-47 km (radiometer) and 1-3 km (SAR), 10 km soil moisture
Coverage: global
Temporal resolution: (revisit time) 3 days
Launch planned in 2014

In situ measurements

COSMOS campaign in Kenya from 2011
AMMA campaign in Niger from 2005
International Soil Moisture Network (ISMN)

Satellite data archives

SSEC (Space Science and Engineering Center) data center
http://www.ssec.wisc.edu/data/
NOAA CLASS (Comprehensive Large-Array Data Stewardship System)
http://www.class.ngdc.noaa.gov/saa/products/welcome
NOAA NCDC (National Climatic Data Center)
http://www.ncdc.noaa.gov/oa/ncdc.html
USGS EROS (Earth Resources Observation and Science) Center
http://eros.usgs.gov/#
NASA LaRC (Langley Research Center) ASDC (Atmospheric Science Data Center)
http://eosweb.larc.nasa.gov/HBDOCS/langley_web_tool.html
NASA GES DISC (Goddard Earth Science Data and Information Services Center)
http://disc.sci.gsfc.nasa.gov/
NASA MIRADOR
(http://mirador.gsfc.nasa.gov)
ESA EOPI (Earth Observation Principal Investigator) Website
http://eopi.esa.int

Be aware, there is not a standard format for satellite data.
You will find data in many different formats (netCDF, HDF4, HDF-EOS,N1, E1, E2, GRID, Grib, …)